RESULTS OF STORM-BASED MONITORING OF WATER QUALITY IN THE TILLAMOOK, KILCHIS, TRASK, AND WILSON RIVERS, TILLAMOOK BASIN, OREGON FROM 1996 TO 2002

STATE OF THE BAY REPORT

E&S Environmental Chemistry, Inc.

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Acknowledgments

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Abstract

The water quality in tributaries to Tillamook Bay currently exceeds standards for fecal coliform bacteria (FCB) or alternate parameter, *E. coli*, and temperature. Fecal coliform inputs into the bay have forced periodic closures of the oyster shellfish industry. In addition, impaired water quality may be contributing to reduced salmonid populations in the bay and its tributaries through reduction in the quality of the habitat. Because of these concerns, the Tillamook Bay National Estuary Project (TBNEP) and Tillamook County Performance Partnership (TCPP) implemented a long-term water quality monitoring program for the tributary rivers. A primary objective of the monitoring program is to characterize changes in water quality in the lower portions of selected tributaries to Tillamook Bay in order to allow for analysis of long-term trends in water quality. This report summarizes data collected to date within this monitoring program, including storm-based data on fecal coliform bacteria (FCB) and total suspended solids (TSS), and bi-monthly data on nutrient concentrations in selected rivers.

The Tillamook River consistently had the highest FCB concentrations. TSS concentrations were highest in the Trask and Wilson Rivers, corresponding to the rivers with the largest watersheds and highest flows. High values of TSS were associated with high discharge periods. Inorganic nitrogen concentrations were similar among sites and low relative to values observed in other parts of Oregon. Total phosphorus (TP) concentrations were highest in the Wilson and Trask Rivers, mostly in association with high TSS, and these are the sites where nutrient monitoring has continued. TP was not particularly high relative to other sites in western Oregon, although frequently higher during storm events than the 0.1 mg/L maximum value recommended by U.S. EPA as a goal for prevention of nuisance plant growth in streams.

Monitoring data from 1996 to 2002 are summarized. Results for FCB and TSS are reported by storm, and storms are classified according to season and precipitation patterns in order to minimize intra-annual variability. There are not indications of large changes in water quality throughout the period of record, but it is too early in the program for trends analysis. Storms that exhibited the highest FCB concentrations tended to be those that occurred during fall and/or those that were preceded by relatively dry conditions and included high rainfall intensity. Recommendations are provided for continued monitoring. This monitoring will be important to determine if future basin-wide restoration activities are having their desired effects and to help ensure continued funding, volunteer involvement, and landowner cooperation for on-the-ground actions.

Implementation of storm-based monitoring and classification of storms according to season and/or hydrologic type effectively reduces the enormous variability inherent in the FCB monitoring data, thereby facilitating future trends analysis. Continued storm-based monitoring of FCB and TSS, and also continued collection of rainfall and river discharge data, will provide the database that will be needed to determine to what extent on-the-ground actions and BMPs are having their desired effects.

I. INTRODUCTION

The Tillamook County Estuary Partnership (TCEP) is involved in a continuing effort to implement the Comprehensive Conservation Management Plan (CCMP) for Tillamook Bay. This plan focuses efforts to begin resolving the environmental problems of Tillamook Bay and its watershed, which includes all lands drained by the Miami, Kilchis, Tillamook, Wilson, and Trask Rivers. Previous water quality sampling programs in the Tillamook Bay Watershed have shown that fecal coliform bacteria contamination of surface waters occurs downstream of the forest/agriculture interface. Both agricultural and human sources contribute to the observed high bacterial concentrations. From 1996 to 1998, the Tillamook Bay National Estuary Project (TBNEP) sponsored scoping studies to provide the critical information needed to design a more rigorous water quality monitoring program (Sullivan et al. 1998 a, b). Based on the results of those studies, and on monitoring efforts conducted by E&S Environmental Chemistry, Inc. (E&S), Oregon Department of Environmental Quality, Oregon Department of Agriculture, and the Tillamook County Creamery Association, the Tillamook County Performance Partnership (TCPP) implemented a long-term monitoring strategy in the watershed. The monitoring program focused on storm sampling for fecal coliform bacteria (FCB) and total suspended solids (TSS), bimonthly sampling for nutrients, and continuous monitoring for temperature (Sullivan and Eilers 1999). As part of this effort, E&S conducted water quality monitoring until January 2002 at the primary sites located along the lower reaches of each of the Tillamook, Trask, Wilson, and Kilchis Rivers. This effort included storm-based sampling for FCB and TSS (3 sites each) and also sporadic bimonthly sampling for nutrients (2 sites).

The most important aspect of any monitoring plan is specification of the monitoring objectives and questions to be answered using the monitoring data. Once the monitoring questions are conceived and refined, and some preliminary data are collected with which to evaluate data variability issues, it is possible to specify a plan that will have a reasonable probability of success. The greatest challenge in monitoring plan development is asking the right (best) questions. It is important to decide what it is that you want to know and what uncertainty you are willing to accept in your answers. Many monitoring programs are compromised from the outset because they were not specific about what questions the monitoring program was intended to answer. Specificity regarding the questions can lead to specificity regarding the monitoring design and result in the collection of data suitable for providing the desired answer. For example, if we want to quantify changes in the loading of nitrogen from agricultural lands to the Trask River, we could not rely solely on monitoring data from the lower reaches of the Trask River. This is because most of the nitrogen load in the lower Trask is actually derived from upland potions of the watershed, in forested, rather than agricultural, lands. However, if our question concerned nitrogen loading from the entire watershed, then a single monitoring location in the lower portion of the watershed would be appropriate.

Because it is not possible to monitor at all locations at all times for all parameters, it is important to consider in advance how to make the best choices regarding expenditure of limited funds for monitoring. The most important aspect of monitoring design is setting very specific objectives, and linking these objectives to very specific questions. These questions should entail elements of subject, location, time, trend, and degree (Table 1).

Table 1. Elements to be considered in formulating monitoring questions.

Element	Example
Subject	Total phosphorus concentration
Location	Wilson River near its point of entering Tillamook Bay
Time	During winter storm events of greater than 4 in.
Trend	Is TP increasing from one year to the next during winter storm events of > 4 in. precipitation?
Degree	Is it changing by a statistically significant amount, biologically-meaningful amount?

A well-conceived plan for water quality monitoring should be:

- relevant to the intended beneficial uses of the waters
- specific with respect to sampling locations, depths, parameters, schedule, and methods
- consistent with approved methods
- consistent with regulatory requirements
- specific with recommendations for data analysis, reporting, and flagging
- designed to maintain some continuity with the existing monitoring efforts

Monitoring of water quality is performed to provide resource managers with information on changes in water quality that may require intervention and to document future changes (improvement or deterioration) in known problem areas. Information from a well-designed and properly-executed monitoring plan will allow future evaluation of the effectiveness of best management practices (BMPs) and the potential need for other remedial actions that might be warranted. Such information will be critical to demonstrate that restoration actions within the watershed are having the desired effects. Without such information, it will become increasingly difficult to obtain additional restoration funding, retain volunteer workers, and convince landowners to participate in future restoration efforts.

Because of the possibility for either episodic or incremental degradation of water quality within the basin, it is important to implement a program for monitoring both short and long-term changes. Ideally, monitoring data that provide information on the quality of river water can be used to evaluate the following kinds of issues:

- short-term changes (scale ~ hours to days) in water quality
- long-term changes (scale ~ years to decades) in water quality
- types of water quality changes
- likely cause(s) of water quality changes
- changes in spatial variation of water quality along the rivers
- effects of water quality changes

The ability to assess these issues will be limited largely by the extent and intensity of the monitoring effort. In view of the standard limitation of not being able to sample all parameters

Why do we conduct long-term monitoring of water quality?	Yes	No
• Identify water quality problems	☐	☒
• Identify sources of pollutants	☐	☒
• Evaluate compliance with regulations	☐	☒
• evaluate changes in compliance over time	☒	☐
• determine if problems are getting better or worse over time	☒	☐
• determine whether your restoration actions are having the desired effect	☒	☐
• document, for the benefit of potential volunteer workers, landowners, funding sources, that your actions are making a difference	☒	☐

at all places and times, choices need to be made in setting the priority of monitoring objectives.

Three of the most critical aspects of water quality monitoring design (c.f., Green 1979) include:

1. Concisely and precisely stating the questions to be addressed
2. Conducting a preliminary pilot sampling (or characterization study), and
3. Replicating sampling in time and in space.

The questions to be addressed will arise from the monitoring objectives (Figure 1), and these have been determined for the Tillamook Basin, at least preliminarily (c.f., Sullivan and Eilers 1999). A list of proposed monitoring objectives is provided in Table 2. The pilot sampling has already been conducted (Sullivan et al. 1998a, b). Issues of sample replication were addressed by Sullivan et al. (1998a,b), and replication has been a part of the continued monitoring.

Table 2. Proposed monitoring objectives for the Tillamook Bay watershed. (Modified from Sullivan and Eilers 1999)

Bacteria

To quantify changes in the concentration of FCB in selected Tillamook area rivers during and subsequent to rainstorms.

To quantify changes in the percentage of storms which are accompanied by median or geomean FCB concentration > 200 cfu/100 ml in the Tillamook, Trask, and Wilson Rivers.

To quantify changes in the total FCB storm loads to the bay from the Tillamook, Trask, and Wilson Rivers during fall, winter, and spring storms.

Nutrients

To quantify changes in the total annual loading of nitrogen and phosphorus from the Wilson and Trask River watersheds to Tillamook Bay.

Total Suspended Solids

To quantify changes in the storm loading of TSS during winter storms in the Wilson, Trask, and Kilchis Rivers.

Temperature

To determine the 7-day average temperature throughout the lower reaches of the Tillamook, Trask and Wilson Rivers during summer months.

To quantify changes in the number of days per year that the 7-day average temperature in the Tillamook, Trask, and Wilson Rivers exceeds water quality criteria.

To determine the spatial extent of water temperature exceedences during summer months in the Tillamook, Trask, and Wilson Rivers.

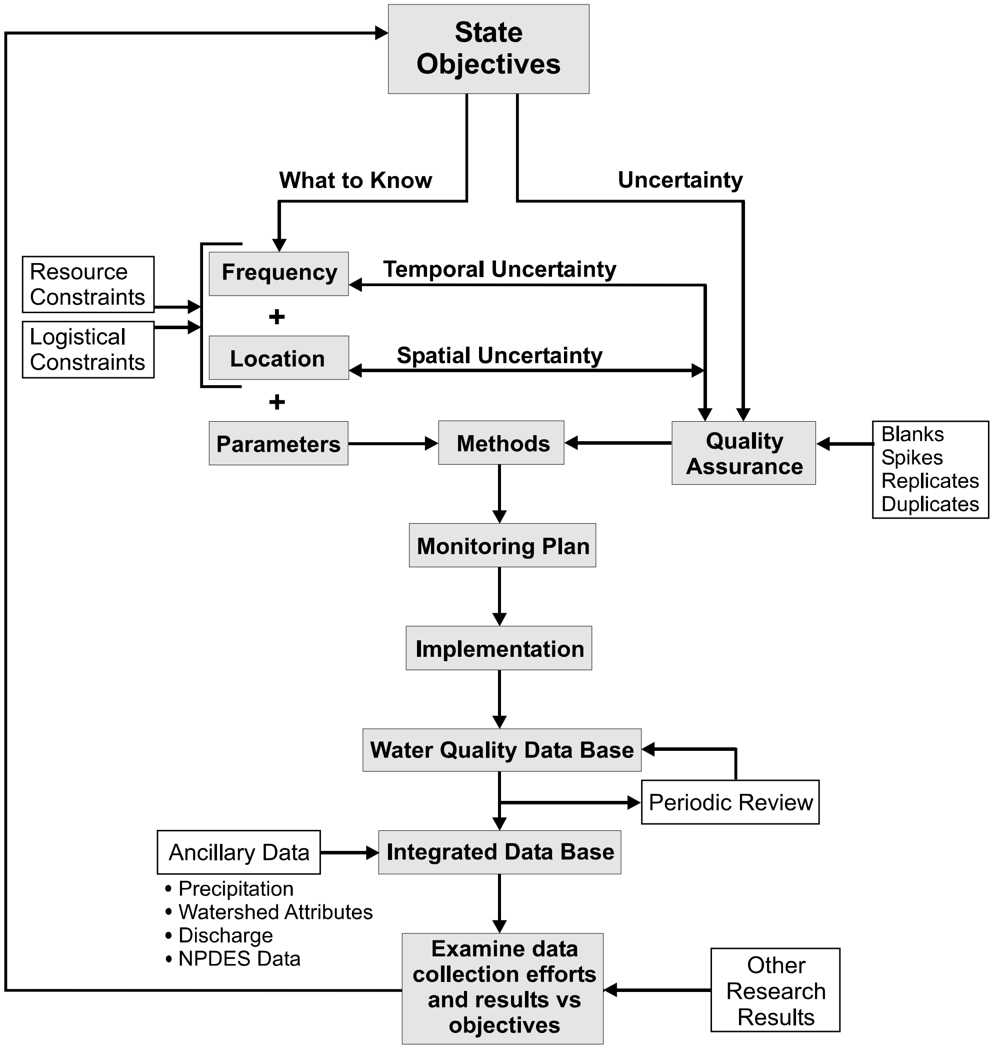


Figure 1. Decision flow chart for water quality monitoring.

An effective monitoring plan stems from a series of questions and constraints that sequentially focus the plan into specific elements that are well-defined and unambiguous. Because information is gained during implementation of a monitoring plan, it is often desirable to revisit a number of elements of the plan to continuously refine and update the monitoring activities. In addition, external factors such as changes in monitoring technology, analytical methods, and regulations will often impinge on the design and execution of the monitoring. For these reasons, routine (e.g., annual) reviews of the results and methods should be incorporated into the monitoring plan. This report represents one such review of the long-term monitoring program for rivers in the Tillamook Basin. Because trend detection is one component of the plan, care should be exercised in making changes to the program that might compromise the integrity of the data set in using past data to infer statistically-significant changes in water quality.

The primary water quality variables to be monitored can include physical, chemical, and /or biological attributes. Choice of variables to be monitored depends on the potential environmental risks, logistical issues associated with monitoring for these parameters, and monitoring costs. Continued water quality monitoring of the Tillamook Bay watershed could involve any number of parameters. The challenge is to select those parameters that are most important with respect to revealing key features of ecological integrity and that can be monitored in a relatively straight- forward and cost-effective fashion with sufficient frequency and temporal resolution as to allow statistical trend detection in the future. Thus, the choice of parameters must be shown to clearly relate to the water quality concerns and to be measurable in a routine monitoring program.

II. OBJECTIVES

The primary objective of this report is to review the results to date of the long-term monitoring program for Tillamook Basin rivers. There are a variety of possible monitoring objectives for the monitoring program itself, and these can relate to trend detection for a host of potentially important water quality parameters.

Based on available data for the five rivers in the watershed, the primary candidate variables for continued monitoring were identified by Sullivan and Eilers (1999) as:

- FCB (or alternative *E. coli*)-currently often in excess of water quality standards in the rivers and the bay.
- temperature - in excess of water quality standards in at least some sections of some of the lower rivers.
- total suspended solids - associated with degradation of salmonid spawning habitat and possible excessive sedimentation of the lower rivers and the bay.
- nutrients - although currently not excessively high, can have serious ecological consequences if concentrations increase in the future.

Additional variables of potential interest for continued monitoring, but that are currently of lesser importance in our judgement for Tillamook Basin rivers than those listed above, include dissolved oxygen, biological oxygen demand and pH. These parameters may be of concern in the lower reaches of the rivers and in the sloughs during summer low-flow periods, but have not been included in the monitoring efforts to date.

Based on available data and the perceived importance of salmonid fisheries, shellfish resources, and sedimentation issues in the watershed, Sullivan and Eilers (1999) constructed a list of potential monitoring objectives. With some modification, some of these objectives have been incorporated into the monitoring project reported here (Table 2).

We have continued the monitoring of FCB, TSS, and nutrients in some, but not all, of the rivers in the Tillamook Bay watershed. In addition, the TCPP has continued the temperature monitoring. These monitoring efforts are intended to answer the kinds of questions outlined in Table 3.

Table 3. Recommended monitoring questions
Is the concentration (flow-weighted storm median concentration) of FCB in the lower reaches of the Tillamook, Trask, and Wilson Rivers increasing or decreasing (and by how much) during typical storm events during the fall, winter, and spring seasons over time scales of years to decades?
Are the storm loads of FCB increasing or decreasing (and by how much) during typical seasonal storm events in the Tillamook, Trask and Wilson Rivers over time scales of years to decades?
Is the total nutrient loading (N, P) to Tillamook Bay from the Trask and Wilson Rivers increasing or decreasing (and by how much) over time scales of years to decades?
Is the total suspended solids loading to Tillamook Bay from the Trask, Wilson, and Kilchis Rivers increasing or decreasing (and by how much) over time scales of years to decades?
What is the frequency and duration of temperature excursions above threshold values in the lower reaches of the Tillamook, Trask, and Wilson Rivers and what is the spatial extent of such excursions?
Are there trends (increasing or decreasing) in the frequency, duration or extent of temperature excursions above threshold values in the downriver sections of the Tillamook, Trask, and Wilson Rivers over time scales of years to decades?

III. APPROACH

A. Discharge and Precipitation

The USGS maintains gauging stations on the Trask and Wilson Rivers. These data have been gathered and included in the hydrologic data set. River flow data for the Tillamook and Kilchis Rivers were collected by the Oregon Water Resources Department (OWRD) and were retrieved from field loggers monthly. Data collection began in the summer of 1995.

E&S was provided the OWRD data files, along with a series of rating curves developed for each of the OWRD stations. These raw data files were merged, and estimates of discharge were calculated from the rating curves and added to the data set.

The data set provided by OWRD for the Tillamook and Kilchis Rivers contained a number of lengthy gaps during which stage data were not collected. These gaps were filled using a series of simple linear regressions. Each equation corresponded to a season and was based on the Wilson River data collected by USGS. Additional details are provided by Sullivan et al. (1998a).

B. Water Quality

Storm sampling was conducted from December, 1996 to January, 2002 on four rivers (to March 2002 on the Tillamook River) as described below and samples were analyzed for fecal coliform bacteria (Tillamook, Trask, and Wilson Rivers), and total suspended solids (Trask, Wilson, and Kilchis Rivers). A total of 24 to 29 storms have been sampled for each river. In addition, nutrient sampling was conducted approximately bimonthly on the Trask and Wilson Rivers, as funding permitted, and samples were analyzed for NO_3^-, NH_4^+, total P, and TKN. Precipitation data were collected hourly in Tillamook by the Oregon Department of Forestry. These data were obtained from ODF for inclusion in this analysis.

1. Fecal Coliform Bacteria

Fecal coliform bacteria (FCB) concentrations were measured at the primary downstream sites on the Tillamook, Trask, and Wilson Rivers, typically during two to three selected storm events during each of three seasons each year (fall, winter, spring; four to eight storms per year). During each storm, typically six to eight samples (plus QA samples) were collected and analyzed for bacteria at each site.

Within each season and/or combination of seasons, storms were classified into a matrix of storm types determined on the basis of precipitation and hydrology during and preceding each storm (Table 4). An effort was made to constrain the number of storms actually sampled to only a few of these types. It is planned that, at a later date, data will be analyzed for trends in bacterial fluxes associated with specific seasons and/or storm types. Flow-weighted median FCB concentrations or loads will be compared from year to year by evaluating results obtained for each storm type for which a sufficient number of storms are successfully monitored (≥ 10) over a sufficiently long period of time. We anticipate that a minimum of ten years of monitoring data will be required for trends analysis.

Table 4. Classification of storms into 12 types, based on precipitation. Storms are separated into categories based on the cumulative precipitation received in Tillamook during the 30-day period preceding the storm, the number of days in advance of the storm during which in excess of 3 cm of precipitation was received, and the rainfall intensity (number of hours during which precipitation of more than 0.3 cm/hr occurred).

Storms preceded by High Precipitation (> 30 cm)

Storm Type	Rainfall Intensity	Precipitation previous to storm (# of days to get > 3 cm ppt)	# of Storms*		
			Tillamook	Wilson	Trask
1	High	Long	0	0	0
2	High	Short	4	3	3
3	Low	Long	0	0	0
4	Low	Short	3	2	2

Storms preceded by Moderate Precipitation (15 - 30 cm)

Storm Type	Rainfall Intensity	Ppt previous to storm (# of days to get > 3 cm ppt)	# of Storms		
			Tillamook	Wilson	Trask
5	High	Long	1	1	1
6	High	Short	3	1	3
7	Low	Long	2	2	2
8	Low	Short	4	2	2

Storms preceded by Low Precipitation (< 15 cm)

Storm Type	Rainfall Intensity	Ppt previous to storm (# of days to get > 3 cm ppt)	# of Storms		
			Tillamook	Wilson	Trask
9	High	Long	2	2	2
10	High	Short	1	0	0
11	Low	Long	6	6	6
12	Low	Short	1	1	1

* Does not include two monitored storms that lacked rainfall intensity data

Storm types are currently defined as:

Rainfall Intensity

- high, > 0.3 cm/hr during ≥ 8 hrs during the course of a storm
- low, > 0.3 cm/hr during < 8 hrs during the course of a storm)

Precipitation Prior to Storm

- long, > 1 week to accumulate > 3 cm
- short, < 1 week to accumulate > 3 cm

Precipitation During Previous Month

- high, > 30 cm
- medium, 15 to 30 cm
- low, < 15 cm

The last variable listed above (precipitation during previous month) is in some ways a surrogate for seasonality. Fall storms are generally classified as low, spring storms as medium, and winter storms as high. However, in the case of the drought water year (2000-2001) during this study, spring storms were preceded by very dry conditions, and in fact behaved more like typical fall storms with respect to bacterial concentrations in the rivers. Thus, this classification metric can be, in some instances, more useful than a classification based on season. We also examined a metric to reflect storm size, represented as the total amount of precipitation during the storm. This variable was not as useful as those outlined above, however, for discriminating among storm types with respect to the bacteria data.

The storm types that have been most frequently sampled to date are:

Type 2

- high rainfall intensity/short antecedent period required to accumulate > 3 cm precipitation/preceded by high precipitation during previous month

Type 8

- low rainfall intensity/short antecedent period required to accumulate > 3 cm precipitation/preceded by moderate precipitation during previous month

Type 11

- low intensity/long antecedent period required to accumulate > 3 cm precipitation/preceded by low precipitation during previous month

2. *Total Suspended Solids*

TSS was measured at the primary downstream sites on the Wilson, Trask, and Kilchis Rivers during each of approximately four to six storm events per year, with an effort to sample high-flow storm events when possible (i.e., when the Wilson River flows exceed 6,000 cfs). During each storm, typically six to eight samples (plus QA samples) were collected and analyzed for TSS at each site. Data were analyzed to estimate the instantaneous TSS load for each sample occasion, using observed discharge and measured TSS. In addition, the relationship between measured TSS and river discharge was quantified.

3. *Nutrients*

Water samples were collected bi-monthly as funding permitted at the primary downstream sites on the Wilson and Trask Rivers and analyzed for the following nutrients: NO_3^-, NH_4^+, TKN, and TP. Existing time series data are presented. Data will be analyzed at a later date to test for trends in nutrient concentrations over time in these two rivers. The intensity of data collection for nutrient monitoring is less than for bacteria and TSS because nutrient concentrations are not believed to pose as serious an environmental threat as are FCB and TSS.

4. *Sampling Site Locations*

One sampling site was selected, at the downstream end of each of the rivers in relatively close proximity to the bay. The primary sampling sites are as follows:

TIL-BUR	Tillamook River at Burton Bridge
TRA-TTR	Trask River at Tillamook Toll Road. This was initially the primary Trask River site. The primary site was changed in 1998 to the 5th St. dock, however, when bridge construction work closed the bridge for an extended period.
TRA-5th	Trask River at 5th St. dock
WIL-SSB	Wilson River at Sollie Smith Bridge
KIL-ALD	Kilchis River at Alderbrook Bridge

Sampling site locations are shown in Figure 2, along with the location of sites that were monitored less frequently during the initial characterization efforts.

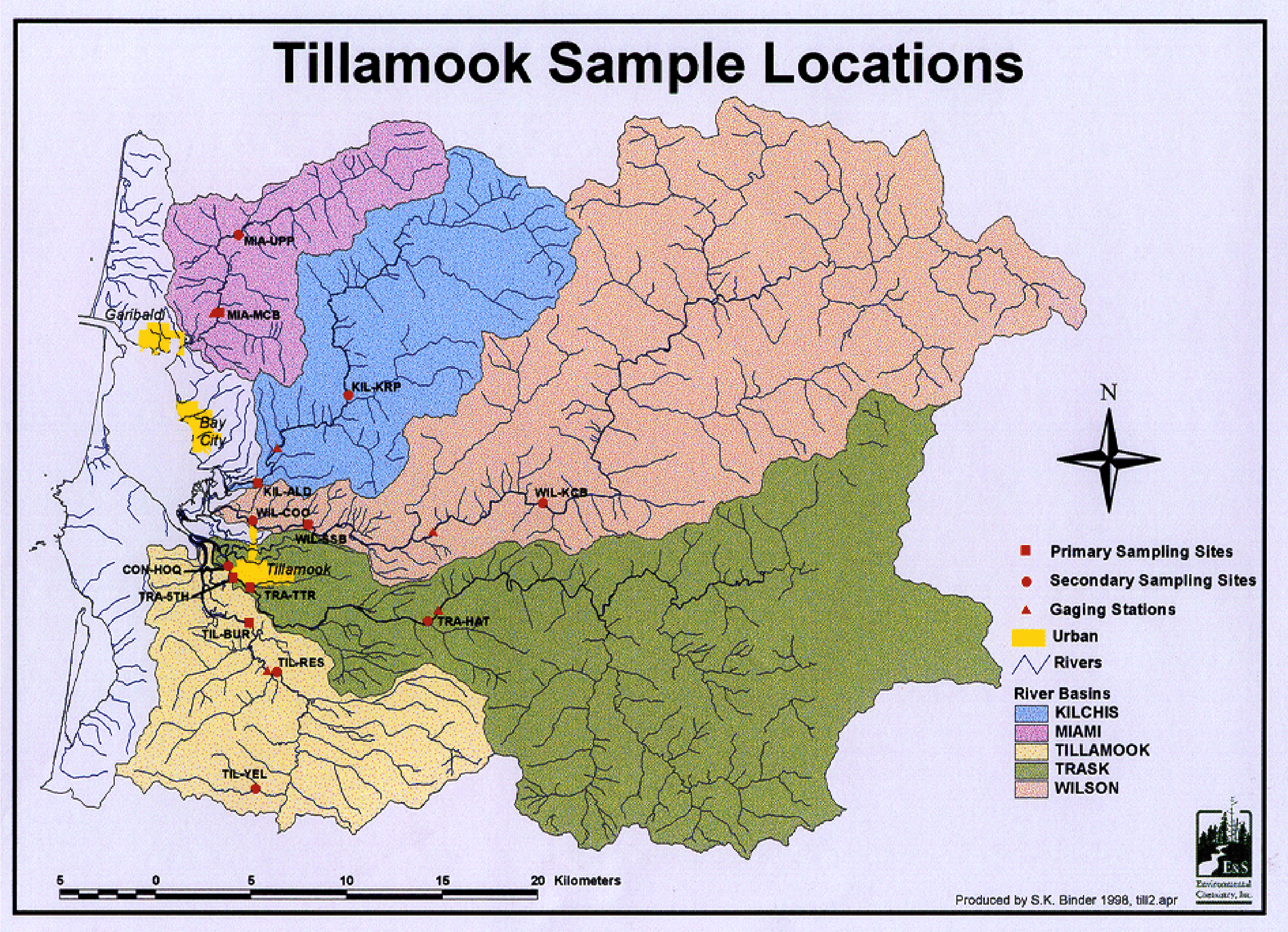


Figure 2. Sample site locations for the continued monitoring effort (TIL-BUR, TRA-5th, WIL-SSB, KIL-ALD) and for the earlier characterization studies.

Storms were selected throughout the study by the expected duration and intensity of rainfall subsequent to a variety of antecedent moisture conditions. The storms were selected in an effort to represent storms of different intensity and differing hydrological response.

IV. RESULTS

A. Discharge

Discharge data are shown in Figure 3. The 1997, 1998, 2000, and 2002 water years were rather typical, with most large storms occurring during the period November through March. The 1999 water year was somewhat unusual in terms of the enhanced frequency of large storm events. The 2001 water year was highly unusual, reflecting a serious drought. There was only one substantial storm during the 2001 water year, and that occurred on Christmas Day and was not sampled.

B. Fecal Coliform Bacteria

Fecal coliform bacteria concentrations were variable from river to river, ranging from 0 to over 12,000 cfu/100 ml at the downriver primary sites on each river in the monitoring program (Figure 4). The range for the secondary sites representing the forest/agriculture interfaces, sampled by Sullivan et al. (1998a), was much narrower, from 0 to 500 cfu/100 ml, and was typically less than about 50 cfu/100 ml.

Seasonal differences in FCB concentrations were observed at all of the rivers included in the monitoring effort. The highest bacterial concentrations were often observed during fall storm events. Many samples were measured during fall storms in excess of 1,000 cfu/100 ml. Concentrations reaching several thousand cfu/100 ml were not unusual (Figure 4). High bacterial concentrations (>500 cfu/100 ml) also were recorded at other times of the year in each of the monitored rivers. Bacteria concentrations increased dramatically during storm events, frequently by more than two orders of magnitude. The most rapid increase was often during the early part of the storm as shown in Figure 5 for the October 1997 storm. During most years studied, the majority of the storms monitored in the Tillamook and Trask Rivers showed storm median and geomean FCB values higher than 200 cfu/100 ml (Table 5), a common threshold criterion for human contact recreation. In contrast, storm data for the Wilson River less commonly exceeded the 200 cfu/100 ml threshold criterion.

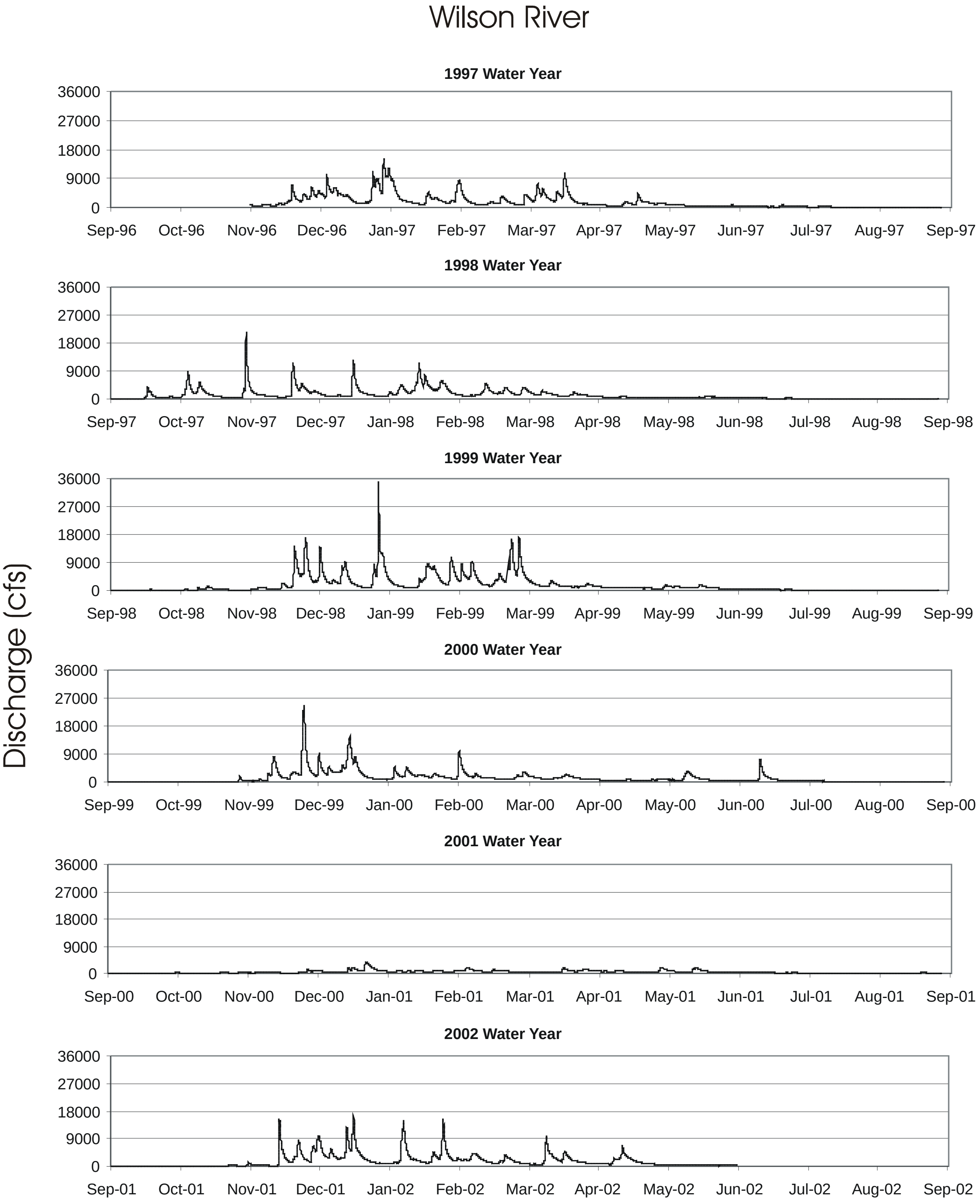


Figure 3. Wilson River discharge during the period of record for the long-term water quality monitoring program

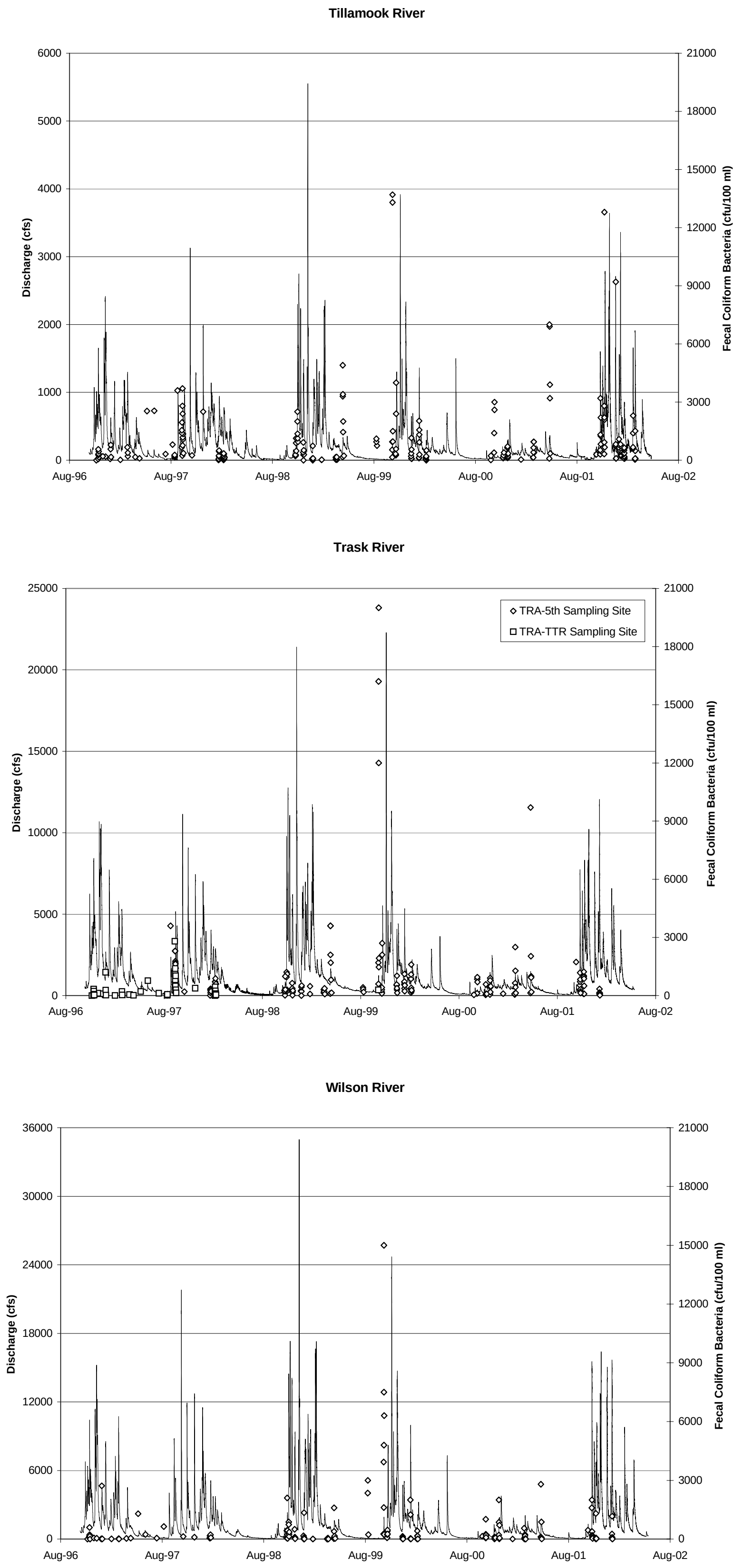


Figure 4. Discharge and measured values of fecal coliform bacteria in the three monitored rivers.

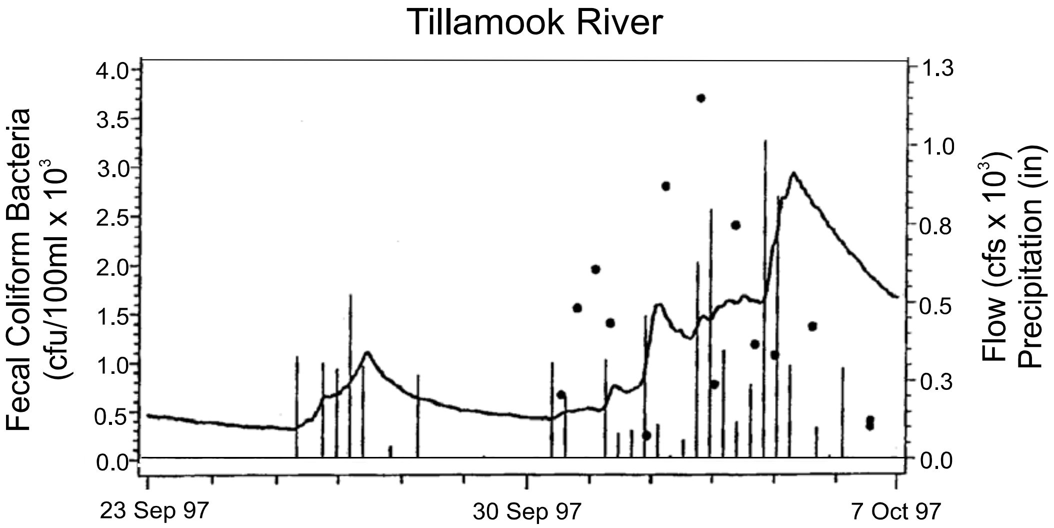


Figure 5. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3), 6 hour precipitation (bar) totals (in), and river discharge (cfs x 10^3) at the primary monitoring site on the Tillamook River for the October 1997 storm.

Table 5. Percent of monitored storms having median or geomean FCB concentration higher than 200 cfu/100 ml.

Water	Tillamook River			Trask River			Wilson River		
Year	n*	Median	Geomean	n	Median	Geomean	n	Median	Geomean
1997	2	100	100	2	0	0	2	0	0
1998	3	33	33	5	80	60	1	0	0
1999	6	67	50	6	100	33	6	33	33
2000	5	80	80	5	100	100	5	40	20
2001	5	80	80	5	80	80	5	0	0
2002	8	88	88	3	67	67	3	0	33

* n is the number of storms sampled

C. Total Suspended Solids

An important primary objective of the monitoring for suspended solids in the Tillamook Basin is to determine the flux of fine particulate sediment from erosional sources in the watersheds to salmonid spawning areas in upland tributary streams and mainstem rivers, the lower reaches of the rivers, and Tillamook Bay. Within this monitoring effort, the focus is on loading to the lower rivers and the bay. Major sources of erosional inputs can include road cuts, mass wasting of unstable upland slopes, erosion from agricultural fields, and river bank erosion. Monitoring the lower reaches of one or more rivers can provide a cumulative index to all of these erosion sources.

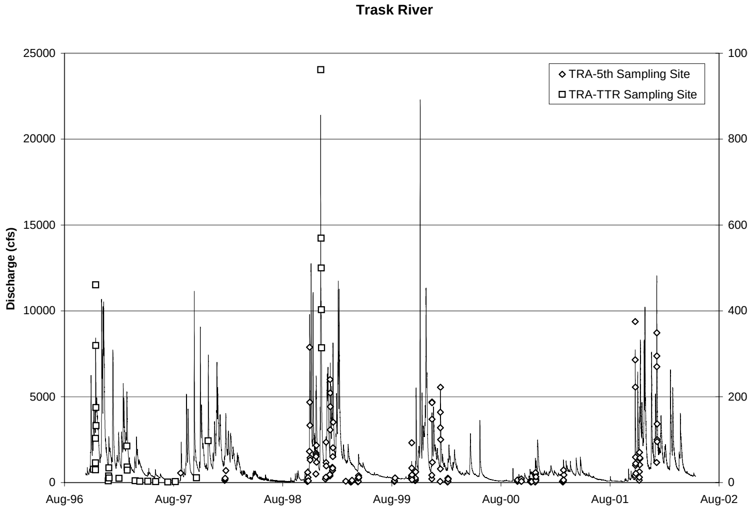
Suspended sediment fluxes are highly episodic in nature. TSS values exceeding 200 mg/L were commonly encountered during high-flow periods in all three of the monitored rivers: Trask, Wilson, and Kilchis (Figure 6). Like FCB, TSS generally increased dramatically with discharge during storm events. It is generally only during storm events that concentrations of either of these parameters are high enough to be of environmental concern. It is therefore necessary to obtain measurements for both of these parameters during the times of largest flux (i.e., storm events).

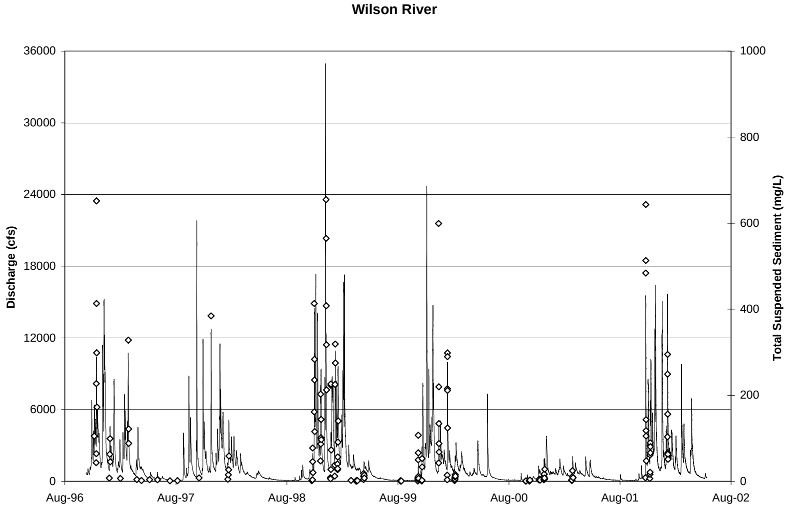
Highest TSS concentrations and loads are found in the Wilson and Trask, and to a lesser extent, the Kilchis Rivers (Sullivan et al. 1998b). For this study, monitoring for TSS has only been conducted in these three rivers, and only at the primary (downriver) monitoring site on each. This measures changes over time in the cumulative flux of TSS from both the forested and at the least a large portion of the agricultural lands in each of these watersheds.

Summary statistics for measured values of FCB and TSS for the four monitored rivers are provided in Table 6 by season and year. Measures of central tendency (i.e., median, quartiles) do not suggest consistent monotonic changes in the concentration of either of these parameters over time. In many instances, however, the impacts of the drought year (Fall 2000 to spring 2001) are evident in reduced sample frequency and lower values of FCB and/or TSS during fall and winter of that year. In contrast, FCB concentrations during spring 2001 tended to be high, more typical of fall data, because spring storms that year were preceded by such dry conditions.

A total of 24 to 29 storms was monitored for each of the four study rivers. Storms were classified by season:

fall - September 1 to November 30
winter - December 1 to February 15
spring - February 16 to May 31





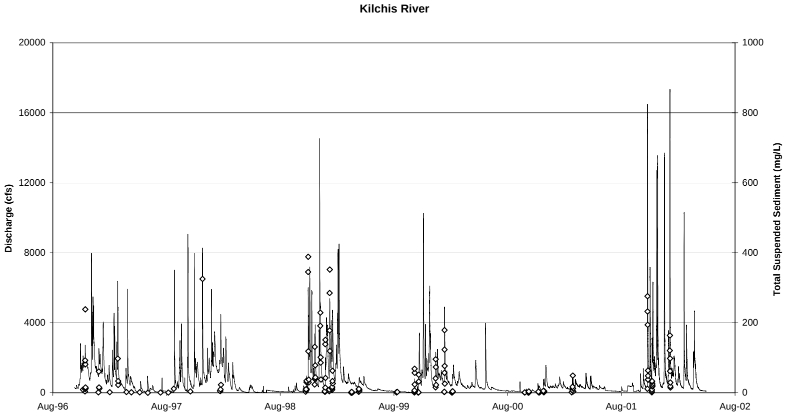


Figure 6. Discharge and measured values of total suspended solids in the three monitored rivers.

Table 6. Summary statistics for all measured values* of FCB and TSS in the four monitored rivers.

	FCB (cfu/100 ml)				TSS (mg/L)			
Year	n**	1st Quartile	Median	3rd Quartile	n	1st Quartile	Median	3rd Quartile
Tillamook River								
Fall								
1996	1				1			
1997	19	260	1070	1750	2	5	8	10
1998	12	278	920	1190	6	6	7	12
1999	14	382	850	2175				
2000	9	137	250	1400				
2001	16	505	1090	2200				
Winter								
1996	9	190	272	332	7	13	19	51
1997	5	170	570	790	5	4	10	27
1998	13	67	280	450	4	5	7	8
1999	8	26	75	86				
2000	22	152	350	692				
2001	1							
2002	29	250	510	725				
Spring								
1996								
1997	7	132	200	525	7	4	6	12
1998	8	56	132.5	245				
1999	13	67	166	2000				
2000	8	45	102	178				
2001	13	350	640	3200				
2002	11	290.5	610	1035				
Trask River								
Fall								
1996								
1997	33	200	570	1390	2	14	17	20
1998	12	220	285	968	13	4	24	73
1999	16	290	1035	2250	14	7	11	18
2000	8	81	345	738	9	3	3	4
2001	17	210	530	970	15	23	44	65
Winter								
1996	9	40	90	225	7	75	133	247
1997	5	40	280	380	5	11	15	34
1998	13	162	220	300	15	24	65	358
1999	8	184	235	450	18	28	43	116
2000	22	248	475	670	20	8	22	133
2001	1				0			

Table 6. Continued.								
	FCB (cfu/100 ml)				TSS (mg/L)			
Year	n**	1st Quartile	Median	3rd Quartile	n	1st Quartile	Median	3rd Quartile
2002	7	68	104	141	7	98	137	282
Spring								
1996								
1997	7	21	30	130	7	4	10	33
1998	16	95	245	502	0			
1999	13	144	310	1700	13	2	3	10
2000	8	268	365	918	8	3	4	9
2001	14	131	535	1204	8	2	4	9
Wilson River								
Fall								
1996	1				1			
1997	1				1			
1998	12	123	305	515	12	3	61	180
1999	15	235	390	4365	16	2	6	37
2000	10	72	98	185	11	1	2	3
2001	16	33	160	398	16	41	82	124
Winter								
1996	9	56	98	156	7	118	227	356
1997	5	16	17	96	5	45	63	99
1998	13	61	75	95	15	53	101	265
1999	8	8	16	107	18	28	48	202
2000	22	19	42	193	21	10	42	211
2001	1				0			
2002	7	18	70	176	7	64	103	202
Spring								
1996								
1997	7	14	21	42	7	4	7	105
1998								
1999	13	15	35	93	13	1	2	11
2000	8	14	17	156	8	4	7	10
2001	13	12	72	230	6	3	5	10
Kilchis River								
Fall								
1996	1				1			
1997	2	190	350	510	2	6	8	10
1998	7	22	35	142	11	10	30	78
1999	1				16	1	4	26
2000	1				10	1	1	2
2001					16	16	32	52

Table 6. Continued.

	FCB (cfu/100 ml)				TSS (mg/L)			
Year	n**	1st Quartile	Median	3rd Quartile	n	1st Quartile	Median	3rd Quartile
Winter								
1996	9	10	19	49	7	12	16	87
1997	5	6	7	42	5	12	16	61
1998	5	5	9	14	15	23	40	94
1999					19	11	27	129
2000					20	3	10	61
2001								
2002					7	24	62	109
Spring								
1996								
1997	7	2	3	18	7	2	2	28
1998								
1999					12	1	3	10
2000					8	1	2	3
2001	8	34	46	51	6	5	9	16

* The data in this table differ from data presented in Table 5 in that summary statistics are presented here for all measured values, irrespective of storm categorization whereas data in Table 5 reflect storm summary statistics.

** n is the number of samples collected

Monitored storms are listed in Tables 7 through 10, along with summary statistics for precipitation, hydrology, FCB, and TSS.

D. Nutrients

Nitrate concentrations were generally between 0.2 and 1 mg/L in both the Trask and Wilson Rivers (Figure 7). Concentrations of nitrate were generally reduced during summer and higher during winter. This is likely due to greater biological demand for N in the aquatic and terrestrial systems during summer months and greater flushing of nitrate from soils to streams during winter.

Total phosphorus (TP) concentrations in both rivers were typically less than about 0.1 mg/L, except during storms when the concentrations sometimes exceeded 0.5 mg/L (Figure 8). In the initial characterization study (Sullivan et al. 1998a), the rivers with largest watersheds (Trask and Wilson), during periods of the highest flows, tended to have the highest TP concentrations, and the river with the lowest flows and smallest watershed (Tillamook) had the lowest TP concentrations.

Table 7. List of monitored storms for the Tillamook River, with summary statistics for hydrology, precipitation, and FCB.

Storm #	Date Storm Began	Season	Total Storm Discharge (L x 10^9)	Total Storm Precip (cm)	Previous 7-day Precip (cm)	# of FCB samples	Discharge-Weighted Storm Median FCB (cfu/100 ml)	Storm Median FCB Load (cfu x 10^6/sec)
1[a]	12/4/96	Winter	7.2	7.3	11.4	7	332	97
2[a]	1/16/97	Winter	3.7	8.2	1.4	4	361	43
3	10/1/97	Fall	7.0	11.6	3.5	11	1255	139
4	2/9/98	Winter	6.8	10.5	4.4	7	172	24
5	2/27/98	Spring	9.2	11.0	5.6	8	158	26
6	11/12/98	Fall	2.4	3.1	3.7	7	279	8
7	11/20/98	Fall	10.8	14.6	4.5	5	1376	650
8	12/11/98	Winter	11.3	10.0	8.0	6	285	93
9	1/12/99	Winter	1.6	3.5	1.9	6	39	3
10	4/7/99	Spring	2.3	3.2	1.3	6	56	3
11	5/1/99	Spring	3.1	7.2	1.5	7	2956	177
12	10/27/99	Fall	0.9	5.4	2.1	7	960	25
13[b]	11/8/99	Fall	1.2	4.3	2.8	6	469	13
14	1/3/00	Winter	3.7	5.3	3.7	6	128	16
15	1/31/00	Winter	6.4	7.6	2.1	7	1295	331
16	2/24/00	Spring	1.8	4.5	3.7	8	73	3
17	10/27/00	Fall	0.5	2.8	0.4	4	2062	28
18	11/28/00	Fall	1.5	2.3	4.9	4	216	8
19	12/14/00	Winter	1.0	5.0	1.2	8	264	13
20	3/16/01	Spring	1.5	4.7	1.3	7	572	19
21	5/14/01	Spring	3.9	6.2	0.0	6	4785	361
22	11/13/01	Fall	6.6	11.8	0.6	8	1197	243
23	11/27/01	Fall	3.9	7.2	9.4	7	2332	531
24	1/7/02	Winter	13.8	14.7	4.1	6	740	317
25	1/19/02	Winter	9.2	7.6	3.8	7	520	155
26	1/24/02	Winter	15.2	14.8	11.3	7	503	274
27	2/6/02	Winter	6.6	6.9	4.9	9	251	41
28	3/10/02	Spring	8.8	11.8	3.8	6	658	170
29	3/18/02	Spring	9.6	5.1	12.7	5	89	30

[a] Storms 1 and 2 have only daily rainfall on record

[b] Storm 13 has gaps in rainfall record filled with values derived from regression with South Fork station

Table 8. List of monitored storms for the Trask River with summary statistics for hydrology, precipitation, FCB, and TSS.

Storm #	Date Storm Began	Season	Total Storm Discharge (L x 10^9)	Total Storm Precip (cm)	Previous 7-day Precip (cm)	# of FCB Samples	Discharge-Weighted Storm Median FCB (cfu/100 ml)	Storm Median FCB Load (cfu x 10^6/sec)	# of TSS Samples	Discharge-Weighted Storm Median TSS (mg/L)	Storm Median TSS Load (mg x 10^4/sec)
1[a]	12/4/96	Winter	39	7.3	11.4	7	84	139	7	144	2371
2[a]	1/16/97	Winter	17	8.2	1.4	4	216	111	4	13	66
3a (5th)	9/30/97	Fall	31	11.6	3.5	17	1229	416			
3b (TTR)	9/30/97	Fall	31	11.6	3.5	9	820	299			
4	2/9/98	Winter	44	10.5	4.4	7	271	151	4	9	46
5a (5th)	2/27/98	Spring	40	11.0	5.6	8	473	284			
5b (TTR)	2/27/98	Spring	40	11.0	5.6	8	120	72			
6	11/12/98	Fall	5	3.1	3.7	7	260	31	7	6	7
7	11/20/98	Fall	40	14.6	4.5	5	570	1022	6	103	1581
8	12/11/98	Winter	57	10.0	8.0	6	242	358	6	63	935
9	12/28/98	Winter	106	16.7	7.3				5	500	13362
10	1/12/99	Winter	8	3.5	1.9	6	155	66	5	43	226
11	1/27/99	Winter	49	4.6	5.9				6	161	2582
12	2/4/99	Winter	57	5.4	4.9				7	34	383
13	4/7/99	Spring	19	3.2	1.3	6	208	66	6	3	8
14	5/1/99	Spring	15	7.2	1.5	7	2094	627	6	10	29
15	10/27/99	Fall	5	5.4	2.1	9	1655	278	8	16	28
16[b]	11/8/99	Fall	4	4.3	2.8	6	366	38	5	7	6
17	1/3/00	Winter	27	5.3	3.7	6	285	276	6	108	1045
18	1/31/00	Winter	32	7.6	2.1	7	420	490	6	115	1431
19	2/24/00	Spring	9	4.5	3.7	8	475	113	8	4	9
20	10/27/00	Fall	3	2.8	0.4	4	818	72	4	3	3
21	11/28/00	Fall	8	2.3	4.9	4	101	16	4	2	3
22	12/14/00	Winter	14	5.0	1.2	8	376	95	7	8	20
23	3/15/01	Spring	16	4.7	1.3	8	400	73	8	4	8
24	5/14/01	Spring	14	6.2	0.0	6	1068	335			
25	11/13/01	Fall	31	11.8	0.6	9	210	183	8	50	446
26	11/27/01	Fall	18	7.2	9.4	7	641	626	7	53	521
27	1/24/02	Winter	67	14.8	11.3	7	128	233	7	137	2485

[a] Storms 1 and 2 have only daily rainfall on record

[b] Storm 16 has gaps in rainfall record filled with values derived from regression with South Fork station

Table 9. List of monitored storms for the Wilson River with summary statistics for hydrology, precipitation, FCB, and TSS.

Storm #	Date Storm Began	Season	Total Storm Discharge (L x 10^9)	Total Storm Precip (cm)	Previous 7-day Precip (cm)	# of FCB Samples	Storm Median FCB Load (cfu x 10^6/sec)	Discharge-Weighted Storm Median FCB (cfu/100 ml)	# of TSS Samples	Discharge-Weighted Storm Median TSS (mg/L)	Storm Median TSS Load (mg x 10^4/sec)
1[a]	12/4/96	Winter	45	7.3	11.4	7	244	132	7	299	5500
2[a]	1/16/97	Winter	30	8.2	1.4	4	18	22	4	53	450
3	2/9/98	Winter	50	10.5	4.4	7	44	77	4	22	157
4	11/12/98	Fall	15	3.1	3.7	7	70	404	7	3	6
5	11/20/98	Fall	69	14.6	4.5	5	752	255	5	236	6936
6	12/11/98	Winter	76	10.0	8.0	6	171	81	6	99	2072
7	12/29/98	Winter	129	16.7	7.3				5	408	9408
8	1/12/99	Winter	11	3.5	1.9	6	27	44	6	58	361
9	1/27/99	Winter	67	4.6	5.9				5	225	4615
10	2/4/99	Winter	61	5.4	4.9				7	40	484
11	4/7/99	Spring	20	3.2	1.3	6	3	10	6	1	3
12	5/1/99	Spring	16	7.2	1.5	7	27	93	6	12	33
13	10/27/99	Fall	5	5.4	2.1	8	636	3238	9	7	11
14[b]	11/8/99	Fall	8	4.3	2.8	6	47	318	6	2	3
15	1/3/00	Winter	26	5.3	3.7	6	35	35	6	142	1394
16	1/31/00	Winter	57	7.6	2.1	7	69	36	7	171	3231
17	2/24/00	Spring	13	4.5	3.7	8	8	23	8	6	21
18	10/27/00	Fall	3	2.8	0.4	6	14	175	6	2	1
19	11/28/00	Fall	10	2.3	4.9	4	17	79	4	3	7
20	12/14/00	Winter	16	5.0	1.2	8	30	94	7	7	26
21	3/15/01	Spring	17	4.7	1.3	8	13	56	6	7	13
22	5/14/01	Spring	19	6.2	0.0	5	33	78			
23	11/13/01	Fall	57	11.8	0.6	9	236	151	8	131	2058
24	11/27/01	Fall	13	7.2	9.4	6	49	29	8	64	1050
25	1/24/02	Winter	80	14.8	11.3	7	160	70	7	103	2362

[a] Storms 1 and 2 have only daily rainfall on record

[b] Storm 14 has gaps in rainfall record filled with values derived from regression with South Fork station

Table 10. List of monitored storms for the Kilchis River with summary statistics for hydrology, precipitation, and TSS.

Storm #	Date Storm Began	Season	Total Storm Discharge (L x 10^9)	Total Storm Precip (cm)	Previous 7-day Precip (cm)	# of TSS samples	Discharge-Weighted Storm Median TSS (mg/L)	Storm Median TSS Load (mg x 10^3/sec)
1[a]	12/4/96	Winter	14	7.3	11.4	7	16	852
2[a]	1/16/97	Winter	16	8.2	1.4	4	14	811
3	2/9/98	Winter	37	10.5	4.4	4	8	449
4	11/12/98	Fall	5	3.1	3.7	6	10	146
5	11/20/98	Fall	29	14.6	4.5	5	172	14924
6	12/11/98	Winter	31	10.0	8.0	6	42	3729
7	12/29/98	Winter	53	16.7	7.3	5	102	9593
8	1/12/99	Winter	6	3.5	1.9	6	33	1024
9	1/27/99	Winter	32	4.6	5.9	6	146	15462
10	2/4/99	Winter	31	5.4	4.9	7	16	923
11	4/7/99	Spring	9	3.2	1.3	5	1	14
12	5/1/99	Spring	8	7.2	1.5	6	10	158
13	10/27/99	Fall	2	5.4	2.1	9	3	23
14[b]	11/8/99	Fall	3	4.3	2.8	6	1	8
15	1/3/00	Winter	13	5.3	3.7	5	35	908
16	1/31/00	Winter	25	7.6	2.1	7	41	3882
17	2/24/00	Spring	7	4.5	3.7	8	2	31
18	10/27/00	Fall	1	2.8	0.4	5	1	4
19	11/28/00	Fall	5	2.3	4.9	4	1	12
20	12/14/00	Winter	8	5.0	1.2	7	3	40
21	3/15/01	Spring	8	4.7	1.3	5	13	219
22	11/13/01	Fall	204	11.8	0.6	8	55	5785
23	11/27/01	Fall	46	7.2	9.4	8	21	1500
24	1/24/02	Winter	228	14.8	11.3	7	62	15082

[a] Storms 1 and 2 have only daily rainfall on record

[b] Storm 14 has gaps in rainfall record filled with values derived from regression with South Fork station

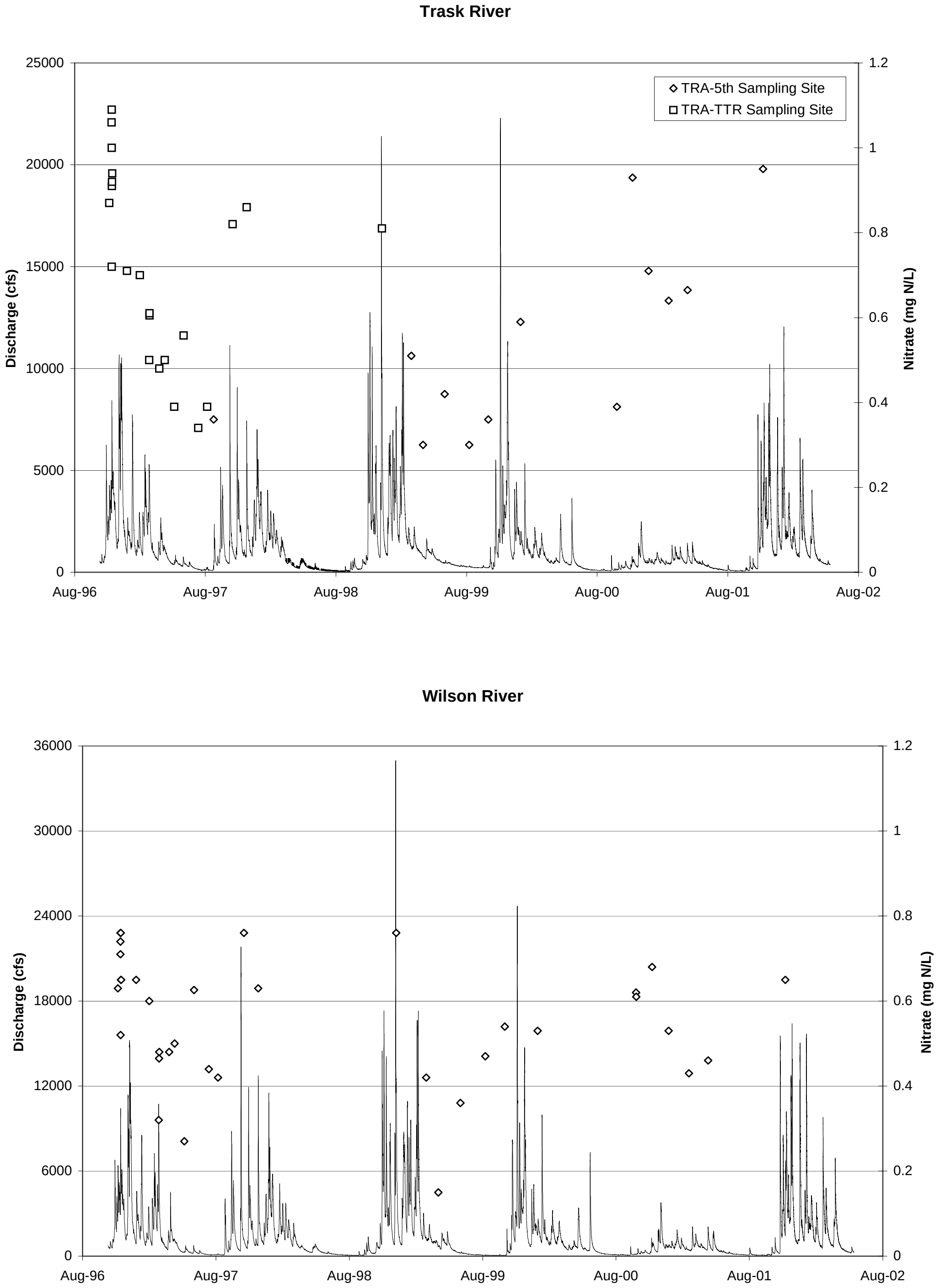
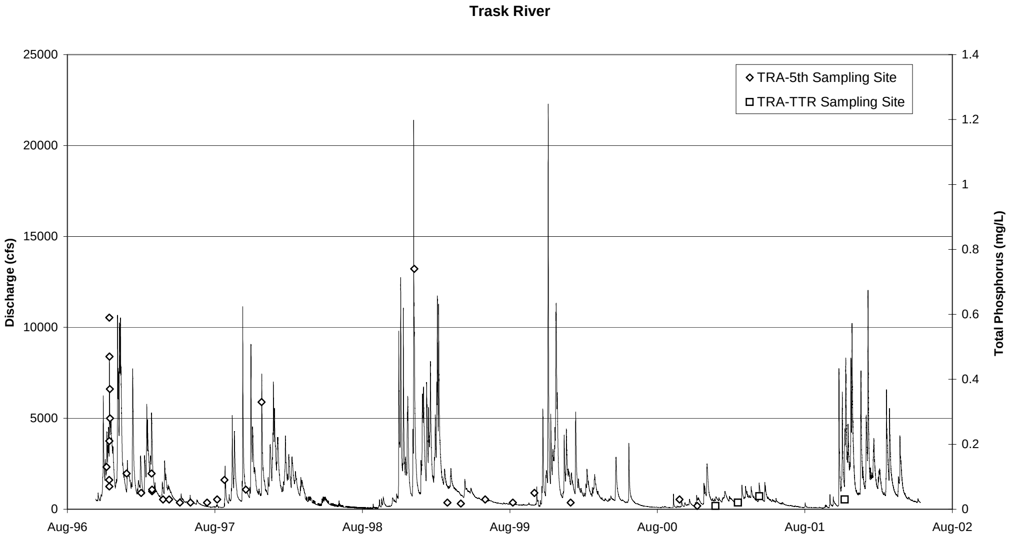


Figure 7. Discharge and measured values of nitrate for the Trask and Wilson Rivers.



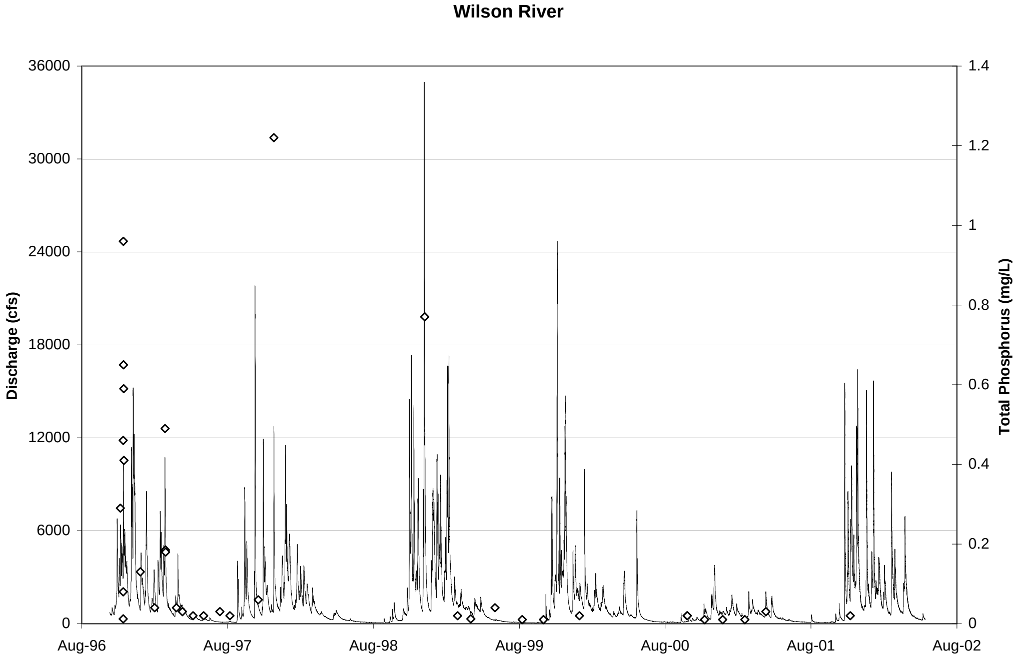


Figure 8. Discharge and measured values of total phosphorus for the Trask and Wilson Rivers.

V. DISCUSSION

A. Fecal Coliform Bacteria

Concentrations of FCB in Tillamook Basin rivers are highly episodic and within-storm values typically change by two orders of magnitude during a period of one or two days (Figure 9, top panels). This variability seriously complicates efforts to document and quantify changes in concentrations over time. This variability can be reduced to about one and a half orders of magnitude by examining trends in the discharge-weighted storm median concentrations (second panel from top, for each river, in Figure 9). If these discharge-weighted storm median values are examined only for a particular season (third panel from top in Figure 9) or particular storm type (bottom panels in Figure 9), the variability can be reduced to one order of magnitude, or for some storm types, much less than that. Thus, classification of storms by season, and especially by type (based on precipitation and hydrology) reduces the variability to the point that trends analyses are much more feasible. Such an analysis allows us to compare “apples with apples” when conducting trends analysis.

FCB concentrations were strongly influenced by antecedent precipitation. For example, if the four days preceding the storm received more than 3 cm of rainfall, the storm almost always (9 of 10 storms) had discharge-weighted storm median FCB in the Tillamook River less than about 800 cfu/100 ml (Figures 10, 11). If, on the other hand, the four days preceding the storm received less than 3 cm of rainfall, the storm often (8 of 19 storms) had discharge-weighted storm median FCB greater than 800 cfu/100 ml.

Of the 11 Tillamook River storms that had discharge-weighted storm median FCB > 800 cfu/100 ml, all except one were either high rainfall intensity (8 of 11) and/or fall season (6 of 11) storms (Figure 12). Similarly, all except two were preceded by less than 30 cm of precipitation during the previous 30-day period (Figure 13).

Storm size, or the total cumulative precipitation recorded during the storm, was not as clearly associated with FCB concentration (Figure 14) as were the amount of rainfall preceding the storm and the rainfall intensity during the storm (Figures 10-13).

A stepwise multiple regression analysis was performed, using backward selection in Statgraphics, to predict the discharge-weighted storm median FCB concentration, using only precipitation and hydrological independent variables. Potential independent variables for this analysis were as follows:

- 30-day cumulative precipitation preceding storm

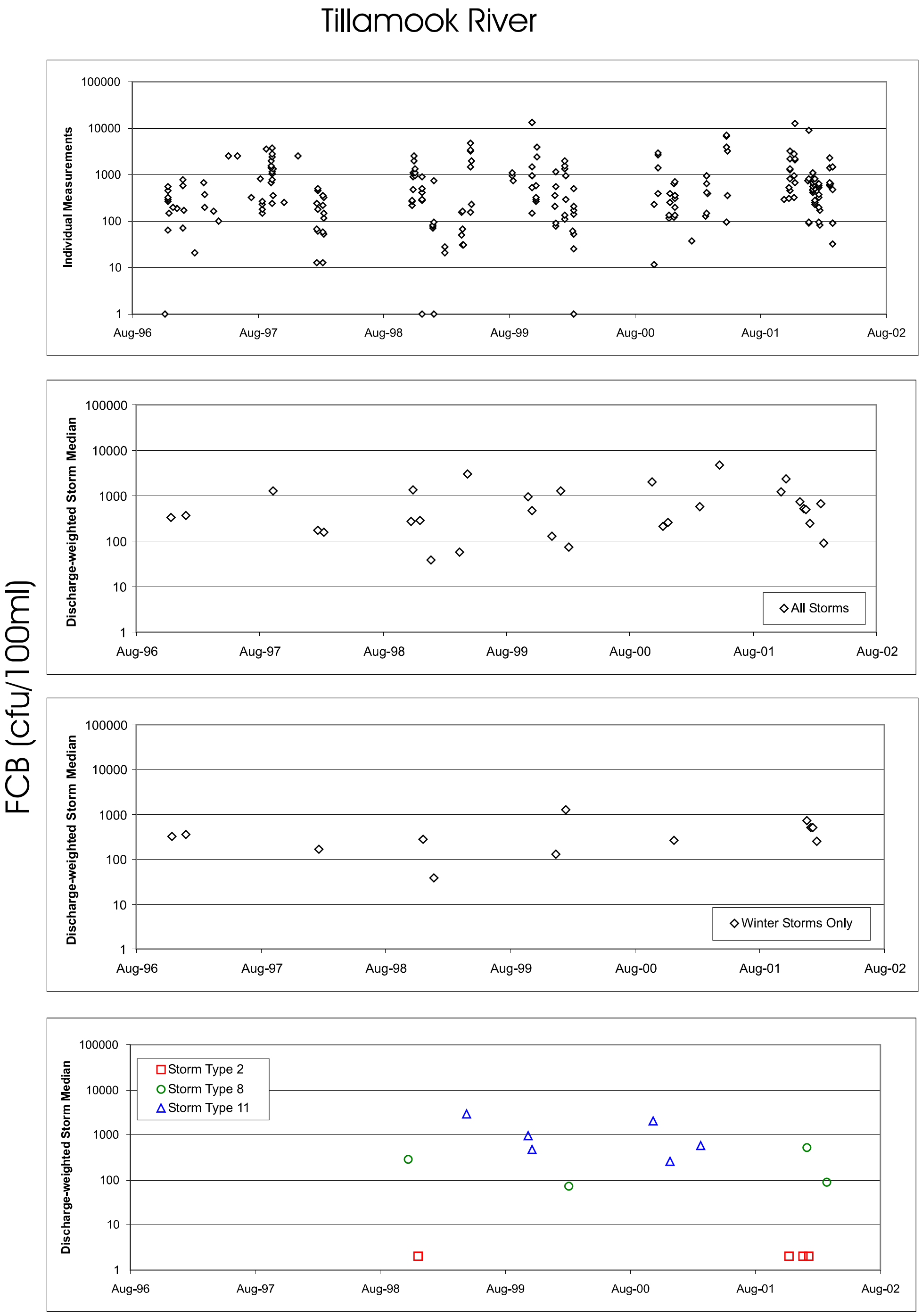


Figure 9. Series of graphs showing selected FCB data for the a) Tillamook River, b) Trask River, and c) Wilson River throughout the monitoring period. All measured values are displayed in the top panel. Discharge-weighted storm median values are displayed in the three lower panels, first showing data for all storms, followed by all storms within a single season, followed finally by all storm types represented by three or more data points. Storm types are defined in Table 4.

Trask River

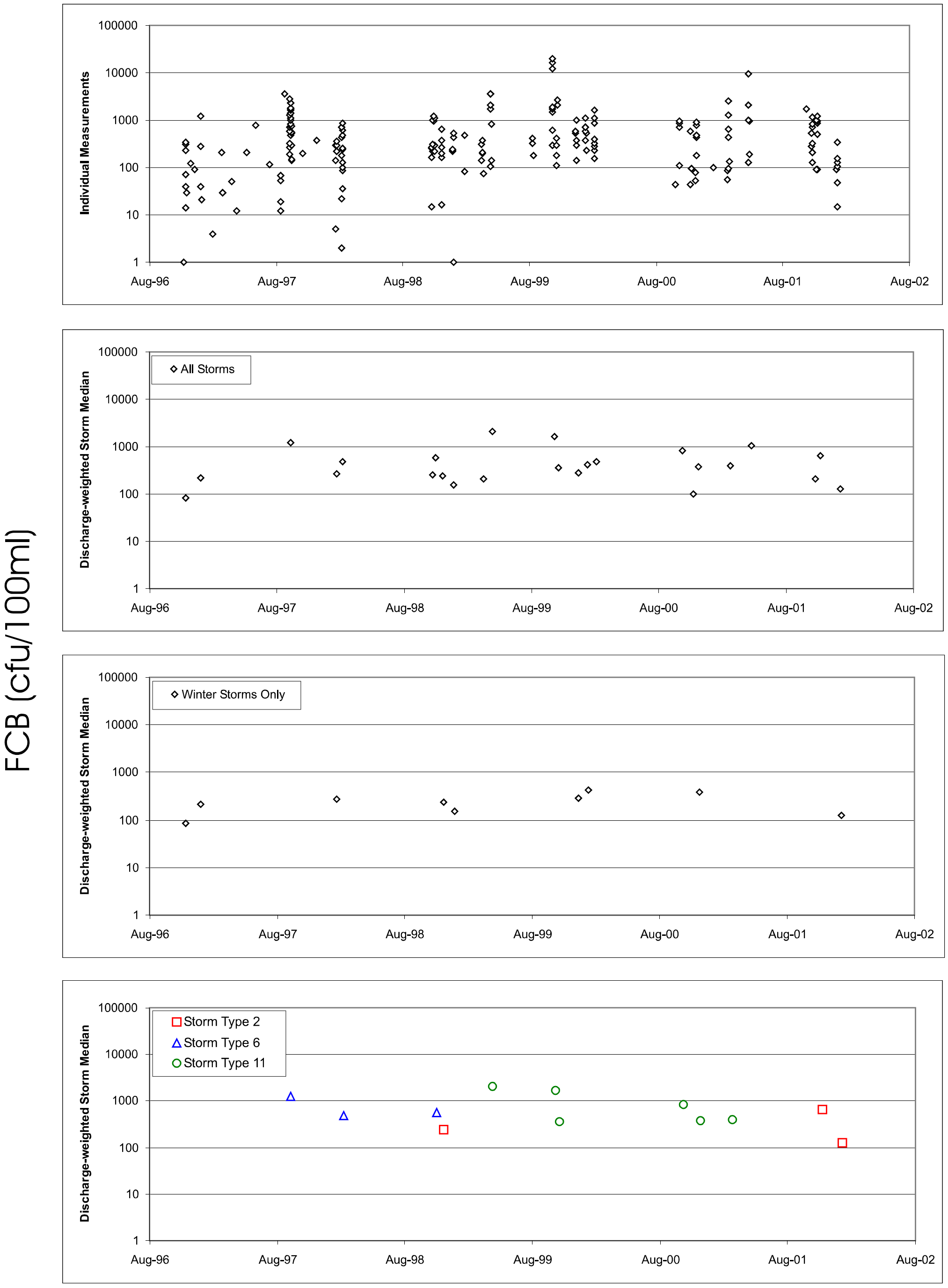


Figure 9. Continued.

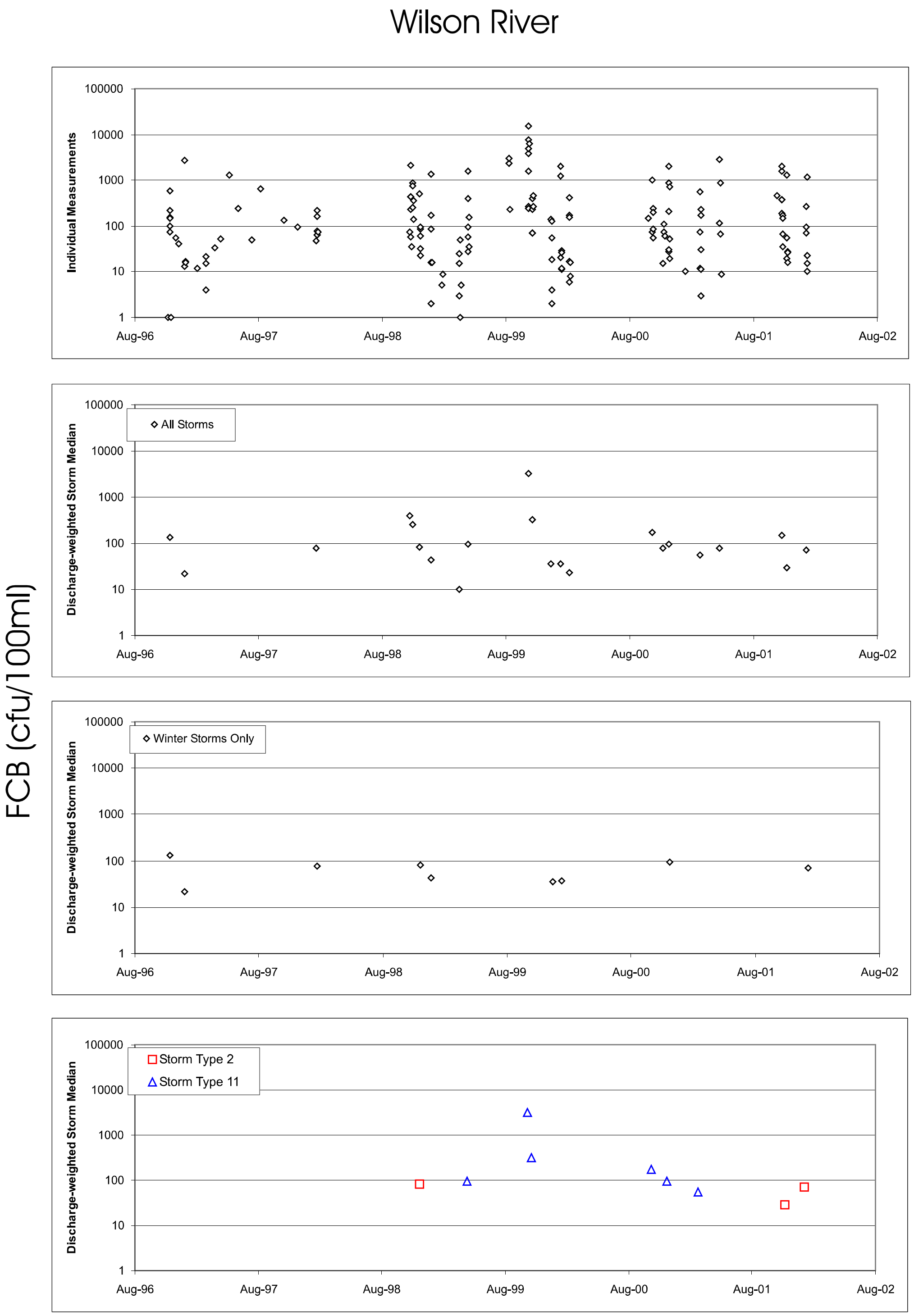


Figure 9. Continued.

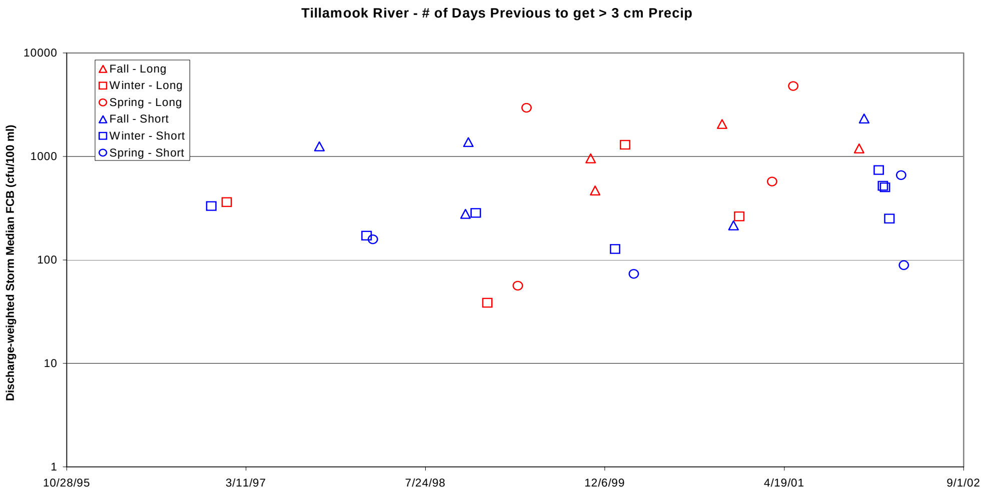


Figure 10. Discharge-weighted storm median FCB recorded throughout the period of record for the Tillamook River. Storms are coded by season (symbol shape) and the number of days in advance of the storm required to accumulate more than 3 cm of precipitation. Storms showing highest FCB generally occurred during the fall season and/or exhibited relatively dry conditions immediately preceding the storm.

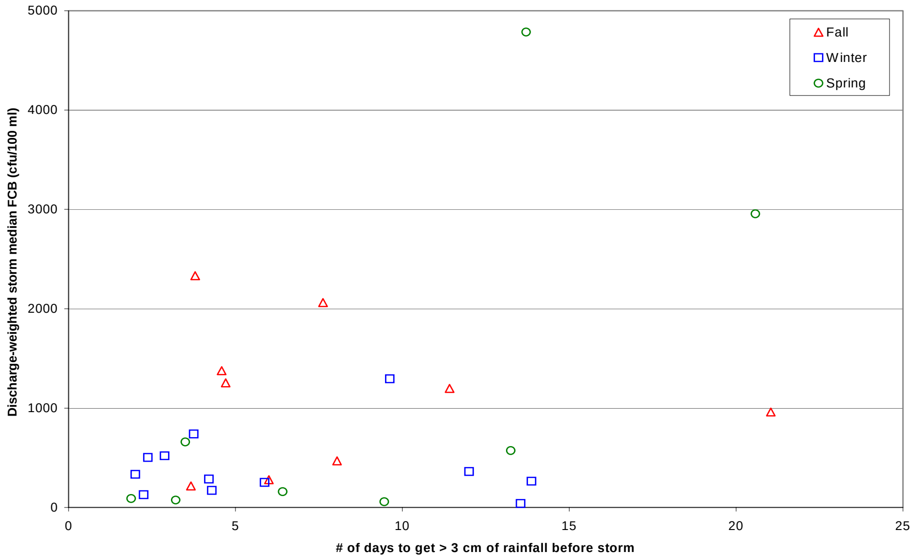


Figure 11. Discharge-weighted storm median FCB in the Tillamook River versus the number of days in advance of the storm required to accumulate more than 3 cm of precipitation. Storms preceded by four or fewer relatively dry days almost always exhibited relatively low FCB. Storms preceded by more than four dry days showed a greater range of FCB response.

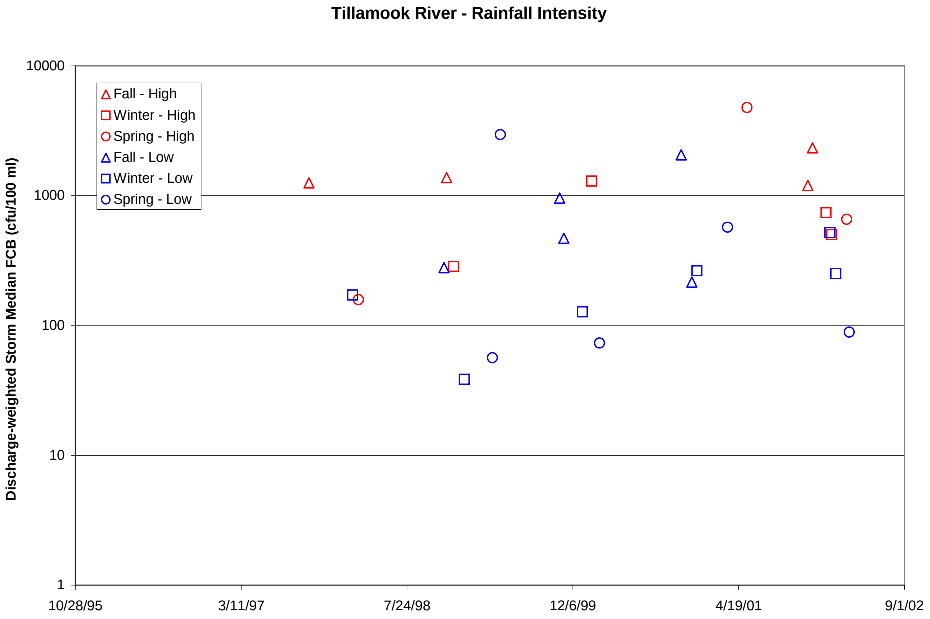


Figure 12. Discharge-weighted storm median FCB recorded throughout the period of record for the Tillamook River. Storms are coded by season (symbol shape) and rainfall intensity (color). Storms showing highest FCB generally occurred during the fall season and/or exhibited high rainfall intensity.

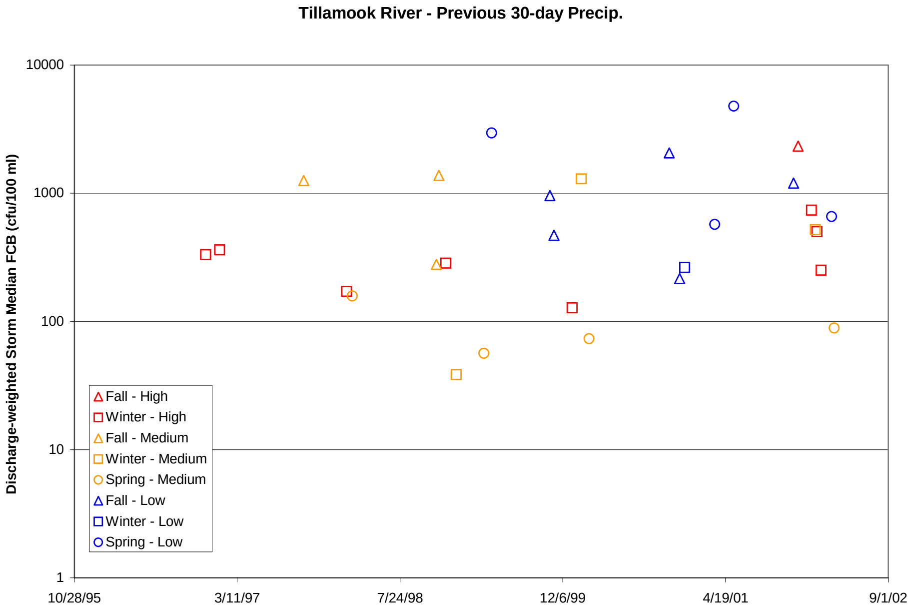


Figure 13. Discharge-weighted storm median FCB recorded throughout the period of record for the Tillamook River. Storms are coded by season (symbol shape) and the cumulative precipitation during the 30 days preceding the storm. Storms showing highest FCB generally occurred during the fall season and/or exhibited relatively dry conditions during the month preceding the storm.

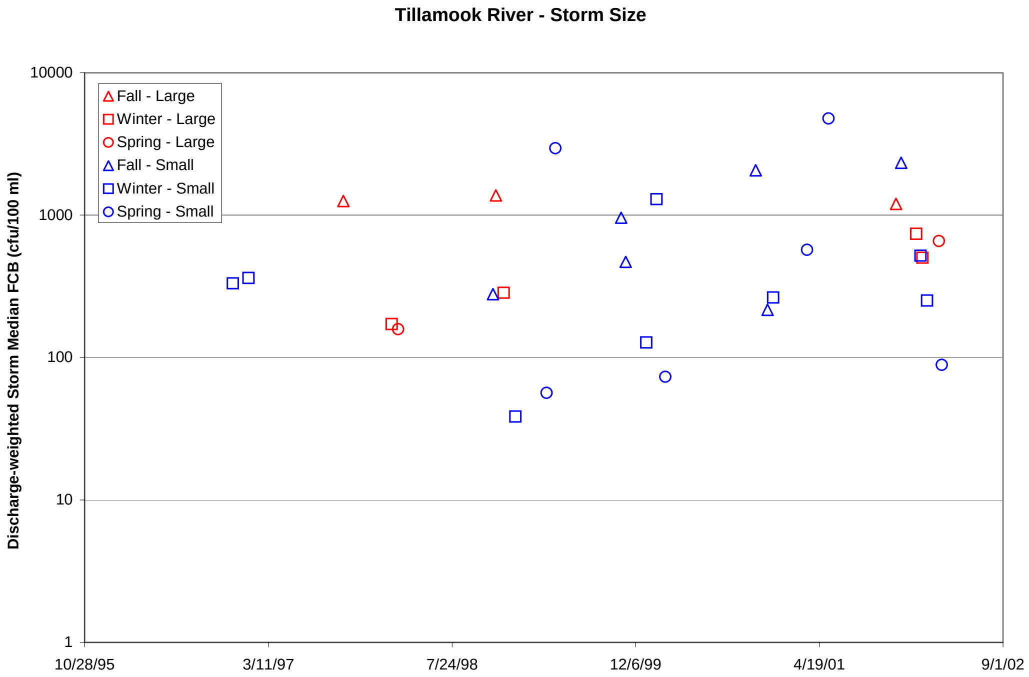


Figure 14. Discharge-weighted storm median FCB recorded throughout the period of record for the Tillamook River. Storms are coded by season (symbol shape) and storm size (color). Storm size (cumulative precipitation) does not appear to be an important determinant of FCB concentration.

- 7-day cumulative precipitation preceding storm
- number of days in advance of storm required to obtain more than 3 cm of cumulative precipitation
- rainfall intensity (number of hours in the storm during which in excess of 0.3 cm/hr of precipitation was recorded)
- peak river discharge during the storm
- cumulative river discharge during the storm
- cumulative storm precipitation

For all three rivers, the most significant predictor of discharge-weighted storm median FCB was the number of days in advance of the storm required to obtain more than 3 cm of cumulative precipitation. This variable was statistically significant for each river, and explained, on its own, from 16% (Tillamook River) to 38% (Trask River) of the variability in FCB concentration. Parameter values selected by the stepwise regression are given in Table 11. The multiple regression explained from 23% (Wilson River) to 52% (Trask River) of the observed variability in FCB concentration, based only on precipitation and hydrological data. Predicted versus observed FCB data are shown for the Trask River in Figure 15.

FCB and TSS respond episodically to rainfall and hydrologic conditions. The biggest challenge in implementing a monitoring effort for parameters such as these is the need to reduce the variability in the data prior to conducting trends analyses. Our aim is to enable year-to-year comparisons that entail "comparing apples with apples". It appears that seasonal and storm-type stratification efforts (Figure 9) are reasonably effective in this regard for rivers in the Tillamook Basin. It does not appear that revisions to the monitoring plan are needed at this time. Our efforts to quantify measurements by storm (e.g., discharge-weighted storm median FCB or TSS) and classify storms by season and/or by type (e.g., on the basis of rainfall patterns), have dramatically reduced the variability inherent in measurement of these important variables. Although it is not clear whether trends analyses will ultimately be conducted using season or storm type as the basis for analysis, continued storm-based monitoring of FCB and

Table 11. Predictive models for discharge-weighted storm median FCB concentration for each river, based on precipitation and hydrology.

River	Parameter	Parameter Estimate	P-value	Model r^2
Trask	Number of days*	51.3	0.007	
	Peak discharge	-0.004	0.061	
	Cumulative storm precip	109.4	0.032	
	Constant	-228.6	0.380	0.52
Tillamook	Number of days*	95.0	0.017	
	Rainfall intensity	51.4	0.132	
	Constant	-234.8	0.616	0.24
Wilson	Number of days*	58.2	0.032	
	Constant	-247.4	0.361	0.23

* Number of days in advance of storm required to obtain greater than 3 cm of cumulative precipitation.

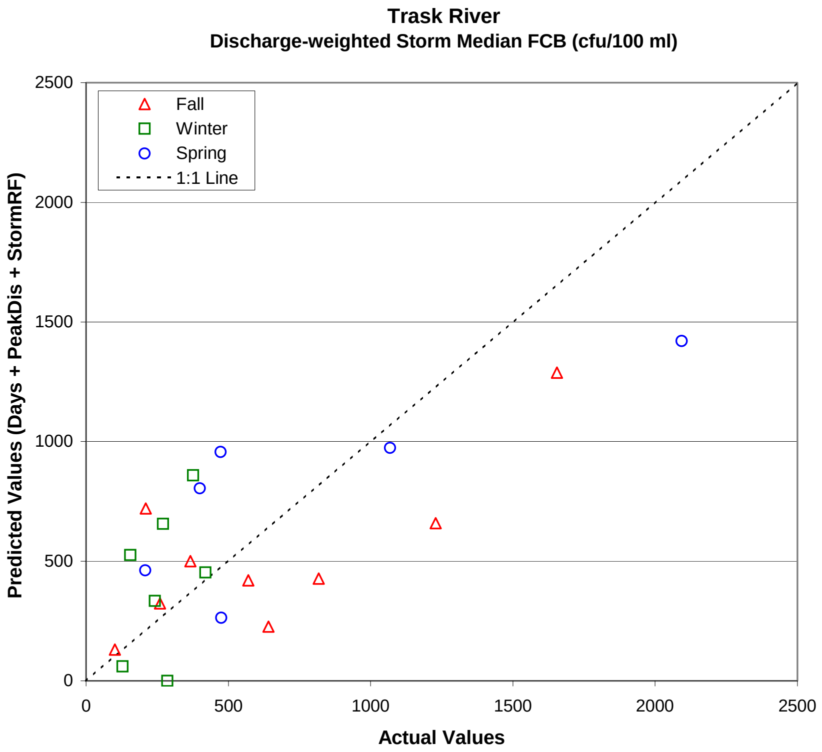


Figure 15. Predicted versus observed discharge-weighted storm median FCB concentration in the Trask River, using the model developed in the stepwise multiple regression analysis (Table 11).

TSS and collection of rainfall and river discharge data will provide a database that will allow future trends detection in the event that sufficient on-the-ground actions are taken within the Basin so as to substantially reduce the concentrations of these constituents in river water.

It is anticipated that at least five more years of monitoring data will be required before trends analysis will be feasible. In the interim, it will be important to continue the monitoring and to increase the level of on-the-ground remediation work to substantially reduce bacterial and/or sediment fluxes in the rivers. Trends analysis will be of limited value if we fail to actually improve water quality conditions. Improvement of water quality conditions will likely be short-lived if we fail to document success. It is generally not possible to maintain local enthusiasm and support or to attract funding for continued work unless a perception develops that some benefits are accruing. The long-term river monitoring program is currently not funded and monitoring is no longer occurring. It could be possible to renew this effort at a later date, and perhaps to develop a database that could be used to document future improvement. However, the larger the gap in the period of record, the larger the actual improvement will have to be before we will be able to measure it. In addition, large climatic variability can be expected to have more influence on our ability to document change if we have a large break in the monitoring database.

Much is known about the factors that influence the movement of sediment and fecal bacteria into river water in the Tillamook Basin. The results of this monitoring program for bacteria, in particular, have been of great value in improving our understanding of water quality degradation in the Basin. Fecal coliform bacteria concentrations are substantially higher during fall than they are during other seasons both at the whole watershed level (data in this report) and at the small subwatershed level (i.e., Beaver Creek data, Sullivan et al. 2002). Bacteria concentrations are considerably higher if a storm is preceded by relatively dry conditions, both in the short-term (days) and in the longer term (weeks or months), than if wet conditions prevail in advance of the storm. In some cases, storms of greater size or intensity produce higher FCB concentrations than smaller or less-intense storms. There are many possible reasons why such patterns occur, but our monitoring data are not sufficient to determine which cause(s) are most important. However, it is our belief that the following factors are especially important in this regard. First, during dry periods, there is opportunity for FCB to build up to higher levels in some areas, which can then be flushed to stream water during the next storm. Such build-ups of FCB might occur in association with a variety of potential source areas, including agricultural land use (i.e., repeated manure spreading), urban land use (i.e., flushing of pet feces through storm drains), and rural residential land use (i.e., improperly functioning septic systems). Second, farmers are encouraged to spread manure on their fields during dry periods and to avoid spreading during rainy periods. The data may therefore reflect the likelihood that many farmers are, in fact, managing manure applications in accordance with such recommendations. Third, dilution is most important during wet periods and such processes occur throughout the watershed system. Dilution of FCB in soil waters in advance of a storm should in turn lead to lower concentrations during the storm.

B. Total Suspended Solids

Total suspended solids generally increased with increasing discharge, although variability was high (Figure 16). Values of TSS exceeding 200 mg/L were almost exclusively confined to high-flow periods (> 4,000 cfs). Similarly, TSS values exceeding 400 mg/L were almost exclusively confined to periods when discharge exceeded 7,000 cfs (Figure 16).

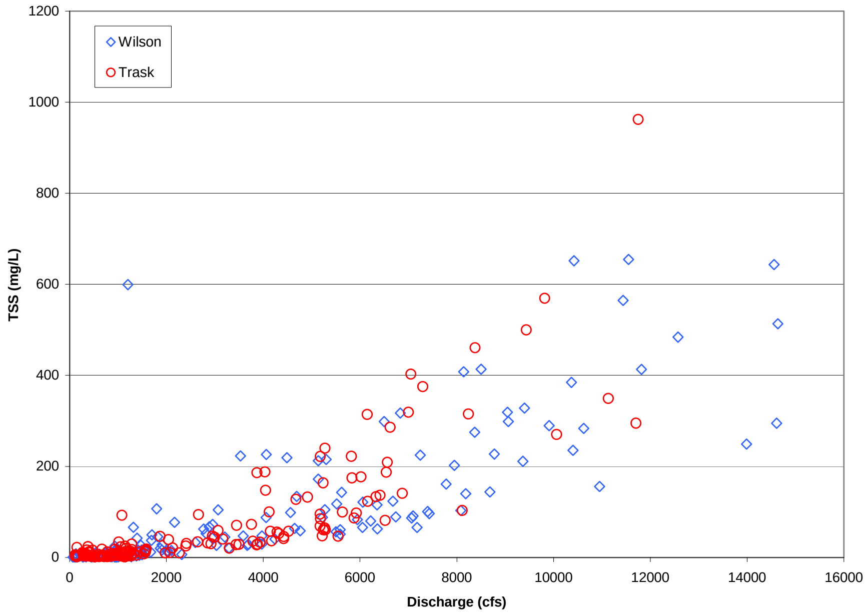


Figure 16. Relationship between total suspended solids and discharge for the Trask and Wilson Rivers.

ODEQ does not list a guide concentration for TSS in rivers of the north coast region, although guidelines for TSS and/or turbidity are under consideration (Eric Nigg, ODEQ, pers. comm.). Individual TSS measurements in the Wilson, Trask, and Kilchis Rivers frequently exceed 100 mg/L during large winter storm events. Discharge-weighted storm median TSS is also often higher than 100 mg/L in the Trask and Wilson during winter storms (Tables 8 and 9).

C. Nutrients

Total phosphorus concentrations in the Trask and Wilson Rivers are highly episodic, and therefore cannot be monitored very effectively with bimonthly monitoring. However, the relatively low concentrations of TP observed in these rivers on most sampling occasions probably does not justify the expense of storm-based monitoring, at least at the present time. Most of the TP in the rivers originates in the upper forested watersheds, rather than in the lower areas of agricultural and urban land use (Sullivan et al. 1998a). Because the TP concentrations are strongly correlated with TSS concentrations (Figure 17), it is likely that much of the observed TP is geologic, rather than anthropogenic, in origin. To the extent that TSS concentrations are reduced in the future, TP concentrations will probably also be reduced.

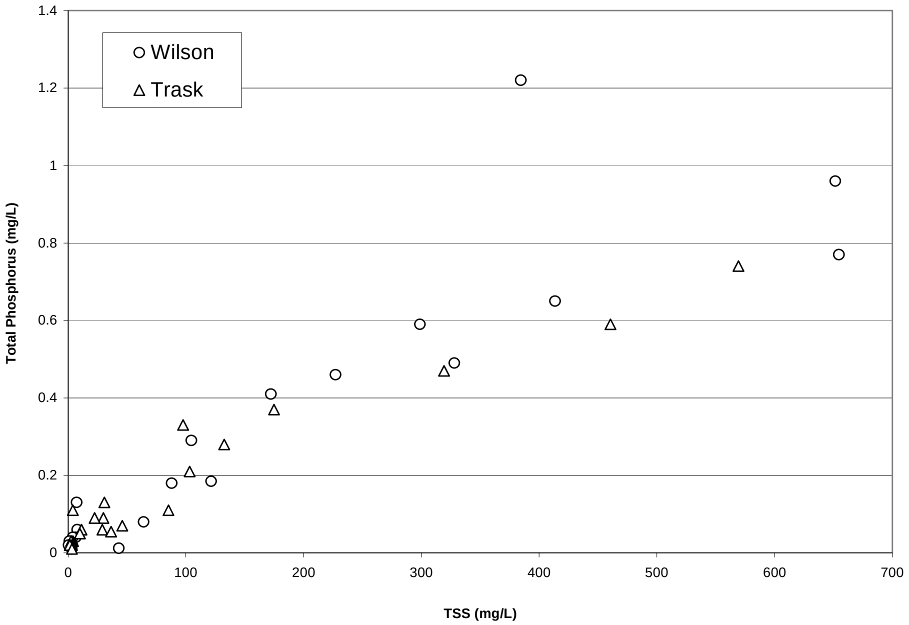


Figure 17. Measured values of total phosphorus versus total suspended solids in the Wilson and Trask Rivers.

Continued low-intensity monitoring for TP can serve as a warning system, in the event that TP concentrations increase substantially in the future. If that should happen, then more intensive monitoring for TP may be warranted.

Concentrations of nitrate in the Trask and Wilson Rivers are generally low, ranging between about 0.2 and 1.0 mg N/L. Continued low-intensity monitoring seems appropriate.

VI. CONCLUSIONS AND RECOMMENDATIONS

The monitoring program for Tillamook Basin rivers seeks to answer, over the long term, questions regarding whether and to what extent water quality constituents in the rivers are increasing or decreasing over time scales of years to decades. The primary constituents and rivers of interest are as follows:

- nutrients (N,P) - Trask, Wilson
- fecal coliform bacteria, Tillamook, Trask, Wilson
- total suspended solids - Kilchis, Trask, Wilson

It is anticipated that at least ten years of monitoring data will be required in order to adequately address such questions. In all cases, the monitoring focuses on the lower reaches of each river, thus integrating contributions of these constituents to river water from essentially all land uses within the watershed.

Storm-based monitoring of FCB and TSS should continue at the primary site on each of the Trask and Wilson Rivers (both parameters), Tillamook River (FCB), and Kilchis River (TSS). These data will provide the foundation for determining to what extent these two key water quality parameters change over time in response to land use activities and to planned watershed-wide restoration activities. If the TCEP, Tillamook Bay Watershed Council, SWCD, TCCA, and other entities are going to continue efforts to implement BMPs and improve habitat and water quality conditions in the Tillamook Basin, it will be important to be able to document success. Storm-based monitoring provides the best opportunity to document and quantify such improvements, if they occur. This is because of the substantial variability that occurs throughout the year, and especially during storm events, and the possibility of classifying storms by season or hydrologic type prior to trends analyses. In addition, it is generally only during storm events that the concentrations of FCB and TSS are high enough to pose environmental concerns. In the absence of such documentation of success (reduced concentrations of FCB and/or TSS), it will become increasingly more difficult to obtain restoration funding, convince land owners to cooperate, and enlist volunteer labor for on-the-ground efforts.

It is hoped that restoration and other BMP-related activities will be underway during the coming years throughout the Tillamook Basin, in conjunction with a variety of other programs and research or restoration efforts. It would be advantageous to focus such efforts on a limited number of watersheds or subwatersheds to the extent practical. This will enhance the likelihood of actually demonstrating water quality improvement in the future. FCB concentrations and loads should be measured above and below these areas of focus, using a storm-based approach as outlined for the primary monitoring sites. Such monitoring will provide critical information regarding BMP effectiveness, and has been conducted during the last four years within the Beaver Creek project (Sullivan et al. 2002).

If erosion control efforts are to be implemented to any significant extent within the basin, it would be advantageous to monitor for the effectiveness of these actions. Because the watersheds are large (especially the Wilson and Trask River watersheds), and contain a multitude of erosional source areas (i.e., mass wasting, road cuts, etc.), it is likely that the results of erosion control efforts implemented in parts of the watershed will not be readily evident at the downriver monitoring sites. We therefore suggest that such erosion control efforts (i.e., culvert repair, slope stabilization, road decommissioning) be concentrated to the extent practical within a limited number of subwatersheds, and these (and perhaps also one or more reference [control] subwatersheds) be monitored for TSS or turbidity during four to six large storm events each year.

There is a need to continue monitoring for N and P in the watershed because of the importance of eutrophication as a potential threat to any estuary, including Tillamook Bay. In addition, analyses conducted for the Wilson and Miami Rivers (Sullivan et al. 2001, Snyder et al. 2001) within the context of recent watershed assessments by E&S for the TCPP show historical trends of increasing NO_3^- concentrations in both of these rivers. However, the immediate risk of nutrient-caused degradation of the ecological integrity of the rivers and the estuary appears less than the risk of degradation caused by other issues, such as bacteria, sediment and temperature. We therefore recommend continued monitoring of nitrogen and phosphorous, but at a lower level of intensity compared with the other parameters. It does not seem necessary to monitor nutrients in all five of the rivers. The largest loads of N and P to Tillamook Bay were found in the Wilson and Trask Rivers, and these watersheds contain a variety of land uses, including agricultural, rural residential, and urban. Continued bi-monthly monitoring of nutrients in these rivers is recommended.

Bi-monthly sampling in the Trask and Wilson Rivers, with the winter-season sampling skewed towards high-discharge periods should provide an adequate database for continued future assessment of nutrient-related issues. Nutrient analyses should include TP, TKN, NO_3^- and NH_4^+. This frequency of sampling will only provide general information on most probable ranges of concentration. If more detailed information on nutrient loading is required, flow-proportional sampling would be required to calculate loads.

It will be important to continue to monitor temperature to more precisely quantify the frequency, duration, and extent of temperature excursions above threshold values in each of the rivers and to document any improvements that result from riparian restoration efforts in the watershed. At a minimum, this should be implemented for the Tillamook, Trask, and Wilson Rivers, and ideally would include the Kilchis and Miami Rivers as well.

There is no indication in the available data to suggest that any of the parameters of interest have changed dramatically over the past five years in the rivers that have been included in these monitoring efforts. Before such changes will become apparent, it will be necessary to affect a substantial amount of on-the-ground improvement in watershed conditions and management practices and to collect at least five more years of monitoring data. The existing monitoring effort is providing the type of database that will be needed for future trends analysis.

VII. LITERATURE CITED

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Appendix A

Additional fecal coliform bacteria data

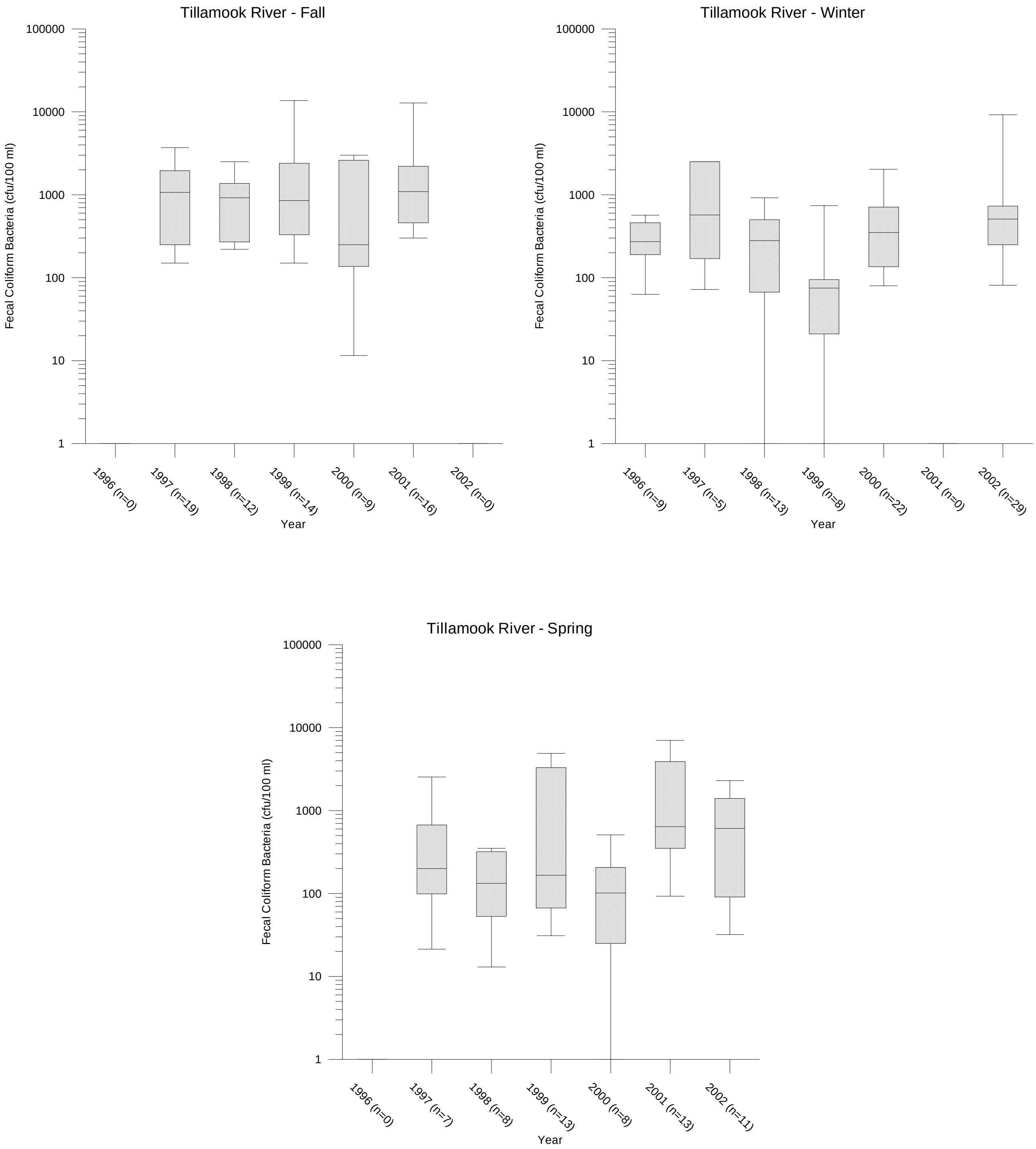


Figure A-1. Box and whisker plots for FCB measurements, by season, for the three monitored rivers. The middle 50% of the distribution of measured data is represented by the box. The line within the box indicates the median value. The range of values is shown by the upper and lower brackets.

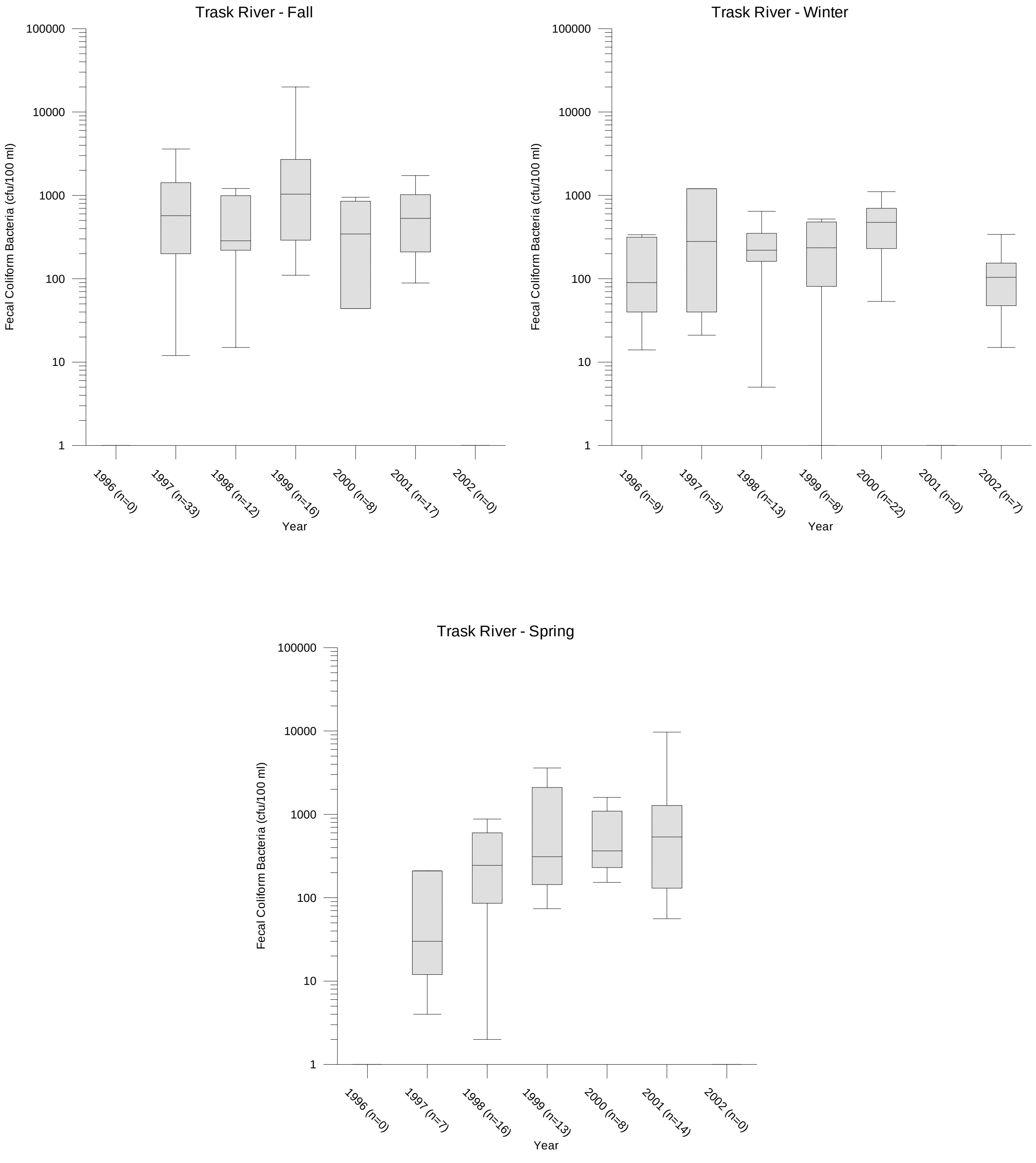
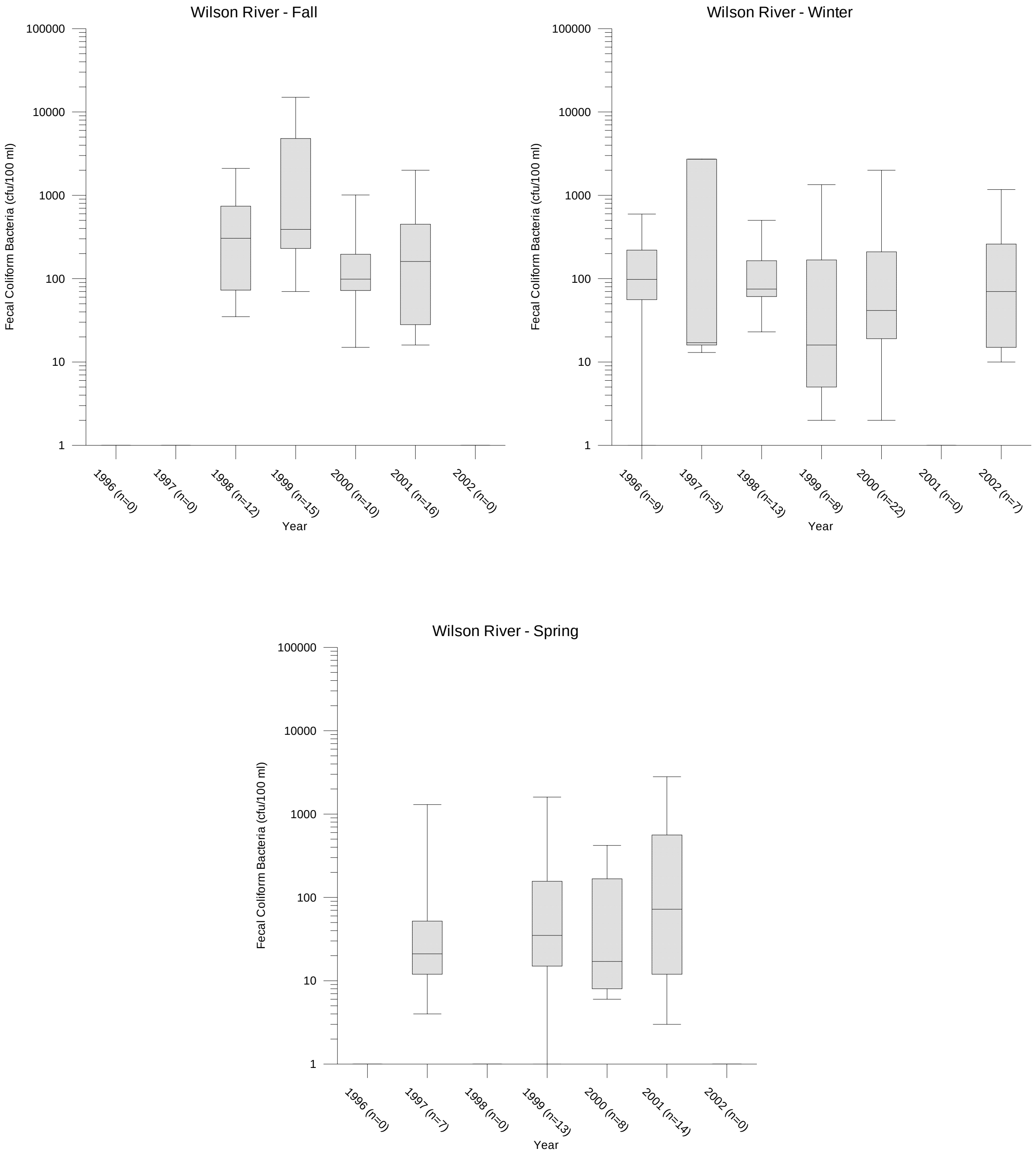


Figure A-1. Continued.



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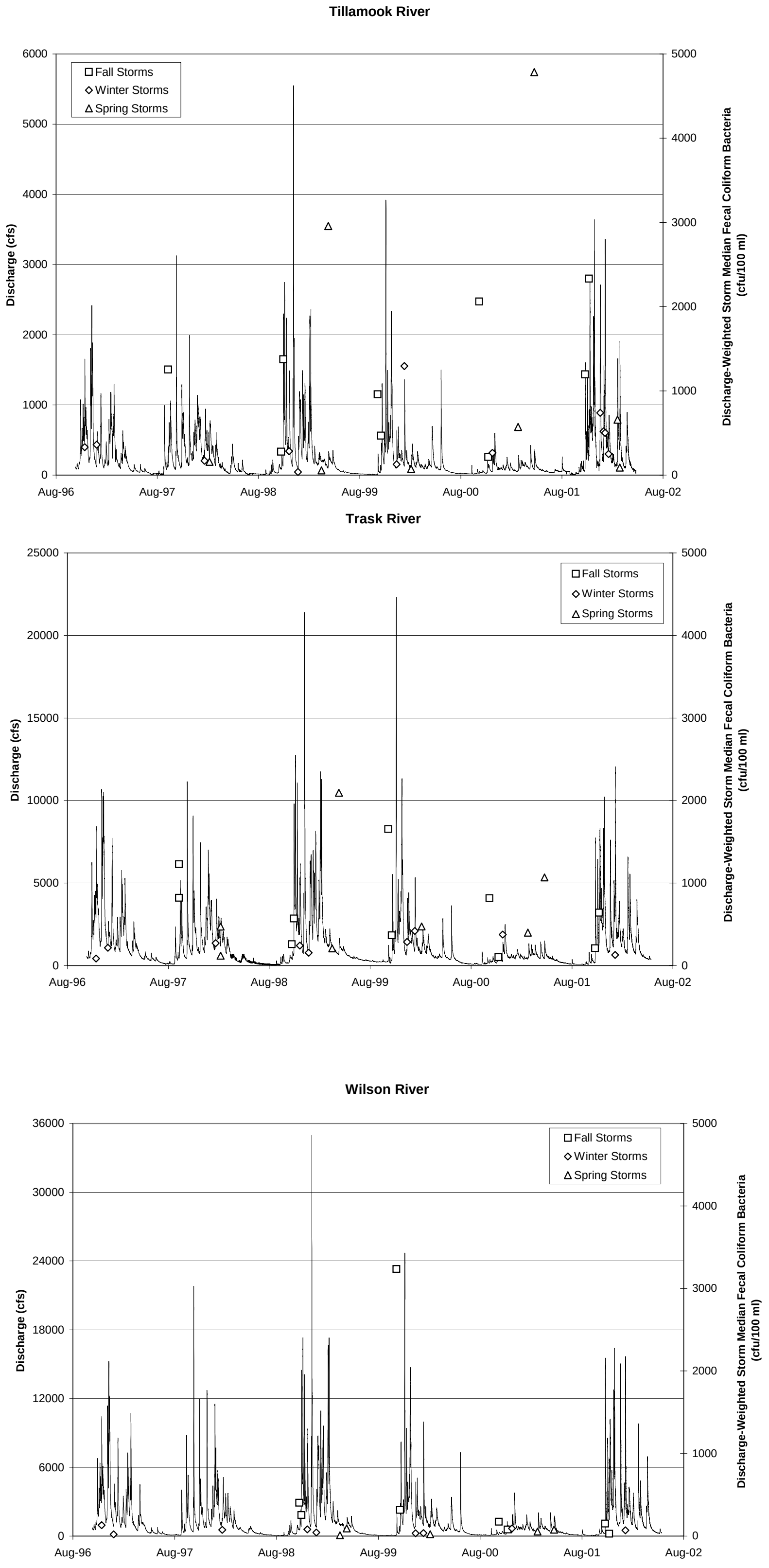


Figure A-2. Discharge and measured discharge-weighted storm median fecal coliform bacteria in the three monitored rivers.

Appendix B

Additional total suspended solids data

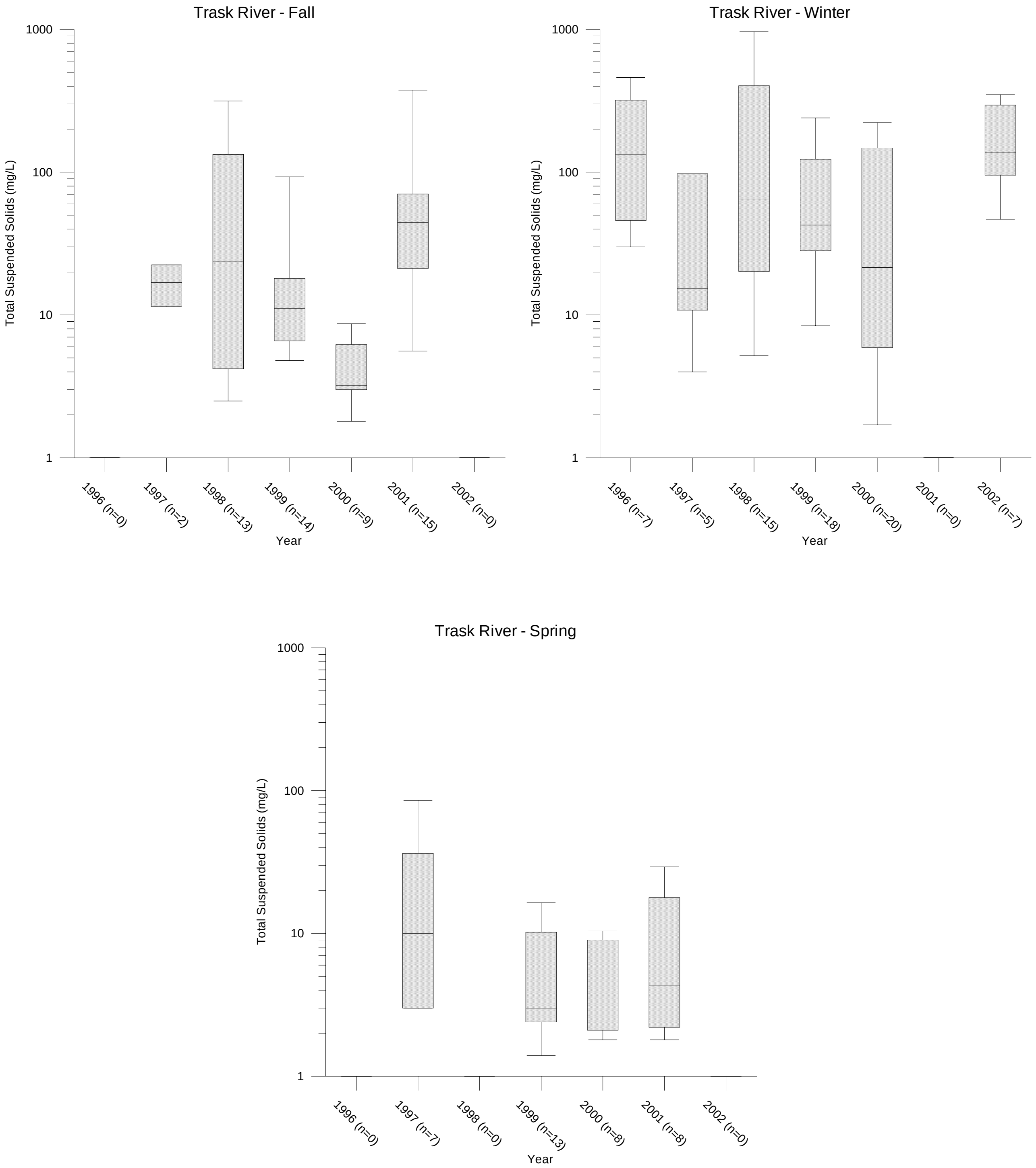
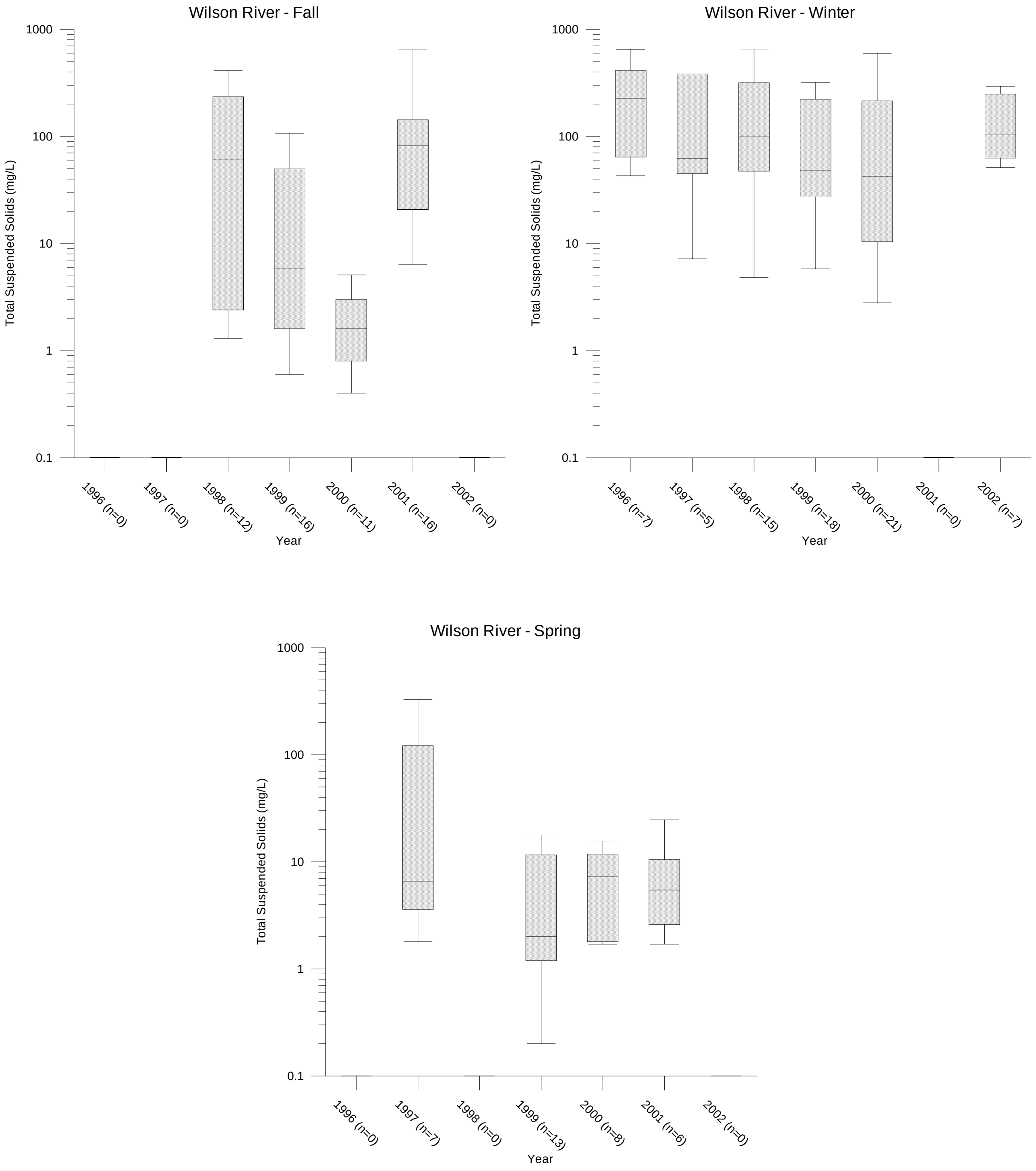


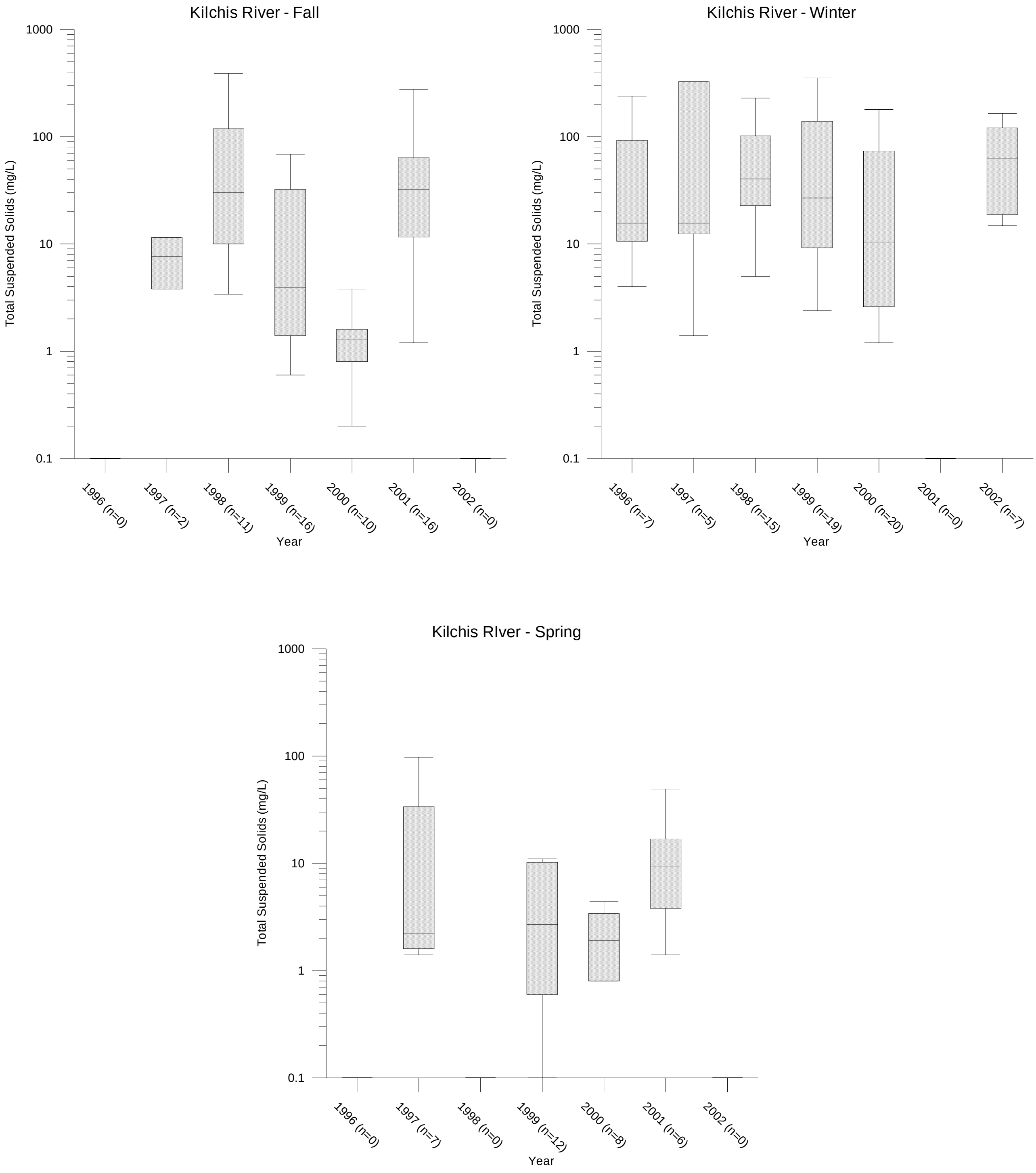
Figure B-1. Box and whisker plots for TSS measurements, by season, for the three monitored rivers.


Wilson River - Fall

Wilson River - Winter

Wilson River - Spring

Figure B-1. continued.

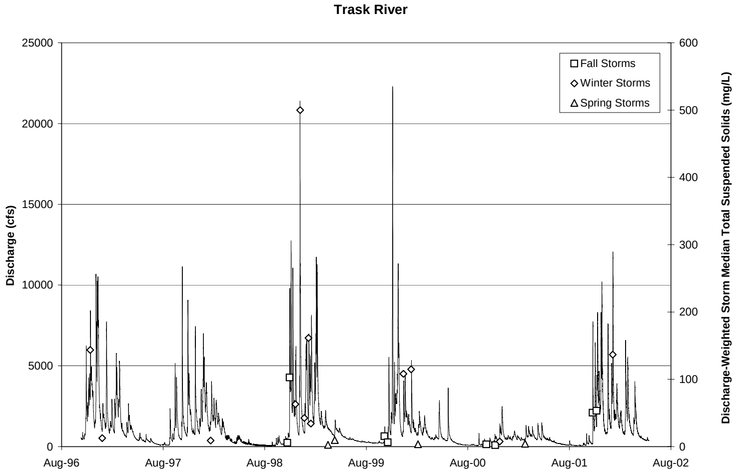


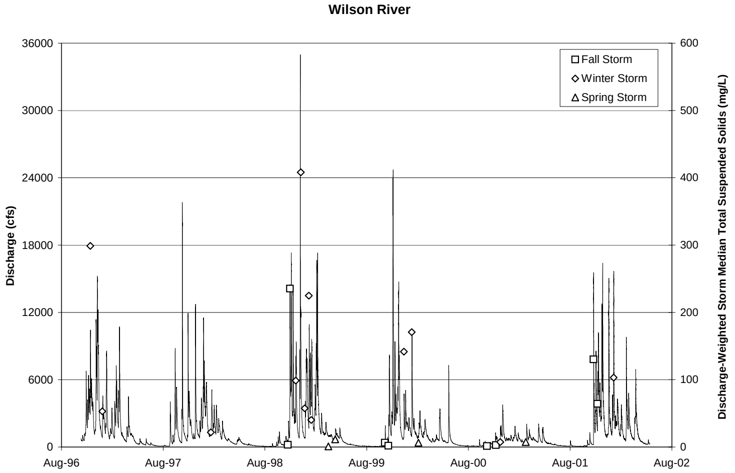
Kilchis River - Fall

Kilchis River - Winter

Kilchis RIver - Spring

Figure B-1. Continued.





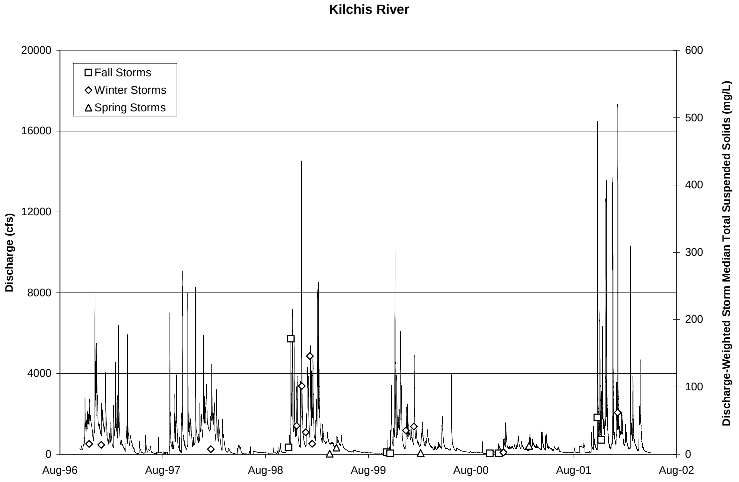
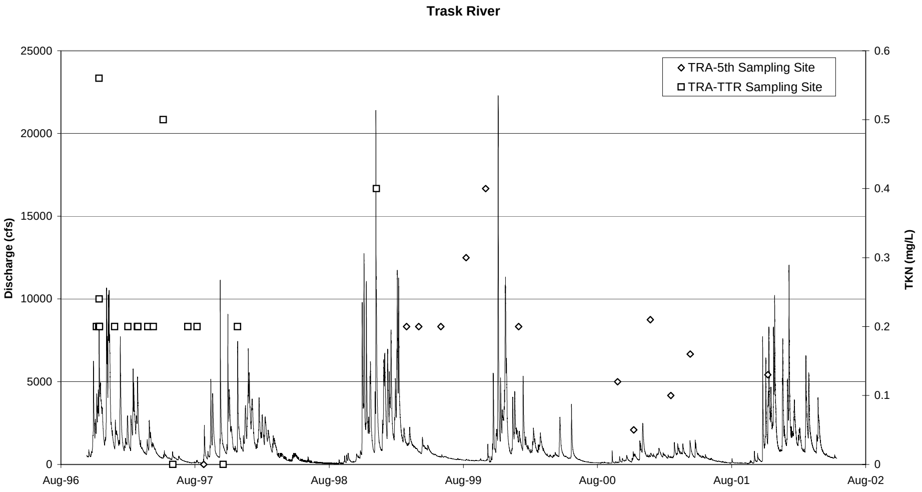


Figure B-2. Discharge and measured discharge-weighted storm median total suspended solids in the three monitored rivers.

Appendix C

Additional nutrient data



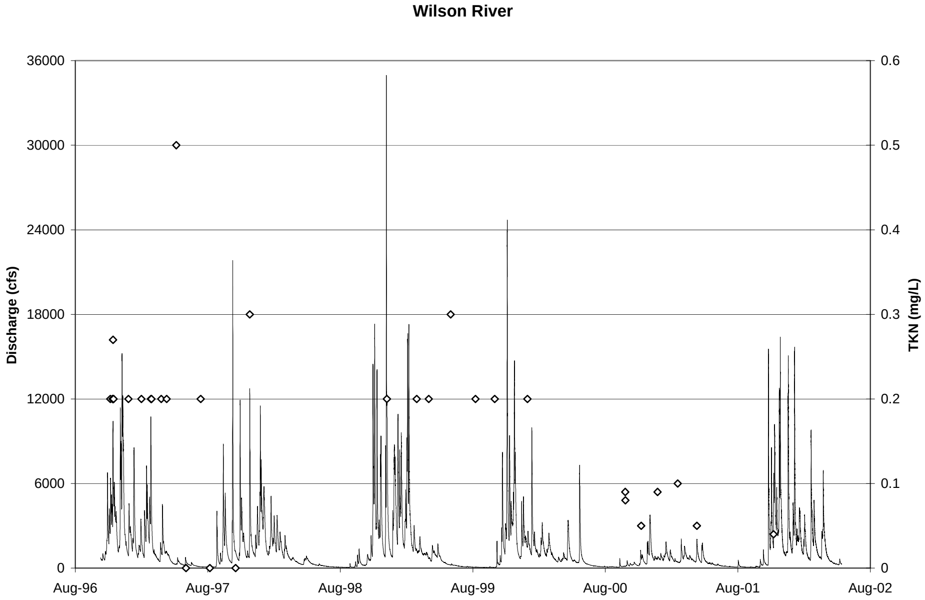


Figure C-1. Discharge and measured values of total Kjeldahl nitrogen (TKN) for the Trask and Wilson Rivers.

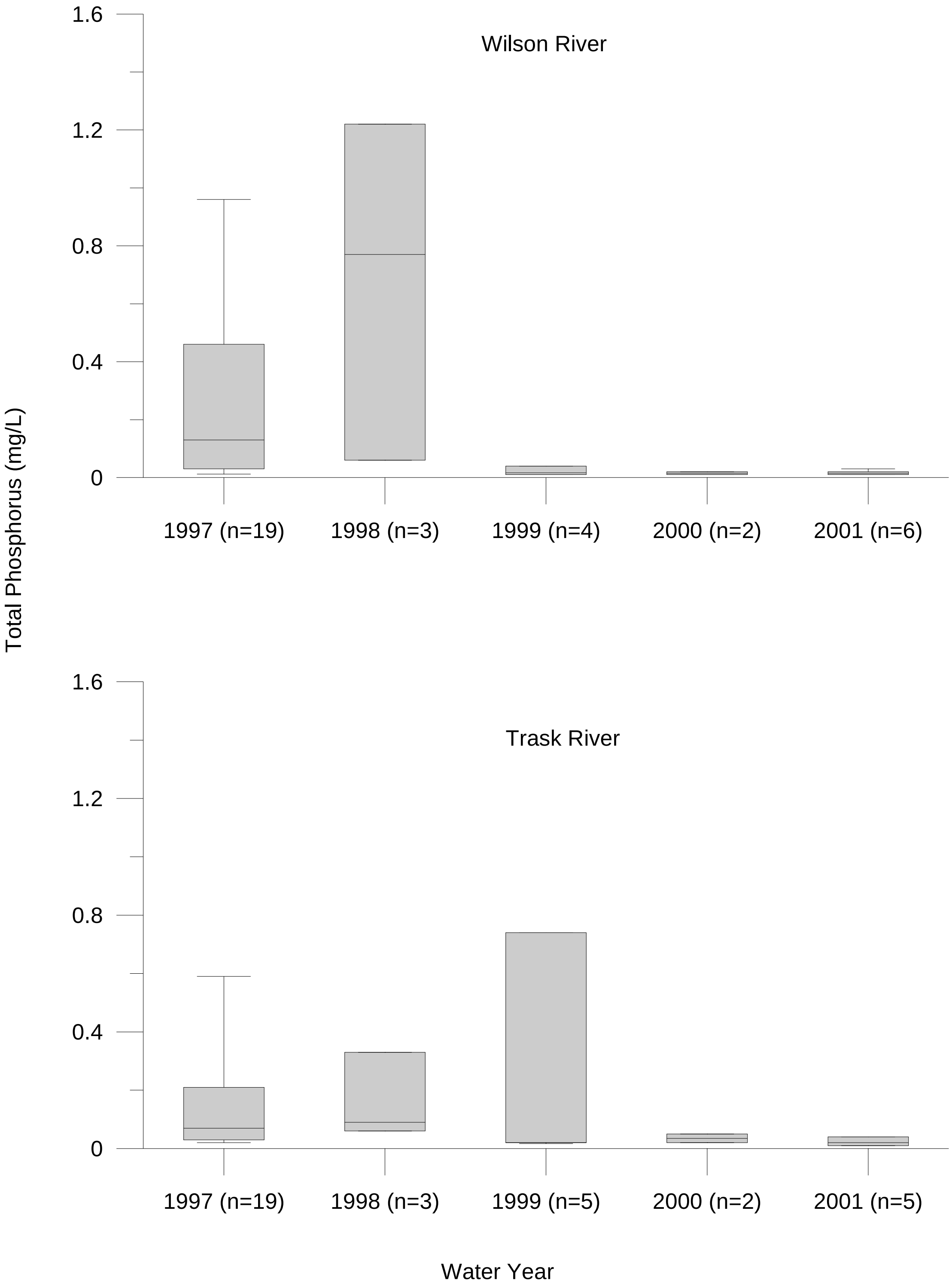


Figure C-2. Box and whisker plots of total phosphorus measurements in the Wilson and Trask Rivers. Because there were gaps in the availability of nutrient monitoring funding, data are sparse for some water years.

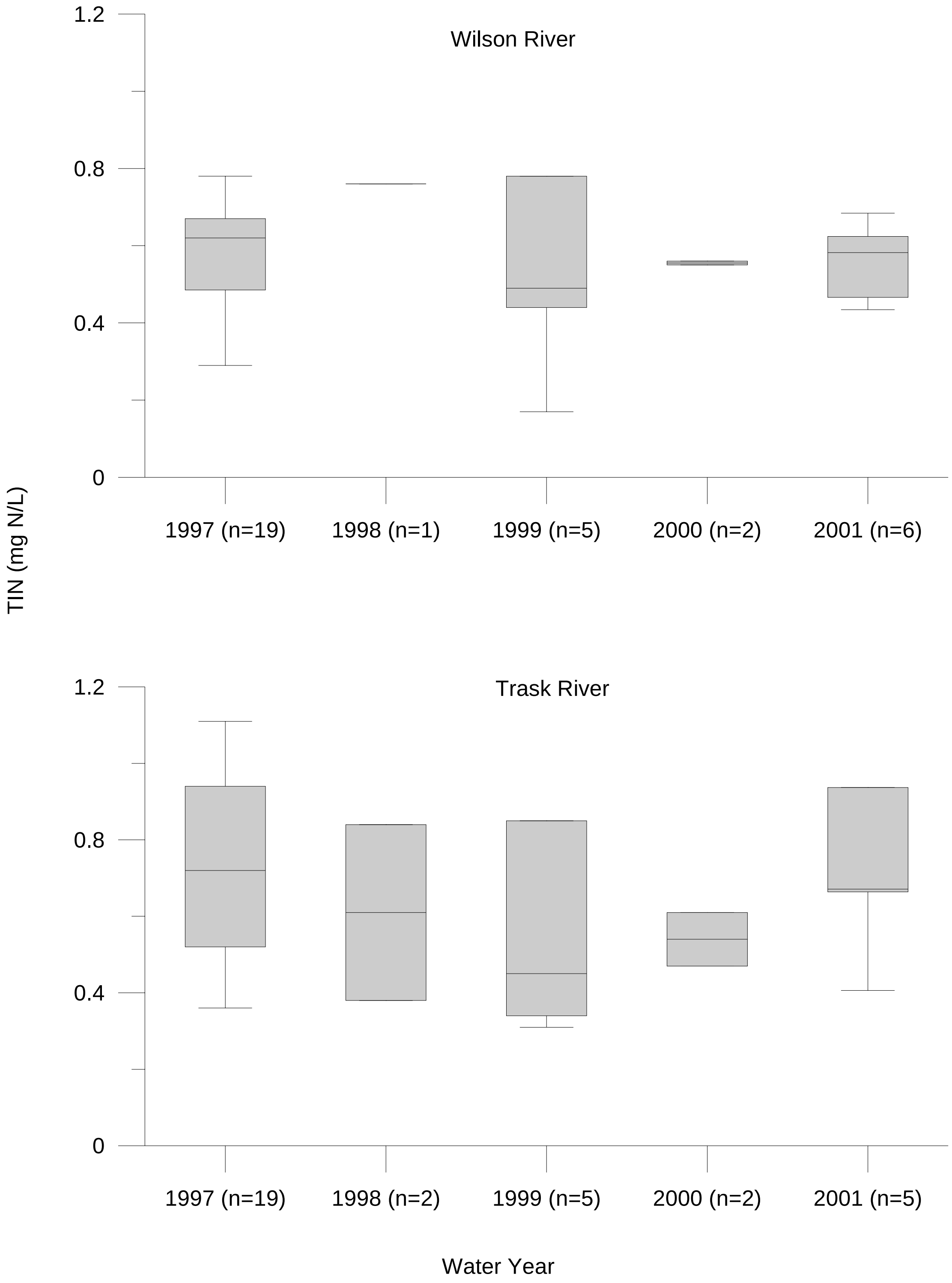


Figure C-3. Box and whisker plots of total inorganic nitrogen (nitrate plus ammonium) measurements in the Wilson and Trask Rivers. Because there were gaps in the availability of nutrient monitoring funding, data are sparse for some water years.