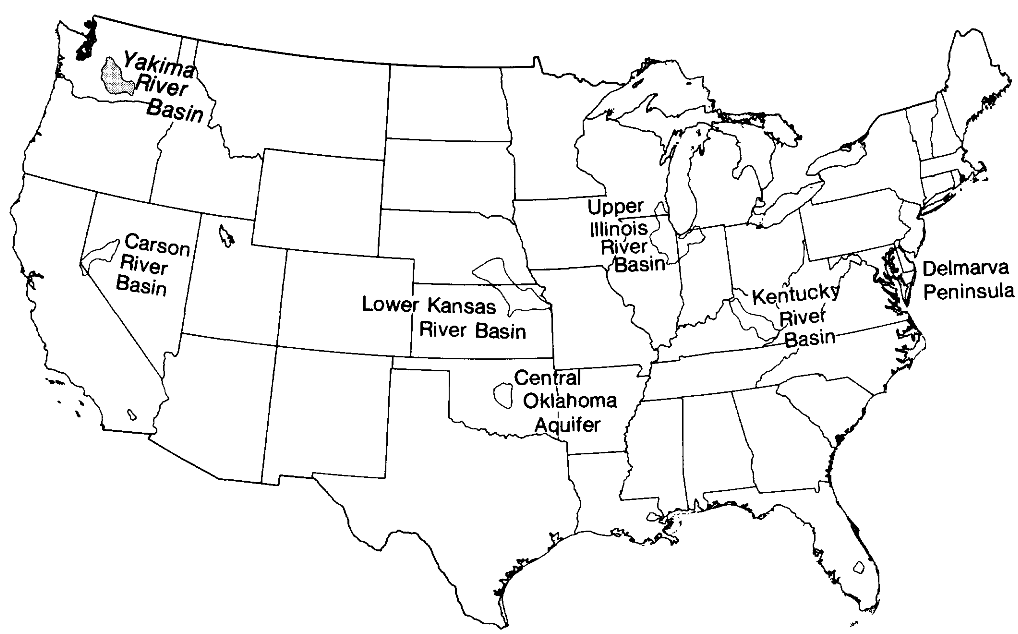
SURFACE-WATER-QUALITY ASSESSMENT OF THE YAKIMA RIVER BASIN, WASHINGTON: AREAL DISTRIBUTION OF FECAL-INDICATOR BACTERIA, JULY 1988

By S.S. Embrey



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FOREWARD

One of the great challenges faced by the Nation's water-resources scientists is providing reliable water-quality information to guide the management and protection of our water resources. That challenge is being addressed by Federal, Tribal, State, Interstate, and local water-resources agencies and by academic institutions. Many of these organizations are collecting water-quality data for a host of purposes, including compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research to advance our understanding of water-quality processes. In fact, during the past two decades, tens of billions of dollars have been spent on water-quality data-collection programs. Unfortunately, the utility of these data for present and future regional and national assessments is limited by such factors as the areal extent of the sampling network, the frequency of sample collection, the varied collection and analytical procedures, and the types of water-quality characteristics determined.

In order to address this deficiency, Congress appropriated funds for the U.S. Geological Survey (USGS), beginning in 1986, to test and refine concepts in a pilot program for a National Water-Quality Assessment (NAWQA) Program that would:

1. Provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources;
2. Define long-term trends (or lack of trends) in water quality; and
3. Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

Four surface-water projects, including the Yakima NAWQA project, and three ground-water projects were conducted as part of the pilot program to test and refine the assessment methods and to help determine the need for the feasibility of a full-scale program. Results are presented in individual reports for specific topics and for each project. In 1991, USGS began a 4-year transition from a pilot program to a full-scale program. The design concepts to be implemented are based, in part, on the pilot program that began in 1986.

NAWQA studies depend heavily on cooperation and information from many Federal, Tribal, State, Interstate, and local agencies. The assistance and suggestions of all are gratefully acknowledged.

Philip Cohen
Chief Hydrologist

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ILLUSTRATIONS

[Plates are located in pocket at end of report]

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TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Temperature	
degree Fahrenheit (°F)	(°F - 32) 5/9	degree Celsius (°C)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

SURFACE-WATER-QUALITY ASSESSMENT OF THE YAKIMA RIVER BASIN, WASHINGTON: AREAL DISTRIBUTION OF FECAL-INDICATOR BACTERIA, JULY 1988

By S. S. Embrey

ABSTRACT

In July 1988, as part of the National Water-Quality Assessment Program's pilot studies, a synoptic survey was made of fecal-indicator bacteria in the Yakima River basin, Washington. The data from the survey were used to describe the areal distribution of concentrations of fecal coliforms and of Escherichia coli, and to describe the analytical and short-term temporal variation observed in concentrations of Escherichia coli. In July, the streamflows would reflect the hydrologic conditions in the basin during the summer irrigation season and frequent contact with the surface waters by farmers and recreationists would be expected. Water samples collected at 58 sites on rivers, streams, irrigation canals, and agricultural return-flow drains were analyzed for fecal-coliform and Escherichia coli bacteria as indicators of fecal contamination and the potential presence of pathogenic bacteria.

The 95-percent confidence limits describing the variability of Escherichia coli were estimated with measurements of analytical precision. The limited data for short-term temporal variation suggested that, for sites with dynamic hydrology influenced by irrigation practices such as the agricultural drains, an understanding of the temporal variation in Escherichia coli concentrations at the site is needed to distinguish differences in bacterial concentrations among such sites.

In the northern part of the Yakima River basin (upstream from the city of Yakima), Escherichia coli concentrations ranged from 1 to 460 colonies per 100 milliliters in water samples from rivers and streams. Larger concentrations, ranging from 730 to 1,200 colonies per 100 milliliters, were determined in samples from three canals near the town of Ellensburg. For 7 of the 21 sites in the northern part of the basin where the fecal-coliform test was performed, the concentrations ranged from 1 to 150 colonies per 100 milliliters. In the southern part of the basin, concentrations of Escherichia coli ranged from 8 to 35,000 colonies per 100 milliliters. The latter value and a fecal-coliform concentration of 31,000 colonies per 100 milliliters were the largest fecal-bacteria concentrations observed during the survey and were determined in samples from a drain near the town of Sunnyside.

In the basin as a whole, 11 sites (19 percent) of the 58 sites exceeded a recommended limit of 576 colonies per 100 milliliters. This limit is one of four, single-sample limits that the U.S. Environmental Protection Agency is recommending to govern water that is used for recreation. Three of these sites are the canals in the northern part of the basin, seven are agricultural drains in the southern part of the basin, and one is a tributary stream to the Yakima River near Union Gap, also in the southern part of the basin. Although these sites are not recreational areas, people do have access to these waters, and the recommended limits can serve as guidelines regarding the potential risks associated with the bacterial concentrations. The probable sources of the large concentrations of Escherichia coli observed at these sites are the numbers of livestock on rangeland areas and in confined beef and dairy operations, animal-waste disposal practices, and irrigation return flows.

Escherichia coli concentrations increased in a downstream direction in the surface waters of the Yakima River basin and corresponded to the increased areal extent of agricultural and urban land uses. For sites in forested areas, the Escherichia coli concentrations were less than 21 colonies per 100 milliliters with a median of 7 colonies per 100 milliliters. Median concentrations of Escherichia coli increased significantly to 35 colonies per 100 milliliters for sites in the rangeland areas and increased again to 87 colonies per 100 milliliters for sites in the agricultural land-use group. As expected, the greatest effect of the basin's land uses was evident for the group of agricultural drain sites that had a median Escherichia coli concentration of 750 colonies per 100 milliliters.

INTRODUCTION

Beginning in 1986, the Congress appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA program are to:

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources,
2. Define long-term trends (or lack of trends) in water quality, and
3. Identify, describe, and explain, to the extent possible, the major factors that affect observed water-quality conditions and trends.

This information, which will be obtained on a continuing basis, would be made available to water managers, policy makers, and the public to provide an improved scientific basis for evaluating the effectiveness of water-quality management programs and for predicting the likely effects of contemplated changes in land- and water-management practices (Hirsch and others, 1988).

At present, the program is completing a pilot phase that lasted about four years. The Yakima River basin is one of four areas selected to test and further develop the assessment concepts for the surface water part of the NAWQA program. The other surface water pilot project areas are the Kentucky River basin in Kentucky, the Upper Illinois River basin in Illinois, Indiana, and Wisconsin, and the Kansas River basin in Kansas and Nebraska (Hirsch and others, 1988).

Data-collection activities during the pilot phase of study in the Yakima River basin include monthly sample collection at seven fixed stations and eight synoptic-sampling surveys. Each synoptic survey is designed to provide an overview of the basin at a point in time by making single measurements at many sites during a short collection period. Each survey focuses on one or more aspects of water-quality assessment including dissolved oxygen, trace elements, nutrients, suspended sediment, trace organic chemicals, biology, and fecal-indicator bacteria (McKenzie and Rinella, 1987).

Sanitary quality of water in the rivers is one of the issues to be addressed by the NAWQA program. Water can serve, and has served as a medium for diseases such as cholera, typhoid fever, and bacillary and amoebic dysentery. Thus, knowledge of the presence and distribution of potentially pathogenic microorganisms is essential in determining the suitability of water for public supply and recreational uses. The detection of pathogens in water samples is difficult, requiring relatively elaborate procedures. Thus, the determination of the microbiological quality of water generally relies on the detection of usually nonpathogenic bacteria that are native to the intestines of humans and other warm-blooded animals and that indicate the presence of fecal matter. These bacteria are called fecal-indicator bacteria.

Purpose and Scope

This report describes the areal distribution of fecal-indicator bacteria in the rivers and streams of the Yakima River basin and evaluates the results of a synoptic-sampling survey of the bacteria with respect to the overall sampling design of the National Water-Quality Assessment program.

Synoptic Survey Study Approach

The synoptic survey of fecal-indicator bacteria was made in July 1988 when streamflows would reflect the summer streamflows in the basin with respect to irrigation practices. The diversion canals and wasteways would be carrying water and streamflow in the main stem Yakima River would vary at points along its course depending on tributary inflows to the river and diversions of water away from the river. In addition, the month of July was chosen for the time of collection because of frequent contact with surface water by farmers and recreationists during the summer.

Streamflows were affected statewide by drought conditions from 1986 through about 1989 (U.S. Geological Survey, 1991). During the synoptic survey, the 1988 streamflows measured at 5 sample-collection sites located on tributaries to the main stem Yakima River or to the Naches River were less than the historical median streamflows for the months of July and of August and tended to approximate the historical minimum discharge of either July or August (table 1). The 1988 streamflows at the sites on the main stem Yakima River upstream from the city of Yakima and controlled by dams at the headwater reservoirs were larger than the historical median streamflows for July and August and approximated the historical maximum streamflows for August. Downstream from Yakima, however, the 1988 streamflows were similar to the historical minimum streamflows for July.

Sample-collection sites were selected by one or more of the following criteria: (1) fixed stations (totaling seven sites), (2) at the mouth of major tributaries to the main stem, (3) upstream and downstream of areas with differing land-use activities, (4) major canals, (5) sites to provide additional basin-wide coverage, and (6) sites where historical, fecal-coliform bacteria data had been collected. Fifty-eight surface-water sites were selected for the survey. Data collection began in the headwaters of the Yakima River in the Cascade Range and progressed downstream to the city of Kennewick.

Water samples were collected for determining concentrations of Escherichia coli (E. coli) and fecal-coliform bacteria. The survey focused on E. coli because, as a member of the fecal-coliform group of bacteria, it is an indicator of fecal contamination and has been correlated with the incidence of gastrointestinal disorders resulting from bodily contact with certain freshwater sources (Cabelli, 1977). The U.S. Environmental Protection Agency (USEPA) (1986) is recommending that E. coli, as one of the preferred organisms to indicate the potential presence of human pathogens in water, be incorporated into State standards governing recreational water. Water samples also were collected for field water-quality measurements and selected laboratory chemical analyses. Stream discharge measurements or gage height readings were made and used to estimate E. coli and dissolved solids mass balances for selected reaches of the main stem Yakima River.

A reconnaissance sampling trip, from June 27 through June 29, 1988, provided training in the method of E. coli collection and analysis to persons who would be responsible for sample collection and processing during the July synoptic survey. Analysis of samples collected at 10 sites in the basin gave insight to the magnitude of the concentrations of E. coli that could be encountered during the survey.

Description of the Yakima River Basin

The Yakima River basin, located in south-central Washington, drains a total of 6,155 square miles (Columbia Basin Inter-Agency Committee, 1964). Beginning in the Cascade Range at the outlet of Keechelus Lake, the Yakima River flows generally southeastward to the Columbia River (fig. 1). For discussion purposes in this report, the Yakima River basin is considered as having a northern part and a southern part with the city of Yakima as a dividing point. Some major tributaries to the Yakima River upstream from Yakima are Cle Elum River, Wilson Creek, and Naches River. Downstream from Yakima, some major tributaries are Moxee Drain, Toppenish Creek, Satus Creek, and Sulphur Creek Wasteway.

Table 1.--Stream discharges measured in July 1988 at sample-collection sites that are at or near gaging stations and selected, historical stream discharge statistics for the months of July and August

[Discharges are in cubic feet per second; statistics are for monthly means]

Station	1988 Discharge	Statistic	Monthly discharges July	Monthly discharges August	Period of record
Yakima River at Cle Elum	4,040	Maximum	4,550	3,870	1907 - 1978
		Minimum	1,080	628	
		Mean	2,690	2,500	
		Median	2,710	2,630	
Teanaway River	37	Maximum	323	90.1	1968 - 1972
		Minimum	51.3	20.2	
		Mean	147	42.6	
		Medium	74.3	34.0	
Naneum Creek	13	Maximum	120	49.7	1957 - 1978
		Minimum	12.5	7.6	
		Mean	47.8	25.1	
		Median	45.7	25.5	
Yakima River at Umtanum	3,760	Maximum	5,480	4,220	1909 - 1989
		Minimum	992	483	
		Mean	2,950	2,820	
		Median	3,020	3,110	
Bumping River	171	Maximum	1,220	600	1909 - 1978
		Minimum	102	88	
		Mean	460	320	
		Median	412	318	
Yakima River at Union Gap	2,940	Maximum	6,880	4,120	1967 - 1989
		Minimum	2,940	2,350	
		Mean	3,820	3,350	
		Median	3,590	3,380	
Ahtanum Creek at Union Gap	7	Maximum	124	26.2	1904 - 1989
		Minimum	8.9	7.3	
		Mean	35.7	15.6	
		Median	23.6	16.3	
Toppenish Creek near Satus	14	Maximum	77.7	26.7	1909 - 1923
		Minimum	4.8	4.7	
		Mean	22.1	13.1	
		Median	18.1	12.7	
Yakima River at Kiona	854	Maximum	6,070	2,330	1906 - 1989
		Minimum	678	172	
		Mean	2,080	1,440	
		Median	1,610	1,500	

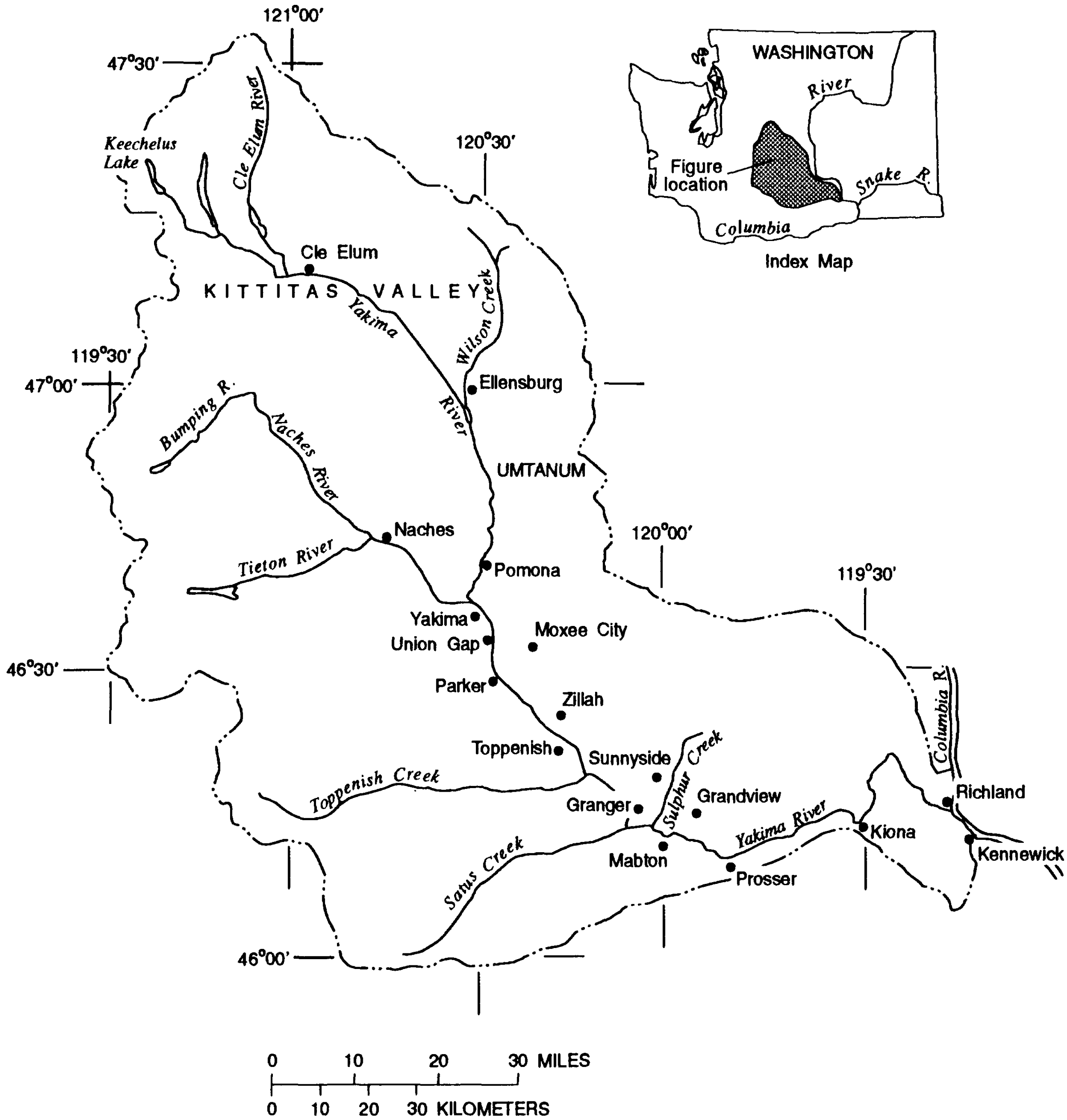

Figure 1.--Location of major streams, geographic names, and major population areas in the Yakima River basin, Washington.

McKenzie and Rinella (1987) describe in detail the characteristics of the Yakima River basin including topography, precipitation, geology, crop production, water and land use, and water quality. The climate of the basin ranges from cool, wet winters and warm, dry summers in the mountains to arid conditions at the lower altitudes. From November through March most of the precipitation in the mountainous northern part of the basin is snow. Mean-annual precipitation ranges from about 140 inches in the northwestern part to less than 10 inches in the southeastern part of the basin downstream from Yakima (McKenzie and Rinella, 1987). Most streamflows in the Yakima River basin are perennial and peak runoff generally occurs in May and June as a result of snowmelt. Six storage reservoirs exist in the basin primarily to augment summer flows for irrigation from July through October. Fourteen major diversions and about 1,900 miles of canals and laterals transport water to support about 450,000 acres of irrigated farmland and orchards. Water from irrigated lands is transported by surface and subsurface drains. The surface drains, which can be natural streams, transport agricultural, animal-production, and urban land-use wastes within the basin.

The major land-use activities in the basin include timber production, dryland grazing, and intensive irrigated agriculture. The Kittitas Valley, in the basin upstream from the city of Yakima, is farmed for crops such as hay. In addition, there are grazing areas scattered throughout the valley and in the hills surrounding the valley, and areas of confined livestock such as the feedlot near Wilson Creek (Mongillo and Faulconer, 1980). Downstream from the city of Yakima, irrigated agriculture is extensive in the river and stream valleys with grazing in the hills and numerous livestock areas. Residential properties with small amounts of acreage located in the unincorporated areas around urban centers tend to keep some livestock. These properties, known as hobby farms or "noncommercial" farms, are noted by the Washington State Department of Ecology (1989) as a relatively new threat to water quality in rivers and streams because of animal-keeping practices that can include giving the livestock free access to the stream.

The January 1988 inventory of livestock by the Washington Agricultural Statistics Services (1990) reported 263,500 cattle and calves in the Yakima River basin. Most (from about 70 to 80 percent) of the livestock were beef or non-dairy cattle kept on rangelands, on commercial farms, on the hobby farms, and in the basin's five second-stage feedlots (known as finishing feedlots). Most of the basin's livestock production is in Yakima County near the towns of Granger and Sunnyside. Four of the five feedlots are in this area (Frank Hammel, Jr., Washington Agricultural Statistics Services, oral commun., February 1991). Of about 80 dairy farms in the basin (U.S. Department of Agriculture, 1988), 72 are in Yakima County and 68 are within a 12-mile radius of Sunnyside (Jim Corliss, South Yakima Conservation District, oral commun., February 1991). Assuming 30,000 adult cattle and 14 gallons of waste per day per animal (Jim Corliss, South Yakima Conservation District, oral commun., February 1991), about 420,000 gallons of waste from dairy cattle alone are generated daily in Yakima County. The wastes are stored in holding ponds and later pumped onto fields as fertilizer. Occasionally, overflow from the ponds and runoff from the fields can result in contaminants reaching the surface waters. At present (1991), about 26 waste treatment systems are in use in the county, that, when managed properly, prevent contaminants from reaching the surface or ground water (Jim Corliss, South Yakima Conservation District, oral commun., February 1991).

Some of the larger populations centering around these agricultural activities and ranging from 48,000 to about 6,000 are in the communities of (in order of decreasing size) Yakima, Kennewick, Richland, Ellensburg, Sunnyside, Toppenish, and Grandview. The combined urban area is about 50 square miles. Sewage treatment plants for the communities of Cle Elum, Ellensburg, Selah, Naches, Yakima, Mabton, Grandview, Prosser, and others discharge to the main stem Yakima River or its tributaries. East Toppenish Drain, Wanity Slough, Granger Drain, and Drainage Improvement District 3 Drain also receive treatment plant effluent. Although the amount of land with irrigated agriculture and urban area is considerably smaller than the areas of timber production and grazing (2,200 and 2,900 square miles, respectively), the intensive activity in the agricultural area has a larger effect on water quality than do other land uses (McKenzie and Rinella, 1987).

Besides water for irrigation, the surface water of the basin is used for public drinking supplies in the upper Yakima River and Naches River basins, for fish propagation, and for recreation. Upstream from Parker, the river basin is used as a cold-water fishery. Downstream from Mabton, rivers and streams support a warm-water fishery. Water skiing on the Yakima River in the reach between Mabton and Prosser was observed during the survey. The 24-mile area of the Yakima River Canyon between Ellensburg and Yakima is one of the popular fishing, camping, and boating recreation areas in the northern part of the basin. The U.S. Bureau of Land Management (1988) estimated that from 2,000 to 4,000 people could be observed using the Yakima River Canyon on a typical weekend from June through August. Upstream from the city of Yakima there are 280,000 acres of developed recreational sites in the basin and vacationers make approximately 1 million trips a year to these sites (John J. Vaccaro, U.S. Geological Survey, written commun., April 7, 1989). Potential water-quality concerns arising from the various water- and land-use activities include excessive turbidity, bacteria, nutrients, trace metals, and trace organic chemicals in the water.

Acknowledgments

The Yakima River basin project team wishes to thank Dr. Bill Barker, Dr. Robert Pacha, and Dr. Curt Wiberg with the Biology Department of Central Washington University, and Dr. Ivar Dolph with the Biology Department of Yakima Valley Community College for providing equipment and laboratory facilities.

METHODS

Methods used for collecting and analyzing water samples for concentrations of bacteria and other water-quality characteristics are described in the following sections.

Collection and Analysis of Water Samples for Fecal-Indicator Bacteria

Depth-integrating samplers (D-77 and DH-81) with autoclaved parts were used to collect cross-sectionally composited water samples for all types of bacterial analyses (Edwards and Glysson, 1988). The samples were chilled in ice chests and transported to the field laboratory for processing within six hours from the time of collection. The field laboratory provided space for incubators and sample processing in an effort to minimize analytical variability. At sites where residual chlorine from sewage treatment plants was likely to affect bacterial growth, sodium thiosulfate was added to samples in amounts according to the American Public Health Association (1989).

Fecal-coliform bacteria were identified and enumerated using the membrane filter procedures described by Greeson and others (1977). Aliquots of water were filtered through 0.7 micrometer (pore size) filters and the filters were incubated on m-FC agar at 44.5 $\pm$ 0.2 °C for 22 $\pm$ 2 hours.

E. coli were identified and enumerated using the membrane filtration method as described by the U. S. Environmental Protection Agency (1985) and Dufour and others (1981). Aliquots of water were filtered through 0.45 micrometer (pore size) filters. The filters were placed on plates containing mTEC agar medium (Difco) and incubated at 35 $\pm$ 0.5 °C for 2 hours to resuscitate injured or stressed bacteria, and then at 44.5 $\pm$ 0.2 °C for 22 to 24 hours. Upon completion of the total incubation period, the colonies were subjected to the urease test to differentiate E. coli colonies from other thermotolerant, gram-negative, lactose-fermenting bacteria.

All reagents and solutions used in bacterial identification and enumeration were freshly prepared from analytical reagent-grade chemicals and deionized water, adjusted to a specified final pH if needed, and autoclaved as necessary. Buffered saline water, made from sodium chloride and sodium phosphate in deionized water, was used for preparing serial dilutions of sample water and for rinsing articles of equipment used during the filtration process.

Collection of Ancillary Data and On-Site Measurements

Water discharges were measured by the method of Rantz and others (1982) at the time of sample collection at sites where stream gages did not exist. At sites where gaging stations existed, discharge values were obtained from stage-discharge ratings using gage readings taken at the time of sample collection. Water temperature, pH, and specific-conductance measurements were made at the time of sample collection at each site using standard U.S. Geological Survey procedures (M. A. Sylvester, L. R. Kister, and W. B. Garrett, U.S. Geological Survey, written commun., September 1990). Cross-sectionally composited water samples for determining suspended-sediment and nutrient concentrations were collected with depth-integrating sampling equipment using methods outlined by Edwards and Glysson (1988). Subsamples of composited water for selected chemical analyses were preserved and stored according to standard U.S. Geological Survey procedures as outlined by Fishman and Friedman (1985).

QUALITY-CONTROL PRACTICES AND ASSESSMENT OF VARIABILITY.

The concentrations of E. coli observed at the study sites have a degree of uncertainty due to water-sample collection and laboratory procedures. This section discusses the methods used to estimate the amount of this uncertainty, expressed as percent variation, and gives the results of quality-control procedures. Quality control is defined as the routine procedures used to regulate measurements and produce data of satisfactory quality (Friedman and Erdmann, 1982). Water samples were collected and analyzed by design for the purpose of estimating the variation that is inherent in: (1) laboratory analysis, (2) water-sample collection, and (3) temporal factors. Other quality-control measures included blank controls on the filtration equipment, dilution and rinse waters, and the growth control on the mTEC medium.

Measurement of Total Variation

Total variation, consisting of the variation associated with the water-sample collection procedure, and the variation associated with the analytical procedure was estimated by the measurement of laboratory precision. To determine numbers of E. coli in a water sample, four to five different volumes were filtered for each water sample. To measure laboratory precision, one or more of these volumes was taken from the water sample and filtered as a replicate pair of plates.

Dufour and others (1981) examined the precision of mTEC laboratory procedures in terms of the standard deviation of the mean counts from sets of replicate filtration plates. Total variation was expressed as a percentage of the mean by the equation:

$$\text{Total percent variation} = \frac{s/\sqrt{n}}{\bar{x}}(100), \qquad (1)$$

where s is the standard deviation of the mean counts, n is the number of replicate filtration plates in a set, and $\bar{x}$ is the mean colony count per replicate set of plates. The 95-percent confidence limits of the standard deviation of the mean, expressed as a percentage of the mean, were estimated by multiplying the total percent variation by two. Using the properties of the Poisson distribution, Dufour and others (1981) estimated the 95-percent confidence limits of the theoretical percent variation of a mean from a population of plate counts as:

$$\text{95-percent confidence limits of theoretical percent variation} = \frac{200}{\sqrt{N\mu}}, \qquad (2)$$

where N is the number of replicate plates and μ is a population mean count. The curve defined by equation 2 represented the limiting precision of the method and, as used by Dufour and others (1981), was the expected total variation comprised of random error and analytical error.

Using the approach outlined above, 90 pairs of replicate filtration plates were used to estimate the 95-percent confidence limits of total percent variation using equation 1 and multiplied by two. Equation 2, with N=2, was used to estimate the curve of the 95-percent confidence limits of theoretical percent variation. The curve represented the expected total variation for numbers of bacteria determined for this particular synoptic survey. Of all 90 points on the graph, 30 percent had variation values that were larger than the theoretical 95-percent confidence limits (fig. 2). In the study by Dufour and others (1981), 35 percent of their values were larger than the expected-value curve. They attributed the larger variation (relative to the theoretical amount of variation) in these values to be a result of analytical error.

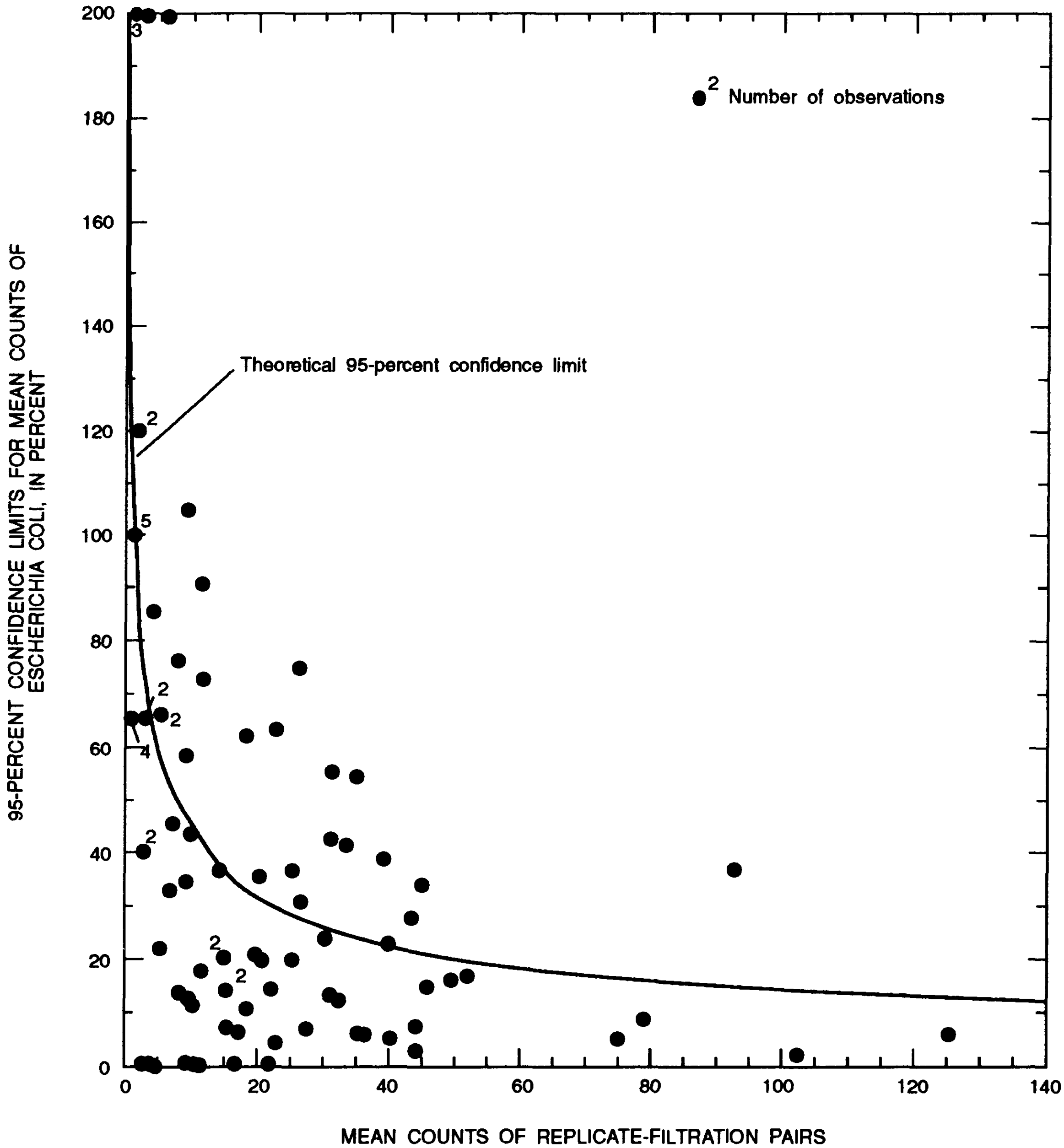

Figure 2.--The 95-percent confidence limits of mean counts of Escherichia coli for replicate filtrations and the theoretical 95-percent confidence limit curve for a population of mean counts with a Poisson distribution.

Estimate of Variation in Water-Sample Collection

Two discrete water samples were collected at six sites for the purpose of estimating the variation in collecting a representative population of E. coli during field sampling. If the two water samples were collected within one-half hour or less of one another and the stream discharge was steady during the time of collection, then the two samples were considered as duplicates. The same person filtered all the aliquot volumes for the duplicate samples and counted the resulting colonies on the plates.

Statistical Analysis System (SAS) nested analysis of variance (ANOVA) was used to examine the magnitude of variation in water-sample collection and to compare this variation with that of laboratory procedures. Nested ANOVA performs analysis of variance for data obtained in an experiment designed with a nested (hierarchical) structure (SAS Institute Inc., 1982, p. 201). Because the procedure assumes normal distribution of data, the E. coli counts were logarithmically transformed before statistical treatment. A test for normality applied to the logarithmic values indicated a satisfactory transformation of the counts.

The design of nested ANOVA progressively analyzes the data for variance from the most complex groups (usually the subgroups) to the least complex groups (or the main groups) of the experimental design groups. In other words, the nested ANOVA is such that analysis of variance begins with determining the variation within subgroups, followed by analysis of variance within the main groups, followed by analysis of variance between main groups. For this study, the subgroups are the duplicate samples and the main groups are the sample sites. The progressive analysis first determines the variance between E. coli counts from replicate-filtration pairs, which is equivalent to the analysis of variance within subgroups (the duplicate samples). The second progression is the analysis of variance between duplicate samples (equivalent to variance within main groups). The third and last progression is the analysis of variance between sampling sites (main groups).

Nested ANOVA results assigned 83 percent of the variation in E. coli counts to be between sampling sites, and 0 percent of the variation to be between the duplicate samples (table 2). The remainder of the variation, 17 percent, nested ANOVA assigned to be between the replicate filtrations (within the duplicate samples). Because variance is additive from subgroups toward main groups in nested ANOVA and because the replicate filtrations differ by 17 percent, the variance between duplicate samples must also differ by at least 17 percent. If variance between replicate filtrations and between duplicate samples differ by the same percent, then no additional error is due to variation between duplicate samples; in other words, the variation associated with water-sample collection is negligible (Dennis R. Helsel, U.S. Geological Survey, written commun., January 1990). On the basis of these results, the estimate of total variation determined from laboratory precision measurements adequately describes the variation about the numbers of E. coli determined for the water samples. Also, the curve of the 95-percent confidence limits for theoretical percent variation reasonably describes the variation observed in the mean counts used to measure laboratory precision. For this survey, then, the 95-percent confidence limits for counts of E. coli were calculated with equation 2 and adjusted for the filtered aliquot of water to give the 95-percent confidence limits of E. coli colonies per 100 milliliters of water.

Table 2.--Nested analysis of variance on groups of Escherichia coli counts determined from replicate pairs of filtrations and duplicate water samples collected at six sites

[Sum of squares, mean squares, and variance component are in logarithmic units]

Variance source	Degrees of freedom	Sum of squares	Mean squares	Variance component	Percent contribution
Between sampling sites	5	6.128	1.226	0.297	83
Between duplicate samples (within sampling sites)	6	0.215	0.036	-0.013	0
Between replicate filtrations (within duplicate samples)	12	0.731	0.061	0.061	17

Assessment of Temporal Factors on Sample Variability

To assess the degree of short-term temporal variation during the week of data collection, water samples were collected from two to seven times at four sites. Two samples were collected at Yakima River at Van Geisen Bridge (site 61) and at Sulphur Creek Wasteway (site 47), one in the morning and one in the evening of the same day. Three samples were collected at different times of the same day at Moxee Drain (site 26). Also, samples were collected on more than one day during the survey; on four days at Moxee Drain and on three days at Naches River at the mouth (site 22).

At the Naches River site, concentrations of E. coli were not different (within the 95-percent confidence limits) from day 1 to day 2 and from day 2 to day 4, although the concentrations were larger on day 4 than on previous days (fig. 3). Stream discharge in the Naches River was also larger on day 4 than on previous days.

At Moxee Drain, the concentration of E. coli in the sample on day 1 was different (within the 95-percent confidence limits) from the mean concentration of E. coli on day 2 (fig. 3). The concentration on day 4 was also different from the concentration on day 3. On day 2, E. coli concentrations in samples collected in the morning and afternoon were the same; however, the concentration in the evening sample was substantially smaller than the concentration in the samples collected earlier in the day.

The morning and evening samples collected at the Yakima River at Van Geisen Bridge (site 61) were not different in concentrations of E. coli. At Sulphur Creek Wasteway (site 47), the concentration of E. coli in the morning was 900 ± 240 col/100 mL (colonies per 100 milliliters) and in the evening, was 3,200 ± 800 col/100 mL (a difference of 72 percent). Stream discharge in Sulphur Creek decreased -21 percent from 174 ft^3/s (cubic feet per second) in the morning to 144 ft^3/s in the evening.

The temporal data showed that, at some sites, E. coli concentrations and stream discharge can vary with the day or the time of day that a water sample is collected. At Moxee Drain, the concentrations of E. coli in samples collected at different times of the day differed by as much as -128 percent and the stream discharge changed by -27 percent. The variable hydrology of Moxee Drain and Sulphur Creek Wasteway reflects their function as drains in a surface-water system dominated by irrigation practices.

During the sampling period, E. coli concentrations in samples from the Moxee Drain site ranged from 1,300 col/100 mL to 360 col/100 mL and averaged 790 col/100 mL. The overall measurement error during the week averaged ± 25 percent. However, temporal variation, which was about ± 60 percent relative to the average E. coli concentration, was substantially larger than the ability to measure concentrations of E. coli. There are not enough data to determine the magnitude of temporal variation for the basin as a whole during the synoptic survey or to assess the variation for individual sites. The data do suggest, however, that to describe the bacterial quality for sites with similar dynamic hydrologic conditions, such as the drains, some understanding is needed of the temporal variation in bacterial concentrations.

Other measures of quality control included tests of aseptic technique and sterilization procedures, and a test of the medium to support growth of E. coli. "Blank" aliquots, representing specific batches of dilution waters and rinse waters, were filtered prior to filtration of sample water. Incubation of the plates produced no bacterial colonies thereby confirming sterile reagents, and equipment. A quality-control sample containing a pure culture of E. coli and distributed by USEPA was used to test the mTEC medium. The sample vial was reported to contain 4.6×10^9 cells of E. coli, with a 95-percent confidence interval of 2.7×10^9 to 6.4×10^9 E. coli cells by the membrane filter test. Incubation of appropriate volumes of the diluted vial contents resulted in a final mean count of 2.8×10^9 cells of E. coli and confirmed the medium acceptable to use.

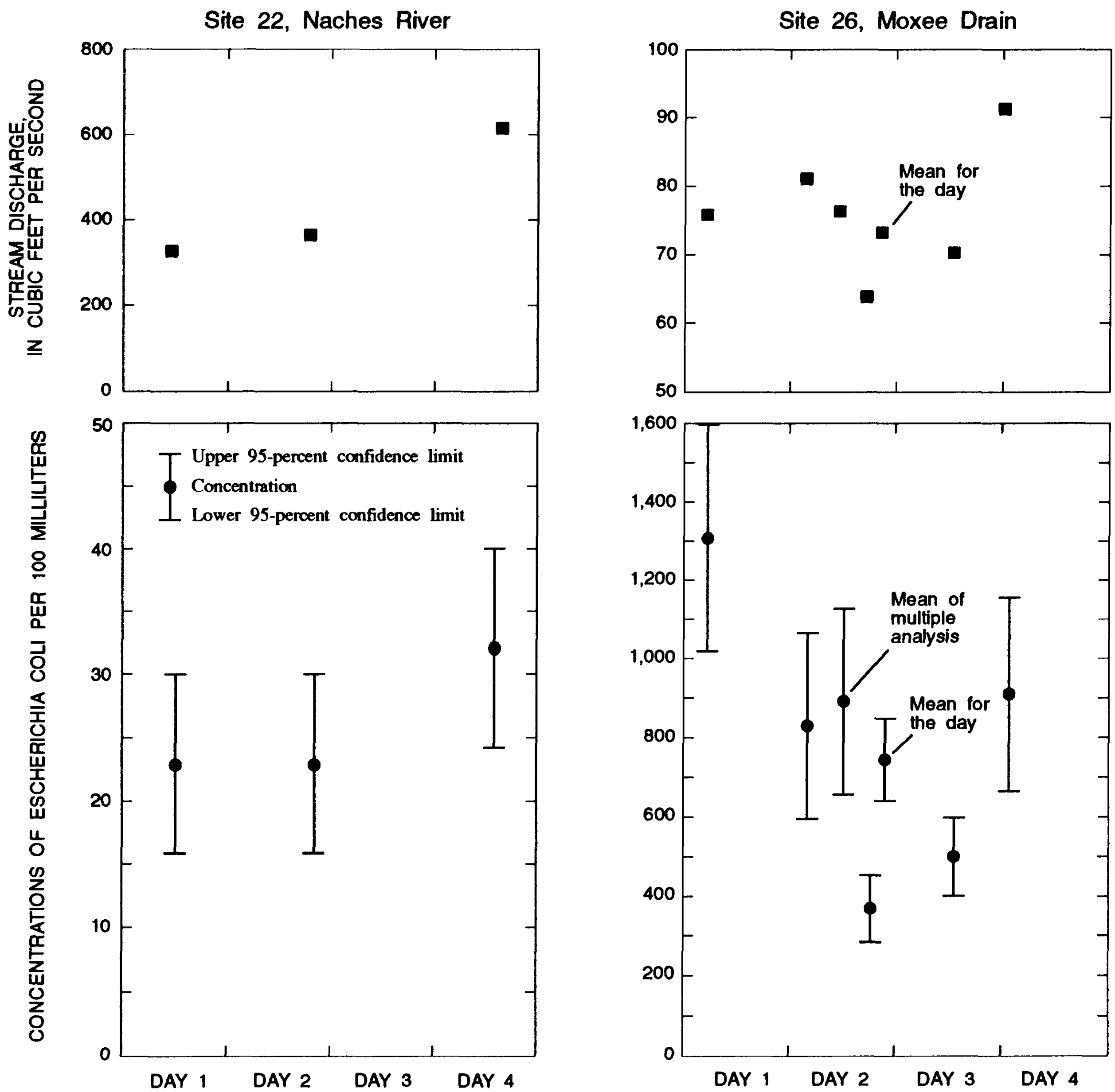

Figure 3.--Concentrations of Escherichia coli in water samples collected at different times from the Naches River at its mouth and from Moxee Drain, and the corresponding stream discharges during the synoptic survey in July 1988.

ESCHERICHIA COLI AND HISTORICAL FECAL-COLIFORM DATA

Limited historical data on concentrations of fecal-coliform bacteria at sixteen sampling sites were available for the summer months of July, August, and September. The data had been collected at the same sampling site that was used in this survey or at a nearby location that was considered representative of the synoptic survey sample-collection site.

Maximum, minimum, and median historical fecal-coliform bacteria concentrations for data collected from 1972 through 1985 are shown in figure 4 with the 1988 concentrations of fecal-coliform bacteria and E. coli. Except for Wide Hollow Creek with only 2 historical values, the Naches River at the mouth (site 22) was the only site of 16 sites with 1988 bacterial concentrations (26 col/100 mL of E. coli and 30 col/100 mL of fecal coliform) greater than the median fecal-coliform bacteria concentration of 6 col/100 mL. However, at the Naches River, the 1988 bacterial concentrations were substantially less than the maximum historical fecal-coliform bacteria concentration of 420 col/100 mL. At Ahtanum Creek (site 29), Toppenish Creek near Satus (site 40), and Satus Creek at Satus (site 41), the 1988 bacterial concentrations were less than the historical minimum concentration; however, few data were available at these sites for comparison. Generally, the concentrations of bacteria in July 1988, from either the fecal-coliform bacteria or the E. coli test, were less than the median and greater than the minimum concentration of fecal coliform for the three-month historical period.

Because E. coli is usually the dominant species of the fecal-coliform group, the concentrations of E. coli were expected to have a similar magnitude of concentration as the fecal coliforms during the survey. Figure 5 shows the relation of fecal-coliform bacteria concentrations with E. coli concentrations from the July 1988 samples. Generally, the fecal-coliform concentrations were within a range of from one-half to 2 times the E. coli concentration. Median values for sites with historical fecal-coliform bacteria data and the fecal-coliform-E. coli relation provided reasonable estimates of the concentrations of E. coli that could be expected in the samples collected during the summer months. Although the procedures of the E. coli test are more complex than those of the fecal-coliform bacteria test, some advantages in using the E. coli test were noted during the survey. The color of the colonies from the E. coli test generally required less subjective "interpretation" of color than did the "blue" color of the colonies from the fecal-coliform test. At some of the sites, fungal colonies, up to about one centimeter in diameter, and non-fecal coliform bacteria that overgrew and prevented the counting of fecal-coliform plates did not grow on the E. coli plates and interfere with the count.

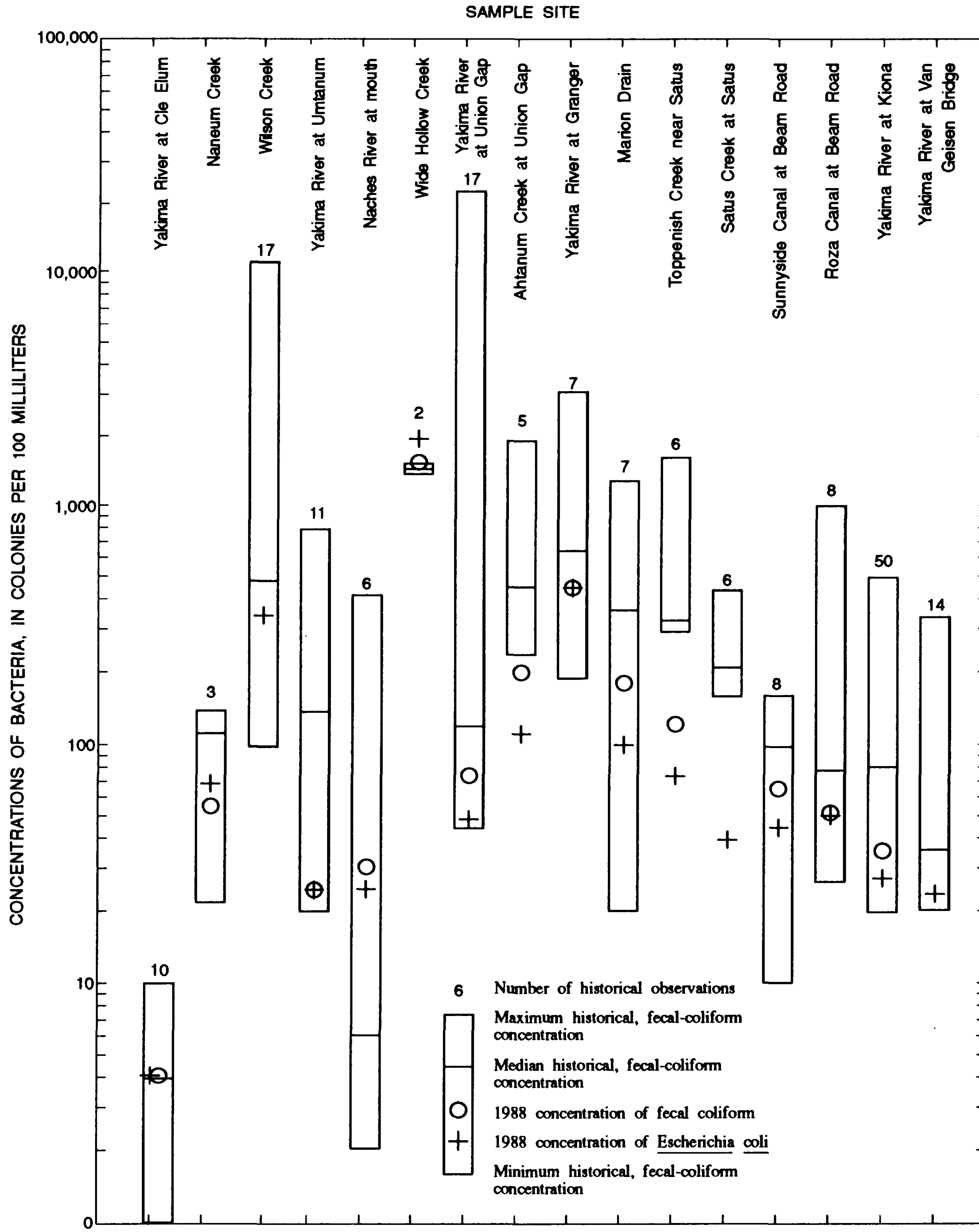

Figure 4.--Maximum, minimum, and medians of historical, fecal-coliform bacteria concentrations for the months of July, August, and September (1972 through 1985) compared with fecal-coliform and *Escherichia coli* bacteria concentrations observed at sixteen sample-collection sites during the July 1988 synoptic survey.

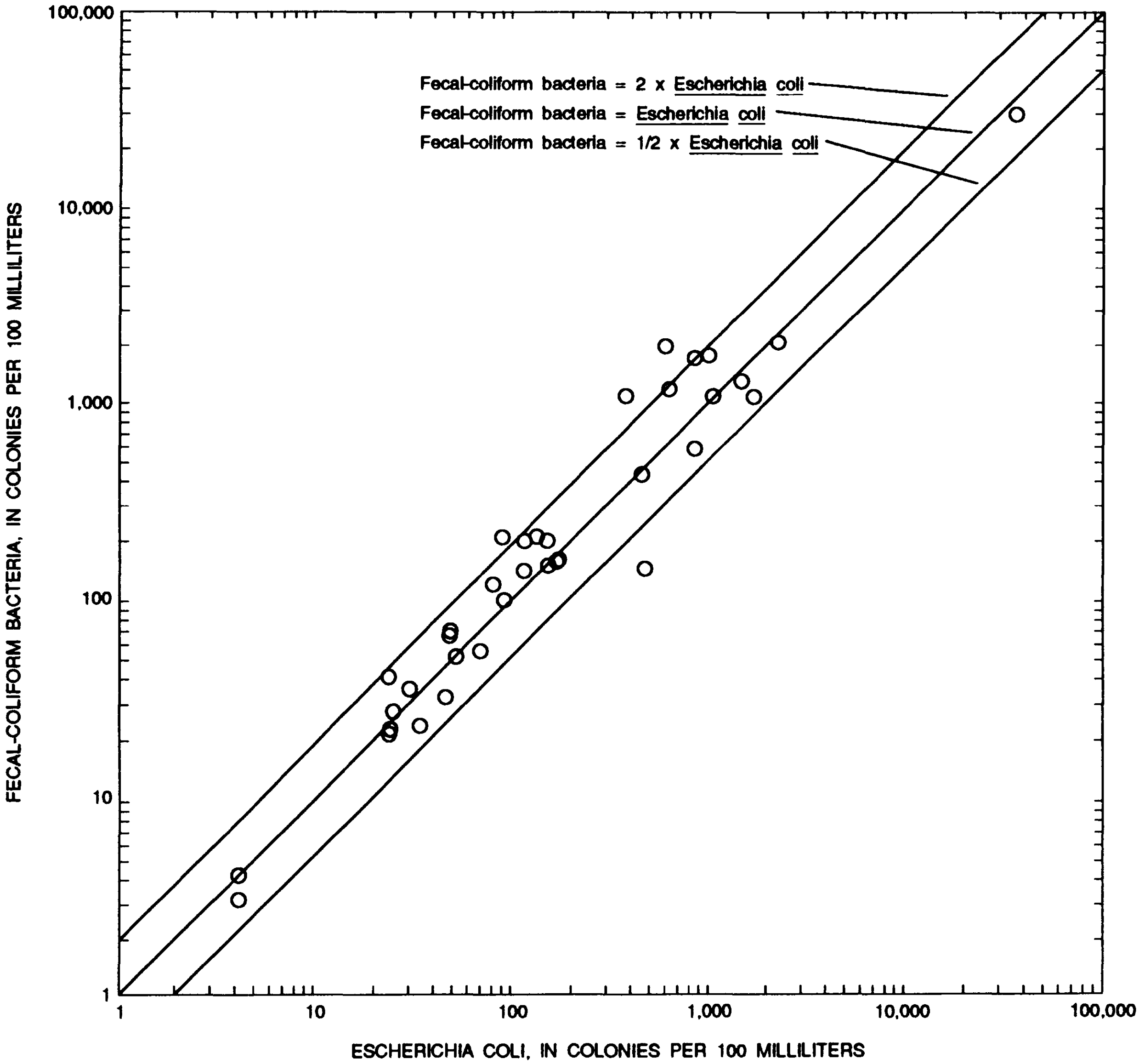

Figure 5.--Logarithmic (log 10) relation between concentrations of the fecal-coliform bacteria group and Escherichia coli bacteria during the July 1988 synoptic survey in the Yakima River basin, Washington.

AREAL DISTRIBUTION OF FECAL-INDICATOR BACTERIA IN THE YAKIMA RIVER BASIN

The location of the synoptic-survey sampling sites in the Yakima River basin and the concentration of E. coli in samples collected at these sites are shown in plate 1. Concentrations of E. coli and 95-percent confidence limits for samples collected during the July 1988 synoptic survey are shown in table 3. The concentrations of fecal-coliform bacteria in samples collected at selected sites also are listed in table 3. In plate 1, enlargement maps detail the vicinities of Union Gap and Granger where sampling sites are clustered near each other.

Escherichia Coli and Fecal Coliform in the Northern Part of the Yakima River Basin

Concentrations of E. coli in samples from rivers and streams in the northern part of the basin upstream from the city of Yakima ranged from 1 col/100 mL (estimate) in the Cle Elum River (site 1) to 460 col/100 mL in Cherry Creek (site 11). E. coli concentrations in the Naches River basin, the largest tributary to the Yakima River, ranged from 2 col/100 mL (estimate) in the Naches River at Cliffdell (site 18) to 75 col/100 mL in the Tieton River at its mouth (site 20). Fecal-coliform bacteria concentrations, in samples from 7 of the 21 northern-basin sites, ranged from 3 col/100 mL (estimate) in the Cle Elum River (site 1) to 150 col/100 mL (estimate) in Cherry Creek (site 11).

The main function of the canals in the Yakima River basin is to provide irrigation water. They might or might not serve as a tributary and return water to the rivers and streams of the basin. Large concentrations of E. coli were determined in samples from three canals in the Kittitas Valley near the town of Ellensburg: 730 col/100 mL in Town Canal (site 8), 1,000 col/100 mL (estimate) in West Side Ditch (site 9), and 1,200 col/100 mL (estimate) in Cascade Canal (site 7).

The USEPA (1986) recommends four different limits on concentrations of E. coli found in a single sample depending on different degrees of risk exposure to gastrointestinal illness during recreational contact with the water. A limit of 235 col/100 mL from a single sample is recommended for designated beach areas with full body contact swimming. The other limits allow for increasingly larger concentrations of E. coli in a single sample up to 576 col/100 mL recommended for water that is infrequently used for bathing and where incidental full body contact occurs through some activity such as water skiing. The single samples from the three canals (5 percent of the sites) had concentrations of E. coli that exceed the recommended limit of 576 col/100 mL for incidental or infrequent full body contact, and the sample from Wilson Creek had a concentration exceeding the 298 col/100 mL recommended limit for moderate, contact recreation (see table 4).

Animal grazing areas near the sites at Cascade Canal (site 7) (Russ Taylor, Washington Department of Ecology, oral commun., October 1988) and West Side Ditch (site 9) (Dan Bunson, Jr., manager, West Side Ditch, oral commun., January 1989) are probable non-point sources of fecal material. Livestock production, grazing, and irrigation return flows are likely causes for the large concentration of E. coli observed at Wilson Creek.

Escherichia Coli and Fecal Coliform in the Southern Part of the Yakima River Basin

Concentrations of E. coli in samples from rivers, streams, and drains in the southern part of the basin downstream from the city of Yakima ranged from 8 col/100 mL (estimate) in the Yakima River main stem at RM 70 (site 42) to 35,000 col/100 mL in Drainage Improvement District (DID) 3 drain (site 46) at the town of Sunnyside. The largest bacterial concentrations observed in the Yakima River basin during the survey were determined in samples from DID 3 drain; the 35,000 col/100 mL of E. coli and 31,000 col/100 mL of fecal-coliform bacteria. The second largest concentration of E. coli in the southern part of the basin and for the survey was 3,200 col/100 mL determined in the evening sample collected at Sulphur Creek Wasteway (site 47).

Table 3.--Concentrations of Escherichia coli and fecal-coliform bacteria in water samples collected during the July 1988 synoptic survey of bacteria in the Yakima River basin

[Concentrations of bacteria are in colonies per 100 milliliters of water. 95-percent confidence limits are based on raw counts of Escherichia coli and adjusted for concentrations of Escherichia coli per 100 milliliters of water; K, estimated concentration based on non-ideal colony count; ---, no data]

Site number	Site name	Date (1988)	Time	Concentrations of Escherichia coli ± the 95-percent confidence limits		Concentrations of fecal coliforms
1	Inflow to Cle Elum Reservoir	7/26	1110	K1	±1	---
2	Yakima River at Cle Elum	7/26	1350	K4	±2	K4
2	Yakima River at Cle Elum	7/26	1405	K4	±3	K3
3	Teanaway River	7/26	1710	10	±3	--
4	Yakima River at Ellensburg	7/26	1115	30	±8	---
5	Naneum Creek	7/26	0850	68	±15	55
6	Kittitas Main Canal	7/26	1450	11	±3	---
7	Cascade Canal	7/26	1100	K1,200	±160	---
8	Town Canal	7/26	1315	730	±120	---
9	West Side Ditch	7/26	1010	K1,000	±140	---
10	South Fork Manastash Creek	7/26	0900	170	±34	---
11	Cherry Creek	7/26	1115	460	±95	K150
12	Wilson Creek	7/26	1635	340[1]	±20	---
13	Yakima River at Umtanum	7/27	1210	24	±7	27
13	Yakima River at Umtanum	7/27	1220	23	±7	K21
14	Yakima River at Pomona	7/27	1130	33	±8	23
15	Little Naches River at mouth	7/27	1015	K11	±5	---
16	Bumping River	7/27	1220	K7	±5	---
18	Naches River at Cliffdell	7/27	1050	K2	±2	---
19	Rattlesnake Creek near mouth	7/27	1300	21	±11	---
20	Tieton River at mouth	7/27	1320	75	±12	---
21	Naches River at Water Treatment Plant	7/27	1315	44	±9	32
22	Naches River at mouth	7/26	1330	23	±7	22
22	Naches River at mouth	7/28	1800	23	±7	K40
22	Naches River at mouth	7/29	1510	32	±8	---
23	Wide Hollow Creek	7/28	1115	2,200	±460	2,100
23	Wide Hollow Creek	7/28	1130	1,600	±400	1,100
24	Drain near Walters Road	7/26	0930	830	±240	590
25	Drain near Birchfield Road	7/26	1100	790	±150	---
26	Moxee Drain	7/26	1100	1,300	±290	---

Table 3.--Concentrations of Escherichia coli and fecal-coliform bacteria in water samples collected during the July 1988 synoptic survey of bacteria in the Yakima River basin--continued

Site number	Site name	Date (1988)	Time	Concentrations of Escherichia coli ± the 95-percent confidence limits		Concentrations of fecal coliforms
26	Moxee Drain	7/27	0915	820	±230	K1,700
26	Moxee Drain	7/27	1345	980[1]	±147	1,800
26	Moxee Drain	7/27	1355	600	±110	1,200
26	Moxee Drain	7/27	1750	360	±84	1,100
26	Moxee Drain	7/28	1520	490	±99	---
26	Moxee Drain	7/29	0800	900	±240	---
27	Sells Well	7/28	1530	<1	---	K1
28	Yakima River at Union Gap	7/27	1645	K47	±21	K69
29	Ahtanum Creek at Union Gap	7/26	1645	110	±27	K200
31	Yakima River at Zillah	7/27	1000	K21	±10	---
32	East Toppenish Drain at Wilson Road	7/27	1330	K580	±260	2,000
33	Sub 35 Drain at Parton Road	7/29	1030	130	±30	---
34	Granger Drain	7/28	0845	1,400	±310	1,300
34	Granger Drain	7/28	0900	1,000	±260	1,100
35	Yakima River at Granger	7/29	0930	440	±110	440
36	Wapato Canal near Terminus	7/28	0905	77	±23	---
37	Wanity Slough at Meyers Road	7/28	0900	130	±29	K210
38	Toppenish Creek near Fort Simcoe	7/28	1400	K17	±7	---
39	Marion Drain	7/28	1245	120	±28	210
39	Marion Drain	7/28	1300	110	±27	140
40	Toppenish Creek near Satus	7/28	1520	77	±23	120
41	Yakima River at River Mile 78	7/28	1130	72	±22	---
42	Yakima River at River Mile 70	7/28	1500	K8	±7	---
43	Satus Creek downstream from Dry Creek	7/28	1755	K10	±5	---
44	Satus Creek at Satus	7/29	1250	70	±14	---
45	Satus Pump Canal 3	7/28	1245	K38	±19	---
46	DID 3 Drain	7/28	1510	35,000	±8,400	31,000
47	Sulphur Creek Wasteway	7/28	0945	900	±240	---
47	Sulphur Creek Wasteway	7/28	1600	3,200	±800	---
49	Yakima River at Grandview	7/28	1225	160	±33	160
49	Yakima River at Grandview	7/28	1250	140	±31	200
50	Sunnyside Canal at Beam Road	7/28	1030	46	±10	K65
51	Roza Canal at Beam Road	7/28	1130	50	±10	K51
52	Chandler Canal	7/29	1015	87	±24	100

Table 3.--Concentrations of Escherichia coli and fecal-coliform bacteria in water samples collected during the July 1988 synoptic survey of bacteria in the Yakima River basin--continued

Site number	Site name	Date (1988)	Time	Concentrations of Escherichia coli ± the 95-percent confidence limits		Concentrations of fecal coliforms
53	Yakima River upstream from Spring and Snipes Creeks	7/29	1535	K50	±23	---
54	Sunnyside Canal at Gap Road	7/29	1400	120	±27	---
55	Roza Canal at Gap Road	7/29	1300	150	±31	150
56	Spring Creek near Whitstran	7/29	1345	230	±50	---
56	Spring Creek near Whitstran	7/29	1350	240	±70	---
57	Snipes Creek near Whitstran	7/29	1400	170	±34	---
58	Kennewick Canal	7/29	0930	130	±30	---
59	Corral Canyon Creek	7/29	1115	100	±26	---
60	Yakima River at Kiona	7/29	1200	K29	±15	K35
61	Yakima River at Van Geisen Bridge	7/29	1050	28	±7	---
61	Yakima River at Van Geisen Bridge	7/29	1300	K19	±15	---
62	Kennewick Canal at Route 14 and 7th Street	7/29	0900	140	±31	---

[1] Mean for the sample time with more than one analyst.

Table 4.--Sites in the Yakima River basin where concentrations of Escherichia coli in water samples collected in July 1988 exceeded the U.S. Environmental Protection Agency's recommended limits governing recreational contact with water

[Concentrations of Escherichia coli, in colonies per 100 milliliters]

Sites Exceeding Single Sample Limits for Concentrations of Escherichia coli			
(576) Infrequent contact recreation	(406) Lightly used contact recreation	(298) Moderate full contact recreation	(235) Designated beach area
Cascade Canal	Cherry Creek	Wilson Creek	Spring Creek near Whitstran
Town Canal	Yakima River at Granger		
West Side Ditch			
Wide Hollow Creek			
Drain near Walters Road			
Drain near Birchfield Road			
Moxee Drain			
East Toppenish Drain at Wilson Road			
Granger Drain			
DID 3 Drain			
Sulphur Creek Wasteway			

The canals in this southern part of the basin did not have the large concentration of E. coli (equal to or exceeding 730 col/100 mL) that were observed in the canals in the northern part of the basin. Concentrations ranged from 38 col/100 mL (estimate) in Satus Pump Canal 3 (site 45) to 150 col/100 mL in Roza Canal at Gap Road (site 55).

Eight sites (14 percent) in the southern part of the basin had concentrations of E. coli in single samples that exceed the recommended limit of 576 col/100 mL for incidental or infrequent full body contact (USEPA, 1986) (table 4). One of these sites, Wide Hollow Creek (site 23), is a tributary to the main stem Yakima River. The other seven sites are agricultural drains. Although the drains are not intended for recreational use, they are accessible to people living in these agricultural areas; therefore the USEPA recommendations can serve as guidelines concerning the potential risk associated with the water in the drains.

Water quality standards for Washington State governing the suitability of water for various uses require median concentrations of fecal-coliform bacteria obtainable from a monitoring program. For a water supply to qualify as at least a Class B water (or "Good"), that may be used for industrial and agricultural water supply, fishery and wildlife habitat, and stock watering, the median concentration of fecal-coliform bacteria is not to exceed 200 col/100 mL and not more than 10 percent of the samples over a specified time period is to exceed 400 col/100 mL (Washington State Department of Ecology, 1977). Seven sites, all in the southern part of the basin, had single-sample fecal-coliform bacteria concentrations that were greater than 400 col/100 mL. These sites were: Wide Hollow Creek (site 23), Drain near Walters Road (site 24), Moxee Drain (site 26), East Toppenish Drain at Wilson Road (site 32), Granger Drain (site 34), Yakima River at Granger (site 35), and DID 3 Drain (site 46).

During the survey, cattle were observed near the bank of Wide Hollow Creek upstream from the sampling site. Livestock and irrigation return flows are likely sources of the large concentrations of fecal-indicator bacteria found in samples from Wide Hollow Creek. Livestock production on both beef and dairy farms, and animal-waste disposal practices are probable sources of fecal bacteria to DID 3 Drain. Large numbers of confined livestock and wastes in the Granger Drain area (U.S. Army Corps of Engineers, 1978) could account for the large concentrations of fecal bacteria determined in samples from the drains in this area.

Moxee Drain, East Toppenish Drain, Granger Drain, DID 3 Drain, and the Yakima River at Granger all receive sewage treatment effluent; however, the concentrations of fecal-indicator bacteria in the effluent at the time of sampling is not known. In a study in the Puyallup River basin that included samples from sewage treatment plants (Ebbert and others, 1987), fecal-coliform bacteria concentrations ranged from less than 4 to 30 col/100 mL in samples from two plants and from less than 10 to 14,000 col/100 mL for a third plant. The 14,000 col/100 mL was associated with a storm. This study suggests that the concentrations are variable for different plants and weather conditions and that the concentrations could be small enough not to affect bacterial concentrations determined in samples at downstream sites. Future sampling surveys might include point-source samples to determine the bacterial quality of the effluent.

SELECTED WATER-QUALITY VARIABLES AND RELATIONS TO CONCENTRATIONS OF BACTERIA

When fecal bacteria that normally inhabit the digestive tract of warm-blooded animals enter a water body, they are subjected to a variety of environmental conditions that affect their survival and die-off rates. McFeters and Stuart (1972) demonstrated that the survival of E. coli varied inversely with water temperatures between 5 and 15 °C. Different types of E. coli survived from 4 to 98 days in seawater depending on temperature and whether or not the type grew in seawater (Geldreich, 1980). Sedimentation and solar radiation affect the numbers of coliform bacteria found in the water column; solar radiation is lethal and sedimentation moves the organisms to the bottom sediments. Bottom sediments then become a protective environment and can contain substantially larger numbers of bacteria than does the overlying water (Van Donsel and Geldreich, 1971). Van Donsel and Geldreich (1971) found 100 to 1,000 times more bacteria in mud sediments than in an equal volume of overlying water. In addition to E. coli, other pathogenic bacteria, including Pseudomonas aeruginosa, Salmonella newport, and Klebsiella pneumoniae, can survive in bottom sediments, particularly in sediments containing at least 25 percent clay (Burton, Jr. and others, 1987). Some studies have reported positive correlations of fecal-coliform bacteria with phosphate and sulfate (Brasfeild, 1972) and with dissolved organic matter (Saylor and Gilmour, 1978); however, Vasconcelos and Anthony (1985) found little correlation between bacteria and nutrients. Geldreich (1976) reported that the persistence of fecal-streptococcal bacteria in storm water runoff appeared to be related to salt content and to a greater availability of certain salts than availability of organic nutrients. Stephenson and Street (1978) stated that the presence or absence of livestock along their study streams overshadowed any effect variations in chemical concentrations in the water might have had on observed concentrations of bacteria. Finally, Baxter-Potter and Gilliland (1988) summarized in a literature review that temperature, hydrologic proximity of pollution sources, livestock-management practices, wildlife activity, fecal-deposit age, and the containment of organisms within the channel and the banks are the major factors affecting the concentrations of bacteria found in runoff from agricultural lands.

Spearman correlation coefficients on rankings of bacterial concentrations, stream discharge, specific conductance, selected nutrients, major-ions, organic-carbon, and suspended-sediment concentrations indicated no strong linear relations between bacteria and these variables for the basin as a whole. The largest coefficient observed, -0.65, was between the fecal-coliform bacteria group and stream discharge; the coefficient with E. coli was -0.39. The next largest correlation coefficient was 0.61 for E. coli and suspended sediment. In general, the correlation coefficients were less than 0.6. Variables that had coefficients ranging from 0.50 to 0.65 when correlated with either E. coli or fecal-coliform bacteria were: stream discharge, suspended sediment, specific conductance, phosphorus, dissolved silica, suspended organic carbon, chloride, sulfate, and ammonia nitrogen (table 5). These variables among the 19 variables examined showed the greatest relation to concentrations of bacteria observed basin-wide for this type of single-sample study design. The relations of bacterial concentration to suspended material, dissolved solids, phosphorus, and sulfate are consistent with the previously discussed observations made by other investigators. Table 6 lists the values of selected ancillary data (stream discharge, suspended sediment, water temperature, and specific conductance) measured during the survey.

Table 5.--Spearman ranked correlation coefficients for Escherichia coli and fecal-coliform bacteria with selected water-quality and physical variables measured during July 1988 at sites in the Yakima River basin

	Spearman Correlation Coefficients on Ranks								
Bacteria	Stream discharge	Suspended sediment	Specific conductance	Dissolved phosphorus	Dissolved silica	Suspended organic carbon	Dissolved chloride	Dissolved sulfate	Dissolved ammonia nitrogen
Escherichia coli	-0.39	0.61	0.55	0.54	0.51	0.57	0.47	0.52	0.31
Fecal coliform	-0.65	0.55	0.58	0.52	0.59	0.37	0.52	0.42	0.52

Table 6.--Ancillary water-quality data collected during the July 1988 synoptic survey of bacteria in the Yakima River basin

[---, no data]

Site number	Site name	Date (1988)	Time	Stream discharge (cubic feet per second)	Suspended sediment concentration (milligrams per liter)	Suspended sediment finer than 0.062 millimeter (in percent)	Water temperature (degrees Celsius)	Specific conductance (micro siemens)
1	Inflow to Cle Elum Reservoir	7/26	1110	607	<1	---	14.7	31
2	Yakima River at Cle Elum	7/26	1350	4,040	5	50	16.5	49
2	Yakima River at Cle Elum	7/26	1405	4,040	3	68	16.5	49
3	Teanaway River	7/26	1710	37	<1	---	24.5	122
4	Yakima River at Ellensburg	7/26	1115	3,590	16	44	15.7	48
5	Naneum Creek	7/26	0850	13	4	85	15.3	84
6	Kittitas Main Canal	7/26	1450	147	6	79	21.7	41
7	Cascade Canal	7/26	1100	---	5	99	18.4	156
8	Town Canal	7/26	1315	---	6	92	---	80
9	West Side Ditch	7/26	1010	---	6	100	17.3	101
10	South Fork Manastash Creek	7/26	0900	15	5	85	13.6	78
11	Cherry Creek	7/26	1115	127	82	82	15.7	412
12	Wilson Creek	7/26	1635	83	10	93	22.0	213
13	Yakima River at Umtanum	7/27	1210	3,760	20	55	15.6	77
13	Yakima River at Umtanum	7/27	1220	3,760	19	56	15.6	77
14	Yakima River at Pomona	7/27	1130	1,800	17	90	18.3	79
15	Little Naches River at mouth	7/27	1015	68	<1	---	13.1	68
16	Bumping River	7/27	1220	171	1	---	16.6	39
18	Naches River at Cliffdell	7/27	1050	349	1	---	14.7	55
19	Rattlesnake Creek near mouth	7/27	1230	55	<1	---	19.6	79
20	Tieton River at mouth	7/27	1320	331	13	80	19.4	71
21	Naches River at Water Treatment Plant	7/27	1315	---	6	77	19.2	68
22	Naches River at mouth	7/26	1330	328	3	82	---	---
22	Naches River at mouth	7/28	1800	382	5	69	22.0	89
22	Naches River at mouth	7/29	1510	620	---	---	---	---
23	Wide Hollow Creek	7/28	1115	26	8	90	18.4	322
23	Wide Hollow Creek	7/28	1130	26	7	84	19.0	332
24	Drain near Walters Road	7/26	0930	13	273	72	16.7	347
25	Drain near Birchfield Road	7/26	1100	18	24	100	17.7	372
26	Moxee Drain	7/26	1100	76	597	88	21.6	296

Table 6.--Ancillary water-quality data collected during the July 1988 synoptic survey of bacteria in the Yakima River basin--continued

Site number	Site name	Date (1988)	Time	Stream discharge (cubic feet per second)	Suspended sediment concentration (milligrams per liter)	Suspended sediment finer than 0.062 millimeter (in percent)	Water temperature (degrees Celsius)	Specific conductance (micro siemens)
26	Moxee Drain	7/27	0915	81	613	86	18.7	285
26	Moxee Drain	7/27	1345	76	443	85	22.8	309
26	Moxee Drain	7/27	1355	76	426	86	22.8	309
26	Moxee Drain	7/27	1750	64	459	91	24.3	315
26	Moxee Drain	7/28	1520	70	565	88	22.9	320
26	Moxee Drain	7/29	0800	91	607	83	17.5	266
27	Sells Well	7/28	1530	---	---	---	---	870
28	Yakima River at Union Gap	7/27	1645	2,940	22	83	21.0	86
29	Ahtanum Creek at Union Gap	7/26	1645	7	3	99	22.4	355
31	Yakima River at Zillah	7/27	1000	163	4	99	21.0	138
32	East Toppenish Drain at Wilson Road	7/27	1330	30	20	93	20.2	262
33	Sub 35 Drain at Parton Road	7/29	1030	34	7	99	21.2	251
34	Granger Drain	7/28	0845	49	421	85	16.8	350
34	Granger Drain	7/28	0900	49	432	85	17.0	328
35	Yakima River at Granger	7/29	0930	282	70	94	20.0	265
36	Wapato Canal near Terminus	7/28	0905	---	21	91	19.2	97
37	Wanity Slough at Meyers Road	7/28	0900	63	5	93	17.6	193
38	Toppenish Creek near Fort Simcoe	7/28	1400	14	3	88	22.2	133
39	Marion Drain	7/28	1245	39	7	97	19.6	257
39	Marion Drain	7/28	1300	39	7	98	19.8	241
40	Toppenish Creek near Satus	7/28	1520	54	13	97	21.5	262
41	Yakima River at River Mile 78	7/28	1130	428	28	97	21.2	250
42	Yakima River at River Mile 70	7/28	1500	513	21	98	23.0	247
43	Satus Creek downstream from Dry Creek	7/28	1755	14	2	85	26.4	127
44	Satus Creek at Satus	7/29	1250	84	21	96	20.0	334
45	Satus Pump Canal 3	7/28	1245	32	225	89	21.2	273
46	DID 3 Drain	7/28	1510	26	356	98	21.3	448
47	Sulphur Creek Wasteway	7/28	0945	174	128	86	17.9	333
47	Sulphur Creek Wasteway	7/28	1600	144	99	88	21.5	382
49	Yakima River at Grandview	7/28	1225	990	26	94	23.1	267
49	Yakima River at Grandview	7/28	1250	990	28	92	23.1	267
50	Sunnyside Canal at Beam Road	7/28	1030	---	35	83	21.0	95

Table 6.--Ancillary water-quality data collected during the July 1988 synoptic survey of bacteria in the Yakima River basin--continued

Site number	Site name	Date (1988)	Time	Stream discharge (cubic feet per second)	Suspended sediment concentration (milligrams per liter)	Suspended sediment finer than 0.062 millimeter (in percent)	Water temperature (degrees Celsius)	Specific conductance (micro siemens)
51	Roza Canal at Beam Road	7/28	1130	---	20	85	18.1	76
52	Chandler Canal	7/29	1015	808	26	95	23.8	300
53	Yakima River upstream from Spring and Snipes Creeks	7/29	1535	206	11	98	25.6	328
54	Sunnyside Canal at Gap Road	7/29	1400	---	181	73	23.4	---
55	Roza Canal at Gap Road	7/29	1300	---	55	81	21.2	80
56	Spring Creek near Whitstran	7/29	1345	24	140	85	23.1	290
56	Spring Creek near Whitstran	7/29	1350	24	136	84	23.8	280
57	Snipes Creek near Whitstran	7/29	1400	33	53	87	24.0	168
58	Kennewick Canal	7/29	0930	---	33	93	23.7	282
59	Corral Canyon Creek	7/29	1115	16	27	70	18.4	410
60	Yakima River at Kiona	7/29	1200	854	22	92	23.8	306
61	Yakima River at Van Geisen Bridge	7/29	1050	707	23	95	23.5	309
61	Yakima River at Van Geisen Bridge	7/29	1300	---	21	91	---	---
62	Kennewick Canal at Route 14 and 7th Street	7/29	0900	---	15	93	23.9	290

EFFECTS OF LAND USE AND COVER ON CONCENTRATIONS OF ESCHERICHIA COLI

Agricultural lands can be large non-point sources of pollutants (including bacteria) in streams, and studies show that concentrations of bacteria commonly exceed water-quality standards regardless of the type of agricultural land use (Baxter-Potter and Gilliland, 1988). The effects of agriculture on the concentrations of bacteria found in water also can be prolonged by certain conditions. For example, Stephenson and Street (1978) reported that fecal-coliform bacteria concentrations in streams adjacent to summer grazing land remained large for several months after cattle were removed from the area. McKenzie and Rinella (1987) demonstrated the effects of agriculture on the water quality of the main stem Yakima River with increased concentrations of nitrite-plus-nitrate nitrogen in the southern part of the basin. Concentrations of nitrite plus nitrate in the main stem were at or near background level from Cle Elum to the town of Toppenish. At Granger and downstream to nearly the mouth, the concentrations increased by an order of magnitude and approximated the concentrations in the drains. Because of the effects of local conditions on bacteria, the concentrations of E. coli found during this survey at main stem Yakima River sites were more variable with respect to site-to-site changes than were nitrite-plus-nitrate concentrations determined in 1987. However, the concentration of E. coli also greatly increased at Granger and by an order of magnitude over concentrations observed at sites upstream on the main stem (fig. 6). Specific conductance, as a conservative indicator of the chemical characteristics of water, was approximately twice as large at Granger as at the upstream site at Zillah and remained larger at all the downstream sites (fig. 6), a result consistent with that of McKenzie and Rinella (1987).

Ranges of E. coli concentrations observed during the survey are shown on plate 2 at site locations in areas of various land uses and cover such as forest, rangeland (dry-land grazing), all types of agriculture (including feedlot and dairy activities, and fruit and row-crop production), and urban. Concentrations of E. coli found in samples at sites located in the forested headwater areas were all less than 21 col/100 mL. Where the forested cover diminishes and rangeland area predominates, concentrations of E. coli increased to 170 col/100 mL observed at South Fork Manastash Creek. Wildlife, as well as livestock and other human-related factors, could affect bacterial concentrations in these rangeland-area streams. Concentrations of E. coli in the basin's surface waters increase in a downstream direction from the Kittitas Valley to nearly the mouth of the Yakima River and correspond to the increased areal extent of agricultural and urban land uses.

Land-use and cover categories were assigned to the sites on the basis of the information shown in plate 2 and the type of land use or cover that is predominant near the site. Because of multiple land-use activities near the major population centers in the basin, 4 sites near urban areas were included with 23 sites near agricultural areas for one land-use group. Boxplots of logarithmically transformed E. coli concentrations grouped by land use and cover show the increasing trend in E. coli concentrations from the forest land to the agricultural areas of land use (fig. 7). Concentrations of E. coli (with a median of 7 col/100 mL) for the group of forest-land sites, tested with the Wilcoxon-Mann-Whitney t-test on the ranks (Iman and Conover, 1983), was significantly less (alpha=0.05, p value <0.0001) than the concentrations of E. coli in the group of rangeland sites and the group of sites in the agricultural areas. The drains function as a terminal point in the agricultural irrigation system; thus, it was expected that these sites would show the greatest effect of agriculture with respect to large concentrations of bacteria. The median concentration of E. coli was 750 col/100 mL for agricultural drains. E. coli concentrations for the group of sites in areas of multiple types of agricultural land uses, with a median of 87 col/100 mL, were significantly larger (alpha=0.05, p value=0.014) than concentrations for the rangeland group of sites with a median of 35 col/mL.

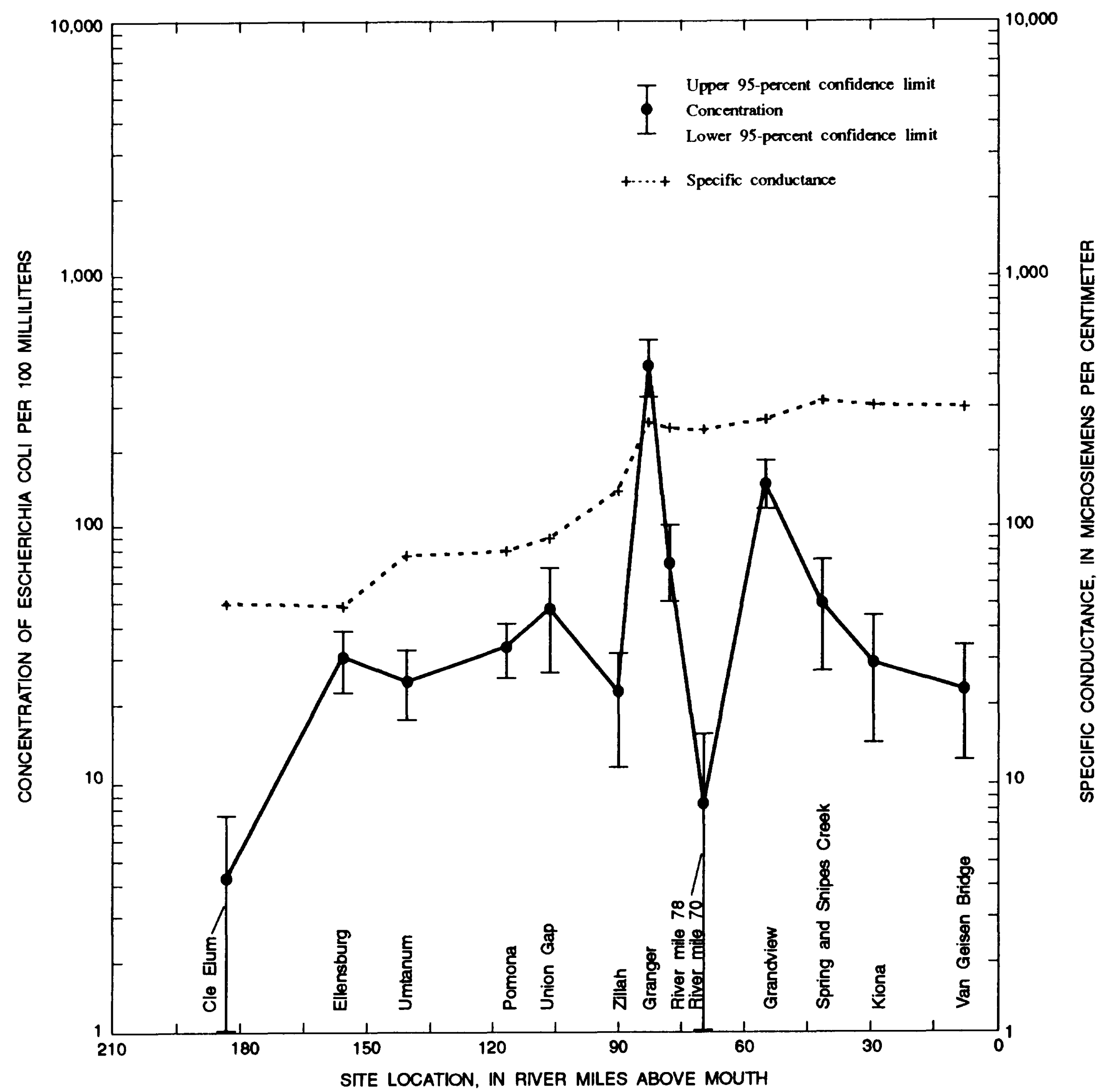

Figure 6.--Concentrations of Escherichia Coli and specific conductance in water samples collected along the main stem Yakima River.

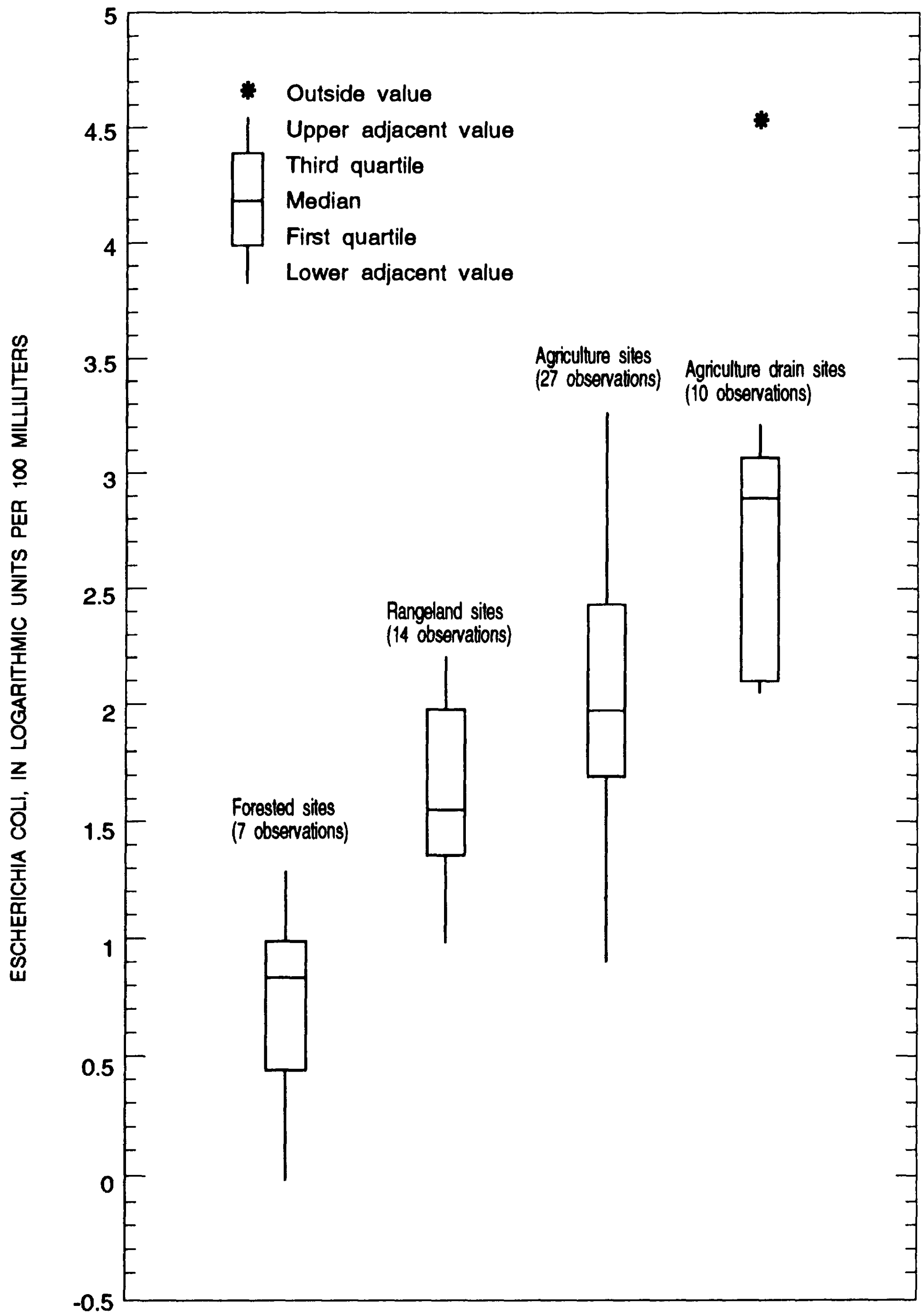

Figure 7.--Boxplots showing logarithmically transformed concentrations of Escherichia coli grouped by land use and cover near the sampling sites in the Yakima River basin. The upper adjacent value is the largest data point less than or equal to the third quartile plus 1.5 times the interquartile range. The lowest adjacent value is the smallest data point less than or equal to the first quartile minus 1.5 times the interquartile range. The outside value is a data point that is from 1.5 to 3.0 times the interquartile range beyond the box limit (defined by the adjacent value).

ESTIMATION OF ESCHERICHIA COLI AND DISSOLVED SOLIDS LOADING AT YAKIMA RIVER MAIN STEM SITES

Twelve reaches of the main stem Yakima River were defined by an upstream and a downstream sampling site for the purpose of estimating the loads of dissolved solids and E. coli in the main stem Yakima River. Dissolved-solids concentrations for the sites were estimated by multiplying site-measured specific conductance values with the factor, 0.65 (Hem, 1985, p.165). Concentrations of E. coli and the estimated dissolved-solids concentrations were then related to stream discharge at each site to convert their site-measured values to discharges in units per second. The conversion, with discharge as the common unit, was made in order to calculate and to compare the mass balances of streamflow, E. coli, and dissolved solids at each site. Stream, E. coli, and dissolved-solids discharges that were calculated for each site are referred to as site-measured discharges and mass balances in this discussion. The discharges for the reaches were estimated by (1) summing tributary discharges along the reach and the discharge calculated for the upstream main stem river site, or by (2) using a ratio of downstream-site to upstream-site stream discharges to estimate a dissolved-solids or E. coli discharge for reaches lacking tributary measurements or for reaches where water withdrawals affect the stream discharge. These are referred to as reach-calculated discharges. Finally, discharge mass balances were estimated by comparing the site-measured discharge values at each downstream site with the corresponding reach-calculated discharge values and expressed as percentage differences in mass balances (table 7). A positive, percentage difference in mass balance implied a gain in discharge at the downstream site from unaccounted sources that included measurement error and unmeasured or unknown point and non-point sources of pollutants. A negative percentage difference implied a loss in discharge to unmeasured or unknown sources that included water withdrawals and measurement error. For E. coli in particular, a large negative percentage difference in mass balance reflects the nonconservative nature of bacteria in response to die-off, which in this discussion includes the loss of organisms from the water column by sedimentation.

In reach 1, between Cle Elum and Ellensburg, the stream discharge in the main stem is affected by water withdrawals (table 7). The dissolved-solids discharge in reach 1 nearly balanced, but the site-measured E. coli discharge at Ellensburg differed from the reach-calculated E. coli discharge by +87 percent. This positive difference indicated unaccounted sources of bacteria to the main stem in this reach and, because urban development is minimal in this part of the basin, the potential sources of bacteria were likely to be non-point sources such as wildlife, agriculture, and recreational activity. In reach 2, between Ellensburg and Umtanum, the stream discharge nearly balances; however, the mass balance for dissolved solids at Umtanum differed by +16 percent, and the mass balance for E. coli differed by -114 percent. These comparisons indicated relatively small unaccounted sources of dissolved solids (and possibly of bacteria) in reach 2, but the large negative difference in E. coli mass balances indicated that die-off was the predominant factor on concentrations of E. coli observed at Umtanum (table 7).

By making similar comparisons of the discharge mass balances for the remaining 10 reaches listed in table 7 in downstream order, the mass balances for E. coli indicated that 2 other reaches, in addition to reach 1, had percentage differences that were positive. Between Umtanum and Pomona, reach 3, E. coli mass balance was +27 percent and between Zillah and Granger, reach 6, the balance was +32 percent. The positive percentage difference at Granger indicates unmeasured sources of bacteria to the main stem other than the concentrations of E. coli measured in East Toppenish Drain (site 32), Sub 35 Drain (site 33), and Granger Drain (site 34), all of which flow into the Yakima River in this reach. Downstream from Granger in reach 7, the balance for E. coli at RM 78 was -330 percent, and in reach 8, between RM 78 and RM 70, the balance for E. coli was -770 percent. These large negative differences resulting from die-off account for the markedly decreasing concentrations of E. coli, from 440 to 72 to 8 col/100mL, observed from Granger to RM 78 to RM 70, respectively.

Negative mass balances for E. coli occurred in 9 of the 12 reaches of the main stem Yakima River; positive mass balances occurred in 3 of the 12 reaches. The incidence of negative mass balances suggests that die-off was the major factor controlling concentrations of E. coli observed during the synoptic survey in the Yakima River main stem and possibly at the other sites in the basin.

Table 7.--Estimated mass balances for stream discharge, dissolved-solids discharge, and Escherichia coli discharge in reaches of the main stem Yakima River

[Stream discharge is in cubic feet per second; dissolved-solids discharge is in grams per second; Escherichia coli discharge is in millions of organisms per second; mass balance is in percent; --, no data]

Reach number	Sample sites: Yakima River main stem	Sample sites: Tributary name	Stream discharge: Site measured, Qa	Stream discharge: Reach calculated Qb	Stream discharge: Mass balance, Qa-Qb(100)/Qa	Dissolved solids discharge: Site measured, La	Dissolved solids discharge: Reach calculated Lb	Dissolved solids discharge: Mass balance, La-Lb(100)/La	Escherichia coli discharge: Site measured, Ea	Escherichia coli discharge: Reach calculated, Eb	Escherichia coli discharge: Mass balance, Ea-Eb(100)/Ea
---------	at Cle Elum		4,040	--	--	3,640	--	--	4.6	--	--
1											
---------	at Ellensburg		3,590	--	--	3,170	3,230	-2	30.5	4.1	+87
2		Cherry Creek	127	--	--	960	--	--	16.5	--	--
		Wilson Creek	83	--	--	325	--	--	7.9	--	--
--------	at Umtanum		3,760	3,800	-1	5,330	4,460	+16	25.6	55.0	-114
3											
--------	at Pomona		1,800	--	--	2,620	2,550	+3	16.8	12.3	+27
		Yakima STP	--	--	--	--	--	--	--	--	--
		Naches River	350	--	--	573	--	--	2.3	--	--
4		Roza Power House[1]	978	--	--	1,420	--	--	9.1	--	--
		Wide Hollow Creek	25.7	--	--	152	--	--	13.8	--	--
		Moxee Drain	74.1	--	--	409	--	--	21.0	--	--
--------	at Union Gap		2,940	3,230	-10	4,650	5,170	-11	39.1	63.0	-61
5		Ahtanum Creek	7.1	--	--	46	--	--	0.2	--	--
--------	at Zillah		163	--	--	414	260	+37	1.0	2.2	-120
		East Toppenish Drain	30.2	--	--	146	--	--	5.0	--	--
6		Sub 35 Drain	34.2	--	--	158	--	--	1.3	--	--
		Granger Drain	48.6	--	--	313	--	--	16.5	--	--
--------	at Granger		282	276	+2	1,380	1,030	+25	35.1	23.8	+32
7		Marion Drain	39.1	--	--	179	--	--	1.3	--	--
		Toppenish Creek	54.1	--	--	261	--	--	1.2	--	--
--------	at river mile 78		428	375	+12	1,970	1,820	+8	8.7	37.6	-330
8											
--------	at river mile 70		513	--	--	2,330	2,360	-1	1.2	10.4	-770
		Satus Creek	83.5	--	--	513	--	--	1.7	--	--
9		Sulphur Creek Wasteway	159	--	--	1,050	--	--	92.3	--	--
		South Drain	--	--	--	--	--	--	--	--	--
		302 Drain	--	--	--	--	--	--	--	--	--
--------	at Grandview		990	756	+24	4,870	3,890	+20	42.1	95.2	-130
10											
--------	upstream of Spring Creek		206	--	--	1,240	1,010	+19	2.9	9.0	-210
		Spring Creek	24.2	--	--	127	--	--	1.6	--	--
11		Snipes Creek	32.9	--	--	102	--	--	1.6	--	--
		Corral Canyon Creek	16.5	--	--	351	--	--	0.5	--	--
		Chandler Canal	43.0	--	--	223	--	--	1.6	--	--
--------	at Kiona		854	323	+62	4,810	2,040	+58	7.0	8.2	-17
12											
--------	at Van Geisen Bridge		707	--	--	4,020	3,980	+1	5.6	5.8	-4

[1] Values for dissolved solids and Escherichia coli were approximated with the values from Yakima River at Pomona.

SUMMARY

In July 1988, a synoptic survey was made of fecal-indicator bacteria in the Yakima River basin, Washington. The information from the synoptic survey was used to describe the distribution of fecal-indicator bacteria in the rivers and streams of the basin with respect to the overall sampling design of the National Water-Quality Assessment program. The data-collection period was scheduled during summer when streamflows in the basin are influenced by irrigation practices and when human contact with the water is expected. At seven of nine sites for which historical streamflow records were available, the 1988 streamflows were less than the historical median streamflows for the months of July or of August and tended to approximate the historical minimum streamflows. The years 1986 through about 1989 were considered drought years in the State. Cross-sectionally composited water samples were collected at 58 surface-water sites with sample collection beginning in the headwaters of the Cascade Range and progressing downstream to the city of Kennewick.

E. coli were identified and enumerated using the membrane-filtration method. The 95-percent confidence limits for concentrations of E. coli observed during this survey were estimated from measurements of laboratory precision. Other water-quality variables measured or collected during this survey included the fecal-coliform bacteria group, water temperature, pH, specific conductance, and concentrations of major ions, nutrients, and suspended sediment.

Multiple samples collected during the week at four sites indicated that the concentration of E. coli could vary over relatively short periods of time. At Moxee Drain and Sulphur Creek Wasteway, stream discharge changed by -27 percent and -21 percent, respectively, in one day from morning to evening. The temporal variation in E. coli concentrations, from morning to evening, was -128 percent at Moxee Drain and 72 percent at Sulphur Creek Wasteway. At Moxee Drain, temporal variation in concentrations of E. coli was larger than the ability to measure the concentrations. For sites with the dynamic hydrologic conditions that characterize the agricultural drains, an understanding of the temporal variation in bacterial concentrations and streamflows is needed to distinguish differences in bacterial concentrations among such sites.

Historical fecal-coliform data collected in July, August, and September (1972 through 1985) at sixteen sites were compared with concentrations of E. coli and fecal-coliform bacteria observed at these sites in July 1988. At the mouth of the Naches River, the mean concentrations of E. coli (26 colonies per 100 milliliters) and of fecal-coliform bacteria (30 colonies per 100 milliliters) were larger than the historical median fecal-coliform concentration of 6 colonies per 100 milliliters but were not larger than the historical maximum of 420 colonies per 100 milliliters. In general, concentrations of fecal-indicator bacteria in July 1988 samples were less than the historical median concentration but greater than the historical minimum concentration of fecal-coliform bacteria. The 1988 fecal-coliform bacteria concentrations were generally within a range of from one-half to 2 times the 1988 E. coli concentrations. This relation and the historical median concentrations of fecal-coliform bacteria concentrations provided estimates of the concentrations of E. coli that could be expected in samples collected during summer. In at least one respect, the E. coli test was advantageous over the fecal-coliform bacteria test at some of the sites because a type of fungus and some non-fecal-coliform bacteria that had excessive growth on the fecal-coliform plates did not grow on the E. coli plate and interfere with colony development and counting.

Concentrations of E. coli in samples from rivers and streams in the northern part of the Yakima River basin (upstream from the city of Yakima) ranged from 1 colony per 100 milliliters (estimate) to 460 colonies per 100 milliliters. Large concentrations of E. coli, ranging from 730 to 1,200 colonies per 100 milliliters, were found in samples from three canals in this part of the basin near the town of Ellensburg. In the southern part of the basin, concentrations of E. coli ranged from 8 (estimate) to 35,000 colonies per 100 milliliters.

The 35,000 colonies per 100 milliliters of E. coli and 31,000 colonies per 100 milliliters of fecal-coliform bacteria, determined in samples from a drain near Sunnyside, were the largest fecal-bacterial concentrations observed for the sites in the basin during the survey. The second largest concentration of E. coli observed during the survey was 3,200 colonies per 100 milliliters in the evening sample taken at Sulphur Creek Wasteway. Both of these drains flow through an area in the southern part of the basin where there are large numbers of confined animals in beef and dairy cattle operations.

For managing recreational waters, the U.S. Environmental Protection Agency is recommending limits of the concentrations of E. coli ranging from 235 colonies per 100 milliliters for a designated beach area to 576 colonies per 100 milliliters for water that is infrequently contacted. Eleven sites (19 percent) of the 58 sites in the Yakima River basin had concentrations of E. coli in single samples that exceed the limit of 576 colonies per 100 milliliters. Seven of these eleven sites are drains, three are canals in the northern part of the basin, and one is a small tributary to the main stem Yakima River at Union Gap. Irrigation return flows, non-point sources of fecal bacteria from pastures, confined livestock operations, and animal-waste disposal practices are likely contributors of bacteria to these sites.

The Washington State Department of Ecology uses concentrations of fecal-coliform bacteria to judge the suitability of water for various uses. The water-quality standards require median fecal-coliform bacteria concentrations obtainable from a monitoring program. For a water supply to qualify for use as an industrial and agricultural water supply, fishery and wildlife habitat, and stock watering, the median concentration of fecal-coliform bacteria is not to exceed 200 colonies per 100 milliliters and not more than 10 percent of the samples over a certain time period is to exceed 400 colonies per 100 milliliters. Seven sites had single-sample fecal-coliform bacteria concentrations greater than 400 colonies per 100 milliliters. These sites, all in the southern part of the basin were Wide Hollow Creek, a Drain near Walters Road, Moxee Drain, East Toppenish Drain at Wilson Road, Granger Drain, Yakima River at Granger, and Drainage Improvement District 3 Drain.

Correlation coefficients on the rankings of bacterial concentrations, stream discharge, specific conductance, and other selected water-quality variables indicated no strong linear relations between bacteria and these variables for the basin as a whole. The variables with the largest coefficients, ranging from 0.50 to 0.65, with observed concentrations of bacteria were stream discharge, suspended-sediment concentrations, specific conductance, and concentrations of phosphorus, silica, suspended organic carbon, chloride, sulfate, and ammonia nitrogen.

Increasing concentrations of E. coli in a downstream direction from the northern part of the basin to nearly the mouth of the Yakima River corresponded to the increased areal extent of agricultural activity and urban land uses. For sites in the forested headwater areas, concentrations of E. coli were less than 21 colonies per 100 milliliters. Where the forest cover diminishes and rangeland area predominates, the concentrations of E. coli increased to 170 colonies per 100 milliliters. The median E. coli concentration of 7 colonies per 100 milliliters for the forested land-use group increased to 35 colonies per 100 milliliters for the sites in the rangeland land-use group and increased again to 87 colonies per 100 milliliters for sites (excluding the drains) in the agricultural land-use group. As expected, the greatest effect of the basin's land uses was evident for the group of agricultural drain sites that had a median E. coli concentration of 750 colonies per 100 milliliters.

Discharge mass balances in dissolved solids and E. coli were evaluated for 12 reaches of the main stem Yakima River. Differences, expressed in percent, between mass balances at downstream sites and upstream sites indicated reaches where unaccounted sources or losses of streamflow and bacteria affected the observed concentrations of bacteria. Three out of 12 reaches had positive mass balances of E. coli that indicated unmeasured or unknown sources of bacteria to the main stem. Nine reaches of the 12 had negative mass balances for E. coli that indicated losses in concentrations of bacteria. The incidence of negative mass balances suggested that die-off, including loss of organisms from the water column by sedimentation, was the major factor controlling the concentrations of E. coli observed during the survey.

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