ASSESSMENT OF WATER QUALITY IN ASSOCIATION WITH LAND USE IN THE TILLAMOOK BAY WATERSHED, OREGON, USA

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ABSTRACT

The water quality in tributaries to Tillamook Bay, Oregon frequently exceeds standards for fecal coliform bacteria (FCB) and temperature. FCB inputs to the bay have forced periodic closure of the oyster shellfish industry. In addition, impaired water quality may be contributing to reduced salmonid populations in the bay and its tributaries through reduction in the quality of the habitat. Because of these concerns, the Tillamook Bay National Estuary Project (TBNEP) conducted several characterization studies and a long-term water quality monitoring program for the tributary rivers. This paper summarizes data collected to date within these efforts, including storm-based data on FCB and total suspended solids (TSS), and bi-monthly data on nutrient concentrations in selected rivers.

Monitoring data from 1996 to 2002 are summarized. Results for FCB and TSS are reported by storm, and storms are classified according to season and precipitation patterns in order to minimize intra-annual variability. There are not indications of large changes in water quality throughout the period of record, but it is too early in the program for trends analysis. Storms that exhibited the highest FCB concentrations tended to be those that occurred during fall and/or those that were preceded by relatively dry conditions and included high rainfall intensity.

Implementation of storm-based monitoring and classification of storms according to season effectively reduces the large variability inherent in the FCB monitoring data, thereby facilitating future trends analysis. Continued storm-based monitoring of FCB and TSS, and also continued collection of rainfall and river discharge data, will provide the database that will be needed to determine to what extent on-the-ground remediation actions and best management practices (BMPs) within the Tillamook Basin are having their desired effects.

Key words: fecal coliform bacteria, nonpoint source pollution, nutrients, Tillamook Bay, water quality

1. INTRODUCTION

Tillamook Bay exemplifies the type of estuary found on the Oregon Coast. The bay and watershed support diverse living resources, including some species that have been federally listed as endangered or threatened. 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, agriculture, and tourism. The U.S. Environmental Protection Agency designated Tillamook Bay as an estuary of national significance in 1992 and included it in the National Estuary Program. The bay faces environmental concerns common to other small estuaries in the Pacific Northwest. Many problems result from forestry and agricultural practices, urbanization, and habitat loss due to a combination of sedimentation and loss of riparian and wetland areas. With the support of citizens and agencies with legal mandates, the multistakeholder Tillamook Estuaries Partnership (TEP) hopes to find solutions to these environmental problems that balance economic interests and serve as a regional model.

Annual precipitation is high, about 225 cm at Tillamook and increasing dramatically in the Coast Range Mountains to the east. Most precipitation occurs in the form of rain during the period October through April. The Tillamook Bay watershed is drained by five rivers, each of which has a substantial salmon and/or steelhead fishery resource. Land use is rather clearly compartmentalized. Uplands are forested and have been managed largely for timber production. Lowland areas are agricultural, with numerous dairy farms. Rural residential housing areas are scattered mainly throughout the agricultural lands. Lower reaches of the Trask and Wilson Rivers flow through portions of the city of Tillamook.

The Tillamook Bay watershed 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 1980s, the Rural Clean Water Program (RCWP) identified bacterial sources to the bay and developed a FCB management plan for the watershed. Cost sharing was provided for farmers to adopt better manure management practices and manure storage facilities. Despite progress in these efforts to restore water quality, both fresh and saline waters in the Tillamook Basin often fail to meet water quality standards for bacteria. Important sources of FCB 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.

High bacterial concentrations often close harvesting in Tillamook Bay, which has been one of Oregon's leading producers of shellfish, particularly oysters. Bacterial concentrations in the bay have historically been high during the wet seasons of the year. 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).

Extensive information about TSS and nutrient levels has not previously been collected, but available data suggested that nutrient levels were 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 Tillamook Bay National Estuary Project (TBNEP) identified bacterial contamination, sedimentation, and salmonid habitat as the three priority issues under consideration.

Subsequently, flooding was 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 was limited and generally of uncertain quality. Data quality, detection limits, and variability were not well known or documented in most cases.

Since November, 1996, E&S Environmental Chemistry, Inc., under contract to TBNEP and Tillamook County, conducted a water quality monitoring project throughout the basin (Figure 1). It has included periodic monitoring for nutrients and intensive storm sampling for FCB and TSS, two parameters that exhibit significant episodic variability. This research was intended to provide detailed information on current water quality conditions at multiple locations in each of the five rivers and to quantify seasonal and episodic variability in that water quality. It provided critical information needed to design a rigorous water quality-monitoring program (Sullivan and Eilers, 1999) and to prepare the Comprehensive Conservation and Management Plan (CCMP) for the watershed (TBNEP, 1999).

The results of this work have been presented in a series of reports to TBNEP (Bernert and Sullivan, 1997; Sullivan and Eilers, 1999; Sullivan et al., 1998a,b; 2002) and in the CCMP (TBNEP, 1999). The major components are summarized here.

2. METHODS AND MATERIALS

2.1 Site Allocation

One primary sampling site was selected at the downstream end of each of the five rivers in relatively close proximity to the bay (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. Bridges and docks were selected as primary sampling locations for logistical purposes. During the course of the study, the Burton Bridge (primary site location on the Trask River) was removed and rebuilt. The 5th street dock, downstream from Burton Bridge, then became the new primary site on the Trask River.

Additional sampling sites were selected at upstream locations. Criteria used in determining site locations included the location of land use transitions, 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. This paper focuses on results for the primary sites and the secondary sites located at the forest/agriculture interface on the respective rivers (Figure 1).

2.2 Sample Collection

Samples for bacteria were collected using a sterilized weighted bottle, which was allowed to fill at about 0.5 m depth. Samples for other laboratory analyses were collected using a van Dorn sampler, weighted collection bottle, or a long-handled pole sampler. Samples were filled to minimize air bubbles and the bottles placed in coolers on ice and transported to the Oregon State University Central Analytical Laboratory in Corvallis for chemical analyses and Kilchis Dairy Herd Services in Bay City for bacterial analyses.

River water samples were collected approximately monthly from November 1996 through December 1997. In addition, storm events were sampled during six years. Storms were selected in an effort to represent storms of different intensity and differing hydrological response. On a number of sampling occasions during Year 1, 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. Comparison of results for these sample pairs was used to evaluate the extent to which constituent concentrations near the river mouths could be attributed to source areas in the upper forested, versus the lower developed, portions of the watersheds.

Early fall storms were generally preceded by a long dry period when there was little flushing of the watersheds. Winter storms were generally preceded by wetter antecedent conditions and more continual flushing of the watersheds due to frequent large rainfall events. Spring storms represented intermittent dry and wet periods. Storms were chosen so that each of these storm types and associated antecedent moisture conditions were represented to the extent possible.

Storm sampling was continued to January, 2002 on four rivers (to March 2002 on the Tillamook River), and samples were analyzed for FCB (Tillamook, Trask, and Wilson Rivers), and TSS (Trask, Wilson, and Kilchis Rivers). A total of 24 to 29 storms have been sampled for each river. In addition, nutrient sampling was conducted approximately bimonthly on the Trask and Wilson Rivers, as funding permitted.

FCB and TSS concentrations were typically measured during two to three storm events during each of three seasons each year (fall, winter, spring). During each storm, typically six to eight samples (plus QA samples) were collected and analyzed for bacteria at each site.

2.3 Discharge and Precipitation

Precipitation data were collected hourly in Tillamook by the Oregon Department of Forestry. River flow data for the Tillamook, Kilchis, and Miami Rivers were collected by the Oregon Water Resources Department (OWRD), and for the Trask and Wilson Rivers by the U.S. Geological Survey (USGS). The data set provided by OWRD for the Tillamook, Kilchis and Miami rivers contained a number of gaps during which stage data were not collected. These gaps were filled using a series of simple linear regressions. Four unique regression equations, each corresponding to a season and based on the Wilson River discharge data collected by USGS, were applied to each of the three basins. The equations, along with quantitative measures of uncertainty (r^2 ranging from 0.85 to 0.97), are given by Sullivan et al. (1998a).

2.4 Laboratory Analysis

River water samples were analyzed for total phosphorus (TP), NO_3^- , NH_4^+, conductivity, TSS, and FCB. Total inorganic nitrogen (TIN) was calculated as the sum of NO_3-N plus NH_4^+-N. FCB was analyzed on nearly all sample occasions, using the membrane filtration method described in Standard Methods for the Examination of Water and Wastewater (APHA, 1995). Conductivity and TSS were analyzed for most samples, using a platinum electrode and gravimetric analysis, respectively. Nutrients (NO_3^-, TP, NH_4^+) were analyzed approximately monthly for the first year and generally bi-monthly thereafter. Samples for nutrients were filtered through a 0.45µ Millipore filter using vacuum filtration. Total P was analyzed by ascorbic acid digestion. Inorganic nitrogen was measured as NH_4^+ using the Perstorp method (SM 4500) and as NO_3-N using ion chromatography. Duplicate and deionized water blank samples were submitted as routine samples to the laboratories as checks on analytical quality.

3. RESULTS AND DISCUSSION

3.1 Hydrology

The Wilson River hydrograph for each water year throughout the period of study is depicted in Figure 2. It shows the pattern typical of the Tillamook Basin: low river flows (generally <500 cfs [14,000 l/s]) during summer, and frequent storms from October through March. Most of the largest storms occur in the period November through January and often achieve peak discharge >10,000 cfs (280,000 l/s) on the Wilson River. Flood stage on the

Wilson River is designated as 14,100 cfs (400,000 l/s). A major drought was experienced during the fall and winter of 2000-2001. No large storms occurred during this period.

3.2 Water Quality Comparisons Across the Five Rivers

Table 1 shows the flow-weighted annual mean for measured water quality variables at the primary sites on all five rivers for the first year of sampling (1997). FCB concentrations were variable from river to river, ranging from 0 to several thousand cfu/100 ml or more at the primary sites (c.f., Figure 3). The highest concentrations were generally found in the Tillamook River and highest loads in the Trask River.

Bacterial concentration data were collected at or near the forest/agriculture interface on four of the rivers. 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 than 100 cfu/100 ml (both on the Trask River).

Throughout the period of study, over 75% of the monitored storms during all seasons for the Tillamook and Trask Rivers exhibited storm median FCB concentration higher than the health standard of 200 cfu/100 ml. As an example, summary statistics for storms monitored in the Trask River are shown in Table 2. In contrast, only 18% of the monitored storms for the Wilson River showed such high median FCB concentrations.

The Tillamook, Trask, and Wilson Rivers had dramatic increases in FCB concentrations associated with fall storm events, which often 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 FCB contributions from the watersheds to the rivers. The median measured FCB concentration exceeded 200 cfu/100 ml in those three rivers during fall, and in the Tillamook and Trask River during all three seasons (Table 3). The highest concentrations of FCB during storms were often achieved well before the time of peak river discharge, and often during the period of most intensive rainfall (c.f., Figure 4).

The largest bacterial loading to the Bay occurred from the Trask River, in response to relatively high concentrations coupled with substantially higher discharge than most of the other rivers (Sullivan et al., 1998b). 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 of bacteria in 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.

During the low-discharge season, when fresh water discharge makes up a smaller component of bay water, 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 Sullivan et al. (1998a) 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, which 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 (Sullivan et al., 1998a). The forest/agriculture interface generally did not exhibit FCB concentrations that were above the 200 cfu/100 ml standard, supporting the earlier findings that the major sources of FCB contamination are found in the agricultural/ urbanized portion of the basin (Jackson and Glendening, 1982).

Total suspended solids generally increased with increasing discharge in the Trask and Wilson Rivers, although variability was high (Figure 5). Values of TSS exceeding 200 mg/L were almost exclusively confined to high-discharge periods (> 4,000 cfs). Similarly, TSS values exceeding 400 mg/L were almost exclusively confined to periods when discharge exceeded 7,000 cfs. The rivers with the greatest flows and the largest watershed areas (Trask and Wilson) had the highest TSS concentrations and the river with the smallest watershed area (Tillamook) had the lowest TSS concentrations.

Loading of TSS was greatest in the winter. TSS loads were strongly associated with storm events. The largest storms, and consequent highest discharge, 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 discharge.

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 6). For each of the four rivers depicted in Figure 6, most drainage water is contributed to the mainstem river above the forest/agriculture interface (Sullivan et al., 1998b). Thus, discharge is similar at the paired sites and concentration differences also reflect load differences. The results of the paired sample analysis therefore suggest a relatively consistent TSS contribution from the lower agricultural portions of the watersheds. The largest contributions of TSS were derived from the upper, forested portions of the watersheds, especially under high discharge conditions when TSS values were 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).

Total P concentrations were variable from river to river, with the highest concentrations consistently found in the Trask, Kilchis, and Wilson Rivers. 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 often exceeded 0.5 mg/L.

Total P concentrations at the forest/agriculture interface were often somewhat lower than at the primary sites (Figure 6). There was a general relationship (r^2=0.47, $p \leq 0.0001$) between TP and discharge. The rivers with largest watersheds, during periods of the highest discharge, tended to have the highest TP concentrations (Trask and Wilson) and the river with the lowest discharge and smallest watershed (Tillamook) had the lowest TP concentrations. There was not a strong relationship, however, observed between TP and discharge either between or within rivers. This contrasts with the much stronger relationship observed between TP and TSS (r^2=0.84; $p \leq 0.0001$) in all of the rivers (c.f., Figure 7). The fact that TP is much more closely related to TSS concentration than either TP or TSS is related to discharge suggests that the P is bound to soil particles. It is likely that the sources of the TP and TSS are the same and that the P 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 (Figure 6) and that TP was mostly generated in the forested part of the watershed where most of the sediment originates. 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, personal communication).

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, and all of the rivers except the Tillamook River had at least one measurement of TP > 0.5 mg/L.

Total inorganic N concentrations (TIN; NO_3-N + NH_4-N) were generally near 1 mg/L (± 0.2 mg/L) in all rivers. 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.

Paired sample analyses 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 watersheds (Figure 6). TIN values at the down-river primary sites tended to be almost 0.2 mg/L higher than at the respective forest/agriculture interface sites (Figure 6). 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 N is not known, but is likely N-fixation associated with 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. Wigington et al. (1998) sampled 48 streams draining predominantly forested watersheds in the Oregon Coast Range and found variable NO_3^- concentrations, frequently between 0.75 and 1.5 mg/L, as NO_3^-N. Wigington et al. (1998) attributed these high NO_3^- concentrations to the prevalence of alder in the study watersheds. 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 could reasonably be contributed by N-fixation in alder stands. Fertilizer applications to forest stands may also constitute a source of N to the rivers.

Concentrations of TIN were reduced during summer and were higher during winter. This was likely due to greater biological demand for N in the aquatic and terrestrial systems during summer months and transport opportunity during winter. The greatest amount of seasonal variability in TIN loads occurred during the winter months, and may have been associated with greater variability in discharge. However, there was not a clear relationship between TIN concentrations and discharge. These results suggest that biological uptake in the aquatic, and perhaps the terrestrial, environments during summer is a more important determinant of N dynamics in the watershed than is the magnitude of the sources and the differential source areas. Overall, the concentrations of N 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). Ten percent of the streams in the Oregon Coast Range that were surveyed by Wigington et al. (1998) had NO_3^-N concentration higher than 1.4 mg/L. 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.

3.3 Trends in Water Quality

Water quality data collected within this project provide the foundation for future trends analysis. As BMPs continue to be implemented within the Tillamook Basin, it is hoped that the concentrations and loads of FCB, and perhaps to a lesser extent TSS and nutrients, will decrease in each of the rivers that flow into Tillamook Bay. It will be important to verify if such improvements do, in fact, occur and to quantify the magnitude of improvement. Future trends analysis will be needed to determine if BMPs are having their desired effects. Unfortunately, the water quality parameters of greatest interest, especially FCB, exhibit pronounced seasonal and episodic variability. FCB concentrations within a given river often change by more than two orders of magnitude within a given rainstorm (Figure 3A). Variability can be reduced by comparing results for discharge-weighted storm median values, rather than individual measurements (Figure 3B), and can be reduced further by considering only storms sampled within a particular season (Figure 3C) or only storms of a particular type (Figure 3D). In the latter figure panel, storms represented by three or more data points are shown. They include:

Storm Type 2 - High rainfall intensity
High (> 30 cm) precipitation during previous 30 days
Relatively wet immediately preceding storm

Storm Type 8 - Low rainfall intensity

moderate precipitation (15-30 cm) during previous 30 days

Relatively wet immediately preceding storm

Storm Type 11 - Low rainfall intensity

Low precipitation (< 15 cm) during previous 30 days

Relatively dry immediately preceding storm

Future trends analysis based on consideration of storm-averaged values for only certain seasons or types of storms may detect trends more readily than analysis of individual storm measurements.

3.4 QA/QC

Sullivan et al. (1998a) presented the results of duplicate sample analysis for FCB, NO_3^--N, TP, and TSS in this study. 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, calculated as the standard deviation expressed as a percentage of the mean) 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).

4. CONCLUSIONS

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

- FCB and TSS concentrations exhibited pronounced seasonal and episodic variability.
- Peak concentrations of FCB occurred during fall 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 River as a consequence of relatively high FCB concentrations coupled with high discharge. High FCB loads were also attained in the Tillamook River, despite the much lower discharge of this river.
- Peak concentrations of TSS coincided with high discharge periods, reaching highest concentrations and loads in the Trask and Wilson Rivers, the two rivers having the largest watersheds and highest discharge.
- TP concentrations increased with discharge, achieving highest values in the Trask and Wilson Rivers, apparently due to the observed close association between TP and TSS.
- TIN (mostly NO_3^-) concentrations showed a distinct seasonal pattern, with lowest concentrations during summer, likely due in part to biological uptake within the watersheds.
- 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. Smaller contributions of TSS, TP, and TIN were also derived from the lower watersheds,

which are dominated by agricultural, rural residential, and (for the Wilson and Trask Rivers) urban land use.

- The highest concentrations and loads of FCB occurred in the portions of the watersheds below the forest/agriculture interface. The likely sources for this bacteria include dairy farming activities, failing septic systems, sewer treatment plants, and urban runoff.

Current water quality conditions in the lower Tillamook Basin are well described. There is no indication in the available data, however, to suggest that river water quality has improved in recent years in response to changes in land management. Nevertheless, 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.

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Table 1. Flow-weighted average concentration of water quality parameters measured during a 12-month monitoring study (1997) at the primary site on each of the five rivers (number of samples 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 (μS/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)
TP (mg/L)	0.11(21)	0.25(4)	0.52(19)	0.22(20)	0.15(21)

[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.

Table 2. List of monitored storms for the lower Trask River with summary statistics for hydrology, precipitation, FCB, and TSS.

Storm #	Date Storm Began	Season	Total Storm Discharge (L x 10^9)	Total Storm Precip (cm)	Previous 7-day Precip (cm)	Discharge-Weighted Storm Median FCB (cfu/100 ml)[1]	Storm Median FCB Load (cfu x 10^6/sec)	Discharge-Weighted Storm Median TSS (mg/L)[1]	Storm Median TSS Load (mg x 10^4/sec)
1 [2]	12/4/96	Winter	39	7.3	11.4	84 (7)	139	144 (7)	2371
2 [2]	1/16/97	Winter	17	8.2	1.4	216 (4)	111	13 (4)	66
3a (5^{th})	9/30/97	Fall	31	11.6	3.5	1229 (17)	416		
3b (TTR)	9/30/97	Fall	31	11.6	3.5	820 (9)	299		
4	2/9/98	Winter	44	10.5	4.4	271 (7)	151	9 (4)	46
5a (5th)	2/27/98	Spring	40	11.0	5.6	473 (8)	284		
5b (TTR)	2/27/98	Spring	40	11.0	5.6	120 (8)	72		
6	11/12/98	Fall	5	3.1	3.7	260 (7)	31	6 (7)	7
7	11/20/98	Fall	40	14.6	4.5	570 (5)	1022	103 (6)	1581
8	12/11/98	Winter	57	10.0	8.0	242 (6)	358	63 (6)	935
9	12/28/98	Winter	106	16.7	7.3			500 (5)	13362

10	1/12/99	Winter	8	3.5	1.9	155 (6)	66	43 (5)	226
11	1/27/99	Winter	49	4.6	5.9			161 (6)	2582
12	2/4/99	Winter	57	5.4	4.9			34 (7)	383
13	4/7/99	Spring	19	3.2	1.3	208 (6)	66	3 (6)	8
14	5/1/99	Spring	15	7.2	1.5	2094 (7)	627	10 (6)	29
15	10/27/99	Fall	5	5.4	2.1	1655 (9)	278	16 (8)	28
16 [3]	11/8/99	Fall	4	4.3	2.8	366 (6)	38	7 (5)	6
17	1/3/00	Winter	27	5.3	3.7	285 (6)	276	108 (6)	1045
18	1/31/00	Winter	32	7.6	2.1	420 (7)	490	115 (6)	1431
19	2/24/00	Spring	9	4.5	3.7	475 (8)	113	4 (8)	9
20	10/27/00	Fall	3	2.8	0.4	818 (4)	72	3 (4)	3
21	11/28/00	Fall	8	2.3	4.9	101 (4)	16	2 (4)	3
22	12/14/00	Winter	14	5.0	1.2	376 (8)	95	8 (7)	20
23	3/15/01	Spring	16	4.7	1.3	400 (8)	73	4 (8)	8
24	5/14/01	Spring	14	6.2	0.0	1068 (6)	335		
25	11/13/01	Fall	31	11.8	0.6	210 (9)	183	50 (8)	446

26	11/27/01	Fall	18	7.2	9.4	641 (7)	626	53 (7)	521
27	1/24/02	Winter	67	14.8	11.3	128 (7)	233	137 (7)	2485

[1] Number of samples is provided in parentheses

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

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

Table 3. FCB and TSS concentrations by season[1] in the four rivers included in the continued storm monitoring, based on data collected during rainstorms between 1996 and 2002.

River	Statistics	FCB Concentration (cfu/100ml)			TSS Concentration (mg/L)		
		Fall	Winter	Spring	Fall	Winter	Spring
Tillamook	n[2]	71	87	60	9	16	7
	1st quartile	285	129	93	5	6	4
	median	890	320	226	7	10	6
	3rd quartile	1975	605	739	12	29	12
Trask	n[2]	87	65	58	54	72	36
	1st quartile	205	93	111	5	18	3
	median	560	234	245	15	54	4
	3rd quartile	1153	440	788	51	152	10
Wilson	n[2]	55	65	41	57	73	34
	1st quartile	71	19	12	2	28	2
	median	230	61	33	11	87	6
	3rd quartile	455	156	156	83	223	12
Kilchis	n[2]	12	19	15	56	73	33
	1st quartile	17	7	10	2	9	1
	median	33	14	31	10	27	3
	3rd quartile	168	44	51	35	93	10

[1] Fall was defined as Sept. 1 to Nov. 30, winter as Dec. 1 to Feb. 15, and spring as Feb 16 to May 31

[2] number of samples analyzed

Figure Legends

Figure 1. Sampling site locations.

Figure 2. Wilson River discharge during the period of record for the long-term water quality monitoring program.

Figure 3. Series of graphs showing selected FCB data for the Tillamook River throughout the monitoring period. All measured values are displayed in the top panel. Discharge-weighted storm median values are displayed in the three lower panels, first showing data for all storms, followed by all storms within a single season, followed finally by all storm types represented by three or more data points. Storm types were defined on the basis of rainfall intensity and antecedent precipitation.

Figure 4. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3, given as dots), 6 hour precipitation (given as bars) totals (cm), and river discharge (L/s x 10^4, given as solid line) at the primary monitoring site on the Tillamook River for the October 1997 storm.

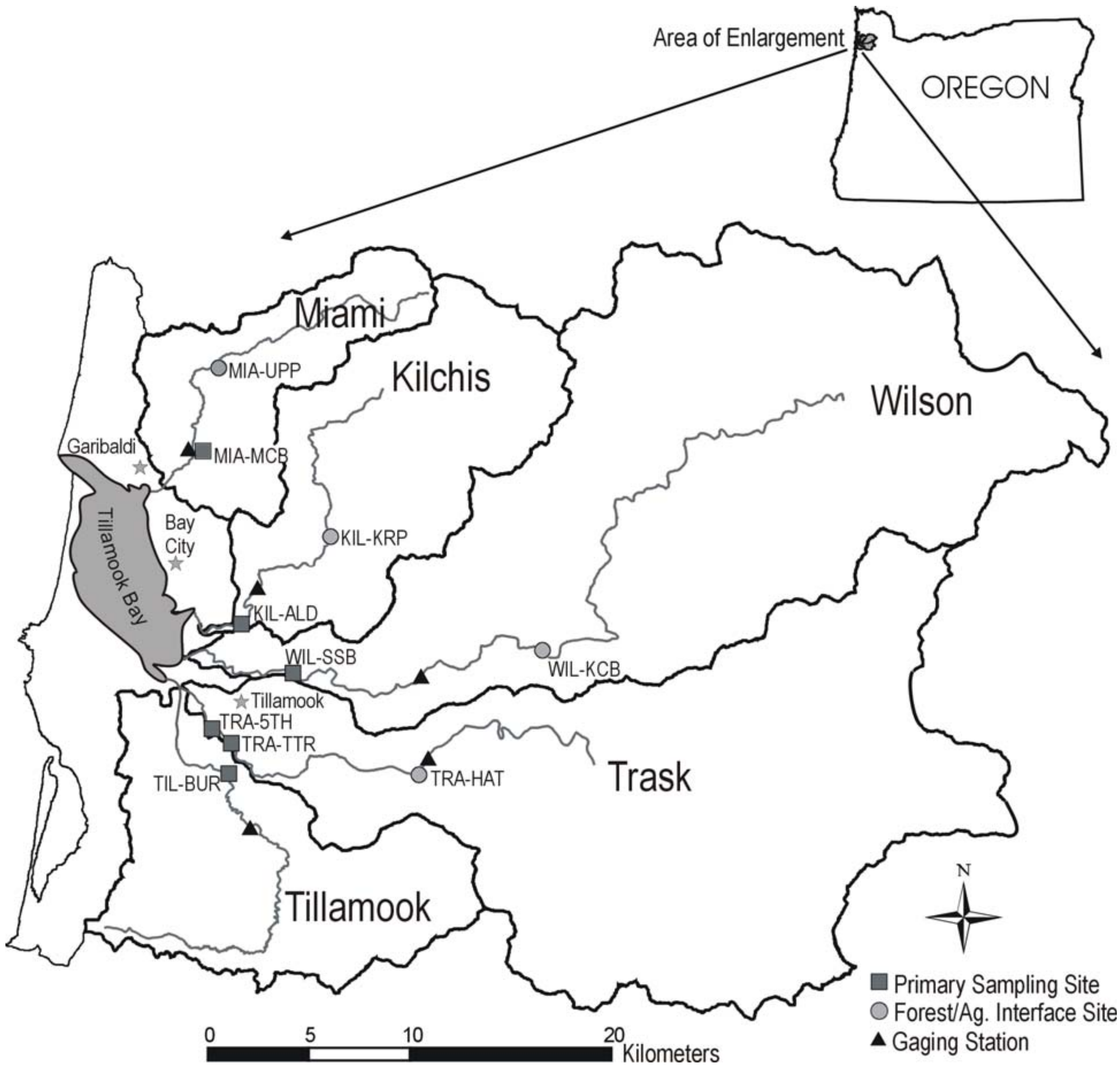
Figure 5. Relationship between total suspended solids and discharge for the Trask and Wilson Rivers.

Figure 6. Results of paired sample analyses for A) total suspended solids, B) total phosphorus, and C) total inorganic nitrogen (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 7. Measured values of total phosphorus versus total suspended solids in the Wilson and Trask Rivers.

Figure 1



Area of Enlargement
OREGON
Miami
Kilchis
Wilson
Trask
Tillamook
Garibaldi
Bay City
Tillamook Bay
Tillamook
MIA-UPP
MIA-MCB
KIL-KRP
KIL-ALD
WIL-SSB
WIL-KCB
TRA-5TH
TRA-TTR
TRA-HAT
TIL-BUR
N
Primary Sampling Site
Forest/Ag. Interface Site
Gaging Station
0
5
10
20
Kilometers

Figure 2

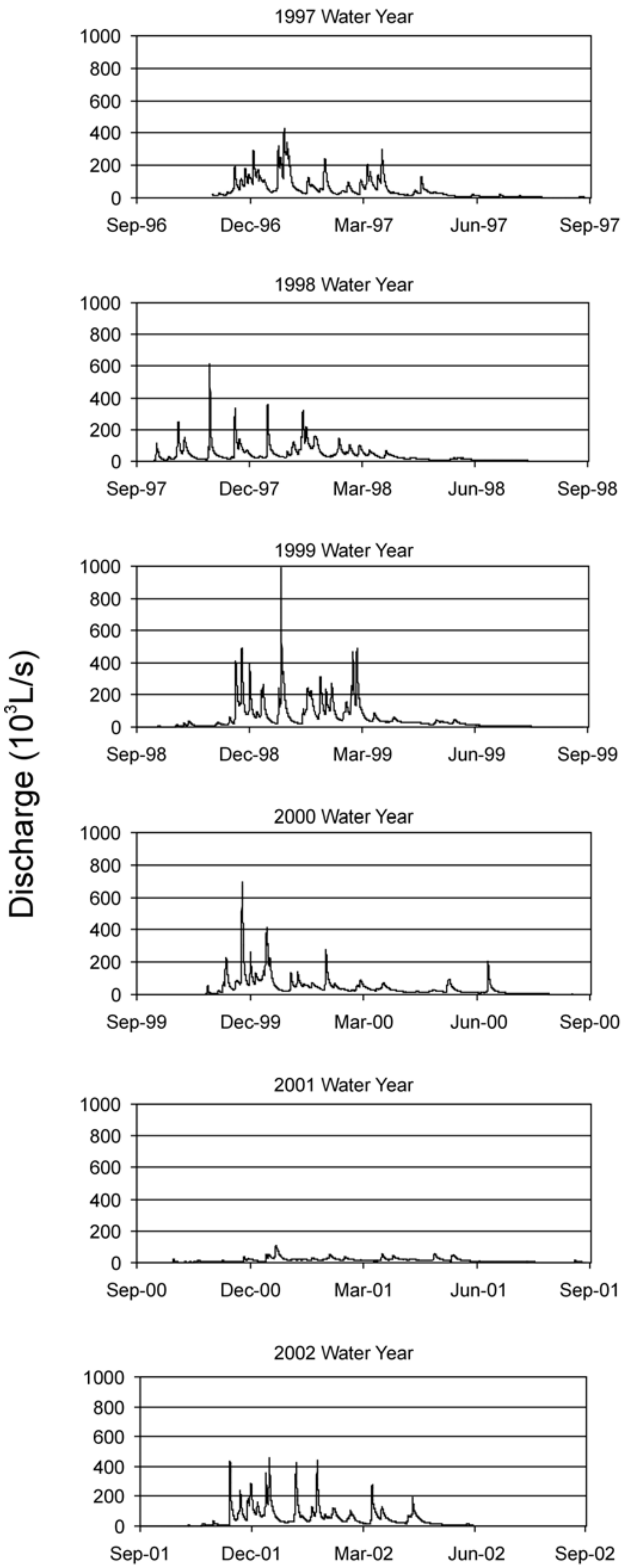

1997 Water Year
1998 Water Year
1999 Water Year
2000 Water Year
2001 Water Year
2002 Water Year
Discharge (10^3L/s)
1000
800
600
400
200
0
Sep-96 Dec-96 Mar-97 Jun-97 Sep-97
Sep-97 Dec-97 Mar-98 Jun-98 Sep-98
Sep-98 Dec-98 Mar-99 Jun-99 Sep-99
Sep-99 Dec-99 Mar-00 Jun-00 Sep-00
Sep-00 Dec-00 Mar-01 Jun-01 Sep-01
Sep-01 Dec-01 Mar-02 Jun-02 Sep-02

Figure 3

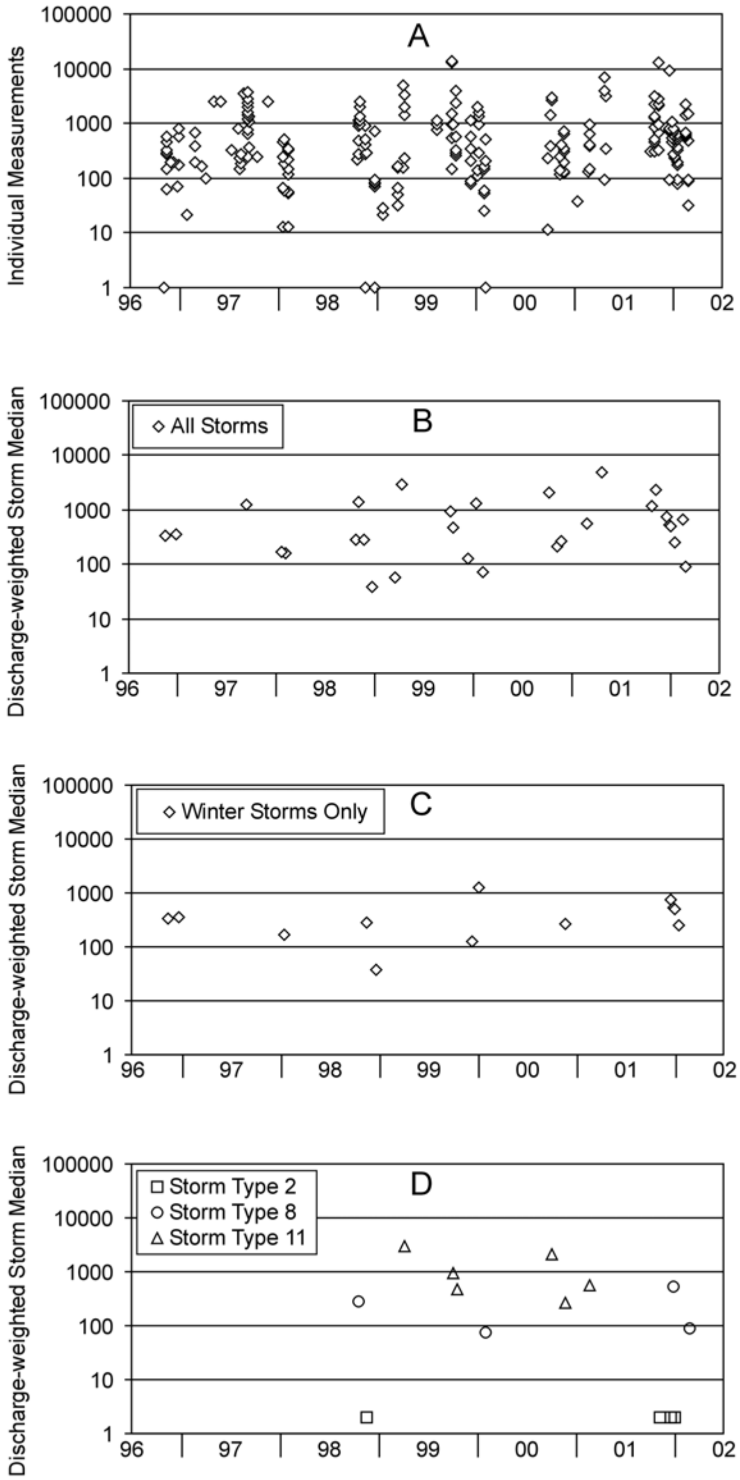

A
B
C
D
Individual Measurements
Discharge-weighted Storm Median
All Storms
Winter Storms Only
Storm Type 2
Storm Type 8
Storm Type 11
100000
10000
1000
100
10
1
96
97
98
99
00
01
02

Figure 4

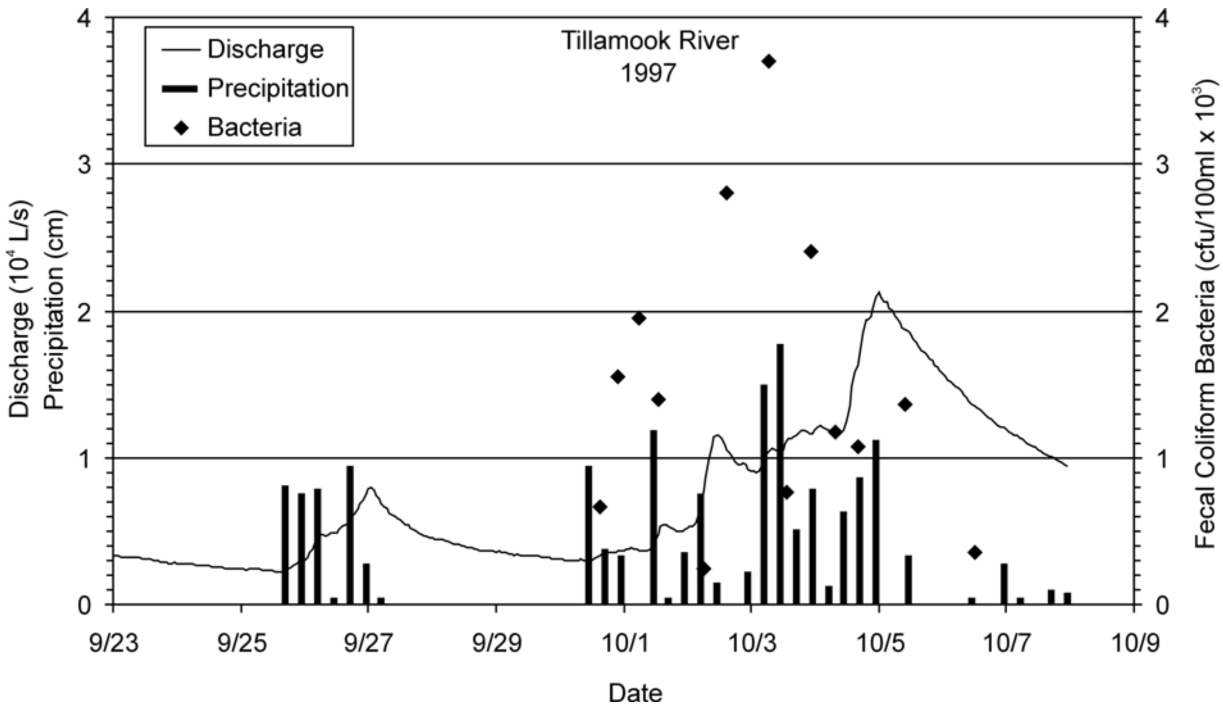
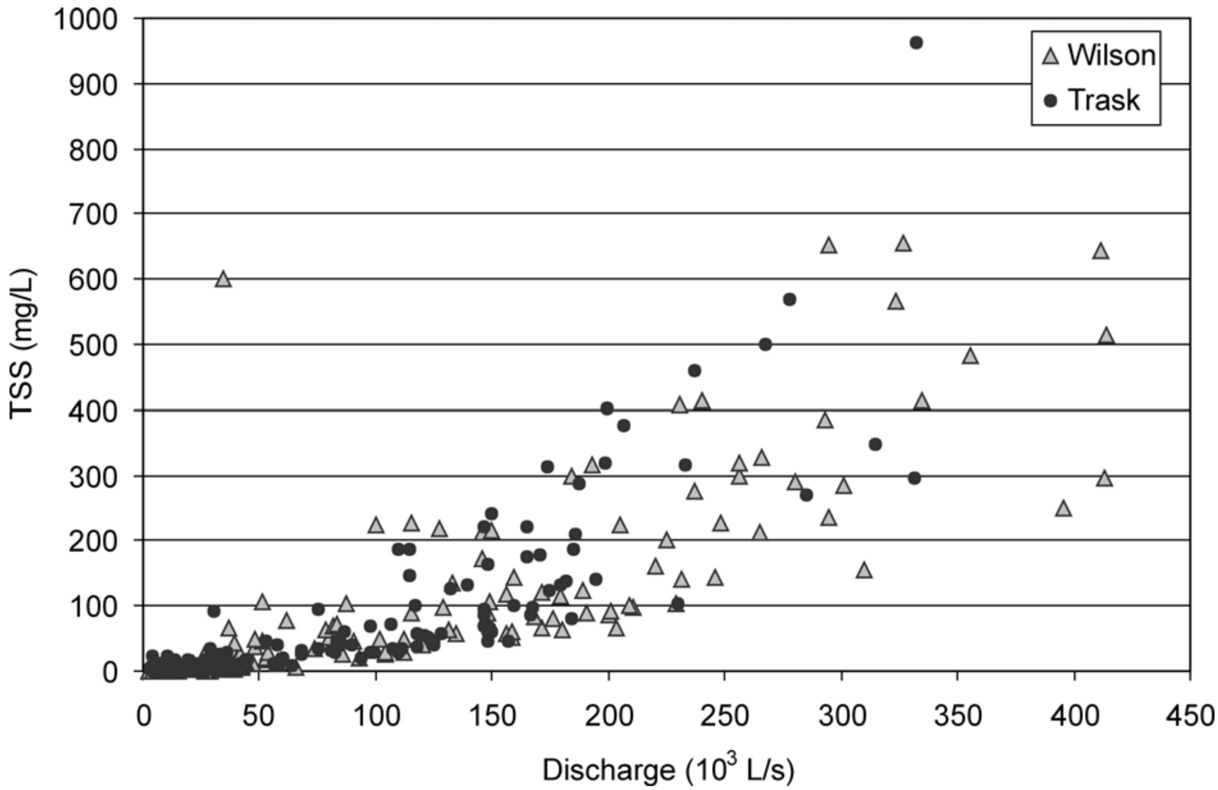

Discharge
Precipitation
Bacteria
Tillamook River
1997
Discharge (10^4 L/s)
Precipitation (cm)
Fecal Coliform Bacteria (cfu/100ml x 10^3)
0
1
2
3
4
9/23
9/25
9/27
9/29
10/1
10/3
10/5
10/7
10/9
Date

Figure 5



Wilson
Trask
TSS (mg/L)
Discharge (10^3 L/s)
1000
900
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
450

Figure 6

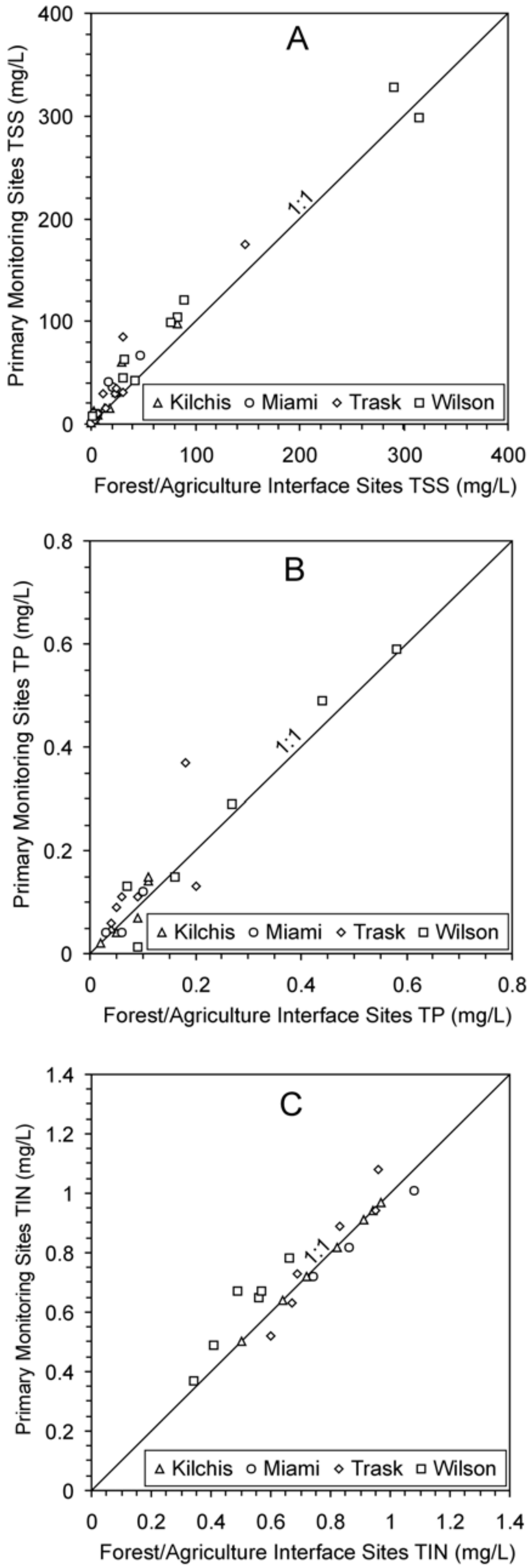
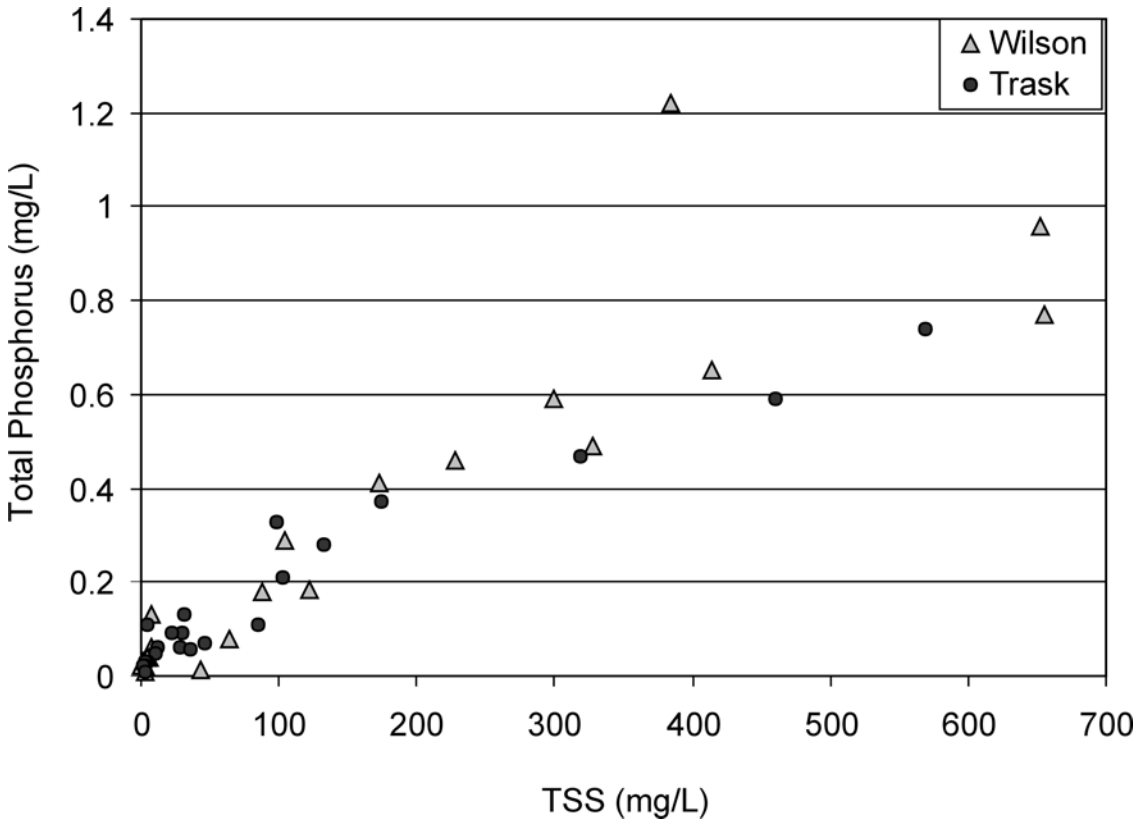

A
1:1
Kilchis Miami Trask Wilson
Primary Monitoring Sites TSS (mg/L)
Forest/Agriculture Interface Sites TSS (mg/L)
0
100
200
300
400
B
1:1
Kilchis Miami Trask Wilson
Primary Monitoring Sites TP (mg/L)
Forest/Agriculture Interface Sites TP (mg/L)
0
0.2
0.4
0.6
0.8
C
1:1
Kilchis Miami Trask Wilson
Primary Monitoring Sites TIN (mg/L)
Forest/Agriculture Interface Sites TIN (mg/L)
0
0.2
0.4
0.6
0.8
1
1.2
1.4

Figure 7


1.4
1.2
1
0.8
0.6
0.4
0.2
0
Total Phosphorus (mg/L)
Wilson
Trask
0
100
200
300
400
500
600
700
TSS (mg/L)