WATER QUALITY MONITORING
IN THE
TILLAMOOK WATERSHED

Results of a One-Year Periodic Monitoring and Storm Sampling Program

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EXECUTIVE SUMMARY

Tillamook Bay and watershed support diverse living resources. Some species have been Federally listed as endangered or threatened and declining numbers of salmon and steelhead have become the focus of research and restoration efforts. The bay and watershed face environmental concerns common to other small estuaries in the Pacific Northwest. Most problems result from forestry and agricultural practices and habitat loss due to a combination of sedimentation and loss of riparian areas.

Tillamook Bay has a long history of bacterial pollution problems. Despite progress in efforts to restore water quality, both fresh and saline waters in the Tillamook Basin often don't meet water quality standards for bacteria. Bacterial concentration has been identified as a priority problem by the Tillamook Bay National Estuary Project (TBNEP). However, Tillamook Basin waters also have other water quality problems. For example, temperatures in the lower reaches of some of the rivers sometimes exceed water quality standards. The TBNEP initially identified bacterial contamination, sedimentation, and salmonid habitat as the three priority issues to be considered. More recently, flooding was added to that list by the management committee. All four relate, in part, to transport of materials (water, bacteria, sediment, nutrients, oxygen-demanding materials) from the watershed to the bay. At initiation of the study, existing information on water quality and hydrology (which is combined with water quality data to generate loading estimates) was limited and generally of uncertain quality. Water quality QA/QC, detection limits, and variability were not well known or documented in most cases. TBNEP determined that it was important that quality-assured monitoring data be collected for each of the major rivers in the Tillamook system, and that water quality data be collected under different flow regimes and combined with hydrology to generate estimates of the relative importance of each of the rivers as sources of bacteria, nutrients, and sediment to the bay. Such information will be critical to development of a comprehensive management plan by TBNEP.

During the past year and a half, E&S Environmental Chemistry, Inc., under contract to TBNEP, has conducted a water quality monitoring project throughout the basin. It has included regular monitoring for fecal coliform bacteria, total suspended solids (TSS), nutrients, and temperature in each of the five rivers that flow into Tillamook Bay. In addition, intensive storm sampling (especially for bacteria) has been conducted during six rainstorm events and is planned for one more rainstorm event.

The purpose of this project was to provide critical information needed to design a rigorous water quality-monitoring program and to prepare the Comprehensive Conservation and Management Plan (CCMP) for the watershed. Results of this study are being reported in two companion reports to TBNEP, of which this is the first. This first report presents the annual overview results and general watershed characterization. The second report (Sullivan et al. 1998) presents the results of the storm sampling and the loading estimates.

One down-stream primary sampling site was selected, in consultation with TBNEP staff, at the downstream end of each of the five rivers in relatively close proximity to the bay. Additional (secondary) sampling sites were selected at upstream locations, on each of the rivers. Criteria used in determining secondary site locations included the location of land use transitions (e.g., forest/agriculture interface), homogeneity of upstream segment characterization, known or suspected problem locations, and sampling logistics. Secondary sites did not remain fixed throughout the study and all secondary sites were not sampled on all sampling occasions.

The Tillamook River consistently had the highest fecal coliform bacteria (FCB) concentrations, with the Kilchis River having the lowest. Total suspended solids (TSS) concentrations were highest in the Trask and Wilson Rivers, corresponding to the rivers with the largest watersheds and highest flows. Conversely, TSS concentrations were lowest in the Tillamook River, which has the smallest watershed area and lowest flows of the five rivers. Total inorganic nitrogen (TIN) concentrations were similar across all of the rivers. Total phosphorus (TP) concentrations were highest in the Wilson River and the lowest in the Tillamook River.

Fecal coliform bacteria concentrations were variable from river to river, ranging from 0 to 3700 cfu/100 ml at the downriver primary sites. The range for the secondary sites representing the forest/agriculture interfaces was much narrower, from 0 to 500 cfu/100 ml.

Seasonal differences in FCB concentrations were seen at all of the primary sites. At the Tillamook and Trask River primary sites, which were sampled most intensively of the five rivers, the highest bacterial concentrations were observed during the storm event of early October, 1997. Many samples were measured during the storm in excess 500 cfu/100 ml. High bacterial concentrations (>500 cfu/100 ml) were also recorded for the Tillamook, Trask, and Wilson Rivers during very small summer rainstorms and during one winter storm in the Wilson River. Highest values were also recorded in the Kilchis and Miami Rivers during summer and fall storms, but the concentration in those rivers seldom exceed 500 cfu/100 ml.

In all cases, small summer storm events caused greater increases in fecal coliform bacteria concentration than larger more intense storms in the winter and spring months. This suggests that the antecedent moisture conditions or length of the dry period preceding the storm may play significant roles in controlling FCB contributions from the watersheds to the rivers.

Measured concentrations of FCB at the forest/agriculture interfaces were always less than 500 cfu/100 ml and only 2 out of 42 samples had fecal coliform concentrations higher that 100 cfu/100 ml (both on the Trask River). On a number of sampling occasions, paired samples were collected within a few hours or less of each other at a primary site and its respective forest/agriculture interface on the various rivers. Concentrations were generally higher at the primary sites as compared to the respective forest/agriculture interface site. In many cases, the concentration of

FCB was dramatically higher at the downstream primary site.

Fecal coliform bacteria loads at the primary sites ranged from 0 to $1.25x10^6$ cfu/sec, with the highest loads in the Trask and Wilson Rivers. However, despite having significantly lower flows than the Trask and Wilson Rivers, the Tillamook River also carried relatively large loads during storms. This was due to the very high bacterial concentrations measured in the Tillamook River. The secondary sites representing the forest/agriculture interfaces on the Trask, Wilson, Kilchis and Miami Rivers had consistently low fecal coliform bacteria loads (<50,000 cfu/sec) which did not change significantly with storm events.

Summer FCB loads were consistently low at all five primary sites as a result of low flow conditions. However, loads did increase with relatively small increases in summer flows, whereas increases in winter FCB loads were associated with much greater changes in flow.

Water temperatures of grab samples generally ranged between about 8E and about 18^o C to 20EC at the primary site on each of the rivers. Peak temperatures were observed in August in all of the rivers, and reached fairly high values in the Tillamook, Trask and Wilson Rivers. Measured August temperature in each was near 20EC, considered to be in the range of stressful to lethal temperature conditions for salmonids. In contrast, maximum observed temperatures in the Kilchis and Miami Rivers were slightly more acceptable (~18E C). The ODEQ temperature criterion for salmon rearing specifies that the seven-day moving average temperature shall not exceed 17.8^oC. More data would be useful during July, August and September from the Tillamook, Trask and Wilson Rivers to document the temporal and spatial duration of high temperature that occurs in these rivers.

Total inorganic nitrogen concentrations (NO_3-N + NH_4-N) were generally near 1 mg/L (± 0.2 mg/L) in all rivers. Limited data from the forest/agriculture interface sites showed similar patterns. Paired sample analyses between the primary and forest/agriculture interface sites showed there was relatively little contribution of TIN to the rivers from the lower agricultural portions of the watershed. Concentrations of TIN were reduced during summer and higher during winter. This was likely due to greater biological demand for N in the aquatic and terrestrial systems during summer months.

Total phosphorus (TP) concentrations in all of the rivers were typically less than about 0.1 to 0.2 mg/L, except during storms when the concentrations sometimes exceeded 0.5 mg/L. Total phosphorus at the forest/agriculture interface exhibited similar patterns although concentrations were often slightly lower than at the primary sites.

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. There was not a consistent relationship observed between TP and flow either between or within rivers. This contrasts with the much stronger relationship observed between TP and TSS (r^2=0.85) in all of the rivers. The fact that TP is much more closely related to TSS concentration than either TP or TSS is related to flow rate suggests that the phosphorus is bound to soil particles. It is likely that the source of the TP and TSS is the same and that the phosphorus is geologic in origin. It is also possible, however, that fertilizer use in the watershed has contributed to the observed phosphorus loads. Paired sample analyses between the primary sites and their respective forest/ agriculture interface site suggested that the contribution of TP from the agricultural parts of the watershed was minimal and that TP was mostly generated in the forested part of the watershed where most of the sediment originates.

As a consequence of this scoping study of water quality of the five rivers that flow into Tillamook Bay, a number of conclusions were drawn with respect to fecal coliform bacteria, sediment, nutrient, and temperature concerns or problems within the watershed. As a result of this study, a baseline is now available against which to compare future water quality data to allow evaluation and quantification of temporal trends.

ACKNOWLEDGMENTS

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1. BACKGROUND AND INTRODUCTION

Tillamook Bay exemplifies the type of estuary found in the Pacific Coast Range Ecoregion. The bay and watershed support diverse living resources including shellfish, salmon, trout, groundfish, and numerous bird species. Some species have been Federally listed as endangered or threatened and declining numbers of salmon and steelhead have become the focus of state, regional, and federal government research and restoration efforts. Natural resources remain the backbone of local and regional economies which depend on fishing, timber, and agriculture.

With the support of Governor Barbara Roberts in 1992, the U.S. Environmental Protection Agency designated Tillamook Bay as an estuary of national significance and included it in the National Estuary Program (NEP). As outlined in the Tillamook Bay National Estuary Project (TBNEP) nomination package, the Project will develop a Comprehensive Conservation and Management Plan (CCMP) to protect the ecological integrity of the estuary. To achieve this objective, the TBNEP convenes a Management Conference consisting of citizen and government agency stakeholders, characterizes the estuary, defines and prioritizes problems, and recommends solutions in the CCMP.

Tillamook Bay faces environmental concerns common to other small estuaries in the Pacific Northwest, allowing the TBNEP to develop a CCMP that will be relevant to similar coastal systems. Most problems result from forestry and agricultural practices, urbanization, and habitat loss due to a combination of sedimentation and loss of riparian areas. With the support of citizens and agencies with legal mandates, TBNEP hopes to find solutions to these environmental problems that balance economic interests and serve as a regional model.

Tillamook Bay has a long history of bacterial pollution problems (Blair and Michener 1962, Jackson and Glendening 1982, Musselman 1986, Oregon Department of Environmental Quality 1994) and of programs to address those problems. In the early 1980's the Oregon DEQ received a federal grant under section 208 of the Clean Water Act, which created the Rural Clean Water Program (RCWP), to identify bacterial sources to the bay and to develop a fecal coliform bacteria (FCB) management plan for the watershed. The Agricultural Stabilization and Conservation Service received federal funding through the RCWP to provide cost sharing for farmers to adopt better management practices and to construct the facilities to do so. Despite progress in these efforts to restore water quality, both fresh and saline waters in the Tillamook Basin often don't meet water quality standards for bacteria.

During the 1980's, major bacterial sources were identified through the RCWP and various measures were taken to decrease bacterial pollution. Important sources of fecal coliform bacteria have been identified as discharge from wastewater treatment plants, runoff from agricultural areas, discharge from malfunctioning septic systems, and direct input from animals in the basin (Jackson and Glendening 1982), although percentages from each source have not been quantified. Within theTillamook Bay drainage basin, there are approximately 24,000 ac of agricultural lands. Animal wastes are spread on about 12,000 ac of pasture lands throughout the year when weather permits. The RCWP provided over $6 million in cost-share money to improve manure management facilities on dairy farms. Many wastewater treatment plants and septic systems were also upgraded during this time period. More recent reports on water quality in the Tillamook Basin have suggested that bacterial concentrations have decreased, although water quality violations still occur (Arnold et al. 1989). These data, however, were perceived to be biased due to sampling in different water years and later studies were performed to test for trends in the water quality data set. Statistical tests generally showed a reduction in fecal coliform concentrations (Dorsey-Kramer 1995) although the overall trend analysis was inconclusive (Wiltsey 1990). During this period, the number of dairy cows increased approximately 37% (Commodity Data Sheets 1980 and 1990), suggesting that implemented land use practices were partially effective in reducing fecal coliform contributions to surface waters of the Tillamook Basin.

Water quality standards for recreational contact and shellfish growing waters differ; but standards in both fresh water and the bay have long been violated in the Tillamook Watershed (Jackson and Glendening 1982). The bacteria standard for recreational contact applies to both fresh and saline waters and is intended to protect people in contact with water, such as swimmers. The shellfish standard is much more stringent, as it is designed to protect people from pathogens which might be consumed with raw shellfish.

Bacterial problems often close harvesting in Tillamook Bay, which has been one of Oregon’s leading producers of shellfish, particularly oysters. Oregon has adopted the water quality standards for bacteria and other pathogens in estuarine water set by the federal Food and Drug Administration (FDA) for interstate commerce (U.S. Dept. of Health and Human Services 1995). Bacterial concentrations in the bay have historically been high during the wet seasons of the year: fall, winter, and early spring. Due to the bay’s unpredictable water quality, the proximity of five wastewater treatment plants to the bay, and many nonpoint sources of bacteria and viruses, oyster culture is allowed only in specified areas, and harvesting is allowed only under certain conditions, as identified in the shellfish management plan for Tillamook Bay (Oregon Department of Agriculture 1991).

Bacterial concentration has been identified as a priority problem by the TBNEP. However, Tillamook Basin waters also have other water quality problems. Temperatures in the lower reaches of some of the rivers exceed water quality standards and may affect salmonid habitat in those reaches during part of the year. Extensive information about nutrient levels has not previously been collected, but available data suggested that nutrient levels are moderately high in some areas of the Tillamook Basin (TBNEP 1997). These are of concern, since estuarine eutrophication is an increasing problem nationwide (National Oceanic and Atmospheric Administration 1996). The causes of many of these problems are related. Nutrients accompany human and animal wastes, as do bacteria, so controlling bacteria will likely affect nutrient loads as well. Stream temperature is related to the loss of shade, the loss of riparian habitat and possibly thermal pollution from wastewater treatment plant effluents. Increased nutrient loads to surface waters may result in decreases in dissolved oxygen as a result of algal blooms, which can stress aquatic organisms such as salmonids which spend time in the tidal flats and salt marsh (TBNEP 1997). Additional concerns have been raised regarding nitrogen and phosphorus loading into estuaries. Increased nitrogen has been linked to habitat loss in the Chesapeake Bay (Burkholder et al. 1992a), and increased phosphorus has been linked to fish kills due to blooms of toxic dinoflagellates associated with phosphorus inputs (Burkholder et al. 1992b). The Tillamook Bay is at a moderate to high trophic level according to the National Oceanic and Atmospheric Administration's estuary trophic characterization (TBNEP 1997).

Section 303(d) of the federal Clean Water Act requires the Oregon DEQ to list water quality impaired water bodies for the entire state. A water body is "water quality limited" when it violates the State's water quality standards. The State's water quality standards include numeric and narrative criteria, beneficial uses, and an antidegradation policy. A water body is considered water quality limited when any portion of the standard is violated. In the Tillamook Bay area, only FCB and water temperature are sufficiently documented to result in water bodies being declared water quality limited. Fecal coliform levels commonly exceed the recreational contact standard in the streams and rivers (200 cfu/100 ml) and exceed both the recreational standard and the shellfish harvest standard (14 cfu/100 ml) in the Bay[1]. Freshwater fecal coliform bacteria concentrations occasionally exceed 12,000 cfu/100 ml and estuarine values reach 1,600 cfu/100 ml. The Tillamook River is listed by DEQ for water contact recreation (fecal coliform) from the mouth to headwaters, and also conditionally listed (in need of more data) for temperature, sediment, nutrients, and habitat modification. The Wilson, Kilchis, and Miami Rivers have also been listed for water contact recreation, and the Wilson and Trask Rivers for temperature.

Water temperatures get high enough in Tillamook Bay Basin to impair water quality. During the summer of 1995, the water temperature standard applicable to the Tillamook Bay Basin was exceeded in both the Trask and Wilson River basins. The seven-day running average maximum temperature reached 70.8^{o}F (21.6^{o} C) in the lower Trask River, and 69.5^{o}F (20.8^{o} C) in the lower Wilson River, leading to the inclusion of these lower river reaches on the 1996 303(d) list of water quality impaired waters. The temperature monitor deployed in the lower Tillamook River was stolen, so similar data are not available for the Tillamook River. However, the 1988 Nonpoint Source

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[1] The freshwater standard used by DEQ for contact recreation has recently been changed from fecal coliform bacteria to *E. coli*. The USDA and ODA public health standards apply to fecal coliform bacteria. There is a generally strong correlation between these two indicators of potential pathogen contamination. An ongoing study is examining this relationship in more detail.

Assessment identified temperature as a concern in the Tillamook River, so it should be evaluated further.

Several stream reaches in the Tillamook Basin were evaluated as being “of concern” for aquatic habitat, flow modification, and sediment. This evaluation was based on data from state and federal agencies, described in the 1988 Oregon statewide Assessment of Nonpoint Sources of Water Pollution (Oregon DEQ 1988). For the Tillamook Basin, most reaches classified as “of concern” for these parameters were selected by observations only. Quantitative data are needed to describe the extent of the problems. The DEQ listed these waters as water quality impaired (the 303(d) list), but classified them as needing more information.

The Oregon Departments of Agriculture and Environmental Quality are charged with developing management plans for all of the waterbodies on the 303(d) list. The Department of Agriculture has established priorities for management plan development, and has included the Tillamook Bay watershed in Tier I of that list. The watershed is also in Tier 1 for ODEQ’s development of total maximum daily load (TMDL) allocations.

The TBNEP identified bacterial contamination, sedimentation, and salmonid habitat as the three priority issues under consideration. Recently, flooding was also added by the TBNEP Management Committee. All priority issues relate, in part, to transport of materials (water, bacteria, sediment, nutrients, oxygen-demanding materials) from the watershed to the bay. At initiation of this study, existing information on water quality and hydrology (which is combined with water quality data to generate loading estimates) was limited and generally of uncertain quality. Water quality QA/QC, detection limits, and variability were not well known or documented in most cases. We determined that it was important that 1) existing water quality data be summarized and evaluated with respect to data quality, 2) quality-assured monitoring data be collected for each of the major rivers in the Tillamook system, and 3) water quality data be collected under different flow regimes and combined with hydrology to generate estimates of the relative importance of each of the rivers as sources of bacteria, nutrients, and sediment to the bay. Such information will be critical to development of a comprehensive management plan by TBNEP. The first need was undertaken by DEQ and included in the Environmental Characterization Report (TBNEP 1997). The project reported here was viewed as a scoping study, and was intended to satisfy needs #2 and #3. It provides detailed information required to evaluate water quality conditions and pollutant loads throughout the watershed and critical information required for designing a rigorous water quality monitoring plan for the watershed. Both the concentration (mass per unit volume) and the load (mass per unit time) are important indicators of pollutant dynamics and potential effects. Water quality standards are generally based on pollutant concentrations, which reveal important information about the quality of the water flowing through a given portion of the river at a given time. However, the influence of the water quality in that river on the water quality of the receiving water body (Tillamook Bay) also depends on the volume of water flowing in the river per unit time. The pollutant load (concentration times river discharge) reflects the overall contribution of the pollutant to the bay. For example, a small stream may have a very high concentration of bacteria but, because the volume of water is small, have little influence on the total loading of bacteria to the bay. In contrast, a large river with only moderate bacterial concentration can be a much more significant source of bacterial loading to the bay.

During the past year, E&S Environmental Chemistry, Inc., under contract to TBNEP, has conducted a water quality monitoring project throughout the basin (Figure 1). It has included regular monitoring for FCB, total suspended solids (TSS), nutrients, and temperature in each of the five rivers that flow into Tillamook Bay. In addition, intensive storm sampling (especially for bacteria) has been conducted during six rainstorm events and is planned for one more rainstorm event.

2. OBJECTIVES

The purpose of this study was to conduct water quality research on each of the five major river systems that flow into Tillamook Bay. Concentrations of nutrients (TKN, NO_3^-, NH_4^+, total P), TSS, FCB, major ions, pH, and conductivity were investigated by conducting a monitoring program for one year on each of the rivers, and conducting intensive sampling during several rain storm events. This research was intended to provide detailed information on current water quality conditions at multiple locations (including the lower reaches) in each of the five rivers throughout an annual cycle, and to quantify seasonal and episodic variability in that water quality. The research was also intended to provide quantitative estimates (first approximation) of bacterial levels and nutrient (N, P) and sediment loads from each of the rivers to the bay. This information will allow assessment of the linkages between existing land uses within the watersheds and pollutant loads to the bay from each of the five river basins. It will also provide critical information needed to design a rigorous water quality-monitoring program and to prepare the CCMP for the watershed. Specific objectives of the research included the following:

- Provide detailed quality-assured information on water quality in the five rivers that flow into Tillamook Bay throughout an annual cycle.
- Quantify seasonal and episodic variability in river water quality, with emphasis on FCB, TSS, and nutrients.
- Provide first-approximation estimates of annual loading of FCB, TSS, and nutrients from each river to the bay
- Evaluate the relationships between major land uses and water quality (concentrations and loads) on chronic and episodic bases.
- Provide chronic and episodic water quality characterization for each watershed.
- Evaluate associations between water quality and major land uses.

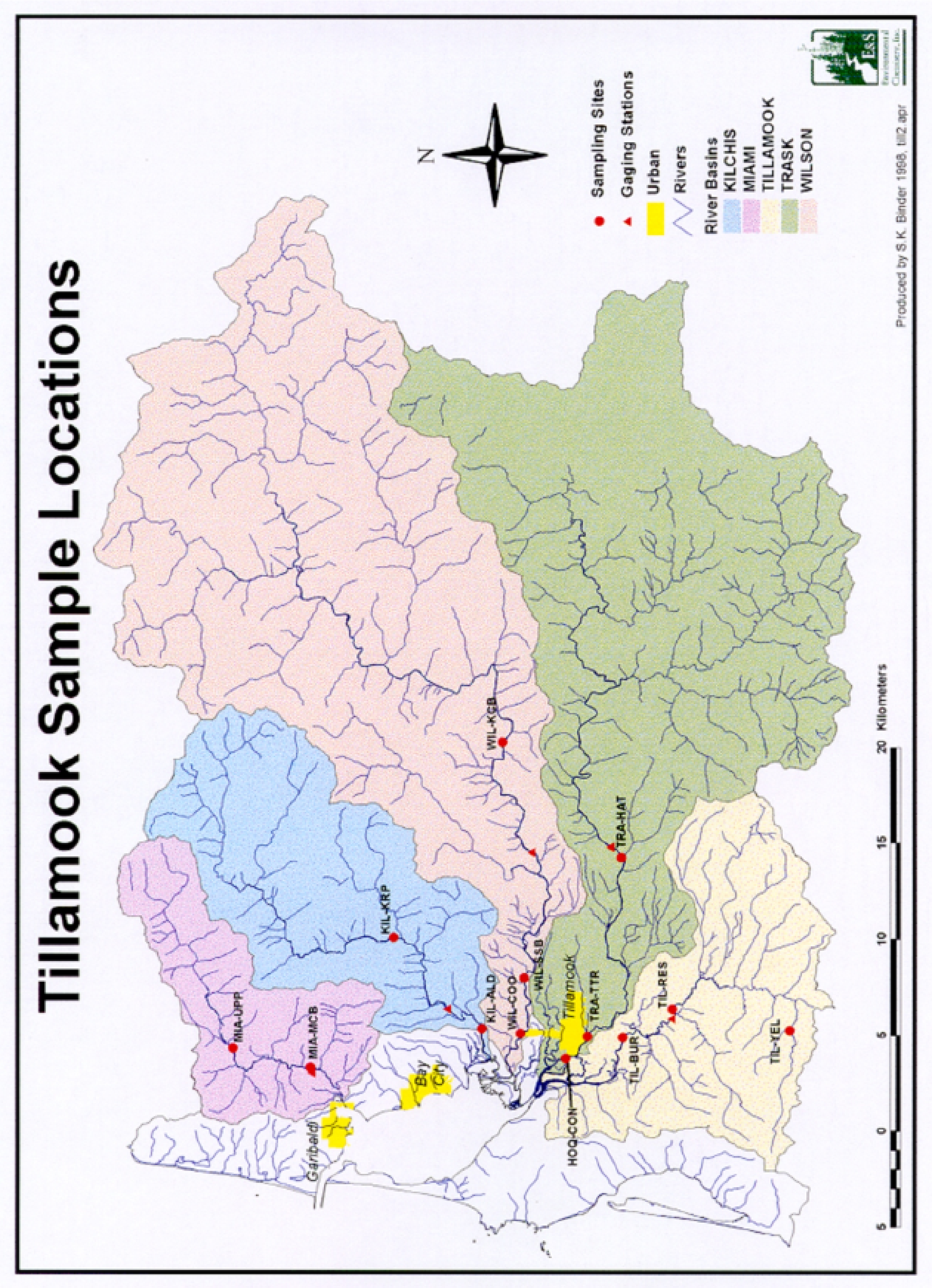


Figure 1. Sample site locations.

- Provide assessment of problem parameters and areas to be further investigated with focused studies.
- Evaluate relative importance of each river/ watershed as contributor to bay water quality.
- Generate structured, testable, hypotheses regarding relationships between fecal coliform bacteria concentrations/loads and predictor variables such as river flows, antecedent hydrological conditions, and watershed characterization. Such hypothesis could then be tested with additional monitoring data.
- Provide the needed data with which to design a focused long-term monitoring program.

This study was not intended to quantify pollutant loads with known uncertainty, discriminate between agricultural and human sources of bacteria in the lower basins, identify the remedial benefits of specific land use practices, or establish linkages between river water quality and bay water quality. Results of this study are reported in two companion reports to TBNEP, of which this report is the first. This first report presents the annual overview results and general watershed characterization. The second report presents the results of the storm sampling and the loading estimates (Sullivan et al. 1998).

3. METHODS

Site Allocation and Sample Collection

Primary Sites

One downstream sampling site was selected, in consultation with TBNEP staff, at the downstream end of each of the five rivers in relatively close proximity to the bay (Miami, Kilchis, Trask, Wilson, Tillamook; Figure 1). Sample sites were selected with an aim to avoid tidal prism influence. To quantify tidal influence, on-site conductivity measurements were taken to ensure that baywater contamination of samples did not occur. Road crossings (bridges) were selected for primary site sampling locations for logistical purposes. Bridge sampling, accomplished using a Van Dorn sampler or a weighted sterile bottle, facilitated collection of water in the middle of the current stream at a depth of at least 0.5 m. Water in this zone tends to be well mixed. During the course of the study, the Burton Bridge (primary site location on the Trask River) became the site of extensive construction activity. Beginning in January 1998, this site was no longer available for sample collection because the bridge had been largely removed. The 5th street dock, downstream from Burton Bridge, then became the new primary site on the Trask River.

Secondary Sites

Additional sampling sites were selected at upstream locations, on each of the rivers. Secondary site selection was determined jointly by members of the project team and TBNEP staff.

Criteria used in determining site locations included the location of land use transitions (e.g., forest /agriculture interface), homogeneity of upstream segment characterization, known or suspected problem locations, and sampling logistics. Secondary sites did not remain fixed throughout the study and all secondary sites were not sampled on all sampling occasions. Priorities for site location and sampling were forest/agriculture transitions, probable point sources of bacteria and nutrients, and intensive agriculture. Most of the sampling and analysis focused on the primary sites and the secondary sites located at the forest/agriculture interface on the respective river. Those locations are given in Table 1.

Table 1. Site locations of primary and forest/ agriculture secondary sites on each of the rivers.

River	Site Location in River Miles from Mouth	
	Primary Site	Forest/Agriculture Interface
Tillamook	4.0	NA
Trask	2.4	9.8
Wilson	3.9	14.1
Kilchis	1.5	7.1
Miami	1.7	5.3

Most of the secondary sites were not located at bridge crossings. Sampling at these sites was accomplished using a weighted sampling bottle which was thrown into the mid-current section of the river and retrieved by rope after filling. Filling of the bottle occurred at depth. Shallow sites were sampled by submerging a Nalgene bottle directly in the stream using a pole to sample at depth and avoid sample contamination. Samples were filled to minimize air bubbles and the bottles placed in coolers on ice and transported to the Oregon State University Soil Science Laboratory in Corvallis for chemical analyses and the Kilchis Analytical Laboratory in Bay City for bacterial analyses.

Bay Sites

A limited number of water samples were also collected from several sites in the southern portion of Tillamook Bay on three days during a storm in early October, 1997. These samples were analyzed for FCB.

Sampling Schedule

Monitoring was initiated November 27, 1996 and river water samples were collected approximately monthly through December, 1997. Primary sites were sampled most frequently. An effort was made to schedule many sampling trips to coincide with relatively high-flow periods, especially conditions of rising hydrographs. Four storm events were sampled during 1997, and two storms in 1998 (to date). Storm loads were estimated for FCB, TSS, and nutrients, and the results of those analyses are presented by Sullivan et al. (1998).

Discharge

River flow data for the Tillamook, Kilchis, and Miami 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. The USGS maintains gauging stations on the Trask and Wilson Rivers. These data have also been gathered and included in the hydrologic data set. USGS provides flow data in a completed format. See Table 2 for a list of the data sets, period of record, and sample intervals.

Table 2. Hydrologic data obtained for this study.

River	Recorded Interval	Period of Record	Agency	Major Data Gaps
Trask	30 min	4/10/96-12/31/97	USGS	No major gaps
Wilson	30 min	10/1/94-12/31/97	USGS	No major gaps
Kilchis	15 min	12/18/95-12/31/97	OWRD	No major gaps
Miami	15 min	10/01/95-12/31/97	OWRD	No major gaps
Tillamook	15 min	11/22/95-12/31/97	OWRD	3/17/96-4/25/96 7/23/96-2/26/97 5/7/97-7/30/97

Discharge Database Development and Quality Assurance

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

1. Spot-checks of discharge and stage in the complete data set vs. discharge and stage in the rating curves.
2. An automated procedure that compares discharge between 15 minute intervals. Any two adjacent data points producing a change of greater than 75 cfs are flagged and then manually verified. Since data loggers periodically produce erroneous stage measurements, this procedure identifies many of these errors.
3. Visual analysis of time series plots of discharge.

Discharge Database Manipulation

The data set provided by OWRD for the Tillamook, Kilchis and Miami contained a number of gaps during which stage data were not collected. These gaps were filled using a series of simple linear regressions (Figure 2). Four unique regression equations, each corresponding to a season,

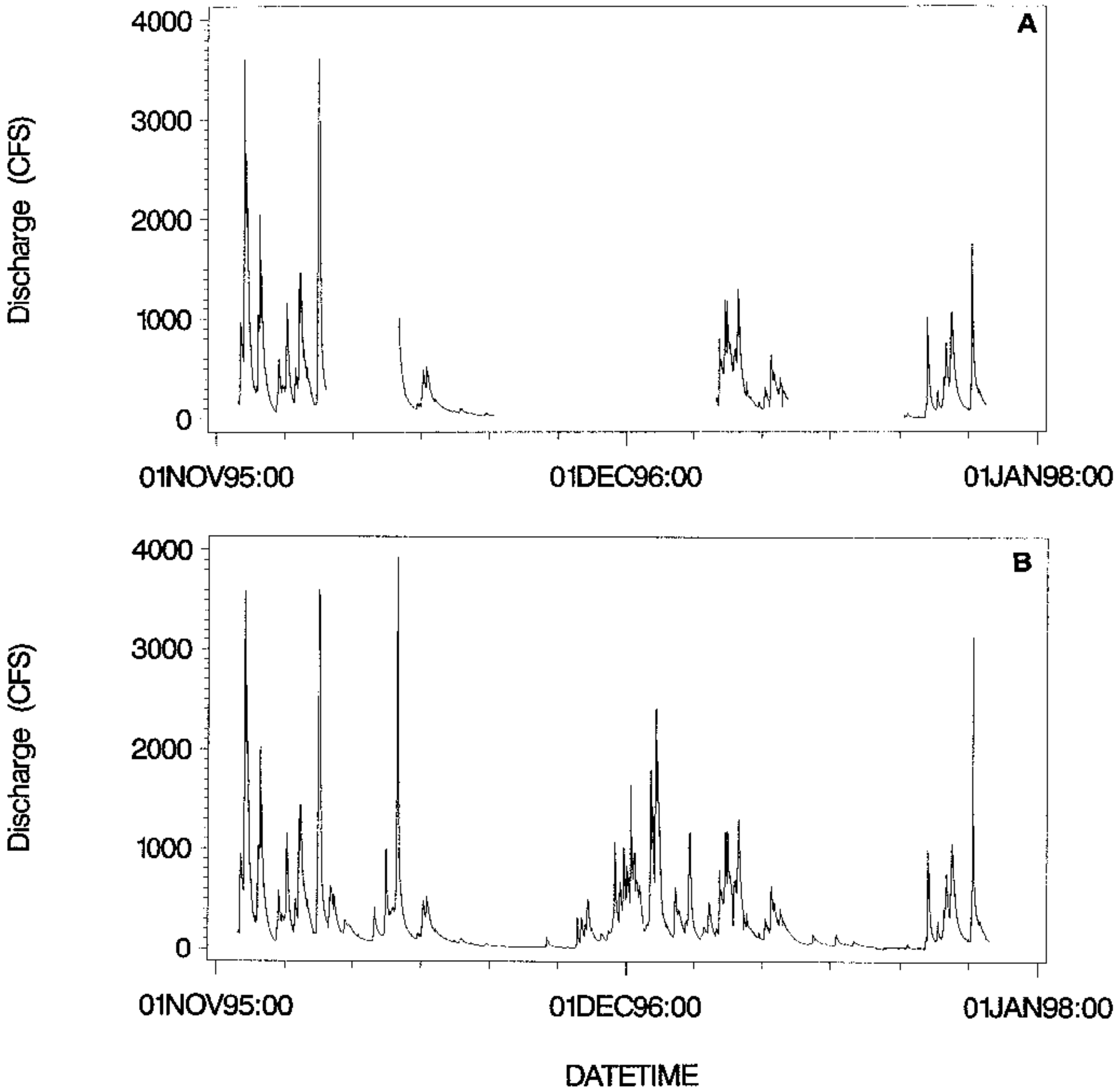


Figure 2. Raw data (A) and corrected data (B) on Tillamook River flows (cfs) during the period of study. Corrections were made to fill in missing data points on the basis of linear regression relationships between measured Wilson River flows and Tillamook River flows (Table 3). Similar corrections were made for the flow data for the Miami and Kilchis Rivers.

were applied to each of the three basins. The equations, along with quantitative measures of uncertainty, are shown in Table 3. Note that each of the regressions is based on the Wilson River data collected by USGS. This data set was the most complete of the five collected in the basin and did not contain any gaps.

Data were collected at 15 minute intervals for each of the OWRD sites. Data provided by USGS were collected at 30 minute intervals. Each of these data sets was reduced to hourly data before the regressions were run. Consequently, the final database is hourly.

Table 3. Parameter values of regression relationships used to estimate flow in the Tillamook, Miami and Kilchis Rivers from flow rates measured by USGS in the Wilson River.

Season	River	Slope	R square	Standard error
Fall	Tillamook	0.158	0.9306	0.001314
Spring	Tillamook	0.205	0.9579	0.000870
Summer	Tillamook	0.236	0.9694	0.001077
Winter	Tillamook	0.136	0.8858	0.001176
Fall	Miami	0.181	0.8529	0.001124
Spring	Miami	0.229	0.9580	0.000862
Summer	Miami	0.343	0.8811	0.002090
Winter	Miami	0.183	0.9057	0.000938
Fall	Kilchis	0.415	0.9224	0.002664
Spring	Kilchis	0.547	0.8799	0.003098
Summer	Kilchis	1.049	0.8459	0.007677
Winter	Kilchis	0.491	0.9403	0.001932

Sample Analysis

River water samples were analyzed for total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrate, ammonium, conductivity, TSS, FCB, pH, and temperature. Fecal coliform bacteria were analyzed on all sample occasions. Conductivity, temperature, TSS, NO_3^-, TP, NH_4^+, and TKN were analyzed for most samples. Base cations, acid anions and pH were measured for a small subset of samples. The chemical analytical methods are summarized in Table 4. It is important to note that values reported below the detection limit were set to zero for statistical analysis. Duplicate, triplicate, and deionized water blank samples were submitted as routine samples to the laboratory as checks on analytical quality. *In situ* measurements were collected for temperature and conductivity.

Table 4. Chemical methods and detection limits for analysis of samples at Oregon State University.

Parameter	Detection Method	Reporting Limit	Unit
pH, lab	Electrode	-	s.u.
Conductivity, lab	Platinum electrode	1.0	S/cm
Calcium, as Ca^{2+}	AA flame	0.05	mg/L
Magnesium, as Mg^{2+}	AA flame	0.05	mg/L
Sodium, as Na^+	Flame emission	1.0	mg/L
Potassium, as K^+	Flame emission	0.5	mg/L
Sulfate, as SO_4^{2-}	Ion chromatography	1	mg/L
Chloride, as Cl^-	Ion chromatography	0.2	mg/L
Nitrogen, $NO_2 + NO_3^-$ as N	Ion chromatography	0.05	mg/L
Nitrogen, NH_3 as N	Perstorp (SM4500)	0.01	mg/L
Nitrogen, Kjeldahl as N	BD-40 auto. phenate	0.05	mg/L
Phosphorus, tot. as P	Digest./ascorbic acid	0.002	mg/L
Solids, tot. susp. (TSS)	Gravimetric 103C	2	mg/L

Description of Laboratories and QA/QC

The overall quality assurance objectives for the project were to implement quality control-requirements for laboratory analysis that would provide data that could be used to achieve the program objectives, and to follow procedures that would provide data of known quality in terms of precision, accuracy, completeness, representativeness, and comparability.

About 10% of the samples analyzed were allocated to QA/QC, and these included field duplicates and blanks. QA/QC samples were used to quantify sampling and analytical variability and analytical detection limits.

Temperature and conductivity were measured in the field. Samples were stored on ice in coolers and transported to the Oregon State University Department of Soil Science and Kilchis Analytical Laboratory in Bay City for additional analysis. The core analytes completed for most samples were TSS , nutrients, and FCB.

Glass and Plasticware Preparation

All plasticware and aliquot bottles for measurement of TSS were Nalgene® high density polyethylene (HDPE). Bacteria samples were transferred from the van Dorn sampler into, or collected into, new sterile bottles or sterilized sample bottles (using an autoclave).

Sample Collection

Samples were collected from near mid-stream in mid-water column on the upstream side of a bridge, when available. If no bridge was available, samples were collected with a float weight sampling device. The sample bottle and sample collection device was rinsed twice prior to collection of each sample. The number of samples collected on each sample occasion varied depending on the number and type of aliquots required for a given situation.

Analytical Methodologies

Kilchis Dairy Herd Services (KDHS) provided the sample collection crew with unmarked, clean sterile Nalgene (or similar) screw top bottles. The bottles ranged in size from 100 to 250 ml. The sampling crew attached a label at the time of sample collection. This label contained a three-letter code to identify the river, then a three-letter or number code to identify the sampling location, followed by a two-number code to identify sample number. As an example, TRA-101-02 would be a sample from the Trask River collected at the Highway 101 bridge and this would be the second sample collected at this site.

QA samples of bacterial analyses included several different types, each of which provided information regarding one or more sources of uncertainty. These include:

- blank-sample of deionized water
- replicate-sample collected from same site immediately following collection of a routine sample
- split-sample divided into two aliquots sent two different analytical laboratories

On the E&S Environmental Chemistry, Inc. chain of custody record form there is information to determine sample name, date, time of day, test requested, and comments.

When the samples were delivered to the laboratory (KDHS), a second chain of custody form was started for use in the lab. On this was noted the name of who collected the samples and the date and time the samples were delivered to the laboratory. The person who received the samples signed them in and recorded the date and time. This form also identified the project name and number and contained the sample date and number.

The laboratory also utilized a worksheet which showed who collected, analyzed, and counted the plates and the three dates for these activities. On the worksheet, there was a sample number, identifying number, volume of sample water filtered, plate count, and calculated cfu/100 ml. Information from these worksheets was transferred to a results form. This showed the sample identification and the resulting plate count. This form was reviewed and the reviewer signature was noted.

Within the laboratory, the equipment is maintained and monitored to public health certification standards. Fecal coliform bacteria were determined using the membrane filter technique described in Standard Methods for the Examination of Water and Wastewater.

Laboratory Blank Samples

Laboratory blank samples were made for each analysis requiring sample preparation. These samples indicate control of contamination during sample preparation. The laboratory blank was made from reagent grade water and was prepared in the same manner as the samples. A single laboratory blank was generated for each sample preparation batch. For samples not requiring preparation, a laboratory blank was used to monitor background changes in measurement systems. These were made from reagent grade water and treated in an identical fashion to samples prepared for these tests. The laboratory and reagent blank DQO is expected to be less than twice the analytical detection limit. Results of laboratory blank analyses indicated that sample contamination did not occur.

Sample Custody and Documentation Procedures

Sample bottles were labeled with indelible ink. Sample identification included the year, month, day and station code in the form “ymmddss” where “y” is the last digit of the year, “mm” is the number of the month, “dd” is the day of the month, and “ss” is the station code. This information was recorded on a multi part chain of custody record along with information about the desired analyses and the identity of the sample collector. A field log book was kept in which station codes, date and time of sampling, and all field data were recorded. Notes on any unusual conditions at the sample sites or any circumstances that my have caused deviation from normal procedures were also recorded in the field book.

Document control procedures included the following:

- records were clear, comprehensive, and written in indelible ink;
- corrections to data sheets and logbooks were made by drawing a single line through the error and initialing and dating the correction;
- before release of data, records were cross-checked for consistency between sample tags, custody records, bench sheets, personal and instrument logs, and other relevant data; and
- documents were archived in the project records.

Data Reduction and Validation

Laboratory data reduction and validation were performed according to standard quality assurance plans. Data were reported as hard copy delivered by the laboratory to the contractor, E&S Environmental Chemistry. Field data were recorded in a field notebook, examined for internal consistency, and reported. All data were entered into a computer database in a format compatible with Excel for Windows version 4.0a.

Prior to data analysis and interpretation, all data entered into the database were validated by evaluation of blanks, duplicate samples, split samples, checks for time series anomalies, and outlier analysis.

Description of Laboratories

The Central Analytical Laboratory at Oregon State University is an analytical service laboratory which serves the university community as well as other governmental agencies. It supports the university in its research and extension missions in agriculture and related environmental issues. The laboratory concentrates its efforts in the area of soil, plant tissue, and water analysis with the emphasis on the analysis of nutrients. Major instrumentation includes:

- Perkins-Elmer Optima 3000 DV ICP Optical Emissions Spectrometer,
- Perkin-Elmer Model 4000 Atomic Absorption Spectrometer,
- Perkin-Elmer Model 5000 Atomic Absorption Spectrometer,
- LECO Model CNS-2000 Carbon/Nitrogen/Sulfur Analyzer,
- Perstorp Model 3500 Continuous Flow Analyzer,
- Alpkem Model 300 Continuous Flow Analyzer,
- Tecator Aquatec Flow Injection Analyzer, and
- CEM Corp MDS-2000 Microwave Digestion System.

The laboratory has been involved in nutrient analysis of soils and plant tissue since the early 1950's. The Central Analytical Laboratory, as it exists today, is the result of merging the Soil Testing Laboratory and the Plant Analysis Laboratory/Horticulture into one facility. Water quality analysis was added in the 1980's. The laboratory has worked closely with researchers, instrument manufacturers, and other laboratories in order to develop procedures to give consistent low level nutrient analysis necessary for water quality work. Recent projects involving water quality analysis include the Willamette River Basin Water Quality Study and the Tualatin Basin Monitoring Program (Oregon Department of Forestry).

Quality of the analysis is maintained by a QA/QC program which may vary depending on the needs of the research. Minimum requirements for the laboratory include:

- Maintaining instrument log books including identification of samples run, calibration information, instrumentation settings, maintenance performed, and other observations which may affect the quality of the results.

- Calibration of instruments is performed with each set of samples analyzed with no more than 35 samples between recalibrations.

- An independent check standard or check sample is run with each calibration.
- A minimum of two blanks, one duplicate, and one spiked sample are analyzed with each sample set.

In addition to the above laboratory QA/QC program, the laboratory also participates in the Interlaboratory Quality Control Sample Split for the Tualatin Basin. Other participants in this program are Clackamas County, Multnomah County, Oregon Graduate Institute, City of Portland, Unified Sewage Agency, Department of Environmental Quality, and United States Geology Survey. The Central Analytical Laboratory has taken pride in being among the best laboratories in the program as rated by accuracy of known samples, recovery of spiked unknowns, precision of blind triplicate analyses, and bias from the mean value of unknowns.

Chain of custody of samples was maintained by a log-in system that assigns a number unique to the sample set and sample. This number is marked on each sample and a preprinted label is applied to the log sheet when the sample enters the laboratory. This number is used for any subsequent analysis identification. All sample logs and data are kept on a computer system which is backed up daily by the network administrator and weekly by a computer specialist. Hard copies are also kept to ensure no loss of data or chain of custody.

The Kilchis Analytical Laboratory is located in Bay City, Oregon and provides bacterial analysis laboratory services. The laboratory is directed by Dr. Mark Wustenberg and Judy Wustenberg and is certified for FCB presence/absence determinations for drinking water. The laboratory staff work closely with the local dairy industry and are involved in educational efforts concerning herd management and implementation of Best Management Practices.

4. RESULTS

Water Quality Comparisons Across the Five Rivers

Table 5 shows the flow-weighted annual means for all measured water quality variables at the primary sites on all the rivers. Means were flow weighted to account for differences in flows at time of sampling, the fact that some samples were taken during high flow periods, and differences in seasonal flows. The Tillamook River consistently had the highest FCB concentrations, with the Kilchis River having the lowest. TSS concentrations were highest in the Trask and Wilson Rivers, corresponding to the rivers with the largest watersheds and highest flows. Conversely, TSS concentrations were lowest in the Tillamook River, which has the smallest watershed area and lowest flows of the five rivers. Inorganic nitrogen concentrations were similar across all of the rivers, with the highest concentrations in the Miami River and lowest concentrations occurring in the Wilson River. Total phosphorus concentrations were highest in the Wilson River and the lowest in the Tillamook River. Chloride ions were highest in the Tillamook River, corresponding to the river

Table 5. Flow-weighted average concentration of water quality parameters measured during the course of this study at the primary site on each of the five rivers (n is in parentheses).

	Flow Weighted Average Concentration				
Parameter	Tillamook[1]	Trask[1]	Wilson	Kilchis	Miami
Fecal Coliform Bacteria (cfu/100ml)	523(41)	169(26)	152(34)	36(32)	124(32)
NH_4-N (mg/L)	0.02(20)	0.02(18)	0.02(19)	0.02(20)	0.02(20)
NO_3-N (mg/L)	0.78(21)	0.82(19)	0.59(20)	0.73(21)	0.93(21)
Conductivity (FS/cm)	56(32)	66(13)	50(27)	44(24)	52(22)
pH	6.6(15)	7.0(22)	7.0(14)	6.9(15)	6.9(15)
TSS (mg/L)	38(24)	137(19)	253(23)	86(24)	60(24)
TKN (mg/L)	0.31(21)	0.25(19)	0.22(20)	0.24(21)	0.27(21)
TP (mg/L)	0.11(21)	0.25(4)	0.52(19)	0.22(20)	0.15(21)
Ca (mg/L)	3.1(4)	7.2(4)	7.8(4)	4.3(4)	3.97(4)
Mg (mg/L)	1.5(4)	4.3(4)	7.4(4)	2.8(4)	2.1(4)
Na (mg/L)	4.0(4)	3.9(4)	3.4(4)	2.9(4)	3.6(4)
K (mg/L)	0.614(4)	0.32(4)	0.47(4)	0.20(4)	0.27(4)
SO_4-S (mg/L)	0.62(4)	0.61(4)	0.49(4)	0.29(4)	0.35(4)
Cl (mg/L)	6.5(4)	3.2(4)	2.7(4)	3.3(4)	5.0(4)

[1] Data collected for the Tillamook and Trask Rivers during an intensively monitored storm event in October, 1997 were excluded from this analysis because comparable data were not available for the other three rivers.

whose watershed is situated closest to the ocean and therefore likely receives the largest contribution of marine aerosols.

Fecal Coliform Bacteria

Fecal Coliform Bacteria Concentrations

Fecal coliform bacteria concentrations were variable from river to river, ranging from 0 to 3700 cfu/100 ml at the primary sites (Figure 3). The range for the secondary sites representing the forest/agriculture interfaces was much narrower, ranging from 0 to 500 cfu/100ml (Figure 4). The highest concentrations were found in the Tillamook River, where concentrations increased dramatically with relatively small increases in flow, particularly in the upper watershed, at the Yellow Fir Rd. and Rest Area sites (Figure 5). It is important to note that flows in the Tillamook and Miami

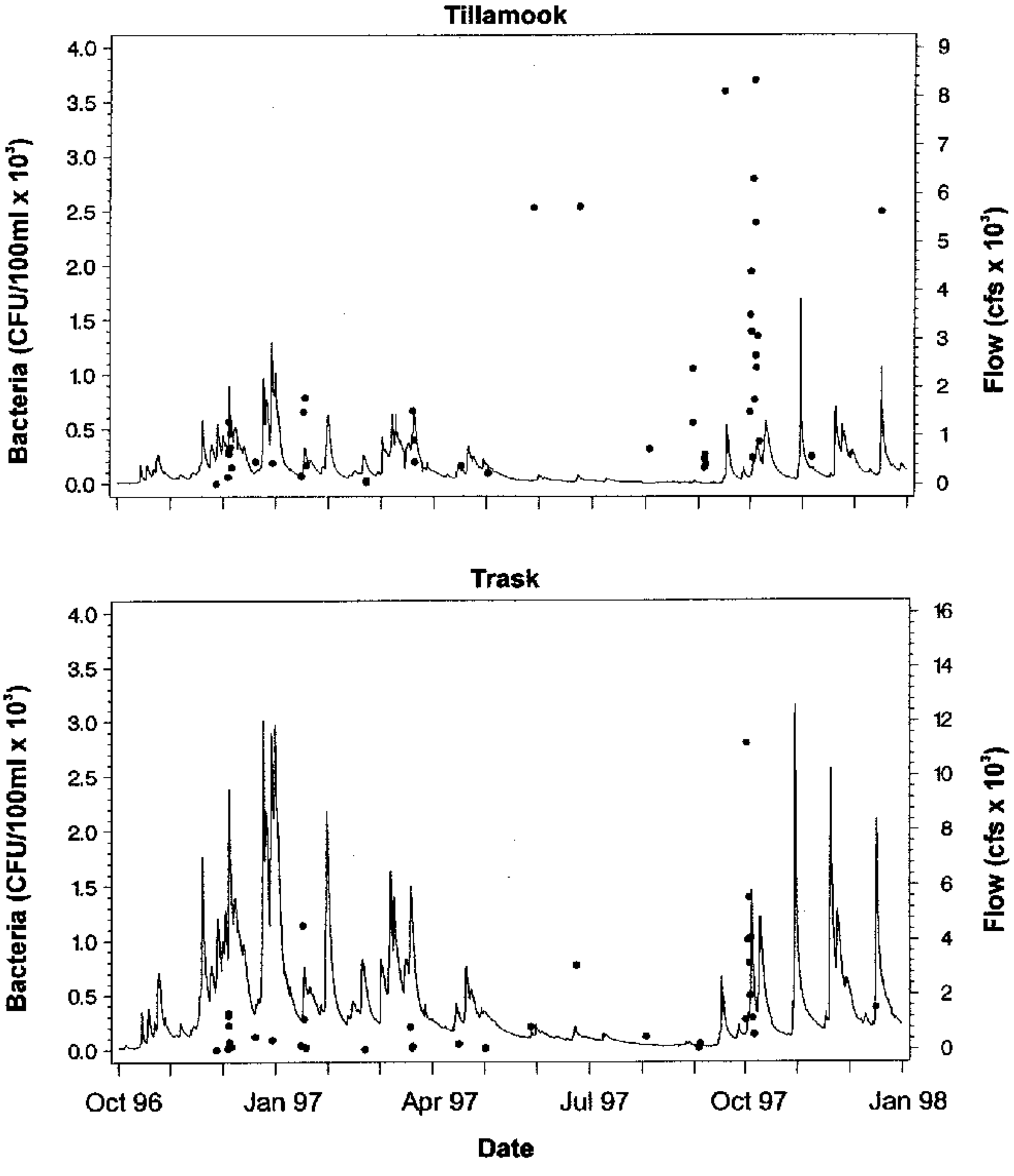
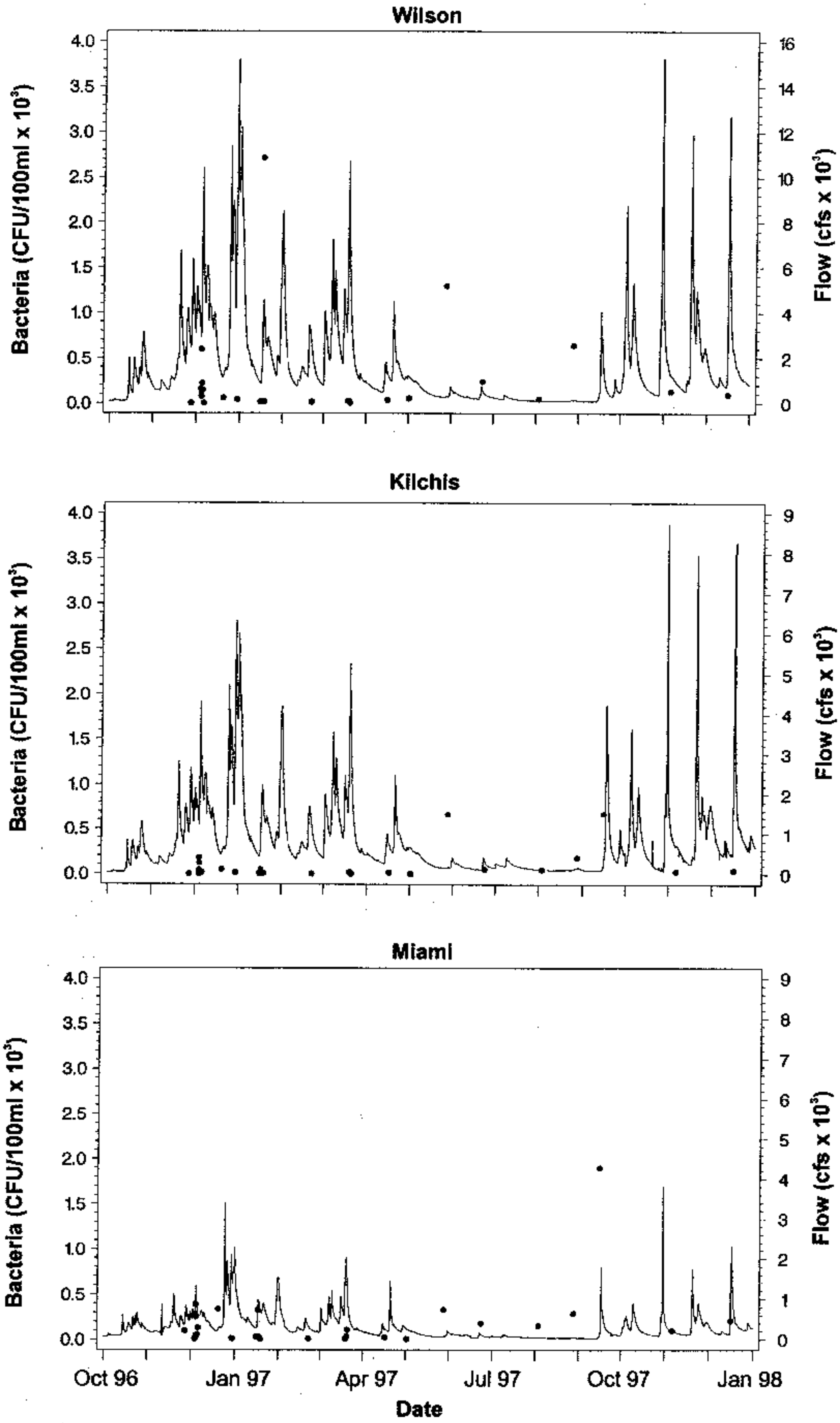


Figure 3. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3) and river flow (cfs x 10^3) at the primary monitoring site on each river. The scale for bacteria is standardized across rivers for this and subsequent figures. However, two scales are used for flow, one for the two large rivers (Wilson, Trask) and another for the three smaller rivers.



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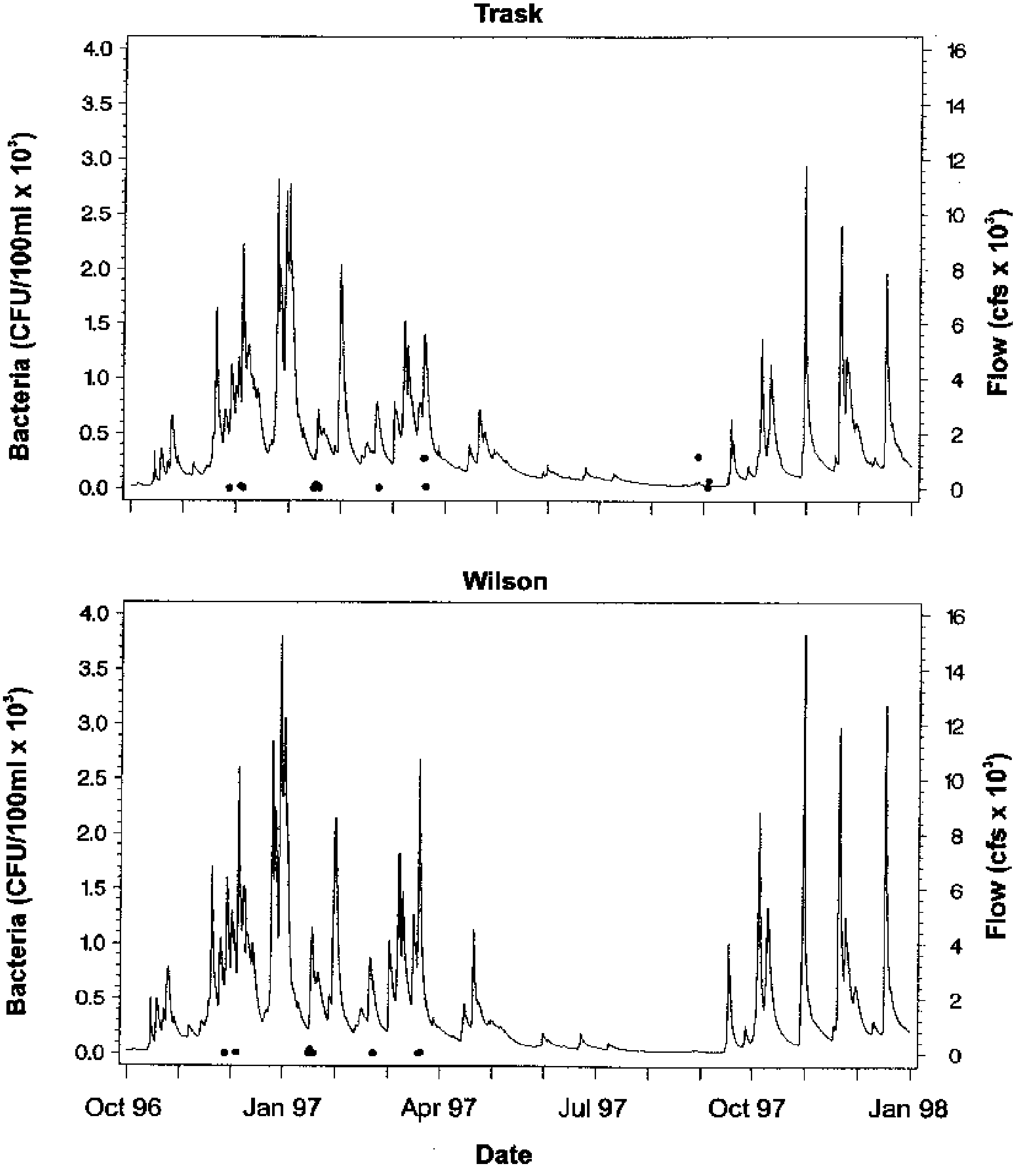
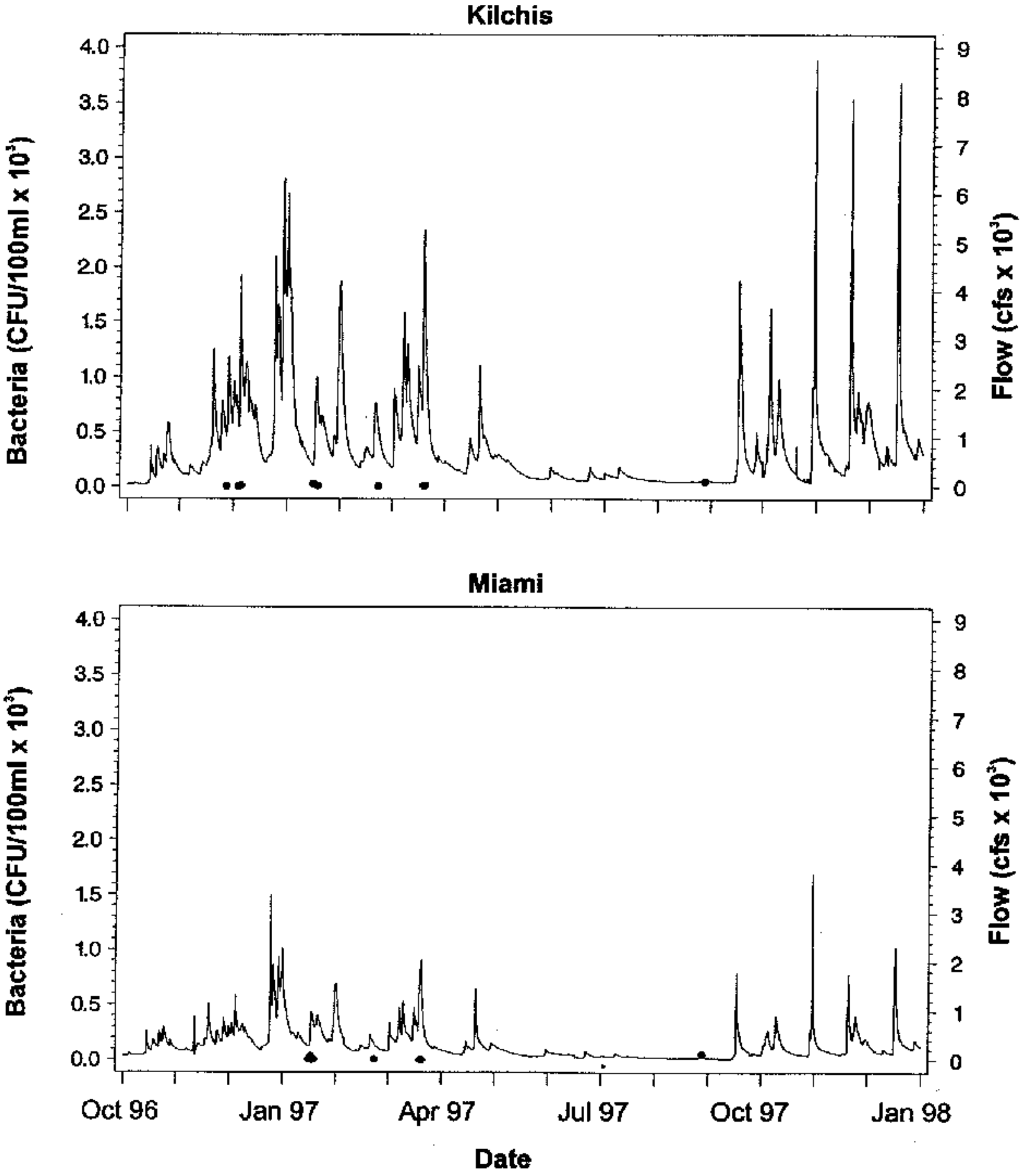


Figure 4. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3) and river flow (cfs x 10^3) at the secondary monitoring sites located approximately at the forest/agriculture interface on the Trask, Wilson, Kilchis, and Miami Rivers.



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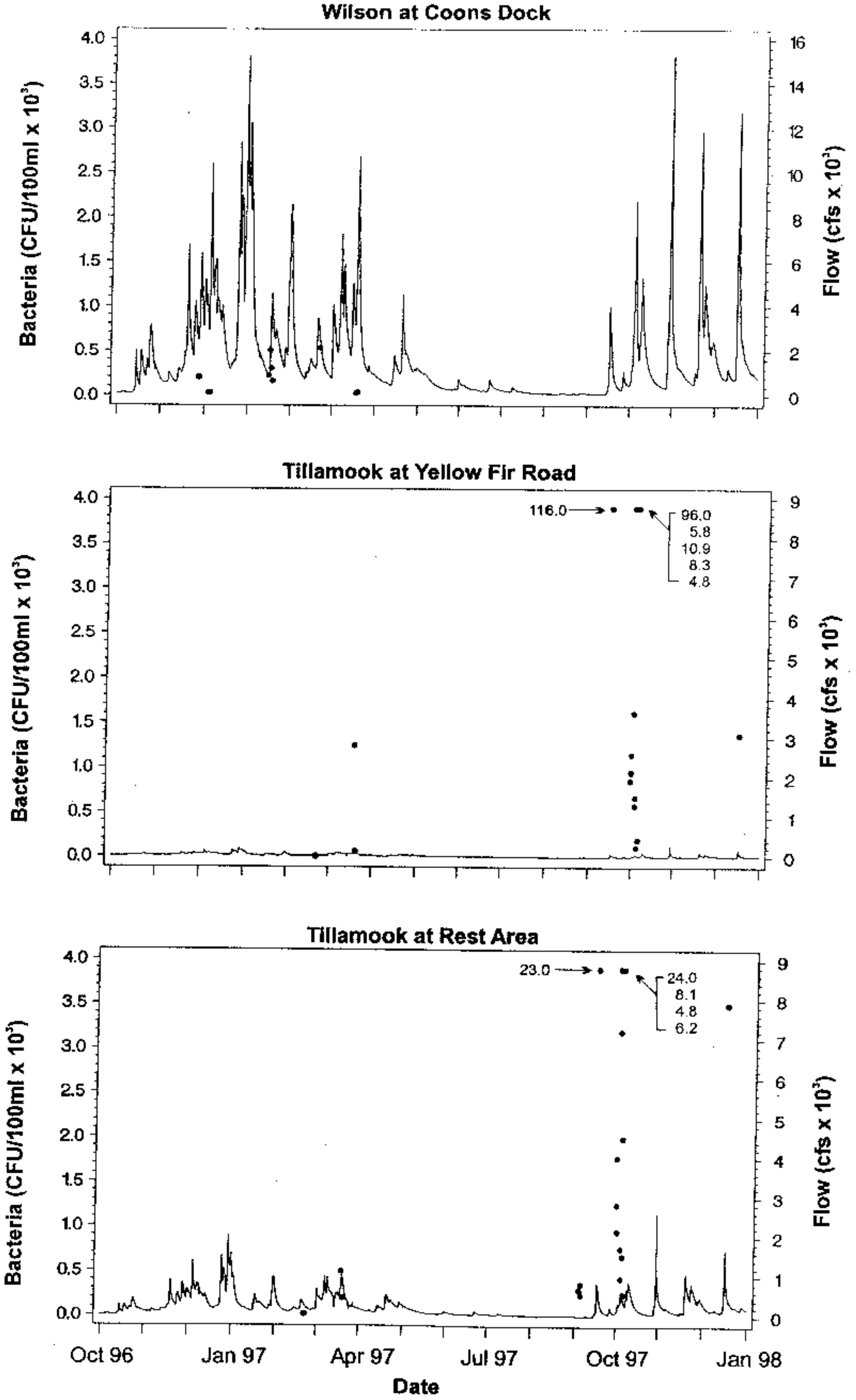


Figure 5. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3) and river flow (cfs x 10^3) at the secondary monitoring sites located at Coons dock on the lower Wilson River, and at Yellow Fir Rd. and the Rest Area on the upper Tillamook River.

Rivers are significantly lower than in the other rivers because their watersheds are smaller, resulting in less dilution and sometimes higher concentrations of FCB.

Seasonal differences in FCB concentrations were seen at all of the primary sites. At the Tillamook and Trask River primary sites, which were sampled most intensively of the five rivers, the highest bacterial concentrations were observed during the storm event of early October, 1997. Many samples were measured during the storm in excess 500 cfu/100 ml. Similar results were obtained for bacteria in the Wilson River, which was sampled and analyzed during the October storm by the Tillamook County Creamery Association (TCCA; data not shown). Quite high bacterial concentrations (>500 cfu/100 ml) were also recorded for the Tillamook, Trask, and Wilson Rivers during very small summer rainstorms and during one winter storm in the Wilson River. Highest values were also recorded in the Kilchis and Miami Rivers during summer and fall storms, but the concentration in those rivers seldom exceed 500 cfu/100 ml (Figure 3). Jackson and Glendening (1982) also found high concentrations of FCB during the summer season of 1980 in all of the rivers in the Tillamook Basin. One-third of the July samples taken by Jackson and Glendening (1982) at the primary site on the Kilchis River and two-thirds or more of the July samples at the primary site on the other four rivers had FCB concentrations above the health standard of 200 cfu/100 ml.

All five rivers had dramatic increases in FCB concentrations associated with summer and fall storm events. Spring concentrations were generally low for all of the primary and secondary sites (<100 cfu/100ml) except for the Tillamook-Burton Bridge site where there was a peak associated with a spring storm event. In all cases, small summer storm events caused greater increases in FCB concentration than larger more intense storms in the winter and spring months. This suggests that the antecedent moisture conditions or length of the dry period preceding the storm may play a significant role in controlling fecal coliform contributions from the watersheds to the rivers.

Bacterial concentration data at or near the forest/agriculture interface on four of the rivers are shown in Figure 4. A forest/agriculture interface was not sampled on the Tillamook River because most contributions to runoff from forested lands to that river are derived from a number of tributary streams rather that a single mainstem river. Measured concentrations of FCB at the forest/agriculture interfaces were always less than 500 cfu/100 ml and only 2 out of 42 samples had fecal coliform concentrations higher that 100 cfu/100 ml (both on the Trask River). On a number of sampling occasions, paired samples were collected within a few hours or less of each other at the primary site and at the forest/agriculture interface on the various rivers. Results of bacterial measurements for these sample pairs are shown in Figure 6. Concentrations were generally higher at the primary sites as compared to the respective forest/agriculture interface site. In many cases, the concentration of FCB was dramatically higher at the downstream primary site. Bacteria were also measured at several other locations within the basin at various times (Figure 1) in an effort to gain a better understanding of major source areas. These additional areas included Coon’s Dock on

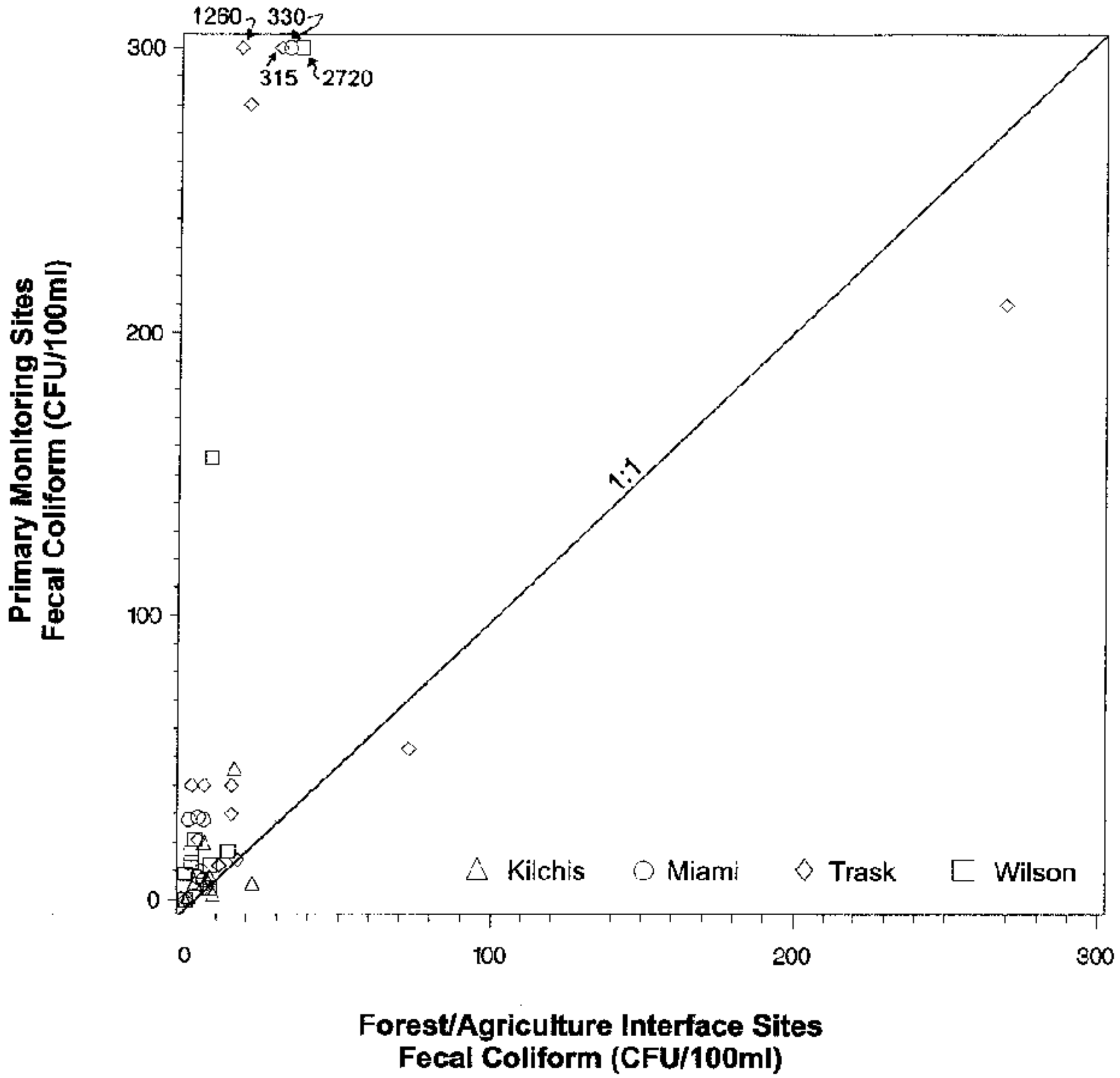


Figure 6. Results of paired sample analyses for fecal coliform bacteria at the primary site and its respective forest/agriculture interface site for the four rivers in which both types of samples were collected. A 1:1 line is provided for reference.

the lower Wilson River; Hoquarten Slough adjacent to the Hospital Hole site on the Trask River; and two upland sites (Yellow Fir Road crossing and the Rest Area) on the Tillamook River. The Coons dock site is located along the lowest stretch of the Wilson River, just above the bay. It was selected because there is a long section of the Wilson River below the primary site bridge crossing which includes intensive dairy farming and also contains the outflow of the point source discharge from the TCCA. It was anticipated that this lower section of the Wilson River might be a major source area of bacteria. The results of eleven paired samplings at Coons dock and the primary site indicates, however, that bacterial concentrations are not generally much higher at Coon's dock (Figure 7). Because the Tillamook River contained the highest measured concentrations of FCB, two additional sites were added in the upland portions of the Tillamook River watershed midway through the study (Figure 5). Paired sample analysis between these two sites (Yellow Fir Road crossing and Rest Area) and the primary site suggested that FCB concentrations in the upland portions of this watershed were higher than in the lower parts of the watershed much of the time (Figure 8).

Previous measurements of FCB in Hoquarten Slough have been quite high on many occasions (TBNEP 1997). We therefore sampled this slough near where it enters Tillamook Bay, on 19 occasions during this study. Although not part of the river systems, Hoquarten Slough drains a sizeable area of farmland and parts of the city of Tillamook (Figure 1) and therefore has the potential to be a significant contributor of bacteria to the bay. Results of our bacteria analysis of samples from the slough are shown in Figure 9 with Wilson River flows as a reference to hydrologic conditions. Slough FCB concentrations were quite high during the first fall storm event and some spring storm events suggesting that it is a significant contributor of FCB.

Fecal Coliform Bacteria Loads

Fecal coliform bacteria loads at the primary sites ranged from 0 to 1.5 x 10^6 cfu/sec with the highest loads in the Trask and Wilson Rivers (Figure 10). However, despite having significantly lower flows than the Trask and Wilson Rivers, the Tillamook River also carried relatively large loads (compared to the Miami and the Kilchis) during storms. This was due to very high bacterial concentrations measured in the Tillamook River. The Yellow Fir Rd. and Rest Area sites on the Tillamook followed the same pattern as the Tillamook primary site, where loads increased significantly during a fall storm event (Figure 11; see also Sullivan et al. [1998] for detailed analysis of storm response). The secondary sites representing the forest/agriculture interfaces on the Trask, Wilson, Kilchis and Miami Rivers had consistently low FCB loads (<50,000 cfu/sec) and did not change significantly with storm events (Figure 12).

Seasonal variations in FCB loads were seen at all of the sites except for the forest/agriculture interface sites. Summer loads were consistently low at all five primary sites as a result of low flow

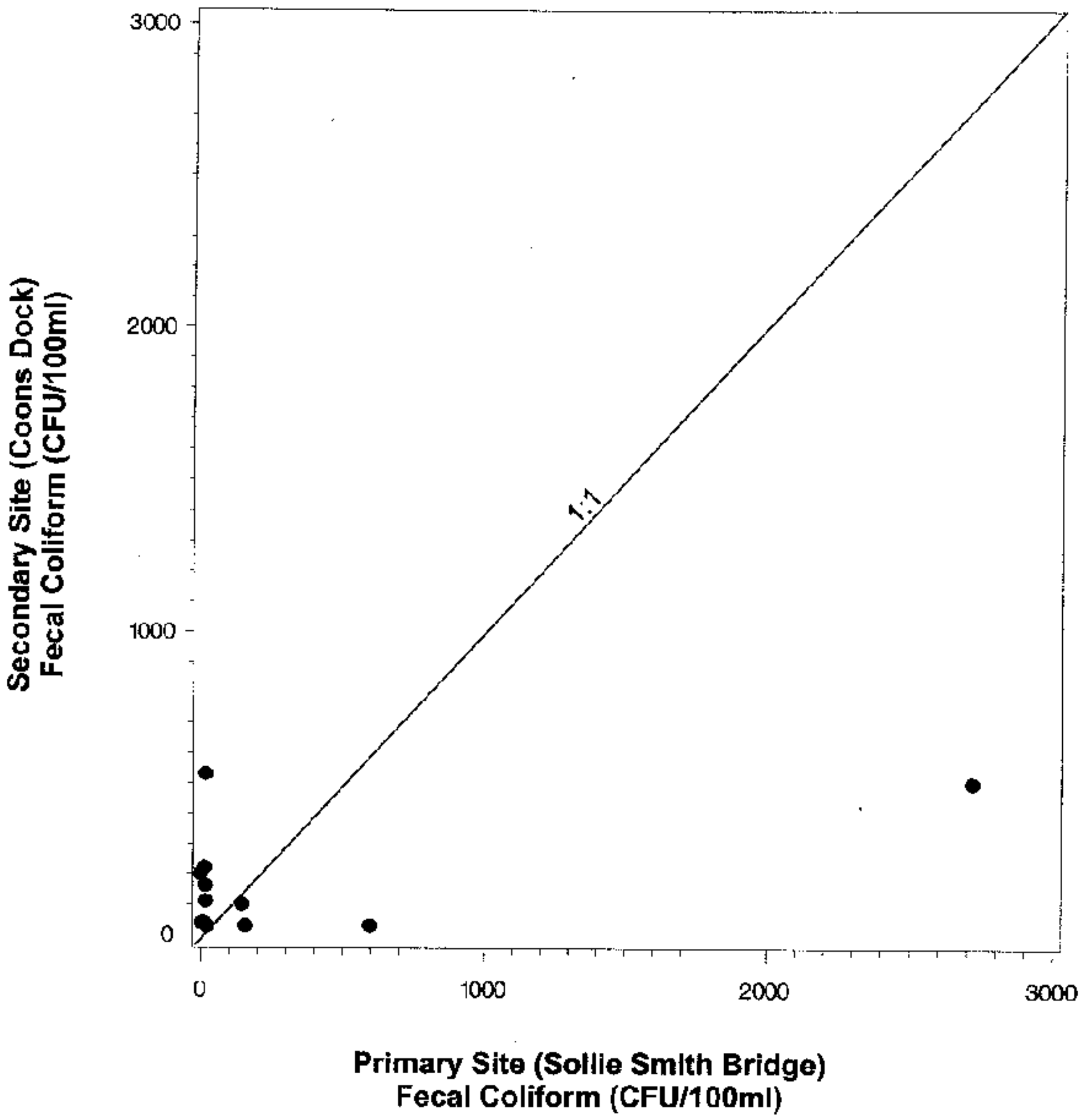


Figure 7. Results of paired sample analyses for fecal coliform bacteria at the primary site on the Wilson River and at a location further down river (Coons dock). A 1:1 line is provided for reference.

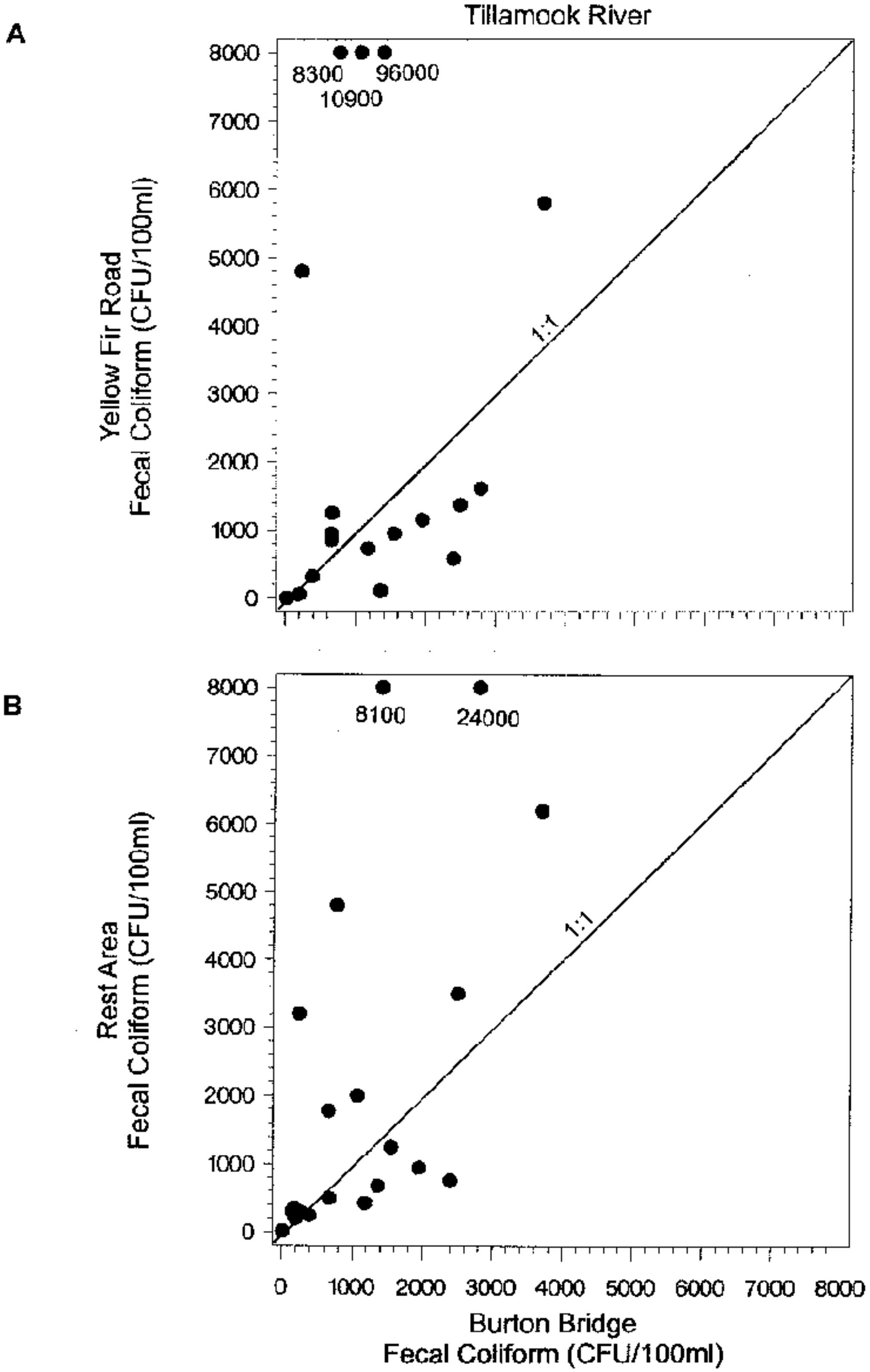


Figure 8. Results of paired sample analyses for fecal coliform bacteria at the primary site on the Tillamook River and at two up-river locations: Yellow Fir Road Crossing (A) and Rest Area (B). A 1:1 line is provided for reference.

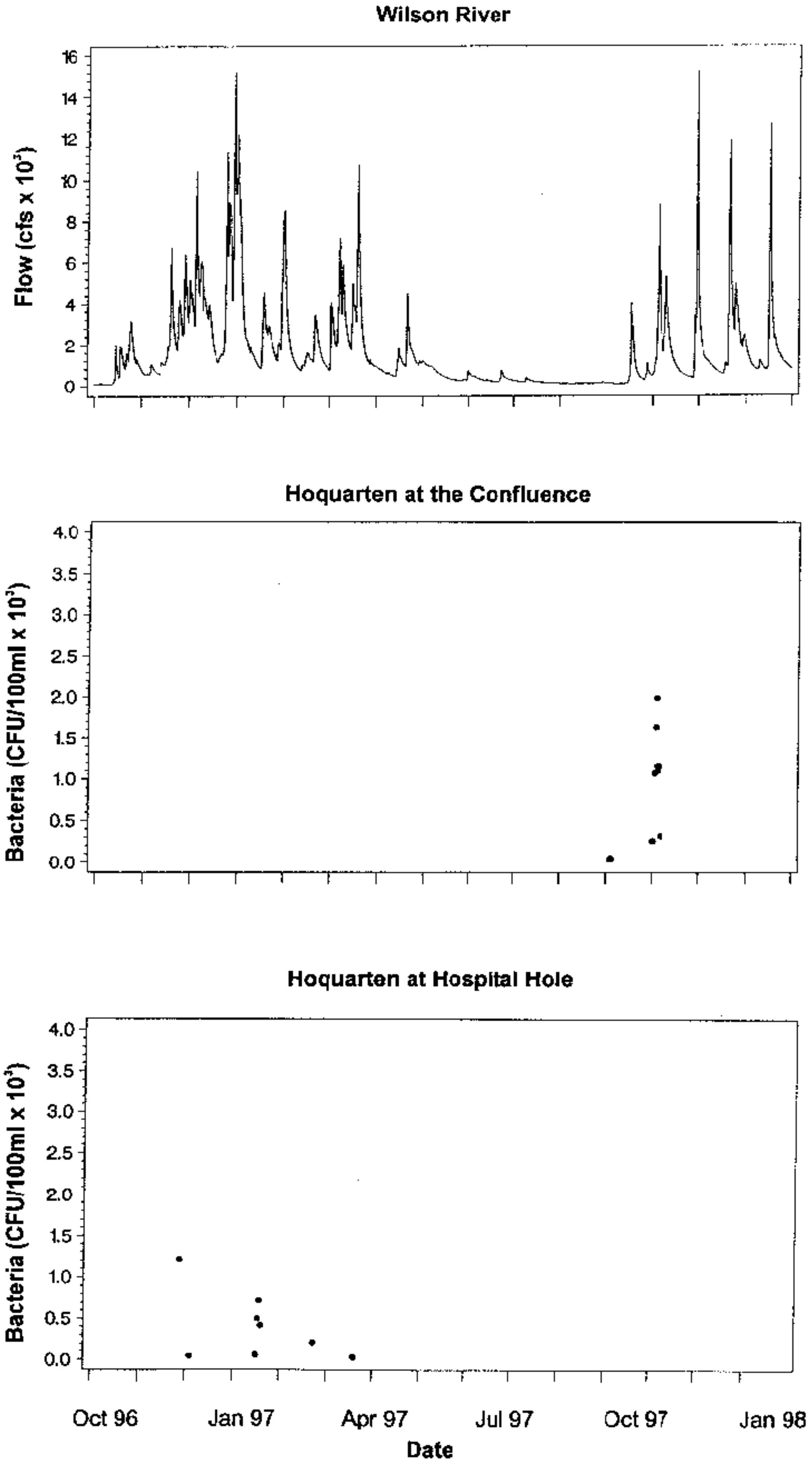


Figure 9. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3) at two sites in the Hoquarten Slough (Hospital Hole and the Trask River Confluence). Also shown are the Wilson River flows to use as a reference for hydrologic conditions at the time of sampling.

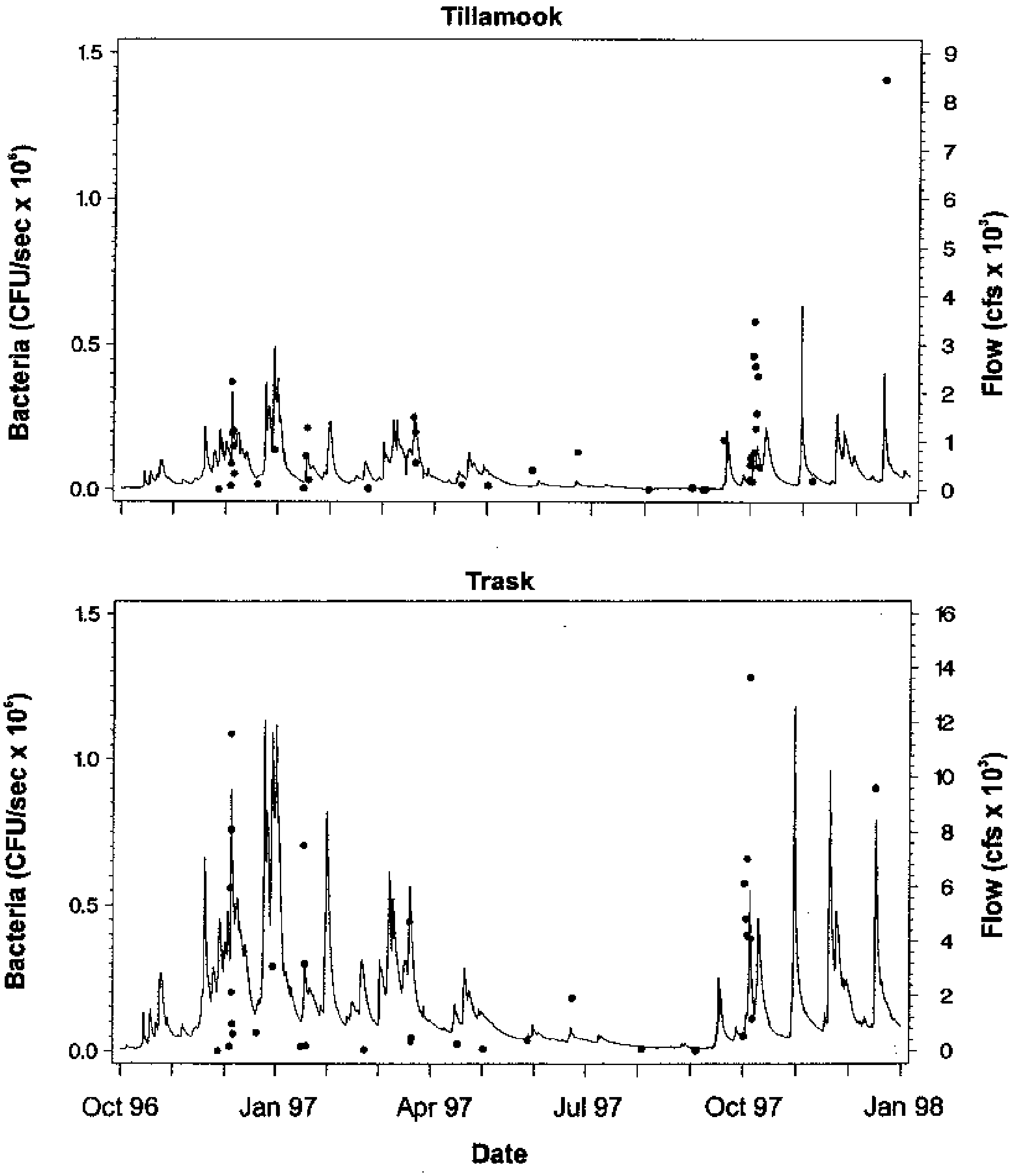
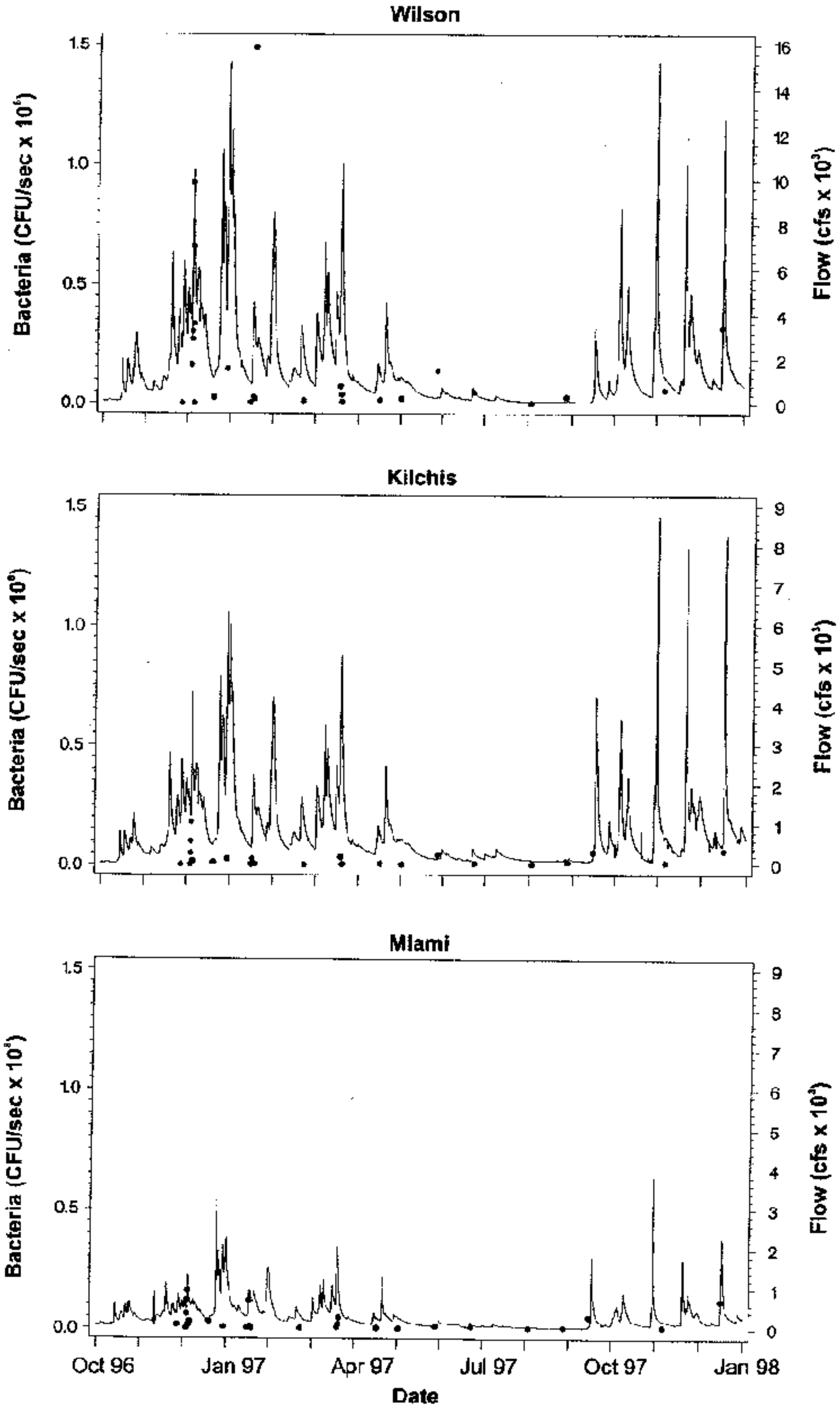


Figure 10. Load of fecal coliform bacteria (cfu/sec x 10^6) and river flow (cfs x 10^3) at the primary monitoring site on each river.



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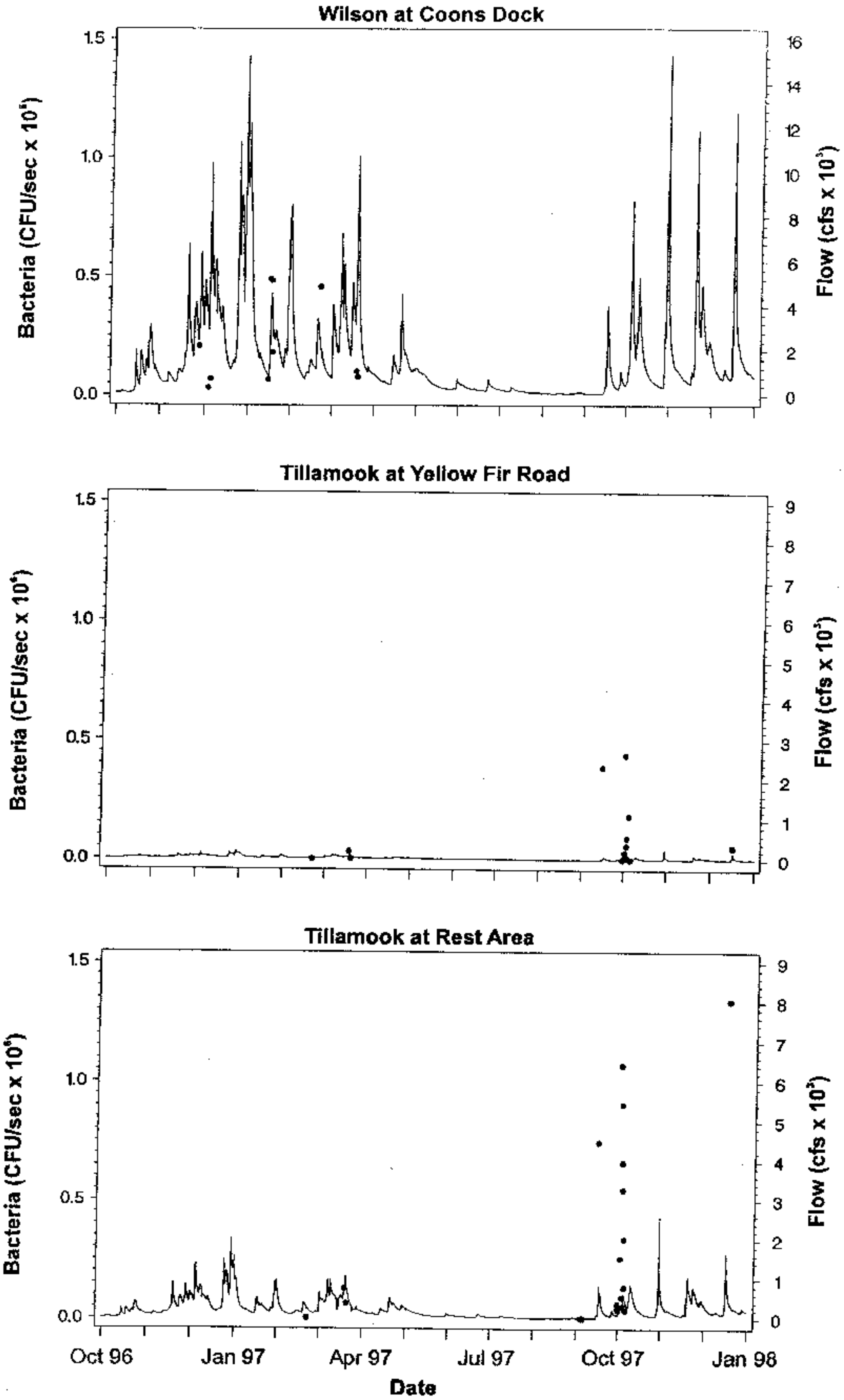


Figure 11. Load of fecal coliform bacteria (cfu/sec x 10^6) and river flow (cfs x 10^3) at the secondary monitoring sites located at Coons dock on the lower Wilson River, and at Yellow Fir Rd and the Rest Area on the upper Tillamook River.

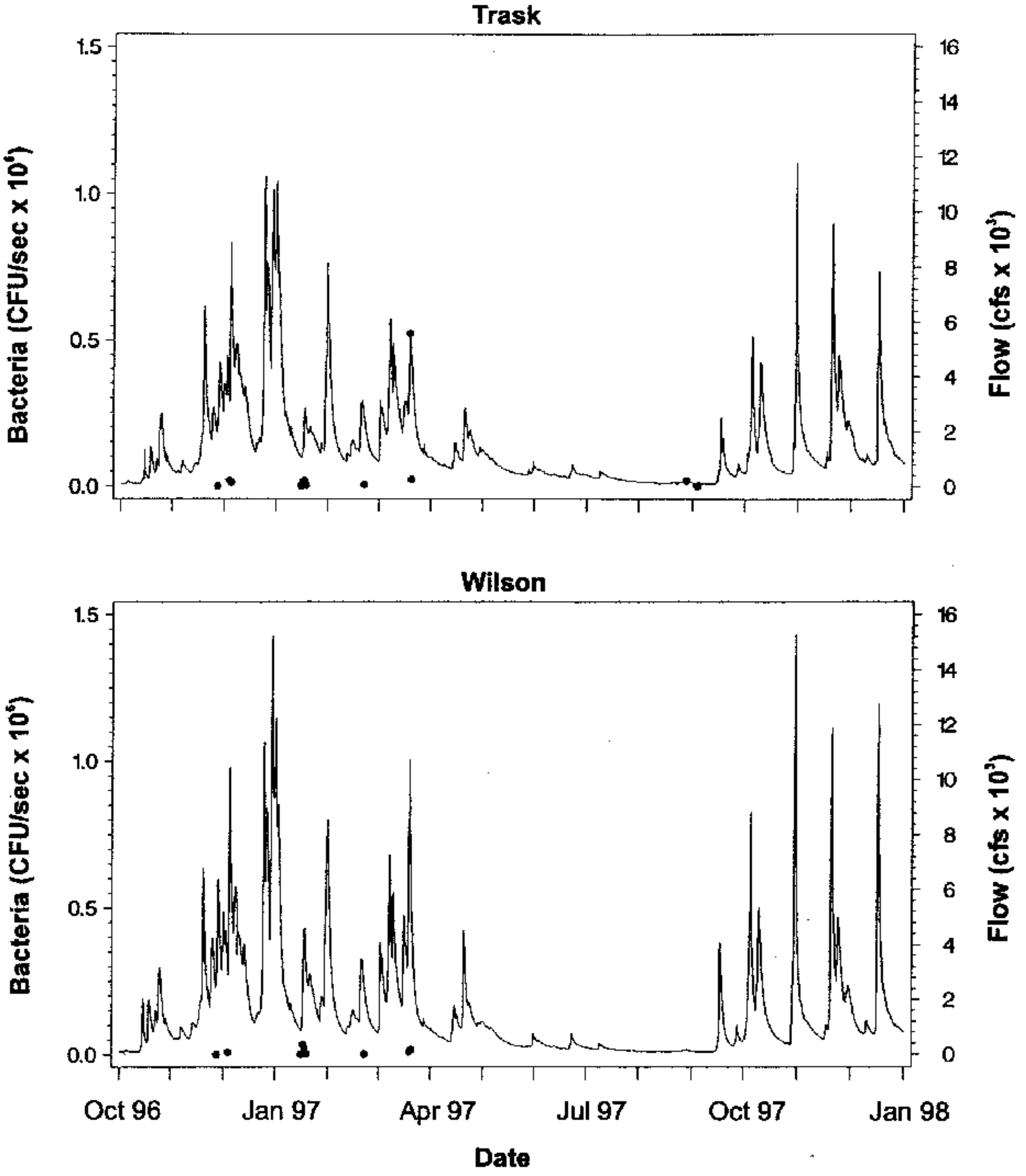


Figure 12. Load of fecal coliform bacteria (cfu/sec x 10^6) and river flow (cfs x 10^3) at the secondary monitoring sites located approximately at the forest/agriculture interface on the Trask, Wilson, Kilchis, and Miami Rivers.

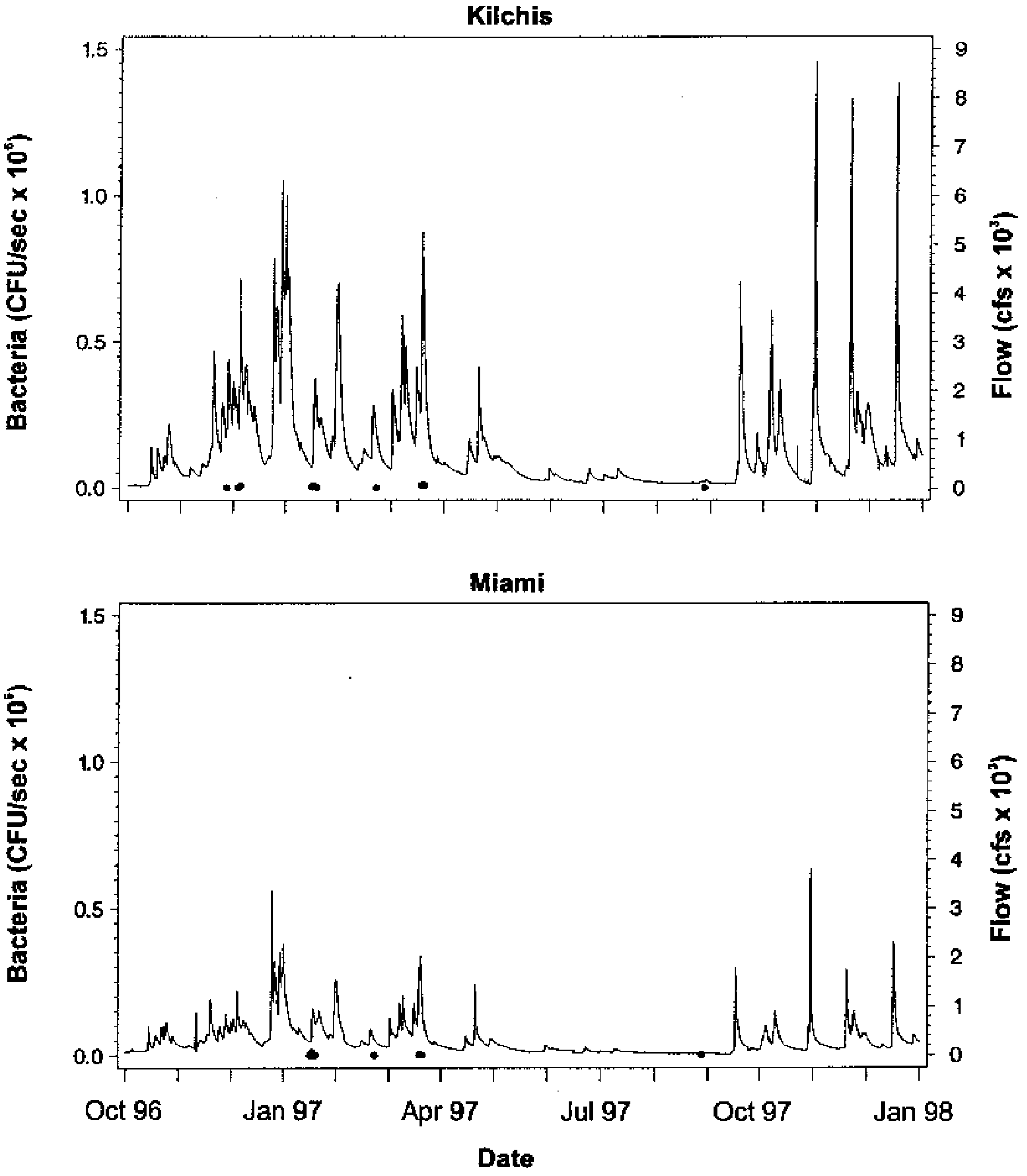


Figure 12. Continued.

conditions. However, loads did increase with relatively small increases in summer flows, whereas increases in loads were variable winter loads were associated with much greater changes in flow. Fall and winter FCB at all of the primary sites. The Trask and Wilson Rivers had the most pronounced changes as a result of the larger drainage basins and consequent higher flows.

Water Temperature

Water temperatures of grab samples (~0.5 m depth) at the time of sample collection generally ranged between about 8EC and about 18°C to 20EC at the primary site on each of the rivers (Figure 13). Peak temperatures were observed in August in all of the rivers, and reached fairly high values in the Tillamook, Trask and Wilson Rivers. Measured August temperature in each was near 20EC, ranging from 19.9EC in the Trask River to 20.4EC in the Wilson River. These temperatures are considered to be in the range of stressful to lethal temperature conditions for salmonids. In contrast, maximum observed temperature in the Kilchis and Miami Rivers were slightly more acceptable (18E and 18.2EC, respectively), but still above the ODEQ reference temperature for its temperature standard. ODEQ specifies that the seven-day running average maximum temperature shall be below 17.8°C. More data would be useful during July, August and September from the Tillamook, Trask and Wilson Rivers to document the duration of high temperature that occurs in these rivers. The peak temperatures measured in our study typically occurred in August, corresponding to increased summer temperatures combined with low flow conditions. The temperature followed an increasing pattern as the summer progressed, and then decreased about the time of the first autumn storm. Greater sampling frequency would be needed to document the peak values attained and the duration of high temperature conditions in each of these rivers. Also of interest, but not examined in this study, is the spatial variability of the high temperature values in each of the rivers.

Total Suspended Solids

Total suspended solids (TSS) concentrations were typically in the range of about 5 to 100 mg/L in all of the rivers except the Wilson, which had consistently higher TSS concentrations (5 to 425 mg/L; Figures 14-16). Substantially higher TSS concentrations were observed during storm events.

There was a general relationship between TSS concentrations and flow in each of the rivers, with greater flows resulting in increased TSS concentrations (Figure 17). This response was seen in all of the rivers. The rivers with the greatest flows and the largest watershed areas had the highest TSS concentrations (Trask and Wilson) and the river with the smallest watershed area (Tillamook) had the lowest TSS concentrations. However, at a given flow rate, TSS was actually often higher in the Miami and Kilchis Rivers than in the Trask and Wilson Rivers (Figure 17). TSS concentrations were consistently higher at the primary site as compared with the forest/agriculture interface site as shown by paired sample analysis (Figure 18), suggesting that the agricultural and residential portions of the watersheds do contribute sediment loads to the rivers. However, the difference in

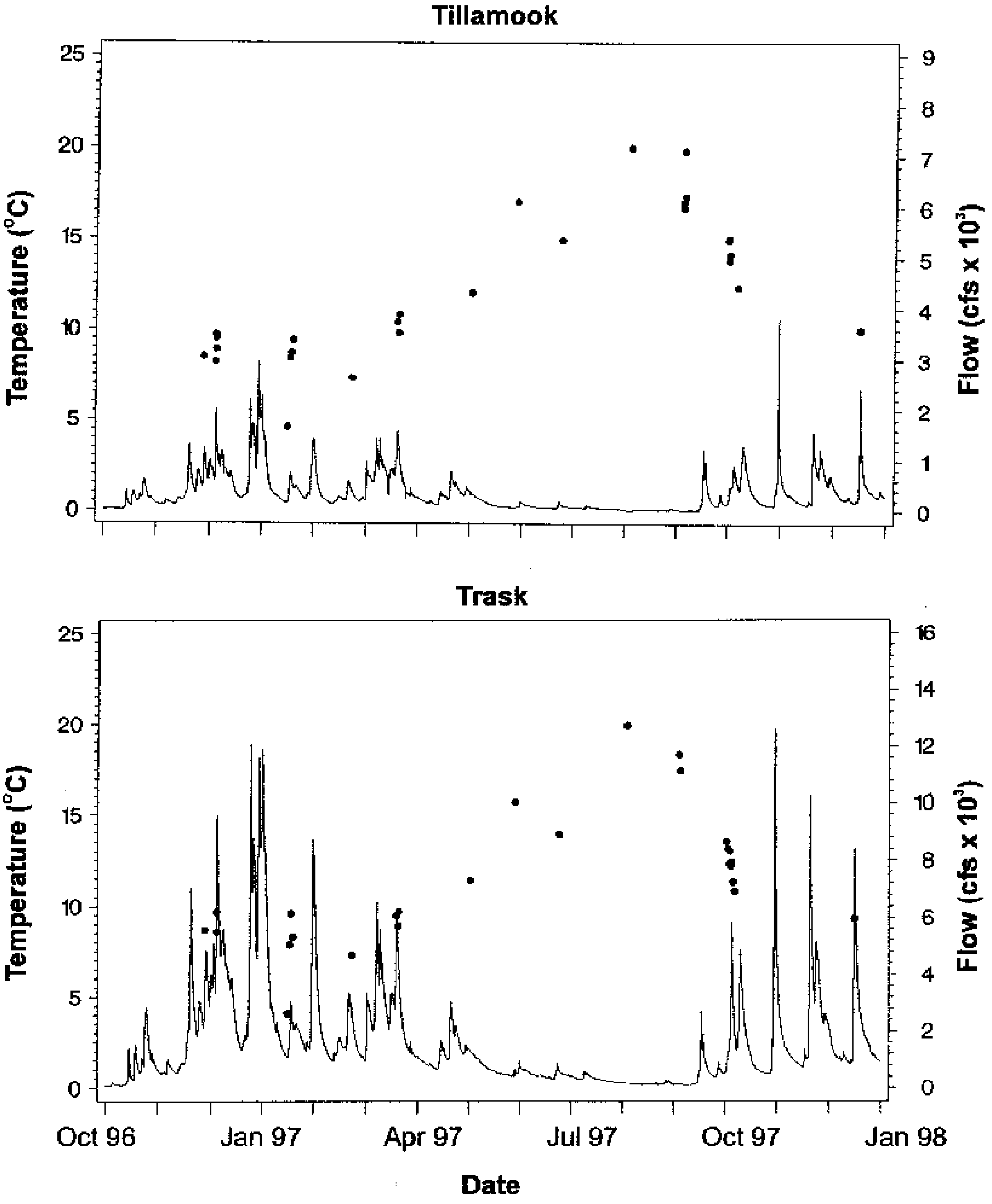


Figure 13. Water temperature (°C) and river flow (cfs x 10^3) at the primary monitoring site on each river.

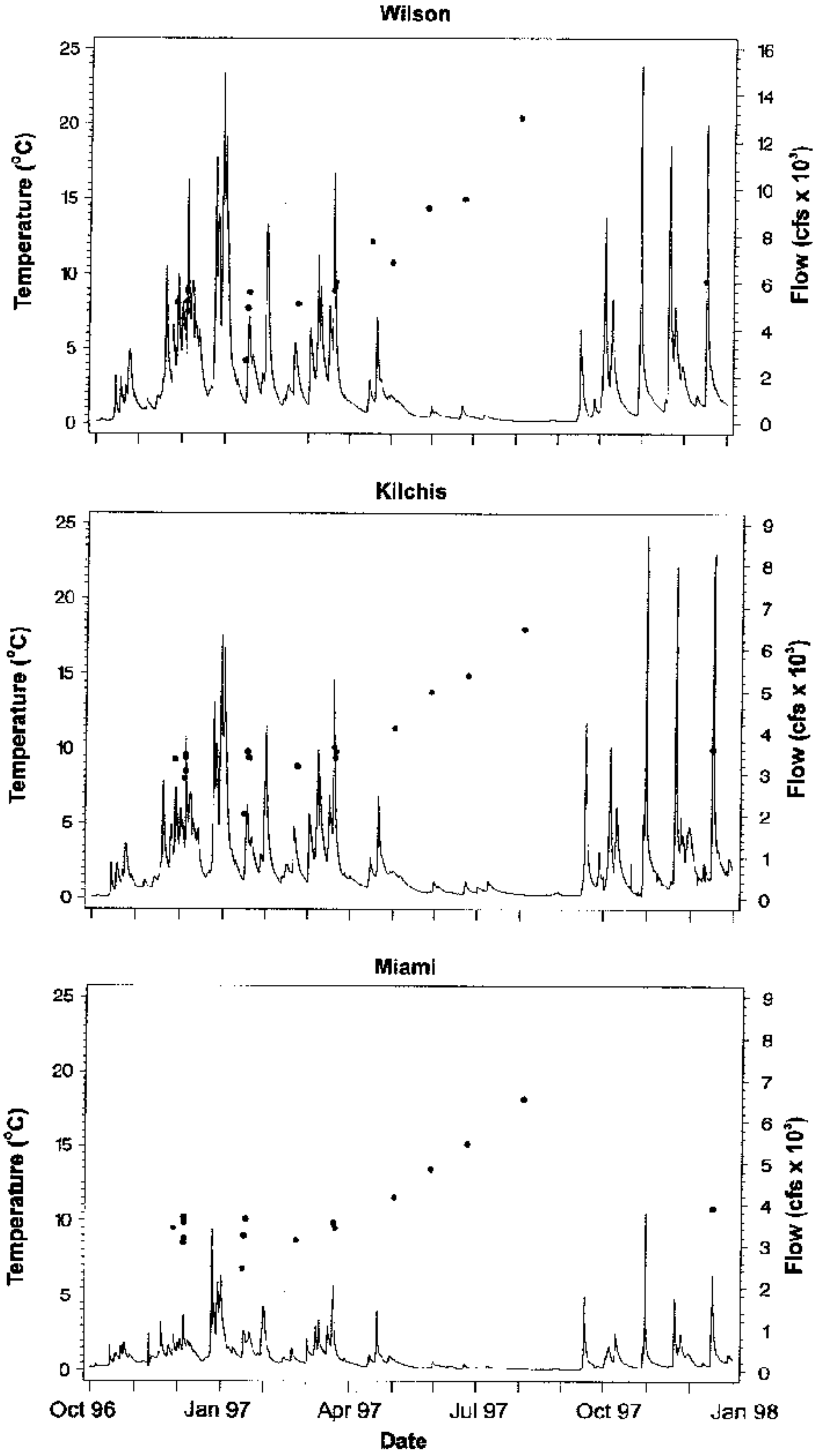


Figure 13. Continued.

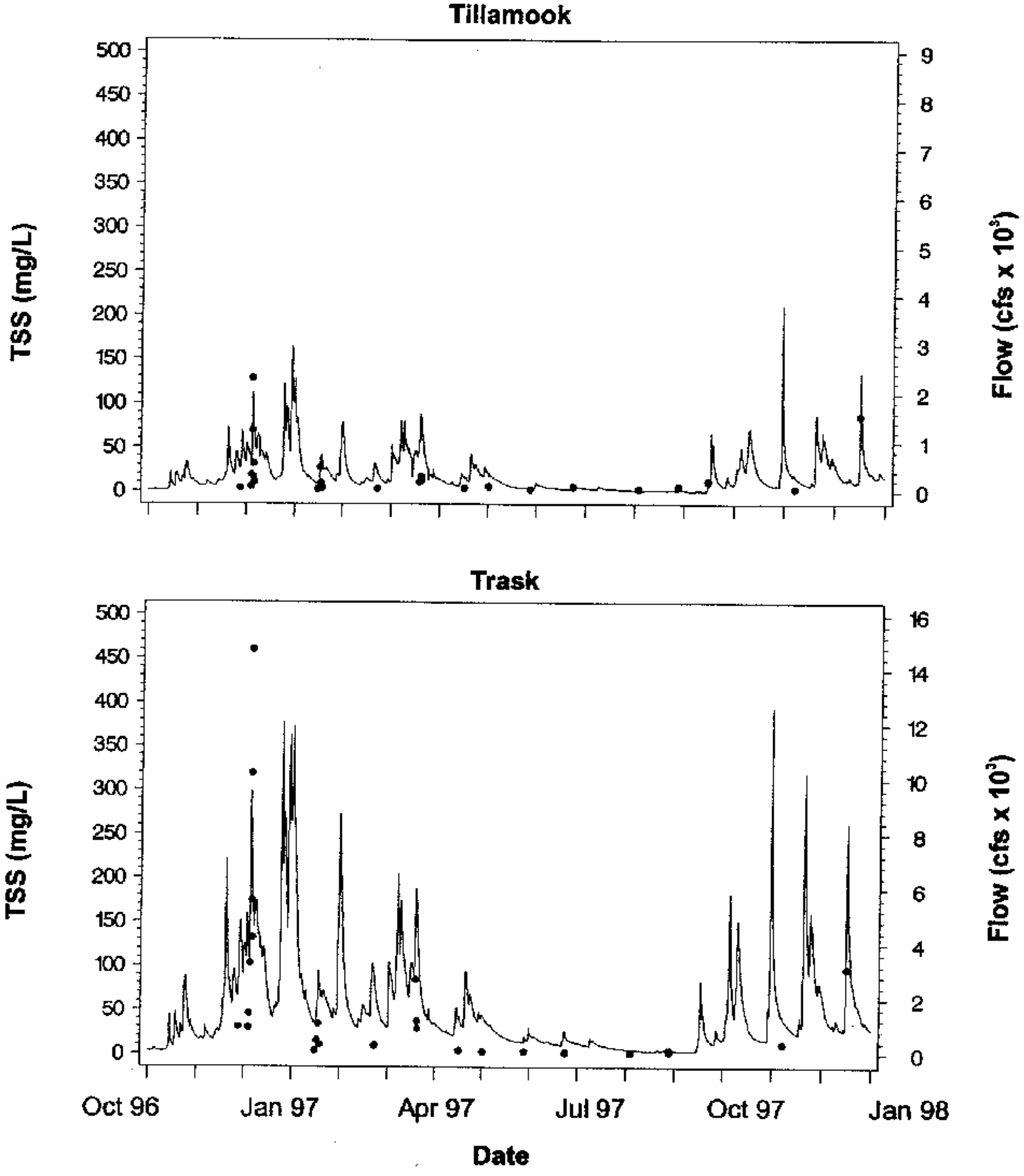
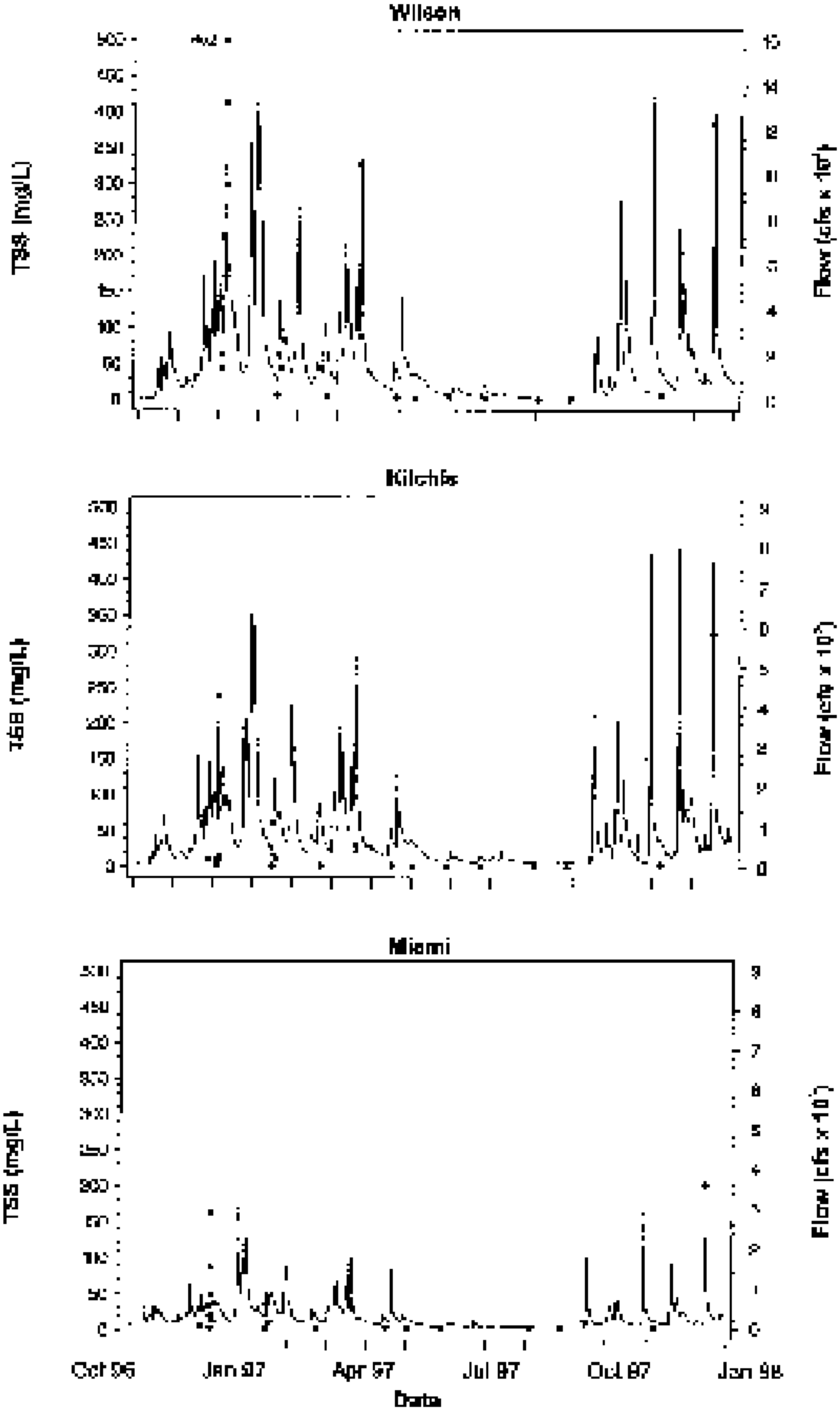


Figure 14. Concentration of total suspended solids (mg/L) and river flow (cfs x 10^3) at the primary monitoring site on each river.



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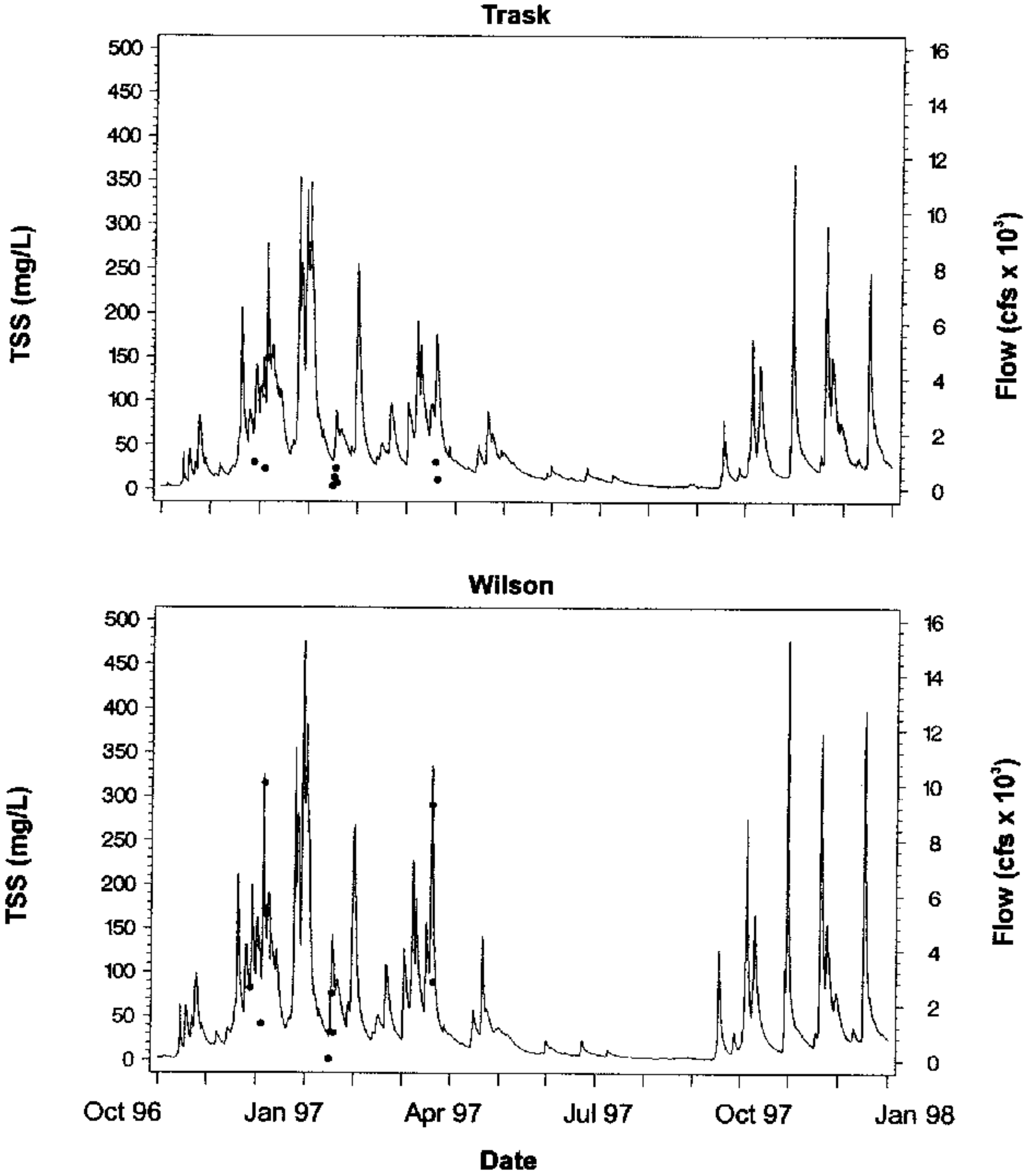
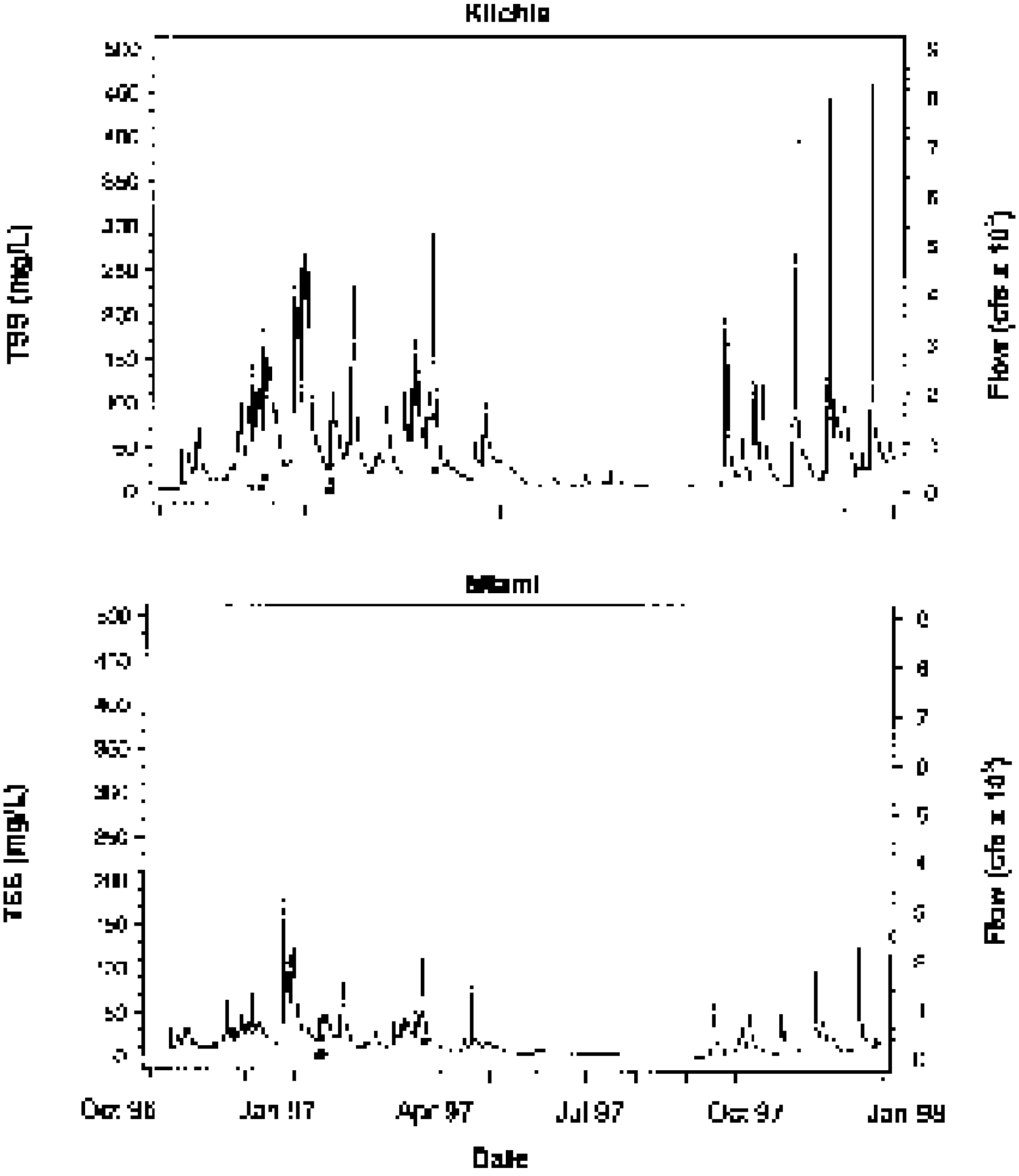


Figure 15. Concentration of total suspended solids (mg/L) and river flow (cfs x 10^3) at the secondary monitoring sites located approximately at the forest/agriculture interface on the Trask, Wilson, Kilchis, and Miami Rivers.



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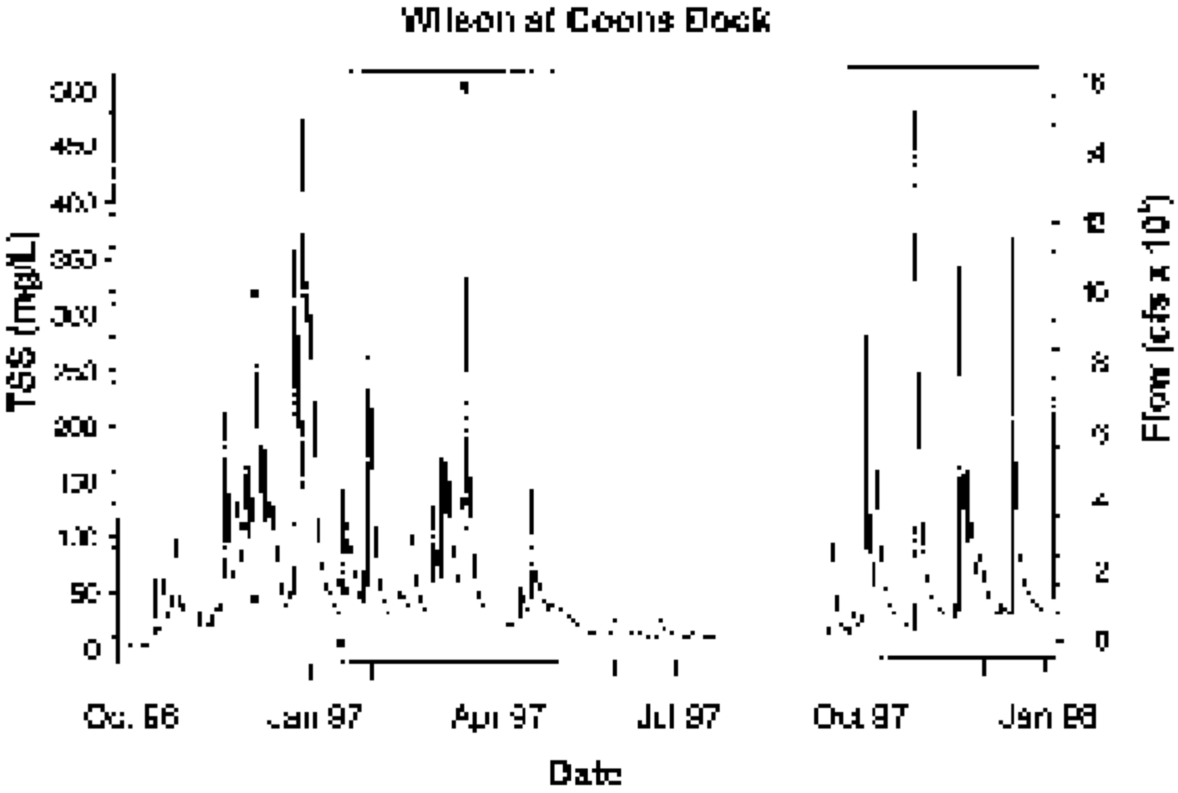


Figure 16. Concentration of total suspended solids (mg/L) and river flow (cfs x 10^3) at the secondary monitoring site located at Coons dock on the lower Wilson River.

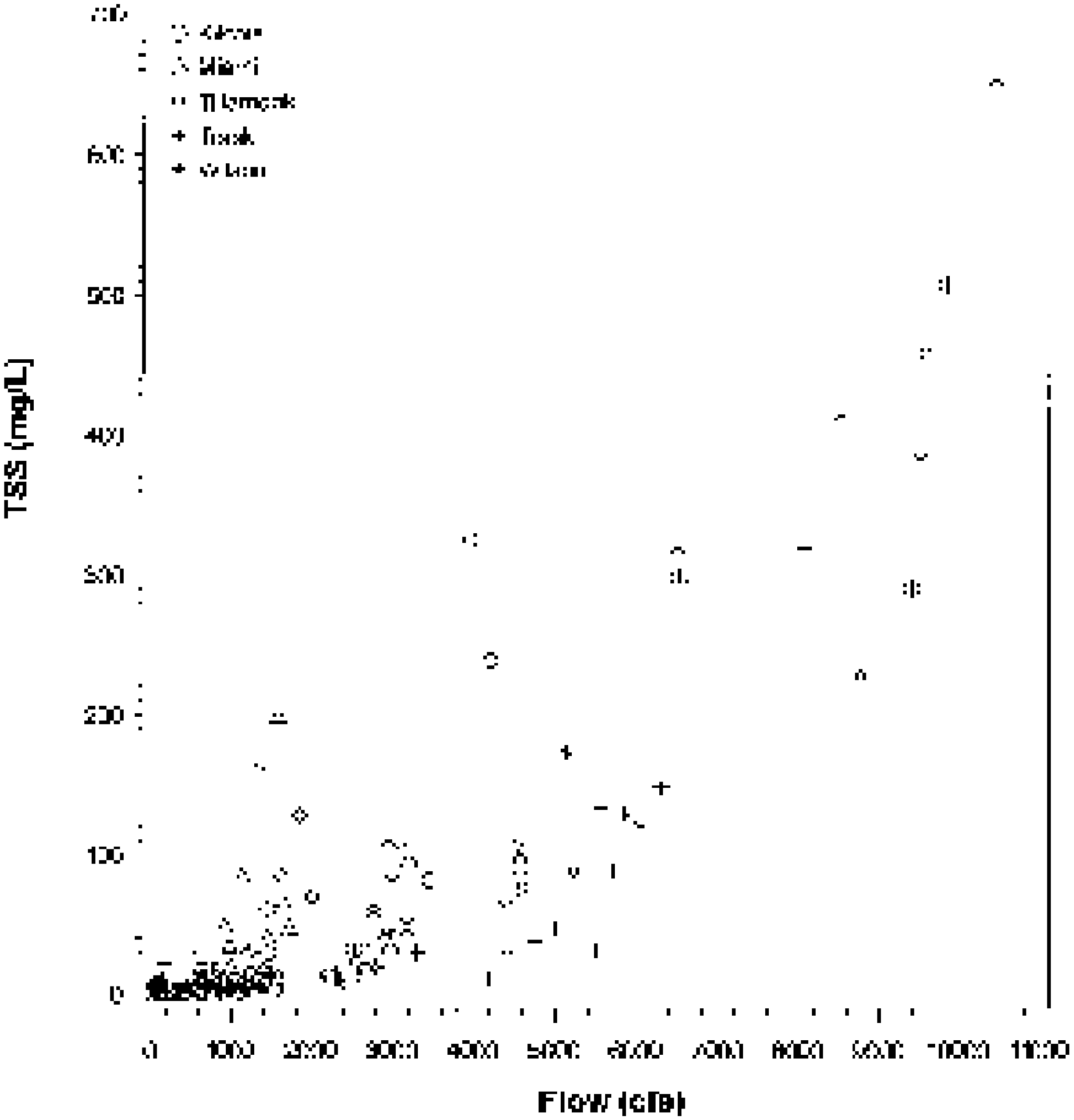


Figure 17. Relationship between TSS (mg/L) and flow (cfs) for all sites on all rivers. Different symbols represent each of the five rivers.

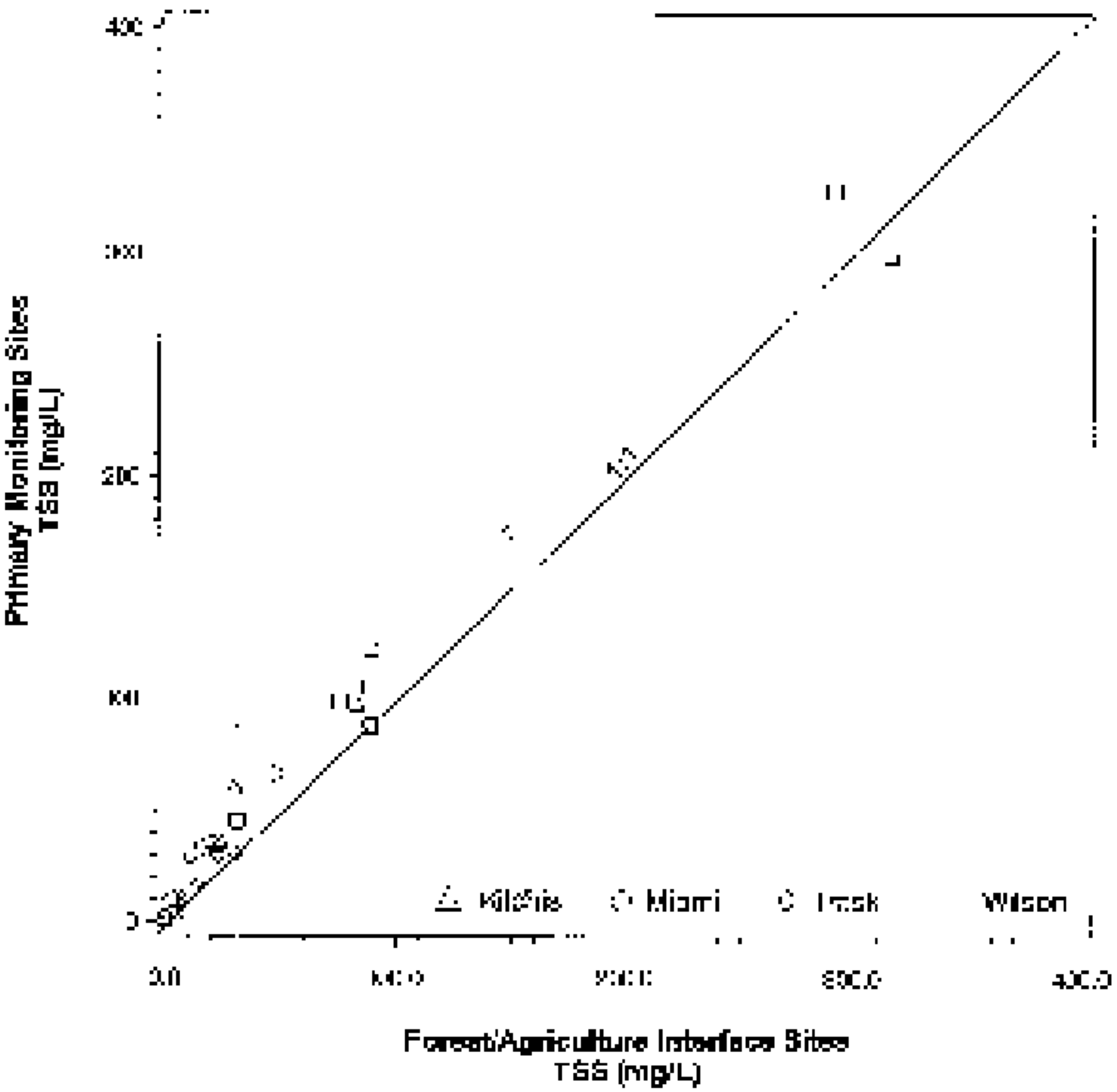


Figure 18. Results of paired sample analyses for total suspended solids (mg/L) at the primary site and its respective forest/agriculture interface site for the four rivers in which both types of samples were collected. A 1:1 line is provided for reference.

measured TSS values at the paired sites was generally small, less than about 30 mg/L, even at relatively high TSS values (> 50 mg/L). This suggests that most of the TSS is derived from the forested uplands, but that some TSS is also derived from the agricultural lowlands. A more precise quantification of the relative contribution of sediment loads associated with different land uses would require calculation of storm loads at each location during several different storm events. This has been done for the primary sites (Sullivan et al. 1998), but not for the forest/agriculture interface on each of the rivers.

The greatest loads of TSS were found in the Wilson and Trask Rivers, although some winter storm events also produced high loads in the Kilchis and Miami Rivers (Figure 19). TSS loads were high at all of the Wilson River sites (Figures 19-21). The Tillamook River had the lowest TSS loads of all rivers, due to having both the lowest TSS concentrations and the lowest flows of any of the rivers. However, a TSS storm response was also observed in the Tillamook River during the winter storms. Summer TSS concentrations were low (<25 mg/L) in all five of the rivers and exhibited little or no response to changes in summer flows. Consequently, summer TSS loads remained low (<150 mg/sec).

Inorganic Nitrogen

Total inorganic nitrogen concentrations (TIN; NO_3-N + NH_4-N) were generally near 1 mg/L (± 0.2 mg/L) in all rivers. TIN concentrations tended to be highest in the Miami River and lowest in the Wilson River (Figure 22). TIN was typically composed of >95% NO_3^-, with a very small NH_4^+ component. Limited data from the forest/agriculture interface sites showed similar patterns (Figure 23). Paired sample analyses (samples taken within a few hours of each other) between the primary and forest/agriculture interface sites showed their was little contribution of TIN to the rivers from the lower agricultural portions of the watershed (Figure 24). The Coon's Dock site followed the same pattern as the Wilson primary site (Figure 25).

Concentrations of TIN were reduced during the summer time, especially in the Miami and Trask Rivers, and were higher during the winter. This was likely due to greater biological demand for N in the aquatic and terrestrial systems during summer months. The greatest amount of seasonal variability in TIN loads occurred during the winter months, and may have been associated with the greater variability in winter flows. However, there was no clear relationship between TIN concentrations and flow (Figure 26).

Nitrogen loads were highest in the Wilson and Trask Rivers, corresponding to greater flows in those rivers (Figure 27). The forest/agriculture interface sites were similar in N loads to the primary monitoring sites, with the Trask and Wilson Rivers having the largest loads (Figure 28). The Coon's Dock site followed the same pattern as the primary site on the Wilson River (Figure 29). Summer TIN loads at all of the five primary sites were low, usually less than 20 mg/sec.

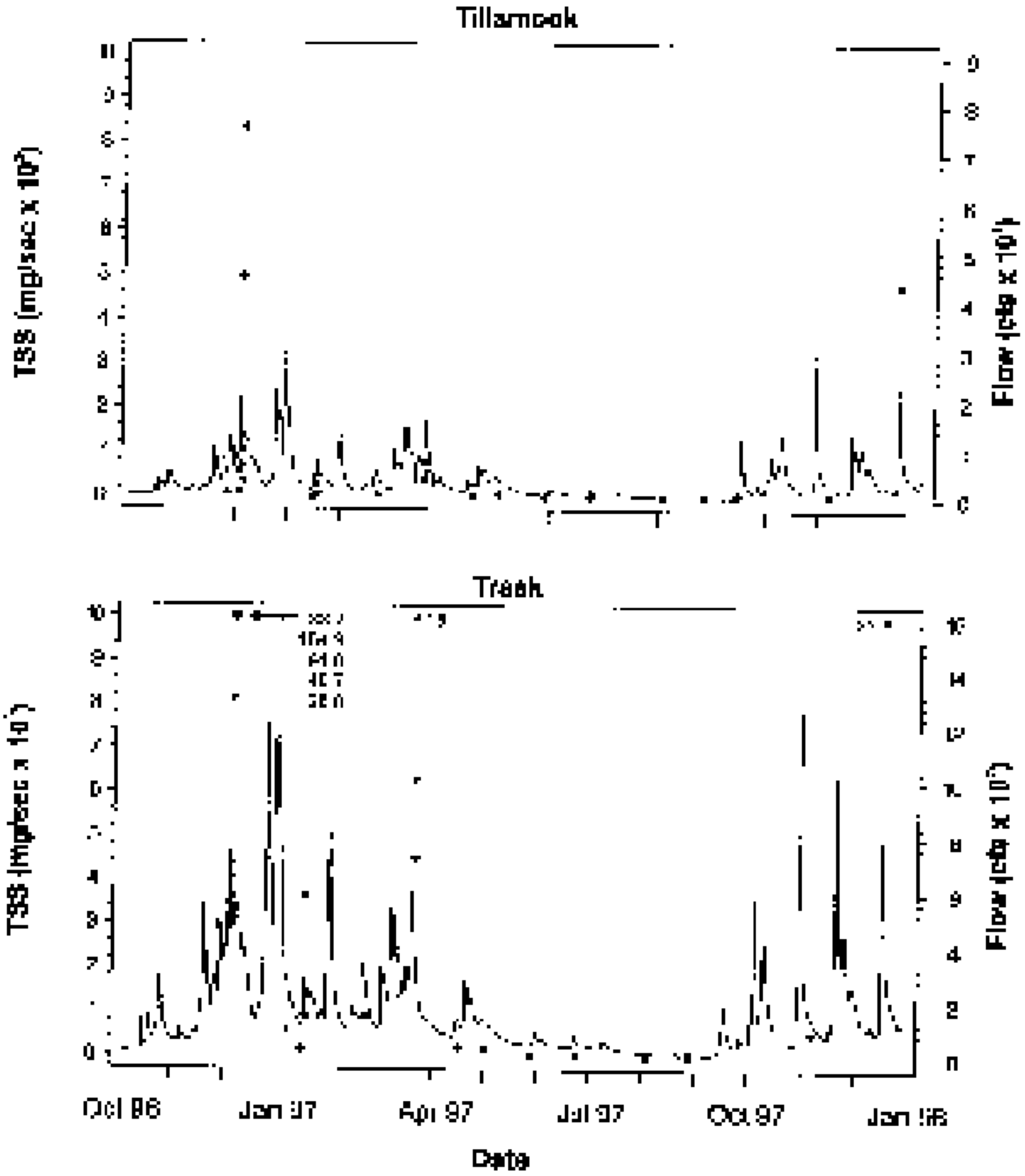
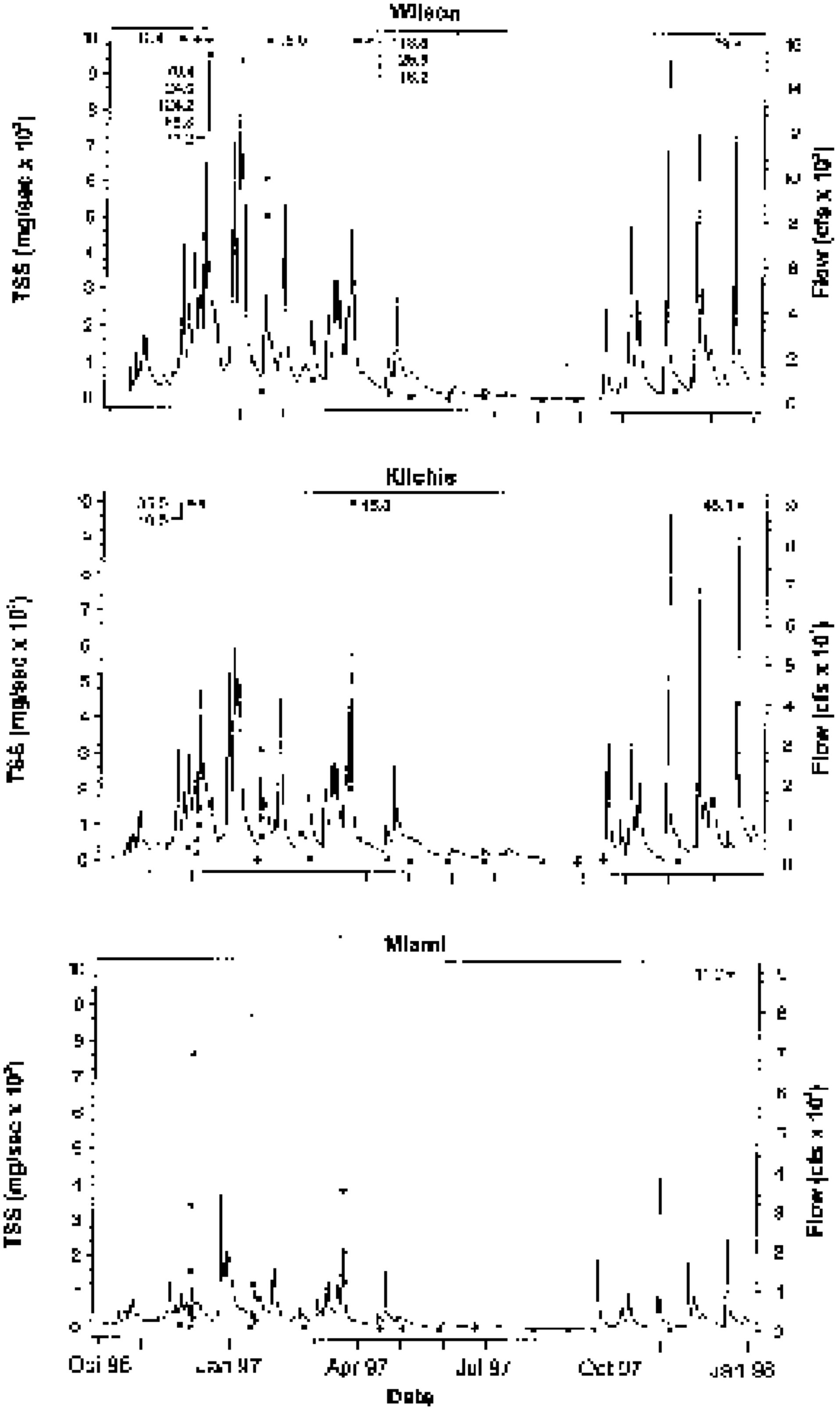


Figure 19. Load of total suspended solids (mg/sec) and river flow (cfs x 10^3) at the primary monitoring site on each river.



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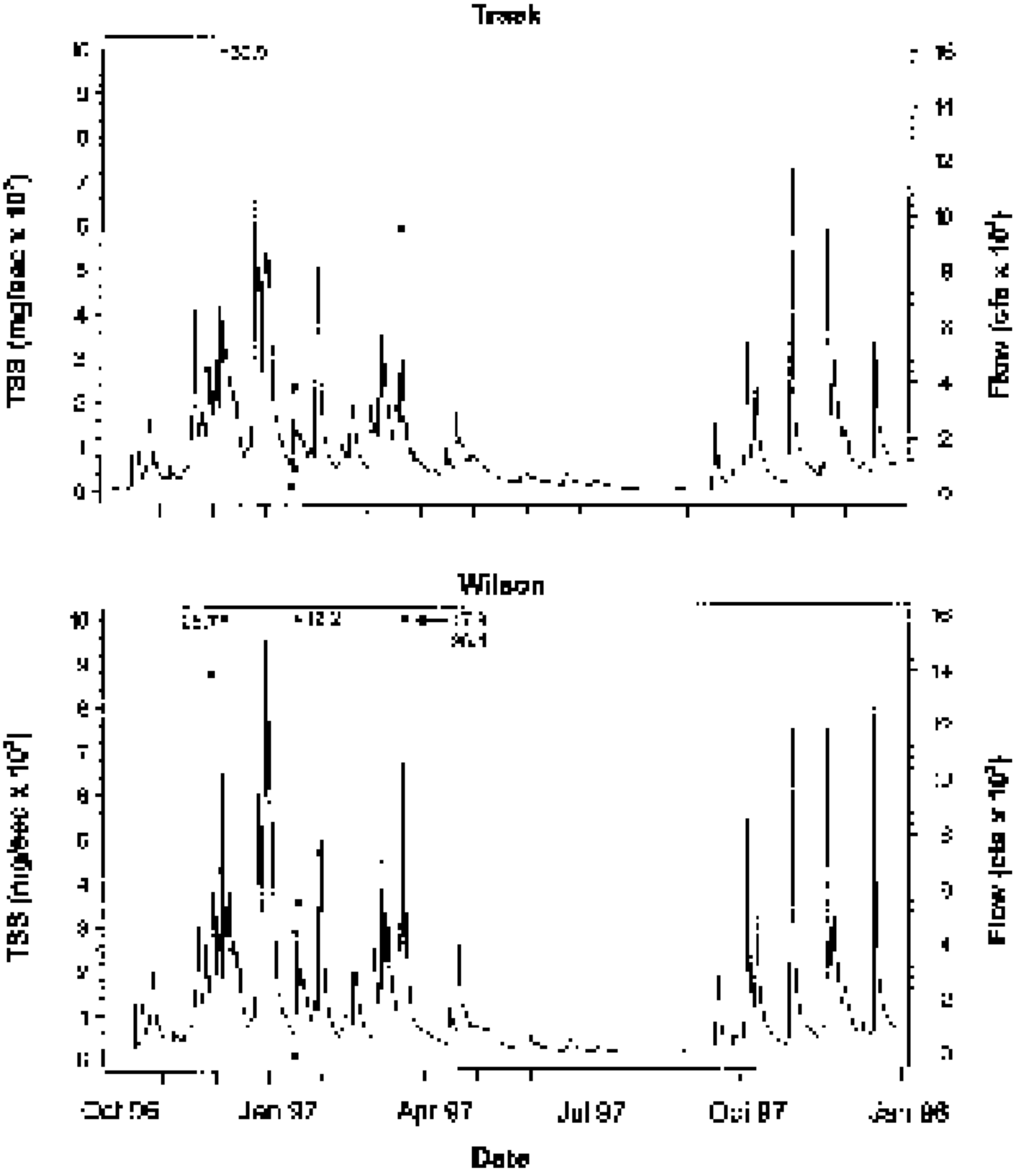
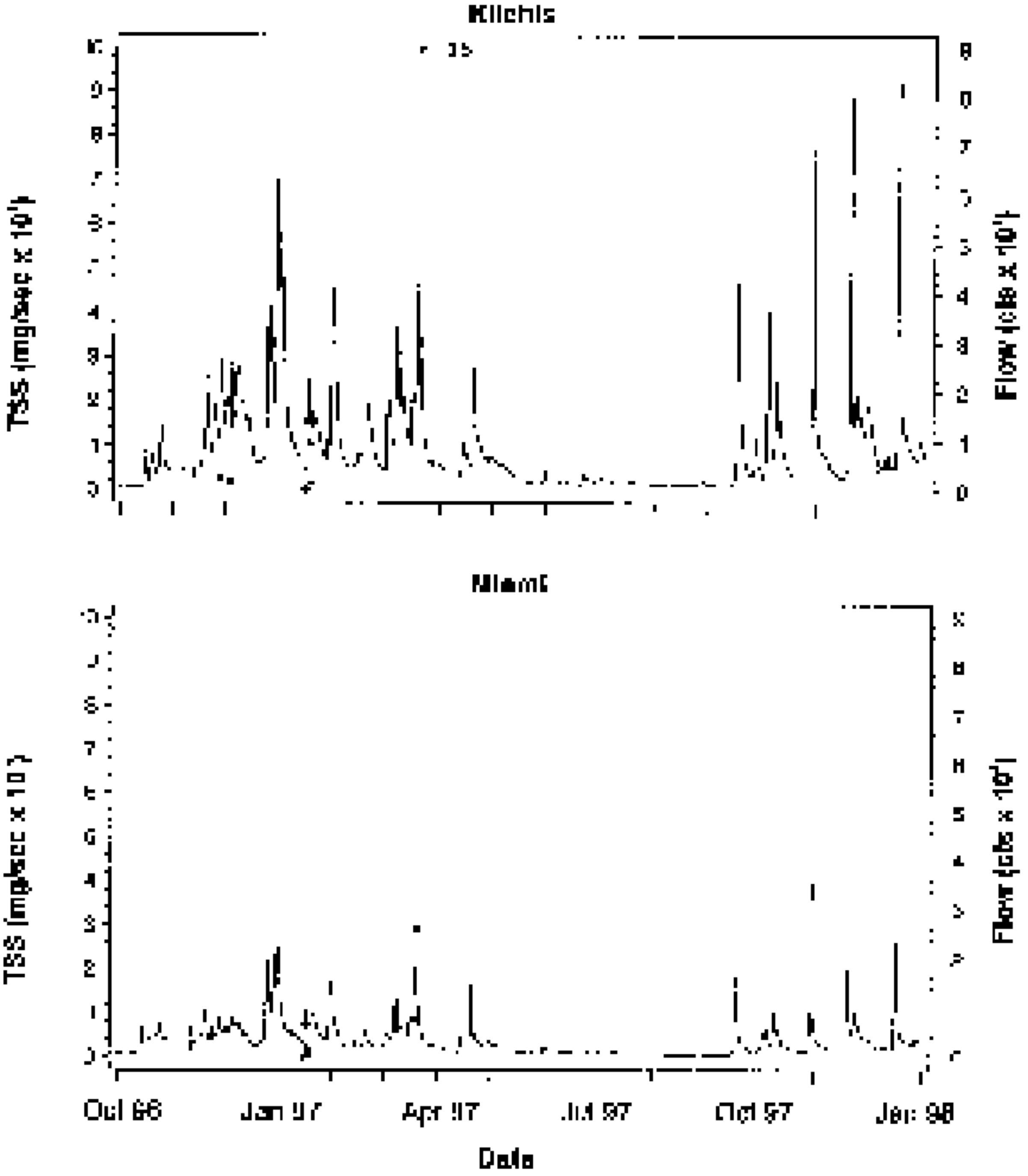


Figure 20. Load of total suspended solids (mg/sec) and river flow (cfs x 10^3) at the secondary monitoring sites located approximately at the forest/agriculture interface on the Trask, Wilson, Kilchis, and Miami Rivers.



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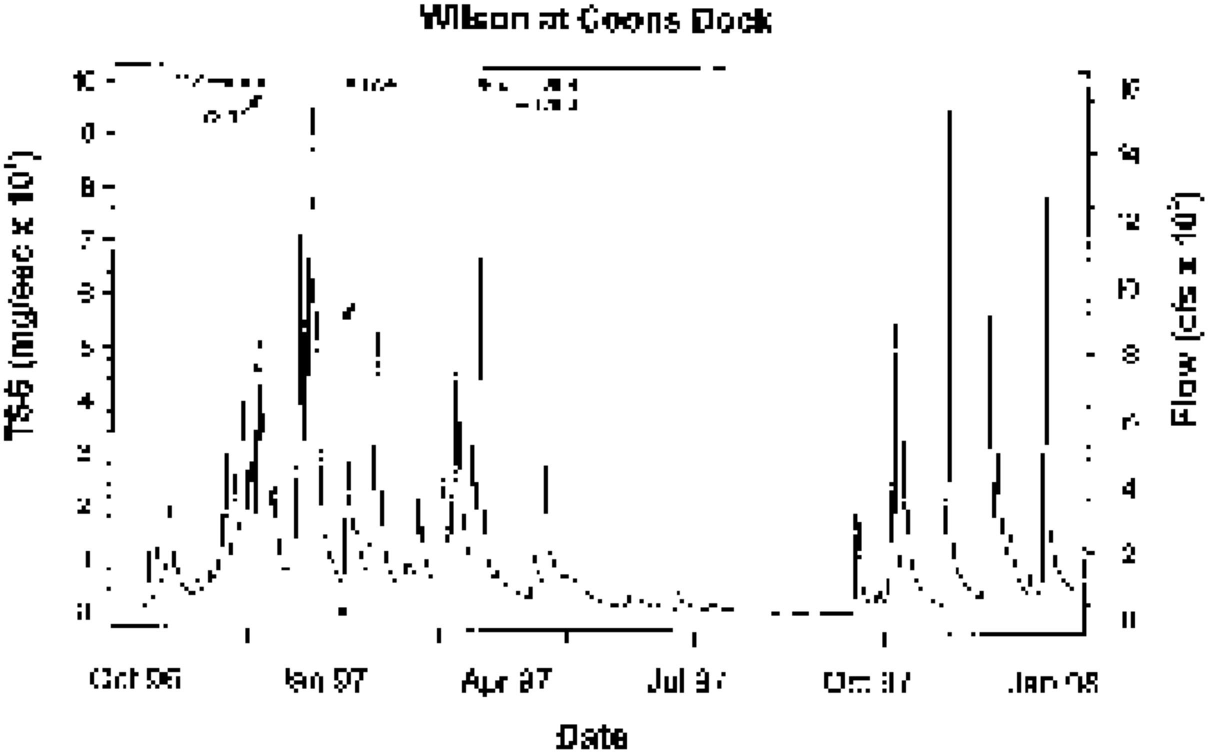

Figure 21. Load of total suspended solids (mg/sec) and river flow (cfs x 10^3) at the secondary monitoring site located at Coons dock on the lower Wilson River.

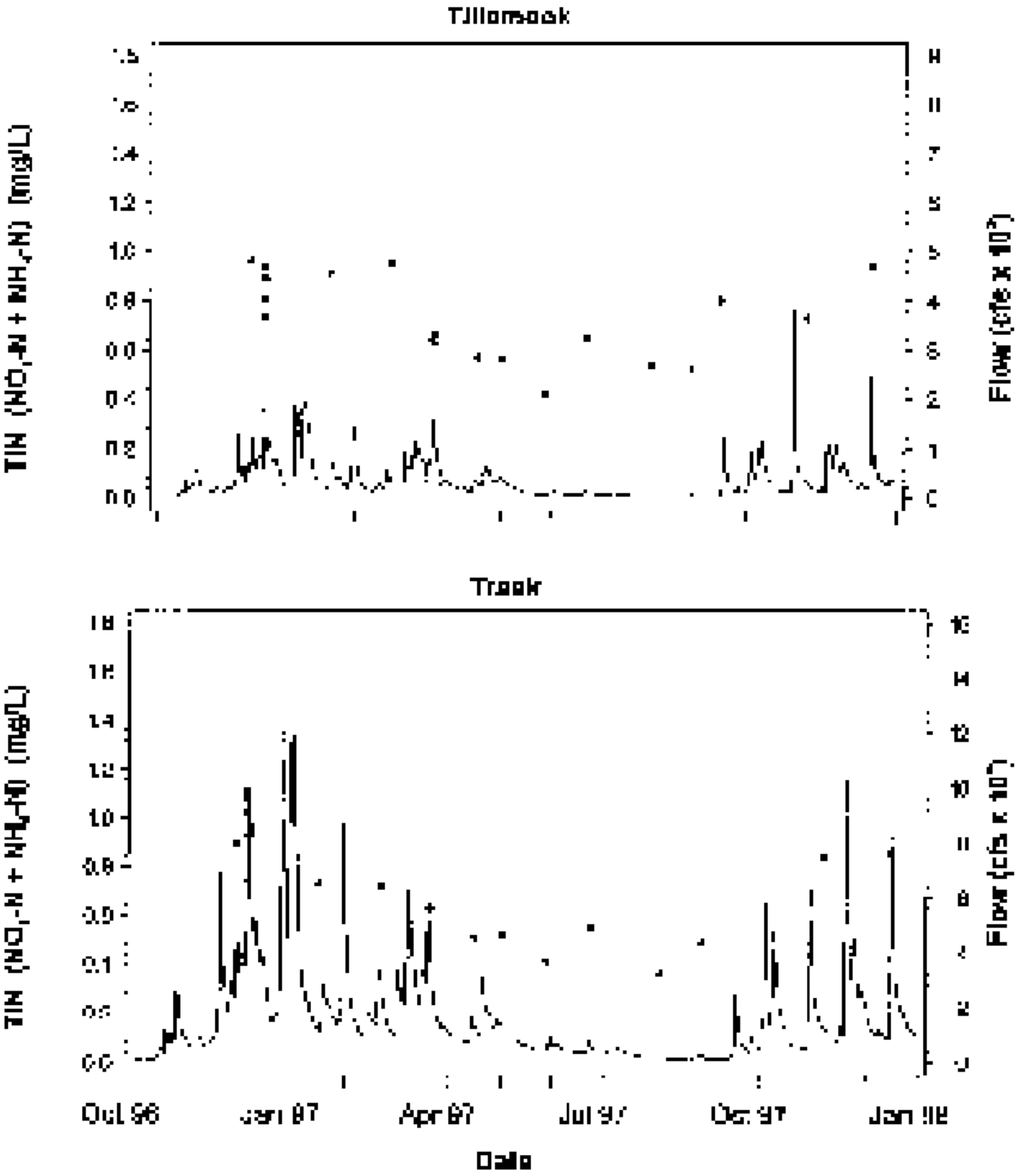

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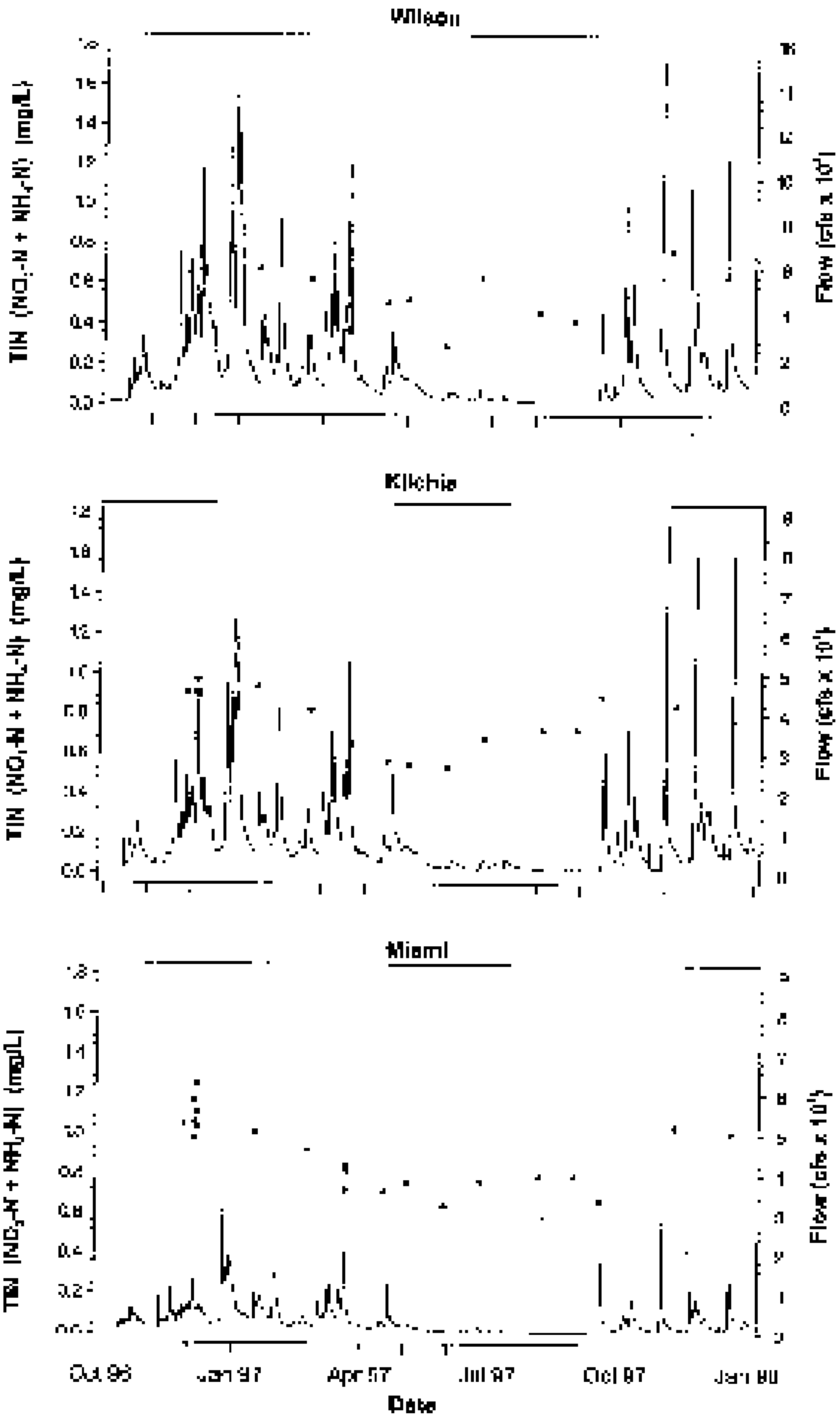
Figure 22. Concentration of inorganic N (mg/L) and river flow (cfs x 10^3) at the primary monitoring site on each river.



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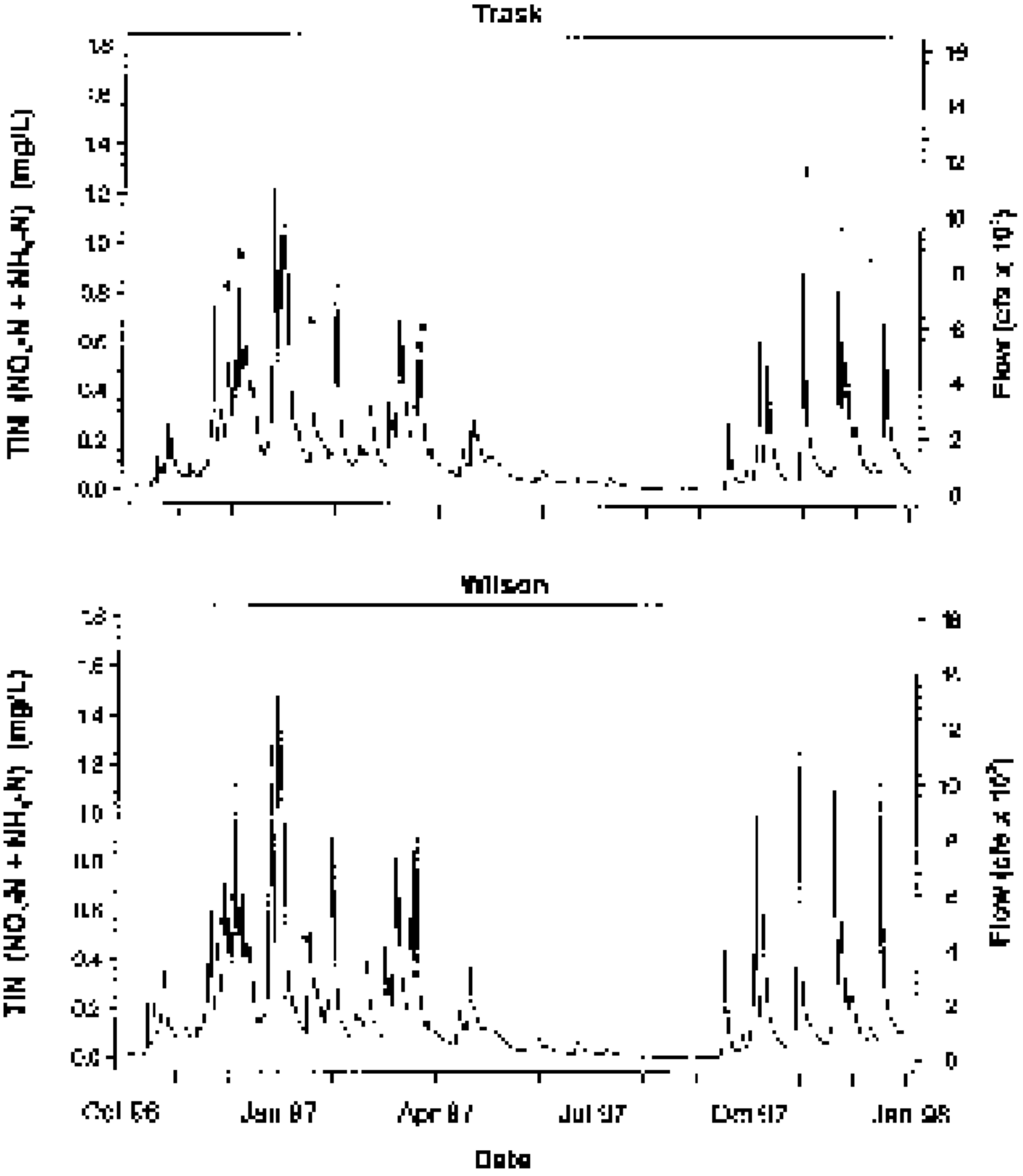
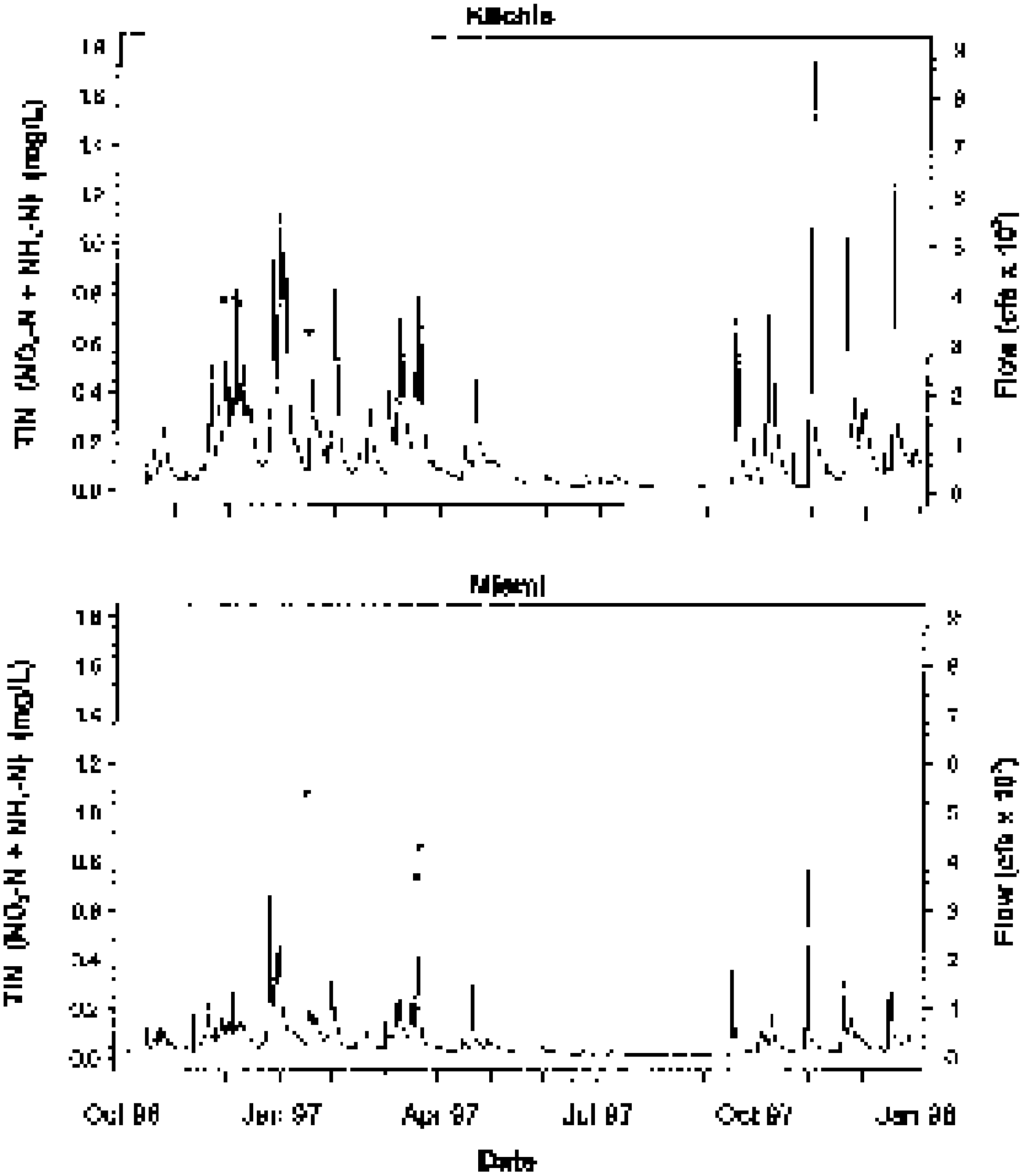


Figure 23. Concentration of inorganic N (mg/L) and river flow (cfs x 10^3) at the secondary monitoring sites located approximately at the forest/agriculture interface on the Trask, Wilson, Kilchis, and Miami Rivers.



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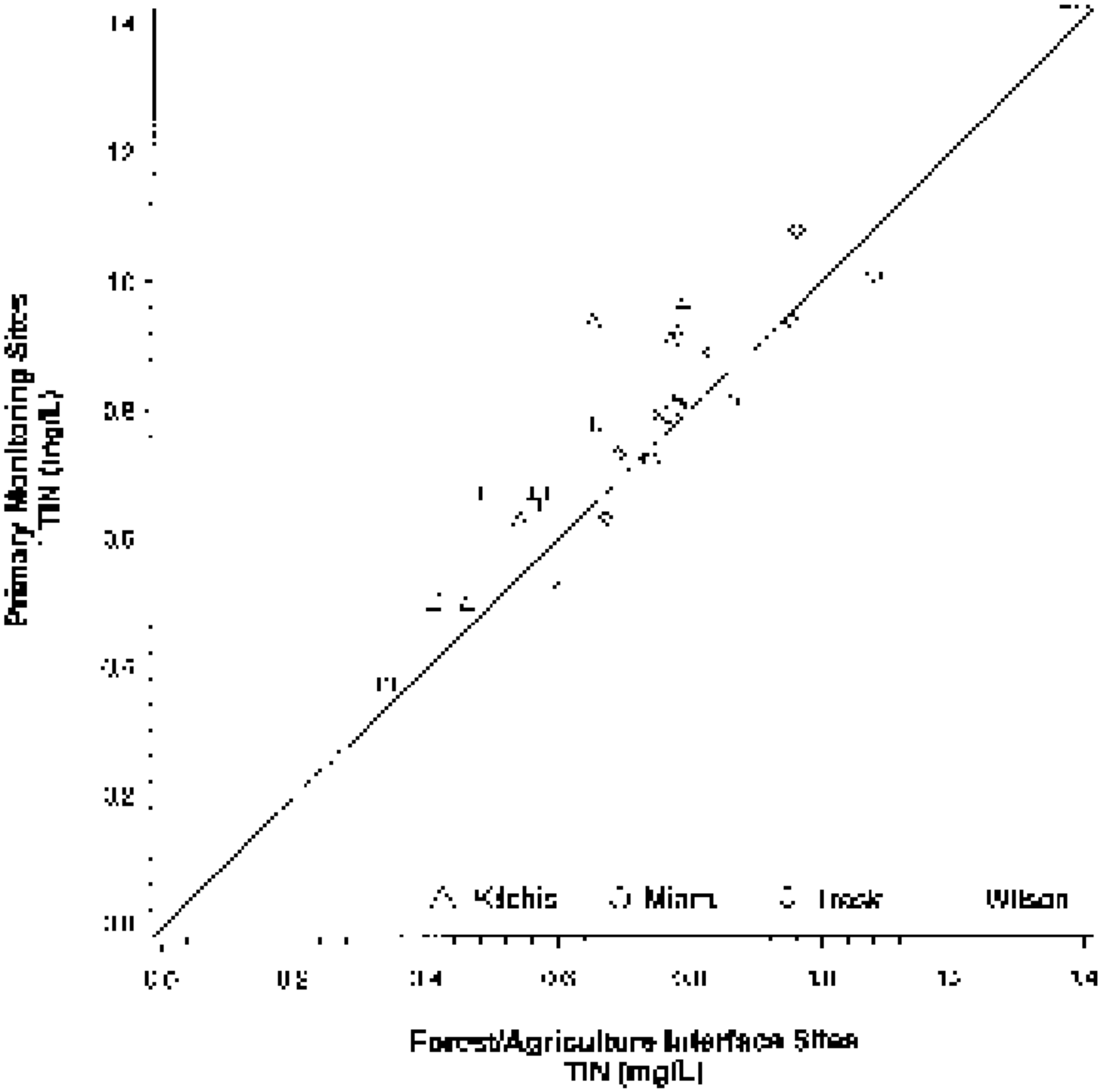


Figure 24. Results of paired sample analyses for Total Inorganic Nitrogen (NO_3-N + NH_4-N; mg/L) at the primary site and its respective forest/agriculture interface site for the four rivers in which both types of samples were collected. A 1:1 line is provided for reference.

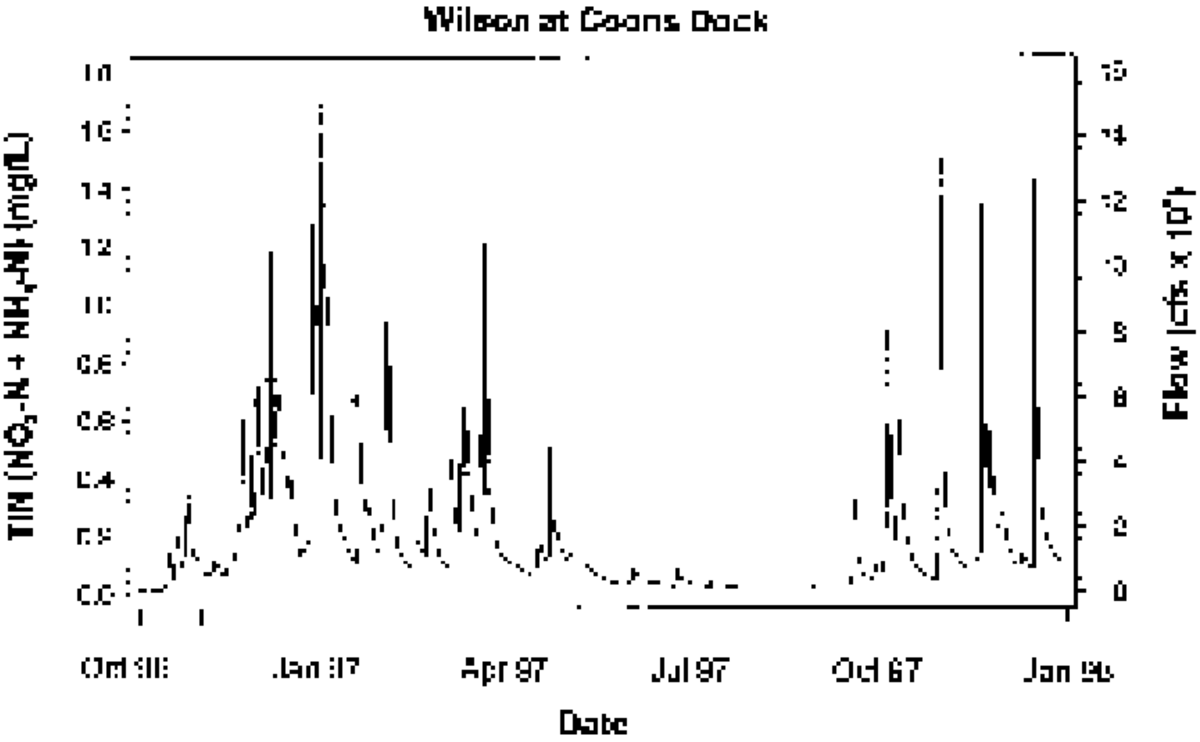


Figure 25. Concentration of inorganic N (mg/L) and river flow (cfs x 10^3) at the secondary monitoring site located at Coons dock on the lower Wilson River.

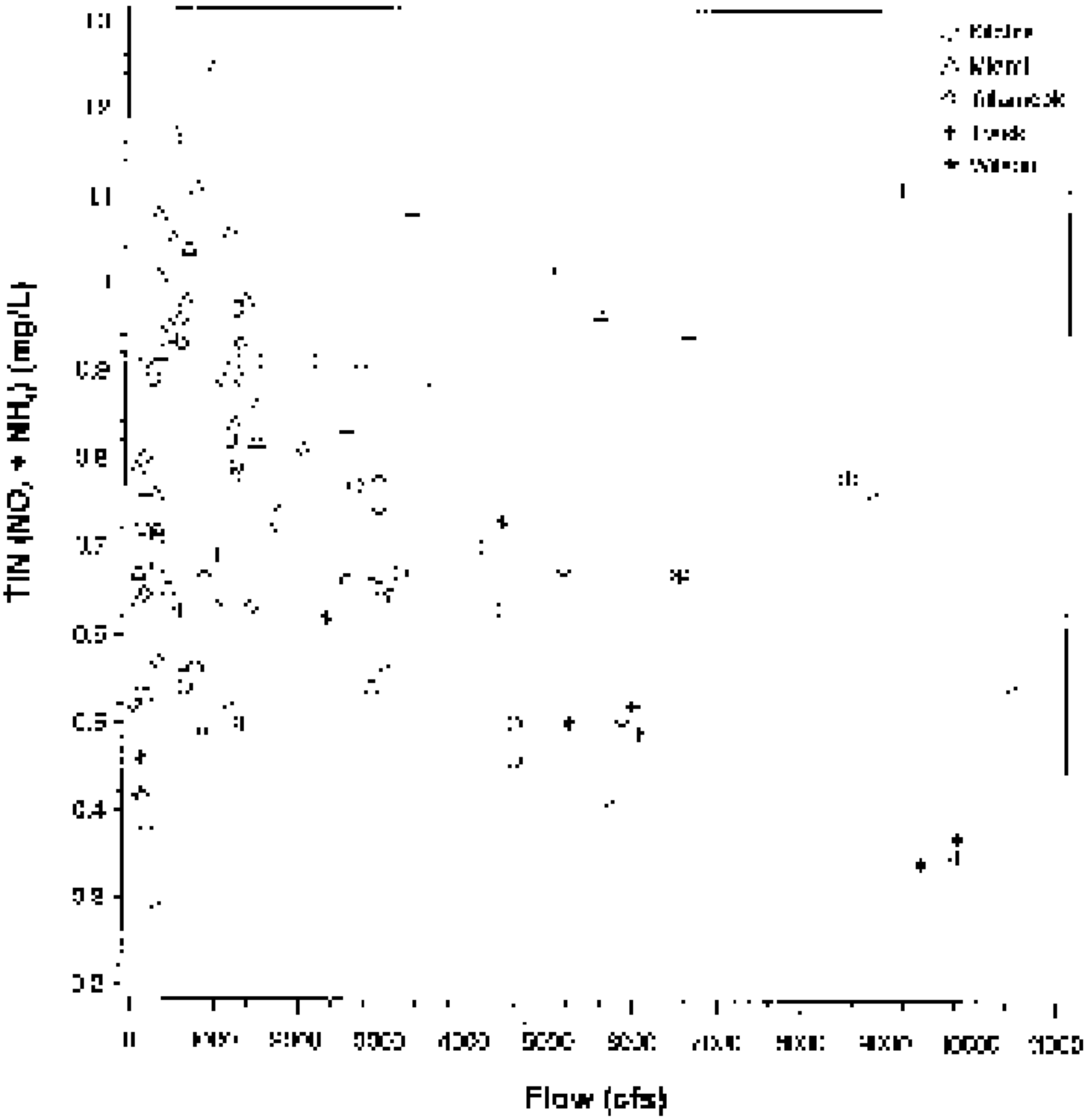


Figure 26. Relationship between TIN (NO_3-N + NH_4-N; mg/L) and flow (cfs) for all sites on all rivers. Different symbols represent each of the five rivers.

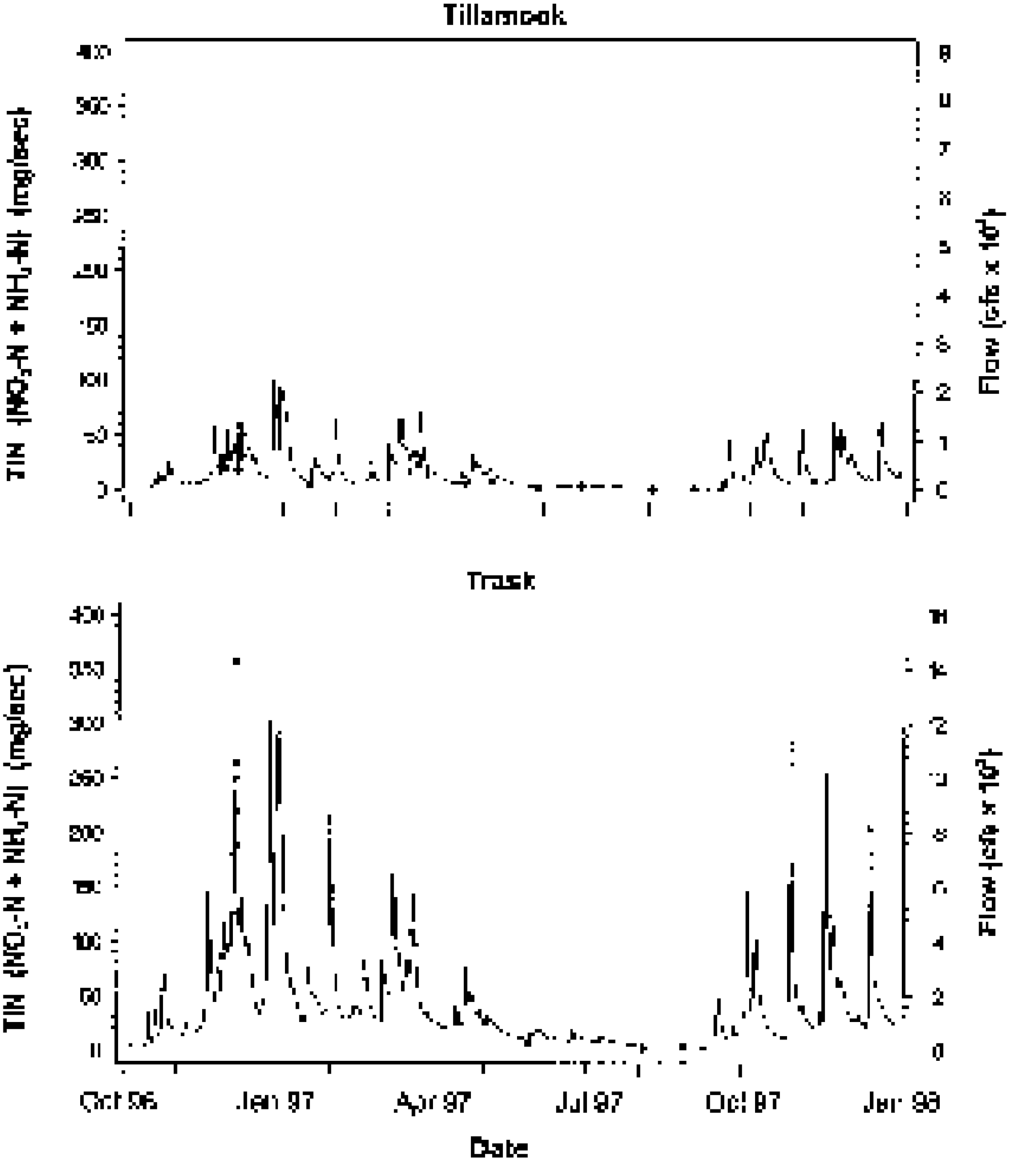
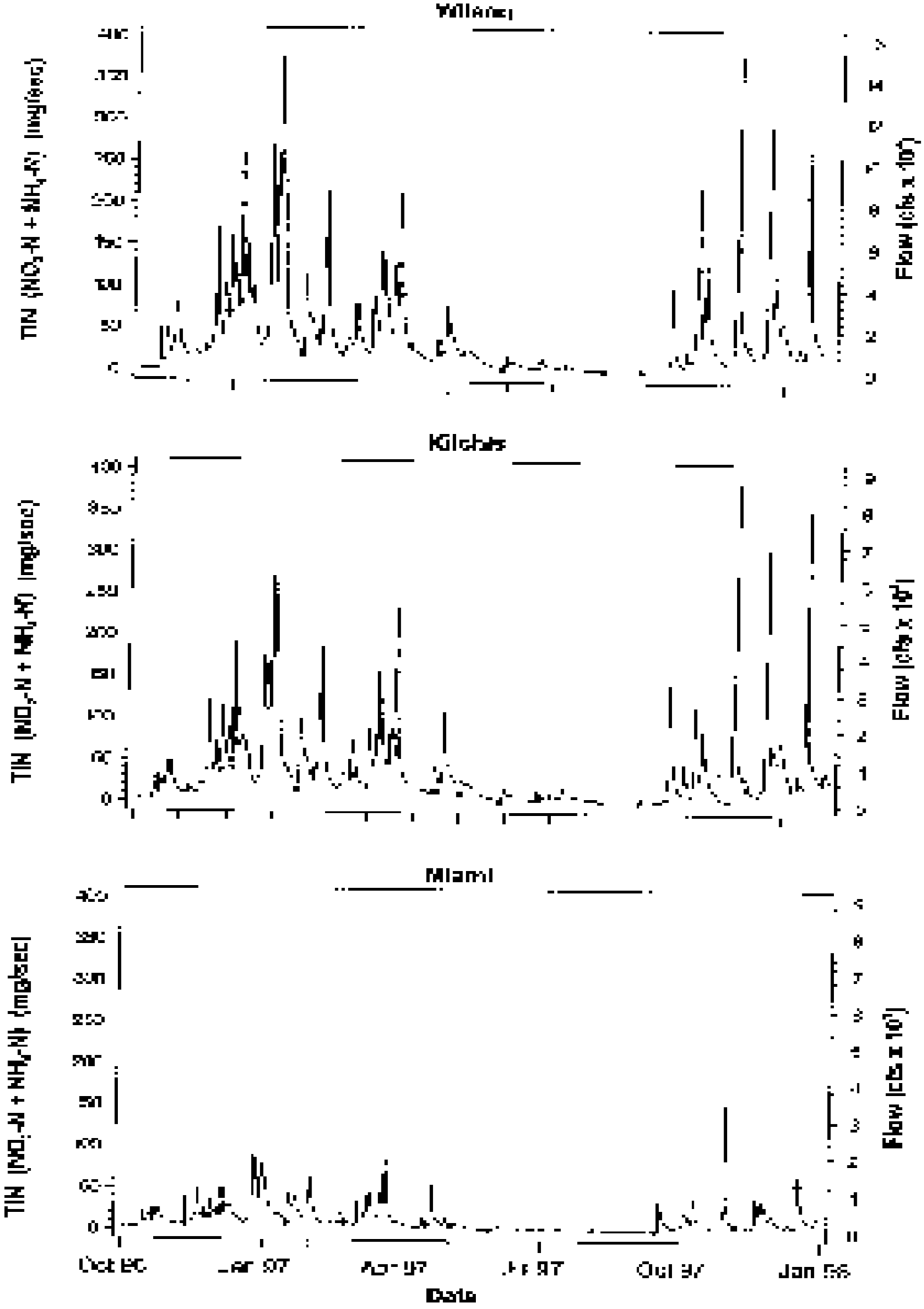


Figure 27. Load of inorganic N (mg/sec) and river flow (cfs x 10^3) at the primary monitoring site on each river.



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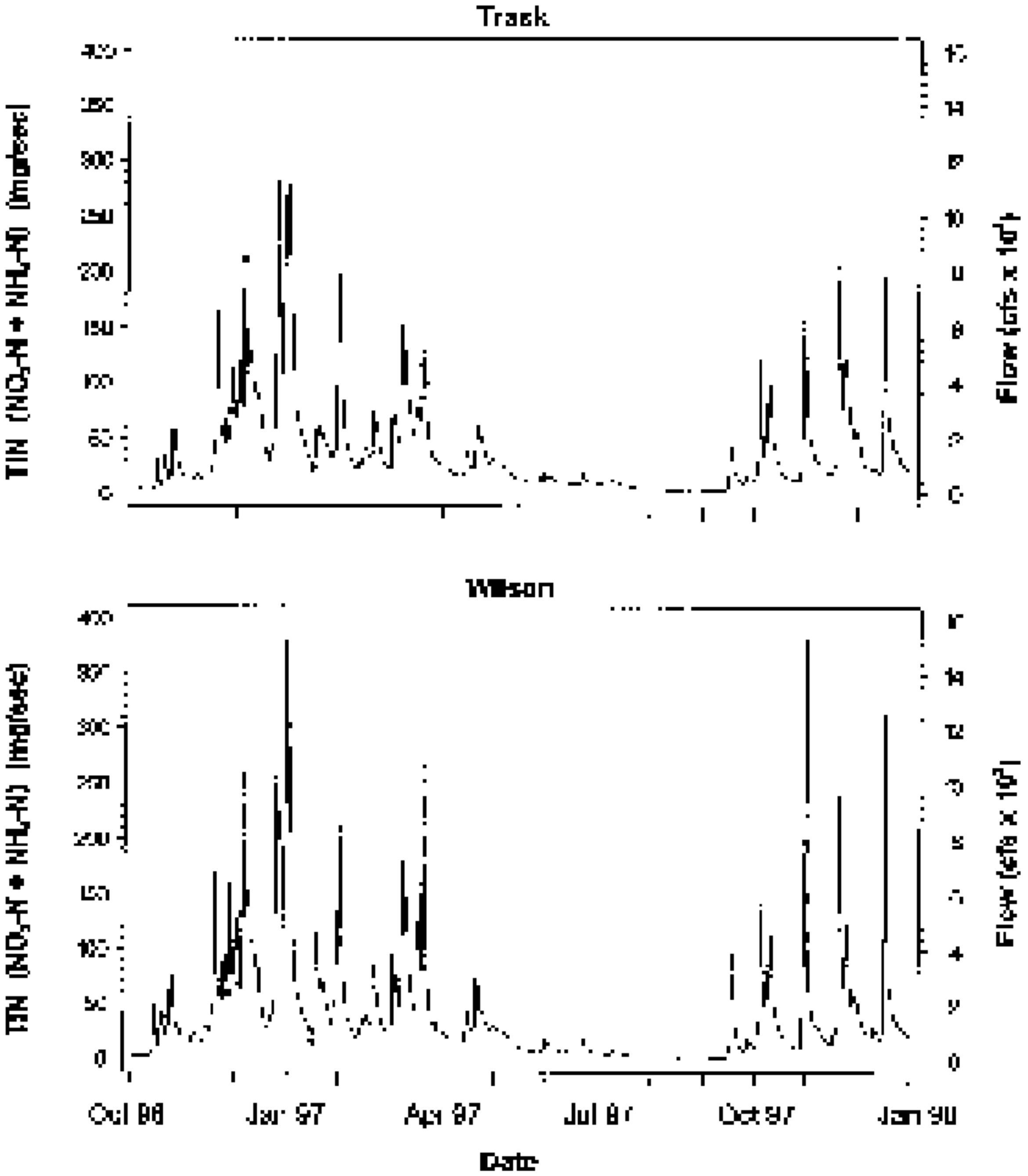
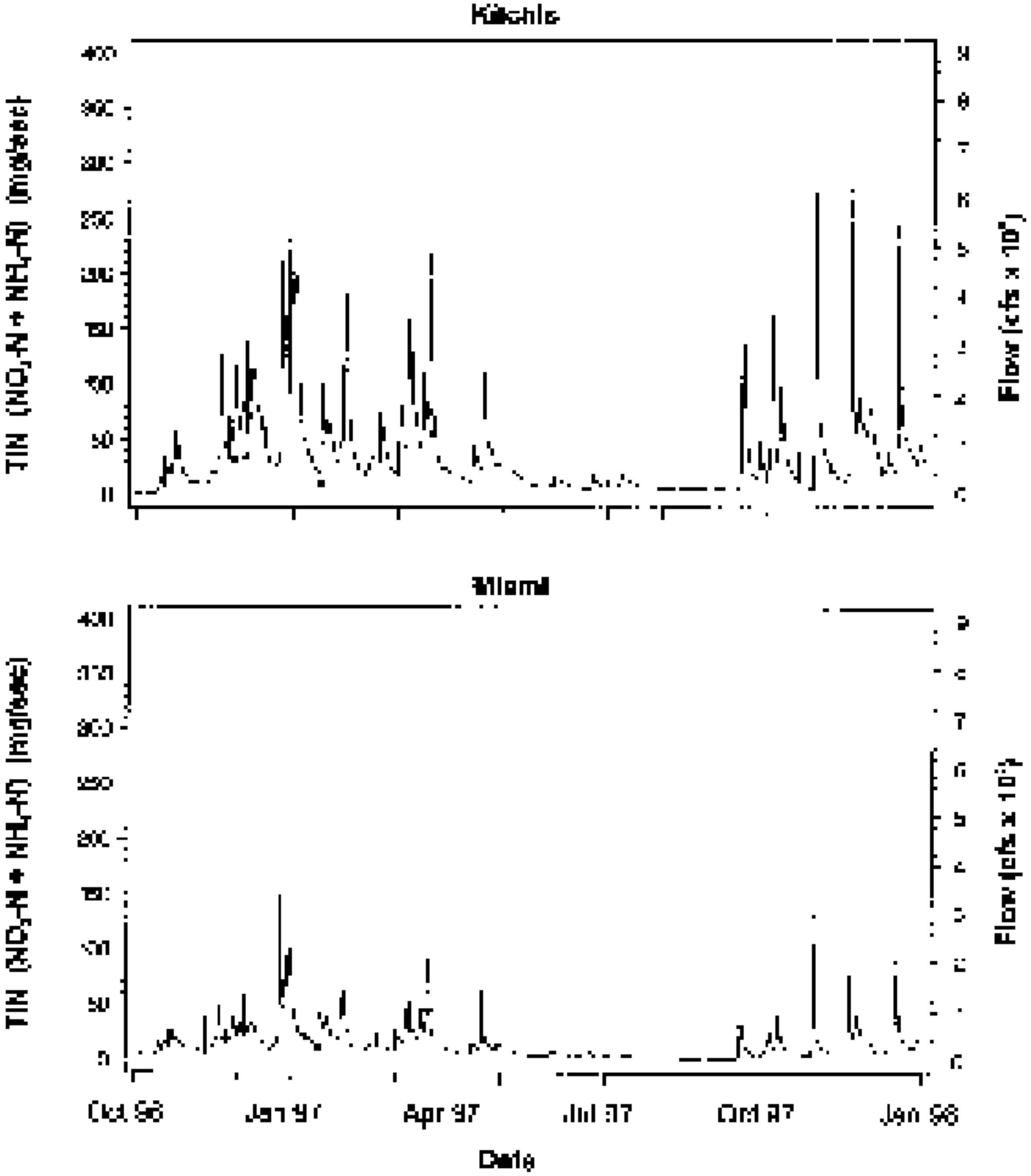


Figure 28. Load of inorganic N (mg/sec) and river flow (cfs x 10^3) at the secondary monitoring sites located approximately at the forest/agriculture interface on the Trask, Wilson, Kilchis, and Miami Rivers.



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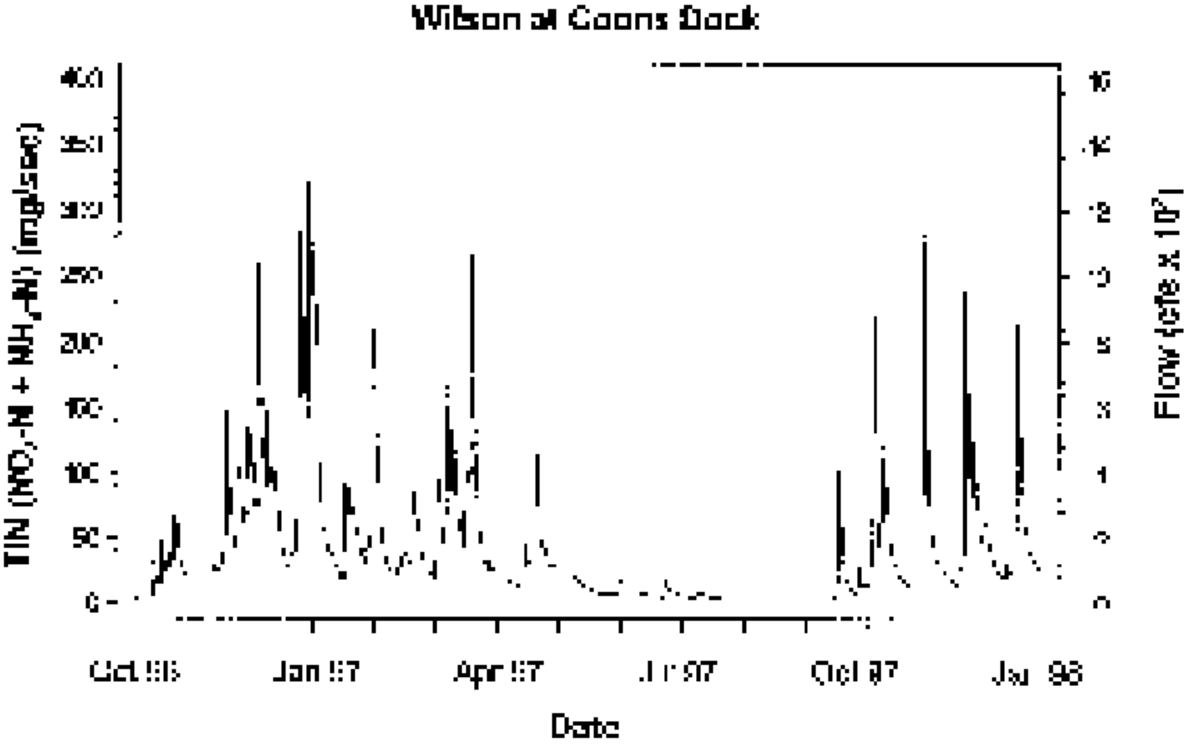


Figure 29. Load of inorganic N (mg/sec) and river flow (cfs x 10^3) at the secondary monitoring site located at Coons dock on the lower Wilson River.

Total Phosphorus

Total phosphorus (TP) concentrations were variable from river to river, with the highest concentrations consistently found in the Trask, Kilchis, and Wilson Rivers (Figure 30). Total phosphorus concentrations in all of the rivers were typically less than about 0.1 to 0.2 mg/L, except during storms when the concentrations sometimes exceeded 0.5 mg/L. Total phosphorus at the forest/agriculture interface exhibited similar patterns (Figure 31), although concentrations were often somewhat lower than at the primary sites (Figure 32).

Summer TP concentrations were below 0.1 mg/L at all of the primary sites. Similarly, summer TP loads were below 10 mg/sec for all of the primary sites, following the same pattern as TP concentrations. Winter loads were low (<20 mg/sec) and relatively stable in the Tillamook, Kilchis and Miami Rivers, compared with loads in the Trask and Wilson Rivers, which were greatly increased by changes in flow (20 to 200 mg/sec; Figure 33). Total phosphorus loads were typically below 20 mg/sec except for the Wilson and the Trask Rivers where both higher concentrations and loads were found (Figure 33-34).

There was a general relationship (r^2=0.47, p # 0.0001) between TP and flow (Figure 35). The rivers with largest watersheds, during periods of the highest flows, tended to have the highest TP concentrations (Trask and Wilson) and the river with the lowest flows and smallest watershed (Tillamook) had the lowest TP concentrations. There was not a strong relationship, however, observed between TP and flow either between or within rivers (Figure 35). This contrasts with the much stronger relationship observed between TP and TSS (r^2=0.84; p # 0.0001) in all of the rivers (Figure 36). The fact that TP is much more closely related to TSS concentration than either TP or TSS is related to flow rate suggests that the phosphorus is bound to soil particles. It is likely that the sources of the TP and TSS are the same and that the phosphorus is geologic in origin. Additionally, paired sample analyses between the primary site and the forest/agriculture interface site suggested that the contribution of TP from the agricultural parts of the watershed was minimal and that TP was mostly generated in the forested part of the watershed where most of the sediment originates (Figure 18). We cannot discount the possibility that a significant fraction of the observed TP load is derived from fertilizer use within the watershed, although it appears that the largest fraction originates from forested rather than agricultural land. Fertilizers that include P are applied to forested areas to a limited degree by private landowners within the basin. In contrast, the limited amount of fertilizer application that has occurred in recent years on state land has been restricted to the Wilson and Trask River watersheds and has included only N (Steve Dutton, Oregon Department of Forestry, pers. comm.).

There was a general relationship between the TN/TP ratio and flow (Figure 37). The rivers are often P limited (TN/TP>14) during low flow conditions. However, at flows greater than 5000 cfs the rivers move to an N limitation, although only the Trask and Wilson Rivers reached such high flows.

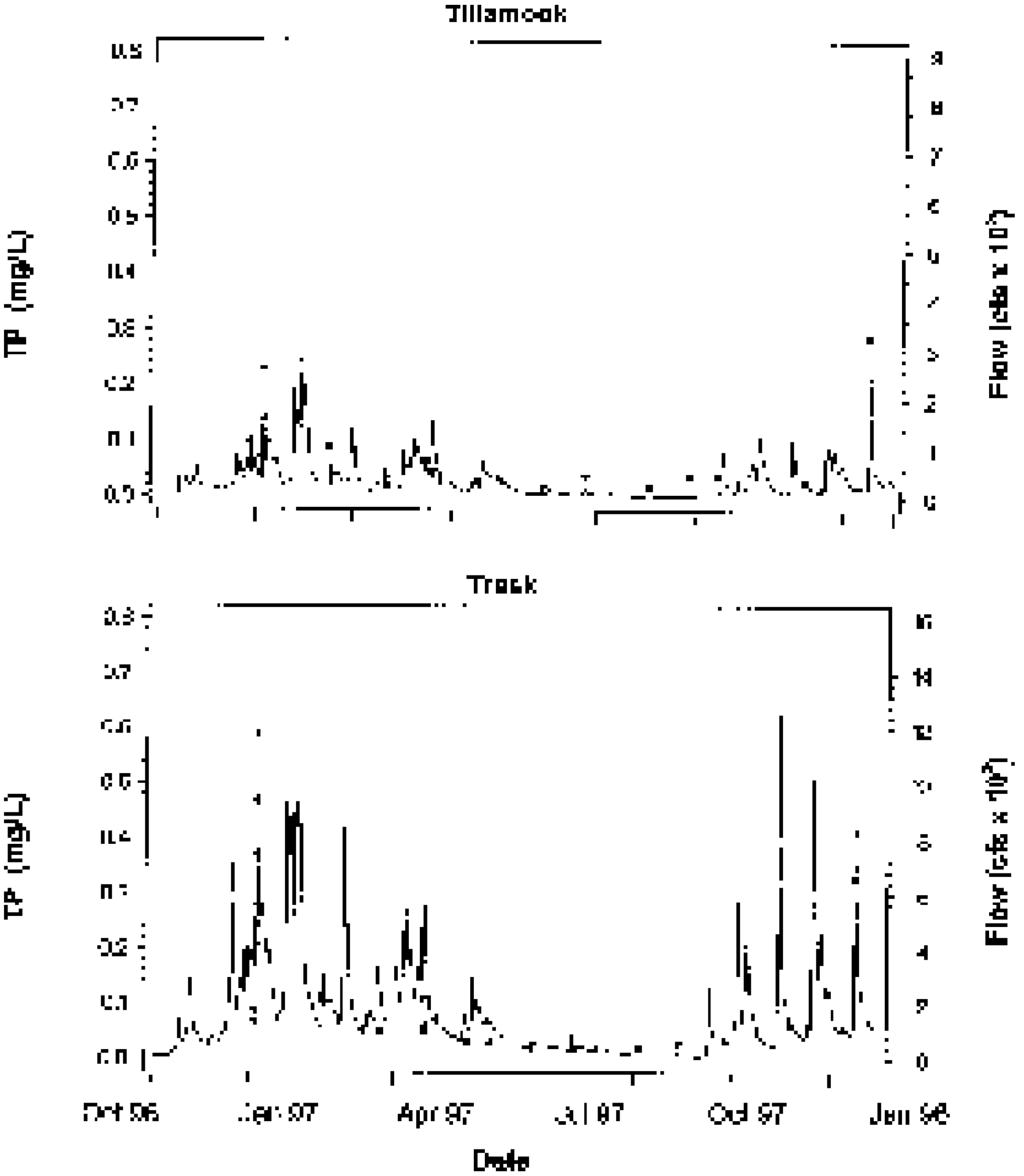
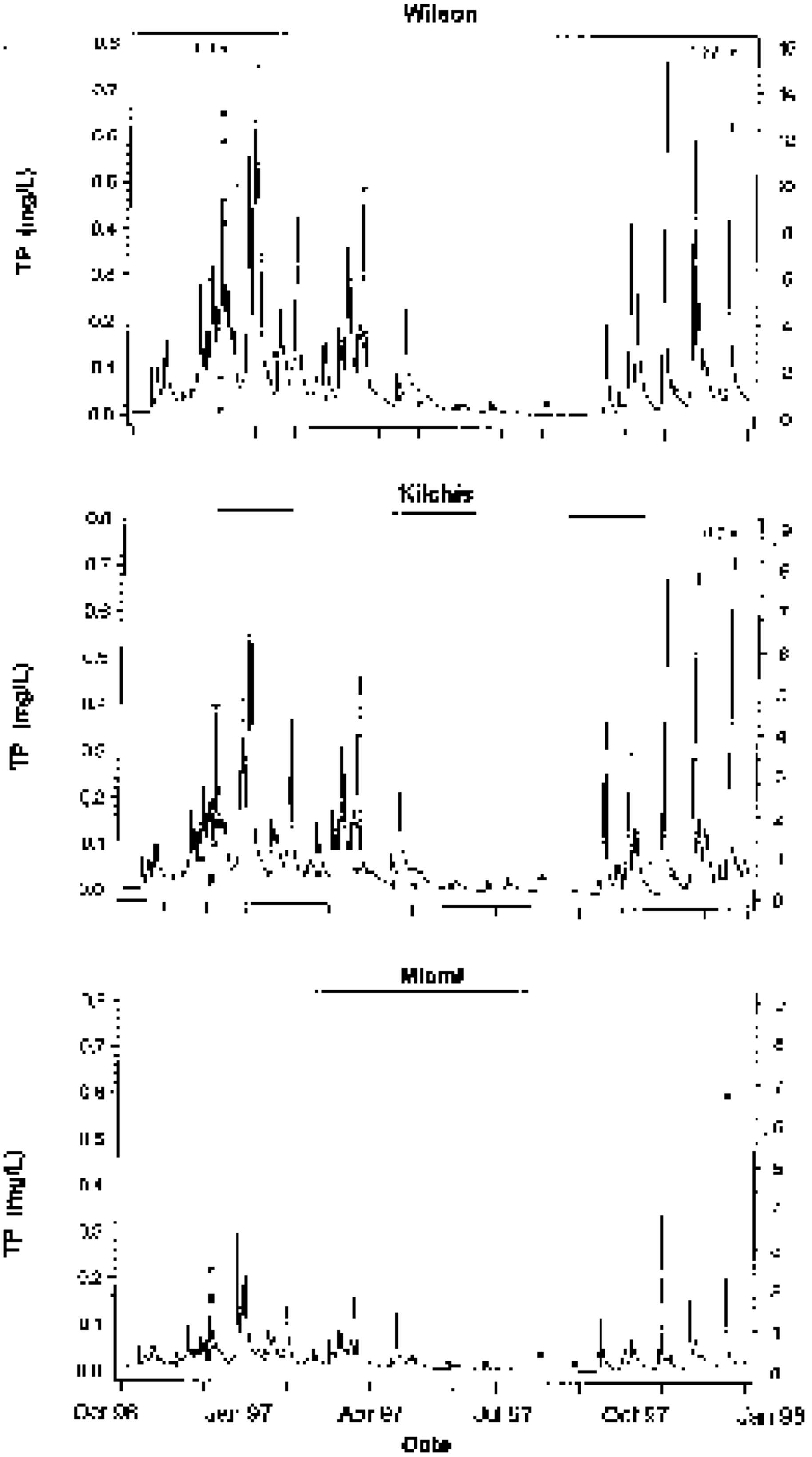


Figure 30. Concentration of total phosphorus (mg/L) and river flow (cfs x 10^3) at the primary monitoring site on each river.



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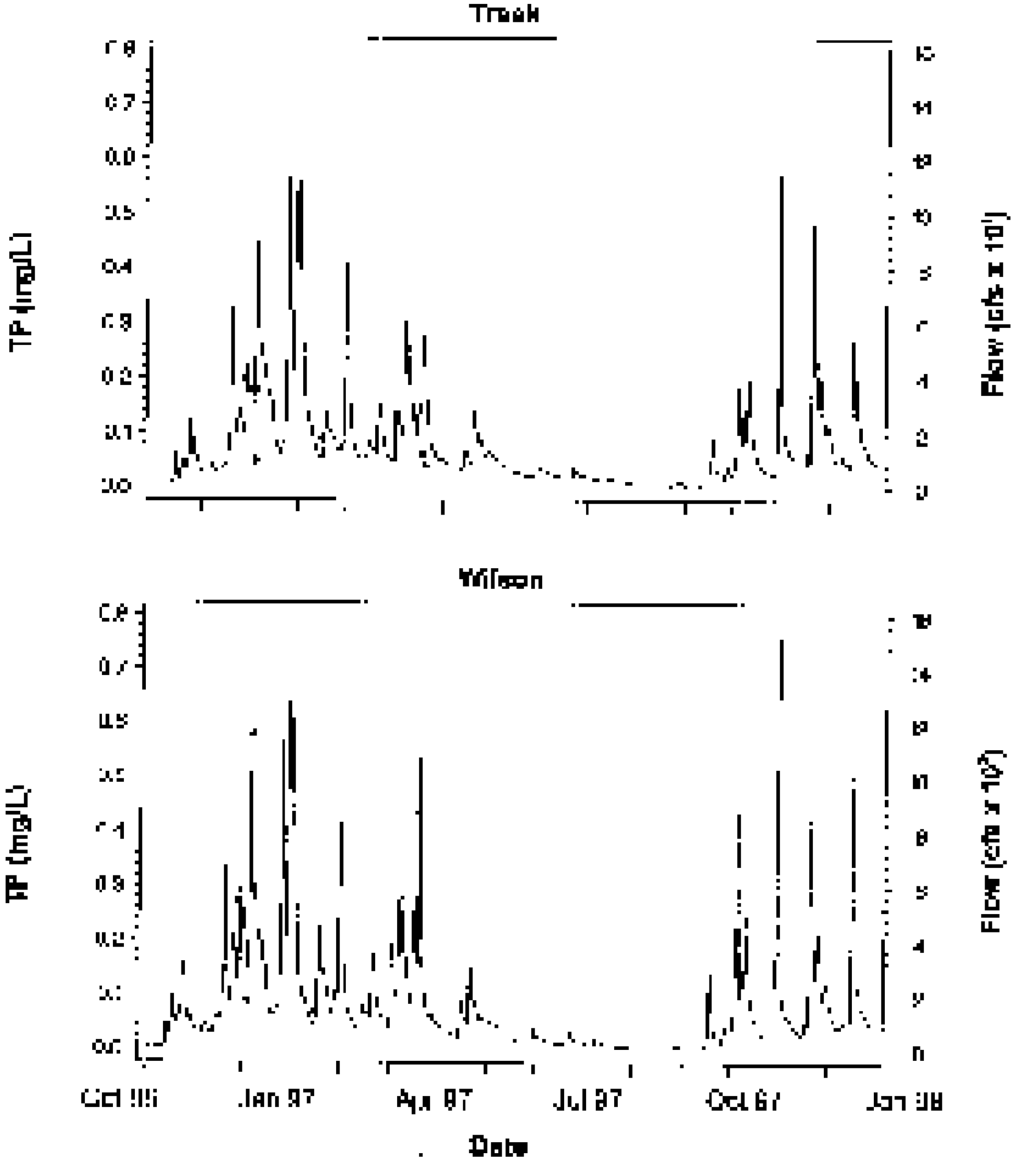
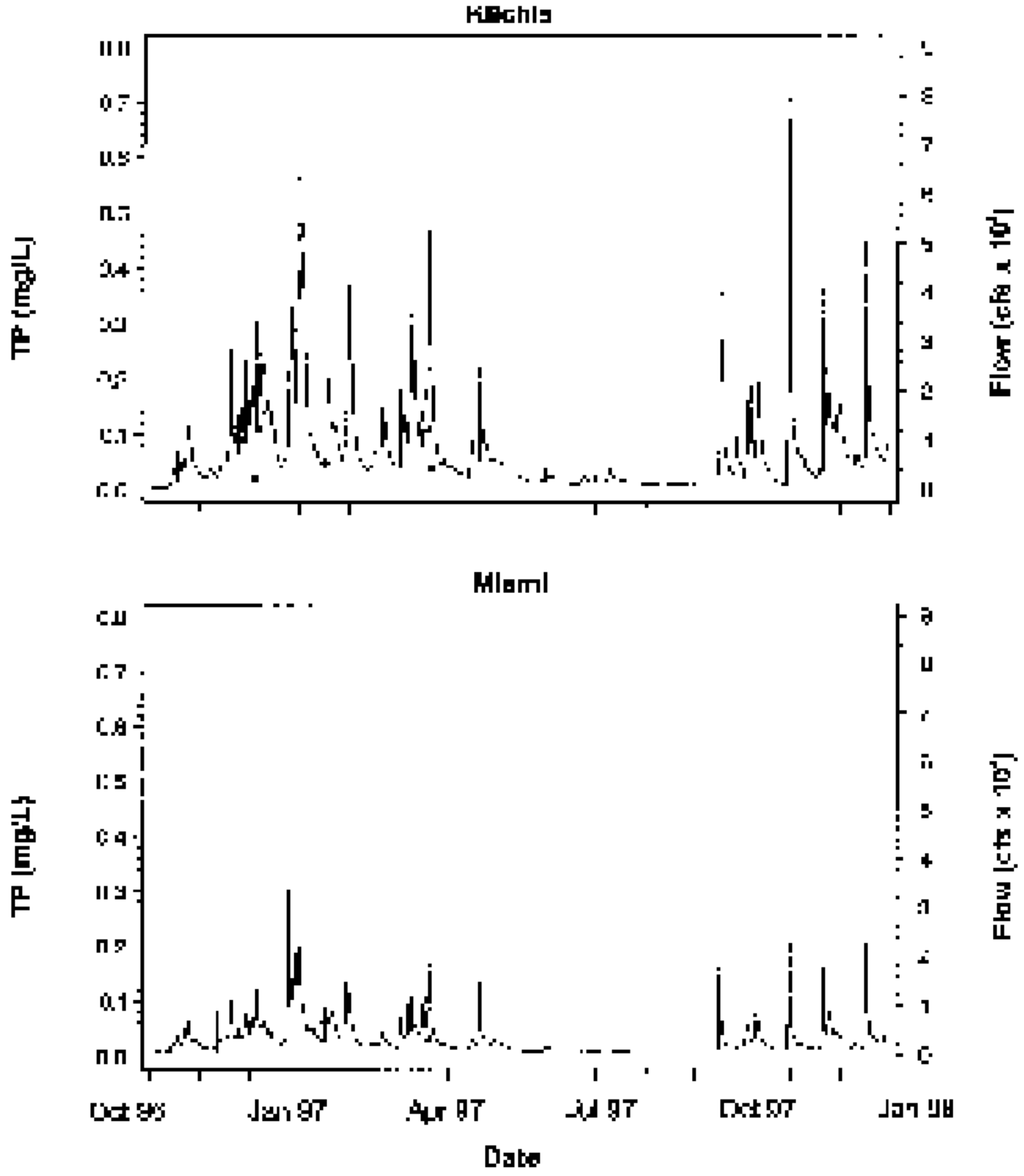


Figure 31. Concentration of total phosphorus (mg/L) and river flow (cfs x 10^3) at the secondary monitoring sites located approximately at the forest/agriculture interface on the Trask, Wilson, Kilchis, and Miami Rivers.



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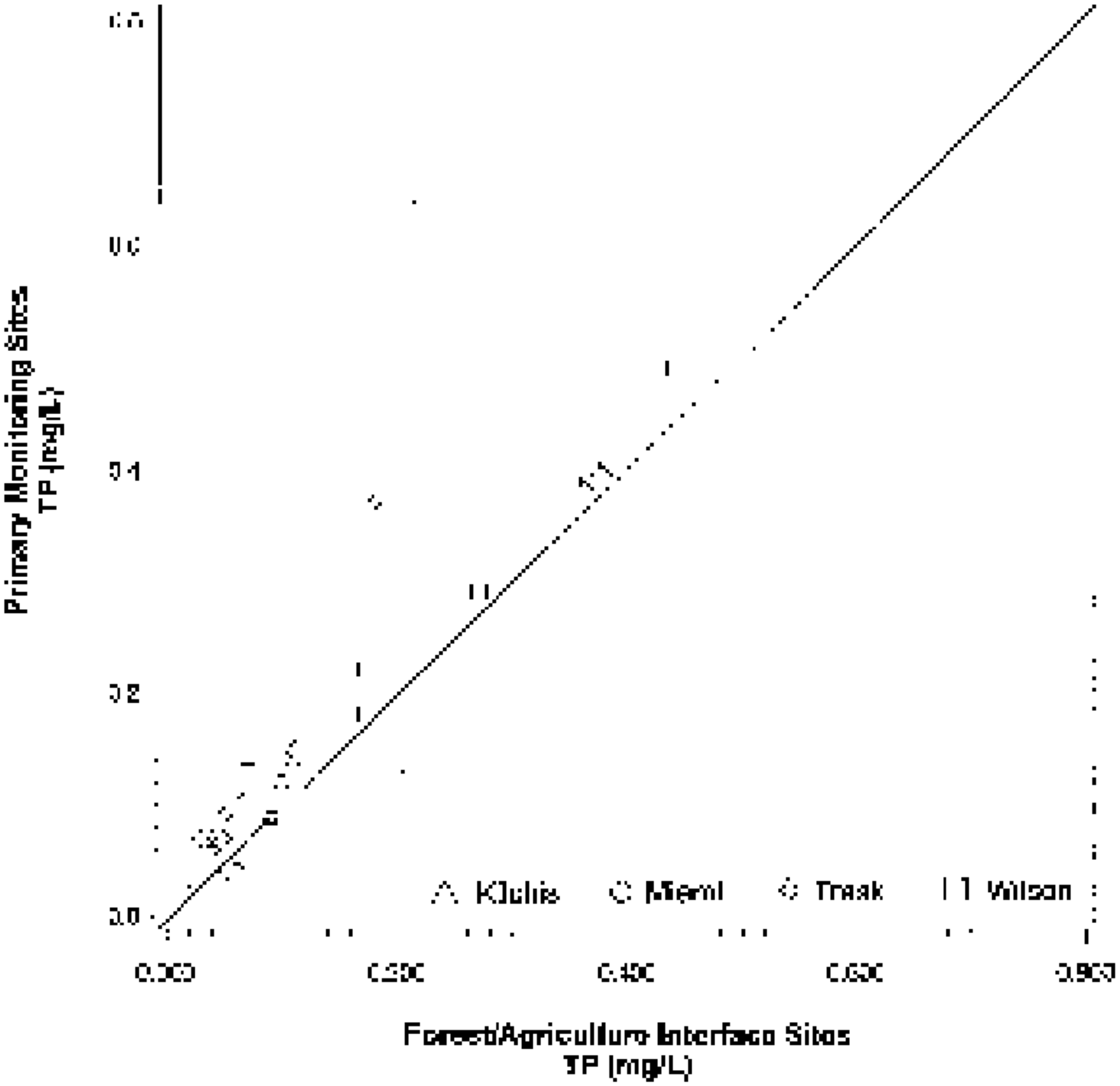


Figure 32. Results of paired sample analyses for total Phosphorus (mg/L) at the primary site and its respective forest/agriculture interface site for the four rivers in which both types of samples were collected. A 1:1 line is provided for reference.

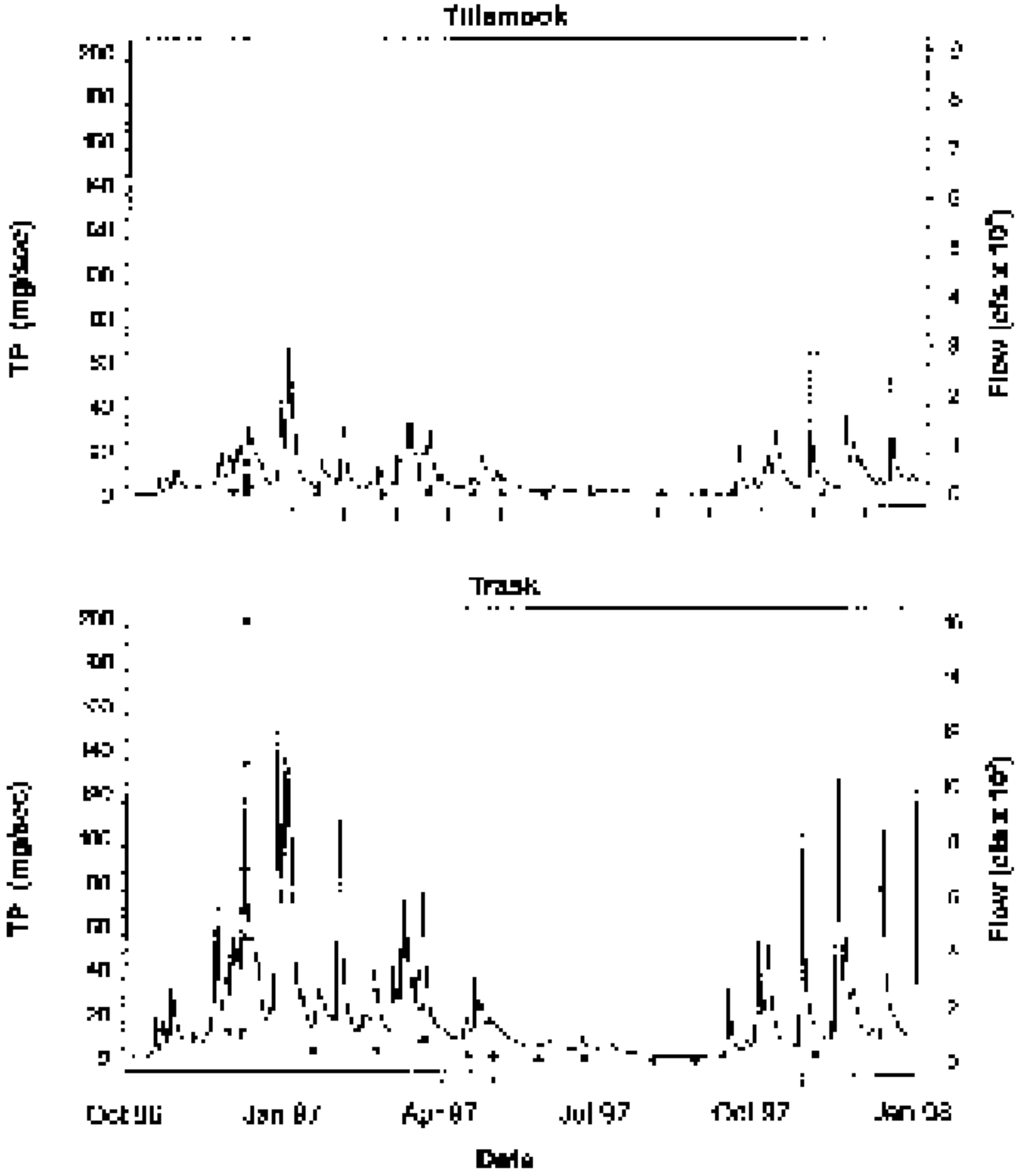
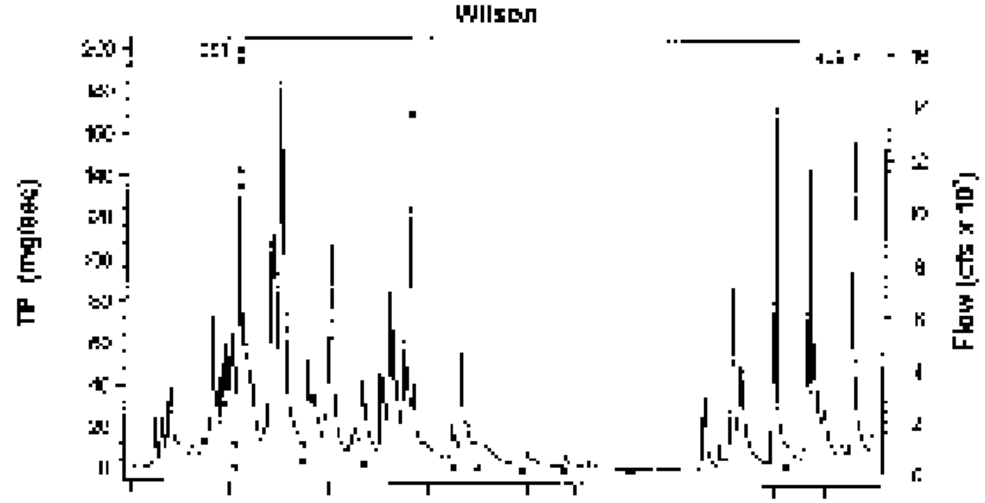
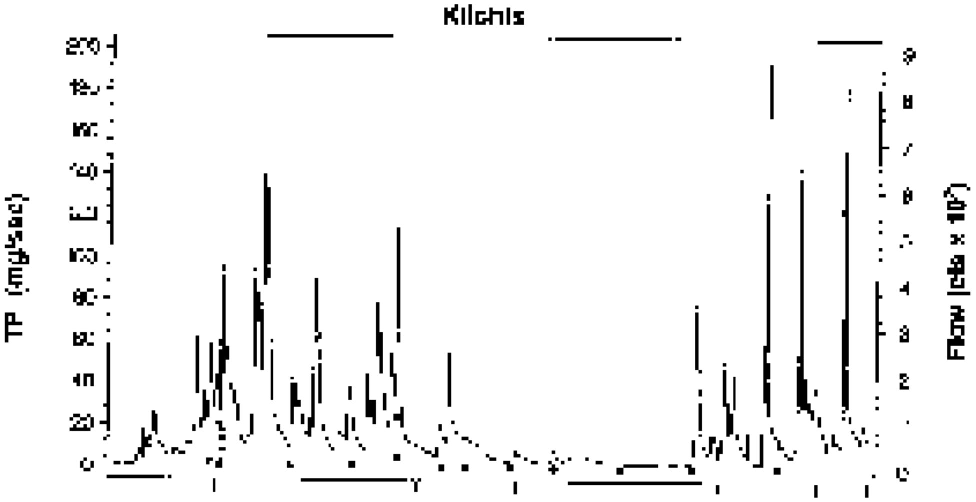
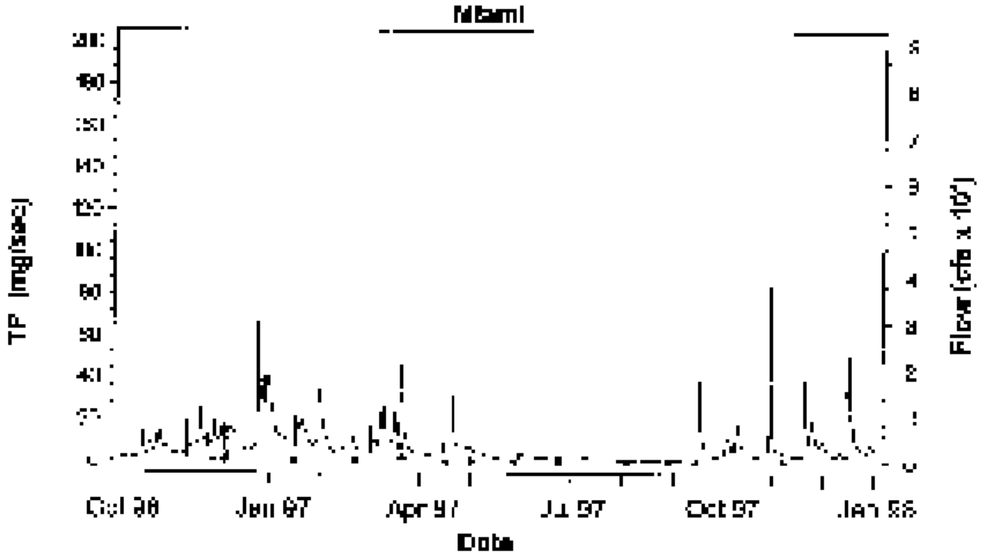


Figure 33. Load of total phosphorus (mg/sec) and river flow (cfs x 10^3) at the primary monitoring site on each river.







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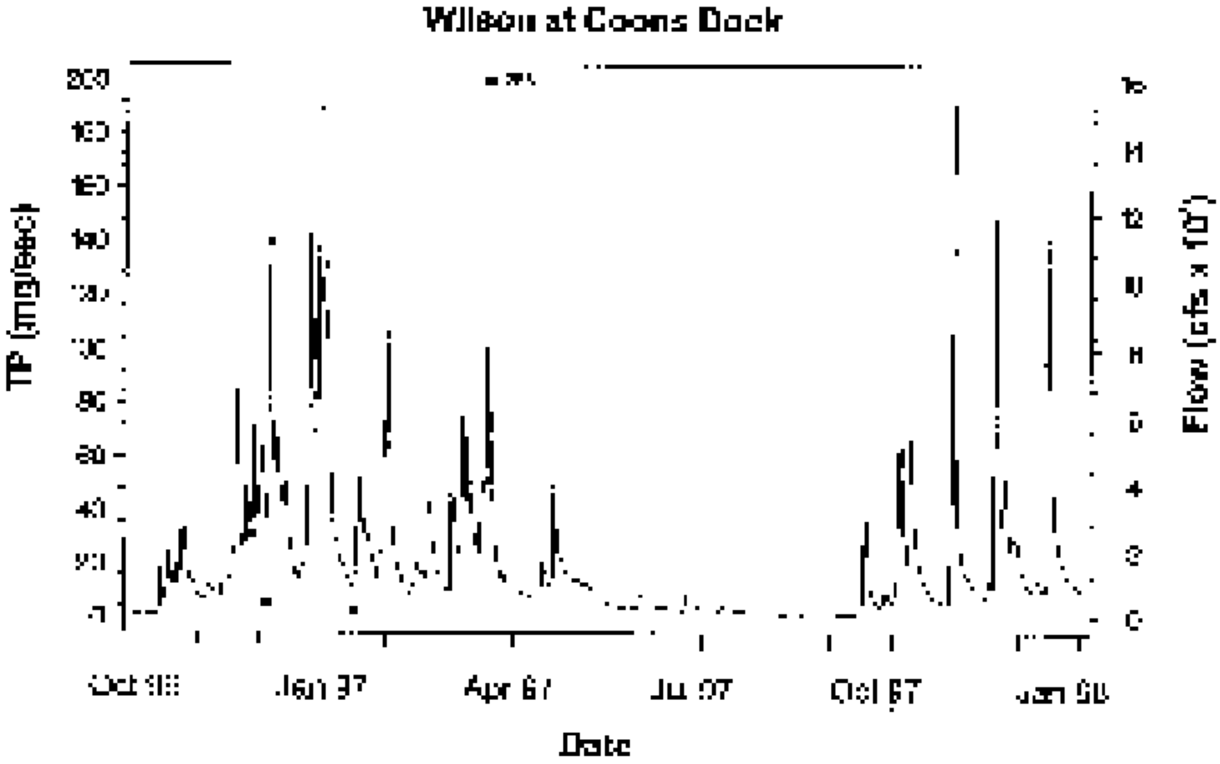

Figure 34. Load of total phosphorus (mg/sec) and river flow (cfs x 10^3) at the secondary monitoring site located at Coons dock on the lower Wilson River.

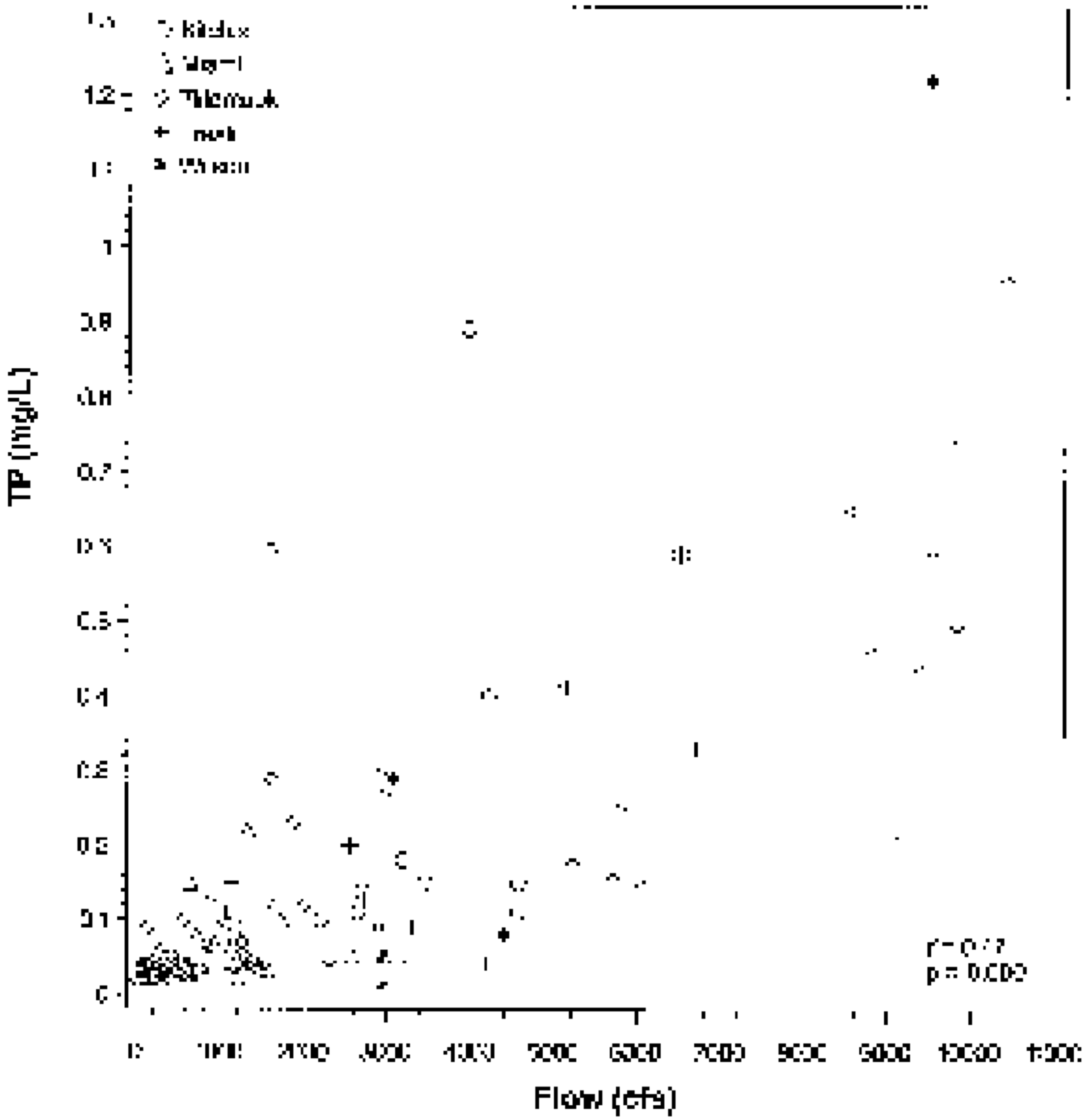

Figure 35. Relationship between TP (mg/L) and flow (cfs) for all sites on all rivers. Different symbols represent each of the five rivers.

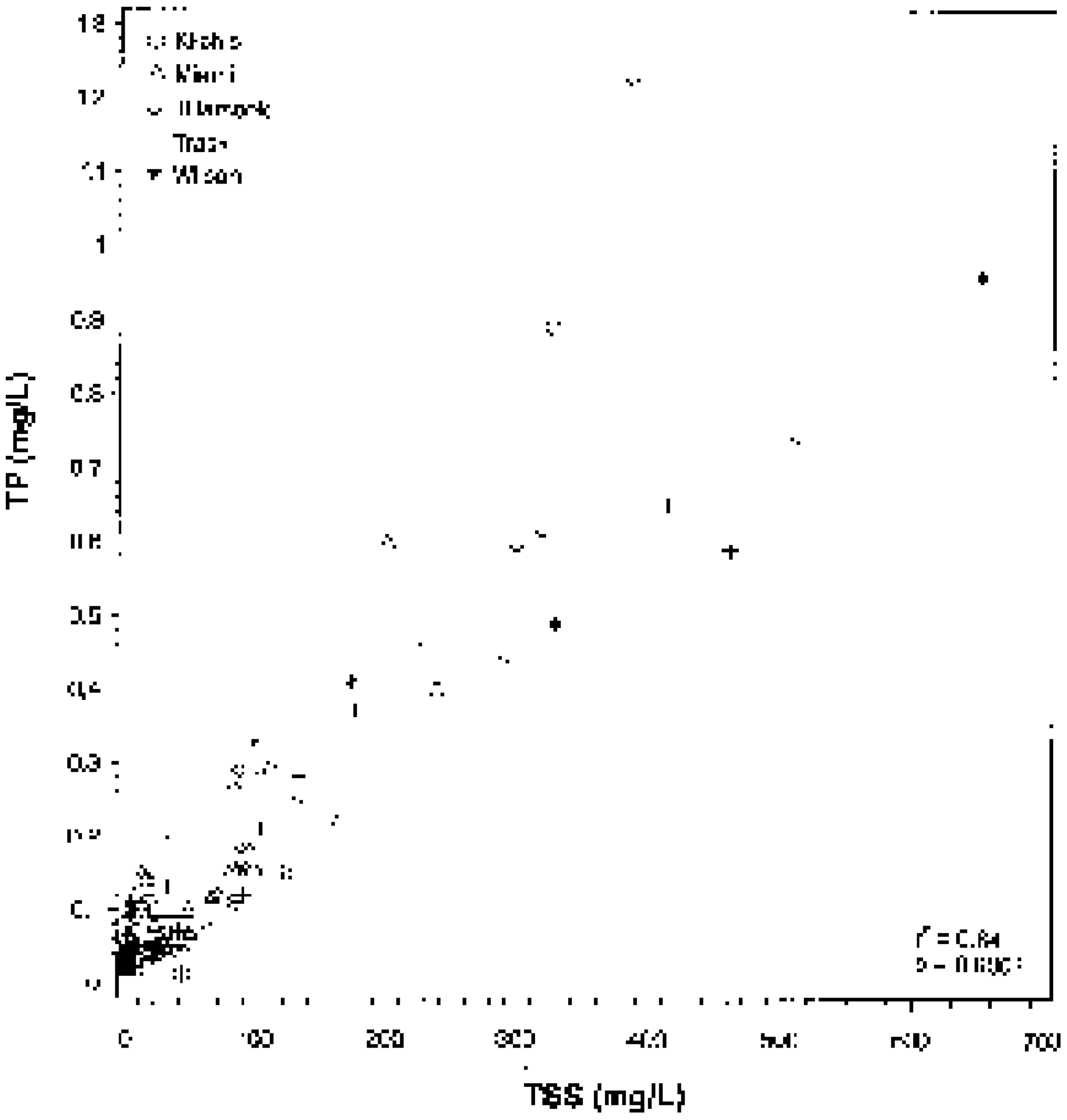

Figure 36. Relationship between TP (mg/L) and TSS (mg/L) for all sites on all rivers. Different symbols represent each of the five rivers.

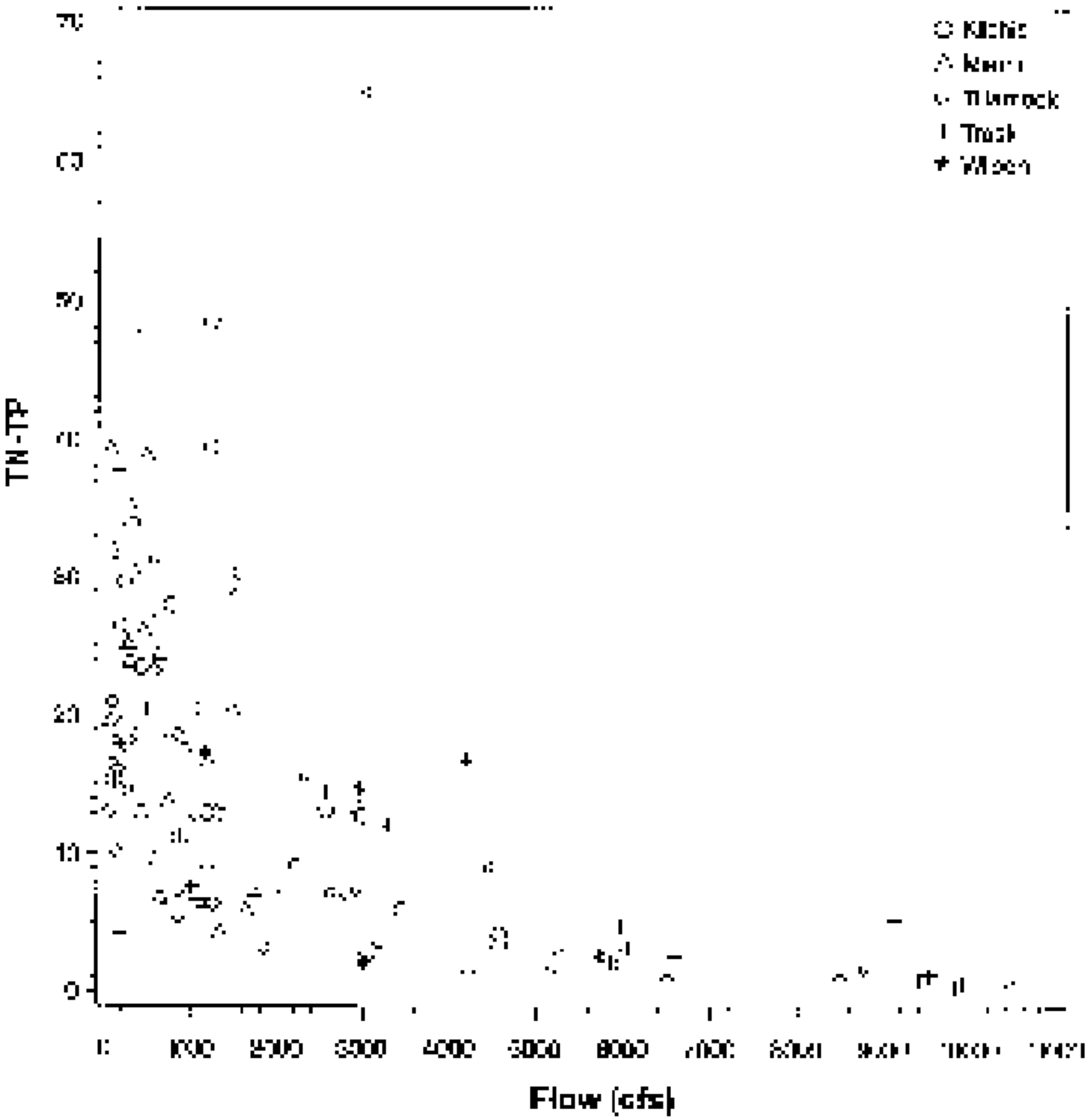

Figure 37. Relationship between TP/TN ratio and flow (cfs) for all sites on all rivers. Different symbols represent each of the five rivers.

QA/QC

A QA/QC sampling and analytical plan was prepared and submitted to TBNEP (Bernert and Sullivan 1997). This plan described the methods of sample collection, field processing, analytical methodology, data quality objectives, and methods to meet these objectives.

About 10% of the samples analyzed were allocated to QA/QC, and these included field duplicates, field triplicates, field splits, and blanks. QA/QC samples were used to quantify sampling and analytical variability and analytical detection limits.

Figure 38 presents the results of duplicate sample analysis for bacteria and Figure 39 presents the results of duplicate sample analysis for NO_3^--N, TP, and TSS. In all cases, the duplicate variability is acceptable. These data illustrate the cumulative variability associated with: 1) short-term temporal variability in water quality, 2) sampling variability (i.e. depth and manner of sample collection), and 3) laboratory analytical reproducibility. The observed cumulative variability for replicate bacterial sampling and analysis was good; the mean coefficient of variation (CV) was 25%, although the data were not normally distributed. Consequently, variation is best illustrated by a percentage of samples within a CV range. For FCB, 87% of all sample pairs (duplicates) were below a CV of 50% (n=55). 70% of all FCB sample pairs were below a CV of 35%. NO_3-N samples had a mean CV of 1.95% and 86% of the duplicate pairs had a CV below 5% (n=7). TP had a mean CV of 19% and 71% of the duplicate pairs had a CV below 15% (n=7). TSS had a mean CV of 9% and 88% of the duplicate pairs had a CV below 15% (n=8).

5. DISCUSSION

Data collected in this study on the concentrations of bacteria, nutrients, and suspended solids were combined with river flow data to generate estimates of the loads or fluxes of these constituents from each of the rivers to the bay. Although precise quantification of pollutant loads would require more intensive event sampling than conducted here, the results of this study provide a good basis for determining the relative importance of the five rivers, and also specific sub-basins and/or land uses, in contributing nutrients, sediment, and bacteria to the bay. A companion report (Sullivan et al. 1998) quantifies the results from specific storm-based sampling. This is required for generation of annual load estimates for each of the rivers.

Animal waste and sediment were judged to be the major contributors to water quality problems related to agriculture in the Tillamook Drainage Basin Agricultural Non-point Source Abatement Plan (Tillamook SWCD 1981). The results of the present study confirm that FCB (which are largely associated with animal waste management and/or human habitation) and sediment continue to be important water quality concerns and that water temperatures may also be problematic. Nutrient concentrations are only moderate, however, and do not appear to constitute a significant problem at the present time.

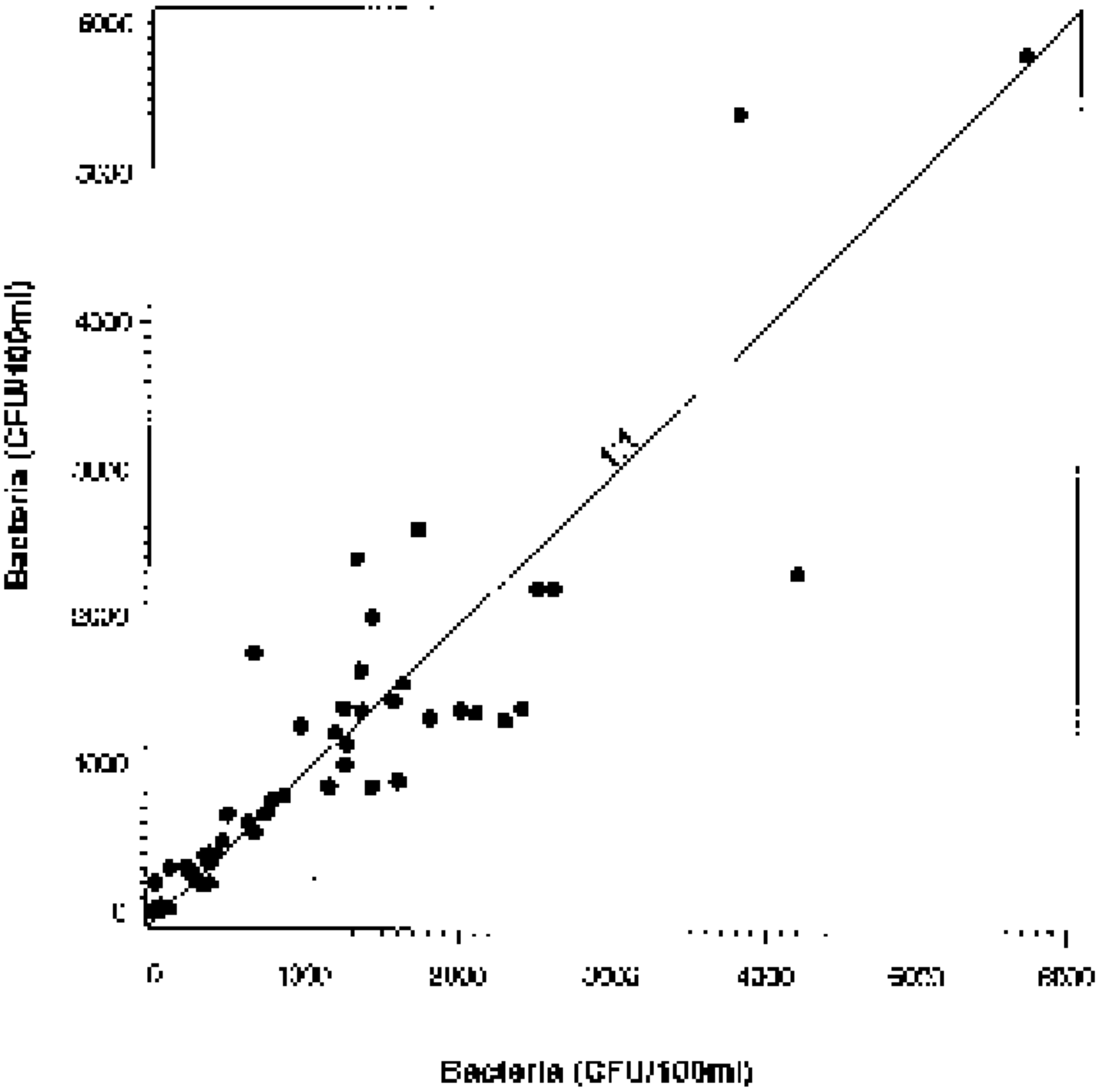

Figure 38. Results of paired sample analyses for duplicate samples collected from each of the five rivers and analyzed for fecal coliform bacteria (N=55). A 1:1 line is provided for reference.

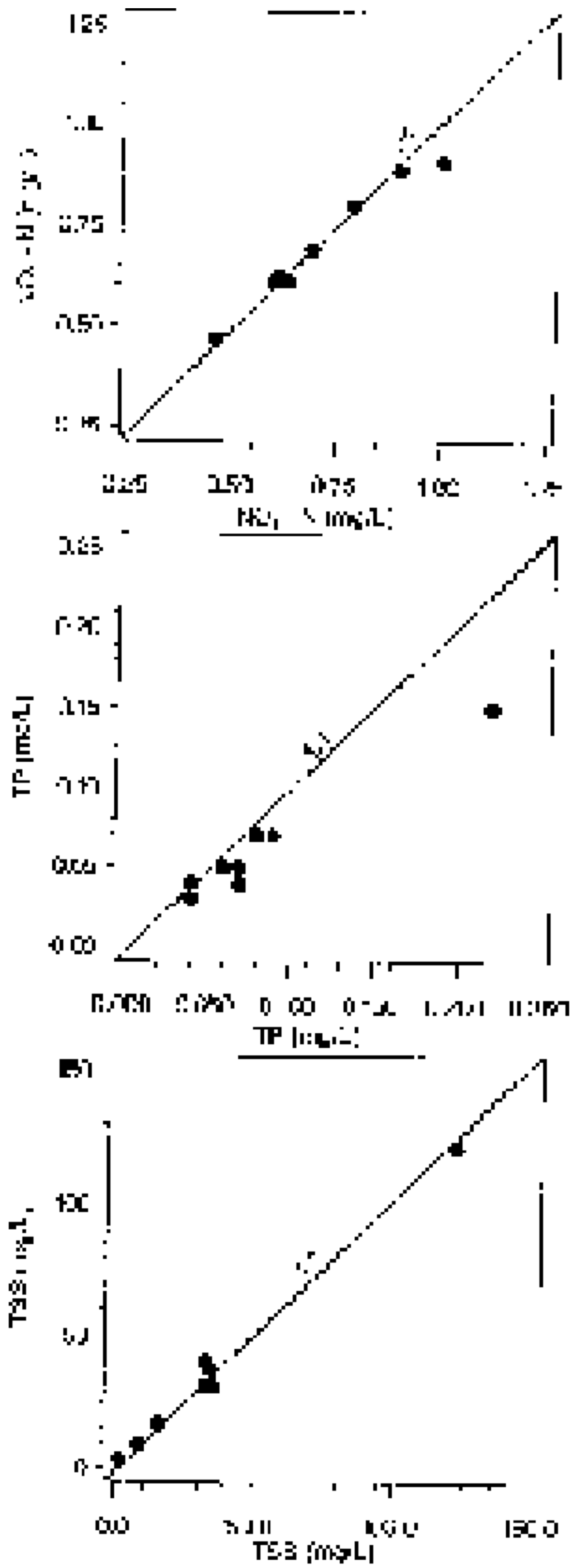

Figure 39. Results of paired sample analyses for duplicate samples collected from each of the five rivers and analyzed for nitrate, total phosphorus, and total suspended solids. A 1:1 line is provided for reference.

Fecal Coliform Bacteria

The largest bacterial loading occurred from the Trask and Wilson Rivers, corresponding to relatively high concentrations coupled with substantially higher flows than the other rivers. High loading also occurred in the Tillamook River where flows were much lower than the Wilson and Trask Rivers, but FCB concentrations were often much higher. In a previous study of FCB in the Tillamook Basin by Jackson and Glendening (1982), these same three rivers were identified as the major sources of FCB to the bay. Loading of FCB was greatest in the winter when river flows are highest, although summer loads increased dramatically with relatively small increases in flow. With low amounts of precipitation in the summer, there is little or no flushing of the watersheds. Apparently, relatively small pulses of precipitation pick up large contributions of FCB from the watershed (Figure 6). Jackson and Glendening (1982) suggested that the summer is more critical with respect to bay water quality concerns due to optimal feeding conditions during summer for oysters and therefore a greater chance of oyster contamination from FCB loading.

Both bacterial loads and concentrations are of concern in assessing the water quality in Tillamook Bay and its contributing rivers. It is important to know which rivers contribute the largest loads to the bay because the loads of the various rivers will be mixed to some extent within the bay and will ultimately determine the concentration of FCB in baywater. However, the concentration (as well as the load) of bacteria in the river water is also an important determinant of the ultimate baywater concentration. This is especially true in a bay such as Tillamook Bay, which is essentially a suite of drowned river mouths. Most of the freshwater discharge from the watershed enters the bay in its southernmost portion, with the Tillamook River entering to the southwest followed by the Trask River, and finally the Wilson River to the northeast (Figure 40). During high discharge periods, there is often a substantial current flowing from south to north within the bay, and the water that reaches the location of the major oyster-growing areas (along the western shore near and south of mid-bay) often likely consists largely of river discharge from the Tillamook, and perhaps to a lesser extent, the Trask and Wilson Rivers. This can be visualized in the channelization patterns evident in the bathymetry map depicted in Figure 40. It can also be seen in the pattern of results obtained in the limited bay sampling that we conducted during a storm in early October, 1997 (Figure 41). Highest FCB concentrations were found along the western shores of the bay, especially on October 3rd and 5th, when FCB concentrations were extremely high (generally > 500 cfu/100 ml). These concentrations correspond with high FCB measurements in the Tillamook, Trask, and Wilson Rivers during that same storm. Thus, the concentration of bacteria in Tillamook River water, and to a lesser extent the concentration of bacteria in Trask and Wilson River water, may better reflect contributions of bacteria to the major oyster-growing areas of the bay than does the load contributed by any of these rivers. This is particularly likely to be true during the high-discharge season (October through April).

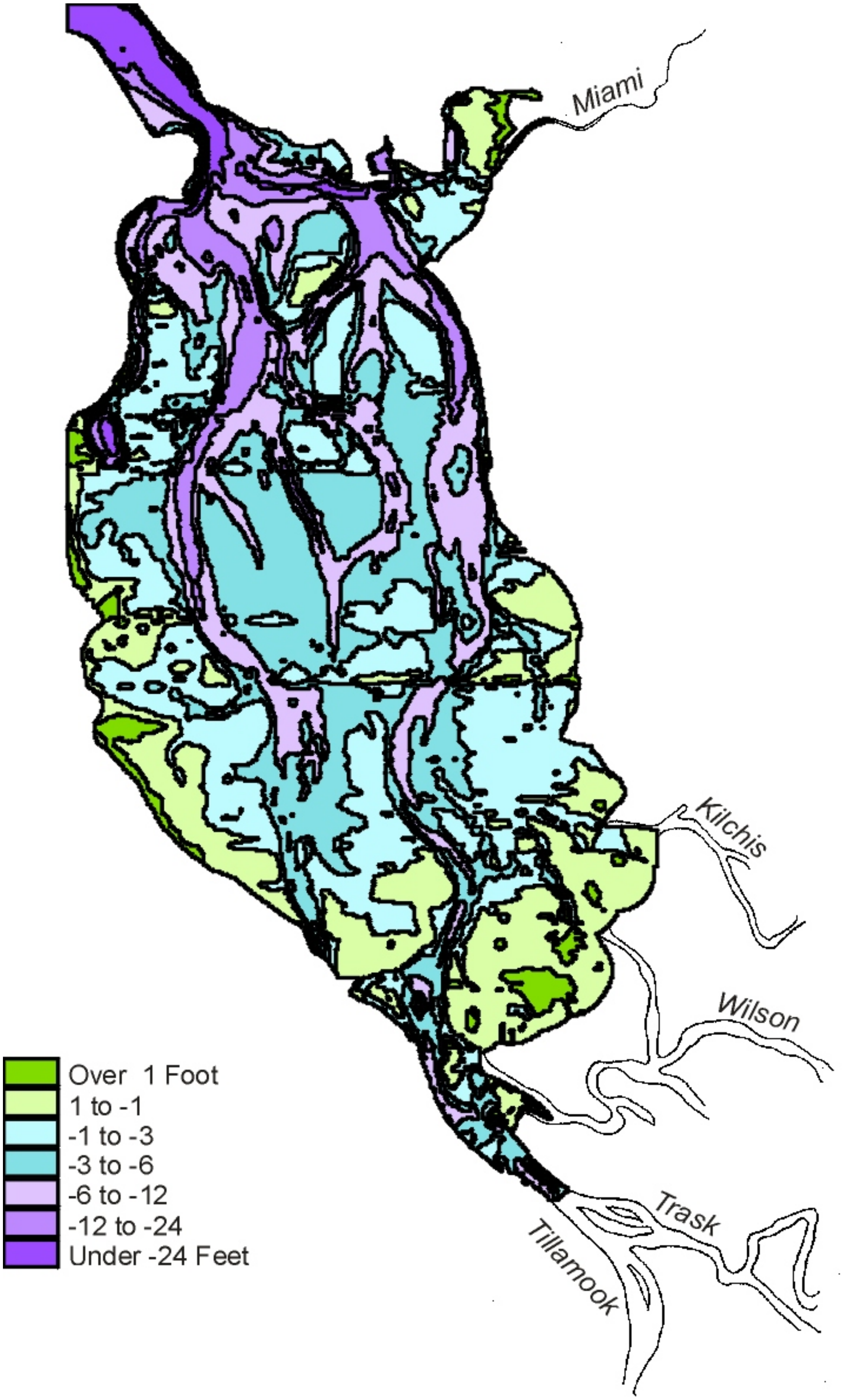

Figure 40. Map of the Tillamook Bay bathymetry showing the location where each of the five rivers enters the bay.

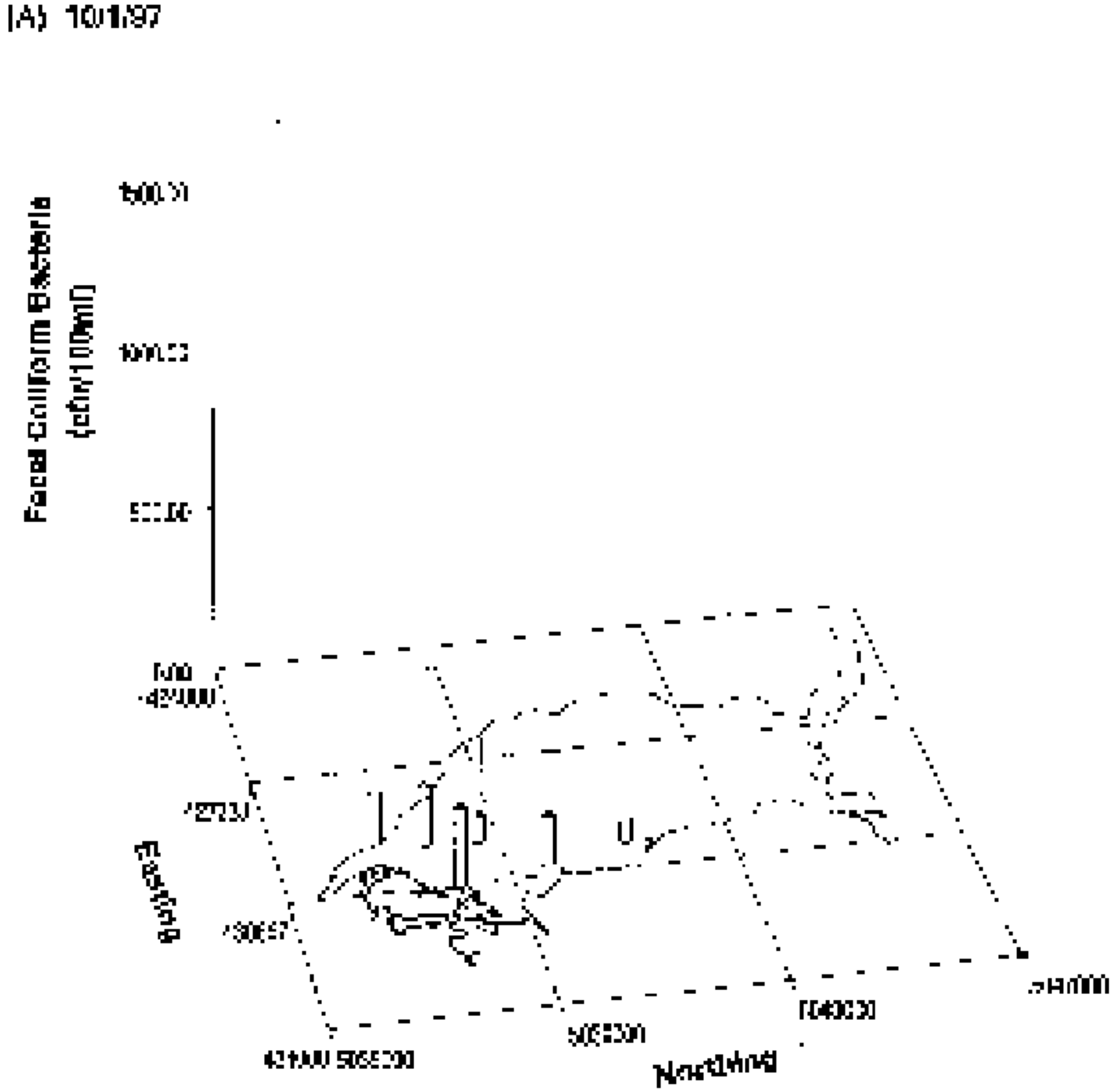

Figure 41. Measured concentrations of fecal coliform bacteria (cfu/100 ml) at a variety of sample locations in the southern portion of Tillamook Bay during a storm in early October, 1997. Results are depicted for samples collected on (A) October 1 (early in the storm), (B) October 3 (peak bacterial concentrations in rivers), and (C) October 5 (peak river discharge).

(B) 10/3/97

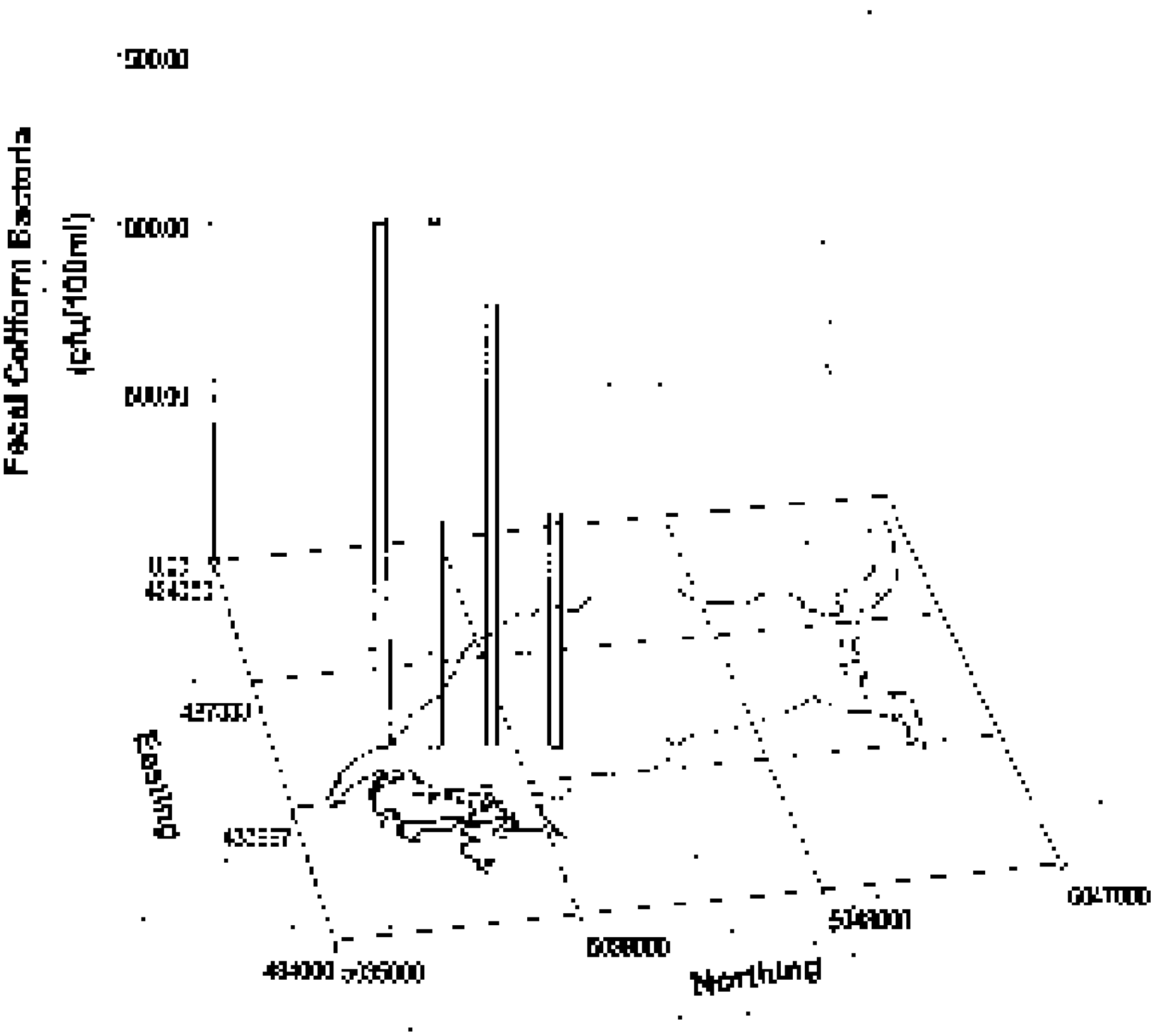

Figure 41. Continued.

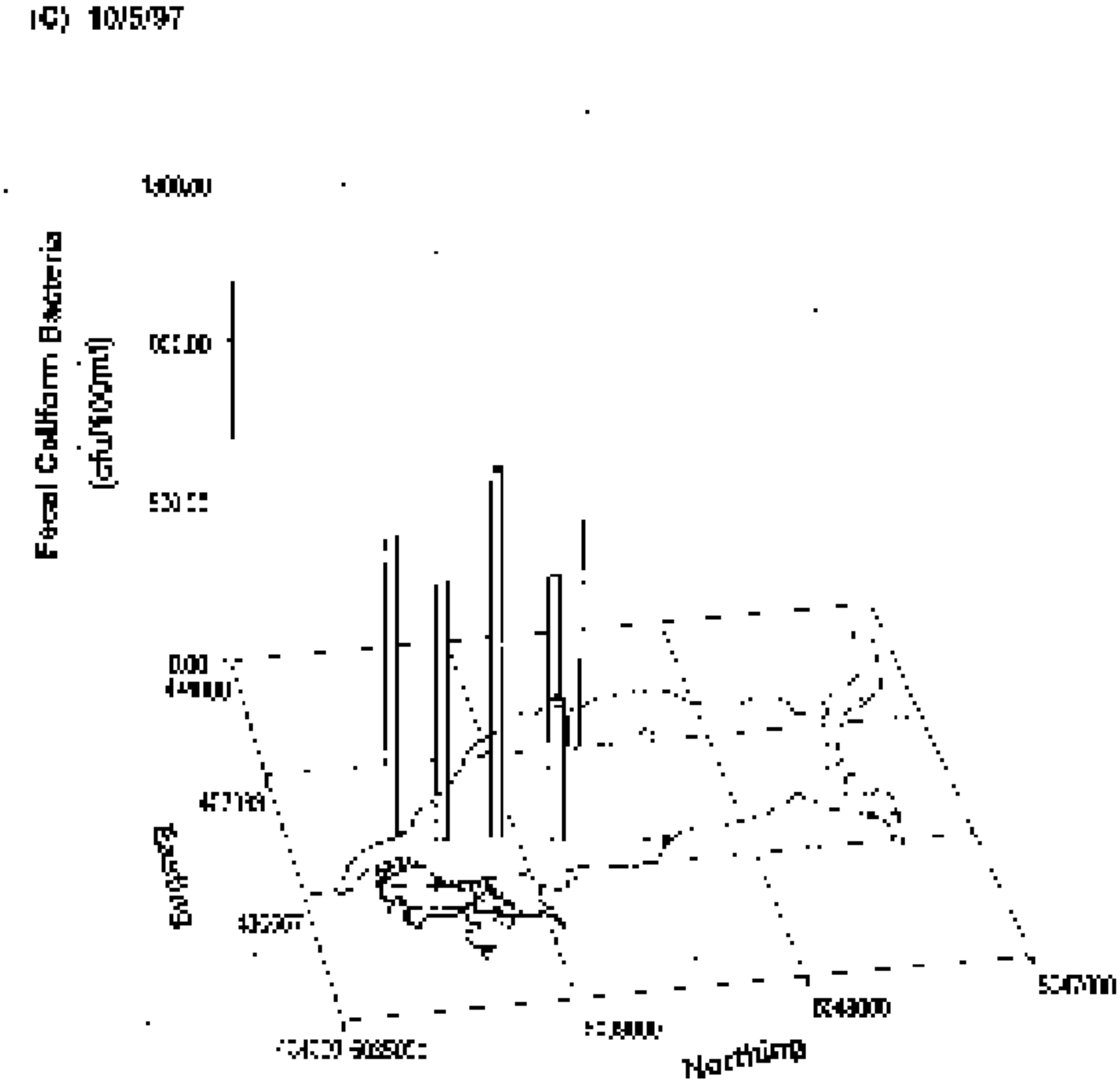

Figure 41. Continued.

During the low-discharge season, when fresh water discharge makes up a smaller component of bay inputs, the loads contributed by the various rivers, rather than bacterial concentrations in river water, are likely more important. Limited data collected on baywater concentrations of FCB by Jackson and Glendening (1982) and in this study (Figure 41) showed that the highest concentrations of bacteria in the bay are observed along the southwestern shore, just north of where the Tillamook and Trask Rivers enter the bay. High loads of FCB from the contributing rivers result in bay concentrations that often close oyster harvesting. Additionally, bacterial concentrations often exceed standards for recreational contact, diminishing the quality and recreational value of the region's rivers.

Concentrations of FCB tended to be highest by a considerable margin in the Tillamook River, and the river having lowest concentrations has consistently been the Kilchis (Figure 3). The Tillamook River has a relatively small watershed area, a high proportion of agricultural land use within the watershed, and more dairies and dairy waste per unit area than any of the other watersheds (Jackson and Glendening 1982). The Trask River, which contributes the largest bacterial loads, has the largest number of dairies, confined animal feedlot operation (CAFO) permits, and human population (Figure 42). Concentrations of FCB above 100 cfu/100 ml were routinely encountered in all rivers except the Kilchis. Concentrations above 200 cfu/100 ml were frequently encountered in the Tillamook River and occasionally encountered in the Trask, Wilson, and Miami Rivers, usually during summer storm events. Past studies have shown that the lower basins of these rivers had recorded unacceptable FCB concentrations most of the year (Jackson and Glendening 1982). Very high (> 500 cfu/100 ml) concentrations were mostly confined to the Tillamook River, although some storm events produced very high concentrations in the remaining four rivers. Generally, the highest concentrations were associated with fall or summer storm events, which tended to be preceded by relatively dry periods. The high concentrations seen in the summer months were attributed by Jackson and Glendening (1982) to input from streams that run in close proximity to barns and dairy pastures, resulting in direct loading of fecal coliform to tributary waters due to direct access by cows. The forest/agriculture interface generally does not exhibit fecal coliform concentrations that are unacceptable, supporting the earlier findings that the major sources of FCB contamination are found in the agricultural portion of the basin (Jackson and Glendening 1982).

Large changes in both loads and concentrations of FCB were associated with storm events. It has been suggested that prior moisture conditions and amount and intensity of rainfall play important roles in controlling the flux of FCB into surface waters (Dorsey-Kramer 1995; Jackson and Glendening 1982). Particularly high concentrations have consistently been observed during small summer storm events and the first storms after the summer low flow season (Figure 3; Jackson and Glendening 1982). Concentrations observed at these times tend to be much higher than are typically

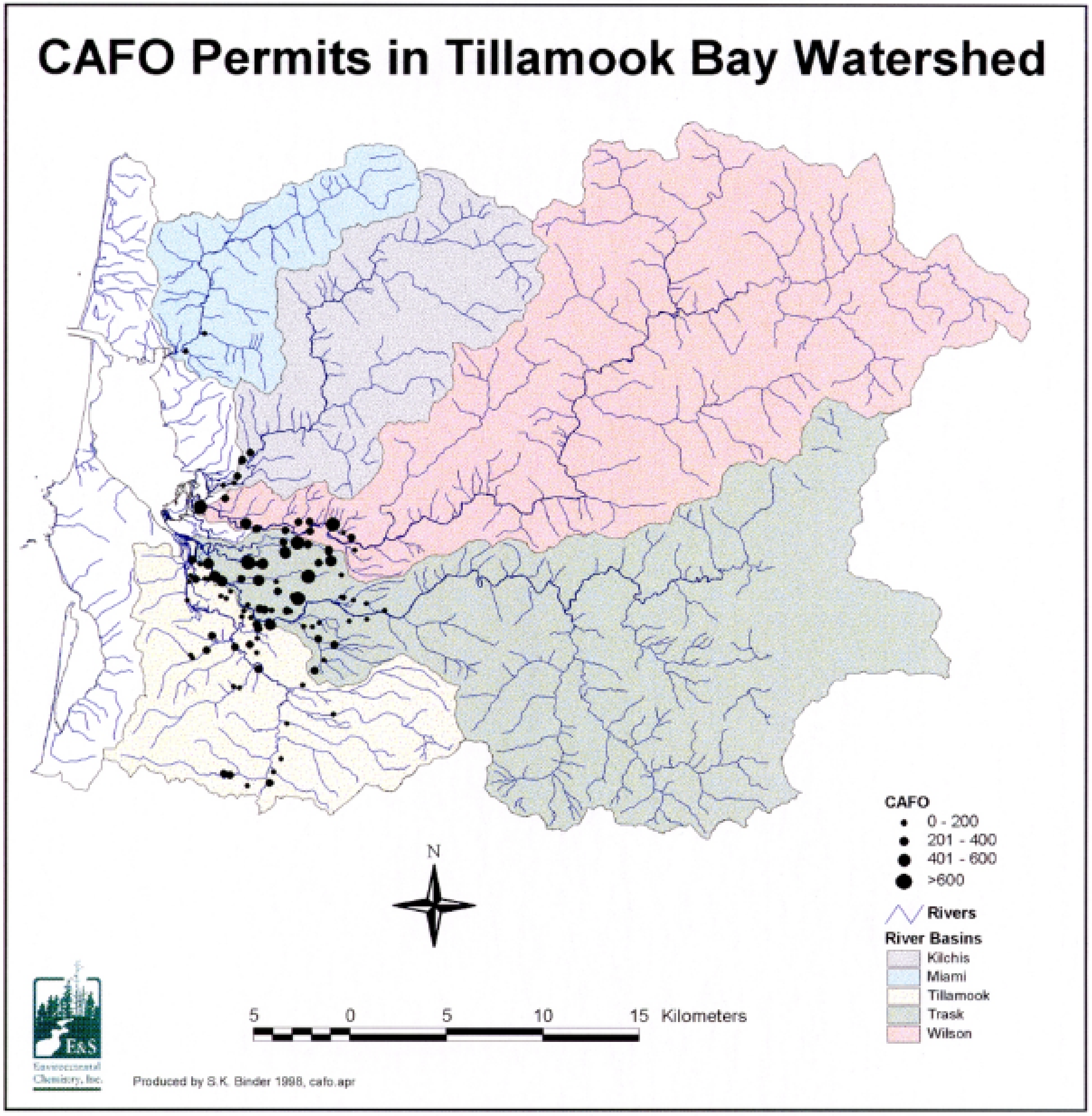

Figure 42. CAFO permits in the Tillamook Basin.

observed during winter or spring storms. This pattern was attributed in the earlier study to dilution during winter and spring of a relatively constant source of FCB.

The data collected in this study can only be used in a very limited fashion to examine whether or not the concentrations of FCB have changed appreciably since the last major study of this type in 1979/1980 (Jackson and Glendening 1982). During that earlier study, a number of samples were analyzed for bacteria at the same locations as were sampled at the primary sites of our study. A sufficient number of samples were analyzed within both studies during the months of October and December to permit such a comparison. The percent of samples at the primary site in each river found to exceed the bacterial standard (200 cfu/100 ml) during this study was actually quite similar to that found by Jackson and Glendening (Table 6). Although the available data are too limited to allow for a statistical evaluation, they are consistent with the belief that major changes in the extent of bacterial contamination of the rivers have not occurred in recent decades.

Table 6. Comparison of fecal coliform bacteria results for samplings by Jackson and Glendening (1982) and this study at the primary sites in the rivers included in both studies.

	Percent of samples exceeding criterion value (200 cfu/100 ml) (number of samples collected in parentheses)			
	December		October	
River	1979	1996-1997	1980	1997
Tillamook	100 (8)	70 (10)	57(7)	100 (11)
Kilchis	0 (11)	0 (10)	0 (8)	-
Trask	-	44 (9)	57 (7)	89 (9)
Wilson	25 (8)	22 (9)	67 (6)	100 (8)*
Miami	63 (8)	50 (10)	88 (8)	-

* TCCA data

Other Water Quality Variables

Loading of TSS was greatest in the winter, with summer loads being rather small. TSS loads were strongly associated with storm events. The largest storms, and consequent highest flows, produced the highest TSS concentrations and loads. Loading was greatest for the Trask and Wilson Rivers, corresponding to those rivers with the largest watersheds and highest flows. However, all of the rivers had high loads during storms. Results of paired sample analyses suggested that TSS concentrations were higher at the primary sites than at the forest/agriculture interfaces, but the magnitude of the differences was small, generally less than about 40 mg/L (Figure 18). These results suggest a relatively consistent TSS contribution from the lower agricultural portions of the watersheds. The largest contributions of TSS, however, are derived from the upper, forested portions of the watersheds, especially under high flow conditions when TSS values are highest. There is concern that sedimentation of the lower river and the bay has increased markedly since the last century, and that major causes of this increased sedimentation include road building, forestry, forest fires, and agriculture. Unfortunately, uncertainties in the bathymetric databases that are available for the bay preclude quantifying the extent of sedimentation that has occurred (Bernert and Sullivan 1998).

Eutrophication is of concern in many US estuaries and will continue to be a concern as US coastal populations increase (Day et al. 1989). Tillamook Bay has been classified as moderate to high in NOAA's estuary eutrophication classification (1996). TIN concentrations measured in the rivers remained relatively constant throughout the year, compared with the observed seasonal and episodic variations in bacterial concentrations and TSS. There was, however, suppression of TIN concentrations during summer compared with rest of the year (Figure 22). Summer is the period of low flows, and an increase in TIN concentrations would be expected due to less dilution if TIN behaved in a conservative fashion. Due to the relatively constant concentrations, TIN loads were highly dependent upon flows, with the periods of greatest nitrogen loads to the bay directly corresponding to the periods of greatest flows. These results suggest that biological uptake in the aquatic, and perhaps the terrestrial, environments during summer is a more important determinant of nitrogen dynamics in the watershed than is the magnitude of the sources and the differential source areas. Overall, the concentrations of nitrogen in the rivers were not especially high compared with rivers elsewhere in Oregon. For example, the median concentration of NO_3-N sampled in the Willamette Basin during the period April, 1993 through September, 1995 was 1.1 mg/L (n=289), with the upper 10% of concentrations above 5.9 mg/L (Rinella and Janet 1998). In this study, flow-weighted average concentrations of NO_3-N ranged from 0.73 mg/L in the Kilchis River to 0.93 mg/L in the Miami River and none of the measurements exceeded 1.3 mg/L.

TIN values at the down-river primary sites tended to be slightly less than 0.2 mg/L, higher than at the respective forest/agriculture interface sites (Figure 24). Most of the TIN at the down-river sites can be accounted for by examining the observed concentration in the river water draining the forested portions of the watersheds. The source of this upland nitrogen is not known, but is likely N-fixation in roots of alder trees which are common in upland riparian zones throughout the basin. Stottlemyer (1992) found an increase in streamwater NO_3^- concentration of about 0.6 mg/L downstream of an alder stand along Rock Creek, Denali National Park, Alaska. Thus, the concentrations of NO_3^- observed at the forest/agriculture interface on the rivers in the Tillamook Basin seem to be within the range of what would reasonably be contributed by N-fixation in alder stands. Fertilizer applications to forest stands may also constitute a significant source of N to the rivers.

Total phosphorus concentrations were highest in the Wilson and Trask Rivers. Summer concentrations were lower than winter concentrations, suggesting there is little or no dilution of TP with higher flows. The observed positive relationship between TP and flow (Figure 35), and especially between TP and TSS (Figure 36), suggest that phosphorus is mainly associated with soil particles. These likely originate from erosion sources within the watershed, although fertilizer sources cannot be ruled out. Overall, the measured concentrations of TP were moderately high compared to other watersheds in Oregon. The median concentration of TP reported for the Willamette Basin by Rinella and Janet (1998) was 0.09 mg/L and the upper 10% of their measured concentrations were above 0.36 mg/L. In this study, the flow-weighted average concentration of TP ranged from 0.11 mg/L in the Tillamook River to 0.52 mg/L in the Wilson River (Table 5), and all of the rivers except the Tillamook River had at lease one measurement of TP > 0.5 mg/L. The limit for TP considered necessary for the prevention of nuisance plant growth in streams is 0.10 mg/L (Mackenthun 1973).

6. CONCLUSIONS

As a consequence of this scoping study of water quality of the five rivers this flow into Tillamook Bay, a number of conclusions can be drawn, as follows:

- Fecal coliform bacteria (FCB) and total suspended solids (TSS) concentrations exhibited pronounced seasonal and episodic variability. This feature makes it difficult to monitor for changes in concentrations over time.

- Peak concentrations of FCB occurred during fall and summer storms, often reaching concentrations that were much higher than public health standards at the sites in the lower reaches of the rivers. Highest concentrations were found in the Tillamook River.

- Highest FCB loads were achieved in the Trask and Wilson Rivers as a consequence of relatively high FCB concentrations coupled with high flow rates. High FCB loads were also attained in the Tillamook River, despite the much lower flow rates of this river.

- Peak concentrations of TSS coincided with high flow periods, reaching highest concentrations and loads in the Trask and Wilson Rivers, the two rivers having the largest watersheds and highest flows.

- High temperatures (~ 20^{o}C) were recorded at the time of sampling in August in the lower reaches of the Tillamook, Trask, and Wilson Rivers. Due to concerns about the potential adverse effect of such temperatures on fisheries, the temporal and spatial variability in summer water temperature in these rivers should be further evaluated.

- Nutrient concentrations (N, P) were low to moderate in each of the rivers. Total phosphorus (TP) concentrations increased with flow, achieving highest values in the Trask and Wilson Rivers, apparently due to the observed close association between TP and TSS.

- Total inorganic nitrogen (TIN, mostly NO_3^-) concentrations showed a distinct seasonal pattern, with lowest concentrations during summer, likely due to biological uptake within the watershed.

- The major sources of TSS, TP, and TIN occurred within the upper watersheds, above the forest/agriculture interface. The most likely sources of the TSS and TP include erosional activities associated with land slides, roads, logging and previous forest fires. The most likely source of TIN is N-fixation in riparian alder stands. Small contributions of TSS, TP, and TIN were also derived from the lower watersheds, which are dominated by agricultural land use.

- The major sources of FCB occurred in the portions of the watersheds below the forest/agriculture interface on all rivers for which data were available to evaluate this issue (all except Tillamook River). The likely sources for this bacteria include dairy farming activities, failing septic systems, sewer treatment plants, and urban runoff.

As a result of this study, a baseline is now available against which to compare future water quality data to allow evaluation of temporal trends. A water quality monitoring plan will be developed and described in a subsequent report to TBNEP.

7. REFERENCES

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons. 1989. SWRRB, A basin scale simulation model for soil and water resources management. Texas A&M Press, College Station, TX.

Bernert, J.A. and T. J. Sullivan. 1997. Quality Assurance Plan for the Tillamook Bay National Estruary Project, River Water Quality Monitoring Project, E&S Environmental Chemistry, Inc., Corvallis, OR. Report Number 96-20-01.

Bernert, J.A. and T.J. Sullivan. 1998. Bathymetric Analysis of Tillamook Bay, E&S Environmental Chemistry, Inc., Corvallis, OR.

Blair, T. and K. Michener. 1962. Sanitary survey of Tillamook Bay and sanitary significance of the fecal coliform organism in shellfish growing area waters. Internal report, Oregon State Board of Health, Portland, OR.

Burkholder, J., K. Mason, and H. Glasgow Jr. 1992a. Water column nitrate enrichment promotes decline of eelgrass *Zostera marina*, evidence form seasonal microcosm experiments. Marine Ecol. Prog. Ser. 81:163-178.

Burkholder, J., E. Noga, C. Hobbs and H. Glasgow Jr. 1992b. New “Phantom” dinoflagellate is the causative agent of major estuarine fish kills. Nature 358:407-410.

Day, J., C. Hall, W. Kemp, and A. Yanez-Arancibia. 1989. Estuarine Ecology. New York City. John Wiley and Sons. 558 pp.

Dorsey-Kramer, J. 1995. A statistical evaluation of the water quality impacts of Best Management Practices installed at Tillamook County dairies. Thesis submitted to Oregon State University, Corvallis, OR.

Jackson, J. and E. Glendening. 1982. Tillamook Bay bacteria study fecal source summary report. Oregon Department of Environmental Quality, Portland, OR.

McKanthun, K.M. 1973. Towards a cleaner aquatic environment. U.S. Government Printing Office, Washington, DC.

Musselman, J. 1986. Sanitary survey of shellfish waters. Tillamook Bay, Oregon, Dec. 1986. U.S. Dept. of Health and Human Services, Public Health Service, Food and Drug Administration, Shellfish Sanitation Branch.

National Oceanic and Atmospheric Administration (NOAA). 1996. NOAA’s estuarine eutrophication survey. Vol. 1: South Atlantic Region. Office of Ocean Resources Conservation and Assessment, Silver Springs, MD. 50 pp.

Oregon Department of Agriculture. 1991. Tillamook management plan for commercial shellfish harvesting. Oregon Dept. of Agriculture, Food Safety Div., Salem, OR.

Oregon Department of Environmental Quality. 1994. Oregon’s 1994 Water Quality Status Assessment Report: 305(b). Oregon Department of Environmental Quality, Portland, OR.

Oregon Department of Environmental Quality. 1988. Oregon statewide assessment of nonpoint sources of water pollution. Oregon Dept. of Environmental Quality, Planning and Management Section, Portland, OR.

Rinella, F.A. and M.L. Janet. 1998. Seasonal and spatial variability of nutrients and pesticides in streams of the Willamette Basin, Oregon, 1993-1995. USGS Water Resources Investigations Report 97-4082C, Portland, OR. 59 pp.

Stottlemyer, R., 1992. Nitrogen mineralization and streamwater chemistry, Rock Creek watershed, Denali National Park, Alaska. Artic and Alpine Research. 24: 291-303.

Sullivan, T.J., J.M. Bischoff, and K. Vaché. 1998. Results of storm sampling in the Tillamook Bay Watershed. E&S Environmental Chemistry, Inc., Corvallis, OR.

Tillamook Bay National Estuary Project. 1997. Tillamook Bay environmental characterization.

Tillamook Soil and Water Conservation District. 1981. Tillamook Bay Drainage Basin Agricultural Non-point Source Abatement Plan, Tillamook County, Oregon, 167pp.

U.S. Department of Health and Human Services, Public Health Service, Food and Drug Admin. 1995. National Shellfish Sanitation Program manual of operations. Part I, Sanitation of shellfish growing waters. Center for Food Safety and Applied Nutrition, Office of Seafood, Program and Enforcement Branch, Washington, DC.

Wiltsey, M. 1990. Tillamook Bay watershed bacterial trends assessment. Dept. of Environmental Quality. Internal report., Portland, OR.