Cover photograph:

Recreation in the Yakima River near Zillah, Washington, during peak irrigation runoff in 2001.

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U.S. Department of the Interior
U.S. Geological Survey

Fecal-Indicator Bacteria in the Yakima River Basin, Washington—An Examination of 1999 and 2000 Synoptic-Sampling Data and their Relation to Historical Data

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Water-Resources Investigations Report 02–4054

Portland, Oregon: 2002

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Telephone: 1-888-ASK-USGS

Suggested citation:

Morace, J.L., and McKenzie, S.W., 2002, Fecal-indicator bacteria in the Yakima River Basin, Washington—An examination of 1999 and 2000 synoptic-sampling data and their relation to historical data: U.S. Geological Survey Water-Resources Investigations Report 02–4054, 32 p.

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, Tribal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.59	square kilometer (km^2)
deciliter (dL)	0.1057	quart (qt)
liter (L)	1.057	quart
milligrams per liter (mg/L)	1	parts per million (ppm)
cubic feet per second (ft^3/s)	0.028317	cubic meters per second (m^3/s)

AFO animal-feeding operation
CAFO concentrated animal-feeding operation
col/100 mL colonies of bacteria per 100 milliliters of water
col/dL colonies of bacteria per deciliter of water, equivalent to col/100 mL
E. coli *Escherichia coli* bacteria
KCCD Kittitas County Conservation District
KRD Kittitas Reclamation District
NAWQA National Water-Quality Assessment Program
PAM polyacrylamide, a flocculant
RM river mile
RPD relative percent difference
RSBOJC Roza-Sunnyside Board of Joint Control
USBR-PNL U.S. Bureau of Reclamation-Pacific Northwest Laboratory
USEPA U.S. Environmental Protection Agency
USGS U.S. Geological Survey

MAPPING SOURCES:

Base map modified from U.S. Geological Survey data and other digital sources:

Basin: USGS-Digitized from DRGs and topographic maps, 1:24,000, compiled 1999.
Counties: Washington State Department of Transportation, 1:500,000, compiled 1995.
Cities: Washington State Department of Transportation, 1:24,000, compiled 2002.
USGS-GNIS, 1:24,000, compiled 2001.
Roads: Washington State Department of Transportation, 1:24000, 1996, compiled 2000.
Hydrography: Pacific Northwest River Reach Files, USGS, 1:100,000, compiled 1999.
Canals: USGS, Digitized from DRGs and topographic maps, 1:24,000, compiled 2000.

Projection: Albers Conical Equal Area.
Datum: North American Datum of 1983 (NAD83).
Spheroid: Geodetic Reference System 1980 (GRS 1980).
Standard parallels: 29^{o}30’00” and 45^{o}30’00”, Central meridian: 119^{o}00’00”.

ACKNOWLEDGEMENTS

SAMPLING
Dewey Copeland
James Ebbert
Sandra Embrey
Gregory Fuhrer
Joe Gilbert
Ellen Harris
Curt Hughes
Hank Johnson
Jennifer Key (Central Washington University)
C.G. Laird
Jan O'Neil
Paivikki "Vicky" Pihl (Tampere University, Finland)
Joseph Rinella
Steve Rodgers
Mike Sarantou
Johnna Sheehy
Ian Waite

SAMPLING SUPPORT
Amy Brooks
Brent Morace (volunteer)

SAMPLING COORDINATION AND ANALYSIS FUNDING
Chris Coffin and
Ryan Anderson
(Washington Department of Ecology)

SAMPLE ANALYSIS
Staff at Washington Department of Ecology's Laboratory in Manchester, WA
Ann Rice and
William Rice
(Roza-Sunnyside Board of Joint Control)

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William Rice
(Roza-Sunnyside Board of Joint Control)
Robert Stevens
(Washington State University, Prosser Irrigated Agriculture Research and Extension Center)
Elaine Taylor
(Yakima County, Planning Department)
Marie Zuroske
(South Yakima Conservation District)

EDITING AND REPORT PUBLICATION
Jacqueline Olson
Donita Parker
Thelma Parks
John Williams

Fecal-Indicator Bacteria in the Yakima River Basin, Washington—An Examination of 1999 and 2000 Synoptic-Sampling Data and their Relation to Historical Data

By Jennifer L. Morace *and* Stuart W. McKenzie

Abstract

The Yakima Basin National Water-Quality Assessment Program collected fecal-coliform bacteria samples during three synoptic samplings to identify and quantify the cause, source, transport, and effects of fecal-indicator bacteria in Yakima River Basin streams. The August 1999 synoptic sampling targeted the Yakima River main-stem and tributary sites, while the July and October–November 2000 synoptic samplings targeted small- and intermediate-sized agricultural watersheds during irrigation and nonirrigation season, respectively. Quality-assurance results indicated that variability in fecal-coliform concentrations is large and, therefore, a difference of an order of magnitude or more between sites or between times is required for the values to be significantly different 90 percent of the time.

The August 1999 synoptic sampling results indicated that (1) 44 percent of the sites visited, including all the main-stem Yakima River sites, met the Class A fecal-coliform 90th percentile standard of 200 colonies per deciliter, (2) tributaries were the likely source of fecal contamination to the main stem, and (3) tributaries with high fecal-coliform concentrations typically also had high suspended-sediment concentrations. Results of the July and October–November 2000 synoptic samplings indicated that (1) 36 and 81 percent of the sites sampled, respectively, met the standard, (2) during the nonirrigation synoptic sampling, four of the six sites not meeting the standard were from the Granger and Sulphur subbasins, and (3) fecal-coliform concentrations during the irrigation season were generally higher than during the nonirrigation season.

Several levels of temporal variability were examined. The short-term variability observed during a synoptic sampling was found to be site specific, with some sites fairly consistent, while others were rather variable. Seasonally, most sites from the 2000 synoptic samplings showed higher concentrations during irrigation than during nonirrigation. Historically, 13 of the 22 sites sampled during both the July 1988 and August 1999 synoptic samplings had higher concentrations in 1999. The three sites with the highest concentrations in July 1988, however, all had decreases in August 1999. When compared against historical (1972–85) minimum and maximum summer-month medians, the August 1999 synoptic-sampling concentrations generally were between these values.

Instantaneous fecal-coliform bacteria loads were calculated for the August 1999 synoptic sampling in an effort to study the dynamics of bacterial transport. Tributaries affected by agricultural, urban, and hobby farm activities were generally the major sources of bacteria to the main-stem

Yakima River during this time. When these August 1999 synoptic-sampling loads in the lower basin reach from the Yakima River at river mile 72 to Kiona (river mile 29.9) were compared to those from the July 1988 synoptic sampling, most sites had higher loads in 1999.

A nonparametric Spearman test was used to detect correlations between fecal-coliform concentrations and physical and chemical data collected during the synoptic samplings. Results for the August 1999 synoptic sampling, which included many mouths of tributaries, showed strong significant correlations with almost every variable. In contrast, only some of the nutrient concentrations showed strong significant correlations during the July and October–November 2000 synoptic samplings, which included small and intermediate-sized agricultural streams.

Looking forward relative to future monitoring goals, research needs, and best management practice development, four hypotheses that deal with processes and sources of bacteria were identified: (1) overland runoff transports bacteria from land surfaces to streams, (2) bacteria in the water column tend to associate with suspended matter, (3) with increasing densities of warm-blooded animals, the likelihood of fecal-coliform contamination in streams also increases, and (4) identification of bacterial sources is difficult, but must be attempted for remediation to be possible.

INTRODUCTION

The NAWQA Program and the Yakima River Basin

In 1986, the U.S. Geological Survey (USGS) established the National Water-Quality Assessment (NAWQA) Program in an effort to better understand how natural and human influences affect water quality in different parts of the Nation. The NAWQA Program works with other Federal, Tribal, State, and local agencies to assess the water quality of more than 50 major river basins and aquifer systems. The Yakima River Basin in central Washington, which is one of the most intensively farmed and irrigated areas in the United States and often is referred to as "The Nation's Fruitbowl," is one of these basins.

Irrigated agriculture in the lower Yakima River Basin.

The Yakima River Basin NAWQA served as a pilot Study Unit for Cycle I of the NAWQA Program during the 1987–91 water years. During this early work, water-quality and ecological-community indices were related to dominant land uses. Agricultural practices were found to greatly increase concentrations of suspended sediment, nutrients, arsenic, pesticides, and fecal-indicator bacteria in streams that receive irrigation-return flows (Morace and others, 1999). The 1999 restart of the Yakima NAWQA for Cycle II presents a unique opportunity to develop a better understanding of water-quality/land-use associations and assist local remediation efforts with information on processes that control the delivery of contaminants to streams.

Basin and Streamflow Conditions

The Yakima River drains 6,155 mi^2 (square miles) of mostly forested, range, and agricultural land in south-central Washington. The river begins in the Cascade Range at the foot of Keechelus Dam and flows southeastward to the Columbia River (fig. 1). The central and eastern parts of the basin consist of basalt flows that form a series of east-northeast to east-southeast trending valleys and ridges. The eastern part

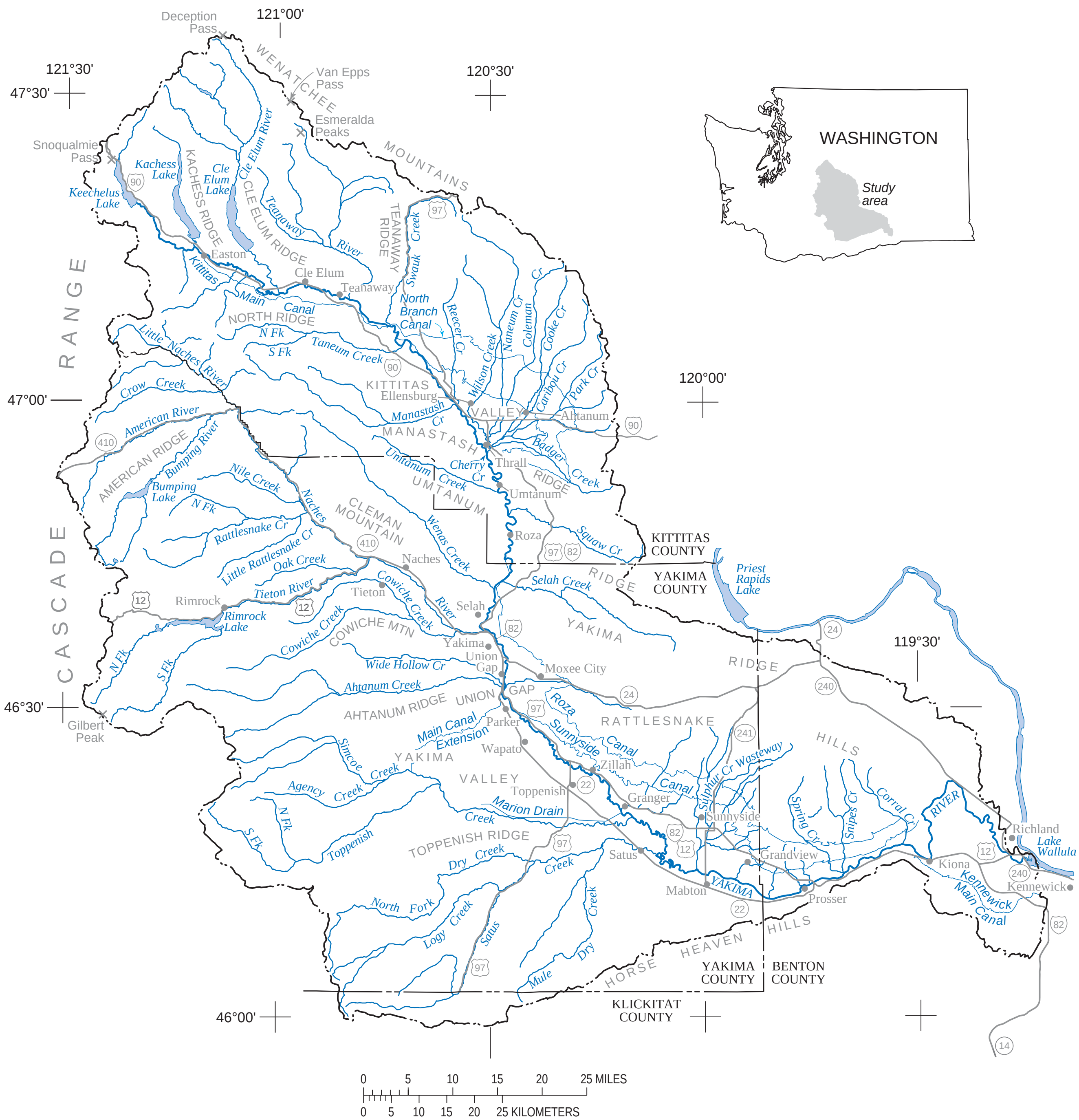


Figure 1. The Yakima River Basin, Washington.

is more arid than the western part, which is forested and mountainous. Mean annual precipitation in the basin ranges from 140 inches per year in the mountains to less than 10 inches per year in Kennewick, near the mouth of the basin. The Yakima River main stem and its largest tributary, the Naches River, are perennial, with peak runoff during peak snowmelt, usually in April and May.

The Bureau of Reclamation's Yakima Project has six irrigation divisions, one storage division, and provides water to irrigate almost one-half million acres. Its facilities include 6 storage reservoirs, 416 miles of canals, 1,701 miles of laterals, 30 pumping plants, 145 miles of drains, 2 small hydroelectric plants, and 74 miles of transmission lines (Bonneville Power Administration, 1985). Many of these waterways, most of which are natural streams, convey agricultural runoff and drainage, livestock wastes, and wastewater-treatment plant effluent to the main stem. Surface-water diversions are equivalent to about 60 percent of the mean annual streamflow from the basin. During the irrigation season, return flows downstream from the city of Yakima contribute approximately 50 to 60 percent of the flow in the lower main stem.

Bacterial Concern

The sanitary quality of the Yakima River Basin is of great importance to water managers, the agricultural community, recreational users, and the general public. Water from streams with poor sanitary quality can transmit diseases such as cholera, typhoid fever, and bacillary and amoebic dysentery. Fecal-coliform bacteria are indicators of fecal contamination and have been correlated with the incidence of gastrointestinal disorders resulting from bodily contact with certain freshwater sources. Wastes from warm-blooded animals, including humans, are sources of fecal contamination.

Fecal-coliform concentrations have been a concern in the Yakima River Basin since the 1970s. The basin has significant numbers of beef cattle on pasture and in forested areas, and the lower Yakima Valley has a large concentration of dairies. The number of dairy farms in the Basin has decreased from 85 in 1994 to 77 in 1999 (Laurie Crowe, South Yakima Conservation District, oral commun., December 1999). The number of dairy cows, however, has increased from about 34,700 in 1982 to 51,400 in 1999 (Washington Agricultural Statistics Service, 1999). The sizeable decrease in the number of farms and the increase in the number of cows equates to larger animal-feeding operations (see box).

A feedlot near Sunnyside.

"The term **animal-feeding operation**, or AFO, is defined in EPA regulations [40 CFR 122.23 (b)(1)] as a lot where animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and where crops, vegetation, forage growth, or post-harvest residues are not sustained over any portion of the lot or facility in the normal growing season" (U.S. Environmental Protection Agency, 2000a). Depending on the total number of animals confined, an AFO can further be defined as a concentrated animal-feeding operation (CAFO). A livestock operation is considered an AFO or CAFO when animals are confined in a relatively small area that is devoid of sustained vegetation.

SAMPLING PROGRAM

Study Design

The Washington Department of Ecology considers temperature and fecal-coliform bacteria to be the primary water-quality concerns in the State. The 1998 Clean Water Act section 303(d) list of impaired and threatened water bodies (Washington State Department of Ecology, 2001) includes 18 listings for fecal-coliform bacteria in the Upper Yakima, Naches River, and Lower Yakima Water Resource Inventory Areas. For these reasons, the Yakima NAWQA worked in cooperation with the Department of Ecology to include analyses of fecal-indicator bacteria in three synoptic samplings in 1999 and 2000. Bacteria-source tracking, however, was not an objective in site selection. Sites were not specifically located to track bacteria from liquid or composted manure farms, urban storm drains, feedlots, or small noncommercial farms. Rather, they were chosen to meet multiple objectives for each synoptic sampling.

In August 1999, a comprehensive LaGrangian synoptic sampling[1] included 34 locations throughout the Yakima River Basin, 25 of which were sampled for fecal-indicator bacteria (pl. 1). These locations included points along the main-stem Yakima River, mouths of tributaries receiving agricultural runoff, water intakes for the cities of Yakima and Cle Elum, effluents from eight wastewater-treatment plants (no bacteria samples), and three sites along a land-use gradient in the Satus Creek subbasin (table 1). In an effort to measure change over the decade since the Cycle-I pilot study, many of these sites were chosen to coincide with those measured during a Cycle-I synoptic sampling in July 1988 that focused on fecal-indicator bacteria (Embrey, 1992). Results from the Cycle-I pilot study revealed that high concentrations of sediment and pesticides were to be expected in late July and early August. Concentrations of fecal-indicator bacteria during this time are also relevant because summer is a time of frequent contact with surface waters by farmers and recreationists. More than 40 samples, in addition to quality-control samples, were collected at these sites. The samples were analyzed for organochlorine pesticides, currently used pesticides, nutrients, dissolved trace elements, major ions, and physical measures of suspended sediment, turbidity, streamflow, water temperature, specific conductance, dissolved oxygen, and pH, as well as fecal-indicator bacteria.

While the data from the August 1999 synoptic sampling provided an overview of the spatial distribution and potential sources of fecal-coliform bacteria, the synoptic samplings in 2000 focused on gaining an understanding of the processes related to contamination within the basin. Sixty-four sites were selected to examine the effects of different agricultural practices (i.e., crop type, irrigation method) on water quality. These sites include those on small agricultural streams (draining less than 10 mi^2 of agricultural land), intermediate streams (roughly 10 to 30 mi^2), and source water from delivery canals, as well as a few reference sites (table 1), which are sites on streams in areas having a minimal amount of anthropogenic activity. Most of the small and intermediate streams receive irrigation-return flows from areas where rill, sprinkler, and drip irrigation methods are used. Samples were collected for the analysis of pesticides and degradation products, nutrients, and the same physical measures listed above, as well as fecal-indicator bacteria. The 2000 synoptic samplings were timed to examine the variability in water-quality conditions during early irrigation (June), peak irrigation (July), and post-irrigation (October–November).

Wheel-line sprinkler in a recently cut hay field.

A rill-irrigated corn field.

[1]A synoptic sampling is designed to give a "snapshot" view of the water-quality conditions over a few days to 2 weeks throughout a river basin during a period of relatively stable streamflows. The LaGrangian design attempts to specify the time of sampling based on the goal of following a "packet of water" as it flows through the basin.

Table 1. Summary of fecal-coliform concentrations, Yakima River Basin, Washington, 1999 and 2000

[Drainage area is reported in square miles; concentration is reported in colonies per deciliter of water (col/dL); main-stem sites are bold; the highest concentration is reported for sites that were sampled more than once during a synoptic sampling (•) and for sites that were sampled at three cross sections (▪); Yak, Yakima River main stem; So, source water from delivery canal; Sm, small agricultural stream; Int, intermediate stream; Mo, mouth of tributary; Ref, reference site; nd, not determined; ≥, "true" concentration is greater than or equal to the value listed due to high plate counts or high background counts; E, estimated, because sample was analyzed 24 hours after collection; <, less than; Dry, no streamflow at the time of visit; Dry; Group I (less than 50 col/dL); Group II (50 to 200 col/dL); Group III (201 to 1,000 col/dL); Group IV (greater than 1,000 col/dL); Not visited]

Map number	Site number	Site name	Site type	Drainage area	Fecal-coliform concentration August 1999	July 2000	Oct–Nov 2000
		Kittitas subbasin					
200	**12479500**	**Yakima River at Cle Elum**	**Yak**	**502**	**▪ 3**		
108	465504120195600	KRD Canal at Wipple Spillway	So	nd		49	
85	465918120193100	Drain at Park Creek Road	Sm	0.86		≥ 6,300	93
84	465907120202800	Park Creek at Park Creek Road	Int	30		≥ 2,700	35
95	465647120265700	Park Creek at South Ferguson Road	Int	69		290	E 29
47	465631120234500	Drain at Sorensen Road	Sm	1.8		1,000	8
114	465537120231500	Cascade Canal at Thrall Road	So	nd		500	
48	465524120220500	Drain at Hamilton Road	Sm	0.32		43	4
96	465640120265700	Johnson Drain at South Ferguson Road	Int	16		< 3	
49	465204120182800	Badger Creek at Silica Road	Sm	1.2		≥ 8,100	≥ 4,300
62	465428120213500	Badger Creek upstream of Wipple Wasteway	Int	25		210	
201	12484100	Wilson Creek above Cherry Creek at Thrall	Mo	180	650		
202	12484480	Cherry Creek at Thrall	Mo	214	260		
		Umtanum subbasin					
203	**12484500**	**Yakima River at Umtanum**	**Yak**	**1,598**	**▪ 66**		
66	12484550	Umtanum Creek near mouth at Umtanum	Ref	53	92	14	21
		Naches subbasin					
204	12496510	Pacific Power & Light Company Wasteway	Ref	nd	17		
205	12499000	Naches River near North Yakima	Mo	1,104	▪ 39		
		Moxee subbasin					
109	463223120184400	Roza Canal at Beane Road	So	nd		34	
97	463228120184400	Moxee Drain at Beane Road	Int	81		≥ 960	E 23
12	463245120205900	319 test site drain near Walters Road	Sm	2.1		96	23
115	463411120223900	Selah-Moxee Canal at Duffield Road	So	nd		≥ 40	
7	463258120222800	Drain at Faucher Road	Sm	0.01		Dry	Dry
2	463350120233000	Drain near Postma Road	Sm	0.63		• 1,500	• 53
69	12500420	Moxee Drain at Birchfield Road near Union Gap	Mo	136	• 2,900	580	120
		Ahtanum–Wide Hollow subbasin					
119	463349120380500	Yakima-Tieton Canal at Occidental Road	So	nd		310	
14	463343120385400	Drain at Draper Road	Sm	1.07		170	Dry
206	12500445	Wide Hollow Creek near mouth at Union Gap	Mo	67	600		
207	**12500450**	**Yakima River above Ahtanum Creek at Union Gap**	**Yak**	**3,480**	**▪ 60**		
99	463147120455700	Ahtanum Creek below Bachelor Creek	Int	124		80	53
107	463254120352800	Ahtanum Creek at 62nd Avenue	Int	140		930	1,600
121	12502500	Ahtanum Creek at Union Gap	Mo	173	370		
		Buena–Zillah subbasin					
120	462644120175000	Union Gap Canal at Blue Goose Road	So	nd		96	
26	462836120202600	Drain at Borquin Road	Sm	7.1		•≥ 3,900	Dry
27	462745120192400	Drain at Lombard Loop	Sm	2.3		380	31
28	462603120174200	Drain at Hiland Drive	Int	7.5		610	Dry
		Toppenish subbasin					
208	12505350	East Toppenish Drain at Wilson Road near Toppenish	Mo	4.5	840		
209	12505410	Sub 35 Drain at Parton Road near Granger	Mo	5.9	350		
210	12505510	Marion Drain at Indian Church Road at Granger	Mo	83	430		

Table 1. Summary of fecal-coliform concentrations, Yakima River Basin, Washington, 1999 and 2000—Continued

[Drainage area is reported in square miles; concentration is reported in colonies per deciliter of water (col/dL); main-stem sites are bold; the highest concentration is reported for sites that were sampled more than once during a synoptic sampling (•) and for sites that were sampled at three cross sections (▪); Yak, Yakima River main stem; So, source water from delivery canal; Sm, small agricultural stream; Int, intermediate stream; Mo, mouth of tributary; Ref, reference site; nd, not determined; ≥, "true" concentration is greater than or equal to the value listed due to high plate counts or high background counts; E, estimated, because sample was analyzed 24 hours after collection; <, less than; Dry, no streamflow at the time of visit; ▪ Dry; ▪ Group I (less than 50 col/dL); ▪ Group II (50 to 200 col/dL); ▪ Group III (201 to 1,000 col/dL); ▪ Group IV (greater than 1,000 col/dL); ▪ Not visited]

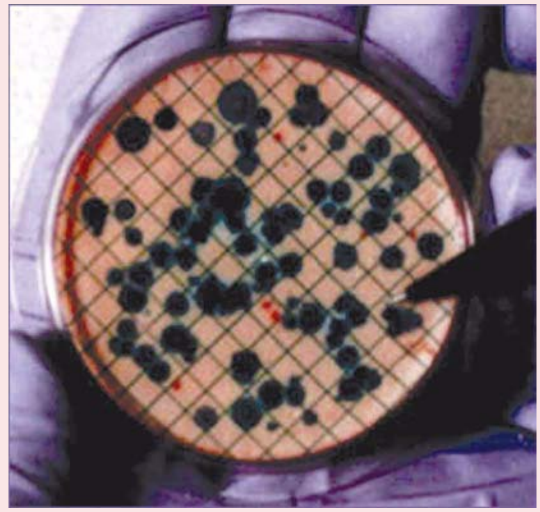
Map number	Site number	Site name	Site type	Drainage area	Fecal-coliform concentration: August 1999	Fecal-coliform concentration: July 2000	Fecal-coliform concentration: Oct–Nov 2000
		Toppenish subbasin—Continued					
59	462138120345900	Drain at Sunray Road	Sm	1.2		Dry	Dry
211	12507508	Toppenish Creek at Indian Church Road near Granger	Mo	599	450		
		Granger subbasin					
135	462158120053200	Sunnyside Canal at North Outlook Road	So	nd		88	
101	462018120075200	JD 32.0 upstream of DR 2	Int	24		540	E 170
92	462046120065600	DR 2 at Vanbelle Road	Sm	0.88		≥ 3,500	270
50	462053120055100	DR 2 near Outlook fire station	Sm	0.61		≥ 1,100	E 6
100	462023120075200	DR 2 at Yakima Valley Highway	Int	4.2		≥ 5,800	≥ 570
67	12505450	Granger Drain at Granger	Mo	62	• 2,100	910	130
		Satus subbasin					
212	**12507585**	**Yakima River at river mile 72 above Satus Creek**	**Yak**	**4,482**	**▪ 150**		
213	12507595	Satus Creek above Shinando Creek near Toppenish	Ref	18	3		
74	12508500	Satus Creek below Dry Creek near Toppenish	Ref	435	100	29	21
113	461810120125200	West Lateral at Satus Pump Station Number 2	So	nd		270	
93	461644120084500	North Drain at Satus Longhouse Road	Sm	3.4		• 240	•E 50
214	12508620	Satus Creek at gage at Satus	Mo	563	140		
102	12508630	South Drain near Satus	Mo	46	720	≥ 240	41
51	461254120051300	Drain at Colwash Road	Sm	0.74		≥ 260	Dry
		Sulphur subbasin					
110	462221119572500	Roza Canal at Ray Road	So	nd		27	
116	461929119561500	Sunnyside Canal at East Edison Road	So	nd		120	
103	461929119581200	JD 37.9 at East Edison Road	Int	15		290	E 170
63	461903119581400	DR 19 at Factory Road	Sm	0.77		•≥17,000	•E 12,000
52	461809119494900	Drain at Snipes Road	Sm	0.33		Dry	Dry
53	461716119504600	Drain at Evans Road	Sm	0.27		31	Dry
104	461700119595400	JD 43.9 at Mabton Sunnyside Road	Int	27		≥ 1,800	E 640
29	462018120012000	JD 34.2 at Woodin Road	Int	4.2		≥ 700	≥ 26
215	12508850	Sulphur Creek Wasteway near Sunnyside	Mo	160	1,400		
		Downstream of Sulphur subbasin					
83	461531119510300	Drain at Griffin Road	Sm	0.44		≥ 4,100	Dry
112	461530119514200	Grandview Pump Lateral at McCreadie Road	So	nd		120	
54	461504119514100	JT DR 2 at Lemley Road	Sm	0.32		≥460,000	<1
87	461141119510100	JD 51.4 at Yakima River	Int	5.9		210	E 66
88	12509492	JD 52.8 at Wamba Road at Prosser	Int	5.5		≥ 2,000	E 51
55	461717119460600	Spring Creek at Evans Road	Sm	25		170	3
105	12509696	Spring Creek at Hanks Road near Prosser	Int	29		60	
217	461404119410400	Spring Creek at Hess Road near Prosser	Mo	41	580		
106	461517119402500	Snipes Creek at McCreadie Road	Int	33		240	E 9
218	461414119404200	Snipes Creek below Chandler Canal near Prosser	Mo	34	210		
219	**12510500**	**Yakima River at Kiona**	**Yak**	**5,612**	**▪ 170**		
58	461359119253500	Drain at Badger Road, Mile 1.8	Sm	0.19		Dry	Dry
57	461117119210500	Drain at Badger Road, Mile 7.3	Sm	0.12		Dry	Dry
56	461032119194900	Drain at Badger Road, Mile 8.8	Sm	0.12		Dry	Dry
Total number of sites visited (number of dry sites)					25	57 (6 dry)	43 (12 dry)

Methods

Surface-water samples were collected for determining concentrations of fecal-coliform bacteria at 25 stream sites sampled during August 2–5, 1999, 51 sites during July 10–20, 2000, and 31 sites during October 30–November 2, 2000 (table 1). An additional 6 and 12 sites were visited during the July and October–November 2000 synoptic samplings, respectively, but samples were not collected because there was no streamflow at the time of the visit. In addition, enterococci were measured at 14 sites and *Escherichia coli (E. coli)* were measured at 9 sites as part of the October–November 2000 synoptic sampling. The U.S. Environmental Protection Agency (USEPA) is strongly encouraging States to convert their water-quality criteria from fecal-coliform bacteria to enterococci and (or) *E. coli* (Hicks, 2000; U.S. Environmental Protection Agency, 1986, 2000b).

The Department of Ecology provided autoclaved 250-milliliter bottles, which were dipped from the surface in the centroid of flow at each site. At the main-stem sites and the Naches River, samples were also collected at the right and left banks to examine variability within the stream and to determine concentrations at the most likely points of human and animal contact. This is consistent with the sample-collection techniques used by the Department of Ecology.

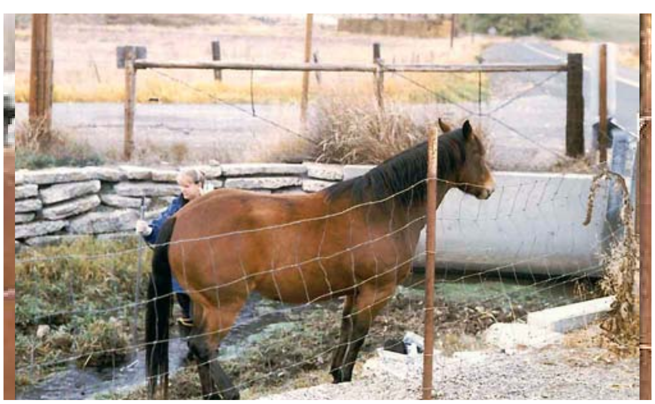
Water samples were stored on ice and shipped to the Department of Ecology laboratory in Manchester, Washington, for analysis within the designated 24-hour holding time. Samples from the Yakima River at Kiona were analyzed at Coffey Laboratories, Inc., in Portland, Oregon, in order to meet requirements for maximum holding times. Fecal-coliform bacteria were identified and enumerated using the membrane-filtration method 9222D described by the American Public Health Association and others (1998). Results were reported in colonies of bacteria per deciliter of water (col/dL), which is equivalent to colonies per 100 milliliter (col/100 mL). Streamflow data at these sites were collected



Counting colonies on a fecal-coliform bacteria plate.

(Photograph courtesy of William Rice, Roza-Sunnyside Board of Joint Control, 2000)

This report discusses three different types of fecal-indicator bacteria. The presence of these organisms in water indicates the possibility of fecal contamination. Because different types serve as better indicators under different conditions, there is no universal indicator organism for determining water quality. The primary strain analyzed in this report is the fecal-coliform group (shown above). Washington State's water-quality criteria for fecal-indicator bacteria are based on fecal-coliform bacteria for fresh or marine water. The USEPA's criteria, however, are based on *E. coli* concentrations for freshwater and enterococci for fresh or marine waters. *E. coli* is a member of the fecal-coliform group of bacteria. Since "*E. coli* is a member of the indigenous fecal flora of warm-blooded animals[, t]he occurrence of *E. coli* is considered a specific indicator of fecal contamination and the possible presence of enteric pathogens" (American Public Health Association and others, 1998). The enterococcus group is a subgroup of the fecal streptococcus group, whose normal habitat is the gastrointestinal tract of warm-blooded animals. Relationships have been found between the occurrence of swimming-associated gastroenteritis and the presence of enterococci. Therefore, enterococcci are thought to be the most efficient bacterial indicator of water quality for recreational surface waters, and the USEPA is strongly encouraging States to convert their water-quality criteria to either enterococci and (or) *E. coli* (American Public Health Association and others, 1998; U.S. Environmental Protection Agency, 1986, 2000b; Hicks, 2000).



Measuring streamflow at Badger Creek at Silica Road (site 49).

according to methods described in Rantz and others (1982).

Three other agencies also collected bacteria data in the Yakima River Basin at the time of this study. The Kittitas Reclamation District (KRD) and Kittitas County Conservation District (KCCD) collected water-quality data every 2 weeks during the irrigation season (April through October) and in the months directly preceding and following the irrigation season. The Roza Sunnyside Board of Joint Control (RSBOJC) collected water-quality data every 2 weeks during the irrigation season and once a month during the nonirrigation season. Although the primary data set used in this report was collected by the USGS and analyzed by the Department of Ecology, the data from these other agencies were used to determine short-term variability, interlaboratory bias, and how representative the USGS synoptic-sampling data are relative to conditions during the year. The KRD and KCCD samples were analyzed by method 9222D at the U.S. Bureau of Reclamation-Pacific Northwest Laboratory (USBR-PNL) in Boise, Idaho, whereas the RSBOJC samples were analyzed at their laboratory in Sunnyside, Washington, by a modified membrane-filtration method described by Myers and Wilde (1997). All three labs used similar field-collection and laboratory-analysis methods.

WATER-QUALITY CRITERIA

The USEPA (1986) defines a recreational water-quality criterion as a “quantifiable relationship between the density of an indicator in the water and the potential human-health risks involved in the water’s recreational use.” Both the USEPA and Washington State have established water-quality criteria for fecal-indicator bacteria. The USEPA’s criteria are based on *E. coli* concentrations for freshwater and enterococci for fresh or marine waters, while Washington State’s criteria are based on fecal-coliform bacteria for fresh or marine waters.

Fishing in the Yakima River near Toppenish.

The Washington Administrative Code (1997) establishes fecal-coliform standards based on fecal-coliform concentrations obtained from a monitoring program and classifications of surface-water bodies by their intended uses (table 2). All sites sampled during the synoptic samplings are rated as Class A water bodies[2], except Sulphur Creek Wasteway, which is a Class B water body[3]. For Class A streams, the geometric mean fecal-coliform concentration is not to exceed 100 col/dL, and not more than 10 percent of the samples used to calculate the geometric mean are to exceed 200 col/dL (the 90th percentile value). For Class B streams, the geometric mean and 90th percentile

Table 2. Summary of Washington State water-quality criteria for fecal-coliform bacteria

Classification of water body	Washington State water-quality criteria[1]	
	Geometric mean	90th percentile standard[2]
Class A streams All synoptic-sampling sites in this study, except...	100 col/dL	200 col/dL
Class B streams Sulphur Creek Wasteway main stem	200 col/dL	400 col/dL

[1] Washington Administrative Code, 1997.
[2] Not more than 10 percent of the samples used to calculate the geometric mean are to exceed this value.

[2]Class A water bodies are categorized as “excellent” and should meet or exceed the requirements for all or substantially all uses. These characteristic uses include, but are not limited to: domestic, industrial, and agricultural water supply; livestock watering; salmonid migration, rearing, spawning, and harvesting; other fish migration, rearing, spawning, and harvesting; clam, oyster, and mussel rearing, spawning, and harvesting; crustacean and other shellfish rearing, spawning, and harvesting; wildlife habitat; primary contact recreation; sport fishing; boating; aesthetic enjoyment; and commerce and navigation (Washington Administrative Code, 1997).

[3]Class B water bodies are categorized as “good” and should meet or exceed the requirements for most uses. These characteristic uses include all listed for Class A, except for domestic water supply; salmonid spawning; clam, oyster, and mussel harvesting; and primary contact recreation, which is replaced by secondary contact recreation (Washington Administrative Code, 1997).

Swimming in Ahtanum Creek at Fullbright Park (near site 207).

values are 200 and 400 col/dL, respectively. Although only single fecal-coliform samples were analyzed at most sites as part of this sampling effort, the 90th percentile Washington State standards of 200 and 400 col/dL for Class A and B streams, respectively, can be used as screening values to evaluate these concentrations. For those sites that were sampled more than once (but less than 10 times), the highest fecal-coliform concentrations measured will be compared to the 90th percentile standard values.

Proposed Changes to Water-Quality Criteria

The Washington Administrative Code (1997) uses fecal-coliform bacteria as its indicator of fecal contamination. The Department of Ecology is currently (2001) considering, and the USEPA is encouraging, a change to either *E. coli* or enterococci methods (Hicks, 2000; U.S. Environmental Protection Agency, 2000b). As part of the October–November 2000 synoptic sampling, the Department of Ecology laboratory used all three fecal-indicator methods at selected sites. Besides fecal-coliform determinations at all sites, tests also were performed for *E. coli* on 15 samples from 9 sites and for enterococci on 17 samples from 14 sites.

Results for the three fecal-indicator tests show that the relationship between fecal coliform and *E. coli* was more significant, with a larger correlation coefficient, than that for fecal coliform and enterococci (fig. 2). Therefore, *E. coli* concentrations may compare better than enterococci concentrations to historical fecal-coliform concentrations. *E. coli* also has the advantage of providing better precision than fecal

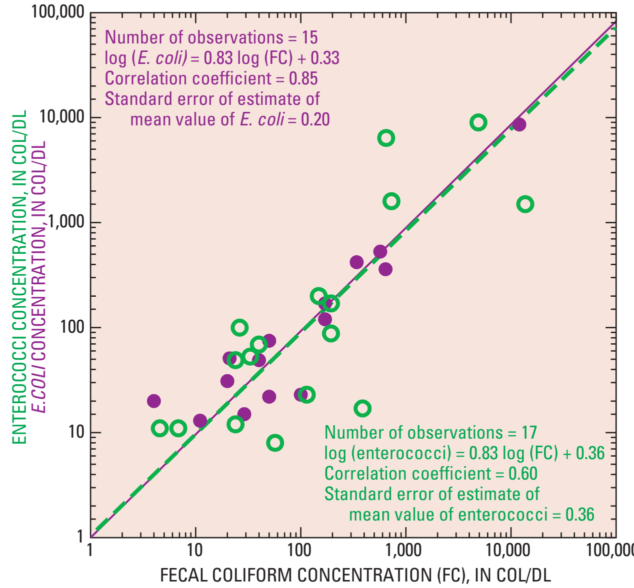


Figure 2. Comparison of fecal-coliform concentrations with *E. coli* and enterococci concentrations, Yakima River Basin, Washington, October 30–November 2, 2000. (Concentrations are reported as colonies per deciliter of water [col/dL].)

coliform when suspended-sediment concentrations are higher (William Rice, RSBOJC, oral commun., March 2001).

QUALITY ASSURANCE OF COLLECTED DATA

Quality assurance is the analysis of quality-control data with the intent to quantify bias, precision, and contamination associated with the collection of water samples. These evaluations make it possible for the data user to assess the exactness and reliability of their data. Bias is the persistent difference between the "true" value and the measured value or between two or more data sets. Because the true value to compare against is rarely known, most evaluations of bias are based on quantifying the differences in data from different laboratories using comparable methods (interlaboratory splits). Precision is a measure of the variability between two or more samples—at the same sampling point and time (field replicates), at different sampling points within a stream at a site (cross-sectional variability), at different locations (spatial variability), or at different times (temporal variability). It is particularly important to understand temporal variability when making comparisons among sites from a synoptic sampling, which is carried out over a

2-week period. Therefore, samples were collected at selected sites to assess variability from morning to afternoon, from day to day, and from week to week. Analytical variability is the variability due to the analytical method (intralaboratory splits) and is part of the error that affects precision. Blanks are collected to check for contamination. Equipment blanks can reveal potential contamination of equipment and reagents, whereas procedural blanks make it possible to identify carryover contamination from the preceding sample

Cleaning and preparing sampling equipment.

during analysis. The results from all of these different types of quality-control data were examined for the USGS, KRD, KCCD, and RSBOJC samples (table 3) before proceeding with the analysis of the environmental data sets.

When comparing differences in concentrations from different sites or different times, the analytical and environmental variability must be considered. Relative percent difference (RPD)[4] values, which provide a measure of how well the concentrations from two samples agree, were calculated for the different types of quality-control data (table 3). Further, by examining the 90th percentile RPD values, which allow the user to consider a majority of the data while minimizing the effects of data outliers, for each type of data, the variability related to each source (field, lab, temporal, interlaboratory, cross-section) can be estimated. As expected, the RPD values for temporal variability are the largest, followed by field replicates, and lab splits, indicating that the overall variability includes both environmental and analytical variability.

To further quantify temporal variability, selected data from KRD, KCCD, and RSBOJC for sites in the Kittitas, Granger, and Sulphur subbasins that have similar characteristics as the USGS synoptic-sampling sites, were grouped by seasons for 1999 and 2000, and RPDs were calculated. The 90th percentile RPD values ranged from 150 to 180 percent for groups of 70 to 1,262 samples. These values are smaller than, but similar to, the RPD values calculated for temporal variability for the USGS data only (table 3). Based on all of these RPD values, two fecal-coliform concentrations from the data sets used here should differ by more than an order of magnitude (equivalent to an RPD of 164) to be considered "different."

The cross-sectional variability measured during the August 1999 synoptic sampling suggests that all sites tested were well-mixed. This may be a result of using large streams to assess cross-sectional variability. Large-stream samples tended to have lower and less variable concentrations than samples from tributary sites.

There was no consistent contamination in the samples from USGS, KRD, KCCD, and RSBOJC. All procedural blanks analyzed at the Department of Ecology laboratory, where the USGS samples were analyzed, were within acceptable limits. Of the 88 equipment-blank samples analyzed at USBR-PNL, the laboratory used by KRD and KCCD, 86 samples had no bacterial growth. The RSBOJC laboratory had no bacterial growth on any of the 180 equipment or 180 procedural blanks.

During the October–November 2000 synoptic sampling, five samples were submitted as interlaboratory splits to the Department of Ecology laboratory and the RSBOJC laboratory. The concentrations measured by the RSBOJC were consistently less than those from the Department of Ecology laboratory, indicating a bias between labs. This bias could be due to the transport of the samples, the holding time after sampling prior to when the samples were filtered, or differences in the analytical methods.

The RSBOJC laboratory also performed interlaboratory splits with the City of Sunnyside Wastewater Treatment Plant Laboratory and the

[4]Relative percent difference (RPD) is calculated as the absolute difference between two values normalized to the average value expressed as a percentage.

$$\mathrm{RPD} = \left|\frac{(\text{Value 1} - \text{Value 2})}{(\text{Value 1} + \text{Value 2})/2} \times 100\right|$$

Table 3. Quality-assurance results for fecal-coliform data collected by U.S. Geological Survey (USGS) and other agencies in 1999 and 2000

[Concentrations are reported as colonies per deciliters of water; --, not collected; nd, not determined because of the small number of samples; E, estimated because of the small number of samples; RPD, relative percent difference; USBR-PNL, U.S. Bureau of Reclamation-Pacific Northwest Laboratory]

Descriptive statistic	Field replicates	Laboratory splits	Temporal variability	Inter-laboratory splits	Cross-sectional variability
USGS August 1999 data (collected by USGS and analyzed at the Washington Department of Ecology laboratory)					
Number of measurements	3	4	2	--	6
Median absolute difference	9	19	1,300	--	6
90th percentile absolute difference	nd	nd	nd	--	33
Median RPD	6	17	72	--	10
90th percentile RPD	nd	nd	nd	--	31
USGS July 2000 data (collected by USGS and analyzed at the Washington Department of Ecology laboratory)					
Number of measurements	20	11	19	--	--
Median absolute difference	64	39	690	--	--
90th percentile absolute difference	1,500	200	13,000	--	--
Median RPD	22	20	90	--	--
90th percentile RPD	110	54	200	--	--
USGS October–November 2000 data (collected by USGS and analyzed at the Washington Department of Ecology laboratory)					
Number of measurements	8	4	15	5	--
Median absolute difference	12	80	32	60	--
90th percentile absolute difference	E 210	nd	12,000	nd	--
Median RPD	33	16	82	11	--
90th percentile RPD	E 120	nd	200	nd	--
Kittitas Reclamation District (KRD) 2000 data (collected by KRD and analyzed at the USBR-PNL)					
Number of measurements	31	74	--	--	--
Median absolute difference	8	13	--	--	--
90th percentile absolute difference	47	100	--	--	--
Median RPD	12	17	--	--	--
90th percentile RPD	64	60	--	--	--
Kittitas County Conservation District (KCCD) 2000 data (collected by KCCD and analyzed at the USBR-PNL)					
Number of measurements	13	74	--	--	--
Median absolute difference	120	13	--	--	--
90th percentile absolute difference	830	100	--	--	--
Median RPD	33	17	--	--	--
90th percentile RPD	120	60	--	--	--
Roza-Sunnyside Board of Joint Control (RSBOJC) 1999–2000 data (collected and analyzed by RSBOJC)					
Number of measurements	110	160	--	[1]25	--
Median absolute difference	90	80	--	120	--
90th percentile absolute difference	600	320	--	800	--
Median RPD	17	11	--	24	--
90th percentile RPD	34	33	--	47	--

[1] Interlaboratory comparisons from RSBOJC include data from 1998 to 2000.

USBR-PNL as part of their routine sampling plan. The 90th percentile RPD value for this data set is slightly higher than those for the RSBOJC field replicates and laboratory splits. For those synoptic-sampling sites that also were monitored by KRD, KCCD, and RSBOJC, a comparison of the fecal-coliform data from the three USGS synoptic samplings and the irrigation and nonirrigation season data from the other agencies showed that the USGS synoptic-sampling data were representative of their sites.

SPATIAL VARIABILITY OF FECAL-COLIFORM CONCENTRATIONS

To illustrate the spatial patterns in fecal-coliform bacteria concentrations, the data are grouped in downstream order into 11 subbasins—Kittitas, Umtanum, Naches, Moxee, Ahtanum-Wide Hollow, Buena-Zillah, Toppenish, Granger, Satus, Sulphur, and downstream of Sulphur (pl. 1; table 1). To further examine the data, the samples have been arbitrarily divided into 5 groups—Group I has concentrations in col/dL of less than 50, Group II has 50 to 200, Group III has 201 to 1,000, Group IV has greater than 1,000, and sites with no streamflow at the time of visit. Samples in Groups I and II have concentrations that are less than the Class A 90th percentile standard of 200 col/dL for fecal-coliform bacteria.

August 1999 Synoptic Sampling

All of the sites sampled during the August 1999 synoptic sampling are Class A streams, except for the Sulphur Creek Wasteway main stem, which is Class B (table 1). The four sites in Group I are mainly influenced by water from forested areas and, to a much lesser degree, urban and agricultural areas. By comparison, the seven sites in Group II include four main-stem sites, Umtanum Creek (site 66), and the two lower sites on the Satus Creek drainage. Umtanum Creek has been closed to grazing the past few years, the Satus Creek below Dry Creek site (site 74) has limited effects from grazing, and the Satus Creek at Satus site (site 214) receives some water from agricultural activities. The low concentration (140 col/dL) measured at this most downstream site (Satus Creek at Satus) may be partially attributable to the Yakama Nation's decision to eliminate agricultural diversions of water for irrigation from the watershed in the last decade (James Thomas, Yakama Nation, oral commun., July 2001). All of these concentrations in Groups I and II, which includes all those from the main-stem Yakima River, are less than the Class A 90th percentile standard for fecal-coliform bacteria.

The sites in Group III are tributaries that drain a combination of agricultural and urban areas, and are from five of the different geographic subbasins. The three August 1999 samples that are in Group IV (Moxee Drain [site 69], Granger Drain [site 67], and Sulphur Creek Wasteway [site 215]) were collected from sites with some of the highest measured suspended-sediment concentrations in the basin (Joy and Patterson, 1997).

Satus Creek upstream of agricultural areas (near site 74).

Summary from the August 1999 synoptic sampling:

- Of the sites sampled, the Class A 90th percentile standard for fecal-coliform bacteria was met at 11 sites (44 percent), including all of the samples from the main-stem Yakima River.
- The tributary streams in watersheds that were dominated by agricultural and urban activities had higher fecal-coliform concentrations than the main-stem Yakima River, indicating that the tributaries were likely sources of fecal contamination in the basin.
- The three tributaries with the highest fecal-coliform concentrations also typically had higher concentrations of suspended sediment.

July 2000 Synoptic Sampling

The July 2000 synoptic sampling focused on sites dominated by agriculture. Of the 57 sites visited (table 1), multiple samples were collected at 4 sites to measure temporal variability during the 2 weeks that samples were collected. The highest concentration for each of these four sites is listed in table 1. Six sites, or 10 percent of the sites visited, had no streamflow at the time of visit, and are listed as “dry.” These sites were dry because irrigation was not occurring in the subbasin at that time or because of the use of best management practices.

The nine sites in Group I, which account for 18 percent of the sites sampled, are distributed throughout the basin and include four canal sites (two sites on one canal), Umtanum Creek (a reference watershed with no irrigation), Satus Creek below Dry Creek (a site with limited grazing), and three agricultural drains. Nine sites, or 18 percent, were in Group II, and include four canal sites (two sites on one canal), Ahtanum Creek downstream of Bachelor Creek (which provides irrigation water), and four agricultural drains. Together, these two groups, which met the Class A 90th percentile standard for fecal-coliform bacteria, account for 36 percent of the sites sampled and have sites in 9 of the 10 subbasins visited.

Group III and Group IV include 20 and 13 sites each, or 39 and 25 percent of the sites sampled, respectively. Three of the sites in Group III are canals that provide irrigation water. The sites in Groups III and IV are distributed throughout the basin, with samples from 8 of the 10 subbasins visited. Concentrations in these two groups did not meet the Class A 90th percentile standard for fecal-coliform bacteria, which indicates that fecal-coliform bacteria contamination exists during the irrigation season. The highest fecal-coliform concentration of greater than or equal to 460,000 col/dL measured at JT DR 2 at Lemley Road was 27 times higher than the next highest concentration measured in July 2000. This high fecal-coliform concentration, along with elevated nutrient concentrations at the site (0.43 mg/L of ammonia in filtered water, 2.83 mg/L of kjeldahl nitrogen[5] in unfiltered water, and 0.70 mg/L of phosphorus in unfiltered water) suggests that there may have been a manure source upstream of the sampling point.

[5]Kjeldahl nitrogen is the measured concentration of ammonia plus organic nitrogen.

October–November 2000 Synoptic Sampling

The October–November 2000 synoptic sampling started about two weeks after irrigation deliveries were stopped, thus, the canals were not sampled. During this synoptic, 15 sites were in Group I, 10 were in Group II, 3 in Group III, and 3 in Group IV (table 1). Twelve sites, or 28 percent of the sites visited, had no streamflow at the time of visit. This is double the number of dry sites during the irrigation season. Combining Groups I and II, 81 percent of the sites sampled, which were distributed throughout 9 of the 10 subbasins visited, met the Class A 90th percentile standard for fecal-coliform bacteria. The sites in Groups III and IV that exceeded the 90th percentile standard, were located in the Kittitas, Ahtanum-Wide Hollow, Granger, and Sulphur subbasins. In general, the fecal-coliform concentrations measured during the irrigation season were higher than during the nonirrigation season, often by an order of magnitude. An exception to this pattern occurred, however, at the Ahtanum Creek at 62nd Avenue site (site 107), where the fecal-coliform concentration measured in October was almost twice as high as that measured in July.

Ahtanum Creek at 62nd Avenue (site 107).

Summary from the July and October–November 2000 synoptic samplings:

- Of the sites *sampled*, 18 during the irrigation season (36 percent) and 25 during the nonirrigation season (81 percent) met the Class A 90th percentile standard for fecal-coliform bacteria.
- Of the sites *visited*, 6 during the irrigation season (10 percent) and 12 during the nonirrigation season (28 percent) had no streamflow when they were visited. These sites were dry because irrigation was not occurring in the subbasin at that time or because of the use of best management practices.
- The JT DR 2 at Lemley Road site had an extremely high fecal-coliform concentration and elevated nutrient concentrations during the July 2000 synoptic sampling, suggesting that there may have been a manure source upstream of the sampling point.
- Four of the 6 sites that did not meet the Class A 90th percentile standard during the October–November 2000 synoptic sampling were in the Granger and Sulphur subbasins.
- The fecal-coliform concentrations during the irrigation season were higher than those during the nonirrigation season, with the exception of the Ahtanum Creek at 62nd Avenue site, which had a higher concentration in October than in July.

TEMPORAL VARIABILITY OF FECAL-COLIFORM CONCENTRATIONS

Short-Term Changes

In order to assess the magnitude and nature of short-term variation that can occur at a site, multiple samples were collected at several sites during each of the 2000 synoptic samplings. The Drain near Postma Road (site 2), Drain at Borquin Road (site 26), North Drain at Satus-Longhouse Road (site 93), and DR19 at Factory Road (site 63), sites were sampled multiple times during both the July and October–November synoptic samplings (table 4). The Drain at Borquin Road site, however, had no streamflow during the October–November synoptic sampling. The data show that the variability observed is site specific. Some sites had fairly consistent concentrations during the sampling (North Drain at Satus-Longhouse Road, fig. 3), whereas other sites experienced three orders-of-magnitude changes during the sampling (DR19 at Factory Road, fig. 3). These results reflect the variable nature of bacterial concentrations, agricultural drains, and irrigation effects.

Seasonal and Yearly Changes

When Department of Ecology compared the 1999 and 2000 data sets from the RSBOJC to a 1992 data set from the South Yakima Conservation District (Zaragoza, 1992), it found that fecal-coliform geometric-mean concentrations in the Granger subbasin for the irrigation season have decreased 94 percent (Bohn, 2001). During water years 1997–2000, the RSBOJC sampled Granger Drain, Sulphur Creek Wasteway, Spring Creek, and Snipes Creek every 2 weeks during the irrigation season (April through October) and monthly during the nonirrigation season (William Rice, RSBOJC, unpub. data, June 2001). The geometric means of fecal-coliform concentrations at these sites show decreases in both seasons at three of the four sites (fig. 4, p. 18). Concentrations in Snipes Creek, however, remained fairly consistent during both seasons all 4 years, except during the 1998 irrigation season when concentrations were more than double those observed in the other 3 years. Although Snipes Creek, like Sulphur Creek Wasteway and Spring Creek, receives operational overflow from the Roza and Sunnyside Canals (William Rice, RSBOJC, written commun., August 2001), irrigation-return flows to Snipes Creek are minimal and help explain the lower concentrations measured. Although three of the four sites show lower concentrations during the nonirrigation season than during the irrigation season, Spring Creek shows the opposite. The higher fecal-coliform concentrations during the nonirrigation season suggest that there are sources of bacteria to Spring Creek that result in higher concentrations when the additional flows from irrigation-return flow are not present.

Spring Creek at mouth (near site 217).

The July and October–November 2000 synoptic-sampling data can also be compared to examine differences between irrigation and nonirrigation seasons (fig. 5, p. 19). There were 43 sites that were visited during both synoptic samplings, 6 of which were dry during both samplings. Additionally, another six sites were dry

Table 4. Short-term variability of fecal-coliform concentrations during the July and October–November synoptic samplings, Yakima River Basin, Washington, 2000

[Dry, no streamflow at the time of visit; --, streamflow not recorded]

Map number	Site name	Date and time of sampling	Streamflow, in cubic feet per second	Fecal-coliform concentration, in colonies per deciliter of water
		Moxee subbasin		
2	Drain near Postma Road	July 11 at 0840	1.9	600
2	Drain near Postma Road	July 11 at 1400	1.7	670
2	Drain near Postma Road	July 12 at 0820	1.8	1,500
2	Drain near Postma Road	July 13 at 1620	1.6	8
2	Drain near Postma Road	July 18 at 1210	1.9	110
2	Drain near Postma Road	October 30 at 0720	.9	23
2	Drain near Postma Road	October 31 at 1550	1.	21
2	Drain near Postma Road	November 1 at 0800	1.	11
2	Drain near Postma Road	November 1 at 1630	.9	53
		Buena-Zillah subbasin		
26	Drain at Borquin Road	July 11 at 1120	.07	2,700
26	Drain at Borquin Road	July 11 at 1650	.03	3,900
26	Drain at Borquin Road	July 12 at 1120	.02	1,600
26	Drain at Borquin Road	July 14 at 0820	0	1,400
26	Drain at Borquin Road	July 18 at 1130	Dry	Dry
26	Drain at Borquin Road	October 30 at 0900	Dry	Dry
		Satus subbasin		
93	North Drain at Satus Longhouse Road	July 11 at 0850	37	140
93	North Drain at Satus Longhouse Road	July 11 at 1420	--	84
93	North Drain at Satus Longhouse Road	July 12 at 1030	38	150
93	North Drain at Satus Longhouse Road	July 14 at 0800	44	236
93	North Drain at Satus Longhouse Road	July 18 at 1410	33	120
93	North Drain at Satus Longhouse Road	October 30 at 0820	4.2	40
93	North Drain at Satus Longhouse Road	October 30 at 1350	4.2	20
93	North Drain at Satus Longhouse Road	November 1 at 1030	4.1	50
93	North Drain at Satus Longhouse Road	November 2 at 1300	3.9	21
		Sulphur subbasin		
63	DR19 at Factory Road	July 11 at 1120	3.2	17,000
63	DR19 at Factory Road	July 11 at 1640	3.6	3,600
63	DR19 at Factory Road	July 12 at 1400	2.9	3,700
63	DR19 at Factory Road	July 14 at 1010	2.5	140
63	DR19 at Factory Road	July 18 at 1130	2.8	860
63	DR19 at Factory Road	October 30 at 1100	1.6	12,000
63	DR19 at Factory Road	October 31 at 0800	1.5	340
63	DR19 at Factory Road	November 1 at 0740	1.4	100
63	DR19 at Factory Road	November 1 at 1320	1.4	50

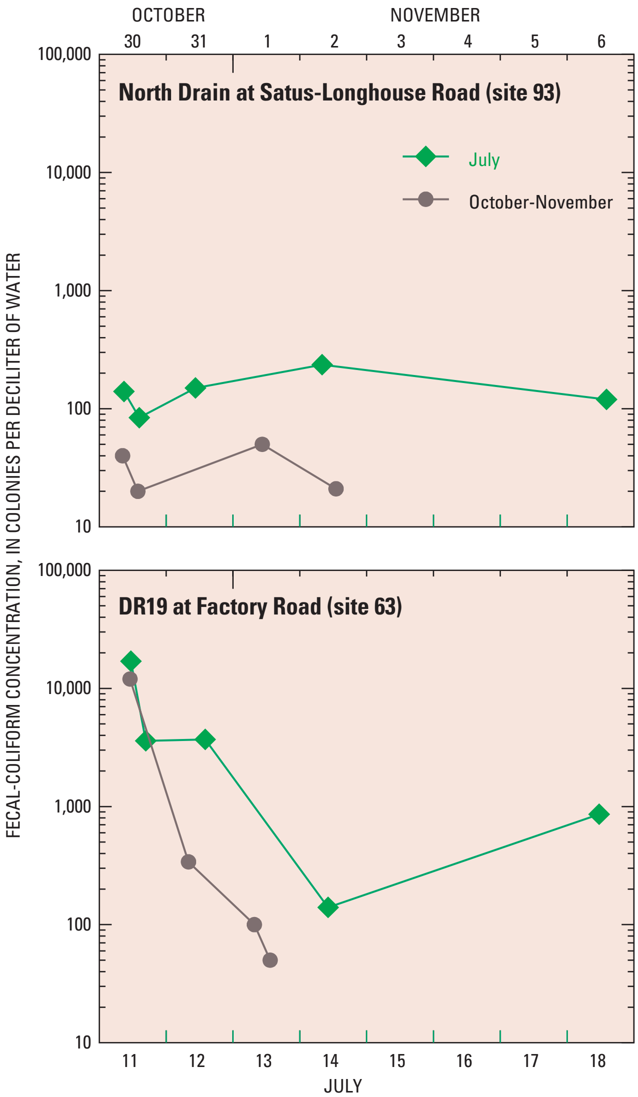


Figure 3. Short-term variability of fecal-coliform concentrations at two sites during the July and October–November synoptic samplings, Yakima River Basin, Washington, 2000. (Lines between data points are drawn to show patterns and are not for interpolation.)

during the October–November 2000 synoptic sampling. Two sites were found to have higher values during the nonirrigation season—Umtanum Creek near mouth, which had low concentrations during both seasons, and Ahtanum Creek at 62nd Avenue, which nearly doubled from the irrigation season to the nonirrigation season. The more common pattern observed, however, was the decrease in concentrations from the irrigation season to the nonirrigation season at 29 of the 31 sites sampled during both seasons. More than half of these decreases, which were observed throughout the basin, were an order of magnitude or larger.

Long-Term Changes

Land-use practices in the Yakima River Basin have been evolving over the past 30 years, and so it might be expected that the fecal-coliform concentrations throughout the basin might also be changing. Given the increased number of cattle in the basin, both in AFOs and on hobby farms, increased bacterial concentrations also might be expected. Alternatively, the increased use of best management practices aimed at decreasing overland runoff into streams and the elimination of discharges from AFOs might lead to expectations of decreasing concentrations. To detect possible long-term changes in fecal-coliform concentrations in the basin, several data sets were compared.

Data from the August 1999 synoptic sampling were compared to data from the July 1988 fecal-indicator bacteria synoptic sampling performed as part of the Cycle-I Yakima NAWQA (Embrey, 1992). Because fecal-coliform concentrations were not measured at all sites during the July 1988 synoptic sampling, *E. coli* concentrations, which were comparable to the fecal-coliform data, were used for sites that did not have fecal-coliform data. Data also were retrieved from EPA's Storage and Retrieval (STORET) database for the same sampling locations to provide historical ranges of concentrations. This historic data set includes minimum, median, and maximum concentrations for the summer months of July, August, and September of 1972 through 1985 (Embrey, 1992).

A dairy operation in the Granger subbasin.

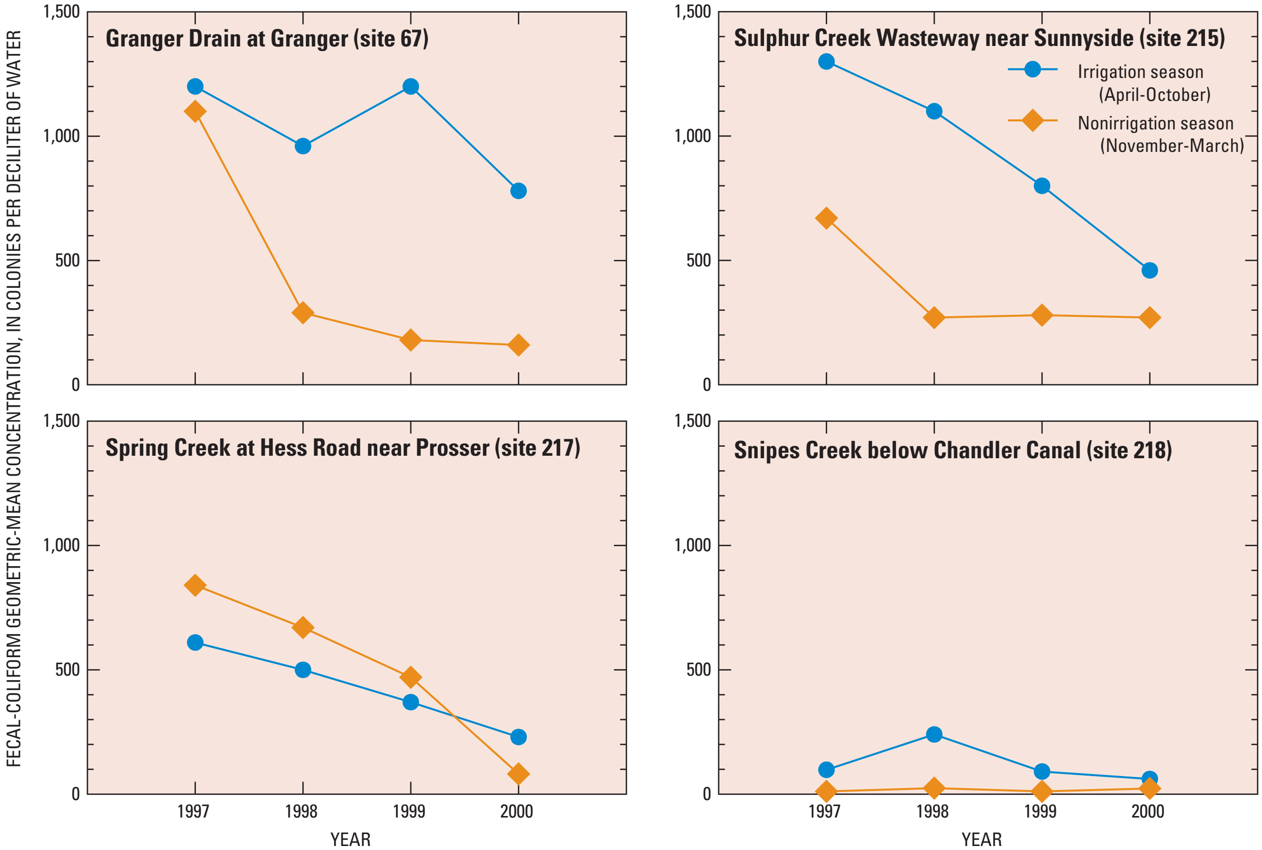


Figure 4. Fecal-coliform geometric-mean concentrations for four tributary streams, Yakima River Basin, Washington, 1997–2000. (Data source: William Rice, Roza-Sunnyside Board of Joint Control, unpub. data, 2000. Lines between data points are drawn to show patterns and are not for interpolation.)

Hobby farms in the Moxee subbasin (near site 69).

When fecal-coliform concentrations from the July 1988 synoptic sampling are compared to the August 1999 data (fig. 6), 15 of the 22 sites were found to have increases in 1999. Most of these increases are equivalent to a doubling of the concentration, which is less than the order-of-magnitude variability observed in the quality-assurance data. The sites with increased concentrations are distributed throughout the basin. Two sites in the Satus subbasin (Yakima River at river mile 72 and Satus Creek below Dry Creek) had order-of-magnitude increases. The three sites with the highest concentrations in July 1988 (Wide Hollow Creek, East Toppenish Drain, and Sulphur Creek Wasteway), however, all had twofold to threefold decreases in August 1999. Streamflow is most likely a contributing factor to these observed differences—in 1988, the annual mean streamflow for the Yakima River at Kiona was very low (1,905 ft^3/s), while in 1999, streamflow was much higher (4,374 ft^3/s)[6].

The differences between the August 1999 synoptic-sampling concentrations and the historical (1972–85) medians are evenly distributed—four sites had increases in 1999 and five sites had decreases, while two remained virtually unchanged (fig. 6). While the increased 1999 concentrations are larger than the historical medians, they are smaller than the

[6]For reference, the median annual mean streamflow for the period of record at the Yakima River at Kiona is 3,555 ft^3/s.

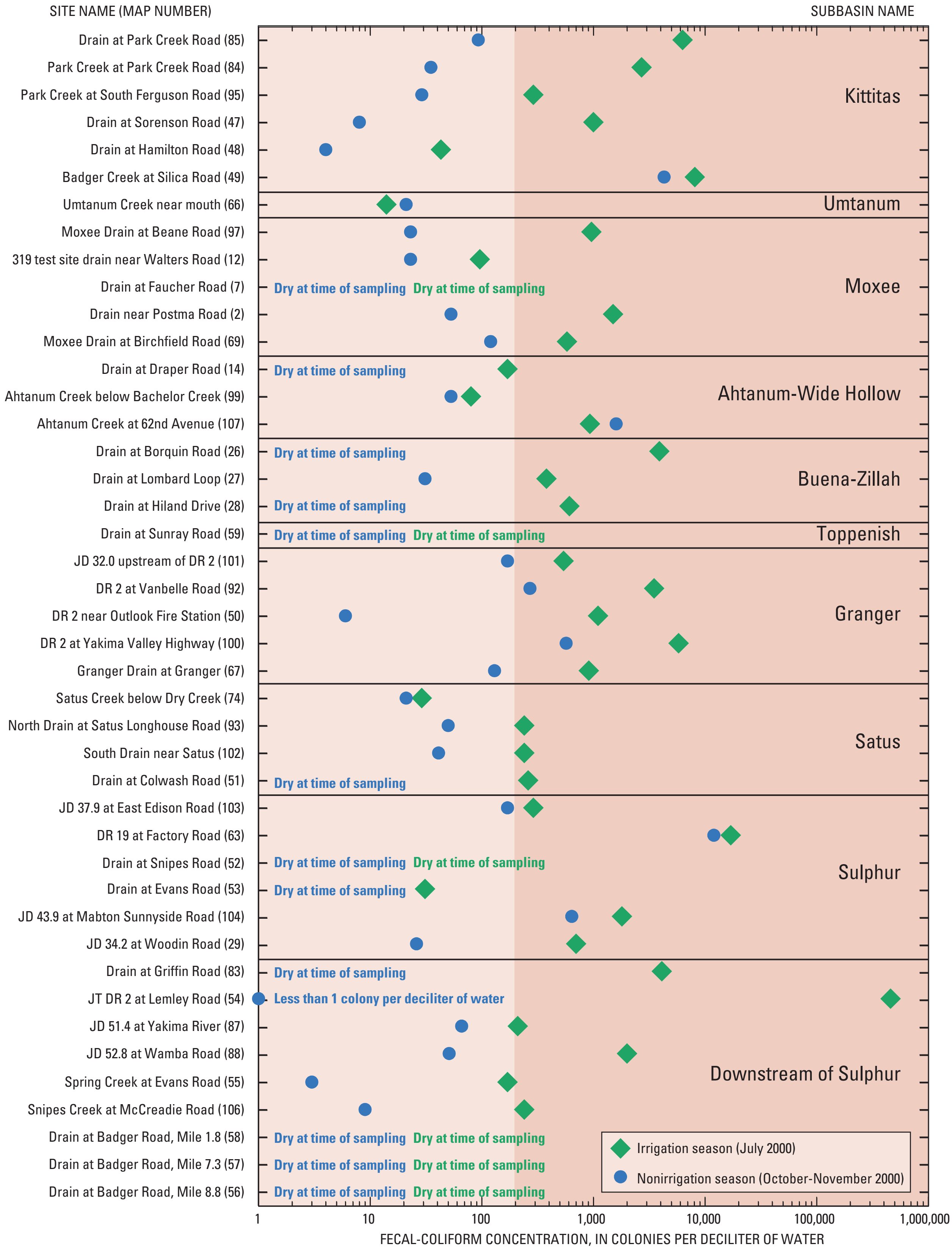


Figure 5. Comparison of fecal-coliform concentrations from the July and October–November 2000 synoptic samplings, Yakima River Basin, Washington. (The highest concentration is shown for sites that were sampled more than once. See table 1 for more details. Background shading indicates the Class A 90th percentile standard of 200 colonies per deciliter for fecal-coliform bacteria.)

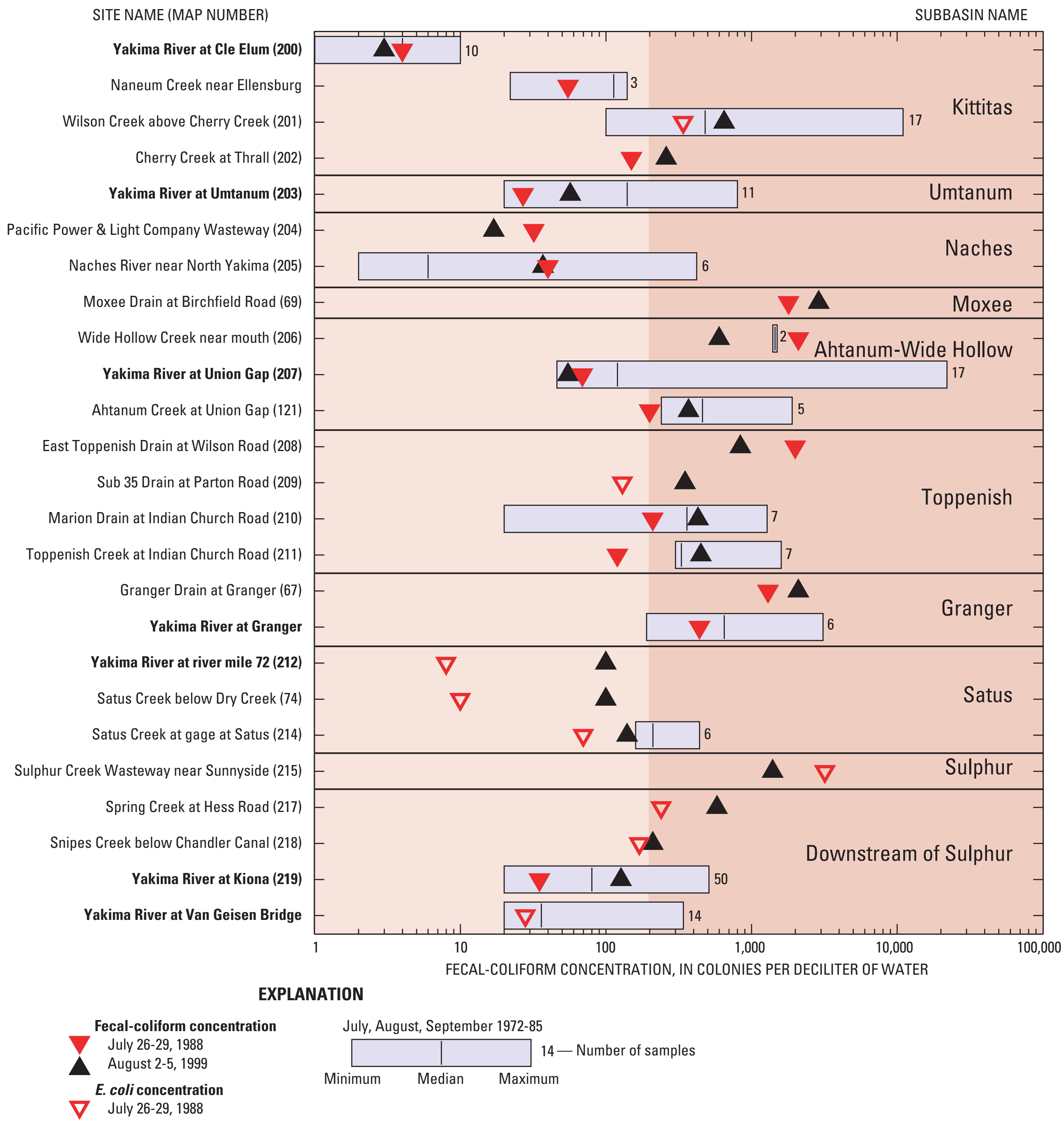


Figure 6. Comparison of historical summary and synoptic-sampling fecal-coliform concentrations, Yakima River Basin, Washington. (Main-stem sites are bold. The highest concentration is shown for sites that were sampled more than once. See table 1 for more details. Because fecal-coliform and *E. coli* concentrations were found to be similar, *E. coli* concentrations are reported for those sites where fecal-coliform concentrations were not determined during the July 1988 synoptic sampling. Background shading indicates the Class A 90th percentile standard of 200 colonies per deciliter for fecal-coliform bacteria.)

historical maximum concentrations. Likewise, the decreased 1999 concentrations are larger than the historical minimum concentrations, except the 1999 concentration at the Satus Creek at Satus site (140 col/dL), which is slightly lower than the historical minimum concentration (160 col/dL). None of the differences, however, were greater than an order of magnitude.

Summary of temporal variability:

- The short-term variability observed during a synoptic sampling was site specific—some sites had fairly consistent concentrations, whereas other sites experienced three orders-of-magnitude changes.
- Within a year, most sites from the 2000 synoptic samplings showed higher concentrations during irrigation season than during nonirrigation season.
- Historically, 15 of the 22 sites sampled during both the July 1988 and August 1999 synoptic samplings had higher concentrations in 1999, however, most of the differences were less than an order of magnitude. The three sites with the highest concentrations in July 1988, however, all had decreases in August 1999.
- The August 1999 synoptic-sampling concentrations were between the historical (1972–85) summer-month minimums and maximums, except one site in the Satus subbasin, where the concentration was slightly lower than the historical minimum.

ESTIMATION OF BACTERIA LOADS

The dynamic nature of bacterial transport is apparent from the instantaneous fecal-coliform bacterial loads for the August 1999 synoptic sampling (table 5). Because the August 1999 synoptic sampling included all major tributaries and followed a LaGrangian sampling schedule aimed at tracking a packet of water through the basin, the effects of these tributaries as sources to the main-stem Yakima River can be examined. An instantaneous load is calculated as the streamflow multiplied by the concentration, with a conversion factor applied. Therefore, the tributary with the highest concentration may or may not, depending on the streamflow, contribute the largest bacterial load to the main stem. Tributaries affected by agricultural, urban, and hobby farm activities, in general, are major sources of bacteria to the main-stem Yakima River. During the August 1999 synoptic sampling, Sulphur Creek Wasteway (site 215), Granger Drain (site 67), and Moxee Drain (site 69) were the largest contributors of fecal-coliform bacteria to the Yakima River (table 5).

Loads also were calculated for the RSBOJC data for Granger Drain (site 67), Sulphur Creek Wasteway (site 215), Spring Creek (site 217), and Snipes Creek (site 218) using the fecal-coliform geometric mean and average streamflow for the 1999 irrigation season (William Rice, RSBOJC, unpub. data, June 2001). When compared with the August 1999 synoptic-sampling instantaneous loads for these four sites, the differences for each site were within an order of magnitude of each other. This implies that the synoptic-sampling loads are representative of the 1999 irrigation season.

As was done with the bacteria concentrations, comparisons of instantaneous loads can also be made between the July 1988 and August 1999 synoptic samplings. The differences between these loads are likely due to a combination of differences in streamflow, the type of organisms measured (some 1988 concentrations are *E. coli*, whereas the rest are fecal-coliform bacteria), water-quality conditions, and agricultural practices. There were differences in streamflow between the 2 years. The annual mean streamflow for the WY 1988 was far below average, whereas since 1995, the Congressional passage of Title XII Section 1205 has required instream flows in the lower Yakima River to be maintained at a higher level than in previous years. To a lesser degree, differences in the fecal coliform and *E. coli* methods could cause some differences in the loads, but this is thought to be within the level of variability measured by field replicates. Embrey (1992) concluded that there was little difference between the *E. coli* and fecal-coliform results during the 1988 synoptic sampling. Water-quality conditions and agricultural practices have changed throughout the basin over the last 11 years with the implementation of best management practices and the 1988 Washington Dairy Nutrient Management Act (State of Washington, 1998). More specifically, the conversion of some agricultural land from rill irrigation to sprinkler or drip irrigation, the use of polyacrylamide (PAM) to reduce the amount of soil leaving the field, and the use of retention ponds as sediment traps have all helped to reduce the amount of sediment entering streams.

By focusing on the lower basin reach from the Yakima River at river mile (RM) 72 (site 212) to Kiona (site 219; RM 29.9), some of these differences can be further explored (table 6). The streamflows at the two main-stem sites and the contributing tributaries between these sites approximately doubled from 1988 to 1999, except at Snipes Creek (site 218), where it decreased by almost two-thirds. The bacteria concentrations also increased (most more than two

Table 5. Instantaneous fecal-coliform bacteria loads, Yakima River Basin, Washington, August 2–5, 1999

[Main-stem sites are bold; the median concentration is reported for main-stem Yakima River and Naches River sites that were sampled at three cross sections]

Map number	Site name	Date and time of sampling	Streamflow, in cubic feet per second	Fecal-coliform concentration, in colonies per deciliter of water	Fecal-coliform load, in millions of colonies per second
200	**Yakima River at Cle Elum**	**August 2 at 1000**	**2,565**	**3**	**2.2**
201	Wilson Creek above Cherry Creek	August 2 at 1750	132	650	24
202	Cherry Creek at Thrall	August 2 at 1700	125	260	9
203	**Yakima River at Umtanum**	**August 2 at 1840**	**2,730**	**57**	**44**
66	Umtanum Creek near mouth	August 2 at 1740	0.52	92	0.01
205	Naches River near North Yakima	August 3 at 0900	2,085	37	22
69	Moxee Drain at Birchfield Road	August 3 at 0740	59	620	10
69	Moxee Drain at Birchfield Road	August 3 at 1940	51	2,900	42
206	Wide Hollow Creek near mouth	August 3 at 1220	19	600	3.2
207	**Yakima River above Ahtanum Creek**	**August 3 at 1030**	**3,560**	**53**	**51**
121	Ahtanum Creek at Union Gap	August 3 at 1420	27	370	2.8
208	East Toppenish Drain at Wilson Road	August 3 at 1840	28	840	6.7
209	Sub 35 Drain at Parton Road	August 3 at 1740	62	350	6.1
67	Granger Drain at Granger	August 3 at 1730	53	1,800	27
67	Granger Drain at Granger	August 4 at 0740	62	2,100	37
210	Marion Drain at Indian Church Road	August 4 at 0820	67	430	8.2
211	Toppenish Creek at Indian Church Road	August 4 at 0840	117	450	15
212	**Yakima River at river mile 72 above Satus Creek**	**August 4 at 1230**	**1,270**	**100**	**36**
213	Satus Creek above Shinando Creek	August 3 at 1340	14	3	0.01
74	Satus Creek below Dry Creek	August 4 at 0950	57	100	1.6
214	Satus Creek at gage at Satus	August 4 at 1500	128	140	5.1
102	South Drain near Satus	August 4 at 1750	33	720	6.7
215	Sulphur Creek Wasteway near Sunnyside	August 4 at 1810	260	1,400	103
217	Spring Creek at Hess Road near Prosser	August 5 at 1740	46	580	7.6
218	Snipes Creek below Chandler Creek near Prosser	August 5 at 1610	12	210	0.71
219	**Yakima River at Kiona**	**August 5 at 1740**	**1,950**	**127**	**70**

Table 6. Comparison of July 1988 and August 1999 synoptic-sampling streamflow and fecal-indicator bacteria concentrations and loads, Yakima River Basin, Washington

[1988 bacteria concentrations and loads are *E. coli* at all sites except Yakima River at Kiona, whereas all 1999 concentrations and loads are fecal-coliform bacteria; main-stem sites are bold; the median concentration is reported for main-stem sites that were sampled at three cross sections in 1999; --, not sampled]

Map number	Site name	Streamflow, in cubic feet per second		Bacteria concentration, in colonies per deciliter of water		Bacteria load, in millions of colonies per second	
		1988	1999	1988	1999	1988	1999
212	**Yakima River at river mile 72 above Satus Creek**	**513**	**1,270**	**8**	**100**	**1.2**	**36**
214	Satus Creek at gage at Satus	84	128	70	140	1.7	5.1
102	South Drain near Satus	--	33	--	720	--	6.7
215	Sulphur Creek Wasteway near Sunnyside	151	260	3,200	1,400	92	103
217	Spring Creek at Hess Road near Prosser	24	46	240	580	1.6	7.6
218	Snipes Creek below Chandler Canal	33	12	170	210	1.6	0.7
219	**Yakima River at Kiona**	**854**	**1,950**	**35**	**127**	**8**	**70**

times) from 1988 to 1999, except at Sulphur Creek Wasteway (site 215), where the 1999 concentration is less than one-half the 1988 concentration. These streamflow and concentration differences are then multiplied into even larger differences between the loads for the 2 years. For example, even though the concentration in Sulphur Creek Wasteway decreased significantly, the doubling of the streamflow effectively canceled out this decrease, and the load is essentially unchanged between the 2 years. The 1999 loads in the main-stem Yakima River, however, increased significantly from 1988. The two tributaries in this reach that also increased their contributions are Satus Creek and Spring Creek.

Spreading solid manure on a field.

RELATIONS OF FECAL-COLIFORM CONCENTRATIONS AND SELECTED WATER-QUALITY VARIABLES

When fecal-coliform bacteria leave the digestive tract of warm-blooded animals and enter a water body, they are subjected to environmental conditions that affect their ability to survive. Sedimentation and solar radiation reduce the numbers of coliform bacteria in the water column. Solar radiation is lethal and sedimentation immobilizes the organisms to the bottom sediments. Bottom sediments can contain substantially larger concentrations of bacteria than the overlying water (Van Donsel and Geldreich, 1971). Stephenson and Street (1978) found that the presence of livestock along streams in their southwest Idaho study area overshadowed any effect that variations in chemical concentrations in the water might have had on observed concentrations of bacteria. Baxter-Porter and Gilliland (1988) summarized in a literature review that temperature, hydrologic proximity of pollution sources, livestock-management practices, wildlife activities, fecal-deposit age, and the containment of organisms within the channel and the banks are the major factors affecting the concentrations of bacteria in runoff from agricultural lands. When Francy and others (2000) examined microbiological-indicator data from six other NAWQA Study Units across the Nation, significant correlations were found between total-coliform concentrations in surface waters and dissolved organic carbon, ammonia plus organic nitrogen (Kjeldahl nitrogen), total phosphorus, nitrite plus nitrate, chloride, suspended sediment, and specific conductance.

Spearman's rank correlation coefficients (ρ) were used to examine the relationships between fecal-coliform concentrations and other water-quality characteristics from the three synoptic samplings done as part of this study in 1999 and 2000 (table 7). The statistics were calculated for several different subsets of the data to examine process-related conclusions. However, a "correlation measures observed co-variation. It does not provide evidence for causal relationship between the variables" (Helsel and Hirsch, 1992).

When all of the data from the three synoptic samplings are tested, the correlations between bacteria concentrations and several parameters are significant, yet only chloride and dissolved organic carbon, both measured only during the August 1999 synoptic sampling, were strongly correlated. Conversely, when only the data from the August 1999 synoptic sampling is used, every correlation is significant, and all but nitrite concentrations and water temperature have strong correlations. The July and October–November 2000 synoptic sampling data had strong significant correlations only with some of the nutrient concentrations.

These differences between the synoptic samplings may be due to the types of sites sampled and water-quality conditions during the samplings. In August 1999, all sites were on the main stem or at the mouths of major tributaries, representing the range of water-quality conditions in the basin. The 1999 sites

Table 7. Correlations of fecal-coliform concentrations and selected water-quality characteristics, Yakima River Basin, Washington, 1999-2000

[Data from multiple synoptic samplings and multiple visits to a site during a synoptic sampling were included in these correlation statistics, which are intended to examine process, not areal variability; (light shading) correlation is significant (probability is less than 0.05); (dark shading) correlation is significant and strong (Spearman's correlation coefficient is greater than 0.5); mm, millimeter; Drip/Sprinkler, drip or sprinkler irrigation; Rill, rill irrigation]

Water-quality characteristic	Spearman's correlation coefficient	Probability (two-tailed)	Number of samples	Spearman's correlation coefficient	Probability (two-tailed)	Number of samples	Spearman's correlation coefficient	Probability (two-tailed)	Number of samples	Spearman's correlation coefficient	Probability (two-tailed)	Number of samples
	All data (74 sites)			August 1999 (25 sites)			July 2000 (51 sites)			October–November 2000 (31 sites)		
Total suspended sediment	0.341	<0.00005	135	0.761	<0.00005	27	0.153	0.220	66	-0.004	0.987	20
Fine-grained suspended sediment (<0.62 mm)	0.340	0.0002	123	0.744	<0.00005	27	0.086	0.533	55	-0.103	0.675	19
Turbidity	0.368	<0.00005	131	0.834	<0.00005	27	0.155	0.230	62	-0.047	0.845	20
Ammonia	0.192	0.032	124	0.534	0.005	26	0.179	0.184	57	-0.010	0.966	19
Nitrite	-0.044	0.0626	122	0.456	0.019	26	0.083	0.545	55	-0.208	0.393	19
Nitrite plus nitrate	0.020	0.822	134	0.751	<0.00005	26	0.170	0.172	66	0.514	0.020	20
Total Kjeldahl nitrogen[1]	0.494	<0.00005	131	0.800	<0.00005	27	0.590	<0.00005	62	-0.038	0.872	20
Total Phosphorus	0.472	<0.00005	135	0.854	<0.00005	27	0.529	<0.00005	66	0.328	0.158	20
Orthophosphate	0.448	<0.00005	123	0.765	<0.00005	27	0.553	<0.00005	55	0.590	0.008	19
Water temperature	0.447	<0.00005	135	0.395	0.042	27	0.003	0.979	66	0.199	0.401	20
Chloride	0.696	<0.00005	26	0.696	<0.00005	26	--	--	--	--	--	--
Dissolved organic carbon	0.630	0.001	26	0.630	0.001	26	--	--	--	--	--	--
Specific conductance	-0.009	0.915	133	0.706	<0.00005	27	0.415	0.001	64	0.327	0.159	20
	Mouths of tributaries (20 sites)			Small agricultural streams (18 sites)			Intermediate streams (18 sites)					
Total suspended sediment	0.745	<0.00005	26	0.156	0.254	55	0.280	0.109	34			
Fine-grained suspended sediment (<0.62 mm)	0.759	<0.00005	26	0.136	0.323	55	0.239	0.250	25			
Turbidity	0.839	<0.00005	26	0.102	0.458	55	0.403	0.022	32			
Ammonia	0.409	0.038	26	0.213	0.119	55	-0.152	0.459	26			
Nitrite	0.387	0.056	25	-0.233	0.087	55	-0.379	0.062	25			
Nitrite plus nitrate	0.470	0.018	25	-0.236	0.083	55	-0.197	0.263	34			
Total Kjeldahl nitrogen[1]	0.736	<0.00005	26	0.515	<0.00005	55	0.002	0.990	32			
Total Phosphorus	0.712	<0.00005	26	0.409	0.002	55	0.118	0.506	34			
Orthophosphate	0.526	0.006	26	0.427	0.001	55	0.214	0.306	25			
Water temperature	0.281	0.164	26	0.594	<0.00005	55	0.442	0.009	34			
Chloride	0.616	0.002	22	--	--	--	--	--	--			
Dissolved organic carbon	0.518	0.016	21	--	--	--	--	--	--			
Specific conductance	0.363	0.068	26	-0.255	0.060	55	-0.418	0.015	33			
	Small streams—Drip/Sprinkler (6 sites)			Small streams—Rill (12 sites)								
Total suspended sediment	-0.269	0.251	20	0.382	0.024	35						
Fine-grained suspended sediment (<0.62 mm)	-0.242	0.304	20	0.339	0.047	35						
Turbidity	-0.272	0.245	20	0.263	0.126	35						
Ammonia	0.089	0.709	20	0.261	0.130	35						
Nitrite	-0.316	0.175	20	-0.247	0.152	35						
Nitrite plus nitrate	-0.555	0.011	20	-0.151	0.388	35						
Total Kjeldahl nitrogen[1]	0.561	0.010	20	0.518	0.001	35						
Total Phosphorus	0.517	0.020	20	0.333	0.051	35						
Orthophosphate	0.648	0.002	20	0.262	0.128	35						
Water temperature	0.808	<0.00005	20	0.489	0.003	35						
Chloride	--	--	--	--	--	--						
Dissolved organic carbon	--	--	--	--	--	--						
Specific conductance	-0.133	0.576	20	-0.350	0.039	35						

[1] Total Kjeldahl nitrogen is the measured concentration of ammonia plus organic nitrogen in unfiltered water.

Nonparametric Statistics[1]

When it is suspected that a data set is not from a normally distributed population, nonparametric techniques may be more appropriate for examining correlations. Nonparametric statistics use rankings of the data rather than the actual values. Although parametric tests (for example, linear regression or a Pearson correlation) are generally more powerful than nonparametric tests for a normally distributed population, the power of a nonparametric test can be increased by increasing the sample size. The sample sizes for all of the correlations in this report are more than adequate for nonparametric tests.

One kind of nonparametric technique is a Spearman test, which calculates a Spearman's rank correlation coefficient (ρ) and a significance level. The Spearman ρ is equivalent to the Pearson product-moment correlation coefficient (r) obtained from a linear regression except that it is calculated on ranked data. Spearman's ρ has values from -1 to +1 for negative and positive associations and values close to 0 for little or no association.

In this report, a correlation is considered statistically significant when the probability level (two-tailed) is less than 0.05 (greater than 95% confidence level). Furthermore, a correlation is considered "strong" when the correlation is significant and the Spearman's ρ value is greater than 0.5 (positive or negative). For example, a correlation with a ρ of 0.75 and a p of <0.00005 would be considered a strong, significant association.

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[1]This information is compiled from: Helsel and Hirsch (1992), Snedecor and Cochran (1989), and P-STAT, Inc. (1990).

Yakima River at Umtanum Creek Wayside (near site 203).

vary from the "clean" water at the Yakima River at Cle Elum to the agriculturally impacted water in the downstream part of the basin and include relatively large watersheds with multiple land uses. Conversely, the objective of the July and October–November 2000 synoptic samplings was to characterize the water-quality conditions associated with various agricultural practices. These sites, therefore, represent a narrower range of water-quality conditions, and necessitate a site-specific or narrowed analytical approach. For this reason, the data set was subdivided by site type, and correlation statistics were generated again (table 7).

There were more strongly correlated variables for the mouths of tributaries than for the small agricultural and intermediate streams. The small-streams data set was further subdivided by the predominant irrigation method used in the watershed. Several nutrient constituents and water temperature were found to be strongly correlated to fecal-coliform concentrations for the sites with drip or sprinkler irrigation, while only total kjeldahl nitrogen was strongly correlated for the sites with rill irrigation.

For the drip and sprinkler irrigated sites, the negative correlation between nitrite-plus-nitrate and fecal-coliform concentrations may be an indicator of ground-water contributions (fig. 7). Elevated nitrite-plus-nitrate concentrations that are often associated with ground-water inputs correspond with the lower fecal-coliform concentrations which would be expected from ground water. It is speculated that ground-water transport plays an important role in areas that are drip or sprinkler irrigated. Conversely, there is a positive correlation between water temperature and fecal-coliform concentrations for these sites (fig. 7). Although there is also a seasonal effect on the water temperatures (July samples were warmer than October–November samples), in general, lower fecal-coliform concentrations correspond with lower temperatures and higher counts with higher temperatures.

PROCESSES AND SOURCES AFFECTING BACTERIA CONCENTRATIONS IN WATER AND SUGGESTIONS FOR THEIR MANAGEMENT

The following is an overview of concepts, stated as hypotheses, concerning processes and sources that contribute to bacteria in water. They are not limited to the Yakima River Basin or the data collected during this study. These hypotheses are provided to help identify research needs, develop monitoring programs, develop best management practices, and develop programs to educate the public about public-health

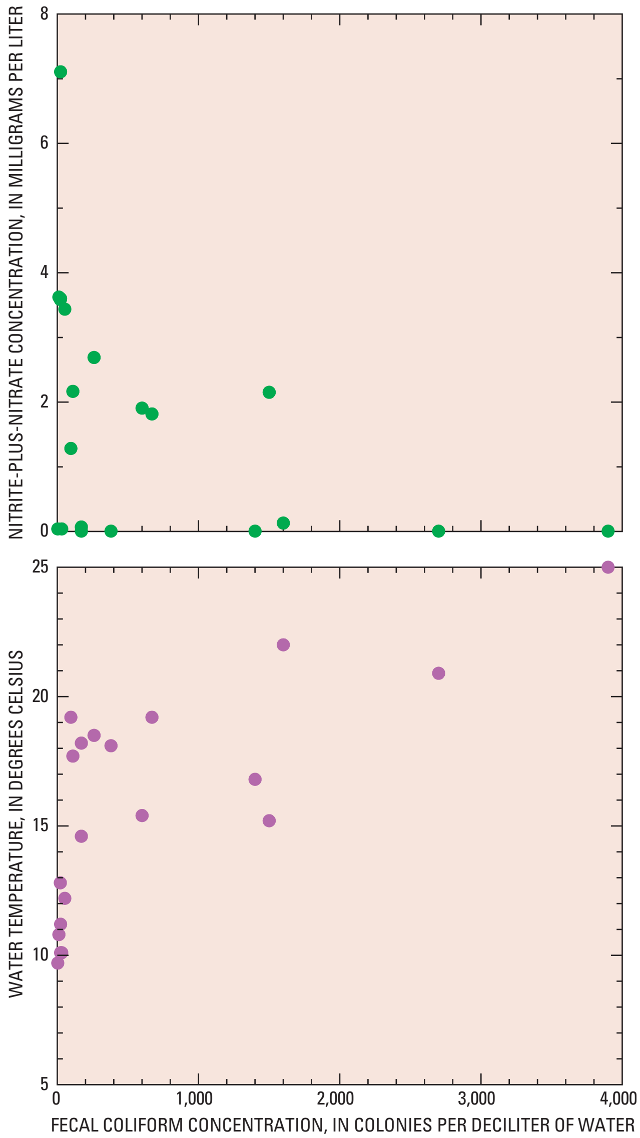

Figure 7. Correlative relations between nitrite-plus-nitrate concentrations and water temperature and fecal-coliform concentrations for small stream watersheds with predominantly drip or sprinkler irrigation, Yakima River Basin, Washington, 2000.

concerns related to bacteria, especially when associated with contact recreation.

Hypothesis I—Overland runoff transports bacteria from land surfaces to streams

Supporting evidence:

- High concentrations of bacteria are measured in streams during storm events, often an order of magnitude (10 times) higher than during base flow (Wittenberg, 1979; Miller, 1978; Miller, 1987).
- Higher concentrations of bacteria are measured in Yakima River Basin agricultural drains during the irrigation season than during the nonirrigation season (fig. 5). It is estimated that the land surface subject to overland runoff is about an order of magnitude (10 times) greater during the irrigation season than during the nonirrigation season or in nonirrigated areas (Robert Stevens, Washington State University, Prosser Irrigated Agriculture Research and Extension Center, oral commun., February 2002).

Management options:

- Landowners can minimize runoff from the land when irrigating by:
  - Changing from rill to sprinkler or drip irrigation where the crop type allows for this.
  - Reusing irrigation runoff water with sprinklers in pastures to minimize runoff to the Yakima River.
- Agency regulators could restrict contact recreation in streams receiving runoff from agricultural and urban areas during and following storm events.

Birds and cows share an irrigated pasture.

Hypothesis II—Bacteria in the water column tend to associate with suspended matter

Supporting evidence:

- The Washington Department of Ecology has quantified a relation between fecal-coliform concentrations and both total suspended solids and turbidity in the Granger Basin (Bohn, 2001).
- For the August 1999 synoptic sampling, fecal-coliform bacteria concentrations were

strongly correlated with suspended-sediment concentrations and turbidity (table 7).

- Livestock that stand in a stream to drink the stream water can disturb streambed sediments, thereby contributing to bacteria concentrations.

In some areas, livestock have direct access to the stream.

Management options:

- Landowners could prevent or minimize the suspension of sediment particles by:
  - – Providing water for animals so that they do not need to stand in the stream to drink,
  - – Fencing livestock from running water,

In other areas, fences separate pastures from the stream.

  - – Using surge irrigation to minimize the quantity of irrigation-return flow,
  - – Using gated pipes and minimizing the length of rills to help manage irrigation-return flow,
  - – Not using rills on steep erosive soils unless sodded, and
  - – Using polyacrylamide (PAM), a flocculant, with rill irrigation.
- Landowners could remove suspended particles from irrigation-return flow by:
  - – Using grass strips in tailwater areas,
  - – Using settling basins to remove suspended sediment, and
  - – Using irrigation-return flow on pastures where vegetation can act as a "living filter," encouraging infiltration and further minimizing runoff (Wittenberg and McKenzie, 1978).

Hypothesis III—With increasing densities of warm-blooded animals, the likelihood of fecal-coliform contamination in streams also increases

Supporting evidence:

- Urban areas have problems with high bacteria concentrations in storm-water runoff (Wittenberg, 1979; Miller, 1978; Miller, 1987).
- When there are larger numbers of livestock in a watershed, there is more manure that needs to be managed.
  - – Liquid manure spread on land is a source of bacteria.
  - – Where there is spreading of liquid manure, accidents can cause very high bacteria counts. For example, a fecal-coliform sample from JT DR 2 at Lemley Road measured 460,000 col/dL in July 2000 (see page 14).
- Irrigated lands in an arid climate support greater numbers of wildlife and, in turn, produce more waste material than nonirrigated lands in the same basin.

Spraying liquid manure where the potential for runoff is low.

Management options:

- Landowners could implement the following practices:

– Use an irrigation method with no overland runoff when liquid manure is spread on land, and

– Not spread liquid manure when natural runoff conditions are likely, and be prepared to provide storage for runoff when storm events occur.

• Pet owners could be encouraged to clean up after pets in urban settings.

Hypothesis IV—Identification of bacterial sources is difficult, but must be attempted for remediation to be possible

Supporting evidence:

• All inhabitants of a watershed contribute to the environmental setting in that watershed. When the source of bacteria is not known, however, many owners of land and businesses contend that they are not responsible.

• Antiquated and nonfunctioning septic tanks are a risk to the public that is not easily identified at this time.

Management options:

• Researchers must develop methods to identify sources of bacteria in water. Ideally, these methods should be inexpensive and applicable to a range of environmental conditions.

• Once sources of bacteria in an area are identified, criteria could be adjusted to reflect the associated human-health risk. For example, an area identified as having a wildlife source of bacteria could be assigned a criterion of 200 col/dL, while an area with a human source might have a criterion of 50 col/dL.

• Agency regulators need scientific evidence of fecal hosts to develop effective remediation actions.

• Prior to estimating the cost-benefit analysis and implementation of various remediation actions, managers need to know what percentage of the sources of fecal contamination may be reduced by the proposed action.

• Community recognition of multiple sources—humans, pets, livestock, wildlife—will lead to more effective remediation actions.

SUMMARY

The U.S. Geological Survey established its National Water-Quality Assessment (NAWQA) Program to better understand how natural and human influences affect water quality in different parts of the Nation. The Yakima River Basin NAWQA was a pilot study for Cycle I during water years 1987–91. The 1999 restart of the Yakima NAWQA study presents an opportunity to improve our understanding of the cause, source, transport, and effects of water-quality contaminants in streams. The sanitary quality of streams in the Yakima River Basin has been and continues to be a concern, with 18 river reaches listed for fecal-coliform bacteria on the Washington Department of Ecology's 1998 Clean Water Act section 303(d) list of impaired and threatened water bodies.

An August 1999 synoptic sampling of 34 sites targeted the main stem and the mouths of tributaries. Further, synoptic samplings in July and October–November 2000 focused on small and intermediate-sized agricultural watersheds. Fecal-coliform bacteria samples were collected by the USGS and analyzed at

The City of Yakima.

Hop fields in the Moxee subbasin.

the Washington Department of Ecology Laboratory. The Kittitas County Conservation District, Kittitas Reclamation District, and the Roza-Sunnyside Board of Joint Control also collected indicator-bacteria data in the Yakima River Basin from 1997 to 2001.

All sites sampled during the synoptic samplings are Class A water bodies, except Sulphur Creek Wasteway, which is a Class B water body. Since synoptic-monitoring programs usually collect single samples, the 90th percentile fecal-coliform standard is used as a screening value for these concentrations. The Class A and B 90th percentile standards for fecal-coliform bacteria are 200 and 400 col/dL, respectively.

Quality-assurance analysis included review of the following quality-control data: field replicates (to test precision), intralaboratory splits (to test analytical precision), repeated single site samples over a 2-week period (to assess temporal variability), point samples in the cross section (to assess cross-sectional variability), interlaboratory splits (to detect bias between laboratories), equipment blanks (to detect contamination) and procedural blanks (also to detect contamination). Analysis of these data indicate that the variability in fecal-coliform concentrations was so large that sample concentrations must differ by more than an order of magnitude between sites or between times to be considered “different.” Since the State of Washington is considering changing the method used for evaluation of the fecal-indicator bacteria criteria from fecal coliform to *E. coli* or enterococci, 15 samples for *E. coli* and 17 samples for enterococci were included with the fecal-coliform samples analyzed during the October–November 2000 synoptic sampling for comparison. When the concentrations from these different methods were compared, *E. coli* showed a stronger and more significant relationship with fecal-coliform bacteria than did enterococci.

Results of the August 1999 synoptic sampling (table 8) indicated that (1) of the sites sampled, the Class A 90th percentile standard for fecal-coliform bacteria was met at 11 sites (44 percent), including all of the samples from the main-stem Yakima River, (2) all of the tributary streams that were dominated by agricultural and urban activities had higher fecal-coliform concentrations than the main-stem Yakima River, indicating that the tributaries were likely sources of fecal contamination in the basin, and (3) the tributaries with the highest fecal-coliform concentrations also typically have higher concentrations of suspended sediment. Results of the July and October–November 2000 synoptic samplings (table 8) indicate that (1) of the sites *sampled*, 18 during the irrigation season (36 percent) and 25 during the nonirrigation season (81 percent) met the Class A 90th percentile standard for fecal-coliform bacteria, (2) of the sites *visited*, 6 during the irrigation season (10 percent) and 12 during the nonirrigation season (28 percent) had no streamflow when they were visited, (3) one site had an extremely high fecal-coliform concentration and elevated nutrient concentrations during the July 2000 synoptic sampling, suggesting that manure was a source to the site, (4) four of the 6 sites that did not meet the Class A 90th percentile standard during the October–November 2000 synoptic sampling were in the Granger and Sulphur subbasins, and (5) the fecal-coliform concentrations during the irrigation season were greater than those during the nonirrigation season, with the exception of one site that had a higher concentration in October.

Table 8. Distribution of fecal-coliform concentrations, August 1999, July and October-November 2000 synoptic samplings, Yakima River Basin, Washington

[col/dL, colonies per deciliter of water; Dry sites, sites where there was no streamflow at the time of visit]

Synoptic sampling	Total number of sites visited	Number of sites based on fecal-coliform concentration				
		Group I (less than 50 col/dL)	Group II (50–200 col/dL)	Group III (201–1,000 col/dL)	Group IV (greater than 1,000 col/dL)	Dry sites
August 2–5, 1999 (Irrigation season)	25	4	7	11	3	0
July 10–20, 2000 (Irrigation season)	57	9	9	20	13	6
October 30–November 2, 2000 (Nonirrigation season)	43	15	10	3	3	12

Several different levels of temporal variability of bacterial concentrations were examined. The short-term variability observed during a synoptic sampling was site specific—some sites had fairly consistent concentrations, whereas other sites experienced three orders-of-magnitude changes. Within a year, most sites from the 2000 synoptic samplings showed higher concentrations during the irrigation season than during the nonirrigation season. Historically, 15 of the 22 sites sampled during both the July 1988 and August 1999 synoptic samplings had higher concentrations in 1999, however, most of the differences were less than an order of magnitude. The three sites with the highest concentrations in July 1988, however, all had decreases in August 1999. When compared against historical (1972–85) summer-month minimums and maximums, the August 1999 synoptic-sampling concentrations were between these values, except one site in the Satus subbasin, which was slightly lower than the historical minimum.

Instantaneous fecal-coliform bacteria loads were calculated for the August 1999 synoptic sampling in an effort to study the dynamic nature of bacterial transport. Tributaries affected by agricultural, urban, and hobby farm activities, in general, were the major sources of bacteria to the main-stem Yakima River during this time. When these August 1999 synoptic-sampling loads in the lower basin reach from the Yakima River at RM 72 to Kiona (RM 29.9) were compared to those from the July 1988 synoptic sampling, most sites experienced increased loads in 1999. Streamflow at all sites approximately doubled, except at Snipes Creek, where it decreased by almost two-thirds. Likewise, all bacteria concentrations increased, except at Sulphur Creek Wasteway, where the 1999 concentration was less than one-half the 1988 concentration. These increases in streamflow and concentration are then multiplied into even larger increases in loads.

A nonparametric Spearman test was used to detect correlations between fecal-coliform concentrations and other water-quality data collected during the synoptic samplings. Results for the August 1999 synoptic sampling, which included many mouths of tributaries, showed significant correlations with every variable, and strong correlations with nitrite concentrations and water temperature. In contrast, there were only strong significant correlations with some of the nutrient concentrations during the July and October–November 2000 synoptic samplings, which included small agricultural and intermediate-sized streams. When only the small agricultural streams were considered, and the data set was further subdivided by the predominant irrigation method used in the watershed, several nutrient constituents and water temperature were found to be strongly correlated to fecal-coliform concentrations for the sites with predominantly drip or sprinkler irrigation, while only total kjeldahl nitrogen was strongly correlated for the sites with predominantly rill irrigation.

In looking forward relative to future monitoring, research needs, and development of best management practices (BMPs), four hypotheses that deal with processes or sources of bacteria were identified. Hypothesis 1 is a process: overland runoff transports bacteria from land surfaces to streams. This process is currently being minimized in the Yakima River Basin by converting rill-irrigated lands to drip or sprinkler systems. Hypothesis 2 is also a process: bacteria in the water column tend to associate with suspended matter. This hypothesis is supported by the correlation results for the August 1999 synoptic-sampling data. Using BMPs to minimize suspension of sediment particles and remove suspended particles from irrigation-return flow can help control the suspended sediment in the water column and, therefore, the transport of bacteria that are associated with this suspended matter. Hypothesis 3 concerns a source: with increasing

Hobby farms in the Ahtanum subbasin.

densities of warm-blooded animals, the likelihood of fecal-coliform contamination in streams also increases. The 1998 Washington Dairy Nutrient Management Act (State of Washington, 1998) calls for improved onsite manure management activities. Additionally, encouraging pet owners to clean up pet waste in urban settings will help reduce this source of bacteria to streams. Hypothesis 4 is also concerned with sources: identification of bacterial sources is difficult, but must be attempted for remediation to be possible. Further research is needed to develop new and better methods of identifying sources of fecal bacteria, so that these methods can be incorporated into the regulation of waters for primary contact recreation and other water uses.

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Fecal-Indicator Bacteria in the Yakima River Basin, Washington—An Examination of 1999 and 2000 Synoptic-Sampling Data and their Relation to Historical Data

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Synoptic sampling sites—PLATE 1
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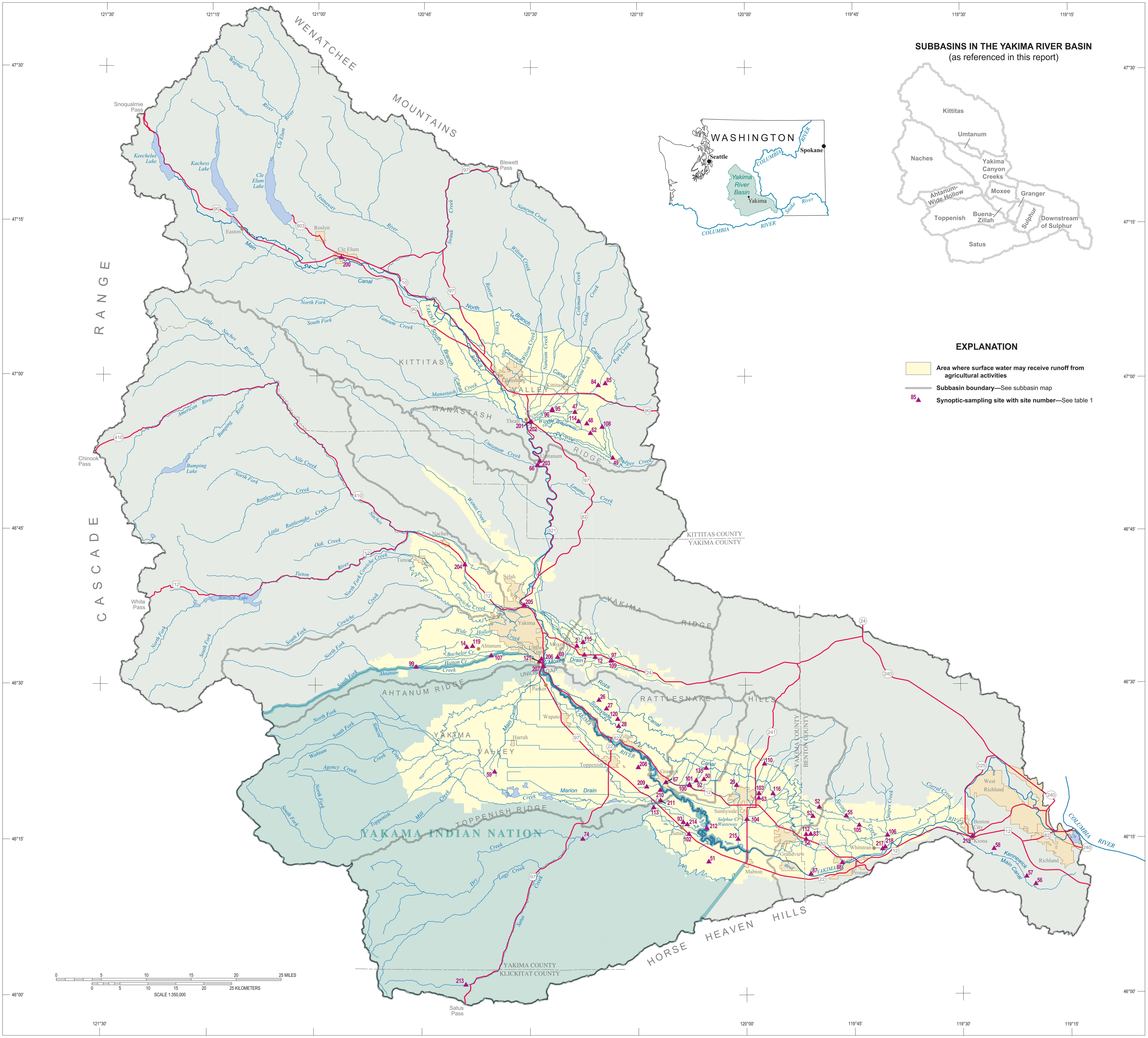

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SYNOPTIC-SAMPLING SITES IN THE YAKIMA RIVER BASIN, WASHINGTON, 1999–2000

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2002