TRAVELTIME, REAERATION, AND WATER-QUALITY CHARACTERISTICS DURING LOW-FLOW CONDITIONS IN WILSONS CREEK AND THE JAMES RIVER NEAR SPRINGFIELD, MISSOURI

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4074

Prepared in cooperation with the

MISSOURI DEPARTMENT OF NATURAL RESOURCES,

DIVISION OF ENVIRONMENTAL QUALITY

Rolla, Missouri

1987

DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound units	By	To obtain SI units
foot	0.3048	meter
foot per foot	1.0	meter per meter
foot per mile	0.1894	meter per kilometer
foot per second	0.3048	meter per second
cubic foot per second	0.02832	cubic meter per second
mile	1.609	kilometer
square mile	2.590	square kilometer
million gallons	3,785	cubic meter
million gallons per day	0.04381	cubic meter per second

Temperature, in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F = 9/5 (°C) + 32.

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ABSTRACT

Before upgrading the Southwest Wastewater-Treatment Plant in Springfield, Missouri, to tertiary treatment, adverse water-quality conditions resulting from discharge of wastewater effluent to Wilsons Creek were documented in the creek and in the James River. About 7 years after the upgrading of the treatment plant, traveltime, reaeration, and water-quality characteristics in Wilsons Creek and the James River were determined.

Traveltime was measured in the James River and Wilsons Creek using Rhodamine WT dye. Traveltime measurements were made for one discharge in Wilsons Creek and for two different discharges in the James River. Traveltime in James River was estimated for discharges between 55 and 200 cubic feet per second at a site near Boaz.

Reaeration coefficients were calculated for five reaches in Wilsons Creek and the James River using the modified-tracer technique. Calculated reaeration coefficients ranged from 0.9 to 6.7 per day, at 20 °Celsius, in base e units. Calculated reaeration coefficients were compared with coefficients predicted by 12 empirical equations and 1 equation was chosen that best fit the data.

Water-quality data were collected during two 44-hour periods, August 14 to 16, 1984 and July 23 to 25, 1985. Samples were collected at the outflow of the Southwest Wastewater-Treatment Plant and at seven sites along Wilsons Creek and the James River. Dissolved-oxygen concentrations in Wilsons Creek and the James River were all larger than Missouri's water-quality standard of 5.0 milligrams per liter. Ammonia concentrations were smaller than 0.08 milligrams per liter as nitrogen and 5-day carbonaceous biochemical oxygen demands were smaller than 4 milligrams per liter, which indicated that the oxygen consumption by oxidizing ammonia and carbonaceous organic material would be insignificant. Measured streambed-oxygen demand in the James River was largest directly downstream from Wilsons Creek. The nitrite plus nitrate and phosphorus concentrations in the wastewater effluent were large enough to possibly contribute to nuisance growth of aquatic plants in Wilsons Creek downstream from the Southwest Wastewater-Treatment Plant and in the James River downstream from Wilsons Creek.

INTRODUCTION

The city of Springfield, Missouri, discharges wastewater effluent into Wilsons Creek at the Southwest Wastewater-Treatment Plant. The treatment plant was upgraded to tertiary treatment in 1977. Before upgrading, fish kills and adverse odors were documented in Wilsons Creek and the James River (Federal Water Pollution Control Administration, 1969). These conditions were attributed toanaerobic conditions caused by large 5-day biochemical oxygen demands and ammonia concentrations. Upgrading the treatment plant markedly improved the wastewater-effluent quality and the water quality in Wilsons Creek and the James River (Berkas, 1982).

From October 1977 to the present (1986), the Springfield Southwest Wastewater-Treatment Plant has provided tertiary treatment. The steps incorporated in tertiary treatment include:

1. Coarse screening and grit removal.
2. Primary clarification.
3. Contact with activated sludge supplied with oxygen.
4. Secondary clarification.
5. Contact with nitrified activated sludge conventionally aerated.
6. Final clarification.
7. Multimedia filtration.
8. Disinfection with ozone.

Tertiary treatment was anticipated to produce a saturated dissolved-oxygen concentration, a minimum 5-day biochemical oxygen demand of 10 milligrams per liter, and a minimum total-ammonia concentration of 1 milligram per liter as nitrogen (Consoer, Townsend, and Associates; and Hydroscience, Inc., 1975). The treatment plant was designed to process an average flow of 46.5 cubic feet per second (30 million gallons per day) and a maximum flow of 65.1 cubic feet per second (42 million gallons per day). A flow-equalization basin with a capacity of 42 million gallons accommodates excessive flows during rainfall. The average daily effluent discharge during 1985 was 46.7 cubic feet per second or 30.1 million gallons per day, (Carol Ramsey, Southwest Wastewater-Treatment Plant, oral commun., 1986).

Purpose and Scope

The purpose of this study, in cooperation with the Missouri Department of Natural Resources, Division of Environmental Quality, was to determine the traveltime and reaeration characteristics of Wilsons Creek and the James River. An additional purpose was to determine the water quality in Wilsons Creek and the James River downstream from the Southwest Wastewater-Treatment Plant, 7 years after tertiary treatment began at the plant. After this period, the assumption was made that past contamination conditions caused by inadequately treated sewage had been eliminated and the river system was in equilibrium with the discharge from the tertiary treatment plant.

Data for this study were collected in July and August 1984 and in July 1985. Rhodamine-WT dye was used to measure traveltime between seven sites on Wilsons Creek and the James River in July and August 1984, and between three sites on the James River in July 1985. Reaeration coefficients were calculated by using the modified-tracer technique (Rathbun and others, 1975) for five reaches on Wilsons Creek and the James River in July and August 1984, and in July 1985. Water-quality data were collected at the treatment plant and at seven sites on Wilsons Creek and the James River from August 14 to 16, 1985, and from July 23 to 25, 1985.

This report presents the results of the study. All data collected during the study are presented in the report.

Previous Investigations

A study by the Federal Water Pollution Control Administration (1969) resulted from complaints about the water quality in Wilsons Creek and the James River. The report cited other reports that documented fish kills and offensive odors in Wilsons Creek and the James River from industrial waste, treatment-plant effluent, and runoff from urban areas. The Federal Water Pollution Control Administration's (1969) study concluded that sewage sludge from the Southwest Wastewater-Treatment Plant had accumulated on the streambed of Wilsons Creek and had created anaerobic conditions in both Wilsons Creek and the James River. Anaerobic means the absence of dissolved oxygen. Under anaerobic conditions, aquatic animals suffocate and decomposing organic material produces hydrogen sulfide and methane gases. During high-flow conditions, some of the sludge was transported and carried downstream, decreasing the dissolved-oxygen concentrations. The study also stated the initial runoff during a storm in the Wilsons Creek basin was of degraded quality, but after the initial runoff the quality improved.

A waste-load allocation study in Wilsons Creek and the James River was made during 1975 by Consoer, Townsend and Associates; and Hydroscience, Inc. A water-quality model was calibrated and verified, and water-quality conditions were simulated using the planned improvements for the Southwest Wastewater-Treatment Plant. Simulations indicated that Missouri's water-quality standards would be achieved in Wilsons Creek and the James River if the treatment plant was upgraded as planned.

Berkas (1980; 1982) characterized the water quality in Wilsons Creek and the James River before and after the Southwest Wastewater-Treatment Plant was upgraded to tertiary treatment in 1977. Before tertiary treatment, the daily minimum dissolved-oxygen concentration in Wilsons Creek downstream from the treatment plant was about zero. After tertiary treatment, the daily minimum dissolved-oxygen concentration seldom was about zero. A statistical analysis of data collected in the James River upstream and downstream from Wilsons Creek indicated that dissolved-oxygen and nitrite-plus-nitrate concentrations increased in the James River downstream from Wilsons Creek after upgrading to tertiary treatment.

Total-ammonia data were not statistically analyzed by Berkas (1982). Average total-ammonia concentrations calculated from data collected by the U.S. Geological Survey at the James River near Boaz (fig. 1, site 15) from October 1975 to September 1977 were 2.89 milligrams per liter as nitrogen, and from July 1978 to June 1980 were 0.21 milligram per liter as nitrogen. These data indicate that upgrading to tertiary treatment at the Southwest Wastewater-Treatment Plant decreased the total-ammonia concentration.

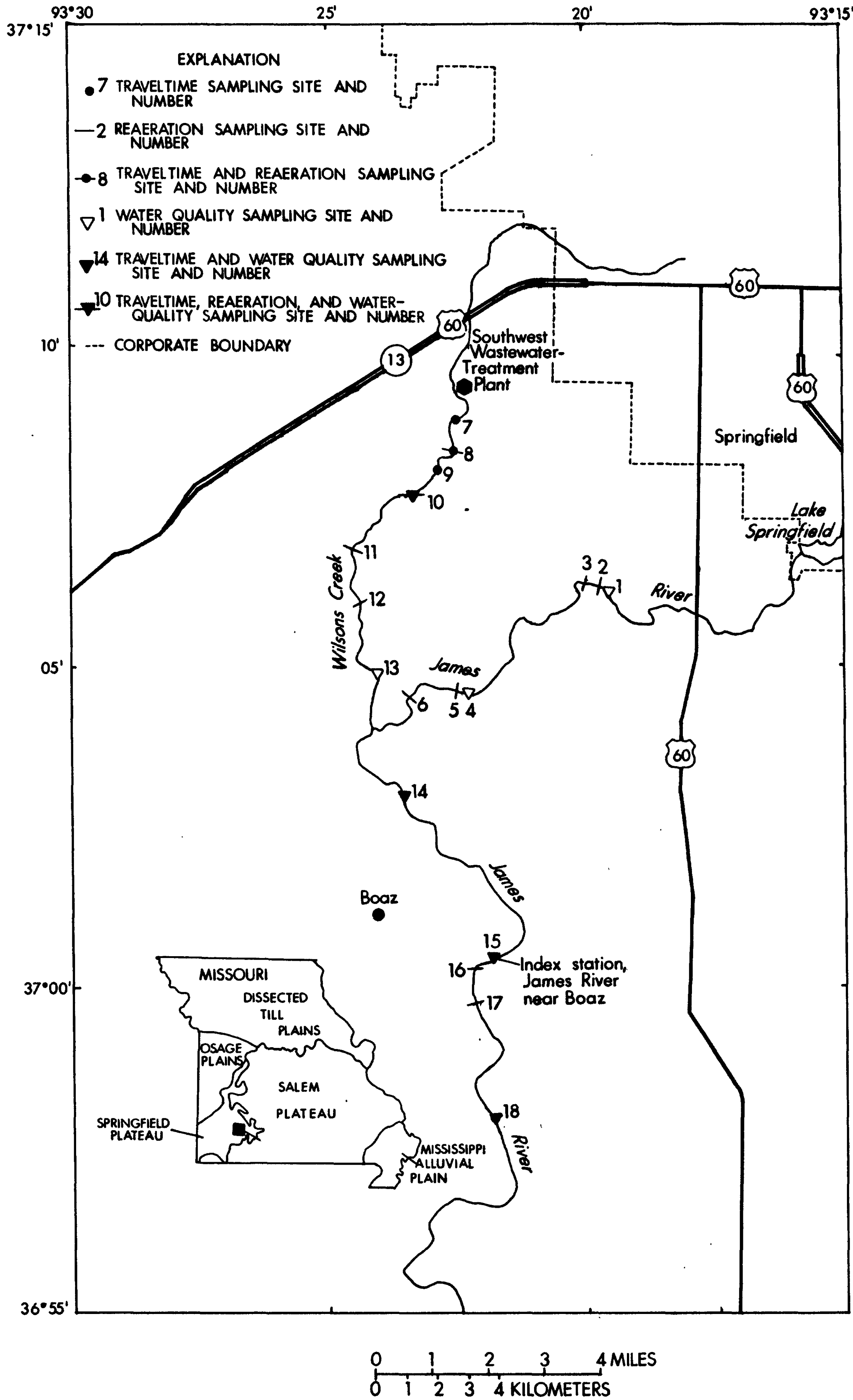

Figure 1.--Location of sampling sites along Wilsons Creek and the James River.

Description of Study Area

The study area is located southeast of Springfield, in the Springfield Plateau (fig. 1). The stream reaches in the study area are Wilsons Creek downstream from the Southwest Wastewater-Treatment Plant, and the James River, 6.4 river miles upstream to 10.1 river miles downstream from Wilsons Creek.

The Springfield Plateau is a physiographic section that is underlain by Mississippian carbonate rocks (Fenneman, 1938). Fractures and solution openings have developed in the carbonate rocks to the extent that sinkholes and springs are prevalent. For instance, within the corporate boundary of Springfield, 195 sinkholes have been identified, which is more than three sinkholes per square mile (Hayes, 1977). The fractures and solution openings intersect streambeds at some locations causing large quantities of water to be gained or lost from streams.

The Wilsons Creek basin is comprised of urban and agricultural areas. Urban areas occur in the headwaters and comprise about one-fourth of the basin. The remainder of the basin is used for agriculture, principally livestock production. The Southwest Wastewater-Treatment Plant is located near Wilsons Creek at the southwestern edge of the urban area. The treatment plant processes most of the sewage from Springfield and discharges the treated effluent into Wilsons Creek, 7.4 river miles upstream from the junction with the James River. During dry weather, Wilsons Creek upstream from the plant does not flow, and although Wilsons Creek receives water from ground-water sources most of the flow downstream from the treatment plant is treated effluent.

In the study area the James River flows through an area that predominately is agricultural. Although a few houses have been built along the river, rowcrop farming and livestock production are the major agricultural land uses.

During low-flow conditions, the study reach of the James River is regulated by Lake Springfield, which is used for cooling at the Springfield powerplant. Releases from the lake do not conform to any specific schedule, although the powerplant operators try to maintain flow in the James River.

Springfield is one of the most rapidly expanding municipalities in Missouri. The population increased from 95,865 in 1960; to 120,096 in 1970; and to 133,116 in 1980 (U.S. Department of Commerce, 1983a).

TRAVELTIME

Traveltime is the time required for water in a stream to travel from one point to another. The average velocity is the distance between two points divided by the traveltime.

Rhodamine WT, a fluorescent dye, was used to determine traveltimes. This dye is a solute that completely mixes with water and moves in a manner similar to water. The traveltime of the dye is assumed to be equal to the traveltime of the water and should approximate the traveltimes of soluble contaminants that may be introduced into the stream.

After Rhodamine WT was injected into the stream, it dispersed in vertical, lateral, and longitudinal directions. Complete mixing occurred in the vertical and lateral directions, and dispersion in these directions ceased. No longitudinal boundaries exist in a channel; therefore, dispersion in this direction continued. The dye formed a cloud that continued to spread in the longitudinal direction as it moved downstream.

As the dye cloud passed, samples were collected in the center of flow and were analyzed for dye concentration using a fluorometer. A fluorometer is an instrument that measures the fluoresence of the sample and converts it to a concentration. This instrument can detect dye concentrations as small as 0.01 microgram per liter. The dye concentrations are plotted against time to form a time-concentration curve, which is used to determine the time to the leading edge, peak, and centroid of the dye cloud. The time to the centroid of the dye cloud is the traveltime for the given discharge. Traveltime and related information for Wilsons Creek and the James River are listed in table 1. A complete description of methods, procedures, dyes, and equipment used in determining traveltime is given by Hubbard and others (1982).

If more than one traveltime measurement is available for a stream reach, traveltime can be estimated throughout a range of discharges by using a graphical method. The graphical method involves plotting traveltimes from one station to another verses the discharge measured at an index station on log-log graph paper. A straight line of best fit, is then drawn using all points. This method is based on the assumption that traveltime verses discharge at an index station is linear on log-log paper (Hubbard and others, 1982).

Two traveltime measurements were made between sites 4 and 18 on the James River. The graphical method was used to estimate traveltime between these sites for a range of discharges at the index station, site 15 (fig. 2). Site 15 was chosen as an index station because a river-stage relation has previously been established (U.S. Geological Survey gaging station 07052250, James River near Boaz). Estimates of traveltime only were determined for discharges between 55 and 200 cubic feet per second at site 15. Estimates of traveltime outside this range of discharge are not appropriate because of the uncertainity of this method to estimate traveltimes under discharge extremes. According to daily discharge data for water years 1973-80 at site 15, discharges less than 55 cubic feet per second occur 4 percent of the time, and discharges larger than 200 cubic feet per second occur 58 percent of the time (Berkas, 1982). Although this flow-frequency data is not currently (1987) accurate because of steadily increasing outflow from the Southwest Wastewater-Treatment Plant, the frequency data indicate that figure 2 can be used to estimate traveltime in the James River about 50 percent of the time.

REAERATION

Reaeration is the absorption of oxygen from the atmosphere by the water in the stream. Reareation is the primary process that replaces the oxygen consumed by oxidizing organic material and ammonia in many streams. The rate of oxygen absorption is proportional to the saturation deficit between the air and the water surface. The reaeration coefficient is the rate constant for the absorption of oxygen from the atmosphere. Knowledge of the reaeration coefficient helps one understand how much oxygen consumption can occur in a stream without depleting the dissolved-oxygen concentration.

Table 1.--Traveltime and dispersion characteristics for Wilsons Creek and the James River

[--, data not collected]

Site number (fig. 1)	Distance downstream from injection, in river miles	Discharge, in cubic feet per second	Cumulative traveltime of dye cloud, in hours: Leading edge	Peak	Centroid	Mean velocity of dye-cloud centroid, in feet per second
Dye injected at site 4, on the James River, July 24, 1984						
4	0.0	13.0	--	--	--	--
14	3.8	46.2	22.5	43.5	45.9	0.12
15	8.5	61.0	38.0	66.5	74.9	.16
18	12.1	61.2	49.5	82.5	93.2	.19
Dye injected at site 4, on the James River, July 22, 1985						
4	0.0	87.0	--	--	--	--
14	3.8	--	10.7	14.7	17.1	0.32
15	8.5	138	19.5	27.2	33.7	.37
18	12.1	168	25.0	34.5	42.5	.42
Dye injected at Southwest Wastewater-Treatment Plant, (Wilsons Creek), August 14, 1984						
7	0.33	15.5	0.87	1.08	1.35	0.36
8	.91	16.9	2.25	3.00	3.32	.40
9	1.35	15.2	3.67	4.58	5.02	.40
10	2.08	32.5	5.50	6.67	7.26	.42

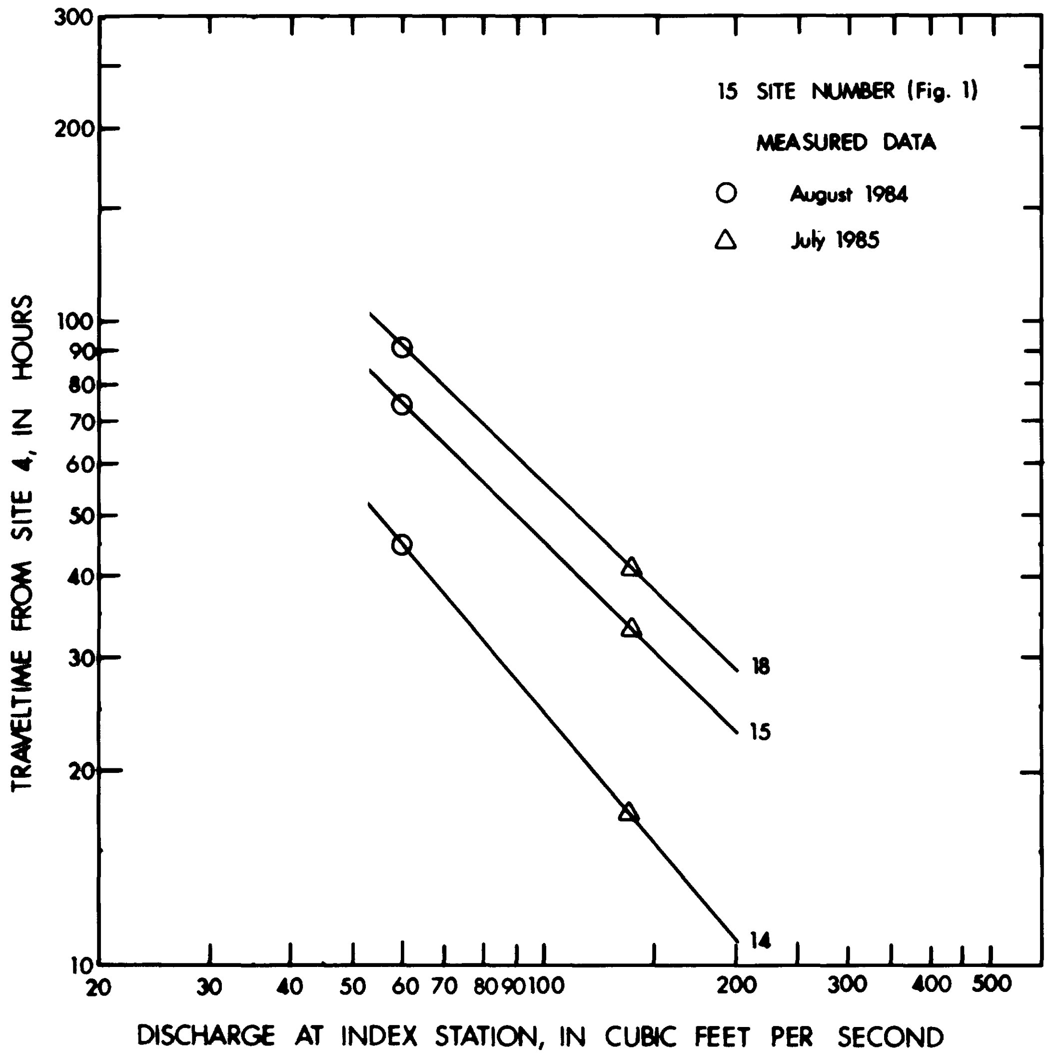

Figure 2.--Estimated traveltime from site 4 to sites 14, 15, and 18, using discharge at the index station (sites 15), James River near Boaz.

Reaeration coefficients were calculated for five reaches in Wilsons Creek and the James River (fig. 1) using the modified-tracer technique developed and described by Rathbun and others (1975). Propane was used as a tracer gas and Rhodamine-WT dye was used as the dispersion and dilution tracer.

The technique consists of injecting a tracer gas and dye into the stream and measuring the gas and dye concentrations at selected locations downstream. The difference between the total quantity of gas measured at two sampling locations is used to calculate a desorption coefficient for the gas. This desorption coefficient is proportional to the reaeration coefficient.

Several investigators believe that reaeration coefficients are a function of channel geometry and water velocity (Bennet and Rathbun, 1972; Owens and others, 1964). As discharge changes, the reaeration coefficient also changes. Several empirical equations have been developed to predict reaeration coefficients. Rathbun (1977) evaluated a number of equations and determined that the equations resulted in a considerable range of reaeration coefficients for a specific set of hydraulic conditions. When selecting an equation, it is best to compare the results to measured reaeration coefficients. The reaeration coefficients calculated for Wilsons Creek and the James River were compared to the following predictive equations:

Equation

Bansal (1973)

$$K_2 = 5.26\ U^{0.60}D^{-1.40} \qquad (1)$$

Bennett and Rathbun (1972)

$$K_2 = 20.2\ U^{0.607}D^{-1.689} \qquad (2)$$

$$K_2 = 106\ U^{0.413}D^{-1.408}\ S^{0.273} \qquad (3)$$

Cadwallder and McDonnell (1969)

$$K_2 = 59.1\ (32.2US)^{0.5}D^{-1.0} \qquad (4)$$

Churchill and others (1962)

$$K_2 = 11.6\ U^{0.969}D^{-1.673} \qquad (5)$$

$$K_2 = 3.33\ U^{-1.049}D^{-2.262}\ (257.6DS/U^2)^{-0.823} \qquad (6)$$

Langbein and Durum (1967)

$$K_2 = 7.61\ UD^{-1.33} \qquad (7)$$

Negulescu and Rojanski (1969)

$$K_2 = 10.9\ (U/D)^{0.85} \qquad (8)$$

O'Connor and Dobbins (1958)

$$K_2 = 12.96\ U^{0.5}D^{-1.5} \qquad (9)$$

Owens and others (1964)

$$K_2 = 23.3\ U^{0.73}D^{-1.75} \qquad (10)$$

$$K_2 = 21.7\ U^{0.67}D^{-1.85} \qquad (11)$$

Padden and Gloyna (1971)

$$K_2 = 6.86\ U^{0.703}D^{-1.054} \qquad (12)$$

where K_2 = the reaeration coefficient per day, at 20 °Celsius, in base e units;

U = average velocity, in feet per second;
D = average channel depth, in feet; and
S = average channel slope, in foot per foot.

Comparisons of calculated reaeration coefficients from the modified-tracer technique and from the empirical equations are shown in table 2. The range and average error of estimate for the various equations are listed in table 3 and were computed as follows:

$$\text{Error of estimate} = \frac{\text{Value calculated by empirical equation} - \text{Value calculated by modified-tracer technique.}}{\text{Value calculated by modified-tracer technique}}$$

The equation that produced the smallest average error of estimate was equation 9, developed by O'Connor and Dobbins (1958). The reaeration coefficients calculated by the modified-tracer technique ranged from 0.9 to 6.7 per day, at 20 °Celsius, in base e units. The reaeration coefficients calculated by the O'Connor and Dobbins equation ranged from 1.0 to 6.5 per day, at 20 °Celsius, in base e units.

WATER QUALITY

Water-quality data were collected at the outflow of the Southwest WastewaterTreatment Plant and at seven sites along Wilsons Creek and the James River, (fig. 1). All water-quality data, except streambed oxygen demand, were collected during two 44-hour periods; August 14 to 16, 1984, and July 23 to 25, 1985, and are listed in table 4. Water samples were analyzed by the Missouri Department of Natural Resources, Division of Environmental Quality, by using procedures recommended by the American Public Health Association and others (1985). Streambed oxygen demand was determined onsite by U.S. Geological Survey personnel in August 1985.

The Missouri Department of Natural Resources (1984) classified Wilsons Creek and the James River as perennial streams. Water-quality standards for perennial streams require that contaminants shall not cause or contribute to the violation of maximum specific limitations for the designated use of the water. Exceptions can be granted by the Missouri Clean Water Commission when the flow in perennial streams is less than the average minimum flow for 7 consecutive days that has a recurrence interval of 10 years (7-day, Q_{10}), and may be granted when the effluent constitutes most of the streamflow. The Missouri Clean Water Commission has not granted exceptions for Wilsons Creek or the James River. No uses have been designated for Wilsons Creek; therefore, only the general water-quality criteria apply. The uses designated for the James River are livestock and wildlife watering, irrigation, boating, and protection of aquatic life.

Table 2.--Comparisons of reaeration coefficients in Wilsons Creek and the James River calculated from the modified-tracer technique and from empirical equations

		Reaeration coefficient, per day, at 20 °Celsius, in base e units						
			Calculated using empirical equations					
Reach as defined by site number (fig. 1)	Date	Calculated using the modified-tracer technique	Bansal, (1973) eq. 1	Bennett and Rathbun, (1972) eq. 2	Bennett and Rathbun, (1972) eq. 3	Cadwallder and McDonnell, (1969) eq. 4	Churchill and others, (1962) eq. 5	Churchill and others, (1962) eq. 6
2-3	8-23-84	1.6	0.48	1.6	2.2	1.2	0.33	0.59
2-3	7-22-85	.90	.37	1.1	1.5	1.1	.27	.22
5-6	8-22-84	3.5	1.3	4.7	5.6	3.3	1.4	1.9
5-6	7-18-85	6.7	2.3	8.0	7.9	5.3	3.4	2.9
8-10	7-25-84	4.5	1.7	5.9	8.0	7.1	2.5	.82
8-10	7-23-85	5.6	1.9	6.5	8.5	7.7	3.0	.85
11-12	7-26-84	5.6	2.5	9.0	9.6	6.8	3.9	2.8
11-12	7-25-85	5.3	2.5	9.0	9.6	6.8	3.9	2.8
16-17	8-21-84	3.6	.82	2.6	3.0	2.2	.88	.65
16-17	7-17-85	3.0	1.1	3.1	3.2	2.8	1.5	.54

		Reaeration coefficient, per day, at 20 °Celsius, in base e units						
			Calculated using empirical equations					
Reach as defined by site number (fig. 1)	Date	Determined using the modified-tracer technique	Langbein and Durum, (1967) eq. 7	Negulescu and Rojanski, (1969) eq. 8	O'Connor and Dobbins, (1958) eq. 9	Owens and others, (1964) eq. 10	Owens and others, (1964) eq. 11	Padden and Gloyna, (1964) eq. 12
2-3	8-23-84	1.6	0.24	0.65	1.5	1.2	1.3	0.45
2-3	7-22-85	.90	.22	.71	1.0	.87	.85	.34
5-6	8-22-84	3.5	.90	1.9	3.8	4.2	4.3	1.4
5-6	7-18-85	6.7	2.4	4.4	5.9	8.2	7.8	2.6
8-10	7-25-84	4.5	1.8	3.6	4.5	6.0	5.6	2.0
8-10	7-23-85	5.6	2.2	4.3	4.8	6.7	6.2	2.2
11-12	7-26-84	5.6	2.6	4.6	6.5	9.3	8.9	2.9
11-12	7-25-85	5.3	2.6	4.6	6.5	9.3	8.9	2.9
16-17	8-21-84	3.6	.70	1.7	2.2	2.4	2.2	.86
16-17	7-17-85	3.0	1.4	3.4	2.5	3.2	2.8	1.2

Table 3.--Error analysis of predicted reaeration coefficients

Equation number	Author	Range of error of estimate	Average error of estimate
1	Bansal (1973)	0.53 to 0.77	0.65
2	Bennett and Rathbun (1972)	.017 to .70	.28
3	Bennett and Rathbun (1972)	.068 to .80	.49
4	Cadwallder and McDonnell (1969)	.046 to .58	.26
5	Churchill and others (1962)	.27 to .79	.53
6	Churchill and others (1962)	.44 to .85	.67
7	Langbein and Durum (1967)	.50 to .85	.66
8	Negulescu and Rojanski (1969)	.12 to .59	.30
9	O'Connor and Dobbins (1958)	.004 to .39	.15
10	Owens and others (1964)	.034 to .79	.27
11	Owens and others (1964)	.054 to .69	.27
12	Padden and Gloyna (1971)	.45 to .76	.60

DISCHARGE

Although discharge is not a water-quality property or constituent, it is significant in water-quality analyses because it indicates the dilution ability of the stream. Discharge is of special concern in this study because of the interest in how the effluent from the Southwest Wastewater-Treatment Plant affects the water quality in Wilsons Creek and the James River. During low-flow conditions, the diluting ability of Wilsons Creek and the James River should be minimal, which would be the best time to evaluate how the wastewater effluent effects the water quality in the streams.

Discharge was measured at the water-quality sampling sites on August 14, 1984, and July 23, 1985 (table 4). During both sampling periods Wilsons Creek was not flowing upstream from the outflow of the Southwest Wastewater-Treatment Plant. At the treatment-plant outflow, a discharge of 15.5 cubic feet per second was measured on August 14, 1984. The average discharge on this day probably was different from this discharge because of the typical daily variation in discharge from wastewater treatment plants. Despite this daily variation, the large difference between the discharge measured at the treatment-plant outflow and at site 10 indicates an increase in discharge from ground-water sources. The discharge measurements made during the traveltime determinations confirm this fact (table 1).

On August 14, 1984, the discharge data indicate that Wilsons Creek and the James River were sampled under low-flow conditions. During water years 1973-80 the U.S. Geological Survey operated a daily discharge gage at site 15, James River near Boaz. Flow-duration data for the period of record indicate that a discharge of 50.7 cubic feet per second would be equaled or exceeded 98 percent of the time. This frequency was not applicable to discharge on August 14, 1984, because of the steadily increasing discharge from the Southwest Wastewater-Treatment Plant, but it does indicate that the discharges are small. Wilsons Creek and the James River at this time would be providing slightly more than the minimum dilution to the wastewater effluent.

On July 23, 1985, discharge data indicate that Wilsons Creek and the James River were receiving inflow from ground-water sources, which is evidenced by large increases in discharge between sites 1 and 4, and between sites 14 and 15. Flow-duration data for site 15 indicate that the discharge of 162 cubic feet per second, measured on July 23, 1985, would be equaled or exceeded 70 percent of the time. Again, this frequency of flow would not be extremely accurate, but it does give a general indication of frequency.

Water Temperature

Water temperature is a significant water-quality property because it affects the biological and chemical processes in water. Growth of aquatic organisms and the rate of chemical reactions generally increase with increasing water temperature, but the solubility of dissolved oxygen decreases with increasing water temperature. Water temperature fluctuates daily because of heating from solar radiation.

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985

[SWTP, Southwest Wastewater-Treatment Plant; --, data not collected; <, less than]

		Sampling site (fig. 1)							
Date	Time	1	4	SWTP	10	13	14	15	18
		Discharge, in cubic feet per second							
8-14-84	--	9.45	12.6	15.5	30.6	27.7	46.2	50.7	49.7
7-23-85	--	53.0	88.6	--	26.9	33.2	140	162	169
		Temperature, in degrees Celsius							
8-14-84	1400	25	26	--	25	25	27	26	26
8-14-84	1800	24	25	--	24	24	27	27	27
8-14-84	2200	23	24	--	22	23	25	26	26
8-15-84	0200	23	24	--	23	23	23	25	25
8-15-84	0600	23	23	--	22	22	22	24	24
8-15-84	1000	23	25	--	24	25	27	26	26
8-15-84	1400	24	25	--	24	23	26	26	26
8-15-84	1800	24	25	--	24	24	27	27	27
8-15-84	2200	23	23	--	22	22	25	25	26
8-16-84	0200	23	24	--	23	23	23	25	25
8-16-84	0600	23	23	--	22	22	23	24	22
8-16-84	1000	23	25	--	24	22	24	25	26
7-23-85	1400	28	27	--	25	24	27	28	28
7-23-85	1800	29	27	--	24	25	27	29	29
7-23-85	2200	28	27	--	23	25	26	28	28
7-24-85	0200	28	26	--	22	24	26	26	27
7-24-85	0600	27	23	--	21	23	26	26	26
7-24-85	1000	27	27	--	23	23	26	27	27
7-24-85	1400	28	27	--	25	25	28	28	28
7-24-85	1800	29	28	--	24	26	28	29	29
7-24-85	2200	28	27	--	23	25	27	28	28
7-25-85	0200	28	27	--	23	24	26	27	28
7-25-85	0600	28	26	--	22	23	26	26	27
7-25-85	1000	28	27	--	23	23	27	28	28

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1)							
		1	4	SWTP	10	13	14	15	18
					pH, in units				
8-14-84	1400	7.2	7.7	--	7.4	7.6	8.2	8.1	8.2
8-14-84	1800	7.7	7.8	--	7.5	7.7	8.2	8.2	8.2
8-14-84	2200	7.7	7.9	--	7.7	7.8	7.9	8.2	8.2
8-15-84	0200	7.7	7.7	--	7.4	7.6	7.5	8.1	8.2
8-15-84	0600	7.2	7.8	--	7.6	7.6	6.5	7.7	8.0
8-15-84	1000	7.4	7.7	--	7.3	7.6	8.2	8.3	8.3
8-15-84	1400	7.8	8.0	--	7.6	7.8	8.3	8.2	8.3
8-15-84	1800	7.8	7.8	--	7.7	7.9	8.4	8.3	8.4
8-15-84	2200	7.9	8.0	--	7.8	8.0	8.1	8.4	8.3
8-16-84	0200	7.3	7.7	--	7.4	7.7	8.0	8.3	8.2
8-16-84	0600	7.3	8.1	--	8.6	8.0	7.7	7.8	7.9
8-16-84	1000	7.5	7.7	[a]7.4	7.5	7.6	7.8	7.9	8.0
7-23-85	1400	7.8	7.9	--	7.4	7.6	8.1	8.1	8.2
7-23-85	1800	8.2	8.0	--	7.3	7.6	8.2	8.4	8.4
7-23-85	2200	7.8	8.0	--	7.4	7.6	8.1	8.2	8.2
7-24-85	0200	8.0	8.0	--	7.5	7.7	8.1	8.0	8.0
7-24-85	0600	8.0	8.0	--	7.4	7.8	7.6	7.7	7.9
7-24-85	1000	8.0	8.0	--	7.4	7.9	7.9	7.9	8.1
7-24-85	1400	8.2	8.2	[b]7.5	7.5	7.9	8.2	8.2	8.2
7-24-85	1800	8.3	8.2	--	7.5	8.4	8.2	8.4	8.2
7-24-85	2200	8.2	8.1	--	7.7	8.1	8.0	8.2	8.2
7-25-85	0200	7.9	7.6	--	7.1	7.4	7.8	7.9	7.3
7-25-85	0600	8.0	7.8	--	7.3	7.7	7.6	7.5	7.2
7-25-85	1000	8.2	8.2	--	7.5	8.0	7.6	7.8	7.5

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1)							
		1	4	SWTP	10	13	14	15	18
Specific conductance, in microsiemens per centimeter at 25 °Celsius									
8-14-84	1400	520	510	--	970	890	740	700	700
8-14-84	1800	520	530	--	985	910	720	700	700
8-14-84	2200	520	520	--	1,040	940	725	700	700
8-15-84	0200	520	500	--	1,000	940	740	690	690
8-15-84	0600	530	500	--	620	940	750	720	720
8-15-84	1000	520	500	--	1,020	930	740	710	690
8-15-84	1400	540	520	--	1,050	1,000	720	670	690
8-15-84	1800	540	520	--	1,010	1,000	725	725	700
8-15-84	2200	525	520	--	1,030	1,000	735	700	680
8-16-84	0200	490	500	--	990	970	770	710	700
8-16-84	0600	500	500	--	1,000	970	770	720	740
8-16-84	1000	520	500	[a]1,040	970	990	820	740	720
7-23-85	1400	360	360	--	925	800	475	480	480
7-23-85	1800	355	360	--	900	795	475	480	470
7-23-85	2200	355	355	--	940	860	500	485	450
7-24-85	0200	355	360	--	965	880	510	500	490
7-24-85	0600	360	360	--	900	890	535	500	500
7-24-85	1000	350	345	--	950	900	540	585	490
7-24-85	1400	360	365	[a]1,200	1,000	920	535	500	515
7-24-85	1800	365	370	--	1,000	900	520	490	475
7-24-85	2200	370	365	--	1,000	930	550	500	470
7-25-85	0200	360	360	--	950	950	510	475	490
7-25-85	0600	365	365	--	900	950	595	545	500
7-25-85	1000	365	360	--	910	950	525	485	485

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1) 1	4	SWTP	10	13	14	15	18
		Dissolved oxygen, in milligrams per liter							
8-14-84	1400	9.8	11.2	--	11.4	8.2	10.8	8.1	8.9
8-14-84	1800	9.9	10.2	--	8.6	9.0	11.0	9.4	9.3
8-14-84	2200	8.0	7.8	--	7.6	7.6	7.7	8.6	7.6
8-15-84	0200	7.2	9.5	--	7.0	7.0	6.3	7.2	6.7
8-15-84	0600	6.8	8.7	--	6.7	6.5	--	--	--
8-15-84	1000	8.0	11.2	--	8.8	7.4	8.5	6.5	7.7
8-15-84	1400	10.0	12.0	--	11.2	9.1	11.2	8.4	9.1
8-15-84	1800	10.6	9.8	--	10.4	9.3	10.8	9.4	9.4
8-15-84	2200	8.0	8.0	--	7.5	7.5	7.7	8.4	7.9
8-16-84	0200	7.2	9.7	--	7.0	6.8	6.5	7.5	6.9
8-16-84	0600	6.7	8.7	--	7.0	6.4	6.0	6.1	6.0
8-16-84	1000	8.1	11.5	--	7.3	7.5	7.8	6.7	7.7
7-23-85	1400	7.9	8.3	--	9.4	8.7	10.3	9.3	9.0
7-23-85	1800	8.7	8.9	--	8.3	8.4	10.0	10.4	9.9
7-23-85	2200	7.5	8.0	--	6.3	7.0	7.6	7.9	7.8
7-24-85	0200	6.6	7.3	--	6.2	6.3	6.7	6.2	6.6
7-24-85	0600	5.6	6.8	--	6.1	5.9	6.2	5.7	6.0
7-24-85	1000	7.0	7.3	--	7.7	6.7	7.9	6.8	6.9
7-24-85	1400	7.8	8.9	--	9.5	8.9	10.1	8.6	8.0
7-24-85	1800	8.4	9.4	--	8.3	8.4	9.2	9.5	8.8
7-24-85	2200	7.3	7.8	--	6.6	6.8	7.4	7.8	7.6
7-25-85	0200	6.5	7.2	--	6.4	6.2	6.3	6.7	6.1
7-25-85	0600	6.1	6.5	--	6.5	6.0	6.3	5.6	5.8
7-25-85	1000	6.7	6.7	--	7.7	6.0	7.6	6.5	6.5

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1)							
		1	4	SWTP	10	13	14	15	18
		5-day carbonaceous biochemical oxygen demand, in milligrams per liter							
8-14-84	1400	<2	<2	--	<2	<2	<2	<2	<2
8-14-84	2200	<2	<2	--	<2	<2	<2	<2	<2
8-15-84	0600	<2	<2	--	<2	4	<2	<2	<2
8-15-84	1400	<2	<2	[c]<2	<2	<2	<2	<2	<2
8-15-84	2200	<2	<2	--	<2	<2	<2	<2	<2
8-16-84	0600	<2	<2	[a]3	<2	<2	<2	<2	<2
7-23-85	1400	<4	<4	--	<4	<4	<4	<4	<4
7-23-85	2200	<4	<4	--	<4	<4	<4	<4	<4
7-24-85	0600	<4	<4	--	<4	<4	<4	<4	<4
7-24-85	1400	<4	<4	[b]<4	<4	<4	<4	<4	<4
7-24-85	2200	<4	<4	--	<4	<4	<4	<4	<4
7-25-85	0600	<4	<4	[d]<4	<4	<4	<4	<4	<4
		Chemical oxygen demand, in milligrams per liter							
8-15-84	0600	<5.0	<5.0	[c]29	20	17	8.5	8.5	5.9
8-16-84	0600	7.0	--	[a]37	20	18	21	16	16
7-24-85	0600	7.0	5.0	[b]24	14	16	11	7.0	6.0
7-25-85	0600	<5.0	<5.0	[d]24	14	14	5.0	10	7.0
		Streambed-oxygen demand, in grams per square meter per day							
7-22 to 7-25 1985		1.1	--	--	--	--	2.2	1.3	--
		Total Kjeldahl nitrogen, in milligrams per liter as nitrogen							
8-15-84	0600	<.50	<.50	[c]<.50	1.37	2.13	--	<.50	<.50
8-16-84	0600	--	--	[a].77	<.50	<.50	<.50	<.50	.61
7-24-85	0600	.96	.01	[b].01	.38	<.01	.14	<.01	<.01
7-25-85	0600	.18	.18	[d].02	.06	.82	.85	<.01	1.35

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1)							
		1	4	SWTP	10	13	14	15	18
		Total ammonia, in milligrams per liter as nitrogen							
8-14-84	1400	0.04	0.01	--	0.03	0.02	<0.01	<0.01	<0.01
8-14-84	2200	.01	<.01	--	.02	.01	.01	.03	.01
8-15-84	0600	.01	<.01	--	.01	.01	.01	.03	.01
8-15-84	1400	.01	.01	[c].04	.03	.04	.01	<.01	.01
8-15-84	2200	.01	.01	--	.03	.01	.01	.01	.01
8-16-84	0600	.01	<.01	[a].05	.03	.01	.02	.01	.03
7-23-85	1400	.01	<.01	--	.06	.08	.03	.04	.03
7-23-85	2200	<.01	<.01	--	.05	--	.04	.04	.04
7-24-85	0600	.01	.01	--	.06	.06	.04	.01	.01
7-24-85	1400	<.01	<.01	[b].11	.05	.04	<.01	<.01	.01
7-24-85	2200	.01	.01	--	.04	.04	.02	.03	.04
7-25-85	0600	.01	.01	[d].04	.02	.01	.01	.02	.02
		Total nitrite plus nitrate, in milligrams per liter as nitrogen							
8-14-84	1400	0.43	0.88	--	10.8	11.3	6.6	4.1	3.6
8-14-84	2200	.57	.90	--	9.1	10.6	6.8	4.0	3.6
8-15-84	0600	.45	.94	--	8.9	9.9	7.0	4.4	3.7
8-15-84	1400	.60	.90	[c]11.2	9.4	8.8	6.6	4.9	3.8
8-15-84	2200	.55	.90	--	9.3	8.5	6.0	5.2	4.0
8-16-84	0600	.55	.90	[a]12.6	10.2	9.2	5.8	5.5	3.8
7-23-85	1400	.61	.77	--	11.6	10.4	3.6	3.0	2.4
7-23-85	2200	.55	.75	--	9.0	10.4	4.1	3.3	2.0
7-24-85	0600	.54	.76	--	9.4	9.8	4.4	3.6	2.9
7-24-85	1400	.61	.78	[b]13.4	10.0	9.1	3.7	3.8	3.3
7-24-85	2200	.51	.75	--	7.2	8.2	3.6	3.6	3.1
7-25-85	0600	.60	.81	[d]12.2	8.6	8.4	3.9	3.5	3.8
		Total phosphorus, in milligrams per liter as phosphorus							
8-15-84	0600	<.05	<.05	[c]7.6	4.7	5.4	2.8	2.0	1.8
8-15-84	0600	<.05	--	[a]6.6	5.0	5.7	3.9	2.4	2.1
7-24-85	0600	.07	.05	[b]6.6	3.0	3.2	1.6	1.3	1.0
7-25-85	0600	.05	<.05	[d]6.0	4.1	3.7	1.4	1.2	1.2

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1) 1	4	SWTP	10	13	14	15	18
		Dissolved orthophosphate, in milligrams per liter as phosphorus							
8-14-84	1400	0.05	<0.05	--	5.1	4.6	2.5	2.0	1.4
8-14-84	2200	.06	<.05	--	5.6	4.6	2.6	2.1	1.7
8-15-84	0600	<.05	<.05	--	5.3	5.0	2.8	2.0	2.2
8-15-84	1400	<.05	<.05	[c]6.4	4.9	2.4	2.9	2.0	1.9
8-15-84	2200	.05	.21	--	5.2	4.5	2.5	2.2	1.9
8-16-84	0600	<.05	<.05	[a]6.7	5.1	4.4	2.8	2.3	1.8
7-23-85	1400	<.05	.19	--	3.7	3.2	1.0	.95	.90
7-23-85	2200	<.05	<.05	--	3.4	3.4	1.2	1.1	.96
7-24-85	0600	<.05	<.05	--	3.6	3.7	1.4	1.2	1.0
7-24-85	1400	<.05	<.05	[b]5.6	3.0	3.3	1.1	1.2	1.0
7-24-85	2200	<.05	<.05	--	3.7	3.0	1.4	1.4	1.1
7-25-85	0600	<.05	<.05	[d]12.2	3.8	3.2	1.4	1.2	1.1
		Chlorophyll a, in milligrams per cubic meter							
8-14-84	1400	10.0	12.0	--	1.0	<1.0	4.0	4.0	2.0
8-15-84	1400	9.0	13.0	--	2.0	--	7.0	7.0	2.0
7-23-85	1400	17.5	18.3	--	2.1	2.7	15.3	19.0	14.9
7-24-85	1400	14.8	10.6	--	3.7	3.0	12.0	13.2	8.5
		Fecal coliform, colonies per 100 milliliters							
8-15-84	0600	130	230	[c]<10	500	750	110	40	30
8-16-84	0600	80	130	[a]100	840	500	270	130	130
7-24-85	0600	60	70	[b]<10	280	440	180	30	40
7-25-85	0600	130	210	[d]<10	330	550	150	70	50
		Fecal steptococi, colonies per 100 milliliters							
8-15-84	0600	40	10	[c]<10	350	330	90	50	60
8-16-84	0600	80	30	[a]<10	550	430	<10	80	40
7-24-85	0600	190	140	[b]<10	480	690	260	1,700	4,000
7-25-85	0600	220	380	[d]<10	680	2,200	390	3,700	7,300
		Total hardness, in milligrams per liter as calcium carbonate							
8-15-84	0600	250	270	[c]160	240	230	240	240	230
8-16-84	0600	250	--	[a]150	230	220	250	250	240
7-24-85	0600	134	134	[b]163	189	214	163	160	167
7-25-85	0600	142	142	[d]160	192	192	160	163	160

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1) 1	4	SWTP	10	13	14	15	18
		Alkalinity, in milligrams per liter as calcium carbonate							
8-15-84	0600	72	150	[c]145	158	152	156	169	182
8-16-84	0600	140	--	[a]141	152	154	162	158	169
7-24-85	0600	130	140	[b]140	160	160	150	150	160
7-25-85	0600	130	140	[d]140	160	160	150	150	150
		Dissolved chloride, in milligrams per liter							
8-15-84	0600	14	13	[c]160	140	120	72	67	68
8-16-84	0600	13	--	[a]180	160	150	81	68	64
7-24-85	0600	9	9	[b]160	120	115	46	36	37
7-25-85	0600	10	9	[d]165	120	140	61	46	39
		Suspended solids, residue at 105 °Celsius, in milligrams per liter							
8-14-84	1400	16	17	--	13	7	25	26	26
8-14-84	2200	21	21	--	21	22	24	24	25
8-15-84	0600	20	19	--	21	26	27	22	18
8-15-84	1400	10	18	[c]2	9	8	16	15	11
8-15-84	2200	24	22	--	12	12	13	19	11
8-16-84	0600	10	10	[a]1	9	9	13	17	13
7-23-85	1400	10	8	--	9	7	21	26	19
7-23-85	2200	12	14	--	13	8	12	22	12
7-24-85	0600	12	12	--	4	28	16	18	16
7-24-85	1400	13	13	[b]5	15	17	18	18	23
7-24-85	2200	15	5	--	10	9	6	12	9
7-25-85	0600	9	12	[d]<1	<1	3	19	14	16
		Dissolved cadmium, in micrograms per liter							
8-15-84	0600	--	<2	--	<2	--	<2	--	--
8-16-84	0600	--	<2	--	<2	--	<2	--	--
7-24-85	0600	--	<2	--	--	<2	<2	--	--
7-25-85	0600	--	<2	--	--	<2	<2	--	--
		Dissolved copper, in micrograms per liter							
8-15-84	0600	--	<5	--	6.8	--	<5	--	--
8-16-84	0600	--	<5	--	8.4	--	<5	--	--
7-24-85	0600	--	10	--	--	10	10	--	--
7-25-85	0600	--	10	--	--	10	10	--	--

Table 4.--Water-quality data collected at the outflow of the effluent from the Southwest Wastewater-Treatment Plant, and at seven sites along Wilsons Creek and the James River, August 14 to 16, 1984, and July 23 to 25, 1985--Continued

Date	Time	Sampling site (fig. 1)							
		1	4	SWTP	10	13	14	15	18
			Dissolved iron, in micrograms per liter						
8-15-84	0600	--	260	--	70	--	40	--	--
8-16-84	0600	--	<20	--	70	--	<20	--	--
7-24-85	0600	--	20	--	--	30	<20	--	--
7-25-85	0600	--	<20	--	--	<20	<20	--	--
			Dissolved lead, in micrograms per liter						
8-15-84	0600	--	<5	--	<5	--	<5	--	--
8-16-84	0600	--	<5	--	<5	--	<5	--	--
7-24-85	0600	--	<5	--	--	<5	<5	--	--
7-25-85	0600	--	<5	--	--	<5	<5	--	--
			Dissolved nickel, in micrograms per liter						
8-15-84	0600	--	<50	--	50	--	<50	--	--
8-16-84	0600	--	<50	--	60	--	<50	--	--
7-24-85	0600	--	<50	--	--	<50	<50	--	--
7-25-85	0600	--	<50	--	--	<50	<50	--	--

[a] Composite sample from 1400 hours on 8-15-84 to 1000 hours on 8-16-84.
[b] Composite sample from 1400 hours on 7-23-85 to 1400 hours on 7-24-85.
[c] Composite sample from 1400 hours on 8-14-84 to 1400 hours on 8-15-84.
[d] Composite sample from 1400 hours on 7-24-85 to 1000 hours on 7-25-85.

Missouri's water-quality standard for water temperature in Wilsons Creek and the James River specifies that water contaminants shall not cause water temperature to be greater than 32.2 °Celsius or to change more than 2.8 °Celsius (Missouri Department of Natural Resources, 1984). Water temperatures measured in Wilsons Creek and the James River during both sampling periods ranged from 21 to 29 °Celsius (table 4).

pH

The pH value is the negative logarithm of the hydrogen-ion activity and ranges from 0 to 14 units. Water with a pH of 7 is considered neutral, a pH less than 7 is considered acidic, and a pH more than 7 is considered alkaline. The pH value of water affects the chemical reactions taking place and, in turn, chemical reactions that take place affect the pH value of water. For example, respiration by living organisms and the decay of organic material produces carbon dioxide (CO_2) that is converted to carbonic acid [H_2CO_3 (aq)]. As the carbonic-acid concentration increases, the pH value decreases. During photosynthesis, carbon dioxide is used, carbonic acid is converted to carbon dioxide, and the pH value increases.

Missouri's water-quality standard for pH in Wilsons Creek and the James River specifies that water contaminants shall not cause the pH value to be less than 6.5 or more than 9.0 (Missouri Department of Natural Resources, 1984). All pH values measured during both sampling periods were within this range (table 4).

Specific Conductance

Specific conductance is a measure of the ability of water to conduct electricity. Electricity is conducted through water by positive and negative ions; thus, specific conductance is proportional to the dissolved minerals in the water.

The specific conductance in the effluent from the Southwest Wastewater-Treatment Plant was the largest of all samples collected during both sampling periods (table 4) because minerals were dissolved in the water as water was being used by the residents of Springfield and also as part of the treatment process at the wastewater plant. The large value of specific conductance of the effluent caused large values of specific conductance in Wilsons Creek and the James River downstream from the wastewater-treatment plant.

Dissolved Oxygen

Dissolved oxygen is essential for all aquatic organisms that respire aerobically. Dissolved oxygen is used by bacteria in the water during decomposition of organic material, by nitrifying bacteria on the streambed during oxidation of ammonia, and by aquatic organisms in the water and on the streambed during respiration. Dissolved oxygen is replenished by reaeration and photosynthesis.

Wastewater-treatment plants have the potential of causing small dissolved-oxygen concentrations in the water downstream from the plant, because wastewater effluent typically has large concentrations of organic material and ammonia. The addition of organic material and ammonia will increase the oxygen use in the stream due to the oxidation of organic material and ammonia. If reaeration and photosynthesis are not sufficient, the increased oxygen use could decrease the dissolved-oxygen concentrations in the stream. The dissolved-oxygen concentrations in Wilsons Creek and the James River are similar (table 4), which indicates that the effluent from the Southwest Wastewater-Treatment Plant apparently does not decrease the dissolved-oxygen concentrations in Wilsons Creek and the James River.

No standards have been specified by the State for dissolved oxygen in Wilsons Creek. Missouri's water-quality standard for dissolved oxygen in the James River specifies that water contaminants shall not cause dissolved-oxygen concentrations to be less than 5.0 milligrams per liter at any time (Missouri Department of Natural Resources, 1984). All dissolved-oxygen concentrations measured during both sampling periods were larger than 5.0 milligrams per liter (table 4).

Carbonaceous Biochemical Oxygen Demand

The carbonaceous biochemical oxygen demand (CBOD) is the quantity of oxygen consumed from the oxidation of carbonaceous organic material by biological processes during a specified period. Although various periods are used in reporting CBOD, the most common period is 5 days. CBOD is a part of the biochemical oxygen demand (BOD), which includes the quantity of oxygen consumed by the oxidation of carbonaceous organic material and oxidizable nitrogen. In the determination of CBOD, an inhibitor was added to the sample to prevent the growth of the nitrogenous bacteria that oxidize nitrogen compounds. By eliminating the oxidation of nitrogen compounds, CBOD was determined.

The 5-day CBOD data collected for Wilsons Creek and the James River during both sampling periods were less than 4 milligrams per liter (table 4). The data indicate that oxygen-consumption potential due to oxidation of organic material probably would be small and probably would be assimilated by Wilsons Creek.

It was anticipated that the minimum 5-day BOD produced by the treatment plant after tertiary treatment began would be 10 milligrams per liter (Consoer, Townsend, and Associates; and Hydroscience, Inc., 1975). The 5-day BOD would be larger than the 5-day CBOD concentration of 4 milligrams per liter, but probably would be less than 10 milligrams per liter. This indicates that the treatment plant would produce smaller 5-day BOD concentrations than originally planned.

Chemical Oxygen Demand

Chemical oxygen demand (COD) is a measure of the oxygen equivalent of organic material that is susceptible to oxidation by a strong chemical oxidant. In the absence of a catalyst, COD determinations fail to include some organic compounds (such as acetic acid), which are available for biological decomposition, while including some biological compounds (such as cellulose) which are not a part of the immediate biochemical oxygen demand (American Public Health Association and others, 1985).

As expected, the largest COD was measured in the effluent from the Southwest Wastewater-Treatment Plant (table 4). The data indicated that the effluent increased the COD in Wilsons Creek and the James River downstream from Wilsons Creek during both sampling periods.

Comparisons between the 5-day CBOD and COD data indicate that COD was much larger. This means that the materials in the wastewater effluent that contributed to the large COD were biological compounds that were not easily consumed or oxidized by the organisms in Wilsons Creek and the James River.

Streambed Oxygen Demand

Streambed oxygen demand (SOD) is the quantity of oxygen in the overlying water that is used during the decay of organic material on the streambed. The organic material can be natural, such as leaves or other dead-plant material, or produced by humans, such as settled-wastewater sludge. SOD was determined onsite using a respirometer modified from P.J. Murphy and D.B. Hicks (U.S. Environmental Protection Agency, written commun., 1985). The respirometer was made of aluminum and was designed to be forced into the streambed. The total volume of the respirometer was 81.4 liters, and it covered a streambed area of 0.267 square meter. Problems with leakage were caused by inadequate contact with the streambed when the streambed was composed of bedrock or coarse gravel.

SOD was measured at sites 1, 14, and 15 (table 4). Measurements were attempted at all water-quality sampling sites, but some measurements were considered unreliable because of leakage from the respirometer; these measurements were not included in table 4. The largest SOD was measured at site 14 in the James River downstream from Wilsons Creek.

Nitrogen

The most common forms of nitrogen occurring in water are organic nitrogen, ammonia (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). Through the process of nitrification, organic and inorganic nitrogenous compounds from a reduced state are changed to a more oxidized state by biochemical processes (Wetzel, 1975). The generalized nitrification reaction is:

$$NH_4^+ \rightarrow NH_2OH \rightarrow H_2N_2O_2 \rightarrow NO_2^- \rightarrow NO_3^-$$

The overall nitrification reaction from ammonia to nitrate is:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$$

which requires 2 moles of oxygen to oxidize 1 mole of ammonia or requires 4.6 milligrams of oxygen as O_2 to oxidize 1 milligram as N of ammonia to 1 milligram as N of nitrate.

Nitrogen species analyzed in this study were total Kjeldahl nitrogen, total ammonia, and total nitrite plus nitrate (table 4). Total Kjeldahl nitrogen includes the ammonia and organic nitrogen, but does not include nitrite and nitrate (American Public Health Association and others, 1985). Total Kjeldahl nitrogen concentrations varied daily during both sampling periods, possibly because organic material typically travels downstream in clumps instead of in solution as ammonia. Although a few total Kjeldahl nitrogen concentrations in Wilsons Creek were large, insufficient data exist to state that Wilsons Creek consistently had larger ammonia and organic-nitrogen concentrations than did the James River.

Wastewater-treatment facilities with primary or secondary treatment typically produce an effluent with large ammonia concentrations. The Southwest Wastewater-Treatment Plant uses tertiary treatment that decreases the ammonia concentrations by adding nitrified activated sludge to the effluent. This procedure adds large populations of nitrifying bacteria to the effluent that oxidizes the ammonia to nitrite and further to nitrate. The effluent from the Southwest Wastewater-Treatment Plant had small ammonia concentrations, but large nitrite plus nitrate concentrations.

Although the largest total-ammonia concentrations were measured in the effluent from the Southwest Wastewater-Treatment Plant, the concentrations were not much larger than the concentrations measured in the James River (table 4). The total-ammonia concentrations in the effluent were such that the quantity of oxygen used in oxidizing this ammonia would be small.

Tertiary treatment at the Southwest Wastewater-Treatment Plant was expected to produce an effluent with a total-ammonia concentration larger than 1 milligram per liter (Consoer, Towsend, and Associates; and Hydroscience, Inc., 1975). Total-ammonia concentrations measured during this study indicate that the treatment plant is functioning more efficiently than anticipated in decreasing ammonia in the effluent.

The large nitrite plus nitrate concentrations in the effluent from the Southwest Wastewater-Treatment Plant increased nitrite plus nitrate concentrations downstream from the treatment-plant outflow (table 4). Nitrite and nitrate are plant nutrients, so increased concentrations could contribute to nuisance aquatic plant growth in Wilsons Creek downstream from the Southwest Wastewater-Treatment Plant and in the James River downstream from Wilsons Creek.

Phosphorus

Phosphorus and orthoposphate are similar to nitrite and nitrate in that they contribute to aquatic plant growth. Because phosphorus usually is the nutrient present in the least quantity, it usually is considered the nutrient that limits the growth of aquatic plants. The U.S. Environmental Protection Agency (1986) recommends that phosphate concentrations in streams not flowing into lakes be less than 0.1 milligram per liter as P to prevent nuisance growths of aquatic plants and to control eutrophication. No water-quality standard for phosphorus has been established in Missouri.

Water samples were analyzed for total phosphorus and dissolved orthophosphate. Results of the analyses indicate that most of the phosphorus was in the form of dissolved orthophosphate (table 4).

The large dissolved orthophosphate concentrations in the effluent from the Southwest Wastewater-Treatment Plant increased the dissolved orthophosphate concentrations downstream from the treatment-plant outflow (table 4). The large dissolved orthophosphate concentrations could contribute to nuisance plant growth in Wilsons Creek downstream from the Southwest Wastewater-Treatment Plant and in the James River downstream from Wilsons Creek.

Chlorophyll *a*

Chlorophyll *a* concentrations usually are used as a measure of the phytoplankton biomass in a stream (U.S. Environmental Protection Agency, 1983). Phytoplankton is an assemblage of small aquatic plants, such as algae, that are "free floating," possess chlorophyll *a*, and have photosynthesis as the primary mode of nutrition (Wetzel, 1975). Because of the "free floating" characteristic, phytoplankton populations are largest in areas of little or no stream velocity.

The data indicate that the larger nutrient concentrations measured in Wilsons Creek and the James River downstream from the treatment-plant outflow did not increase the chlorphyll *a* concentrations (table 4). The smallest chlorphyll *a* concentrations were measured in Wilsons Creek at sites 10 and 13 where the largest nitrite plus nitrate and orthophosphate concentrations were measured. At sites 14, 15 and 18, the chlorophyll *a* concentrations were less than or similar to those concentrations measured at sites 1 and 4. Although larger chlorphyll *a* concentrations possibly could have been measured in stagnate parts of Wilsons Creek and the James River, the data indicate that nutrients had little effect on the chlorophyll *a* concentrations at the sampling sites.

Bacteria

Fecal-coliform and fecal-streptococci bacteria normally are present in the large intestine of humans and other mammals. These bacteria are used as indicators of fecal contamination and the possible presence of intestinal microorganisms that may cause disease. These bacteria do not reproduce freely in a stream environment; therefore, bacterial populations will decrease with time. Generally, a ration of fecal-coliform to fecal-streptococci bacteria of 4.0 or more indicates human sources of contamination, a ratio of 0.7 or less indicates livestock sources of contamination and a ratio between 10. and 4.0 indicates mixed sources of contamination (U.S. Environmental Protection Agency, 1978).

Bacterial concentrations measured in the effluent from the Southwest Wastewater-Treatment Plant were less than 10 colonies per 100 milliliters except on August 16, 1984, when a fecal-coliform-bacteria concentration of 100 colonies per 100 milliliters was measured (table 4). At the wastewater-treatment plant, the effluent is disinfected with ozone. All bacterial concentrations measured downstream from the wastewater-treatment plant were larger than those measured at the treatment plant, which indicates the wastewater effluent contributed few or no bacteria to Wilsons Creek or the James River.

Large fecal-streptococci-bacteria concentrations were measured on July 24 and 25, 1985, at sites 13, 15, and 18. The fecal-coliform-bacteria concentrations measured at the same time were much less, which resulted in a ratio of less than 1.0. The large fecal-streptococci-bacteria concentrations indicate that agricultural activities, such as livestock production, were contributing bacteria to parts of Wilsons Creek and the James River.

Hardness and Alkalinity

Hardness refers to the soap-precipitating capacity of water. Calcium and magnesium ions are the most common ions in water that precipitate soap, but other ions also can precipitate soap. Because more than one constituent contributes to hardness, hardness is reported in terms of an equivalent concentration of calcium carbonate.

Hardness in Wilsons Creek and the James River varies with discharge. The drainage basin of Wilsons Creek and the James River is composed of limestone, which is principally calcium carbonate. Water in the cracks and openings of limestone will dissolve the calcium carbonate. Generally, the longer the water is in contact with the limestone, the larger the calcium carbonate concentration, and the larger the hardness value. During the August 1984 sampling period, the hardness in Wilsons Creek and the James River ranged from 220 to 270 milligrams per liter as calcium carbonate. At this time the discharge was small, which indicated that flow was mostly from ground-water sources. During the July 1985 sampling period, the hardness in Wilsons Creek and the James River ranged from 134 to 214 milligrams per liter as calcium carbonate. The discharge at this time was larger than the discharge during the August 1984 sampling period. The smaller hardness values during the July 1985 sampling period indicate that the ground water contibuting to the flow in Wilsons Creek and the James River had a shorter residence time than during the August 1984 sampling period.

Alkalinity is defined as the capacity of solutes in water to react and neutralize acid. Alkalinity of a solution is determined by titrating with a strong acid until virtually all solutes contributing to alkalinity have reacted or when the rate of change of the pH value per added volume of titrant is at a maximum, generally at pH of 4.4 (Hem, 1985). The most common solutes in water contributing to alkalinity are biocarbonate and carbonate. Alkalinity in the effluent from the Southwest Wastewater-Treatment Plant, Wilsons Creek, and the James River were similar between sampling sites and between sampling periods (table 4).

Dissolved Chloride

Dissolved-chloride concentrations in Wilsons Creek and the James River were increased by the effluent from the Southwest Wastewater-Treatment Plant during both sampling periods (table 4). Dissolved-chloride concentrations at sites 1 and 4 ranged from 9 to 14 milligrams per liter. At sites 14, 15, and 18 dissolved-chloride concentrations ranged from 36 to 81 milligrams per liter. Dissolved-chloride concentration in the effluent from the wastewater-treatment plant ranged from 160 to 180 milligrams per liter.

Suspended Solids

Suspended solids refers to the dried material in a water sample that will not pass through a 45-micrometer filter. Suspended-solids concentration in Wilsons Creek and the James River were similar between sampling sites and between sampling periods. During August 14 to 16, 1984, suspended-solids concentration ranged from 8 to 27 milligrams per liter, and in July 23 to 25, 1985, suspended solids ranged from less than 1 to 28 milligrams per liter. The suspended-solids concentration measured from composite samples of the effluent from the Southwest Wastewater-Treatment Plant was slightly less than that measured in Wilsons Creek and the James River.

Trace Metals

Trace metals are significant in streams because many are toxic to aquatic organisms and humans; however, smaller concentrations are more toxic to aquatic organisms that to humans. To protect aquatic life in the James River, Missouri's water-quality standards state that water contaminants shall not cause the toxic form of trace metals to exceed the following limits (Missouri Department of Natural Resources, 1984):

Trace metal	Limit, in micrograms per liter
Cadmium	12
Copper	20
Iron	1,000
Lead	50
Nickel	100

Uncertainity exists about the toxic form of the trace metals. The above criteria applies only to dissolved concentrations of the metals (J.R. Howland, Missouri Department of Natural Resources, written commun., 1986). For this study, dissolved concentrations of cadmium, copper, iron, lead, and nickel were measured (table 4). All dissolved trace-metal concentrations were smaller than water-quality limits.

SUMMARY

Traveltime was measured at selected sites along Wilsons Creek and the James River by using Rhodamine WT as a dye tracer. Traveltime in Wilsons Creek was only measured in August 1984, whereas traveltime in the James River was measured in August 1984 and in July 1985. Because traveltime measurements were made in the James River at two different discharges, traveltimes for a range of discharges could be estimated. Traveltimes were estimated from site 4 to sites 14, 15, and 18 for discharges between 55 and 200 cubic feet per second at the index station at site 15, James River near Boaz.

Reaeration coefficients were calculated for five reaches of Wilsons Creek and the James River by using the modified-tracer technique developed by Rathbun and others (1975). These calculated reaeration coefficients ranged from 0.9 to 6.7 per day, at 20 °Celsius, in base e units. Comparisons between the calculated reaeration coefficients and coefficients predicted by 12 empirical equations indicated that the most accurate equation (eq. 9) was one developed by O'Connor and Dobbins (1958):

$$K_2 = 12.96\ U^{0.5}\ D^{-1.5}$$

where K_2 = the reaeration coefficient per day, at 20 °Celsius, in base e units;
U = the average velocity, in feet per second; and
D = the average channel depth, in feet.

Water-quality data were collected during two 44-hour periods, August 14 to 16, 1984, and July 23 to 25, 1985. Samples were collected during low-flow conditions at the outflow of the Southwest Wastewater-Treatment Plant, at two sites along Wilsons Creek, and at five sites along the James River. Discharges measured at site 15, James River near Boaz, were 50.7 cubic feet per second on August 14, 1984, and 162 cubic feet per second on July 23, 1985. Water temperatures measured in Wilsons Creek and the James River during both sampling periods ranged from 21 to 29 °Celsius. All pH values measured were within the allowable range of 6.5 to 9.0 units set by the State. During both sampling periods, the specific conductance of the wastewater effluent was largest of any samples. The dissolved-oxygen concentrations were similar during both sampling periods, which indicated that the wastewater effluent did not substantially affect the dissolved-oxygen concentration in Wilsons Creek and the James River downstream from the treatment-plant outflow. The 5-day carbonaceous biochemical oxygen demand, data indicate that the oxygen-consumption potential from oxidation of organic material probably would be small and probably would be assimilated by Wilsons Creek. The largest chemical oxygen demands were measured in the wastewater effluent, which increased chemical oxygen demand in Wilsons Creek and the James River downstream from the wastewater outflow. Streambed-oxygen demand data for the James River indicated that the largest demand was downstream from Wilsons Creek.

The tertiary-treatment process at the Southwest Wastewater-Treatment Plant was designed to decrease ammonia concentrations by adding bacteria that oxidize organic nitrogen and ammonia early in the treatment procedure. Smaller organic nitrogen and ammonia concentrations were produced at the expense of increased nitrite and nitrate concentrations. Determinations of total Kjeldahl nitrogen indicated a few large concentrations in Wilsons Creek, but insufficient data exist to state that these concentrations were consistently larger than those in the James River. Ammonia concentrations in Wilsons Creek and the James River were small, which indicated that the quantity of dissolved oxygen used for ammonia oxidation in Wilsons Creek and the James River downstream from the treatment plant would be insignificant. The large nitrite plus nitrate concentrations from the wastewater effluent increased the nitrite plus nitrate concentrations in Wilsons Creek and the James River downstream from the treatment plant.

The data collected during the study also indicated that large dissolved orthophosphate concentrations from the wastewater effluent increased the dissolved orthophosphate concentrations in Wilsons Creek and the James River downstream from the treatment plant. Although nutrient concentrations were largest downstream from the treatment-plant outflow, the chlorophyll *a* concentrations were small at the sample sites in Wilsons Creek and the James River downstream from the treatment plant. Bacterial data indicate that agricultural nonpoint sources, such as livestock production, caused large bacterial concentrations in Wilsons Creek and the James River, but the wastewater effluent was not contributing significant quantities of bacteria to the streams. The hardness in Wilsons Creek and the James River varied between sampling periods, but alkalinity was similar between sampling sites and sampling periods. The largest dissolved-chloride concentrations were measured in the wastewater effluent, which increased the dissolved-chloride concentrations downstream from the treatment plant. The suspended-solids concentrations in Wilsons Creek and the James River were similar between sampling sites and sampling periods. All trace-metal concentrations in the James River were less than the limits set by the State.

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