RESULTS OF STORM SAMPLING IN THE TILLAMOOK BAY WATERSHED

Timothy J. Sullivan
Joseph M. Bischoff
and
Kellie B Vaché

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E&S Environmental Chemistry, Inc.
P.O. Box 609
Corvallis, OR 97330

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EXECUTIVE SUMMARY

Since November, 1996, E&S Environmental Chemistry, Inc. (E&S), under contract to the Tillamook Bay National Estuary Project (TBNEP), Tillamook County, Oregon, has conducted routine water quality monitoring and intensive storm sampling in all of the five rivers that flow into Tillamook Bay. The purpose of this report is to present the results of the storm sampling conducted by E&S during six rain storm events between November, 1996 and March, 1998.

There were several objectives to the storm sampling efforts. This study was designed to investigate and quantify episodic variability in the concentrations of fecal coliform bacteria (FCB), total suspended solids (TSS), and nutrients during storm events that occur during the rainy season in the Tillamook watershed (about October to March). An additional objective was to estimate the storm-based loading of each of these parameters to the bay in an effort to differentiate among the five rivers regarding their relative contributions of various pollutants to Tillamook Bay.

Prior to and during the course of the monitoring effort, it became increasingly clear that FCB contamination was a widespread problem throughout the basin, with highest concentration in the Tillamook River, and highest loads in the Trask and Wilson Rivers. The source of this FCB was expected to be variable, with the primary contributions believed to include dairy operations, septic systems, sewer treatment plants, and urban land use. The storm monitoring effort was expanded in the fall of 1997 to include intensive sampling during two storms at about 30 sites on the Tillamook and Trask Rivers by E&S. One fall and one winter storm were selected for this component of the study. The principal objective of the intensive storm monitoring was to quantify the major contributing areas of bacterial loads along these river systems in order to allow evaluation of land use/bacterial load interactions. An additional objective was to evaluate differences in storm-driven pulses of bacteria at various locations in the watersheds of these two rivers.

Storms were selected by the expected duration and intensity of rainfall subsequent to a variety of antecedent moisture conditions. Of the storms sampled, 1 was in the fall, 2 were in the winter and 3 were in the spring. The storms were selected in an effort to represent storms of different intensity and differing hydrological response. Four routine storms were sampled at the primary sites close to the mouth of each river. Routine storms were sampled for FCB, TSS, nutrients, and conductivity. Two storms were sampled more intensively for FCB.

Subbasins that drained into each sampling site were delineated and digitized into a GIS coverage. Using this coverage, in conjunction with estimated precipitation throughout the watershed, correction factors were calculated for each site so that river discharge data could be corrected for contributing area and for differential rainfall amounts according to elevation of the sub-basin. River flow was then calculated at each sampling site on each river, from the correction factors and the measured discharge at the gauging station. From these corrected flow values, FCB loads (cfu/sec) were calculated by multiplying the FCB concentration (cfu/100 ml) by the instantaneous flow (ml/sec). This resulted in load estimates associated with individual sub-basins for the Tillamook and Trask River watersheds during different time periods (12 hour time slices) during each of the intensively sampled storm events. Loads associated with each time slice were ranked according to the amount of loading that occurred from each river segment. Scores were then assigned to each sub-basin or river segment across all time slices based upon the number of times that segment ranked the highest in loading, second highest in loading, and so on. This analysis resulted in the identification of the stream segments and their associated subbasins that most frequently contributed the largest loads of FCB to the rivers during these two storms.

Watershed factors thought to influence loading of fecal coliform bacteria to surface waters were also quantified using coverages produced by Alsea Geospatial (Corvallis, OR) for the TBNEP from aerial photographs of the lowland areas (<500 ft elevation). The coverages included information about land use and hydrology, including the locations of drainage ditches. Land use or type was then quantified from these coverages for each subbasin that drained into a particular sampling site, including area used for pastureland or agriculture and area of riparian zone.

Centroids were produced for the development types designated as farm building clusters and rural residential building clusters. Each represented a discrete cluster of residential homes or farm buildings. The total number of centroids and type for each sub-basin were then quantified.

Total storm loads for FCB were calculated for each discrete storm event sampled. This was accomplished by calculating the area under the curve for the hydrograph of each storm, in discrete segments corresponding to the available FCB measurements. For each segment, the FCB measurement taken at the beginning of the time segment was averaged with the FCB concentration measured at the end of the time segment. This average was then multiplied by the cumulative discharge during the time segment. Discharge estimates were generated using the trapezoidal rule to calculate water volume between sampling points.

Annual loads were estimated two different ways for bacteria. The first approach entailed multiplying the flow-weighted annual average of all samples collected at each primary site by the cumulative flow during the 1997 water year. The second approach involved assignment of a discrete load to each storm that occurred in the 1997 water year, based on the storm-based estimates generated for the storms sampled throughout this study. Storm loads were assigned on the basis of season, storm size, and antecedent flow conditions. Discrete storm load estimates were then summed to produce an estimated annual load. Results of these storm-based load calculations, as expected, were lower than the estimates based on flow-weighted average concentration of FCB on all sampling occasions. The estimates differed by only about 50% for the Trask River (3,189 x 10^{12} cfu versus 2,031 x 10^{12} cfu), but about 100% for the Tillamook River (1,623 x 10^{12} cfu versus 793 x 10^{12} cfu). Annual loads for TSS, total inorganic nitrogen (TIN) and total phosphorus (TP) were generated in a manner analogous to the first approach used for bacteria. All of these load estimates should be viewed as first approximations. More rigorous quantification of storm-based, and especially annual, loads would require additional monitoring data and the application of one or more non-point source pollution models.

The largest FCB loads were contributed during the early fall storm in 1997. Measured loads during this storm in the Tillamook and Trask Rivers were more than twice as high as for any other sampled storm. The smallest loads were contributed by the smallest storm (4.3 in precipitation), which occurred in the spring of 1998.

The overall trend for both the Tillamook and Trask Rivers during both the fall and spring intensively-sampled storms was as follows. FCB loads were low at all sites at the beginning and generally at the end (depending on when sampling was discontinued) of the storms. At the uppermost sites, located in the upper section of the agricultural portions of these watersheds, FCB loads remained low. At the uppermost Trask River site (Loren's Landing), this was mainly because FCB concentrations remained low. At the uppermost Tillamook River site (Yellow Fir Rd.), this was because the discharge is low compared to the lower reaches of the Tillamook River (FCB concentrations were frequently high). High loads were found at a variety of locations on both rivers. There was not one major source area of FCB load on either river; the source areas were many and widely scattered. The largest loads in both rivers were generally achieved in the lower two miles or so of river reach. This suggests the cumulative effect of a large number of source areas within the agricultural portions of the watersheds and/or a larger contribution of FCB close to the bay.

A site in the bay was monitored during the two intensive storm monitoring efforts. It was adjacent to Memaloose Boat Launch, just north of where the Tillamook and Trask Rivers enter Tillamook Bay. During the October, 1997 storm, FCB concentrations exceeded 1,000 cfu/100 ml on over half of the sampling occasions, with a peak concentration of nearly 3,000 cfu/100 ml. These are extremely high concentrations given that the bacterial standard for protecting the oyster beds located just north of this sampling location is only 14 cfu/100 ml. Even during the spring storm, which resulted in much lower FCB loads in the Tillamook and Trask Rivers, the FCB concentration at Memaloose Inlet was about 500 to 1,000 cfu/100 ml on half of the sampling occasions.

Evaluation of the spatial land use patterns within the contributing drainage areas to each of the monitoring sites revealed some interesting patterns. Highest loads were associated with high percent urban land use, high percent rural residential land use, and finally high percent agricultural land use. Large numbers of rural residential building clusters were also frequently associated with high FCB loads. These findings provide very strong, albeit circumstantial, evidence that the largest FCB loads within these two watersheds may in fact be provided by human activities other than dairy farming. Urban areas appear to be significant contributors, as do rural residential areas. The latter, however, may also contain intensive dairy farming activities in some cases.

These same land use analyses were repeated for a set of drainage areas (subbasins) defined in a different way. For this second set of land use analyses, the drainage areas contributing to each sampling site were restricted to those within 100m on either side of waterways (river, tributary streams and/or drainage ditches). The results of these analyses further supported the findings that high FCB loading was generally associated with urban and rural residential land use, and to a lesser extent agricultural land use.

These results suggest that the largest contributions of FCB to the Tillamook and Trask Rivers, at least during the two storms that were intensively monitored, occurred in associated with human habitation, especially the urban and rural residential areas of the Trask River watershed and the rural residential and agricultural areas of the Tillamook River watershed. Highest loads were often found in the lower sections of the rivers, which are heavily ditched and where human activity is concentrated, soils are poorly drained, and runoff potential is high.

Key conclusions of this research include the following:

- The largest loads of FCB to Tillamook Bay are contributed by the Trask River, followed by the Wilson and then the Tillamook River. FCB loads in the Miami and Kilchis Rivers are lower than the other three rivers by about an order of magnitude.

- The largest loads of nitrogen to Tillamook Bay are contributed by the Trask River, followed by the Wilson River.

- The largest loads of TSS and TP (which are likely both primarily from erosional materials) are contributed by the Wilson River, followed by the Trask River.

- FCB loads in a given river differed markedly from storm to storm, with highest loads (by a substantial margin) contributed by the early fall storm.

- The highest concentrations of FCB were generally achieved well before the time of peak river discharge, and generally occurred during the period of most intensive rainfall.

- The largest FCB storm loads were reached in the mid-section of the Tillamook River and the lower sections of both the Tillamook and Trask Rivers. However, FCB contributions were substantial throughout both watersheds.

- The land areas that contributed the largest FCB loads to the Trask River were those containing urban land use. Other land uses associated with areas that contributed large FCB loads were rural residential and agricultural land use. The land uses that contributed the largest FCB loads to the Tillamook River (whose watershed does not include urban land use) were rural residential and agricultural land uses.

INTRODUCTION

Tillamook Bay and its watershed have been the site of intensive water quality monitoring since November, 1996. E&S Environmental Chemistry, Inc. (E&S), under contract to the Tillamook Bay National Estuary Project (TBNEP), Tillamook County, Oregon, has conducted routine water quality monitoring in all of the five rivers that flow into Tillamook Bay. In addition, intensive storm sampling has been conducted by E&S at a variety of sites during six rain storm events between November, 1996 and March, 1998. Additional sampling was also conducted on behalf of TBNEP by other agencies and cooperating institutions during two of those storms. Results of the work conducted by E&S is being reported in several technical reports to TBNEP. Quality assurance/quality control issues were addressed by Bernert and Sullivan (1997). Results of the routine monitoring efforts were presented by Sullivan et al. (in review). The purpose of this report is to present the results of the storm sampling conducted by E&S. Results of storm sampling conducted by other participating agencies and organizations will be summarized elsewhere.

There were several objectives to the storm sampling efforts. It is well known that several important water quality parameters typically exhibit significant episodic variability. Chief among these in the Tillamook Basin are fecal coliform bacteria (FCB) and total suspended solids (TSS). There was also concern about the possibility of episodic pulses of nutrients in river water in the basin. This study was designed to investigate and quantify episodic variability in the concentrations of FCB, TSS and nutrients during storm events that occur during the rainy season in the Tillamook watershed (about October to March). An additional objective was to estimate the storm-based loading of each of these parameters to the bay in an effort to differentiate among the five rivers regarding their relative contributions of various pollutants to Tillamook Bay.

Prior to and during the course of the monitoring effort, it became increasingly clear that FCB contamination was a widespread problem throughout the basin, with highest concentration in the Tillamook River, and highest loads in the Trask and Wilson Rivers (c.f., Jackson and Glendening 1982, Sullivan et al. *in review*). The source of this FCB was expected to be variable, with the primary contributors believed to include dairy operations, septic systems, sewer treatment plants, and urban land use (c.f., Jackson and Glendening 1982). The storm monitoring effort was expanded in the fall of 1997 to include intensive sampling during two storms at about 30 sites on the Tillamook and Trask Rivers by E&S, and at eight sites on the Wilson River by the Tillamook County Creamery Association (TCCA). One fall and one winter storm were selected for this component of the study. The principal objective of the intensive storm monitoring was to quantify the major contributing areas of bacterial loads along each of these river systems to allow evaluation of land use/bacterial load interactions. An additional objective was to evaluate differences in storm-driven pulses of bacteria at various locations in the watersheds of these three rivers.

METHODS

Site Allocation and Sampling

Storm Selection

Storm monitoring was initiated in November, 1996 and six storms were sampled through April 1998. Storms were selected by the expected duration and intensity of rainfall subsequent to a variety of antecedent moisture conditions. Of the storms sampled, one was in the fall, two were in the winter and three were in the spring. The storms were selected in an effort to represent storms of different intensity and differing hydrological response. The early fall storm was preceded by a long dry period when there was little flushing of the watersheds. Winter storms were 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.

Two categories of sampling were included: routine and intensive. Four routine storms were sampled at the primary sites close to the mouth of each river and at a few selected secondary sites. Routine storms were sampled for fecal coliform bacteria (FCB), total suspended solids (TSS), nutrients, and conductivity. During the course of the study, it became apparent that the environmental variable of greatest interest with respect to storm response was FCB. An approach was therefore designed to sample two storms more intensively for FCB. These intensive storm sampling activities were confined (by E&S) to the Tillamook and Trask Rivers, which generally experience the highest FCB concentrations and loads, respectively. The same storms were also sampled on the Wilson River by the Tillamook County Creamery Association (TCCA) and on the Miami and Kilchis Rivers by the Oregon Department of Environmental Quality (ODEQ). In addition, some sampling of the bay was carried out by ODEQ, E&S, and by the Oregon Department of Agriculture (ODA).

The Wilson River hydrograph throughout the period of study is depicted in Figure 1. It shows the pattern typical of the Tillamook Basin: low river flows (generally <500 cfs) during summer and frequent storms from October through March. The largest storms generally occur in the period November through January and often achieve peak discharge >10,000 cfs on the Wilson River. Flood stage on the Wilson River is designated as 14,100 cfs. The storms that were monitored during this study are indicated in Figure 1.

Routine Storm Sampling

Primary sites (one on each river) and a few additional secondary sites were sampled for four of the storm events (Figure 2). In consultation with TBNEP staff, a primary site was selected at the downstream end of each of the five rivers (Miami, Kilchis, Trask, Wilson, Tillamook), in relatively

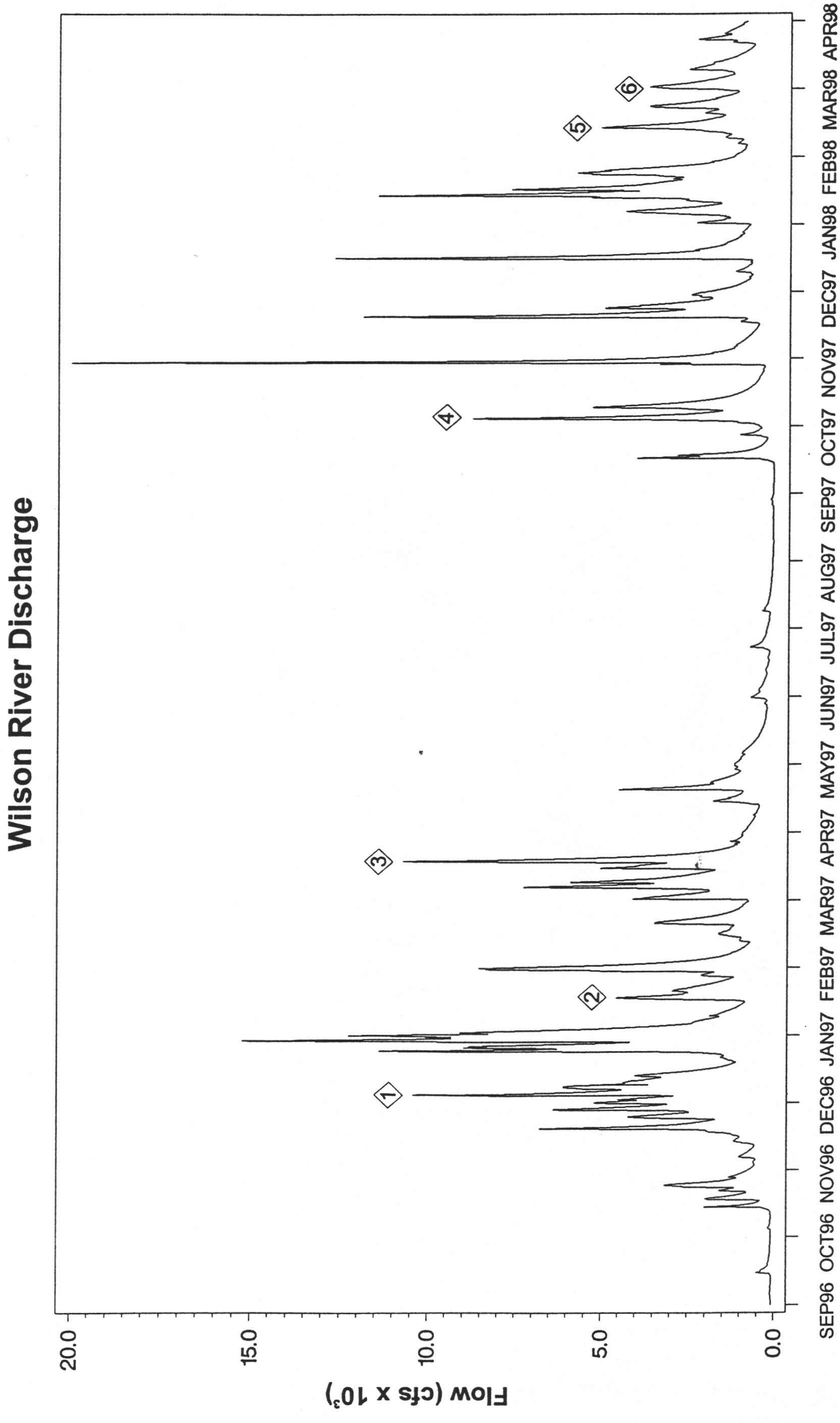


Figure 1. Wilson River hydrograph throughout the period of study. Numbers are added to the six storms sampled in this monitoring effort.

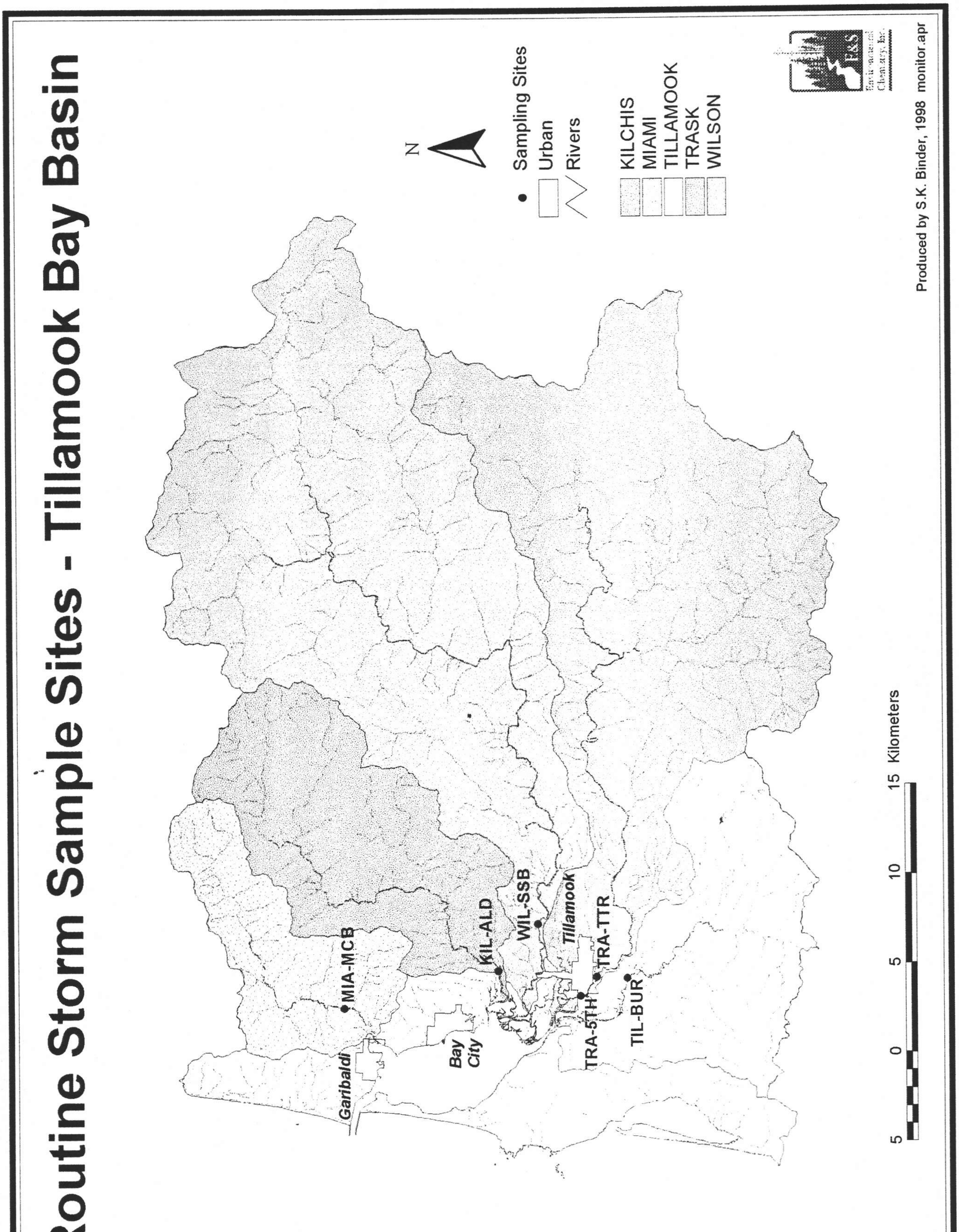


Figure 2. Sample site locations for routine storm sampling.

close proximity to the bay. A few secondary sites were also sampled during these storms. Selection of secondary sites was based on criteria such as known or suspected problem locations, forest/agriculture interface locations, and sampling logistics. All sample sites were selected with an aim to avoid tidal prism influence. To quantify tidal influence, on-site conductivity measurements were taken to determine if baywater contamination of samples occurred. 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 (at a depth of about 0.5 m) where water tends to be well mixed. Shallow sites or sites without bridge crossings were sampled from shore 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.

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 late 1997, this site was no longer available for sample collection because the bridge had been largely removed. The 5th Street dock, 0.9 miles downstream from Burton Bridge, was sampled as the new primary site on the Trask River during Storm 3.

Intensive Storm Sampling

Two storms (October 1997 and March 1998) were sampled intensively at about 30 sites on the Tillamook and Trask Rivers (Figure 3). The Wilson River was sampled by the TCCA during the same storm events and those results will be presented in a subsequent report. Samples were collected along each of the two rivers from the mouth to near the forest/agriculture interface. Site selection was determined jointly by members of the project team and TBNEP staff. Most, but not all, sites were sampled on each sampling occasion. Priorities for site location and sampling were forest/agriculture transitions, downriver of confluence of tributary streams, probable point sources of bacteria and nutrients, and areas of intensive agriculture.

Many sites included in the intensive storms were sampled from a boat using a weighted sterile bottle. Some sample locations were not accessible from the boat (too shallow or boats not permitted) and consequently these sites were either sampled from bridges or from shore as described in the routine storm sampling section. The spatially intensive sampling program allowed identification of stream reaches and specific watershed regions that play significant roles in fecal coliform bacteria contribution to the rivers.

The Tillamook, Trask and Wilson Rivers were selected for the intensive sampling program because they were identified as the rivers that play the largest roles in fecal coliform contribution to

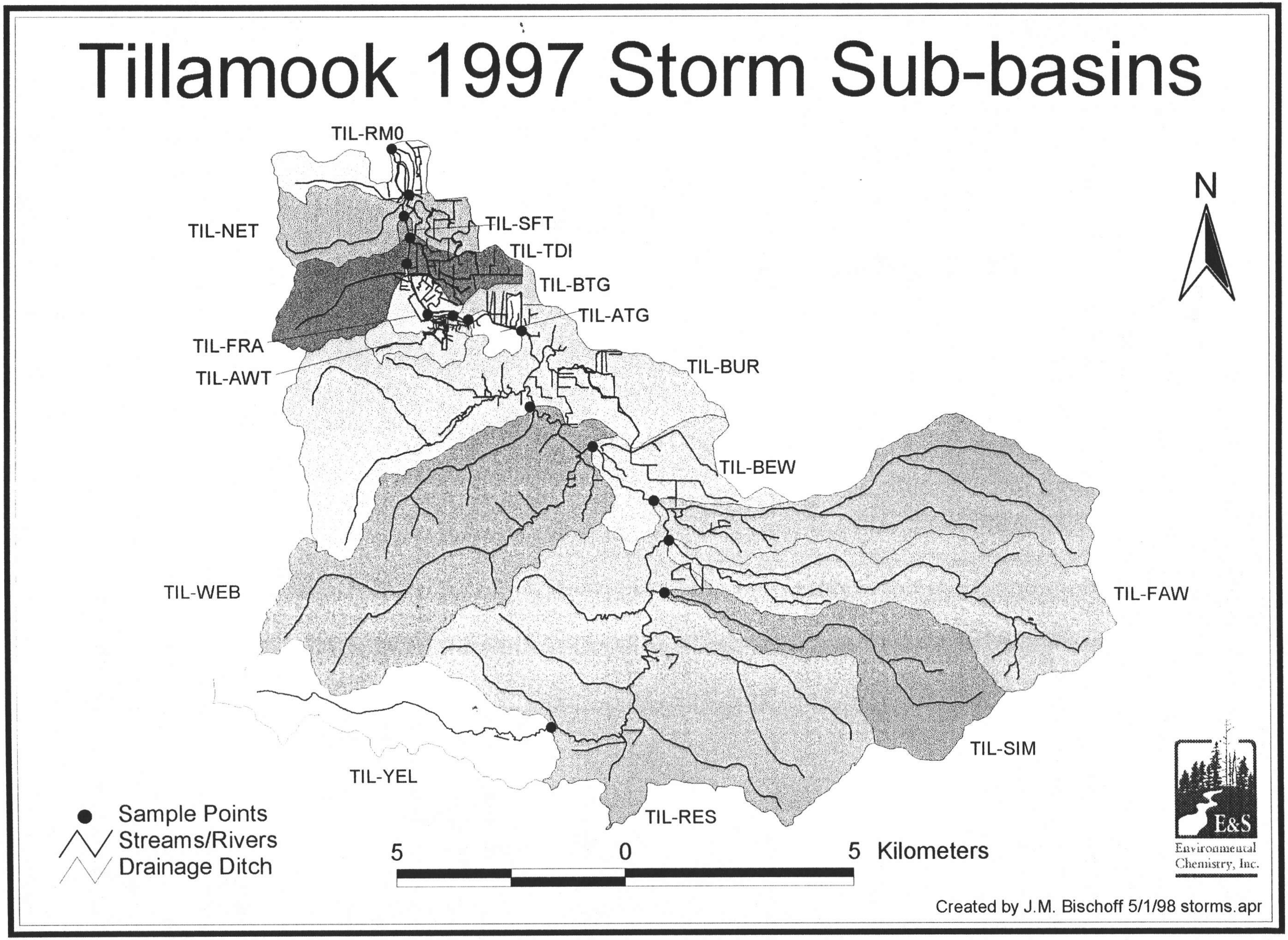


Figure 3. Sample site locations for intensive storm sampling on the Tillamook and Trask Rivers. Also shown are the boundaries of each of the drainage contributing areas to each of the sampling sites.

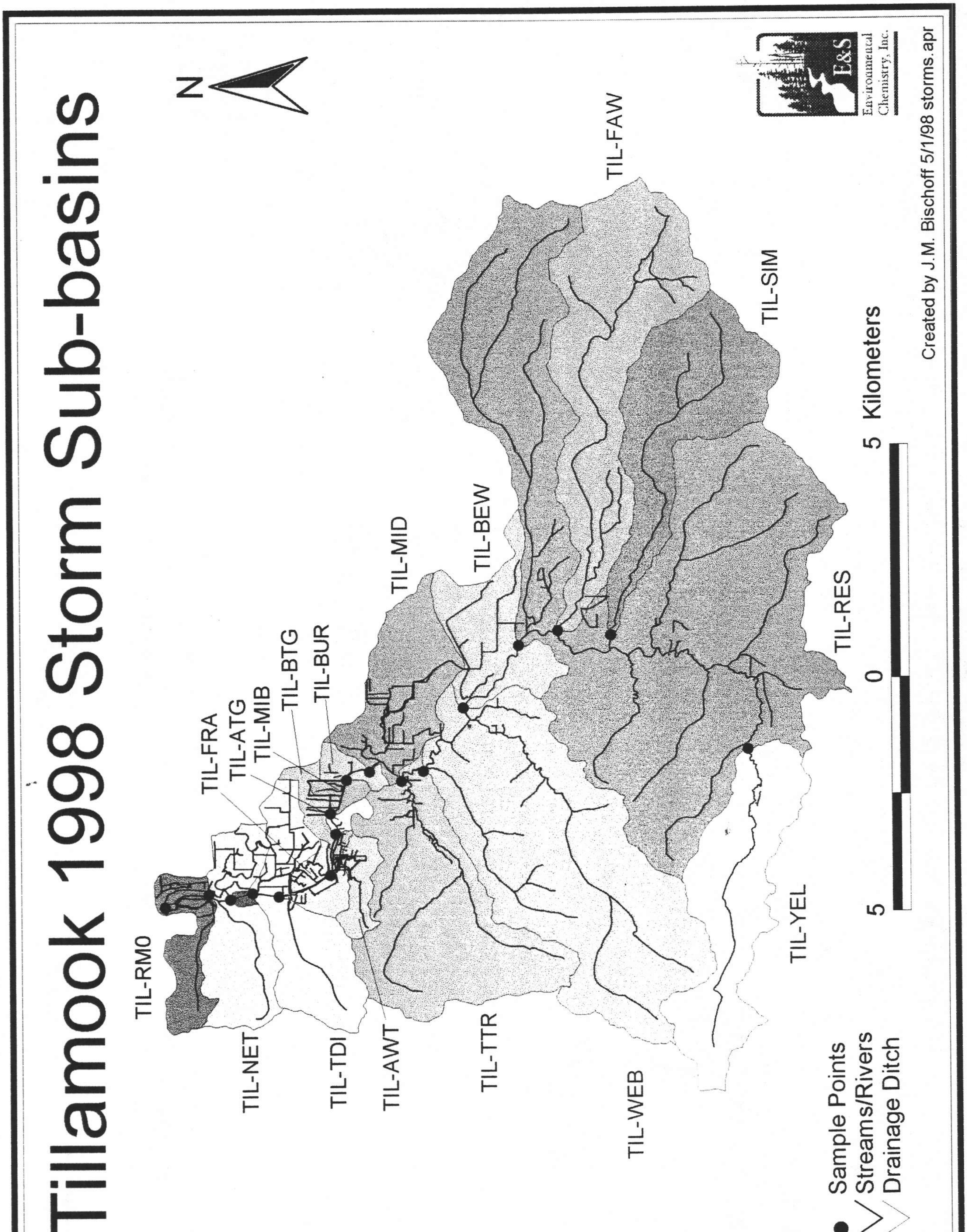


Figure 3. Continued.

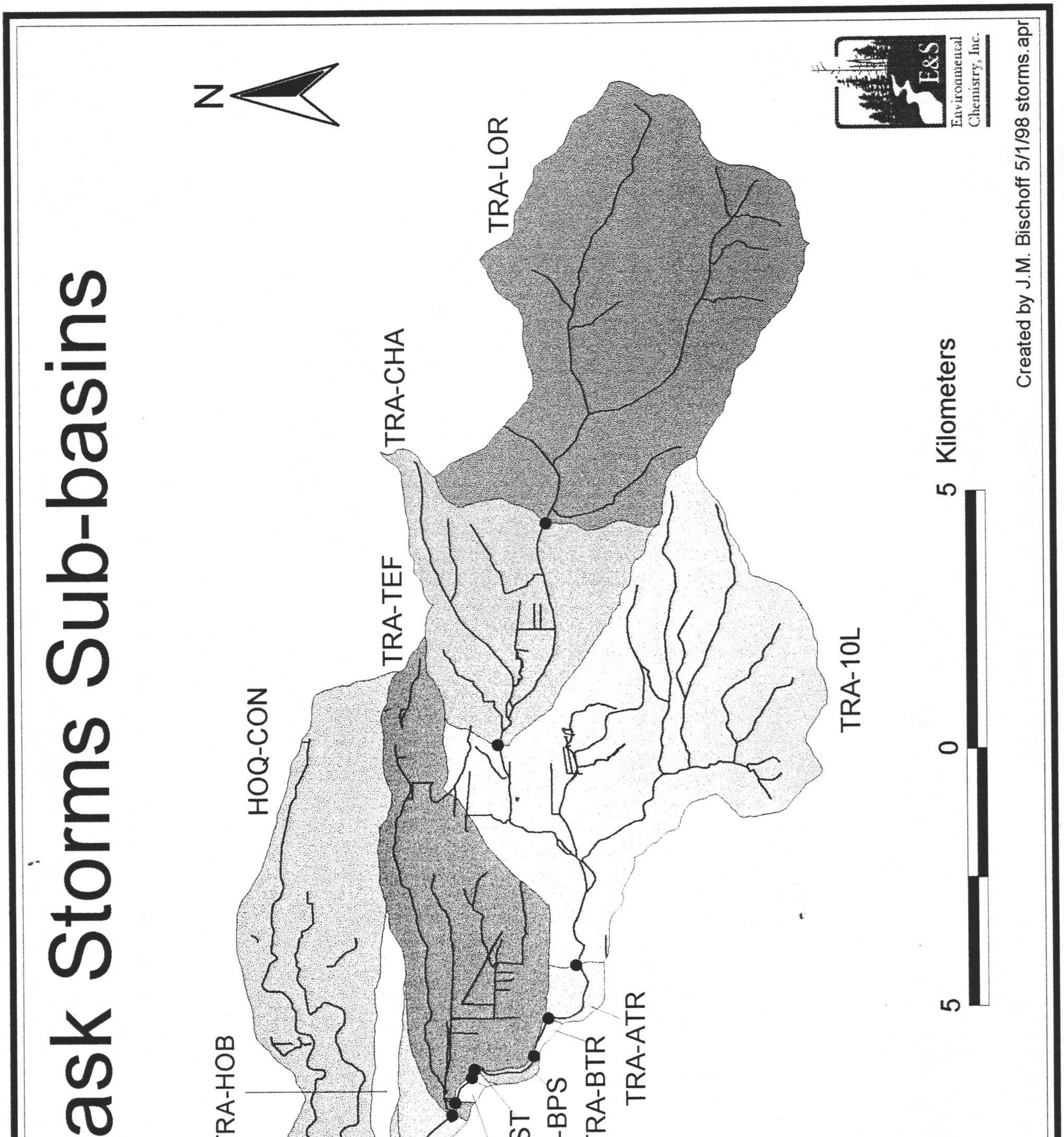


Figure 3. Continued.

the bay as a result of high concentrations and high loads. Analyses reported here focus primarily on the Tillamook and Trask Rivers.

The Tillamook River Subbasin drains 43,000 ac of mostly timber and agricultural lands, with some residential land use. The mainstem of the river originates on the east side of the Cape Lookout Headland about 18 miles south of the bay. There is a network of tributaries that flow into the river from the east side of the subbasin. The lower portion of the subbasin is heavily dissected with drainage ditches and small streams, and about 5 miles of the lower river is diked to control flooding. The upper mainstem and west side tributary watersheds have high runoff potential, and the portion of the watershed behind dikes and tide gates generally has very high runoff potential (USDA-SCS 1978).

The lower 1 to 2 miles of the Trask River Subbasin, in an area of poorly drained soils, is considered to have a very high runoff potential (Jackson and Glendening 1982). There are many drainage ditches because of the poorly drained soils. Portions of the Trask Subbasin also contain concentrated urban land use. The city of Tillamook is situated on a terrace between the Trask River to the south and the sloughs to the north. Two sewage treatment plants (STPs) are located in this subbasin. The Port of Tillamook sewage treatment facilities discharge treated effluent at RM 5. The city of Tillamook's STP discharges at RM 1.5.

Estimation of River 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.

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.

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. Each equation corresponded to a season and was based on the Wilson River data collected by USGS (Sullivan et al. in review).

Sample Analyses

River water samples were analyzed for total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrate, ammonium, conductivity, total suspended solids (TSS), fecal coliform bacteria (FCB), pH and temperature. FCB were analyzed on all sample occasions. Conductivity, temperature and TSS were analyzed for most samples. Nitrate, ammonium, TKN, and TP were measured for a small subset of samples. The chemical analytical methods are summarized in Table 1. FCB were analyzed using the membrane filtration method described in Standard Methods for the Examination of Water and Wastewater (Greenberg et al. 1992). 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. Sampling and analytical methods and QA/QC were described by Sullivan et al. (in review) and Bernert and Sullivan (1997).

Intensive Storm Data Analyses

Transect analyses were performed on the Tillamook and Trask Rivers for the two intensive storms (October 1997 and March 1998). A total of 14 sites were sampled on the Tillamook River, plus two tributary streams, and 18 sites were sampled at various times on the Trask River. In addition, a site in the bay was sampled at Memaloose boat ramp just to the north of where the Tillamook and Trask Rivers enter the bay. Site locations are listed in Table 2.

Table 1. 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

Table 2. Sampling site locations for the intensive storm sampling.

Site Code	River Mile	Location Description
<u>Tillamook River</u>		
TIL-YEL	10.0	Yellow Fir Road
TIL-RES	8.1	Rest Area
TIL-BEW	6.8	Bewley Bridge
TIL-WEB	5.5	Bridge by Weber Road
TIL-TTR	4.9	Tillamook River Road
TIL-MID	4.5	Between TTR and BUR
TIL-BUR	4	Burton Bridge
TIL-MIB	3.5	Between BUR and ATW
TIL-ATG	3.1	Above Large Tidegate
TIL-BTG	2.9	Below Large Tidegate
TIL-AWT	2.6	Above Wetland
TIL-FRA	2	Fraser Road
TIL-TDI	1.5	Below Tide Gate
TIL-SFT	1.1	South Fork Trask
TIL-NET	0.9	Netarts Highway Bridge
<u>Tributaries to Tillamook River</u>		
TIL-FAW	8.8	Fawcett Creek Bridge
TIL-SIM	8.3	Simmons Creek Bridge
<u>Trask River</u>		
TRA-LOR	9	Loren's Landing
TRA-CHA	7	Chance Road
TRA-10L	4.3	101 Landing
TRA-101	4.2	Bridge on Highway 101
TRA-BTR	3.7	Below Trailer Park
TRA-ATR	3.6	Above Trailer Park
TRA-DST	3.2	Downstream Stream
TRA-BPS	2.7	By Piling and Stream
TRA-TTR	2.4	Tillamook River Road
TRA-TEF	2.3	Below Effluent Inflow
TRA-ASF	1.7	Above South Fork
TRA-5TH	1.5	5th St. Boat Ramp (Above STP)
TRA-HOB	1.2	Hospital Bridge
TRA-HOQ	0.8	Above Hoquarten Slough Confluence
TRA-RM0	0	Near Confluence with Hoq. Slough (RM 0)
<u>Bay</u>		
MEM-INL	-0.5	Memaloose
<u>Slough</u>		
HOQ-CON	0	Near Confluence with Trask River

Subbasins that drained into each sampling site were delineated and digitized into a GIS coverage. Using this coverage, in conjunction with estimated precipitation throughout the watershed, correction factors were calculated for each site so that flow data could be corrected for contributing area and for differential rainfall amounts according to elevation of the sub-basin. River flow was then calculated at each sampling site on each river, from the correction factors and the measured flow at the gauging station. From these corrected flow values, FCB loads (cfu/sec) were calculated by multiplying the FCB concentration (cfu/100 ml) by the instantaneous flow (ml/sec). Data were collected over about a four to six day period during each of the storms. The days were divided into morning and afternoon segments creating 12-hour time slices. If two or more samplings occurred within one time slice, then the mean FCB load during the time slice was used for this analysis. This resulted in load estimates associated with individual sub-basins for the Tillamook and Trask Rivers watersheds during different time periods (12 hour time slices) during each of the storm events. Consequently, load analyses could be performed during several parts of the hydrograph (rising limb, peak, falling limb) allowing us to describe differences in fecal coliform loading both spatially (sub-basins) and temporally (time slices). Loads for each sub-basin were then divided by the length of the river segment in river miles or contributing watershed area to adjust for the different length of stream or watershed area that was fed by the individual sub-basins. Loads associated with each time slice were ranked according to the amount of loading that occurred from each river segment. Scores were then assigned to each sub-basin or river segment across all time slices based upon the number of times that segment ranked the highest in loading, second highest in loading, and so on. The site which ranked the highest within a time slice received a score of five; the site contributing the second largest load within a time slice was given a score of 4; and so on. The total score is the sum across all time slices for that particular storm. This analysis resulted in the identification of the stream segments and their associated subbasins that contributed the largest loads of FCB to the rivers during these two storms.

Watershed Analyses

Watershed factors thought to influence loading of fecal coliform bacteria to surface waters were also quantified using coverages produced by Alsea Geospatial (Corvallis, OR) for the TBNEP. Coverages were produced from aerial photographs of the lowland areas (<500 ft elevation) of the Tillamook Bay watershed and areas with some human built structures such as houses or barns. The coverages included information about land use and hydrology, including the locations of drainage ditches. To maintain the continuity of the layer, some higher elevation areas (ridges) were included. Additionally, some areas less than 500 feet elevation, but with no built structures were excluded. The ArcInfo coverages were compiled by Alsea Geospatial by edgematching National Wetlands Inventory ArcInfo coverages and then adding linear features by screen digitizing. Linear features were screen digitized using TBNEP_ORTHO3 grid as a background layer. The grid was compiled by scanning, orthorectifying and mosaicing 1:40,000 scale aerial photographs provided by the Farm Service Agency. The photo year was 1994. The layer covers a portion of the Tillamook Bay Valley less than 500 feet in elevation and containing human settlements. After features had been screen digitized, they were attributed using codes.

Coverages were projected in UTM zone 10 for this analysis. Subbasins draining into each sample point were delineated and digitized. Land use or type was then quantified from these coverages for each subbasin that drained into a particular sampling site, including area used for pastureland or agriculture and area of riparian zone. Development types were also quantified which included the area of rural residential and urban land use within each of the subbasins. Some of these classifications overlapped, such as rural residential and agriculture and were therefore quantified as both types. For example, if a polygon was coded as both rural residential and agricultural, then the area of the polygon was used in calculating both the total agricultural area and the total rural residential area.

Centroids were produced for the development types designated as farm building clusters and rural residential clusters. Each represented a discrete cluster of residential homes or farm buildings. The total number of centroids and type for each sub-basin were then quantified.

Load Calculations

Total storm loads for FCB were calculated for each discrete storm event sampled. This was accomplished by calculating the area under the curve for the hydrograph of each storm, in discrete segments corresponding to the available FCB measurements. For each segment, the FCB measurement taken at the beginning of the time segment was averaged with the FCB concentration measured at the end of the time segment. This average was then multiplied by the cumulative discharge during the time segment. Discharge estimates were generated using the trapezoidal rule to calculate water volume between sampling points. Volumes were calculated hourly, based on discharge data. All time segments during the storm were summed to generate the estimate of total storm load. At the beginning and end of each storm, professional judgement was used when necessary with available baseflow measurements of FCB concentration at each site (Sullivan et al. *in review*) to estimate the FCB concentration before the first sample was collected or after the last sample was collected.

Annual loads were estimated two different ways for bacteria. The first approach entailed multiplying the flow-weighted annual average of all samples collected at each primary site (Sullivan et al. *in review*) by the cumulative flow during the 1997 water year. The second approach involved assignment of a discrete load to each storm that occurred in the 1997 water year, based on the storm-based estimates generated for the storms sampled throughout this study. Storm loads were assigned on the basis of season, storm size, and antecedent flow conditions. Discrete storm load estimates were then summed to produce an estimated annual load. Annual loads for TSS, TIN and TP were generated in a manner analogous to the first approach used for bacteria.

All of these load estimates should be viewed as first approximations. More rigorous quantification of storm-based, and especially annual, loads would require additional monitoring data and the application of one or more non-point source pollution models.

RESULTS

Primary Site Results Across Storms on Each River

Fecal Coliform Bacteria

Results of the analyses for fecal coliform bacteria (FCB) at the primary site on each river are presented in Figures 4 through 15. Results for each storm are presented in two figures, one for bacterial concentration (cfu/100 ml) and the following figure for bacterial load (cfu/sec). To facilitate visual comparison of data across storms and across sites, the scales used in this series of figures were standardized as much as possible. All bacterial data were presented at a uniform scale for each bacterial representation (concentration and load). Because of large differences in discharge among the five rivers, however, the discharge data could not be presented at a common scale. The reader is cautioned, therefore, to carefully note the discharge scale and units for each figure, as they are variable from storm to storm and from river to river. Also note that the precipitation data are presented in each figure on the same scale as the discharge data, and therefore vary in scale among sites and among storms. Each precipitation bar in this series of figures depicts the total precipitation received during a 6-hr period.

The storm that was sampled in December, 1996 (Storm 1) was preceded by a long series of storms on about a three day interval. Cumulative precipitation at Tillamook during the storm was 5.2 in (13cm). Peak discharge reached about 10,000 cfs on the Wilson River during this storm and between about 4,000 and 6,000 cfs on four separate occasions during the two week period preceding the storm (Figure 3). This was one of the largest storms sampled in the study in terms of peak river discharge achieved (Table 3). Peak FCB concentrations were reached around the 12-hr period of peak precipitation. Peak discharge occurred about 6 to 12 hours later. Concentrations of FCB peaked at about 400 to 600 cfu/100 ml in all rivers except the Kilchis, which had peak concentrations about half or less than those of the other rivers (Figure 4). FCB loads during this storm were relatively high, especially in the Wilson and Trask Rivers, which reached peak loads of about 1 x 10^6 cfu/sec (Figure 5). These high loads were largely attributable to the high discharge during this storm, rather than unusually high FCB concentrations. Loads in the Miami and Kilchis Rivers were much lower, with peak values around 0.2 x 10^6 cfu/sec. Peak FCB loads in the Tillamook River were intermediate.

Table 3. Results of storm discharge and fecal coliform bacteria load calculations at the primary monitoring sites on each of the five rivers that flow into Tillamook Bay during the six storms that were monitored during this study.

Storm No.	Storm Dates	Cumulative Precip. (in)	Peak River Discharge (cfs x 10^3)					Peak FCB Concentration (cfu/100 ml)					Cumulative Storm Discharge and FCB Loads: Water Volume (m^3 x 10^6)					Cumulative Storm Discharge and FCB Loads: Total FCB Load (cfu x 10^{12})				
			Tillamook	Trask	Wilson	Kilchis	Miami	Tillamook	Trask	Wilson	Kilchis	Miami	Tillamook	Trask	Wilson	Kilchis	Miami	Tillamook	Trask	Wilson	Kilchis	Miami
1	12/4/96-12/8/96	5.2	2.0	9.5	10.4	4.3	1.3	568	337	596	177	392	11.1	57.1	57.4	23.9	7.1	26.3	46.1	59.9	7.5	8.3
2	1/16/97-1/21/97	5.5	0.8	3.0	4.6	2.3	1.0	790	1140	2720	46	330	5.5	24.7	33.1	16.3	8.0	21.7	66.6	174	2.2	6.4
3	3/19/97-3/25/97	4.5	1.6	6.0	10.7	5.3	2.0	670	210	21	20	109	14.9	57.9	72.7	35.8	14.9	44.1[2]	40.1[2]	6.9[2]	3.7[2]	5.2[2]
4	9/30/97-10/8/97	6.5	0.9	5.8	8.8	3.7	0.6	3700	2800	-	-	-	8.9	37.2	50.4	21.6	6.2	108.0	225	-	-	-
5	2/09/98-2/18/98	5.4	1.2	4.6[1]	5.1	4.5	0.9	500	350[1]	220	130	156	13.9	57.3[1]	54.9	46.7	10.8	15.4	88.8[1]	42.9	9.8	4.5
6	2/27/98-3/08/98	4.3	0.9	3.3	3.7	3.2	1.2	350	440	-	-	-	13.6	49.6	47.2	30.5	13.1	14.9	33.7	-	-	-

[1] indicates samples taken from 5th street dock site on Trask, because the normal primary site was inaccessible.

[2] Storm 2 was sampled at a lower frequency then the other storms in this study, and therefore the FCB load estimates for Storm 3 are subject to greater uncertainty than for the other storms.

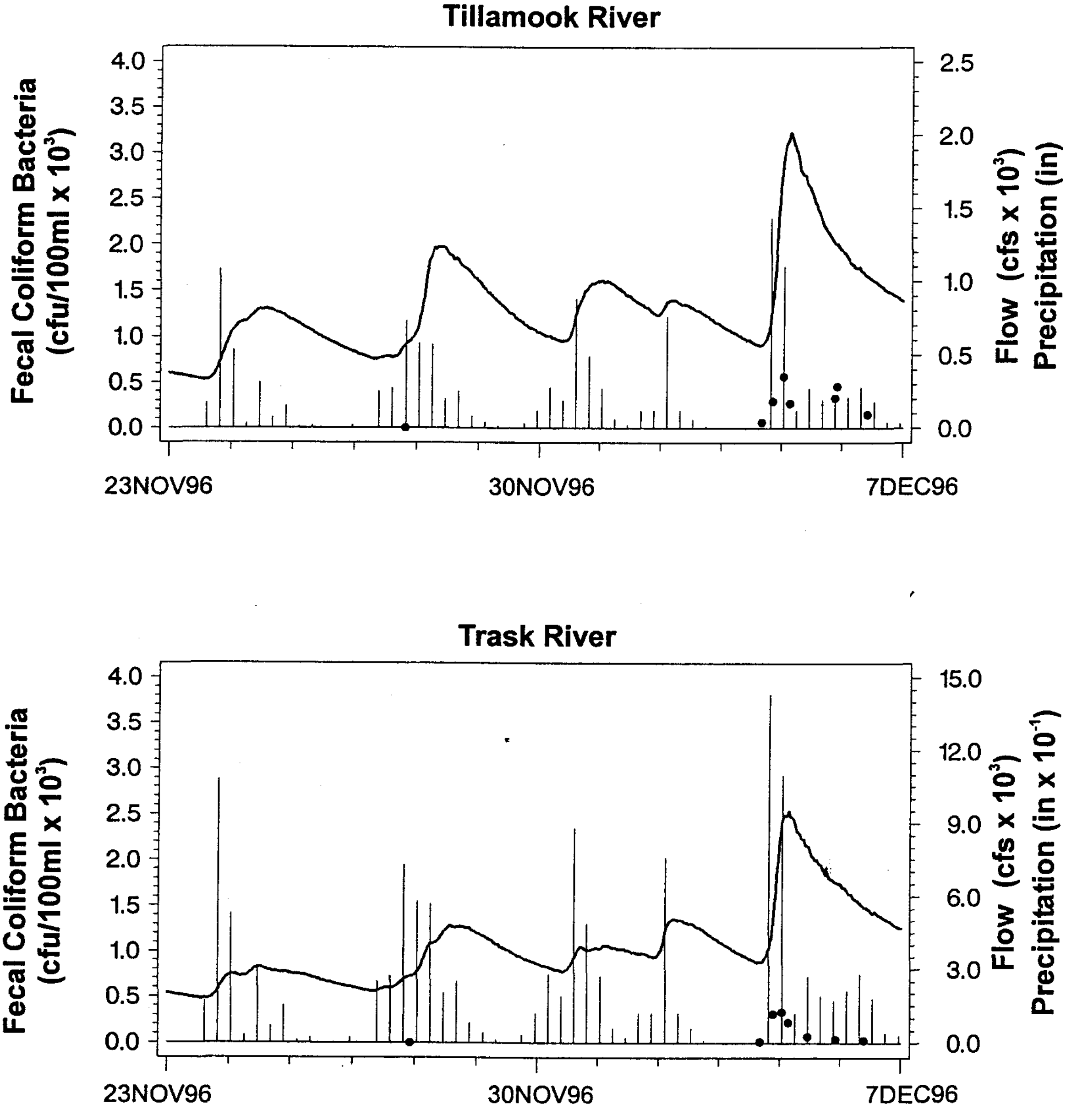
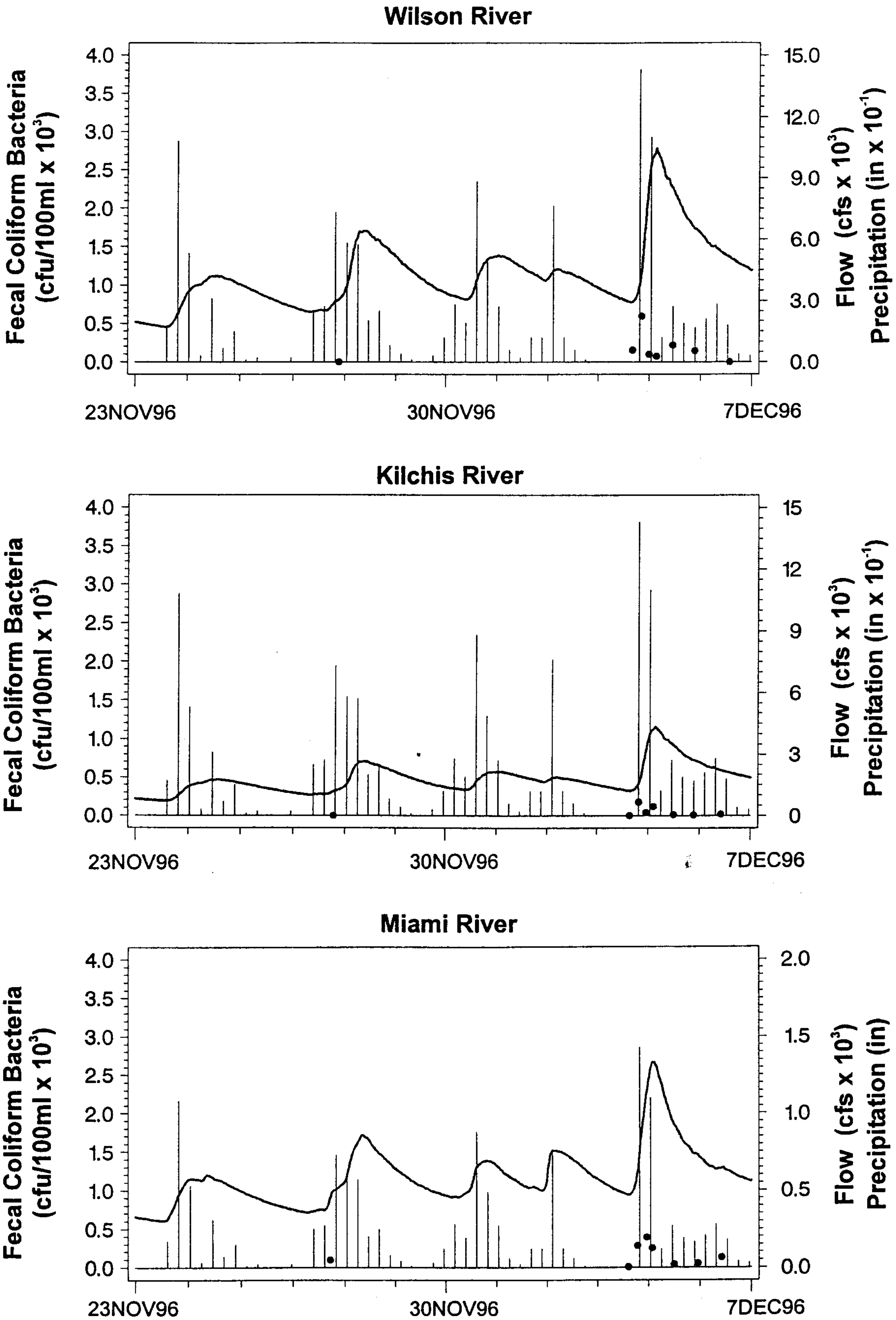


Figure 4. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.



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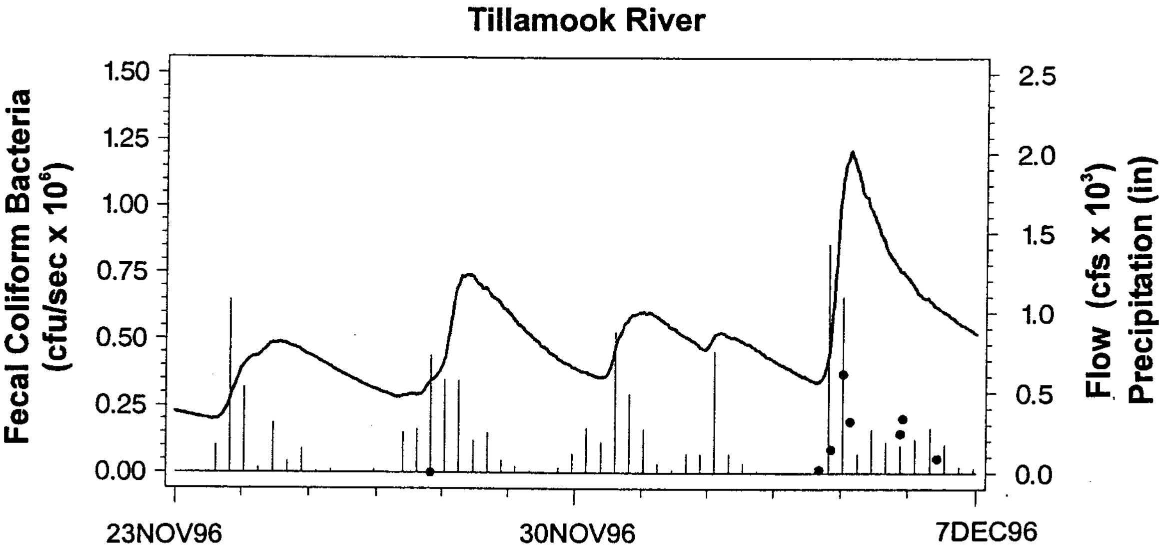


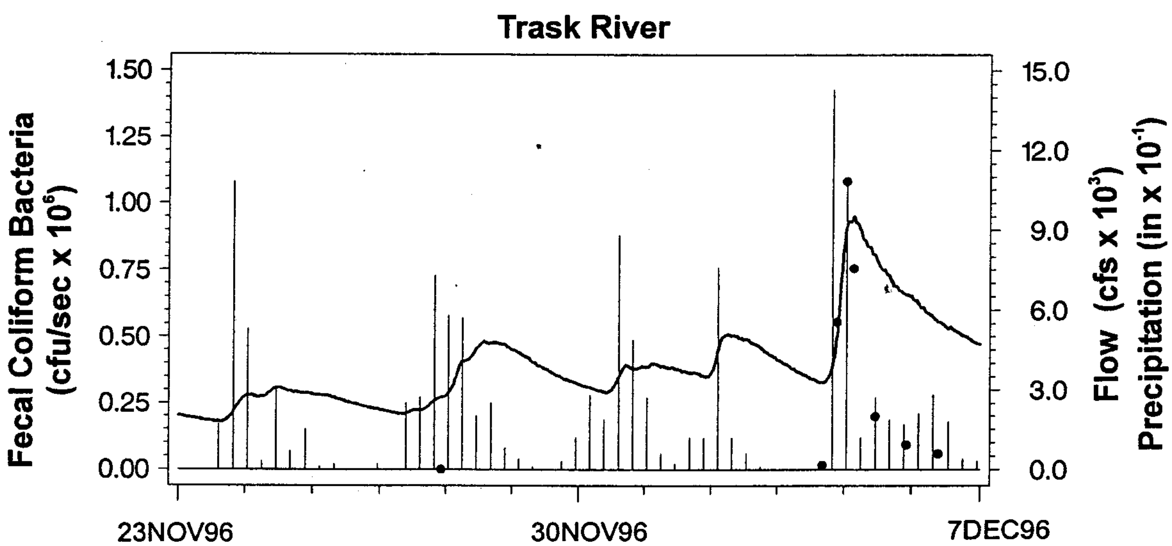


Figure 5. Load of fecal coliform bacteria (cfu/sec x 10^6), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.

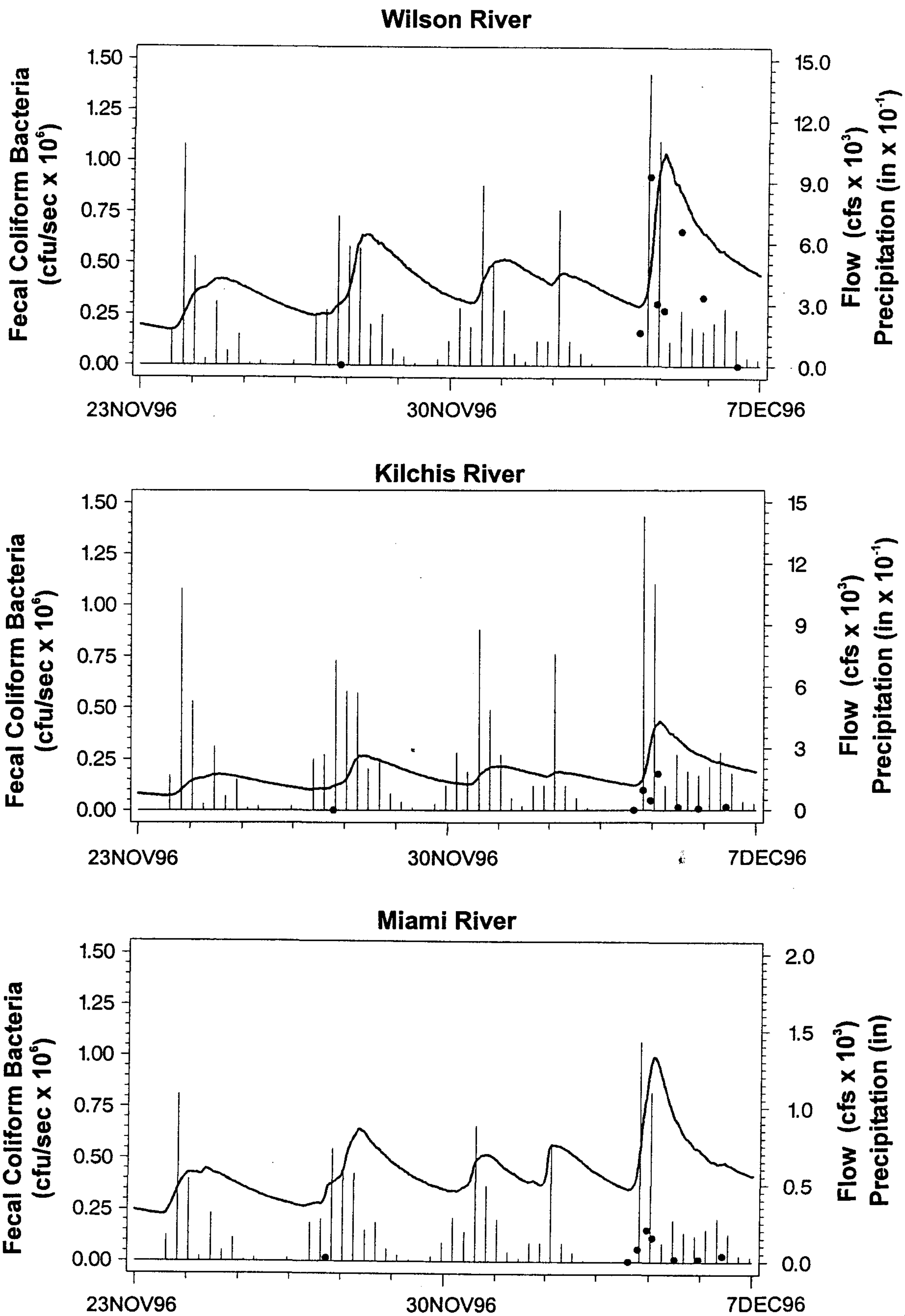
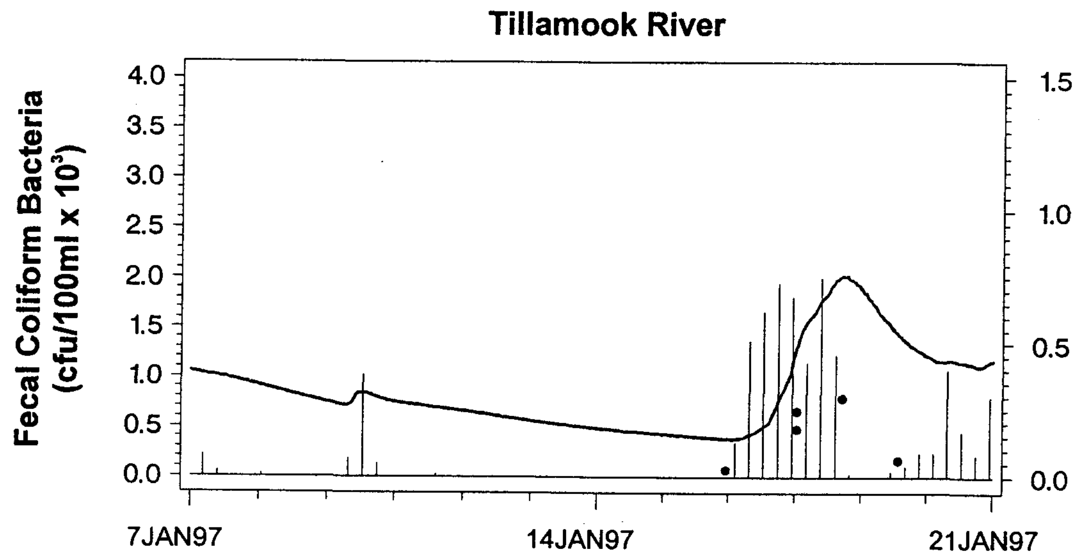


Figure 5. Continued.

The storm that was sampled in January, 1997 (Storm 2) was quite different hydrologically from the December storm. Like the December storm, the January storm was of about two days duration and resulted in 5.5 in (14cm) of precipitation at Tillamook, but it was preceded by a relatively dry period (Figure 6). Virtually no rain occurred during the five days before the storm, and river flows were therefore fairly low. For example, the Wilson River discharge was less than 1000 cfs at initiation of the January storm (Figure 6), about three-fold lower than it had been at initiation of the December storm (Figure 5). Peak discharge in the Wilson River during the storm was about 4,500 cfs. Peak FCB concentrations generally reached higher values during Storm 2, as compared with Storm 1, even though peak river flows were about half of the flows during Storm 1. Peak FCB concentrations approached 1000 cfu/100 ml in the Tillamook River and exceeded that amount in the Wilson and Trask Rivers. Concentrations in the Kilchis River remained very low (Figure 6). FCB loads during this storm were generally lower, however, than were found during the December storm (except for one high value, 1.5 x 10^6 cfu/sec, in the Wilson River; Figure 7). This was due to the lower discharge values reached during the storm.

Samples were collected on only three occasions during Storm 3, a large storm that occurred in March, 1997. A total of 4.5 in (12cm) of precipitation was recorded at Tillamook and this was added to what were already highly saturated conditions throughout the watershed. This storm was not originally scheduled to be sampled in this study. It was therefore sampled at a lower sampling frequency than was typically employed for the storm sampling in this project, and the first sample was not collected until 24 hours after the rainfall started. This storm was preceded by a very wet period; rainfall had been recorded on seven of the previous eight days (Figure 8). Discharge in the Wilson River was at 3,000 cfs at initiation of the storm, and had been near 5,000 cfs only two days previously. Peak Wilson River discharge during the storm reached about 11,000 cfs, close to flood stage and the highest of any storm sampled in this study. FCB concentrations were generally less than 200 cfu/100 ml, except in the Tillamook River, which exhibited much higher concentrations (~200 to 700 cfu/100 ml) (Figure 8). Peak loads were measured in the Trask River (~0.5 x 10^6 cfu/sec) on one sample occasion and in the Tillamook River (~0.25 x 10^6 cfu/sec) on one sample occasion (Figure 9). Other measured loads were substantially lower.

The first storm that was sampled in an intensive fashion, both spatially and temporally, was Storm 4, the first sizable storm of the fall season in 1997. It occurred during early October and resulted in 6.5 in (17cm) of precipitation at Tillamook. Results for the primary sites on the Tillamook and Trask Rivers are shown in Figure 10; results for other sites on these two rivers are shown in subsequent sections of this report. E&S did not sample the other three rivers during Storm 4. However, the Wilson River was sampled by TCCA, and the Kilchis and Miami Rivers were sampled by ODEQ (data not shown). The fall storm was unique in a number of respects. Other than a very small two-day rain event three to four days previously (which did not increase flows much, especially



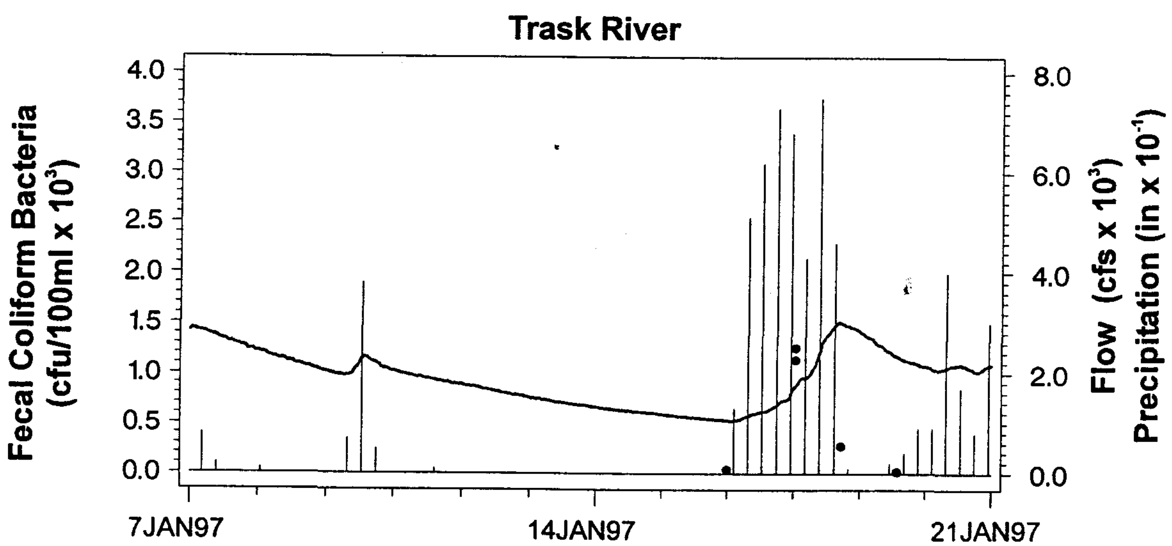
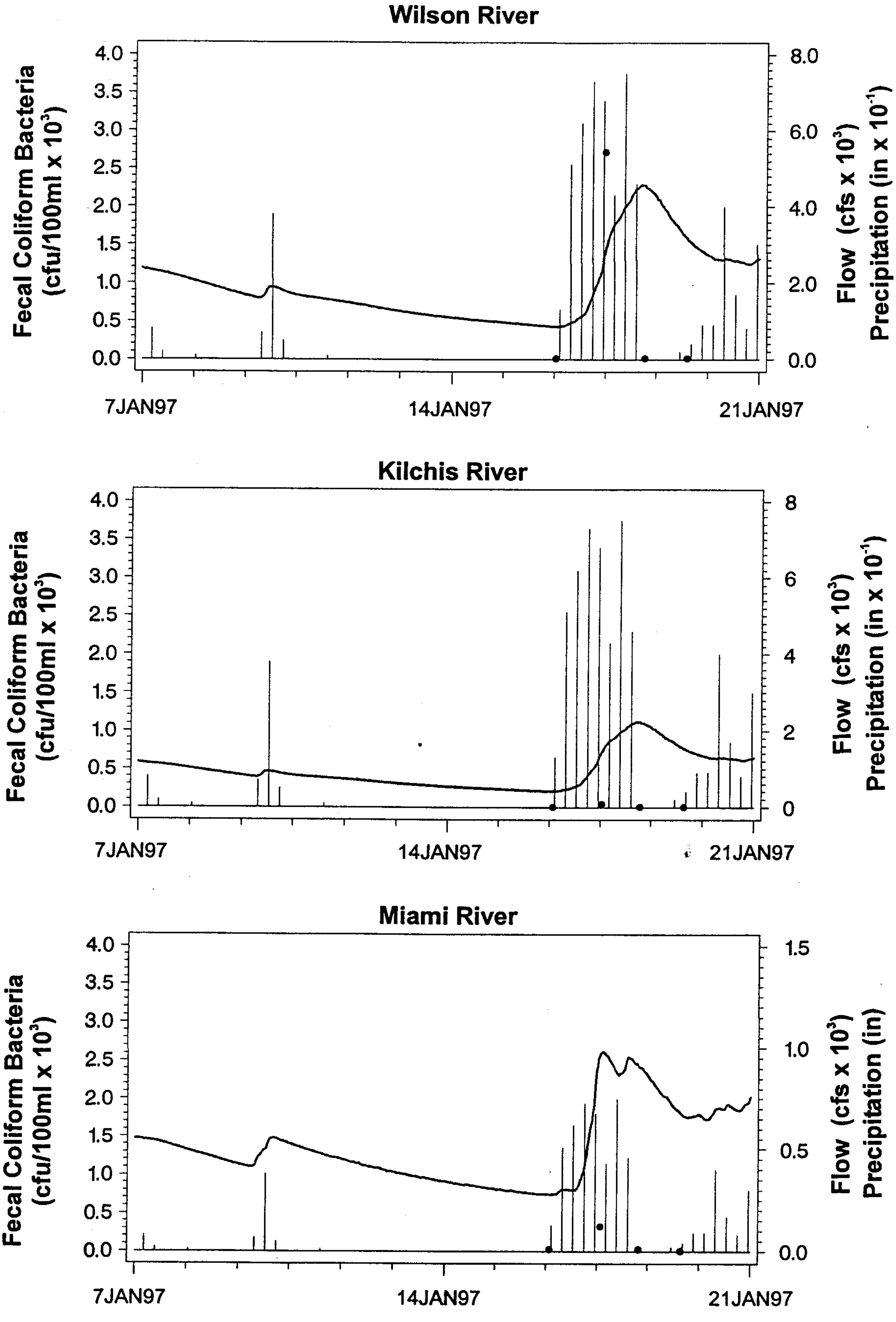


Figure 6. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the January 1997 storm.



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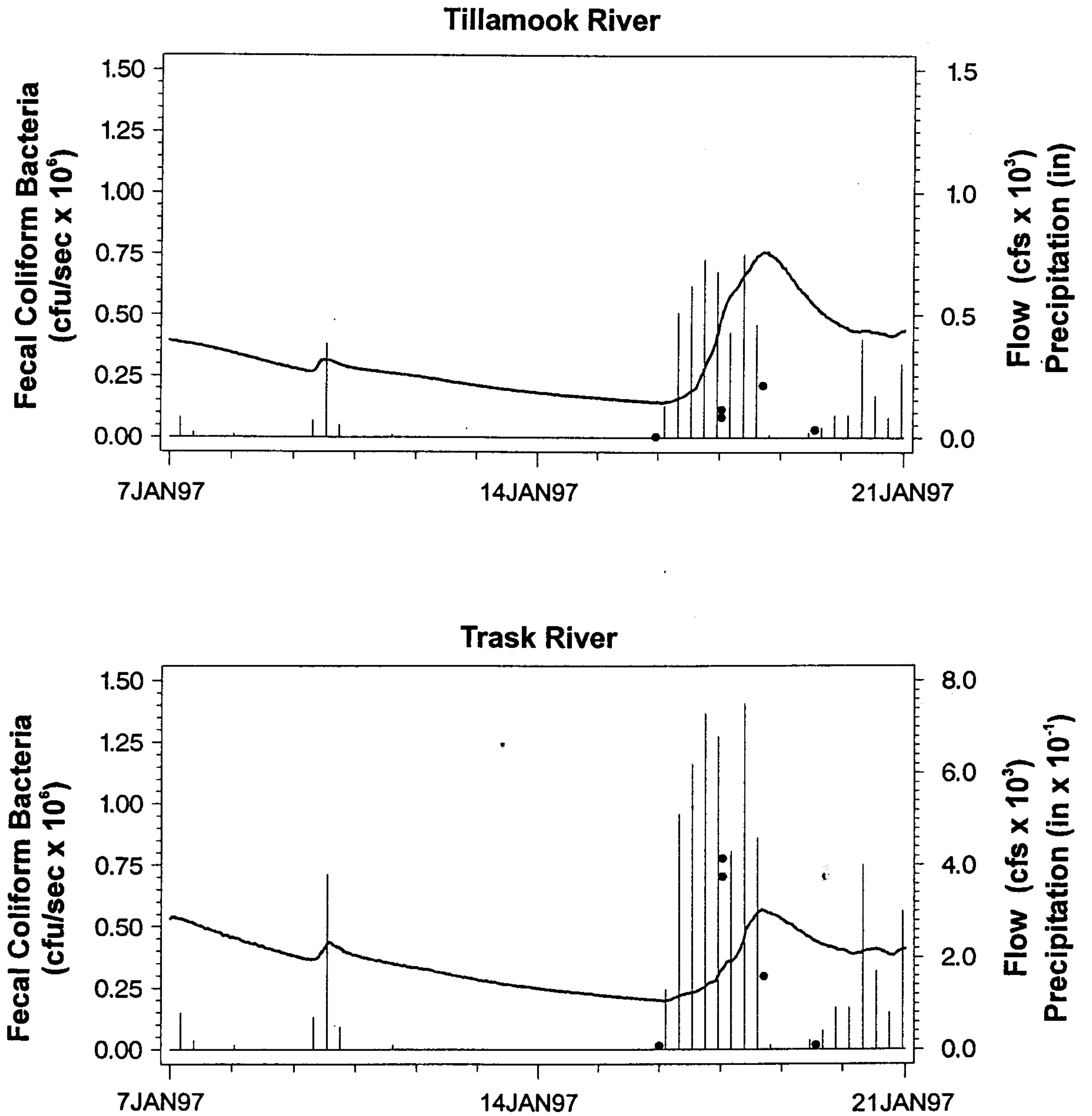
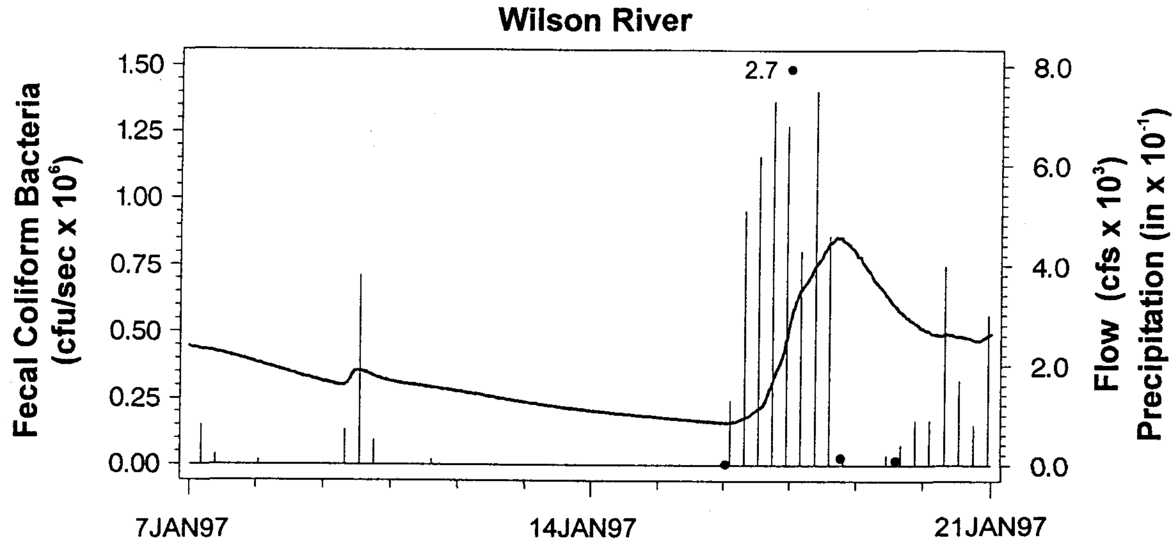
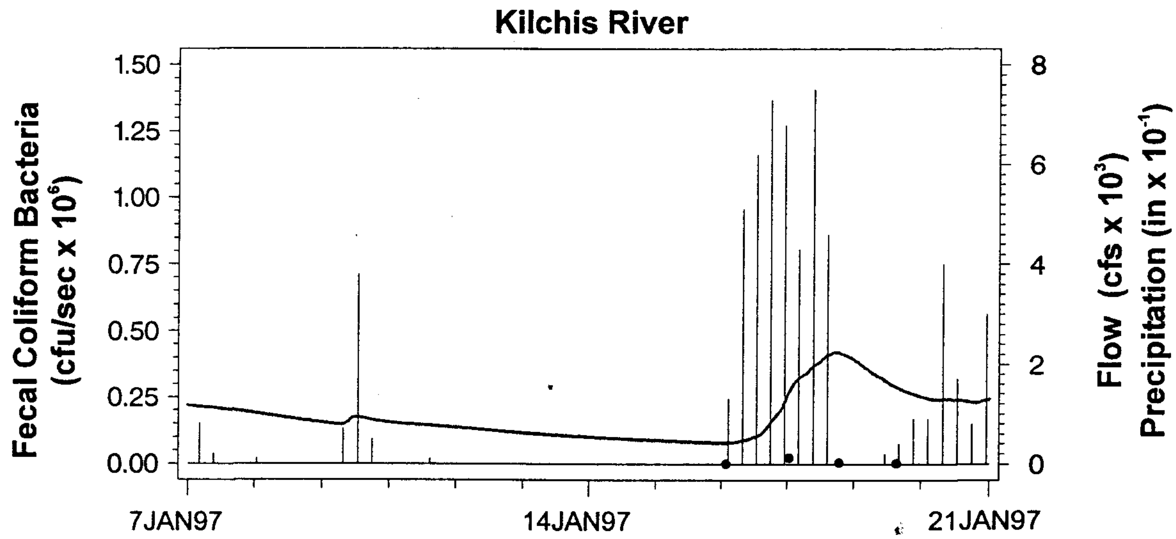
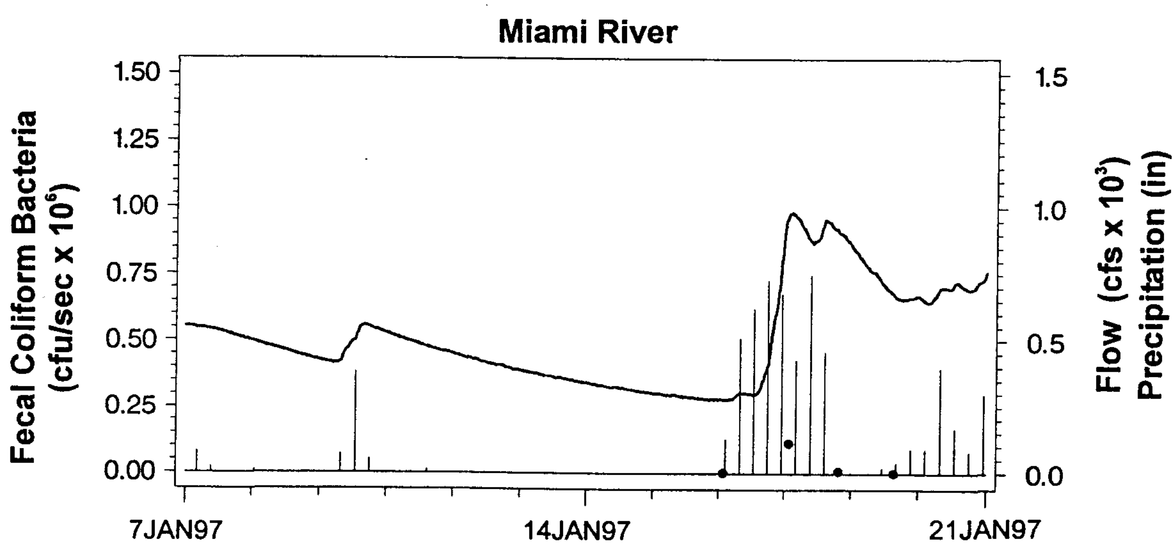


Figure 7. Load of fecal coliform bacteria (cfu/sec x 10^6), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the January 1997 storm.







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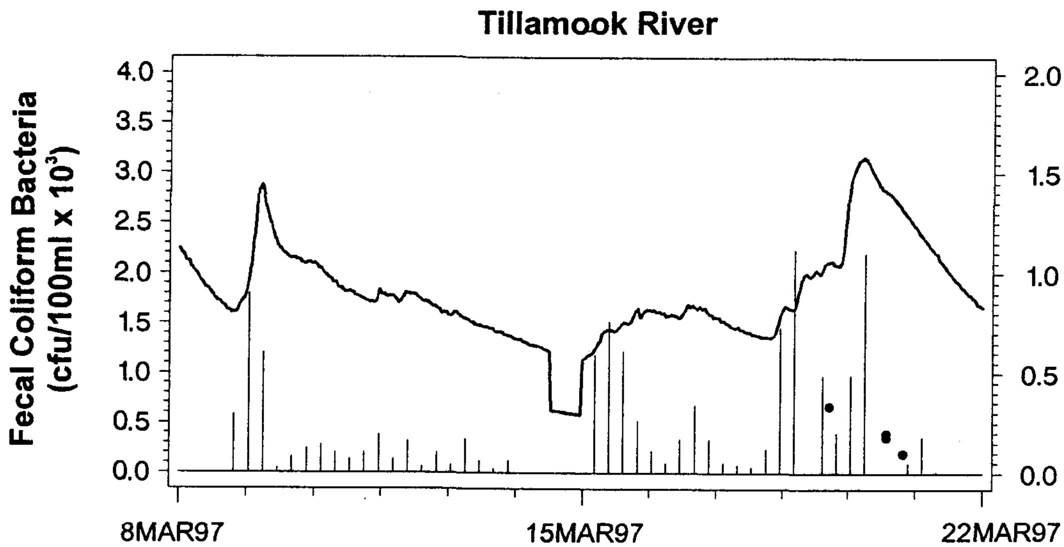


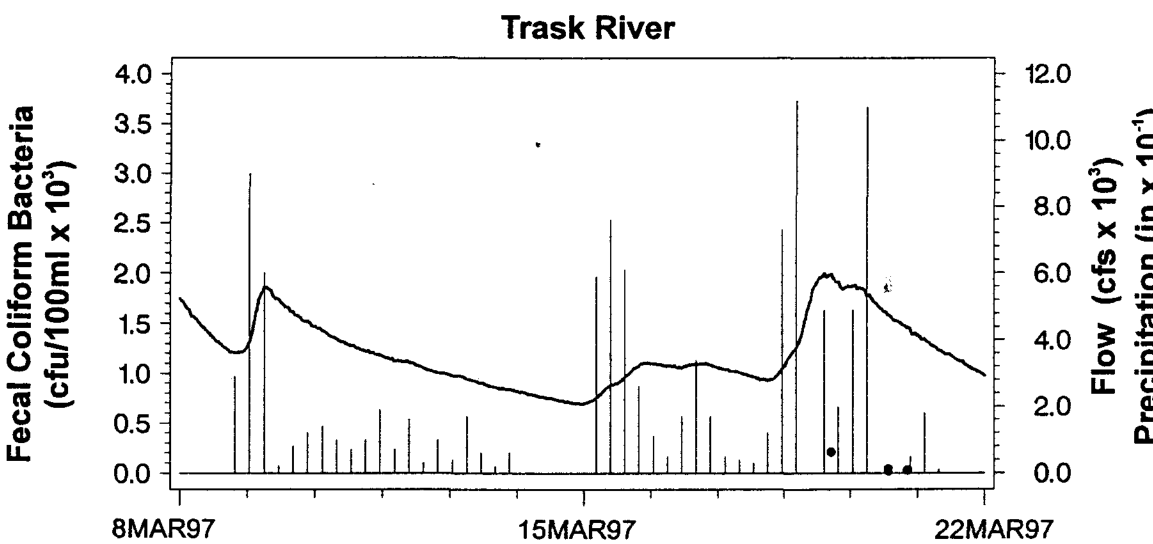
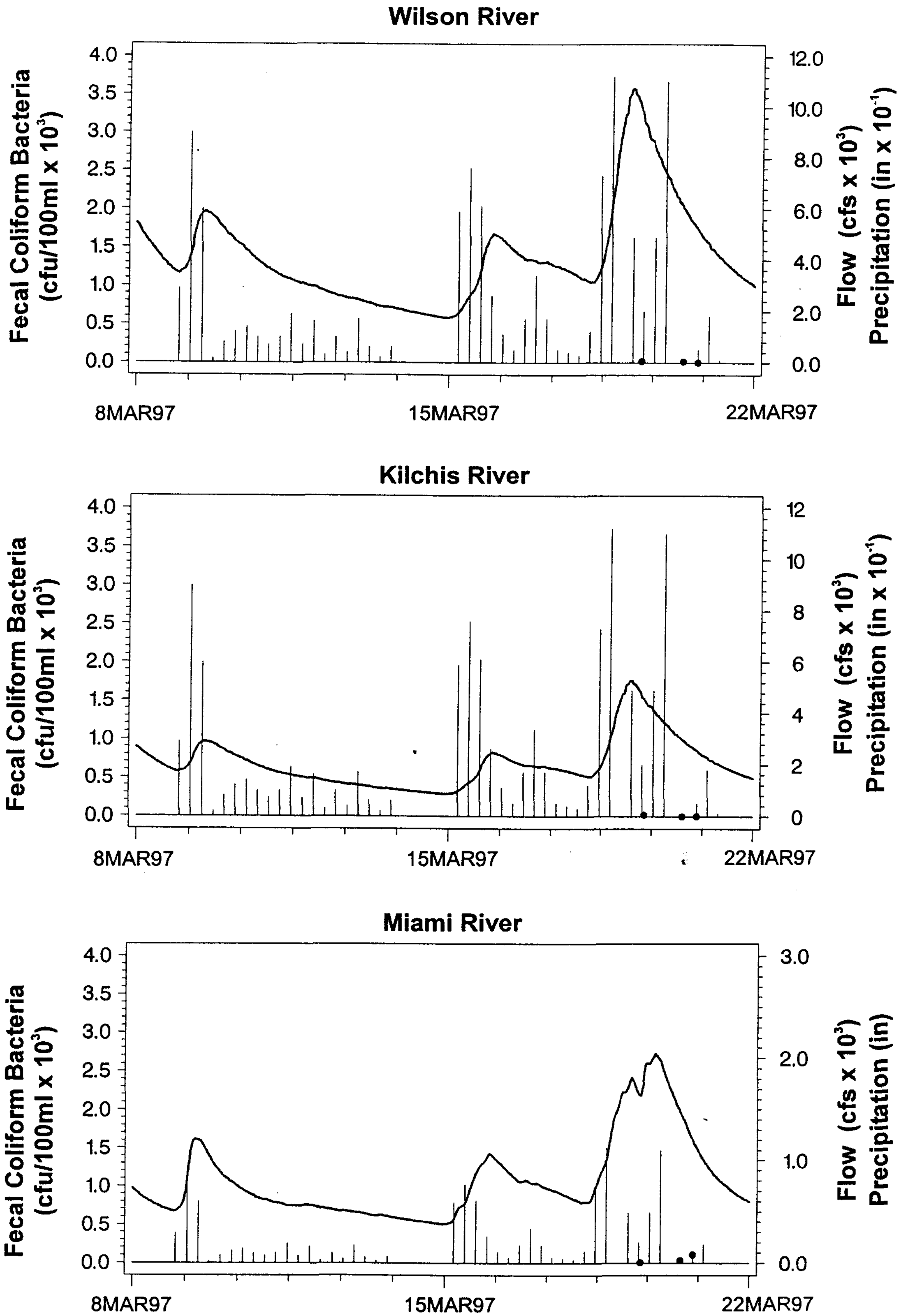


Figure 8. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.



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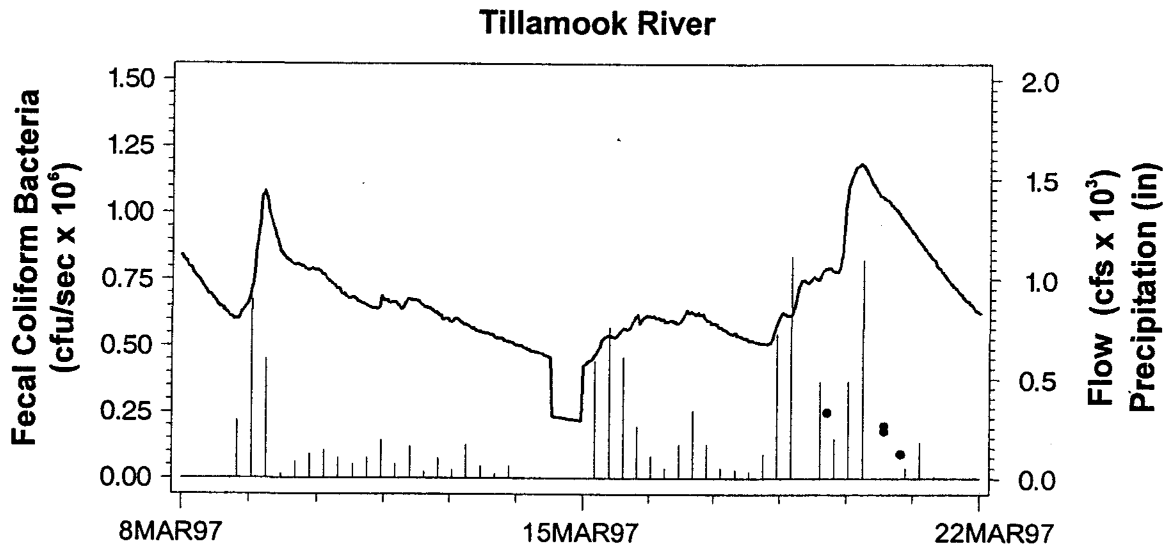


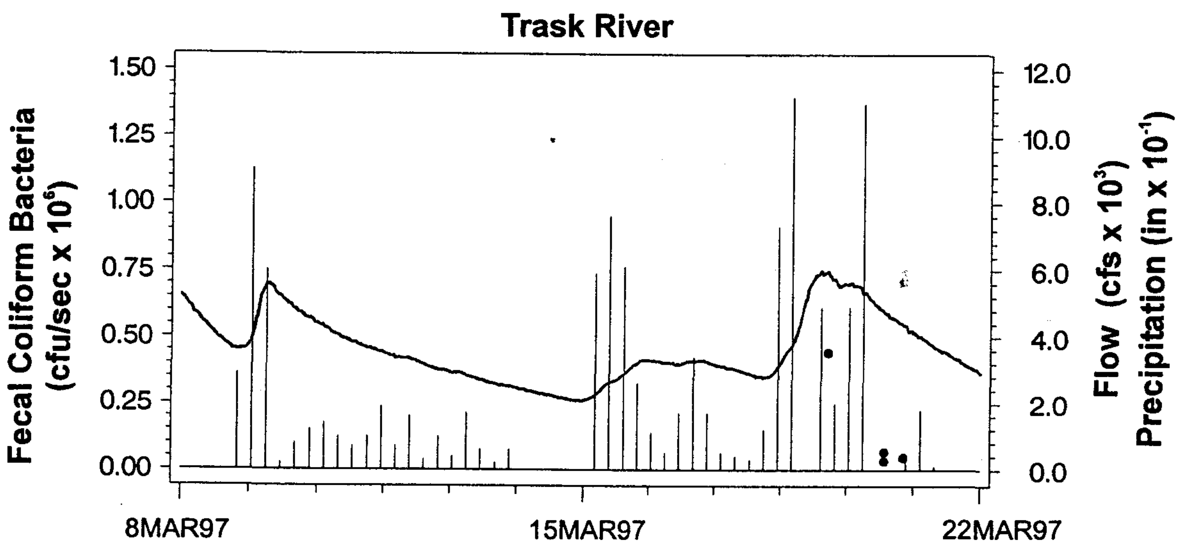
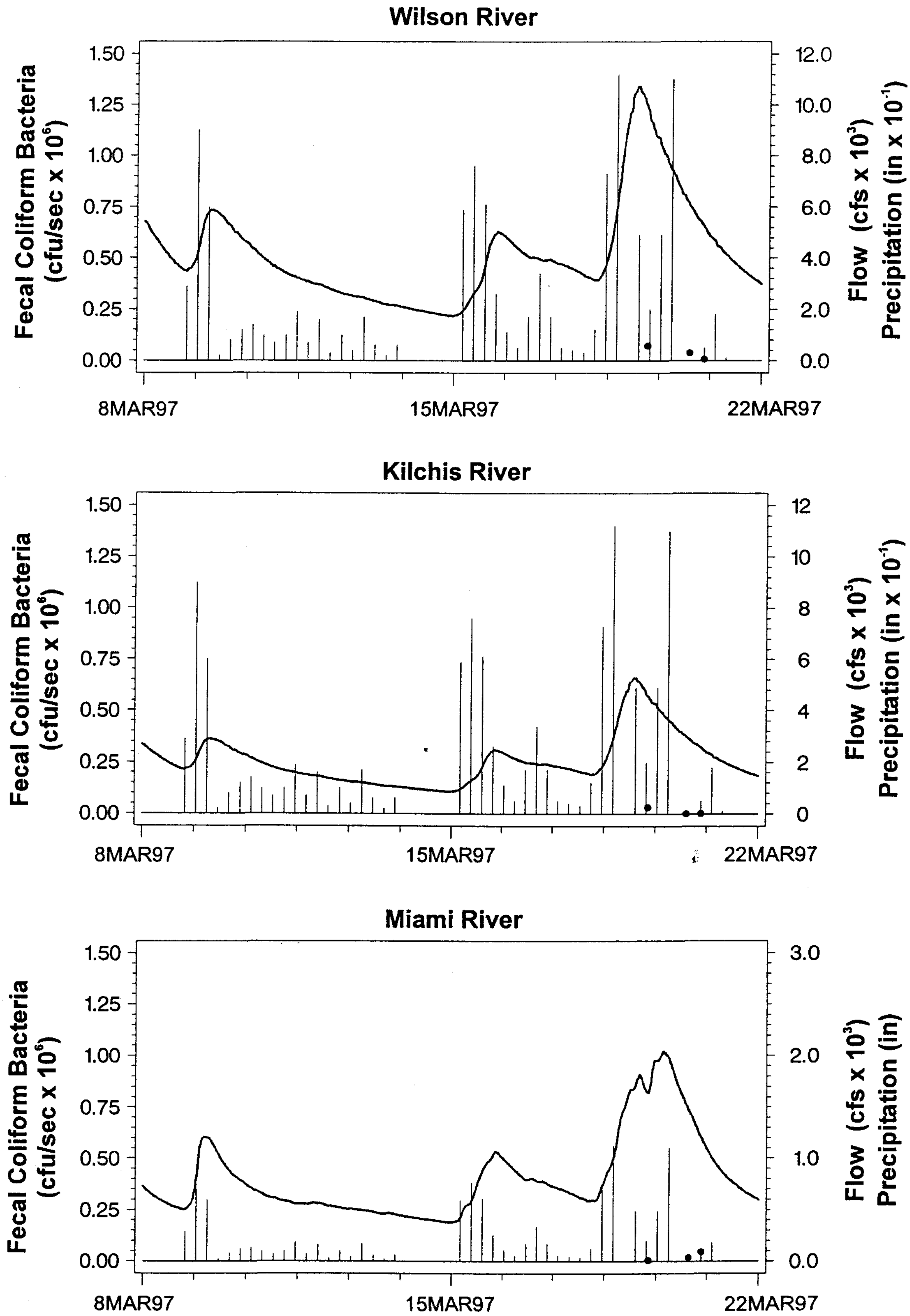


Figure 9. Load of fecal coliform bacteria (cfu/sec x 10^6), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.



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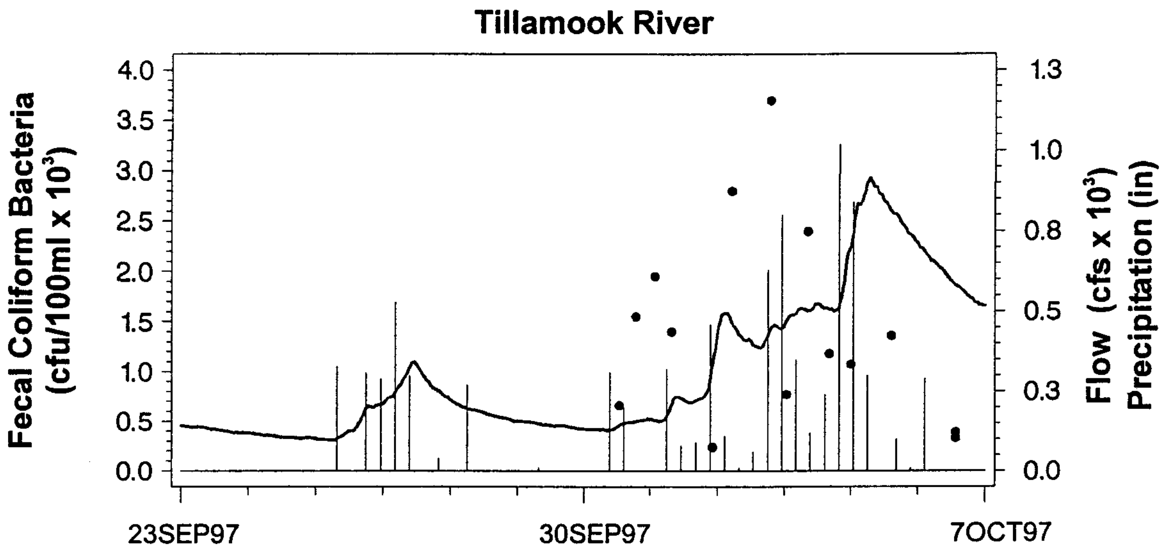


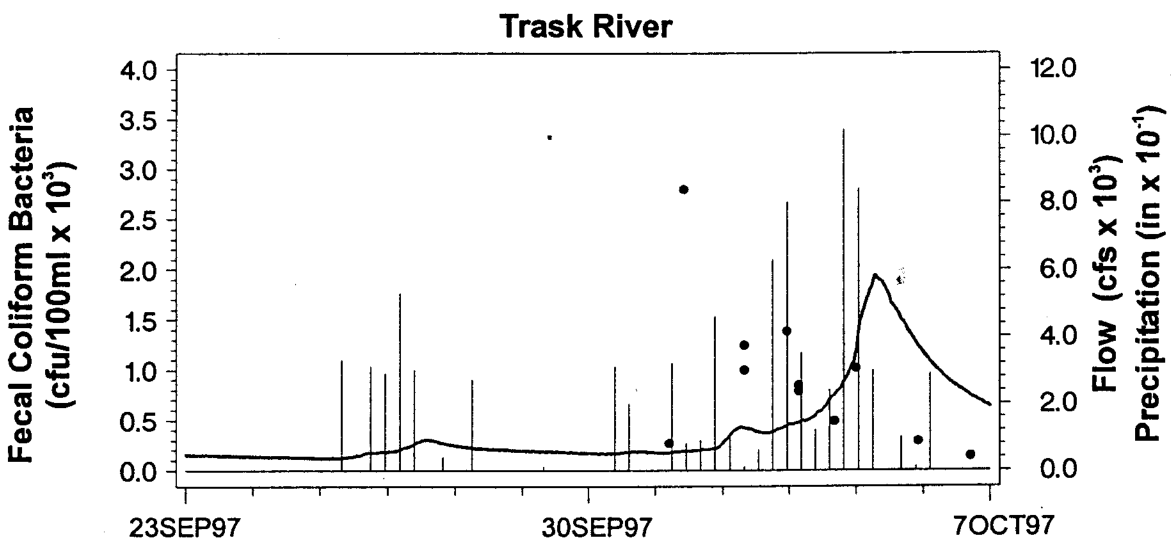


Figure 10. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on the Tillamook and Trask Rivers for the October 1997 storm.

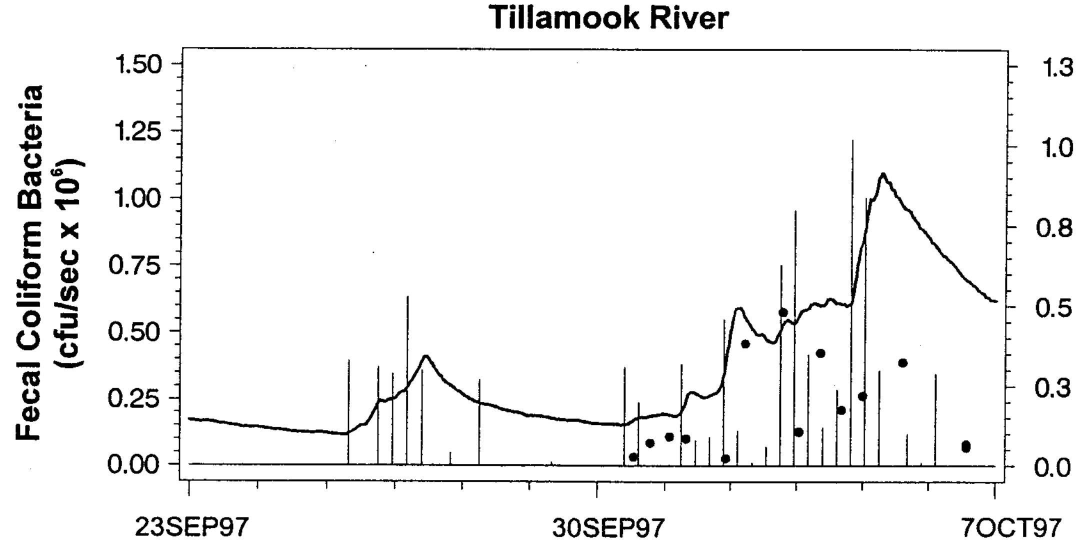
in the larger rivers) and a moderate storm in mid-September, conditions had been dry for months prior to the storm (Figure 1). In addition, this was a fairly large storm, even by winter-storm standards. Discharge in the Wilson River reached nearly 9,000 cfs. The patterns of rainfall and discharge were complex throughout the storm, with numerous short-lived lulls between periods of relatively intense rain (Figure 10).

Two patterns of FCB response are observable in Figure 10. The majority of the measured FCB concentrations followed a clear pattern of increasing concentration, to a peak after three days, followed by decreasing concentrations. Peak FCB concentrations corresponded temporally with the approximate mid-point (peak) of the precipitation inputs. The peak discharge occurred two days later, when bacterial concentrations had already decreased to less than half of the peak FCB concentrations. The second pattern of FCB response, evident in a closer look at the data points, shows greater variability, with a series of rises and falls in FCB concentration, and these corresponded roughly with the pulses of precipitation inputs, especially in the Tillamook River.

FCB concentrations achieved during the fall storm were very high, up to nearly 2,500 cfu/100 ml in the Trask River and over 3,500 cfu/100 ml in the Tillamook River. Similarly high concentrations were recorded by TCCA in the Wilson River. FCB loads in the Trask River exceeded 0.5×10^6 cfu/sec throughout much of the storm, with peak loads over 1.5×10^6 cfu/sec. Peak loads in the Tillamook River were also high (by Tillamook River standards), in the range of 0.4 to 0.6×10^6 cfu/sec (Figure 11).

A storm of moderate size was sampled in mid-February, 1998. It raised discharge in the Wilson River to about 5,000 cfs, and was actually the largest storm of the late winter and spring seasons in 1998. It was preceded by a week of frequent rain showers and relatively constant discharge (~500 to 700 cfs on the Wilson River; Figure 12) and contributed 5.4 in (14cm) of precipitation at Tillamook. As was observed during the fall storm, FCB concentrations followed the overall precipitation pattern relatively well, and peak discharge occurred one or two days later than the peak FCB concentrations. Peak FCB concentrations reached about 500 cfu/100 ml in the Tillamook River, slightly lower in the Trask River, and generally less than about 200 cfu/100 ml in the other rivers. The Trask River achieved the highest loads, but these were only about 0.35×10^6 cfu/sec because neither the FCB concentration nor the discharge rate was particularly high (Figure 13).

The second intensively-sampled storm, and the last storm to be sampled during the 1998 high-flow season, occurred in early March, 1998. It was preceded by a four day period of generally decreasing discharge and little rainfall (Figure 14). The storm was moderate in size and increased Wilson River discharge to over 3,500 cfs, from a pre-storm baseline of just over 1,000 cfs. A total of 4.3 in (11cm) of precipitation was recorded in Tillamook. This storm was unusual in that river discharge increased to relatively high values during the first two days of the storm, and then



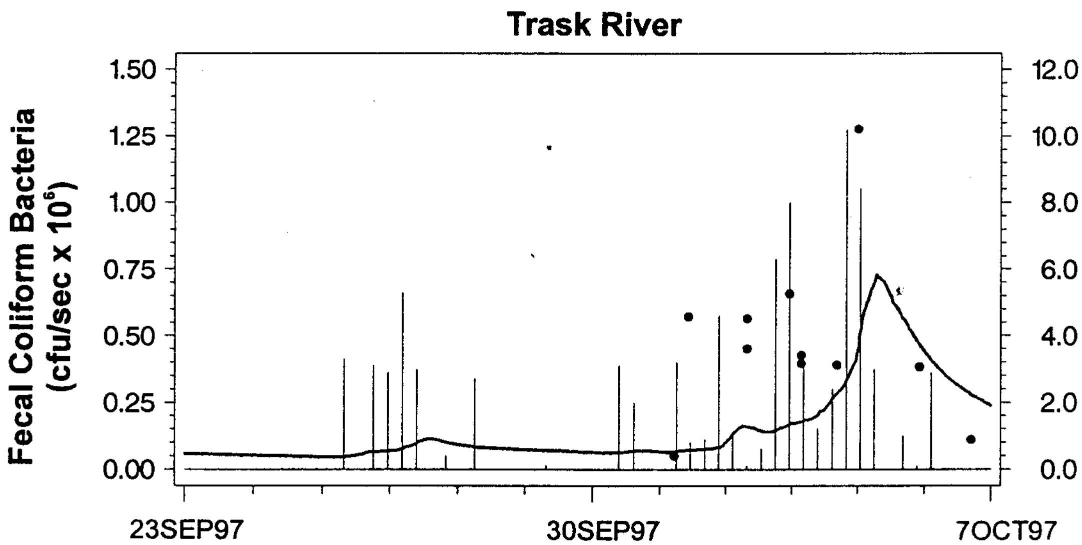
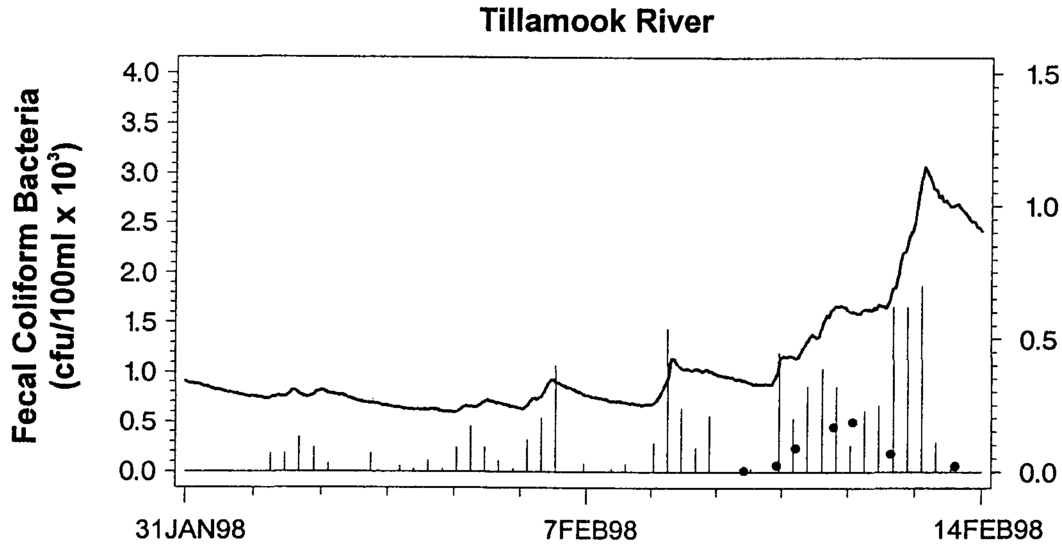


Figure 11. Load of fecal coliform bacteria (cfu/sec x 10^6), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on the Tillamook and Trask Rivers for the October 1997 storm.



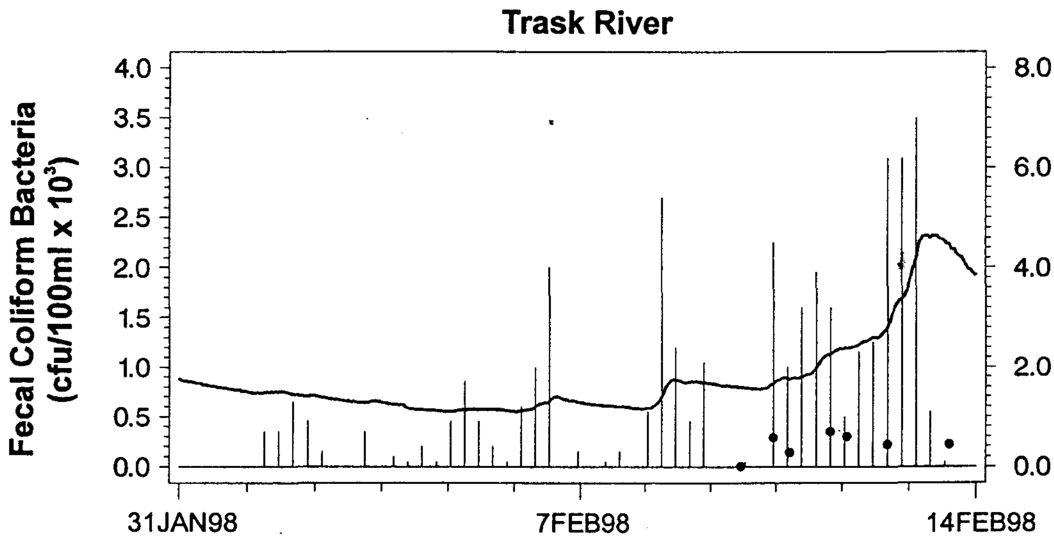
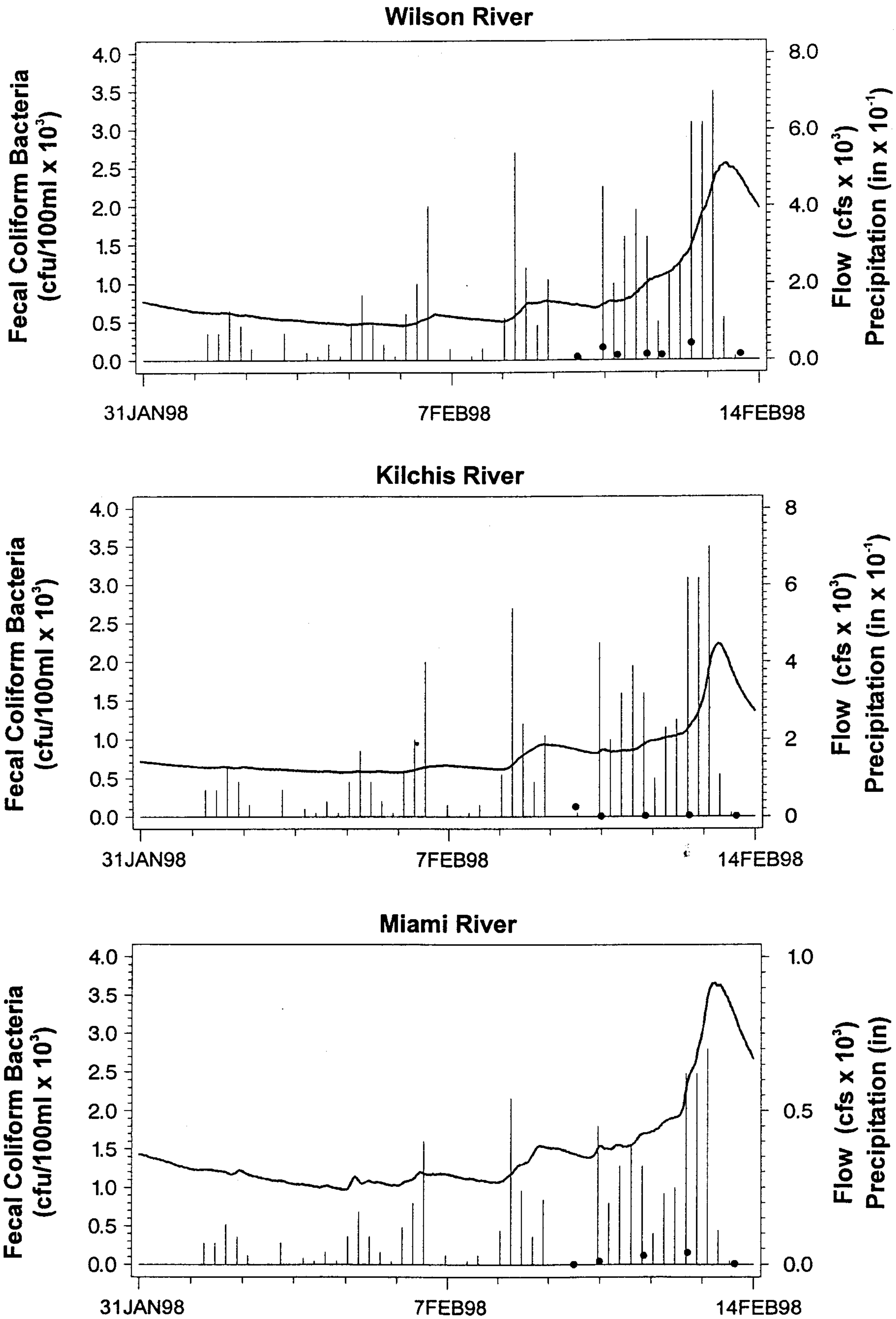


Figure 12. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the February 1998 storm.



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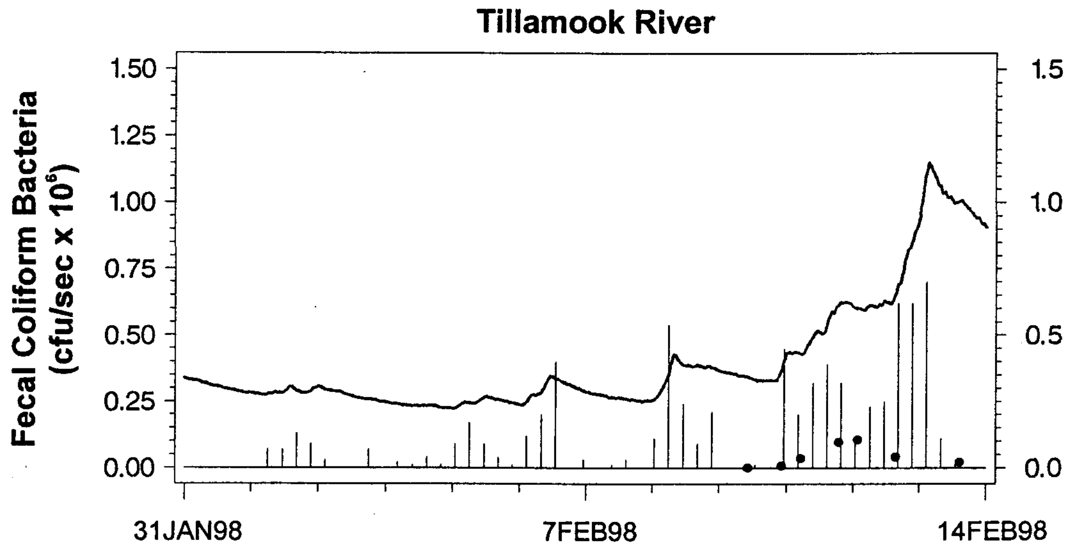


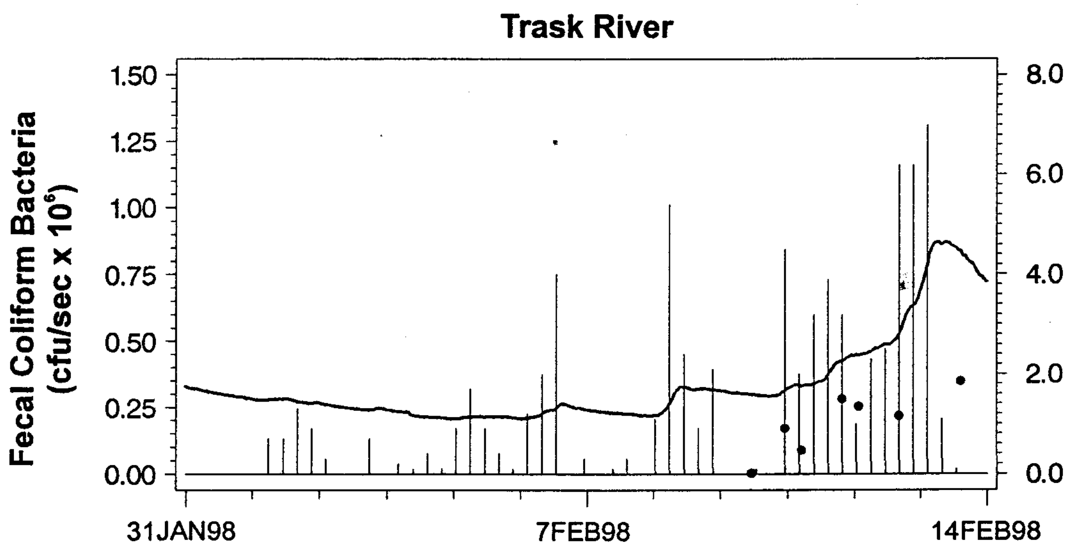
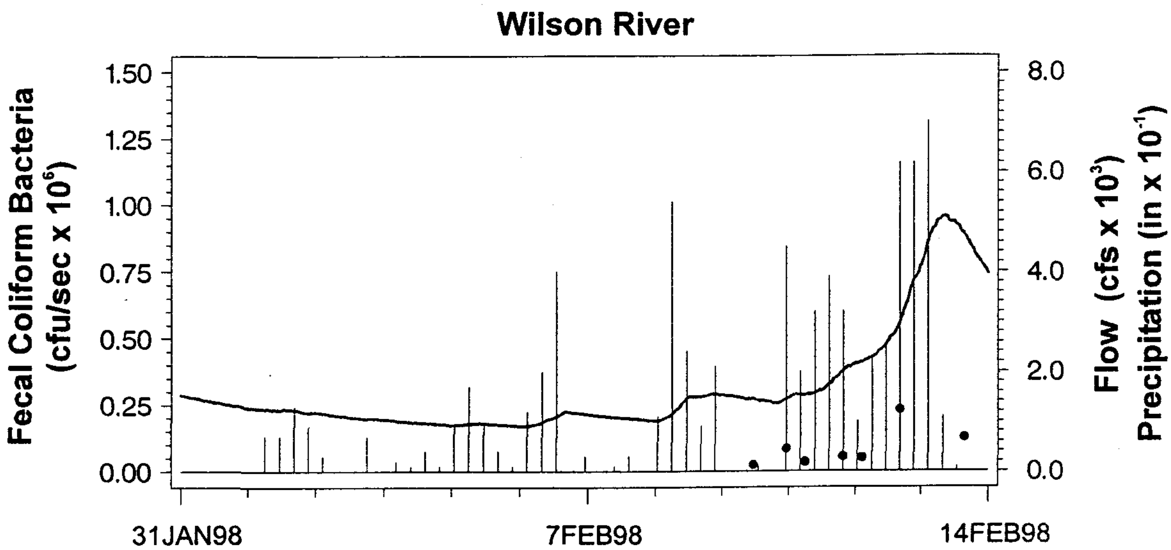
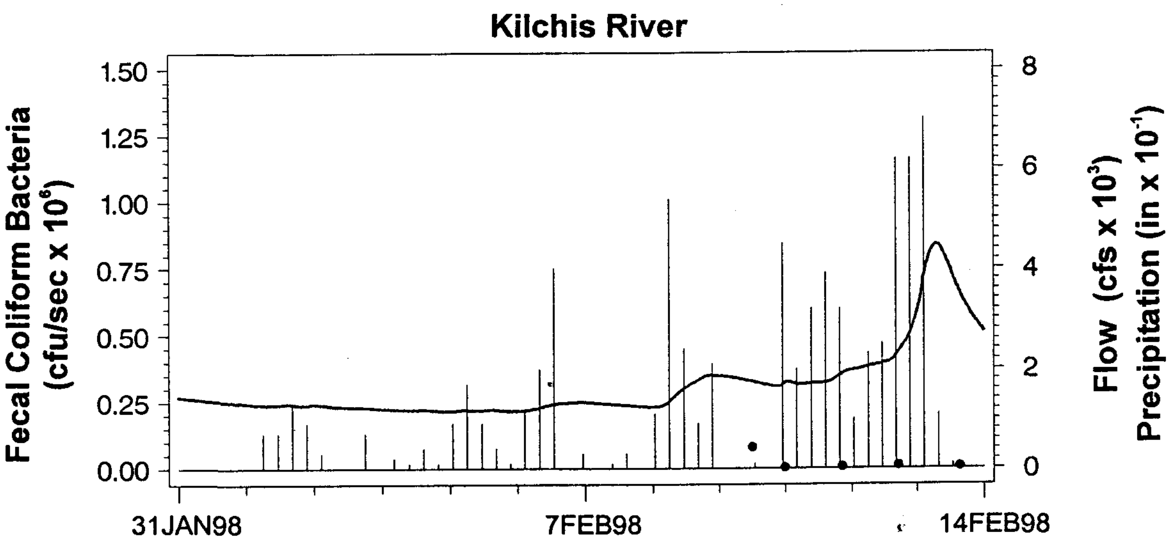
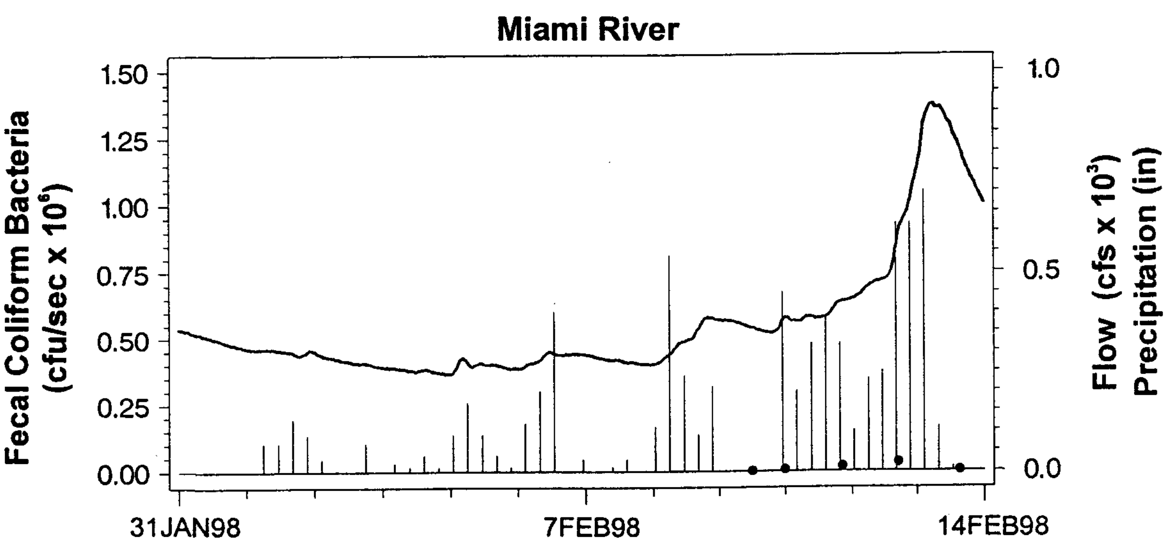


Figure 13. Load of fecal coliform bacteria (cfu/sec x 10^6), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the February 1998 storm.







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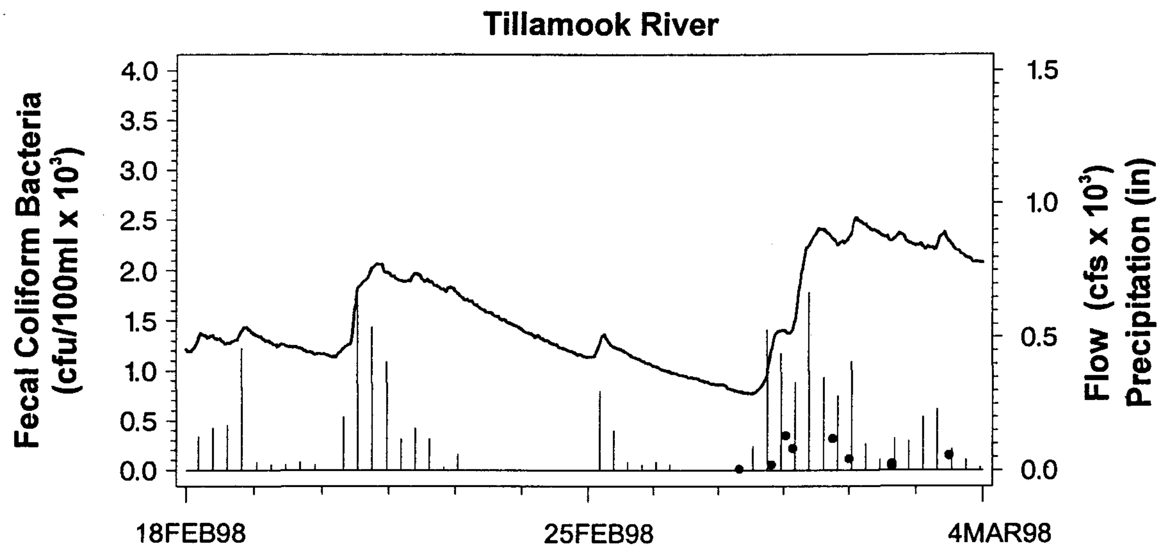


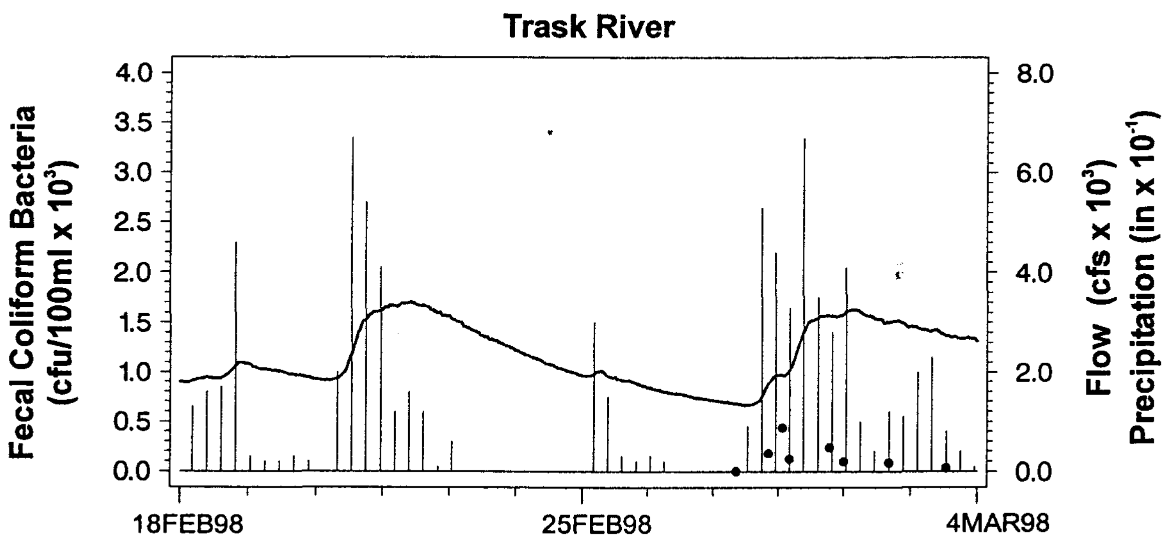


Figure 14. Concentration of fecal coliform bacteria (cfu/100 ml x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on the Tillamook and Trask Rivers for the March 1998 storm.

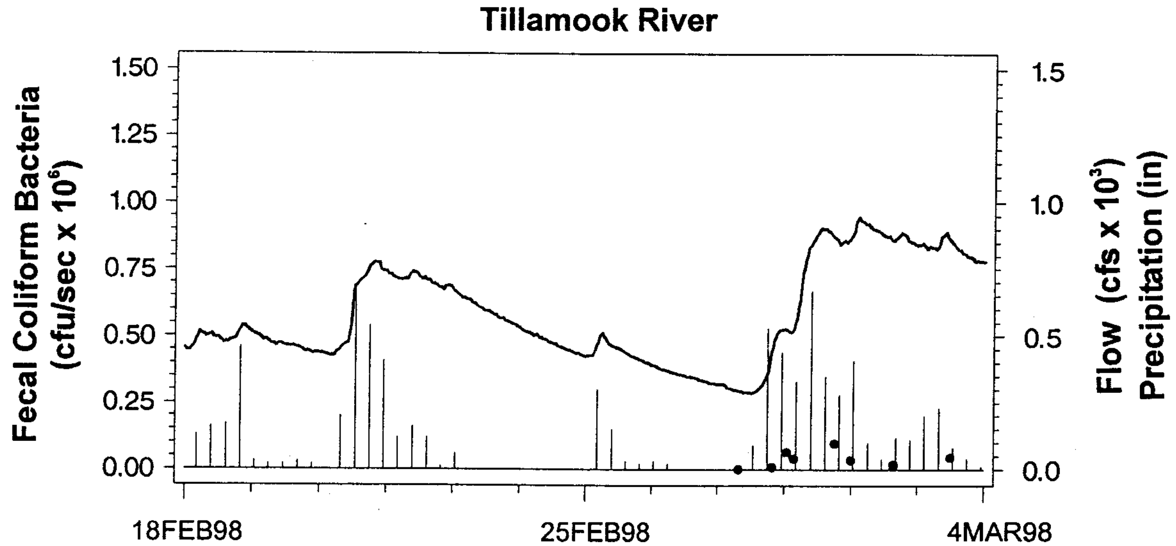
remained relatively constant for a two to three day period. Again, FCB concentrations generally followed the precipitation pattern, reaching peak concentrations near 400 cfu/ 100 ml in the Tillamook and 900 cfu/100 ml in the Trask River. FCB loads in the Trask River were relatively high, reaching a measured peak of about 1 x 10^6 cfu/sec, with several measurements during the storm in the range of 0.3 to 0.6 x 10^6 cfu/sec (Figure 15). Peak loads in the Tillamook River were low (just over 0.1 x 10^6 cfu/sec).

Other Parameters

TSS concentrations were measured at the primary sites during the routine storms (Storms 1, 2, 3, 5). Results of TSS measurements during the four storms are presented in Figures 16 through 23. Both TSS concentrations and loads were highly correlated with discharge throughout the duration of the study (Sullivan et al. *In review*), and followed the pattern of storm discharge closely in each river during each storm (Figures 16-23). Peak TSS concentrations were highest in the Wilson River during each storm, reaching concentrations of about 500 mg/L during Storm 1 (Figure 16) and over 300 mg/L during Storm 3 (Figure 21). Peak TSS concentrations in the Trask River were only slightly lower during the first storm (~450 mg/L) but less than ⅓ of the peak Wilson River value during the third storm. The other rivers typically exhibited peak TSS concentrations that were only half or lower those found in the Wilson River. Peak TSS loads exceeded 80 mg/sec in the Wilson and Trask Rivers during Storm 1 (Figure 17). Peak loads in the Kilchis River were lower by more than a factor of two, and peak loads in the Miami and Tillamook Rivers were lower by more than a factor of ten (Figure 17).

Total inorganic nitrogen (TIN) concentrations did not change dramatically during the two storm events in which they were measured (Figures 24, 25). There was often a general decrease in TIN concentration near peak discharge, likely due to dilution. TIN loads increased with discharge during the storms, however, reaching peak values over 200 mg/sec in the Trask and Wilson Rivers, about 100 mg/sec in the Kilchis River, and less than 50 mg/sec in the Miami and Tillamook Rivers (Figures 26, 27).

Total phosphorus (TP) was measured during two storms and showed a clear pattern of increasing concentration with increasing discharge (Figure 28). Peak values were achieved during Storm 1 in the Trask and Wilson Rivers (~0.8 and 0.6 mg/L, respectively). Lowest concentrations during peak discharge periods (~0.2 mg/L) were achieved in the Miami and Tillamook Rivers, with the Kilchis River being intermediate. TP loads also increased with discharge during Storm 1, an increase of about an order of magnitude over pre-storm values in the Trask River and about two orders of magnitude in the Wilson River (Figure 29). Somewhat lower concentrations and loads were measured during Storm 2, although the general patterns of response were similar (Figures 30, 31).



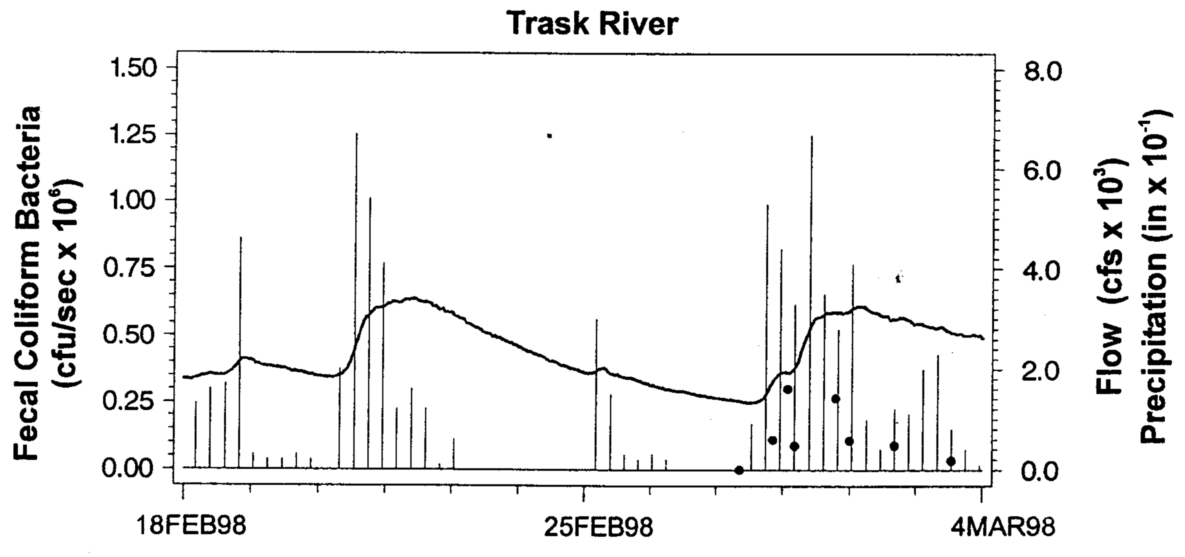
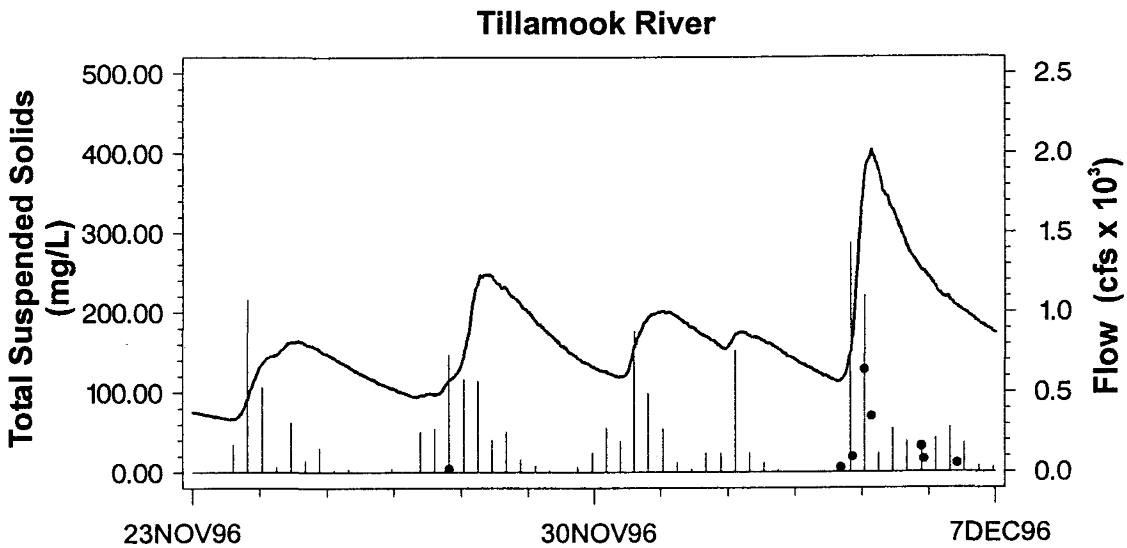


Figure 15. Load of fecal coliform bacteria (cfu/sec x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on the Tillamook and Trask Rivers for the March 1998 storm.



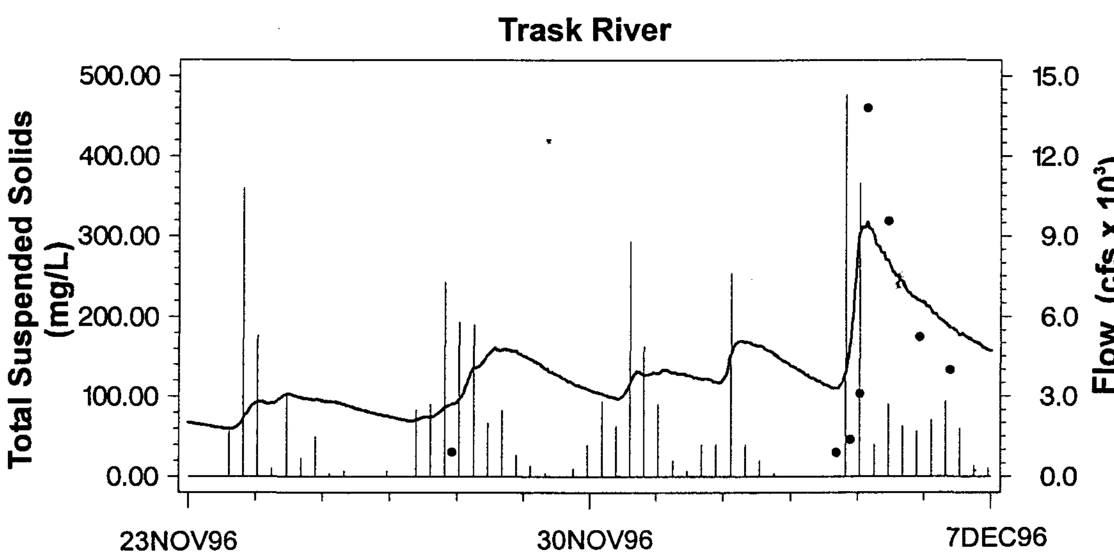
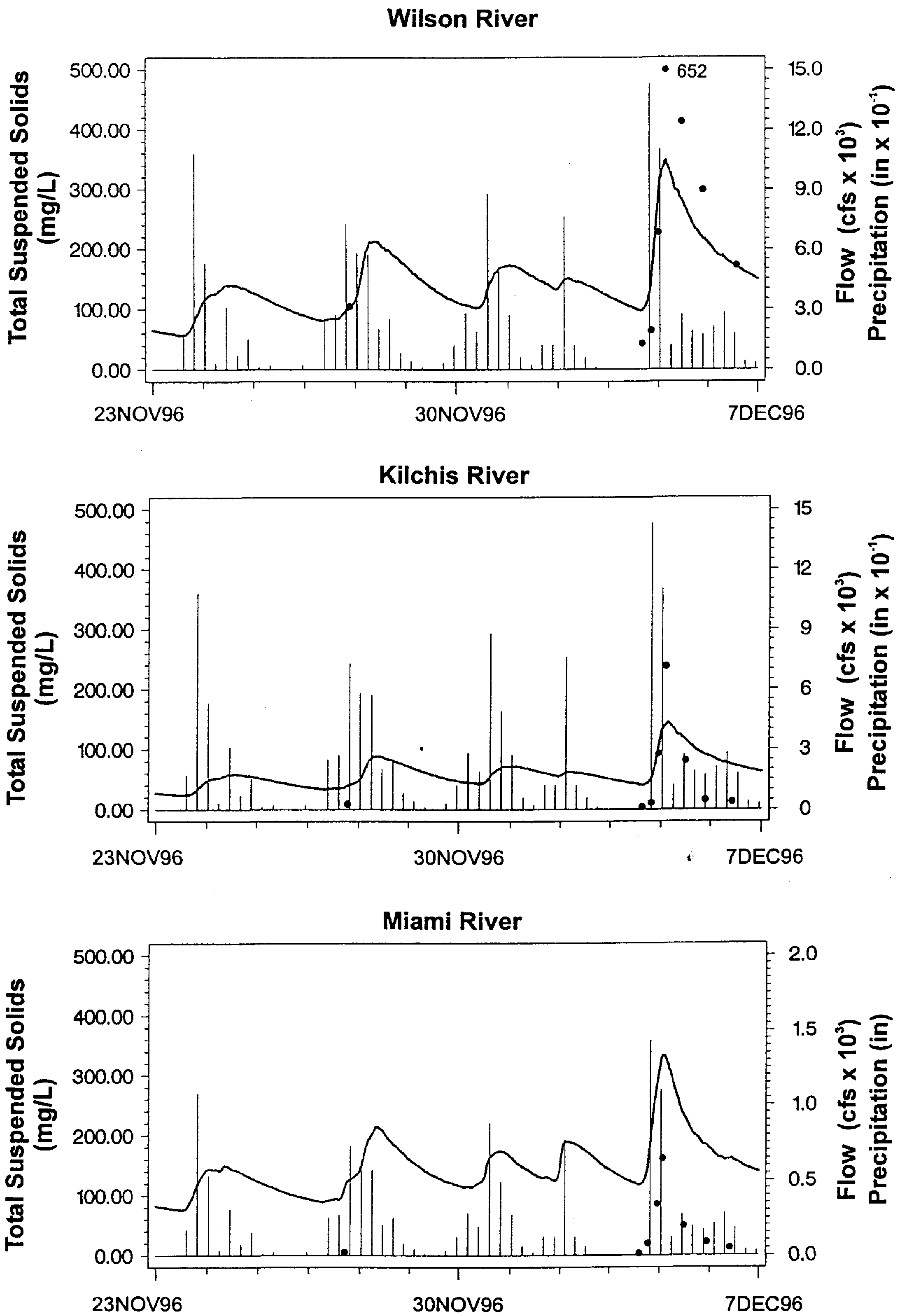


Figure 16. Concentration of total suspended solids (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.



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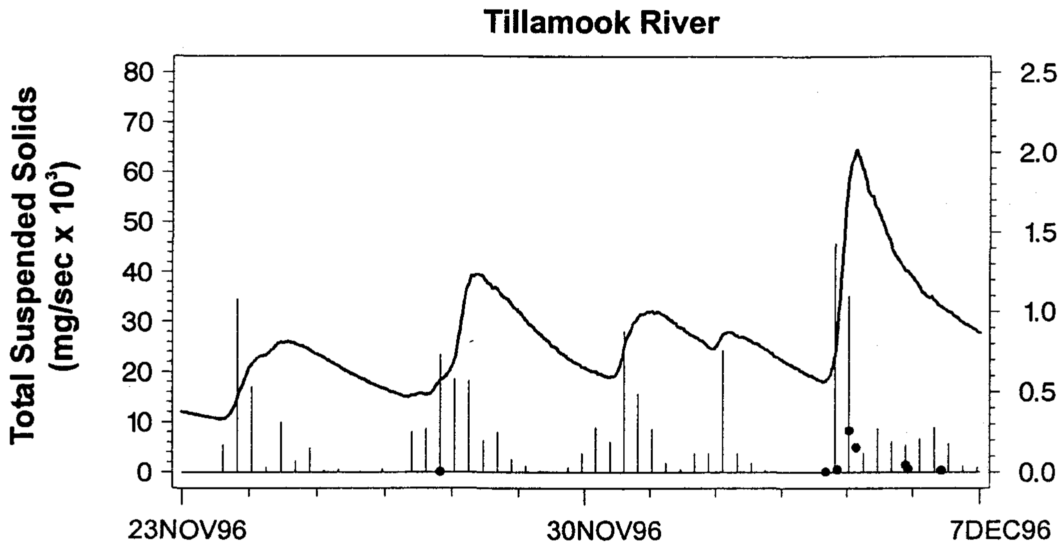


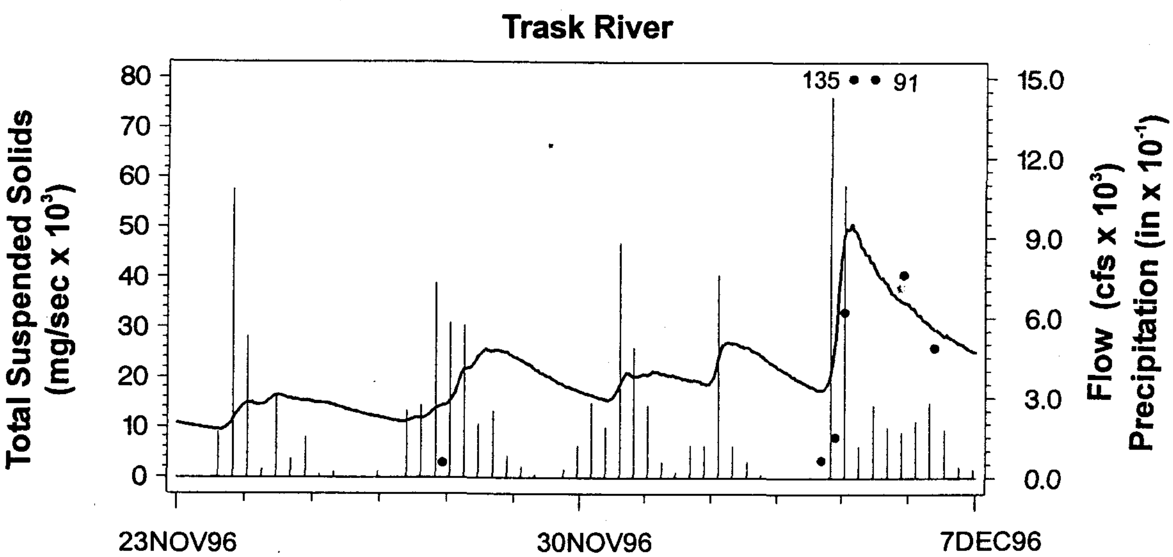
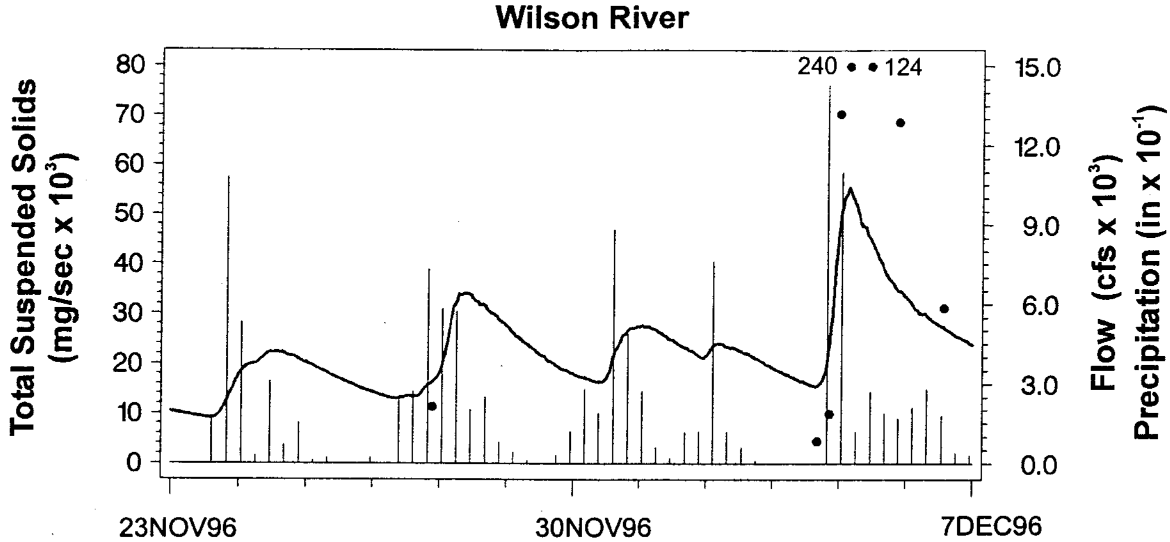
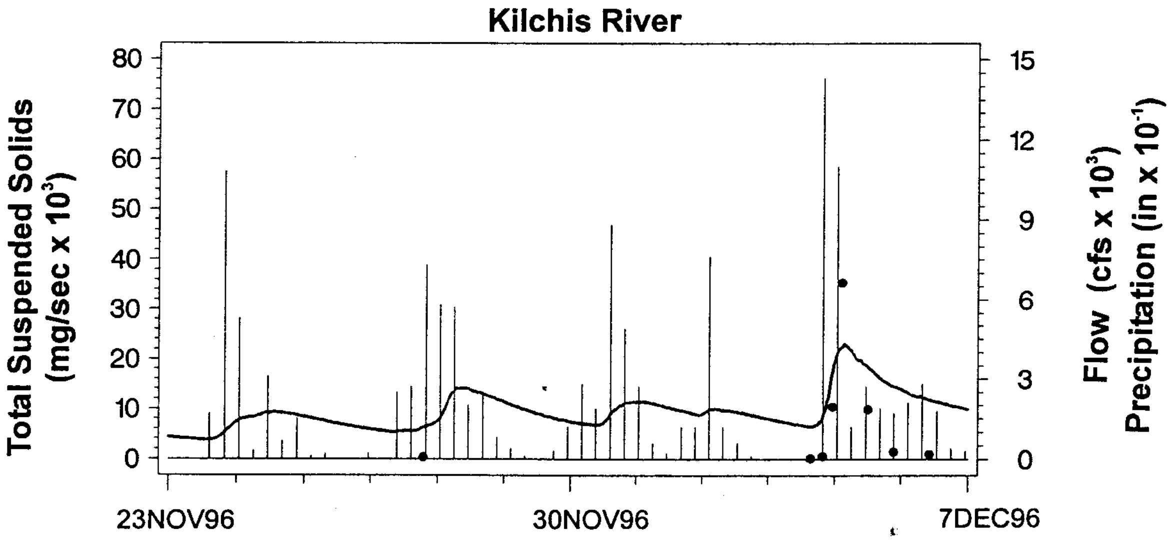
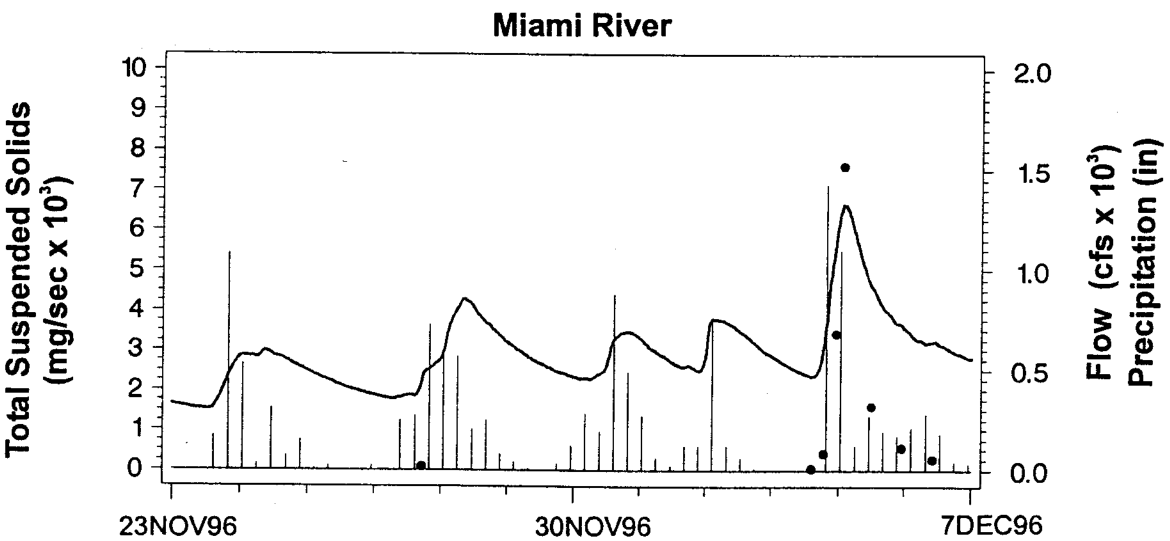


Figure 17. Load of total suspended solids (mg/sec x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.







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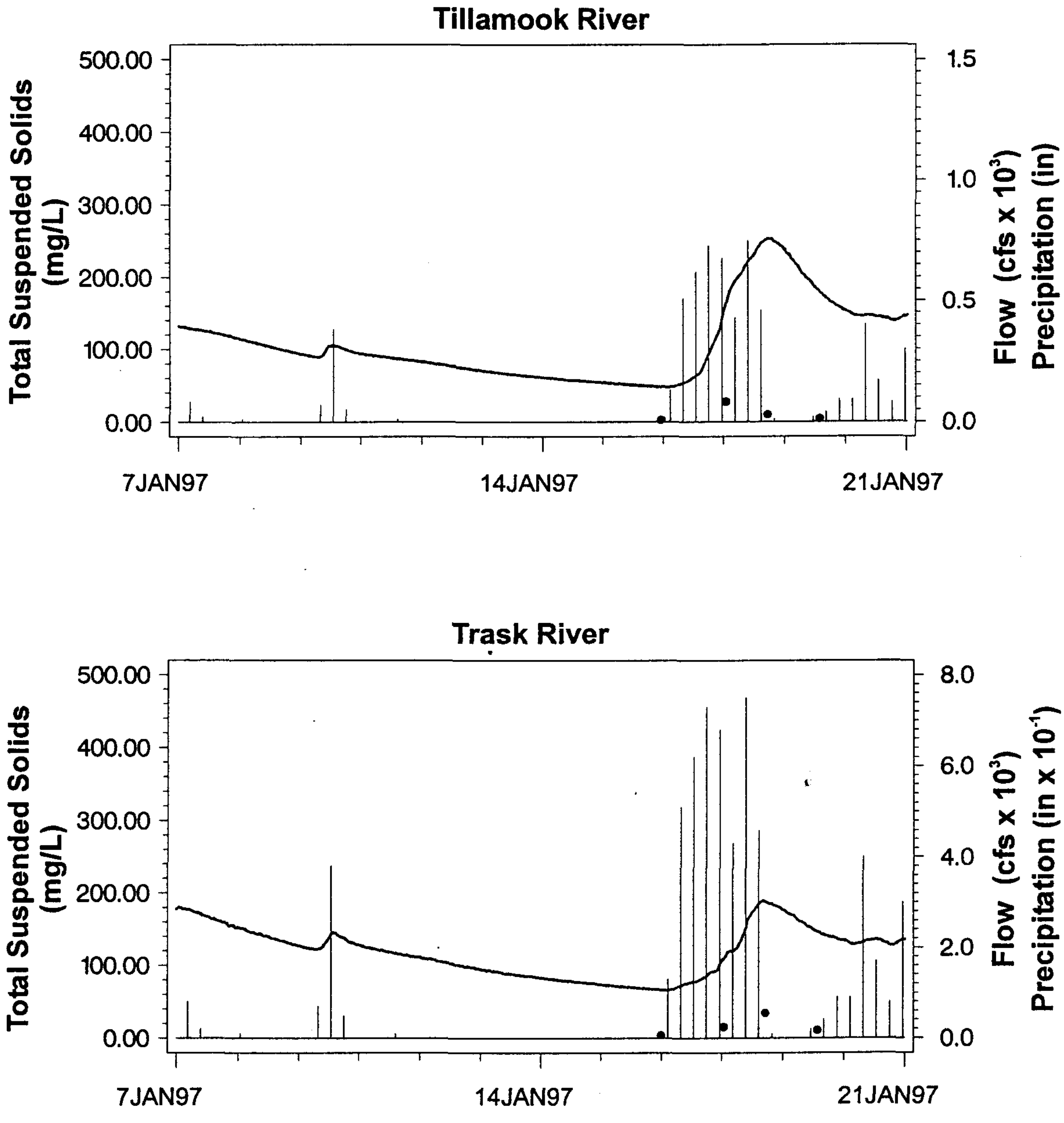
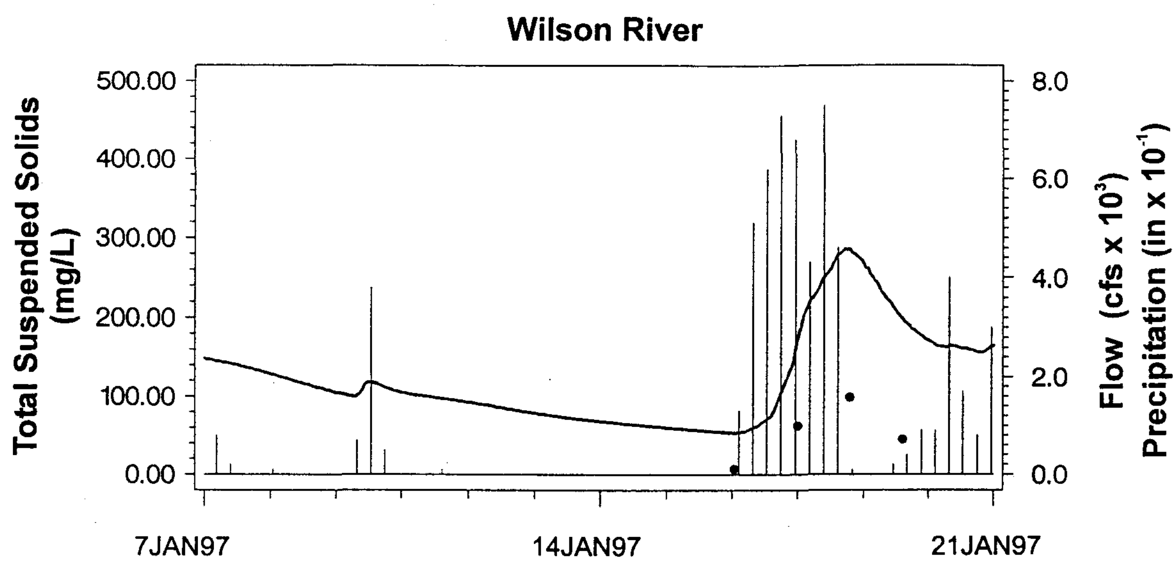
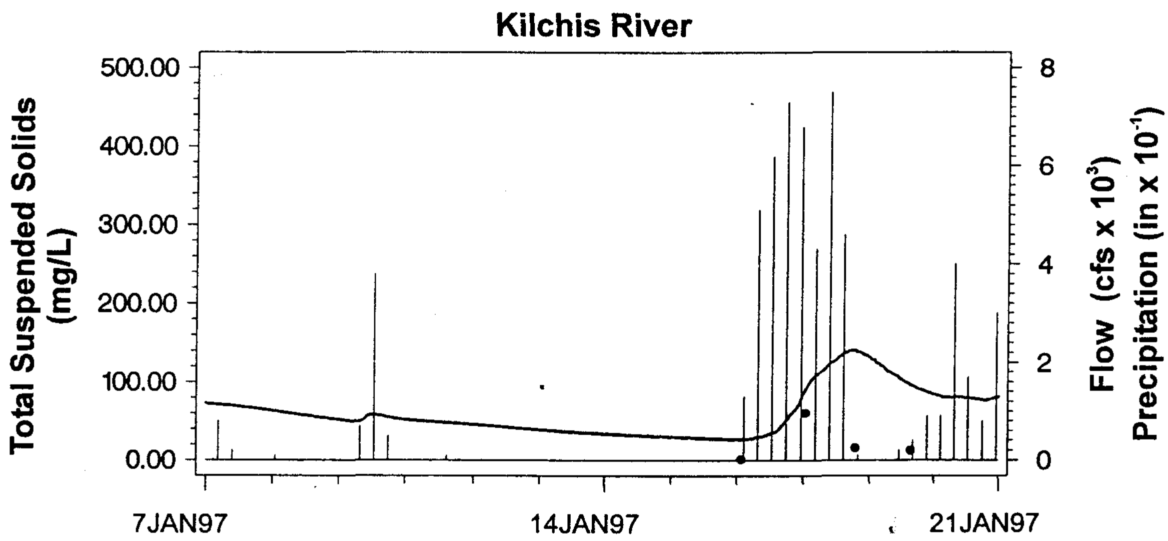
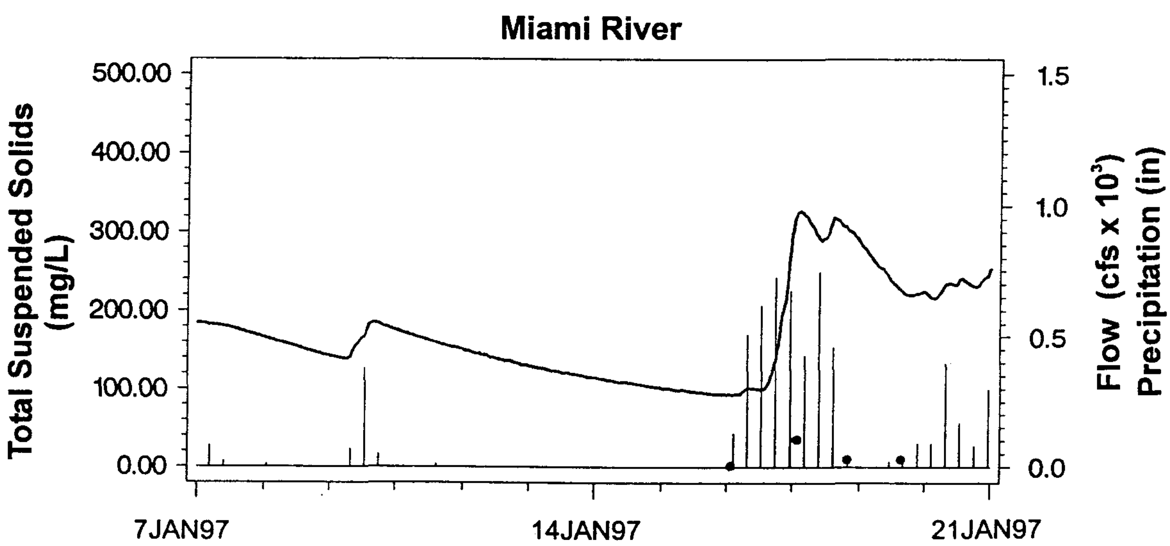


Figure 18. Concentration of total suspended solids (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the January 1997 storm.







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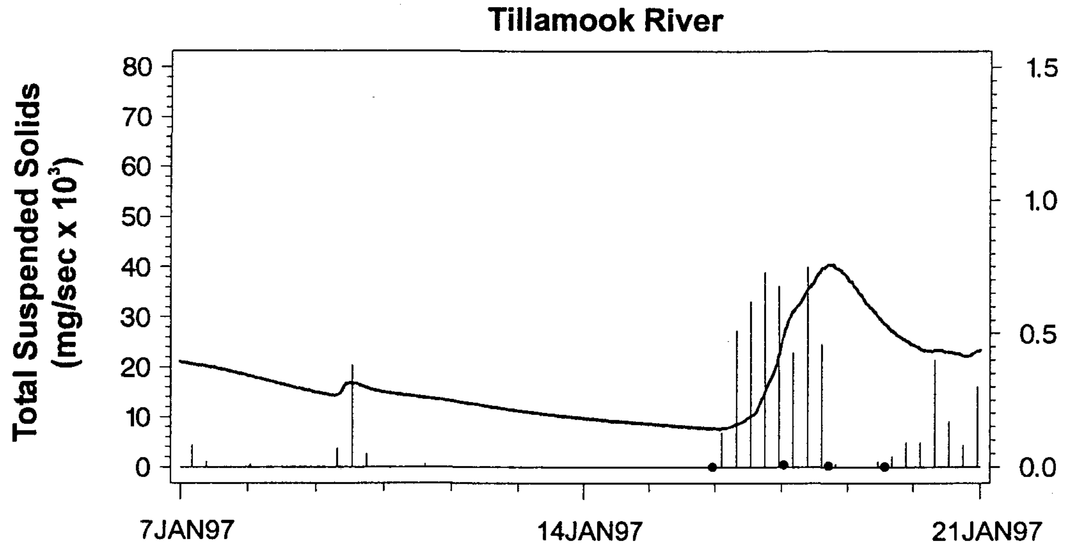


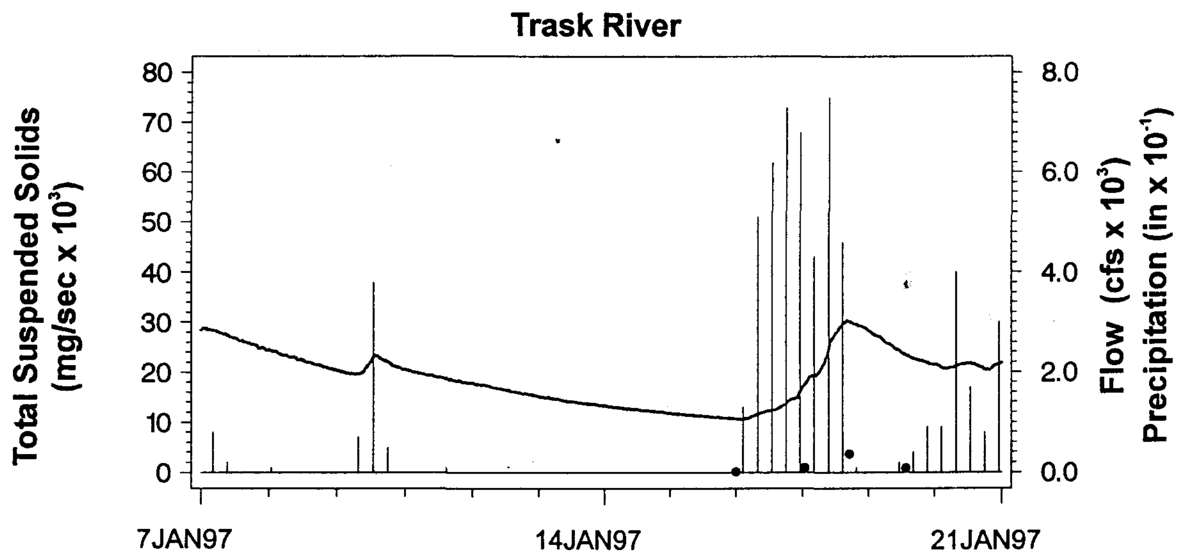
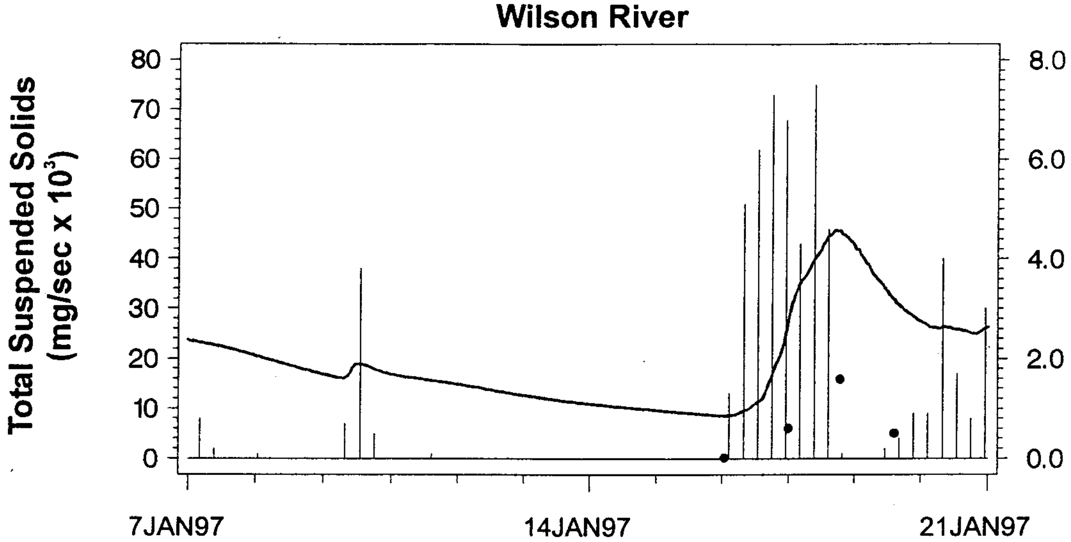
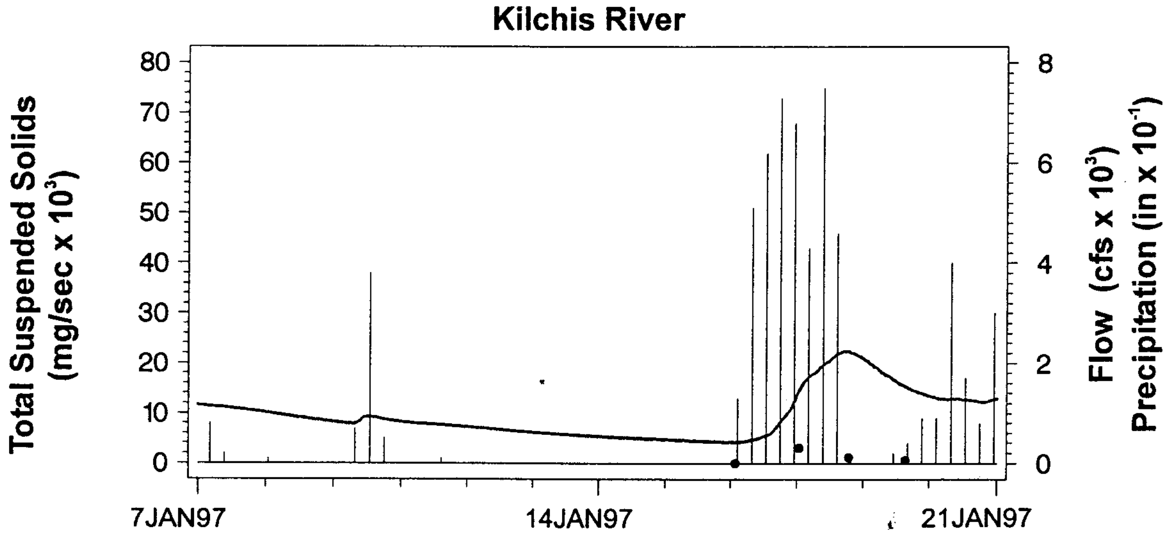
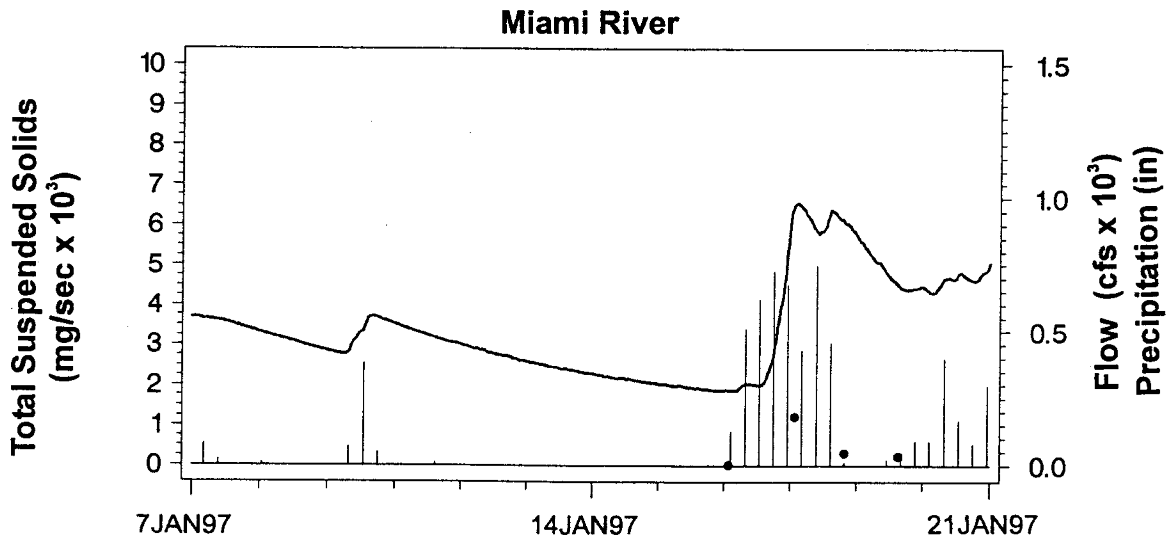


Figure 19. Load of total suspended solids (mg/sec x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the January 1997 storm.







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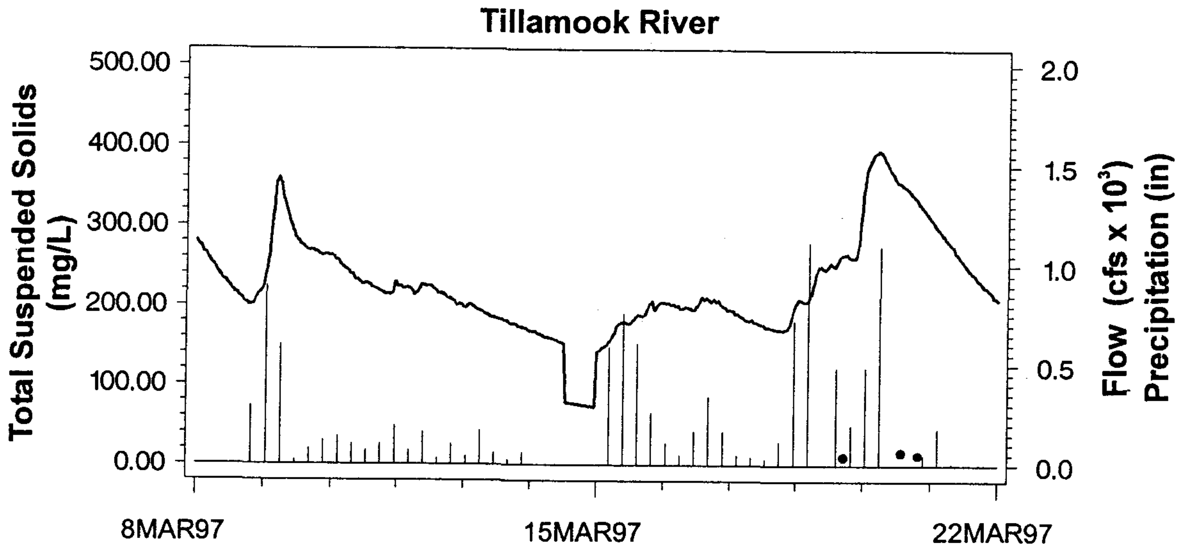


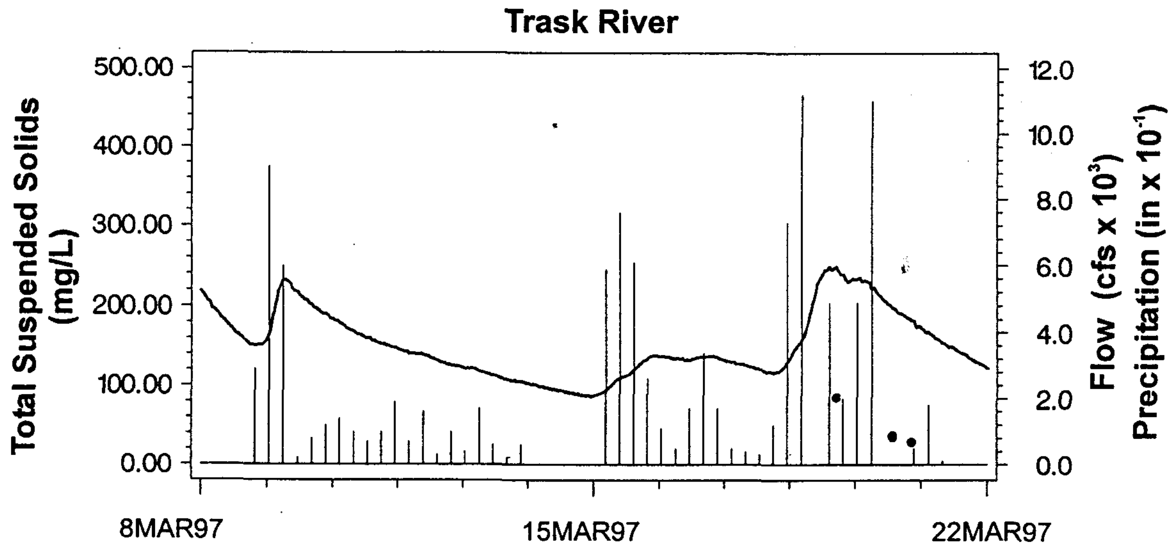
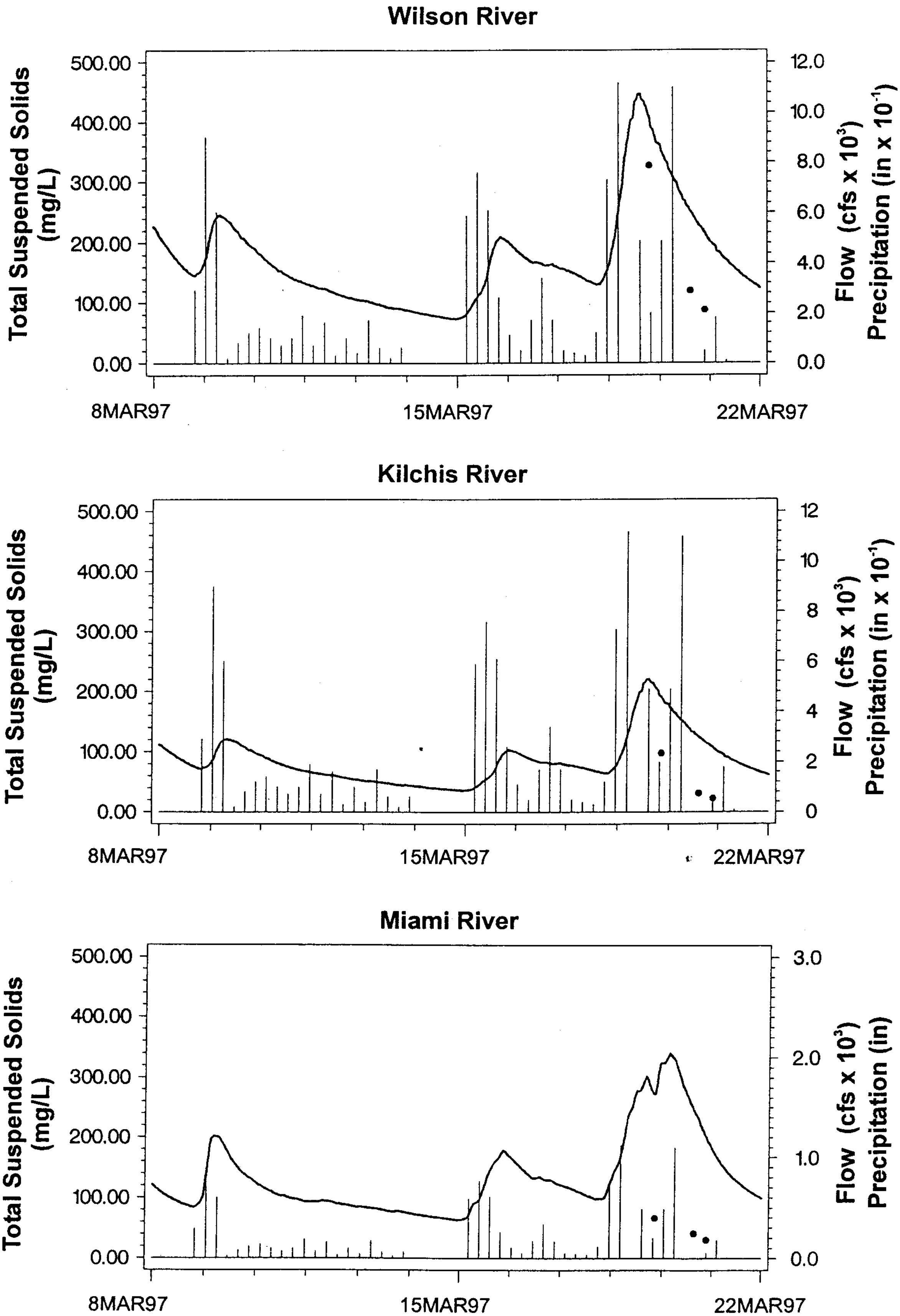


Figure 20. Concentration of total suspended solids (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.



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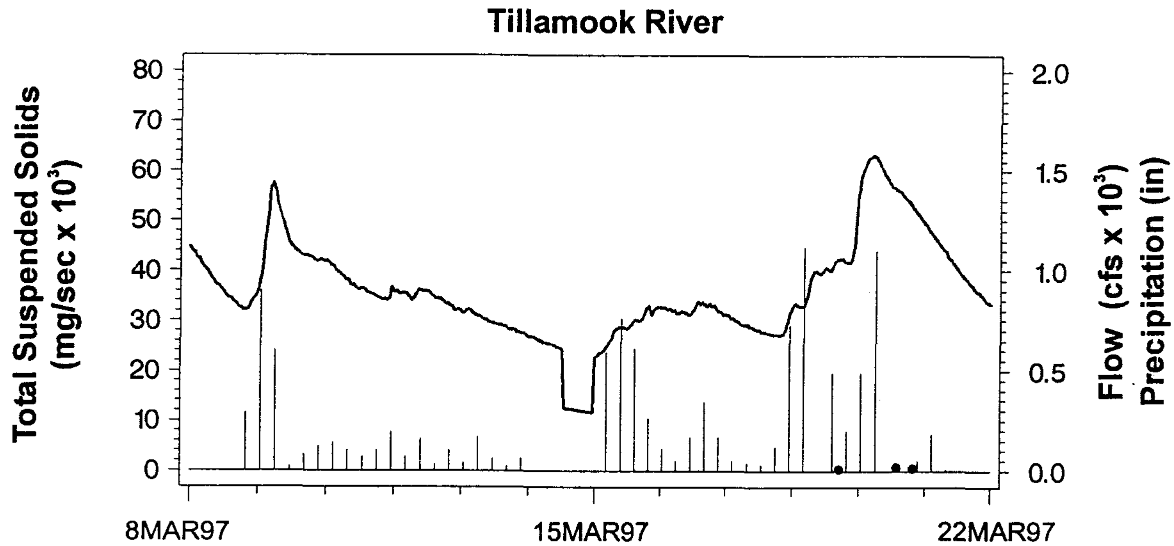


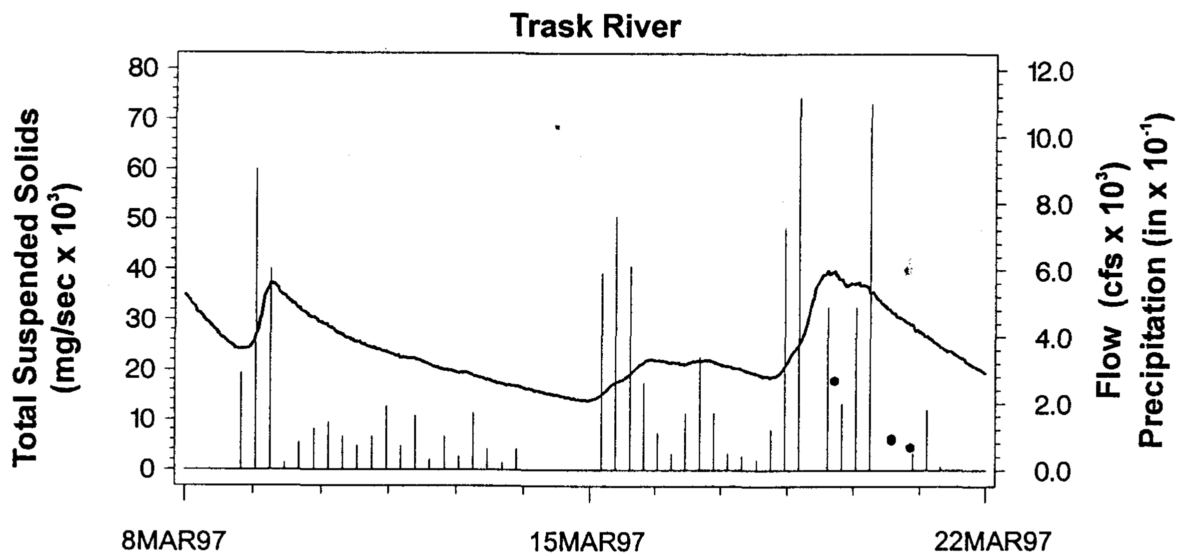
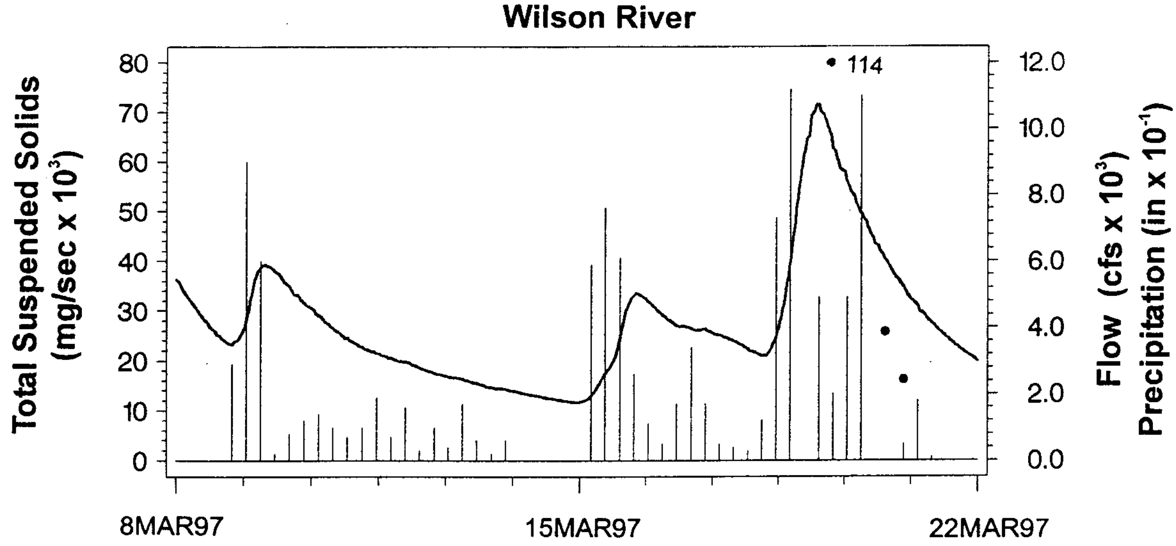
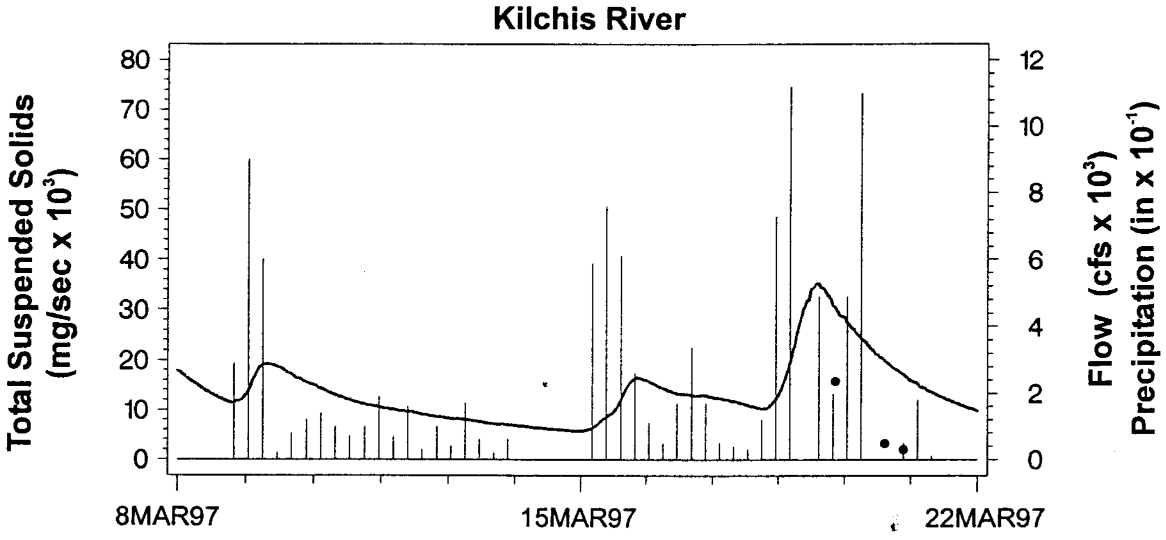
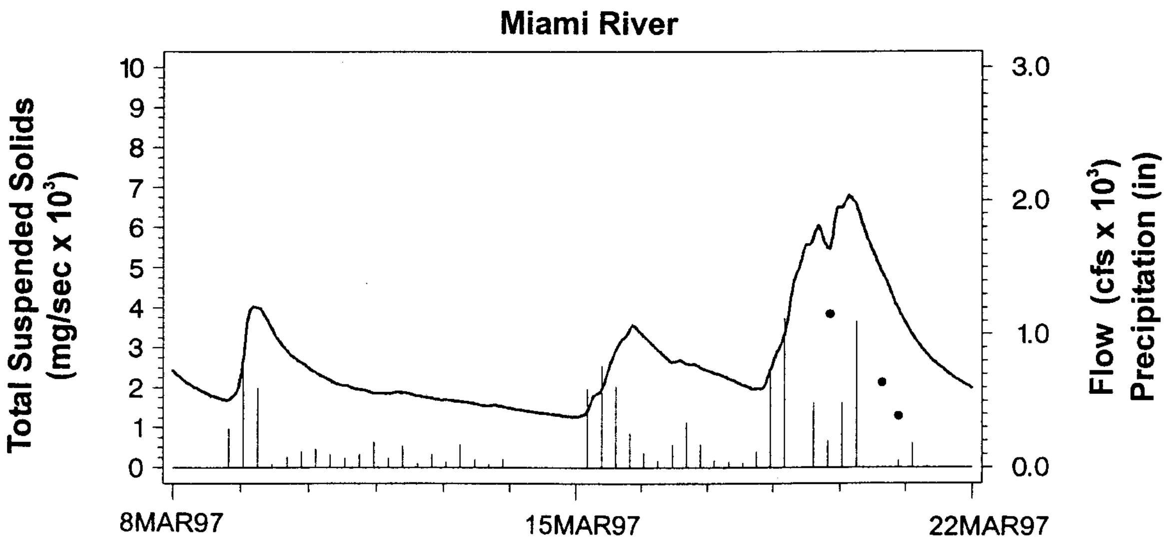


Figure 21. Load of total suspended solids (mg/sec x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.







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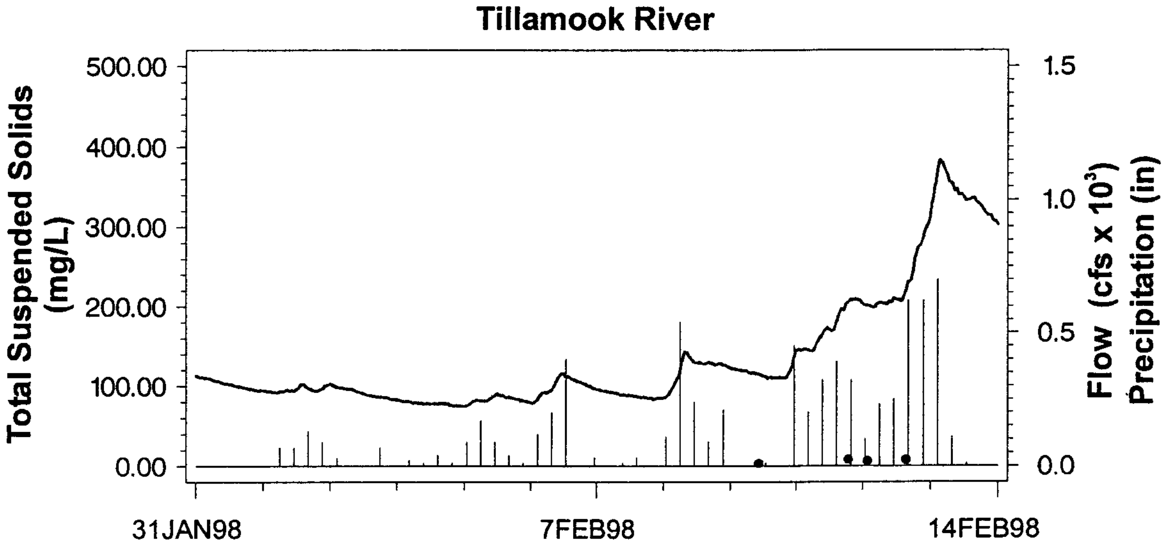


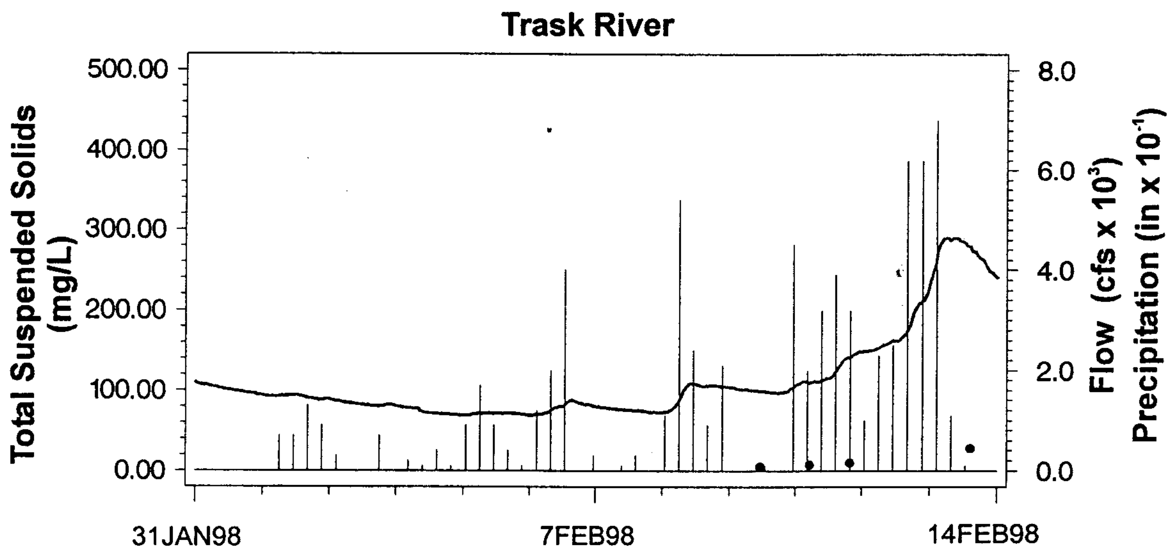
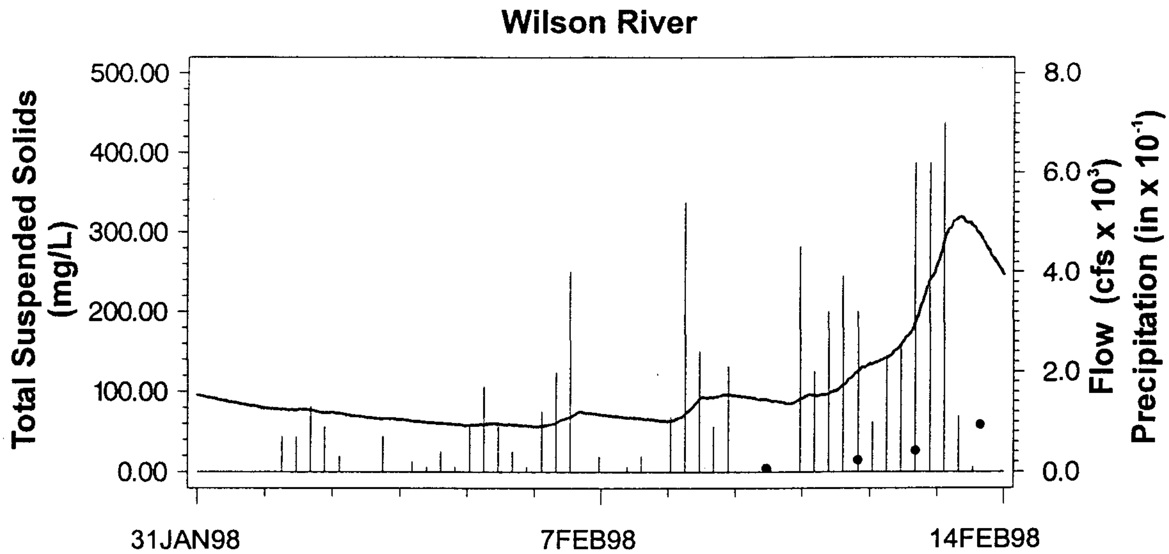
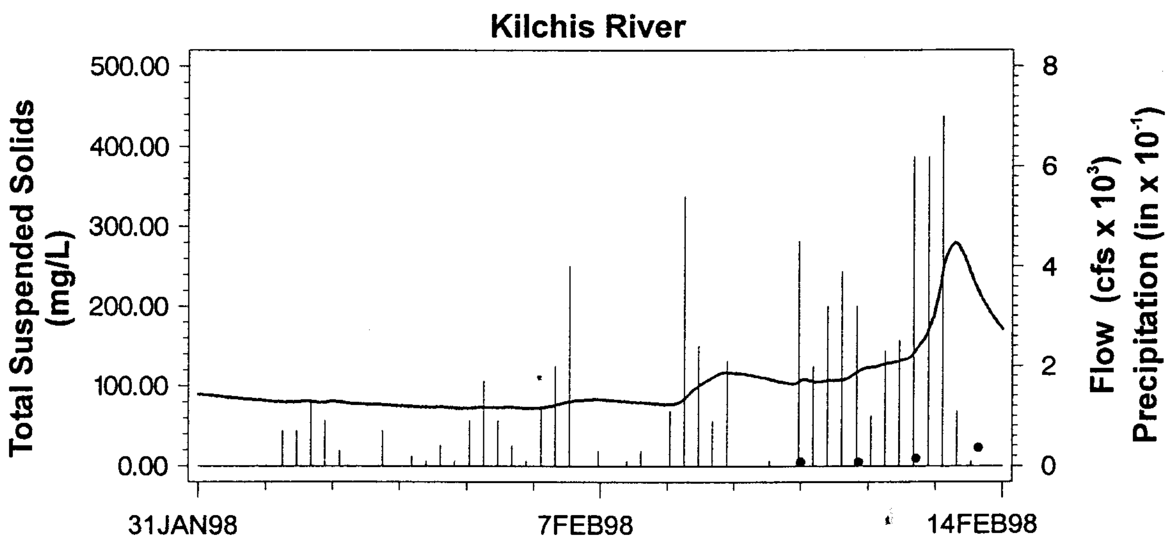
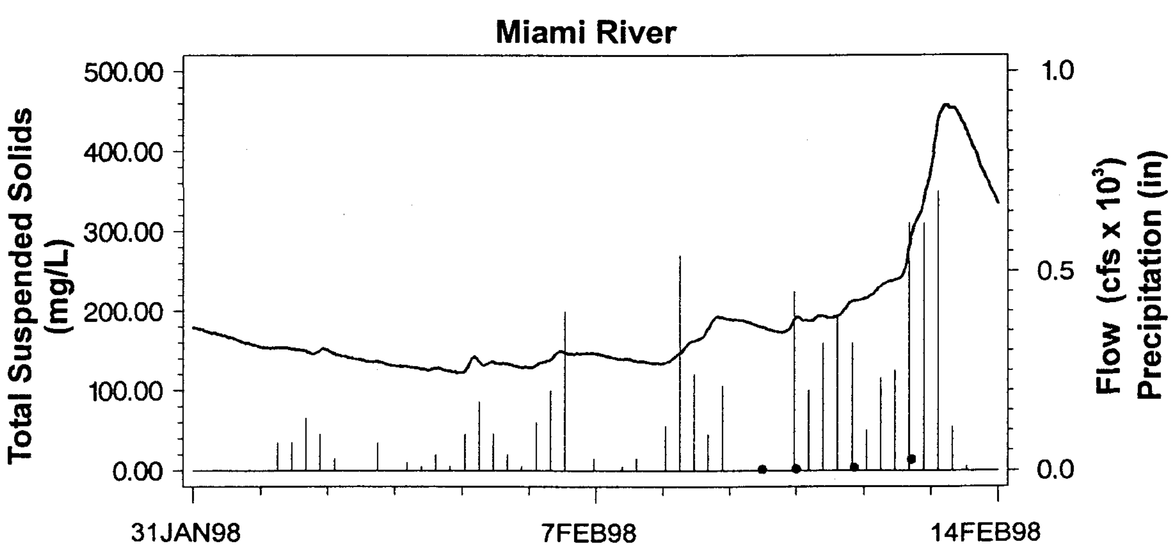


Figure 22. Concentration of total suspended solids (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the February 1998 storm.







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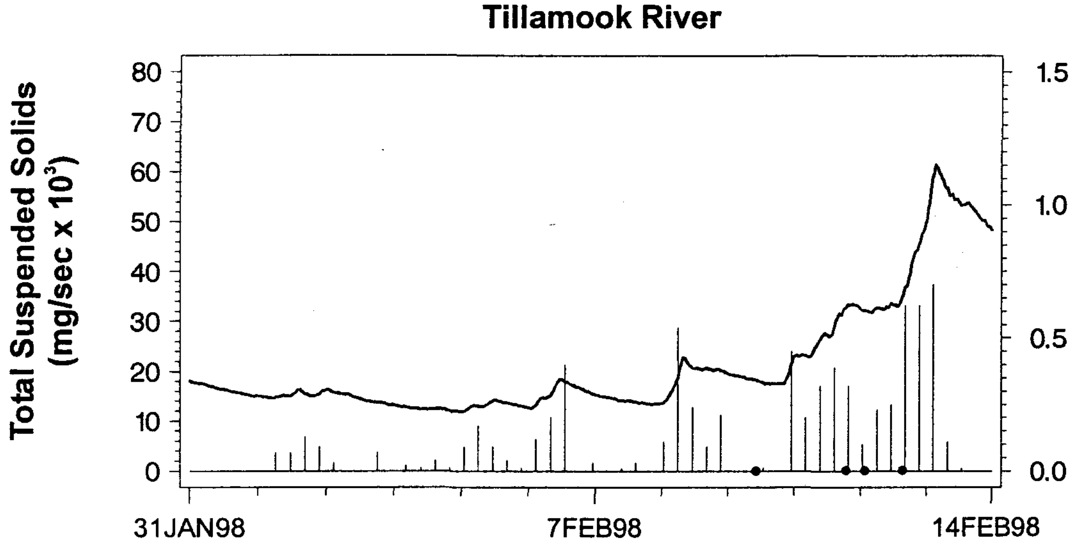


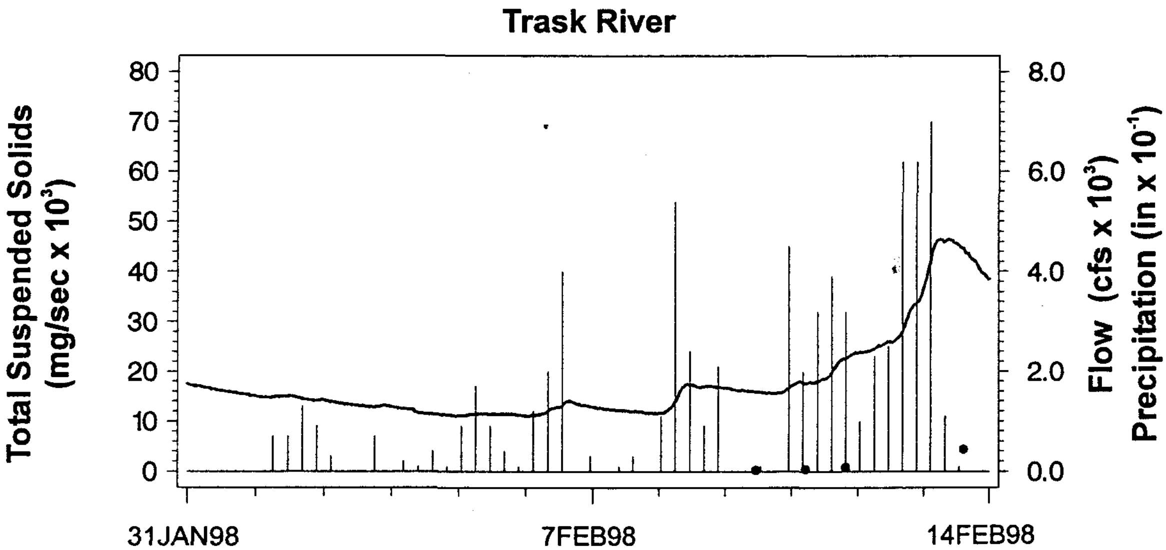
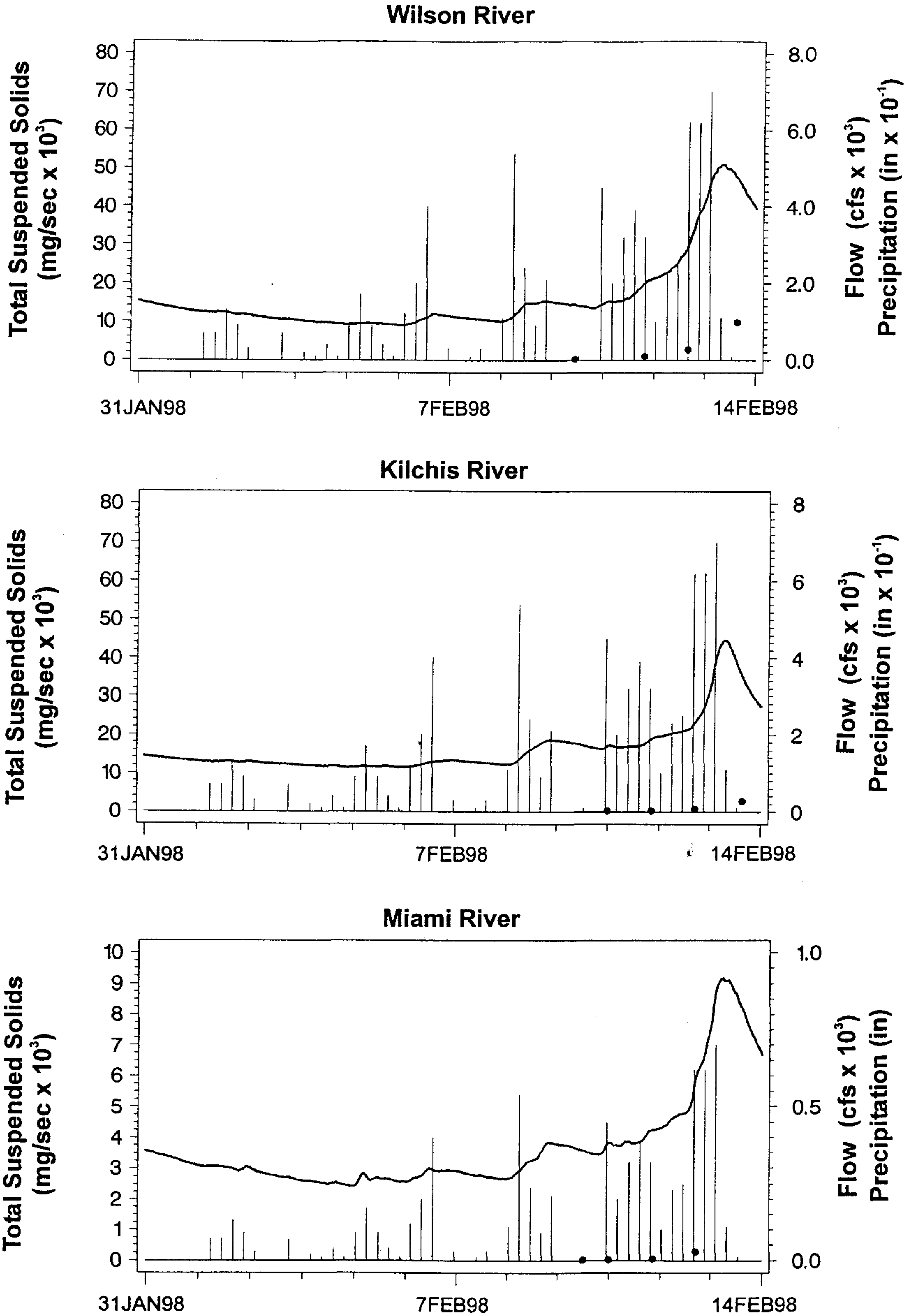


Figure 23. Load of total suspended solids (mg/sec x 10^3), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the February 1998 storm.



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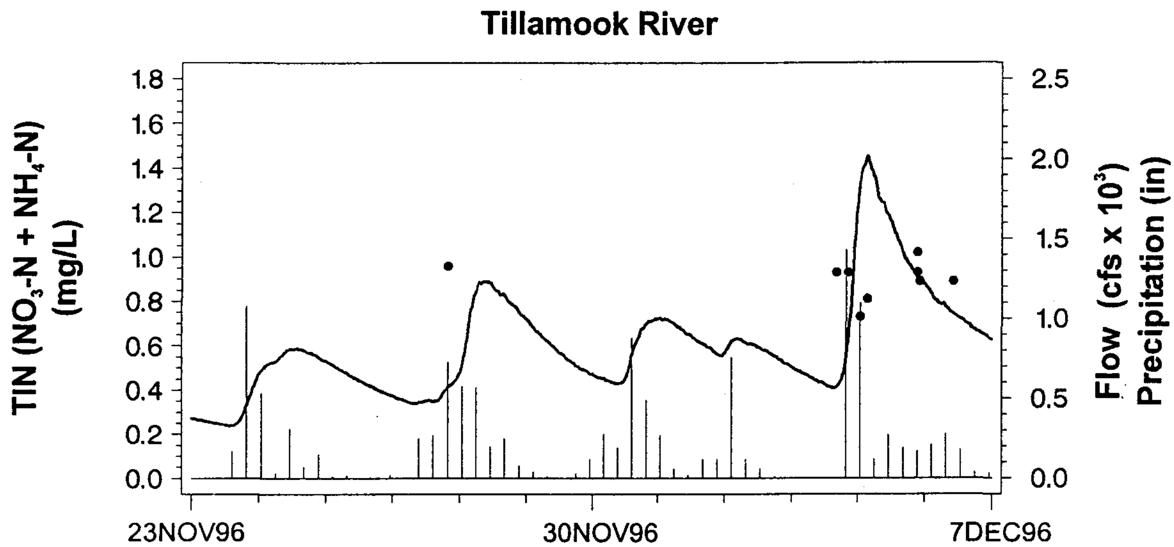


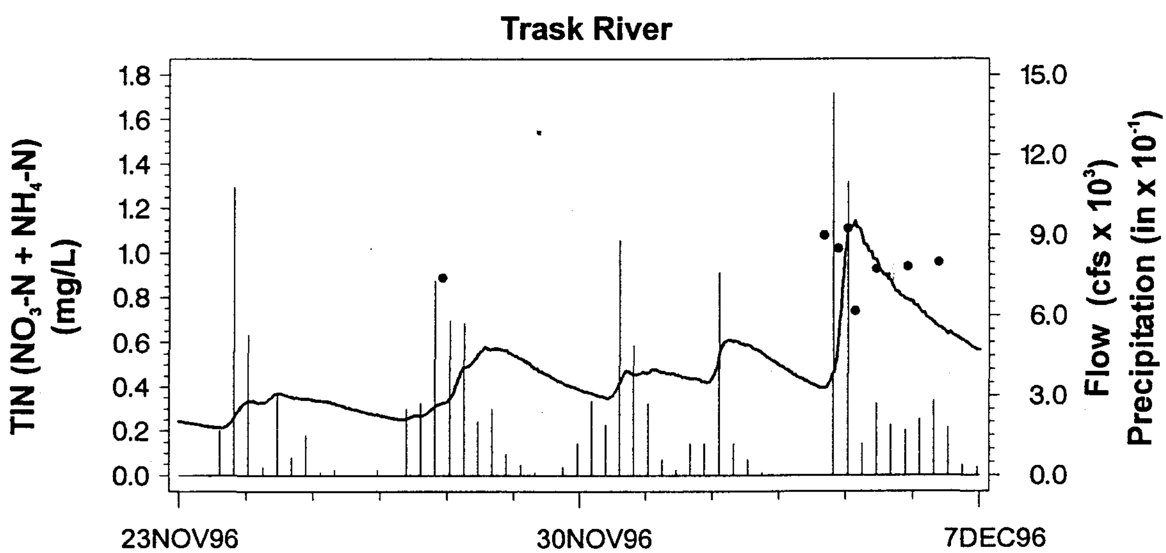
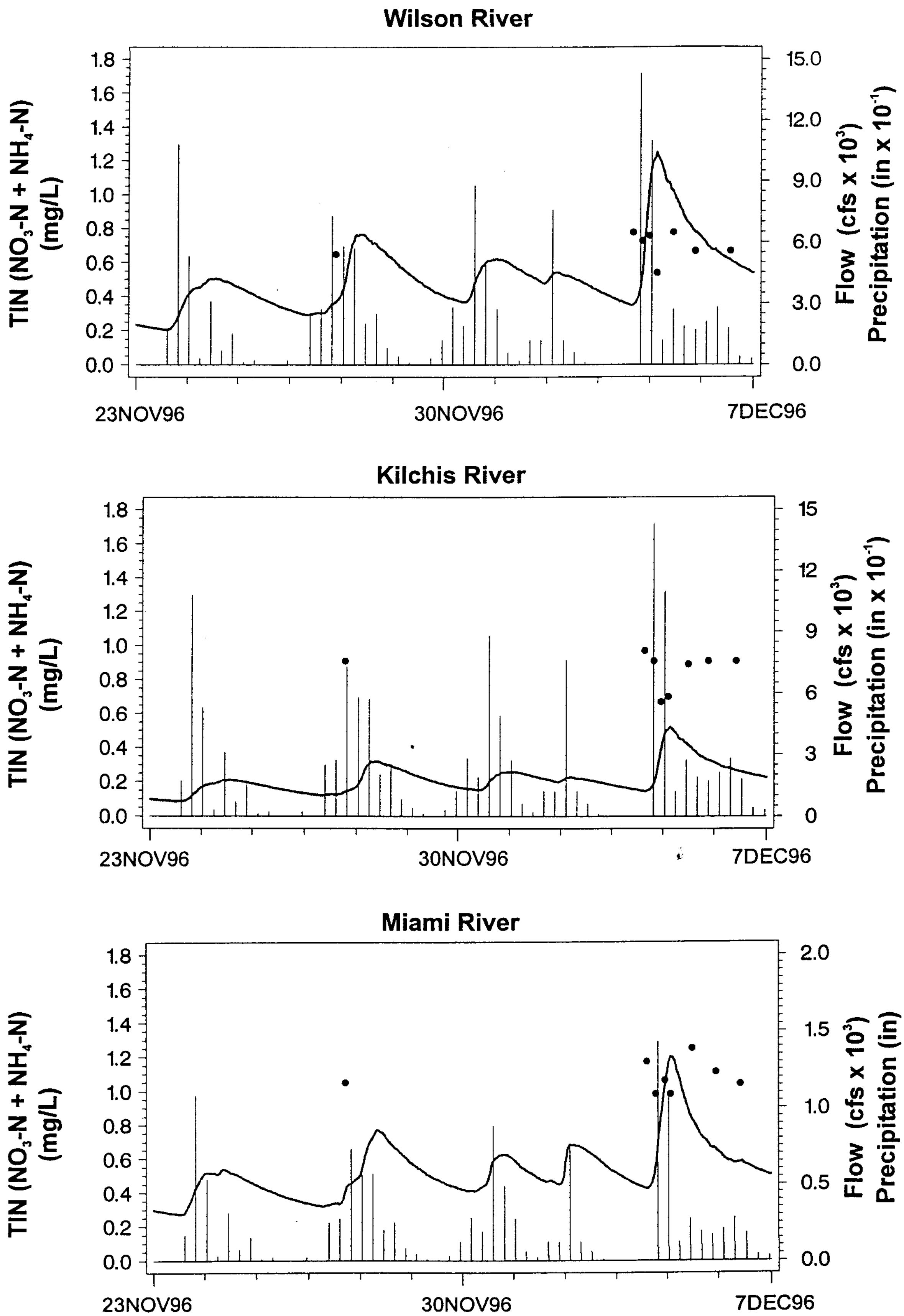


Figure 24. Concentration of total inorganic nitrogen (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.



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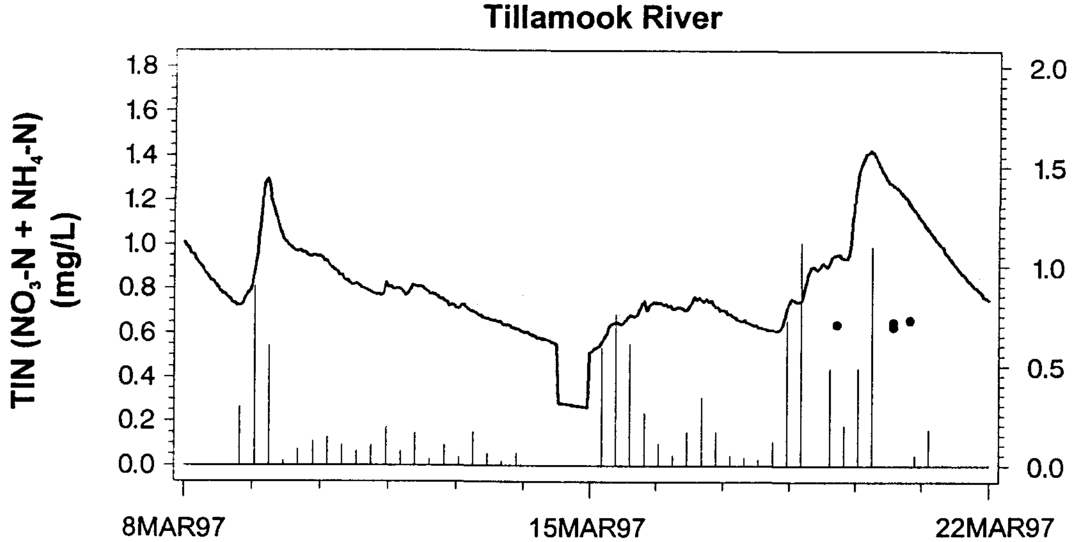


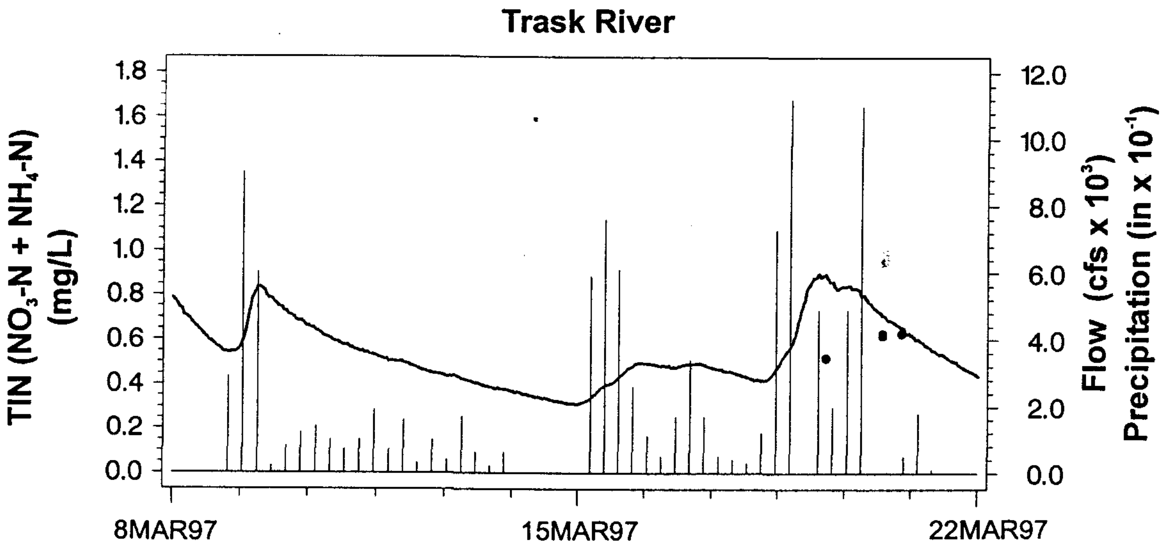
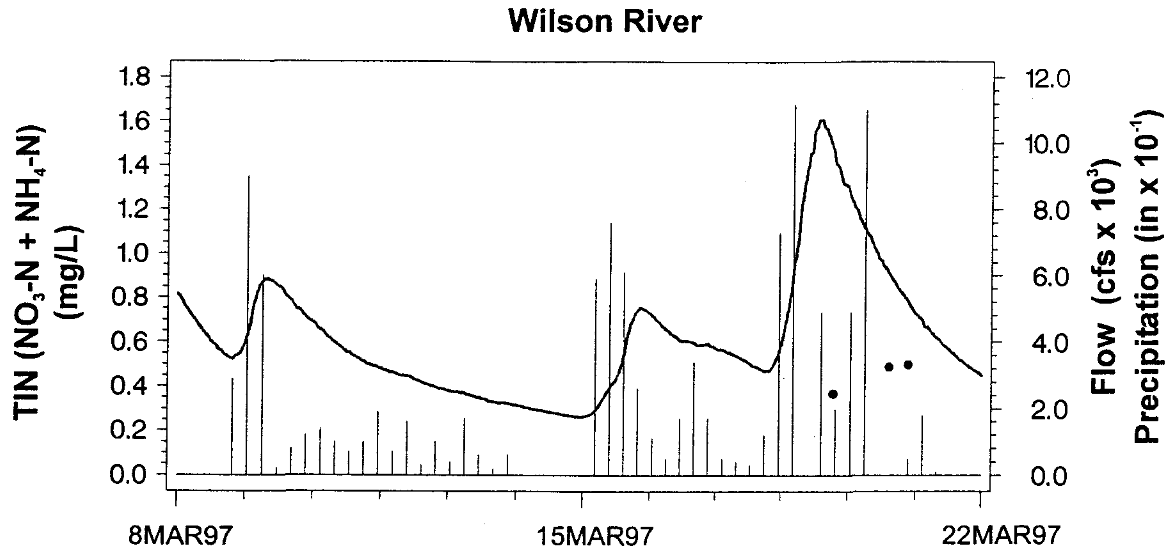
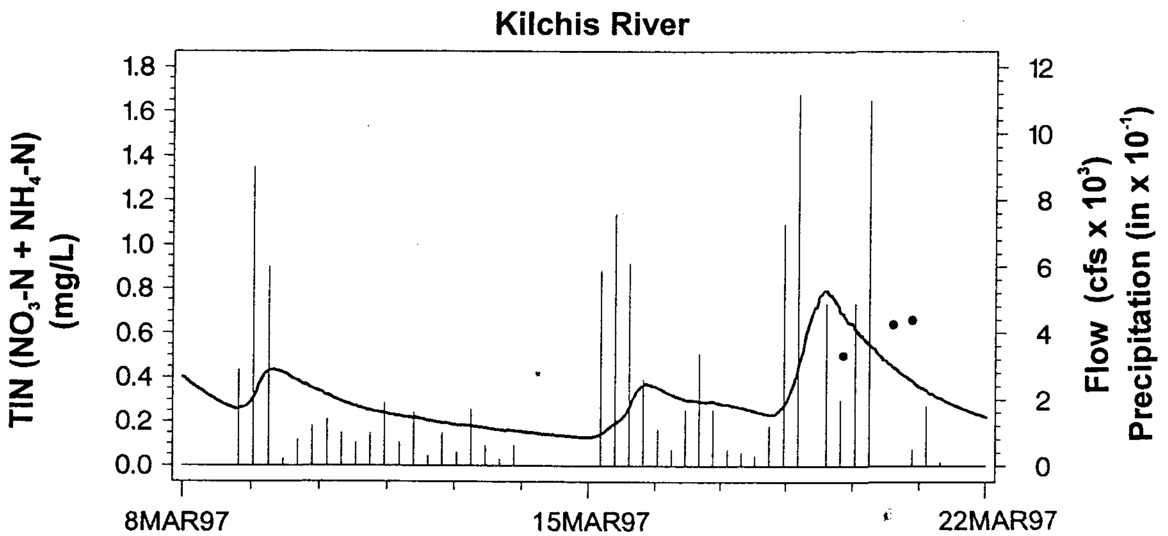
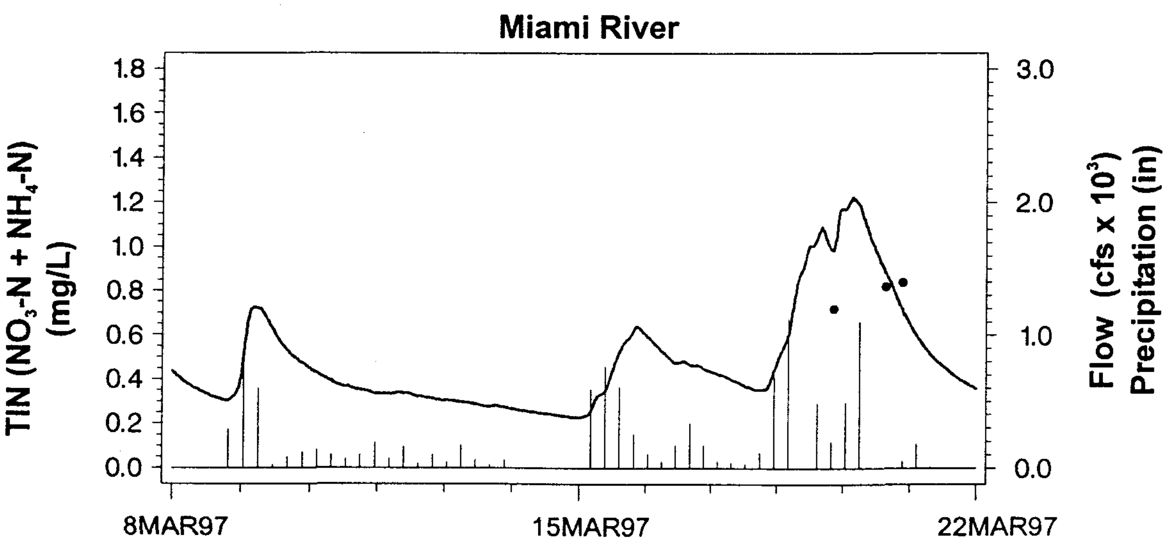


Figure 25. Concentration of total inorganic nitrogen (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.







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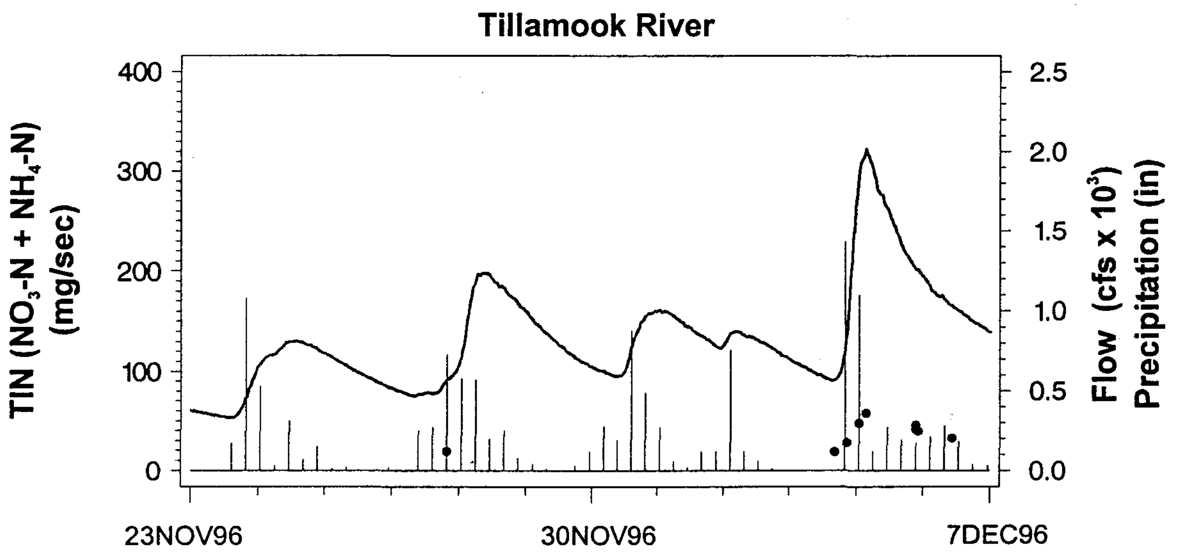


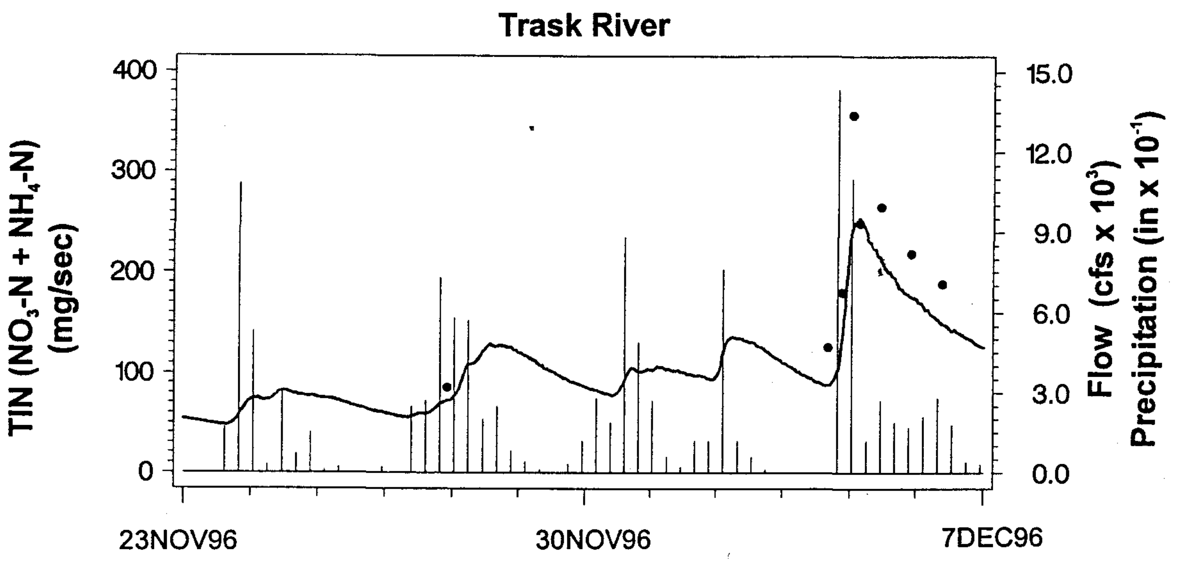
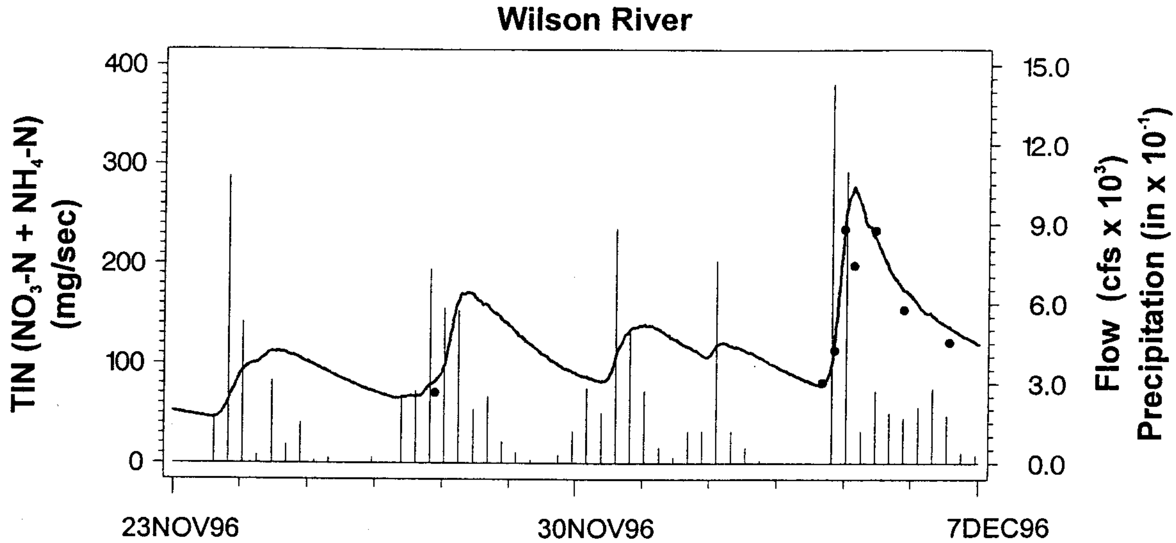
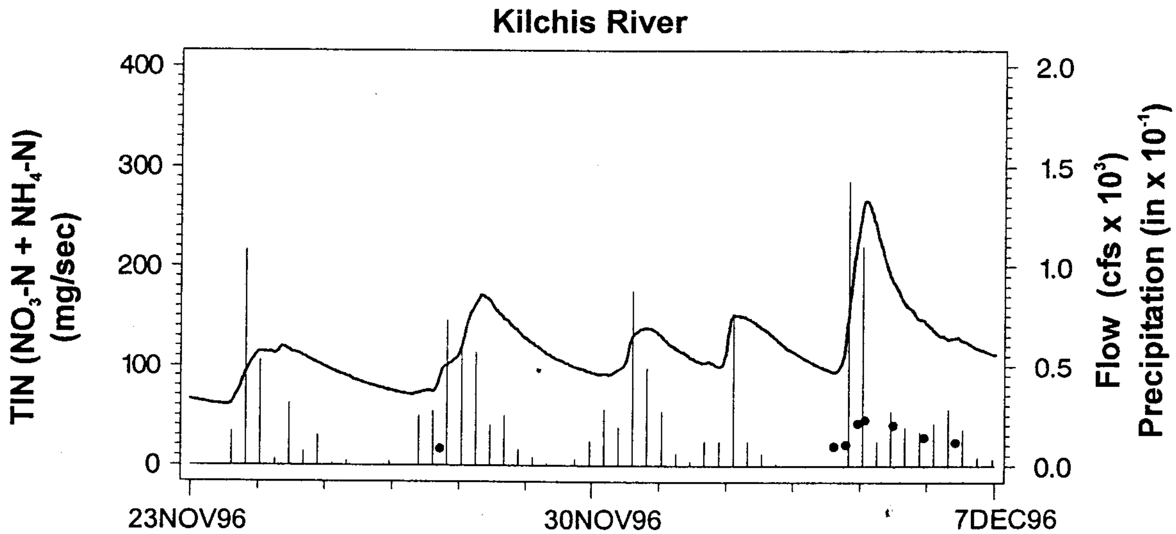
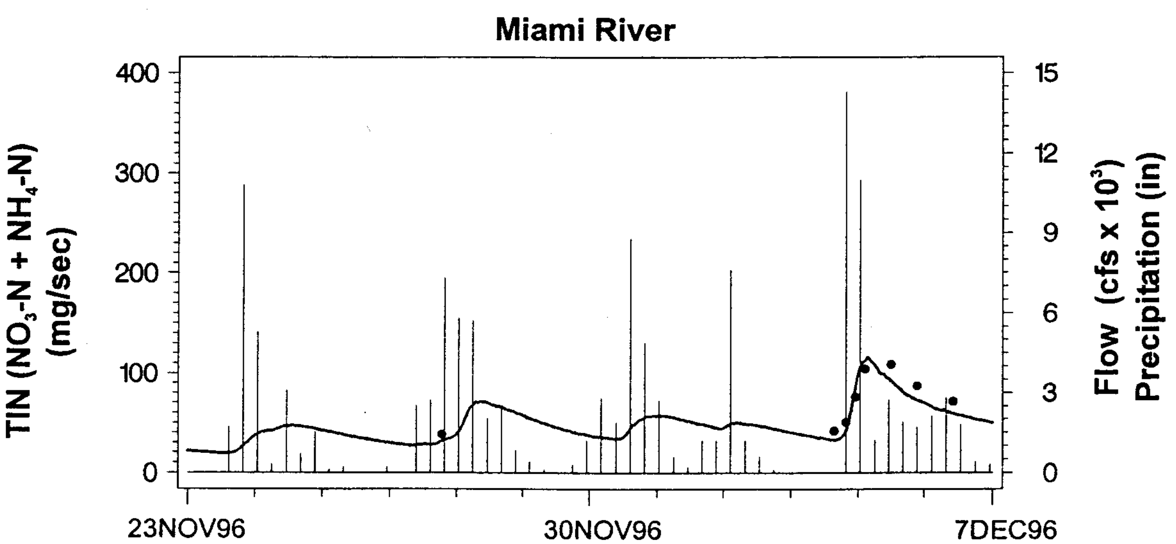


Figure 26. Load of total inorganic nitrogen (mg/sec), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.







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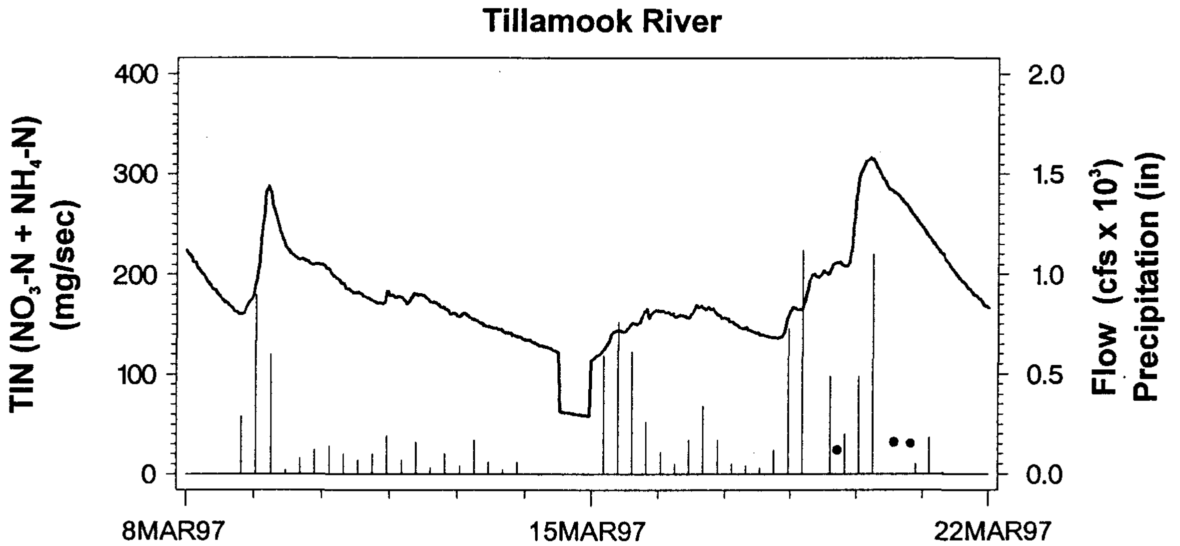


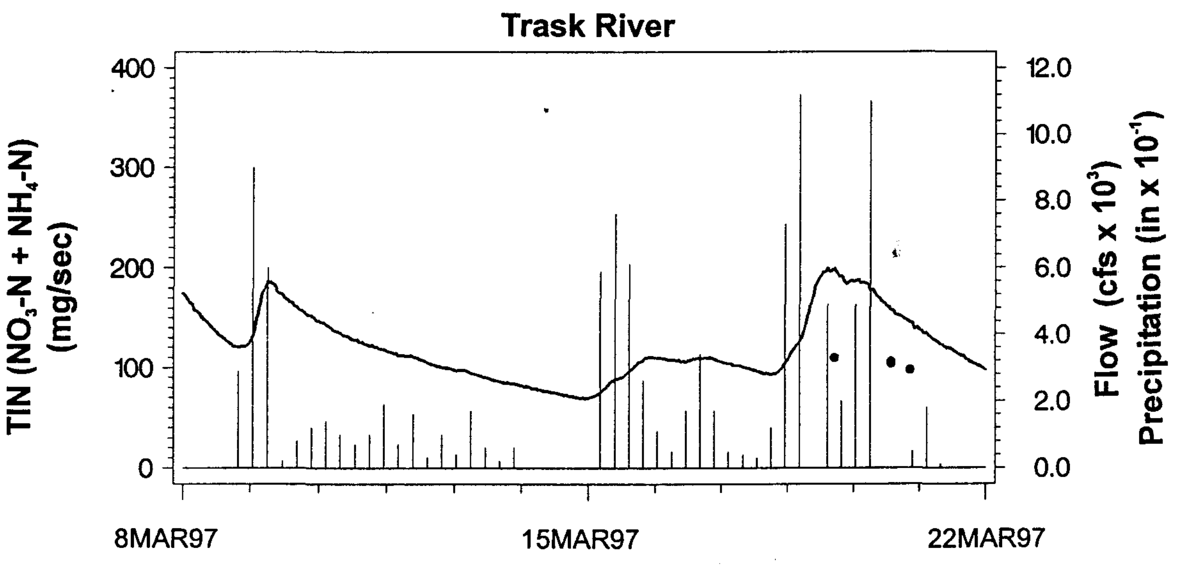
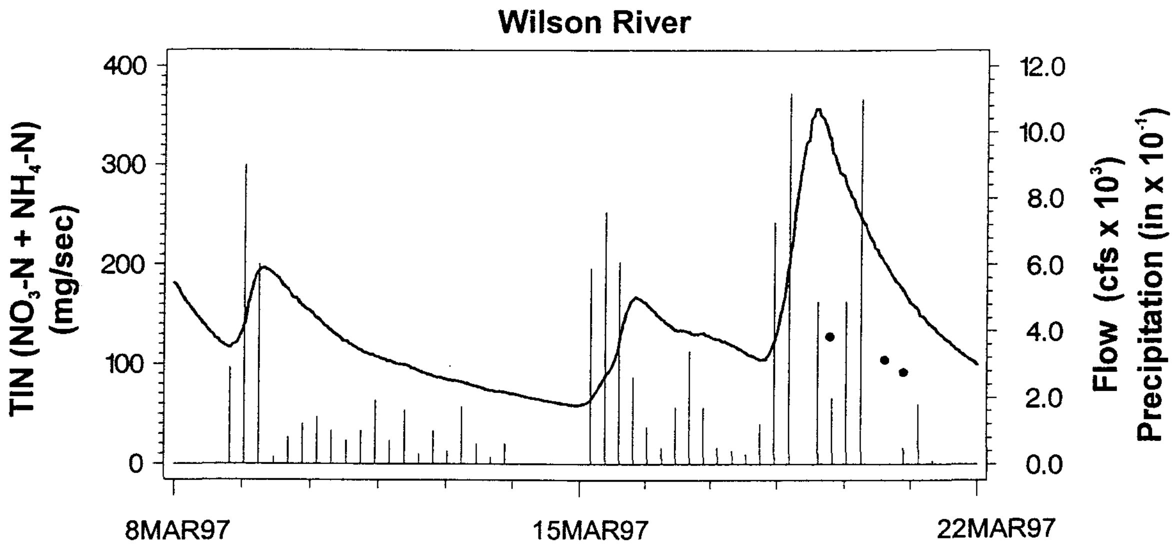
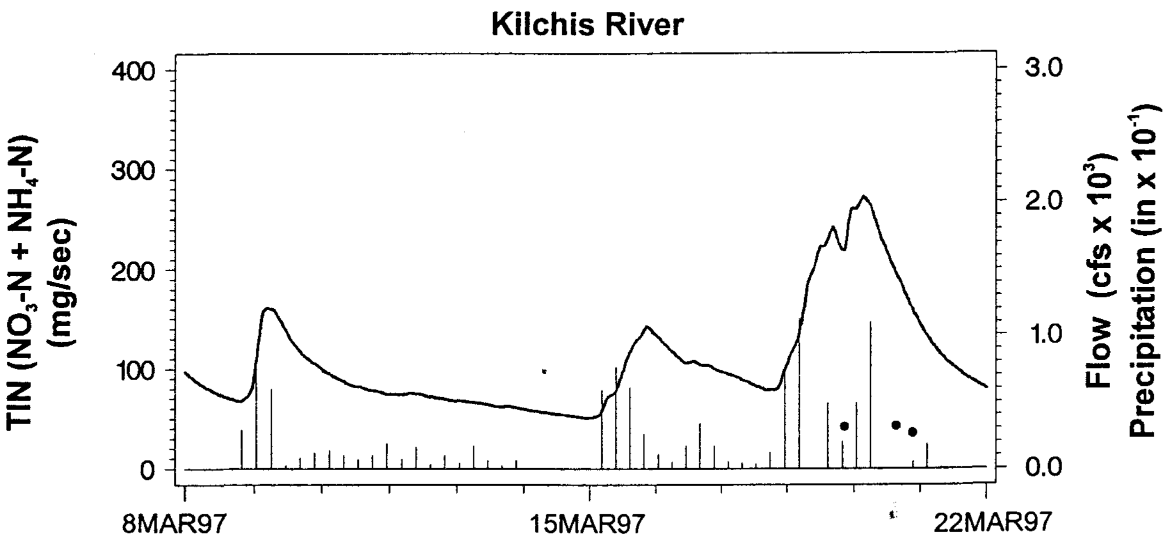


Figure 27. Load of total inorganic nitrogen (mg/sec), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.





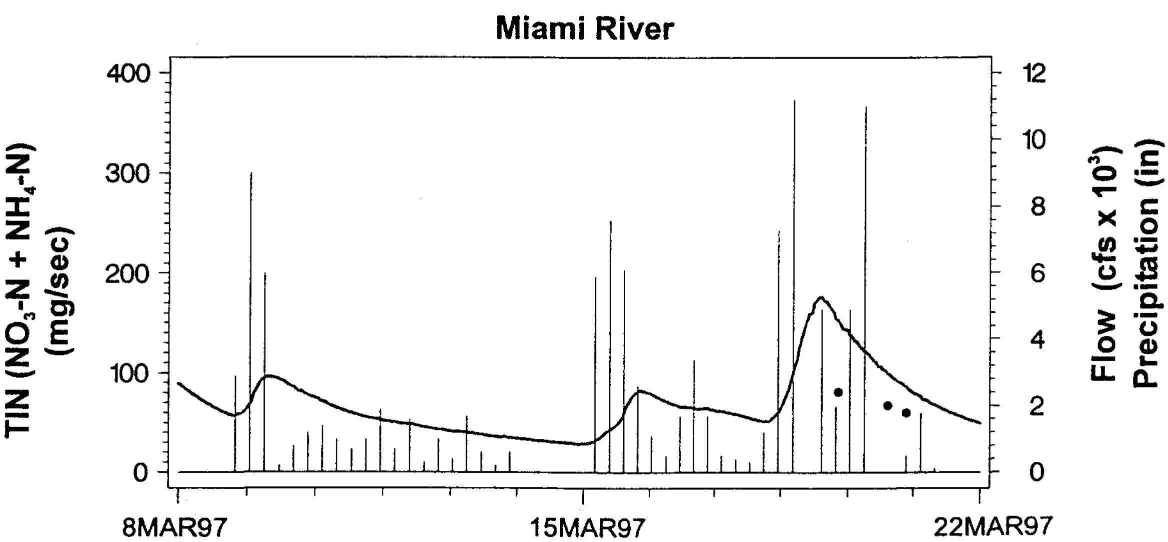
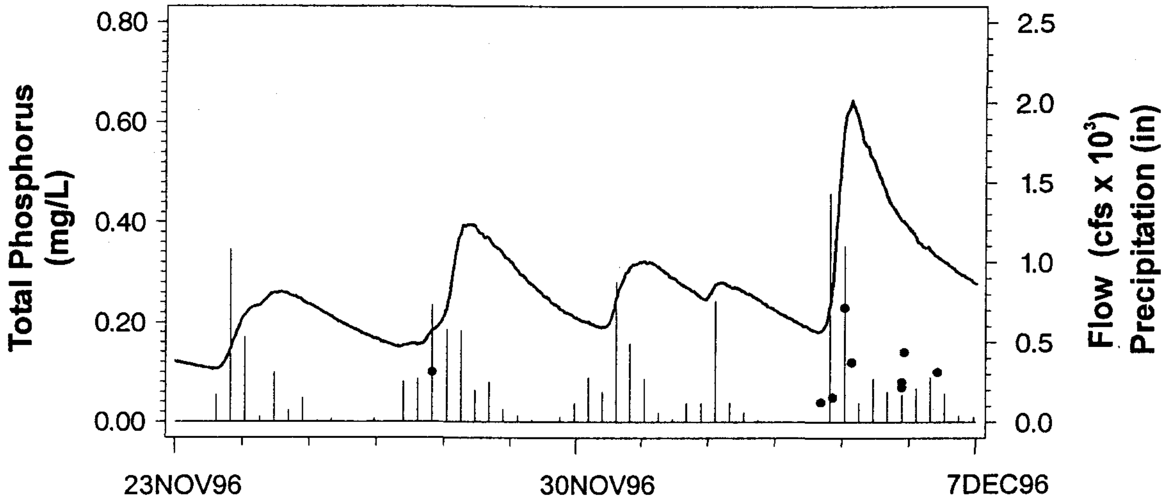


Figure 27. Continued.

Tillamook River



Trask River

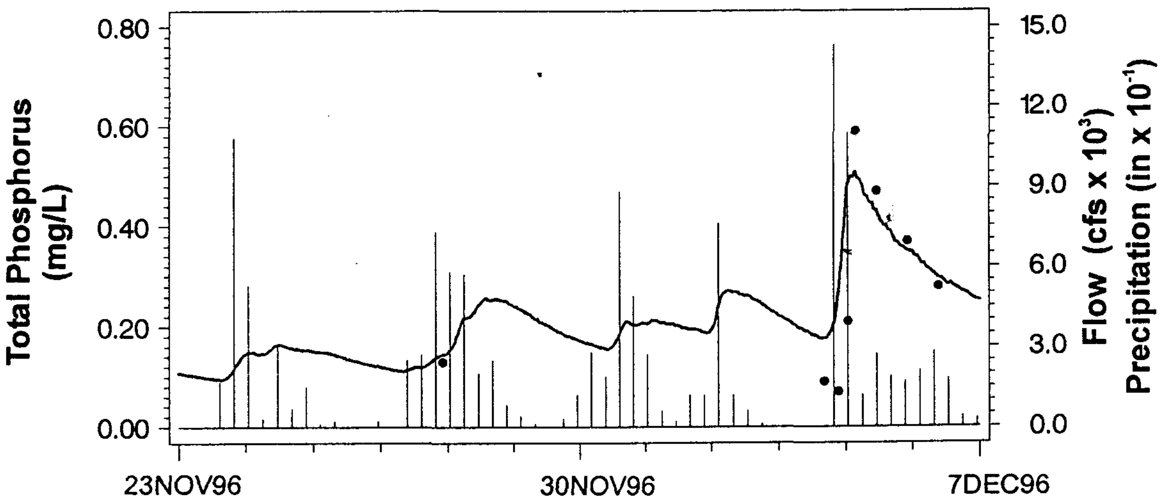
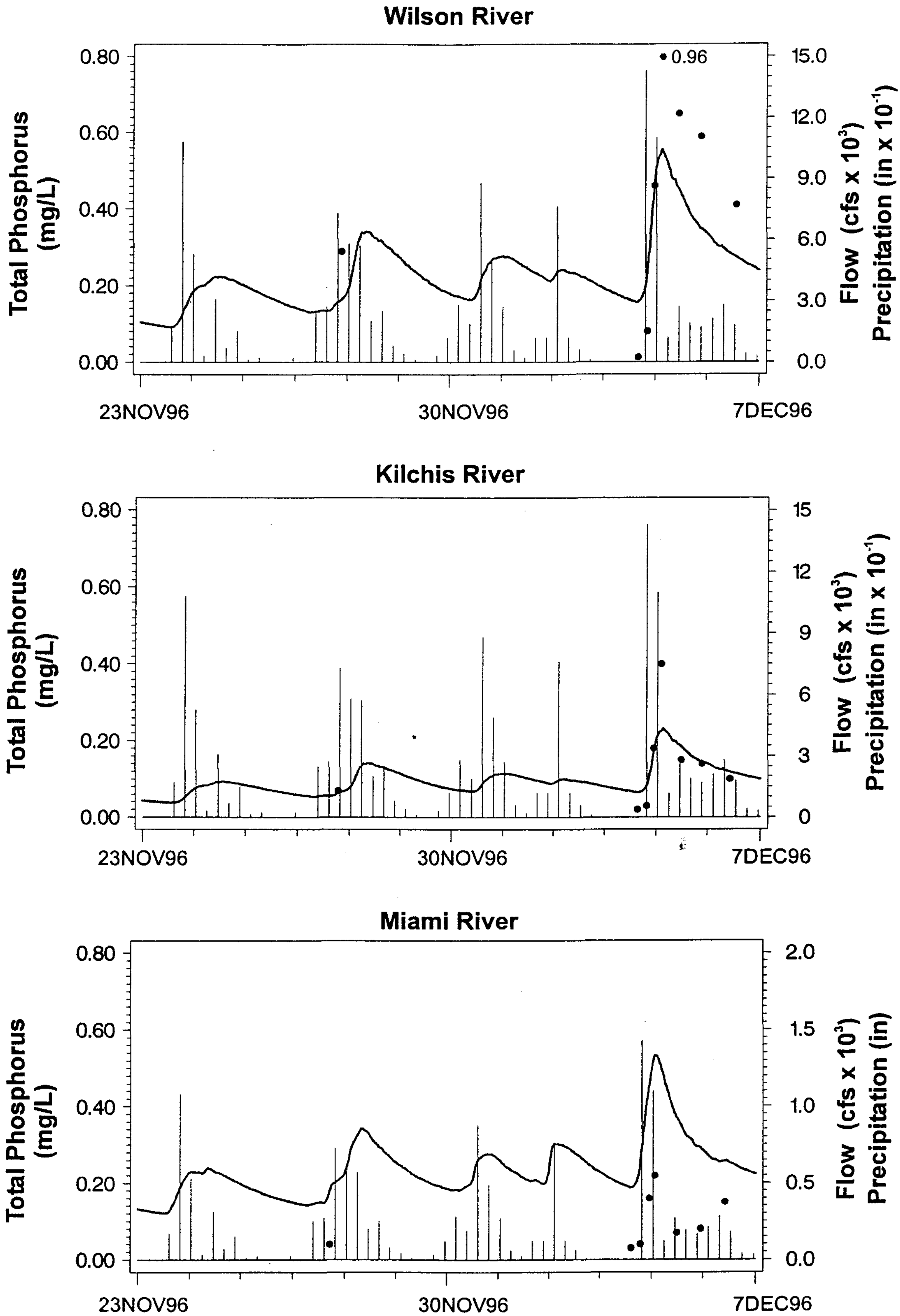


Figure 28. Concentration of total phosphorus (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.



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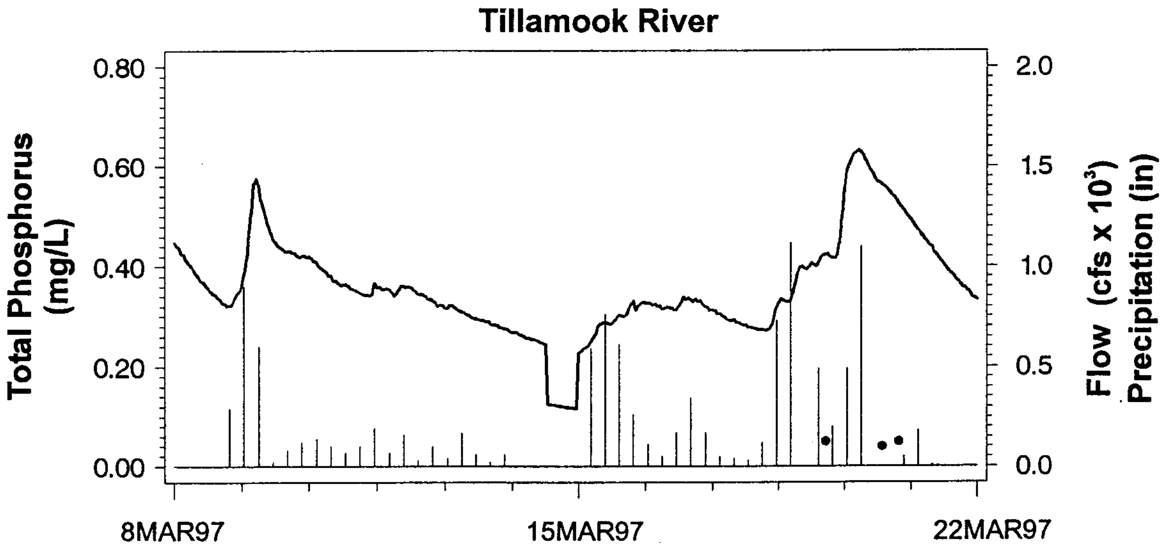


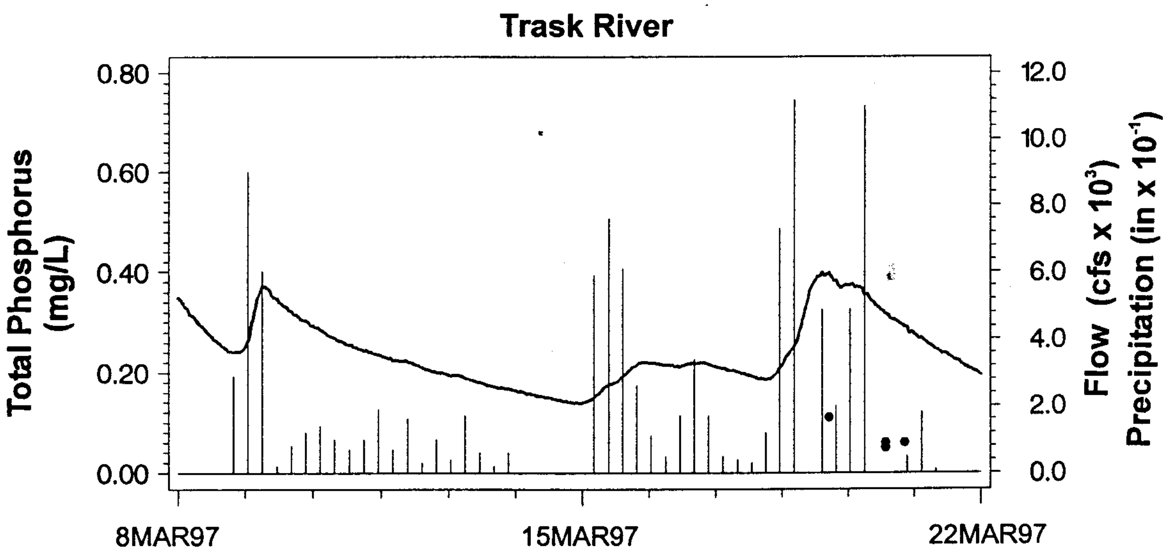
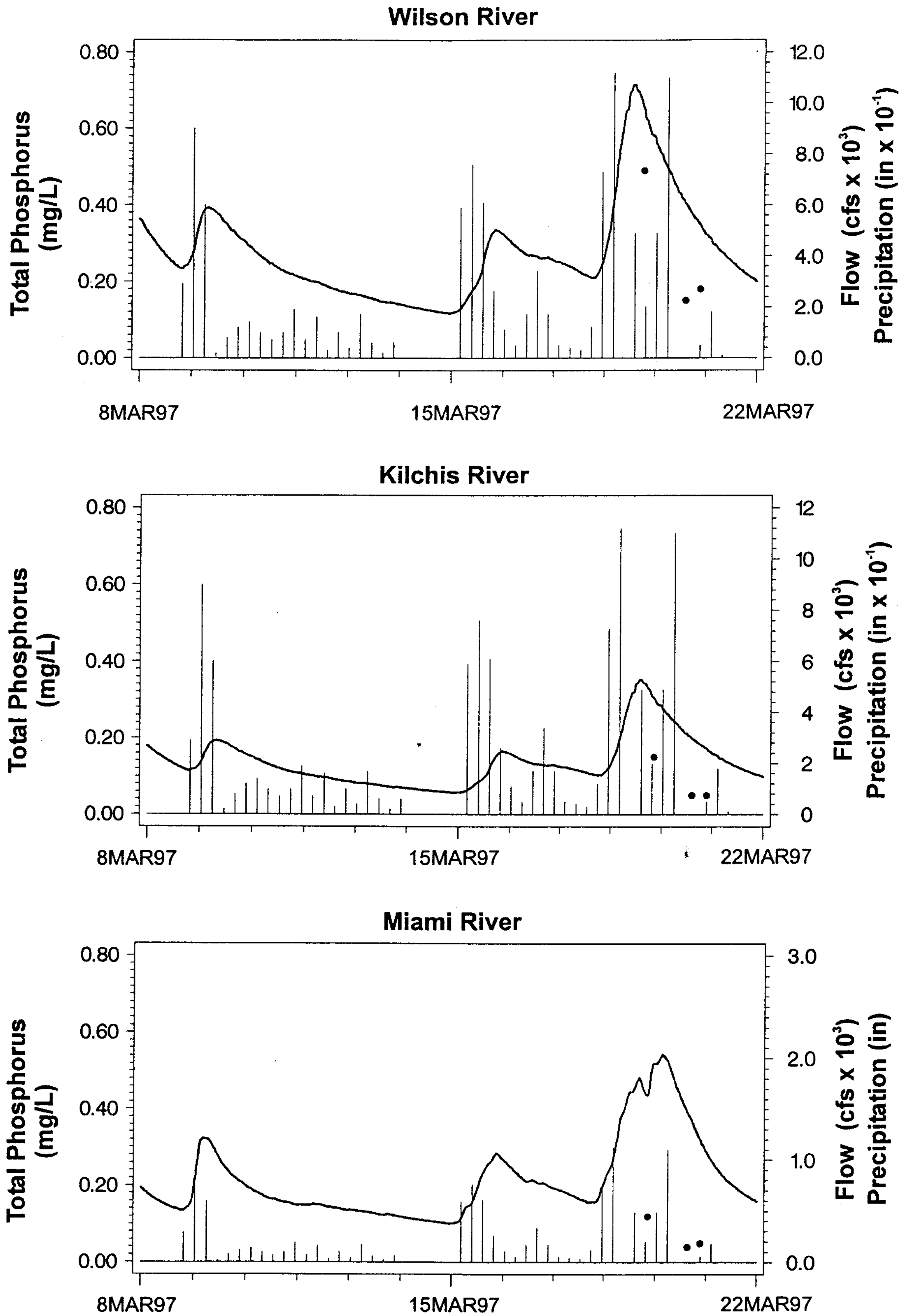


Figure 29. Concentration of total phosphorus (mg/L), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.



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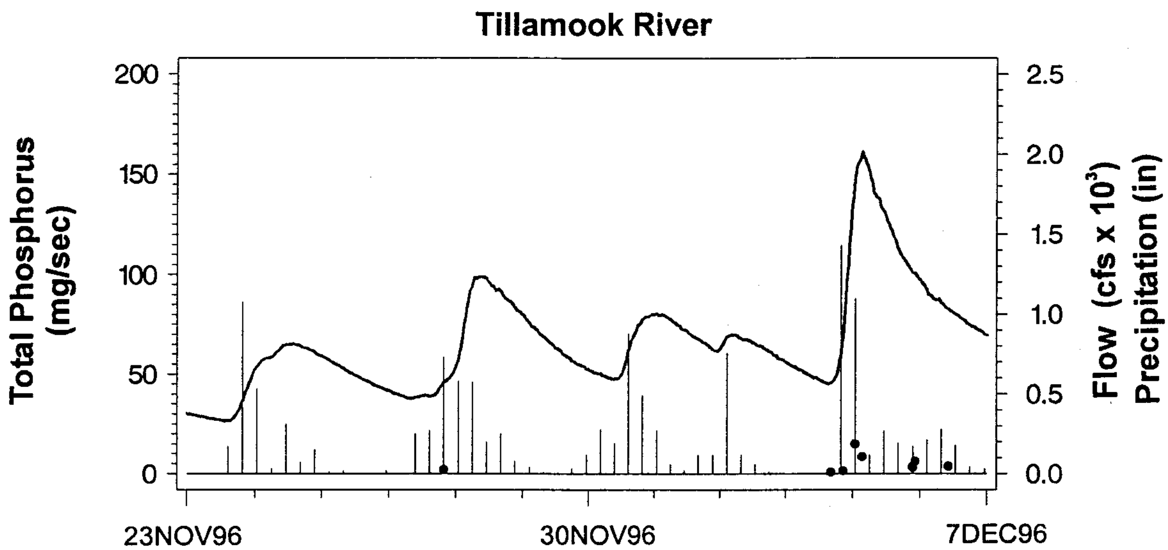


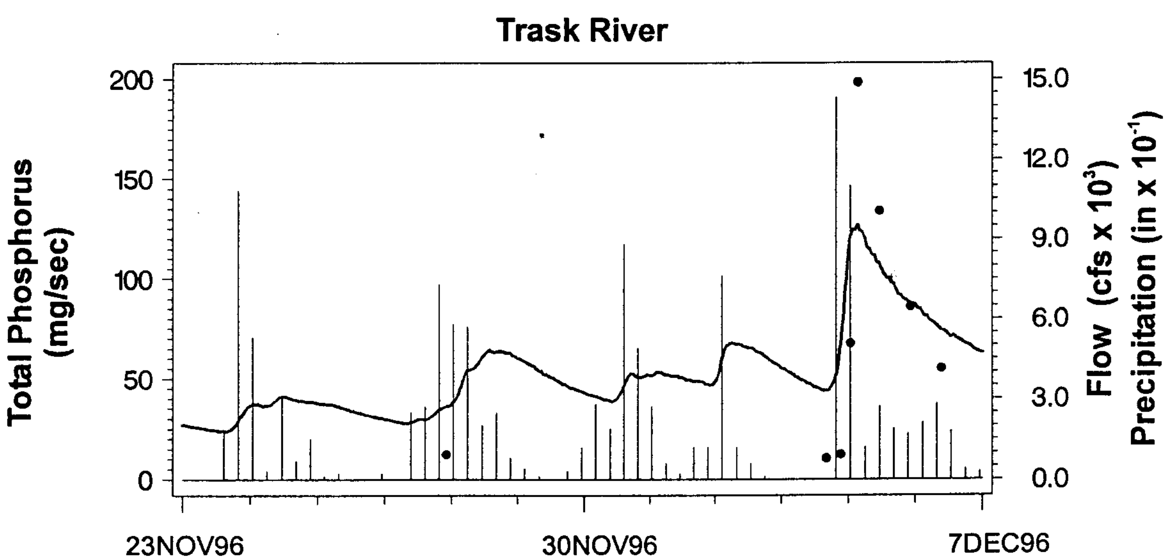
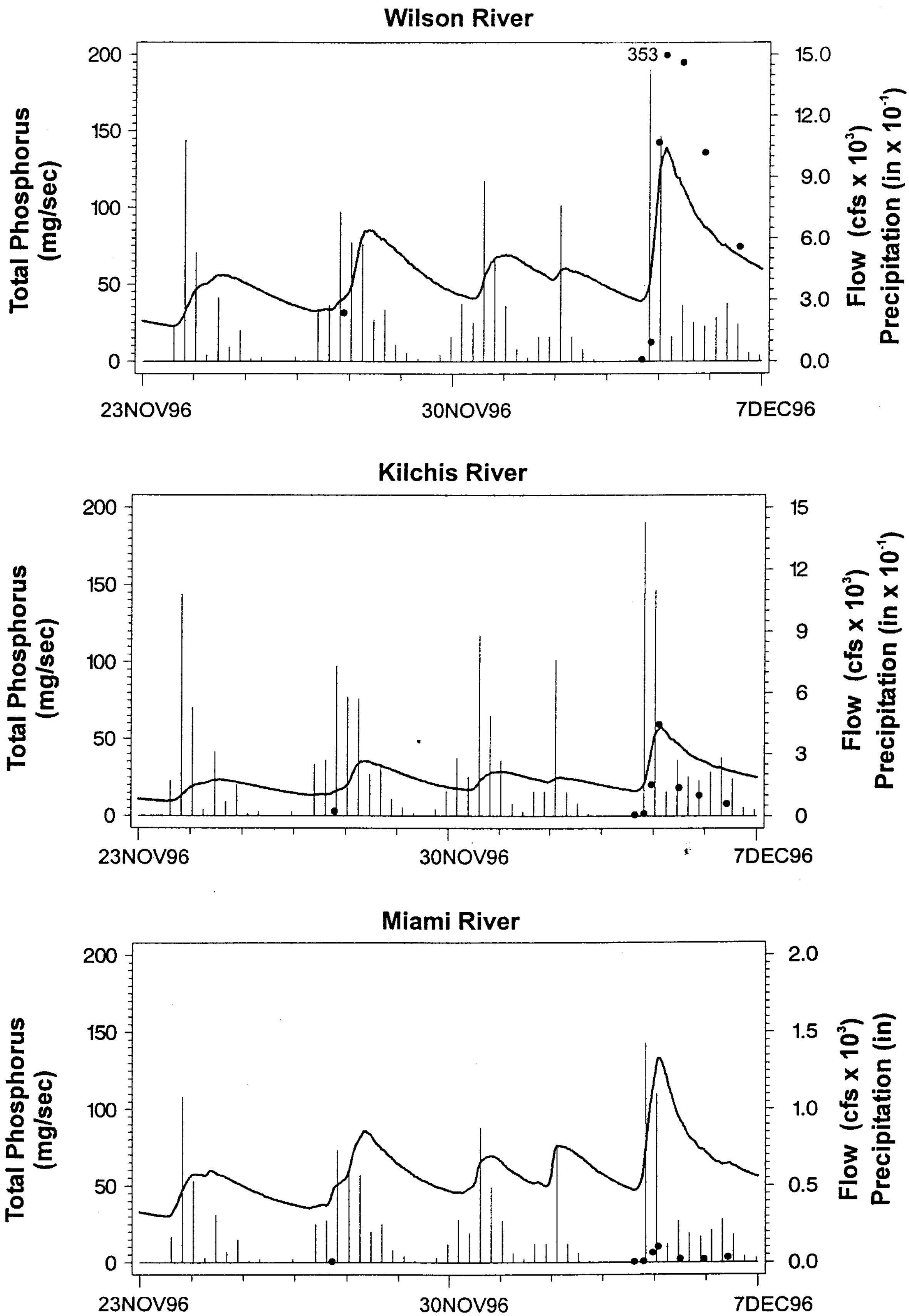


Figure 30. Load of total phosphorus (mg/sec), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the December 1996 storm.



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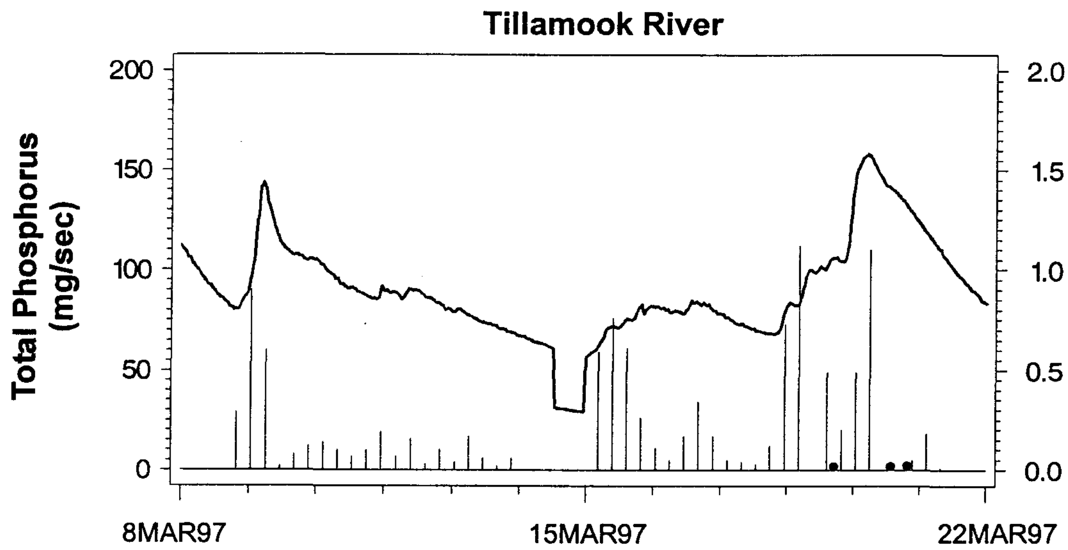


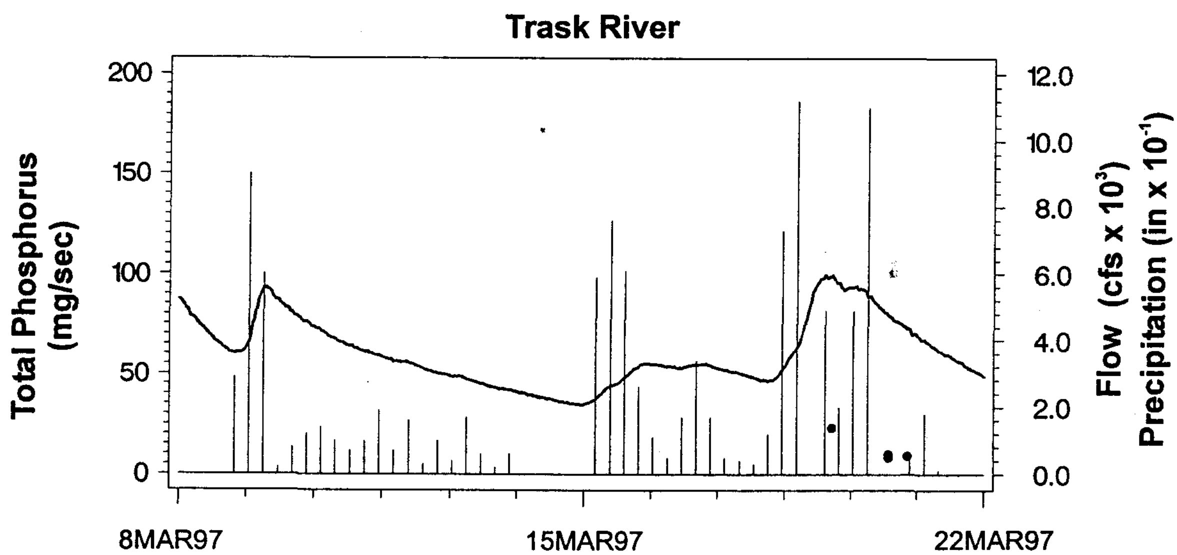


Figure 31. Load of total phosphorus (mg/sec), 6 hour precipitation totals (scale variable by river), and river discharge (cfs x 10^3) at the primary monitoring sites on each of the five rivers for the March 1997 storm.

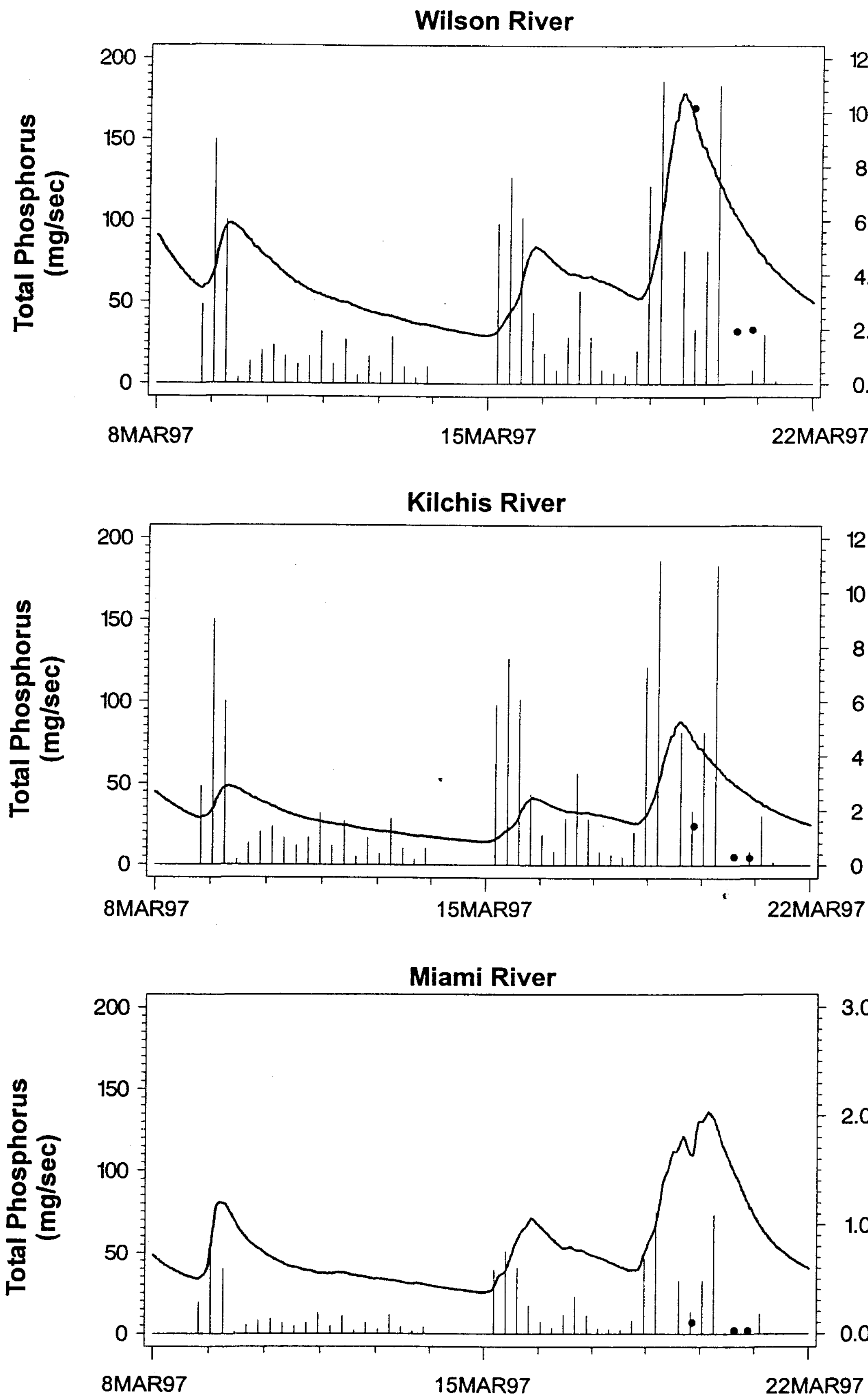


Figure 31 Continued.

Results of Load Calculations

The calculated storm hydrographs at the primary sampling sites were partitioned into segments, based on the various sample occasions. For each segment, average FCB concentration was calculated from the measured values at the leading and trailing ends of that time segment. The average FCB concentration in each segment was then multiplied by the total discharge during that time period to yield a calculated load. Professional judgement and the observed concentrations of FCB during baseflow periods (Sullivan et al. *in review*) were used where necessary to estimate FCB concentrations prior to the first sample collected and subsequent to the last sample collected during each storm. The individual loads for each time segment were then added together to yield an estimate of the total FCB load for each storm. Results of these storm load calculations are summarized in Table 3.

The largest loads were contributed during the early fall storm in 1997 (Storm 4). Measured loads during this storm in the Tillamook and Trask Rivers were more than twice as high as for any other sampled storm (Similar results were found by TCCA for the Wilson River; data not shown). The smallest loads were contributed by the smallest storm (4.3 in precipitation), which occurred in the spring of 1998 (Storm 6, Table 3).

First approximation estimates of total annual loads of TSS, TIN, and TP were derived by multiplying the flow-weighted average of the concentrations measured throughout the study multiplied by the total annual discharge for the 1997 water year (October 1, 1996 - September 30, 1997). Results of these calculations are presented in Table 4.

Annual loads of FCB from each river were estimated in two ways. The first, and simplest, was based on the measured flow-weighted concentration of FCB, as was done for the other variables. However, because bacterial sampling in this project was skewed towards storm-sampling

Table 4. First approximation estimate of annual water volume and load of TSS, TIN, TP, and FCB in each of the five rivers that flow into Tillamook Bay.

FIRST APPROXIMATION ESTIMATE OF ANNUAL LOAD						
River	Water Volume ($m^3 \times 10^{12}$)	TSS ($kg \times 10^6$)	TIN ($kg \times 10^3$)	TP ($kg \times 10^3$)	FCB ($cfu \times 10^{12}$)	
					Based on Flow-weighted Average Concentration	Based on Storm Load Calculations
Tillamook	278	10	223	31	1,623	793
Trask	1,349	185	1,132	341	3,189	2,031
Wilson	1,362	314	832	710	2,065	-
Kilchis	668	49	496	144	238	-
Miami	273	15	259	41	339	-

(especially during rising hydrographs) and because FCB concentrations exhibited such pronounced variability in response to season, antecedent moisture conditions and rainfall intensity patterns, it was anticipated that this method would likely yield an overestimate of the total annual load of FCB. An alternative method was therefore also applied to estimate the annual load of FCB. In this second approach, the storm-based load estimates, which are also presented in Table 3, were used in conjunction with the observed hydrograph to estimate the storm load for each storm during the 1997 water year. Each storm was assigned the load equal to one of the monitored storms. We only used results from 5 of the monitored storms in this calculation, because Storm 3 was judged to have inadequate data. These storm load estimates were summed to provide the estimate of annual load. The cumulative loading during the low flow season was judged to be too small to contribute significantly to the final annual load estimate, and was therefore ignored for this calculation. Loads were estimated in this way for the Tillamook and Trask Rivers, the two rivers for which we had significant data on individual storm loads. Results of these calculations, as expected, were lower than the estimates based on flow-weighted average concentration of FCB on all sampling occasions (Table 4). The estimates differed by only about 50% for the Trask River (3,189 x 10^{12} cfu versus 2,031 x 10^{12} cfu), but about 100% for the Tillamook River (1,623 x 10^{12} cfu versus 793 x 10^{12} cfu, Table 4).

DISCUSSION

The bacterial fluxes measured at each site on the Tillamook River throughout the duration of the first intensive monitoring effort (Storm 4) are shown sequentially in Figure 32. Data are presented from river mile (RM) 10.0 at the Yellow Fir Rd bridge crossing (top panel) downriver to RM 0.9, at the last bridge crossing on the Tillamook River, near where it enters the bay. FCB loads in the Tillamook River during the October, 1997 storm showed pronounced variability among sample occasions at a given site and among sites within a given time period (Figure 32). However, FCB loads were uniformly low at all sites (less than about 0.1 x 10^6 cfu/sec) on the first sample occasion of the storm and again on the last sample occasion of the storm. Loads at several of the sites increased as much as ten-fold or more at various times during the storm, especially on days 2 through 4 (October 1-3).

There were two peaks in FCB load at the uppermost site (RM 10) and these same peaks plus an additional peak in FCB load at the next downriver site (RM 8.1). These three peaks in FCB load at the Yellow Fir Rd and rest area sampling sites corresponded temporally with the pulses of precipitation measured in the watershed (Figure 32). At the downriver sites, from RM 2.6 to RM 0.9, the FCB loads showed relatively smooth patterns; the consistent exception to this occurred on October 3rd, when FCB loads decreased markedly at all five of these sites. This time period

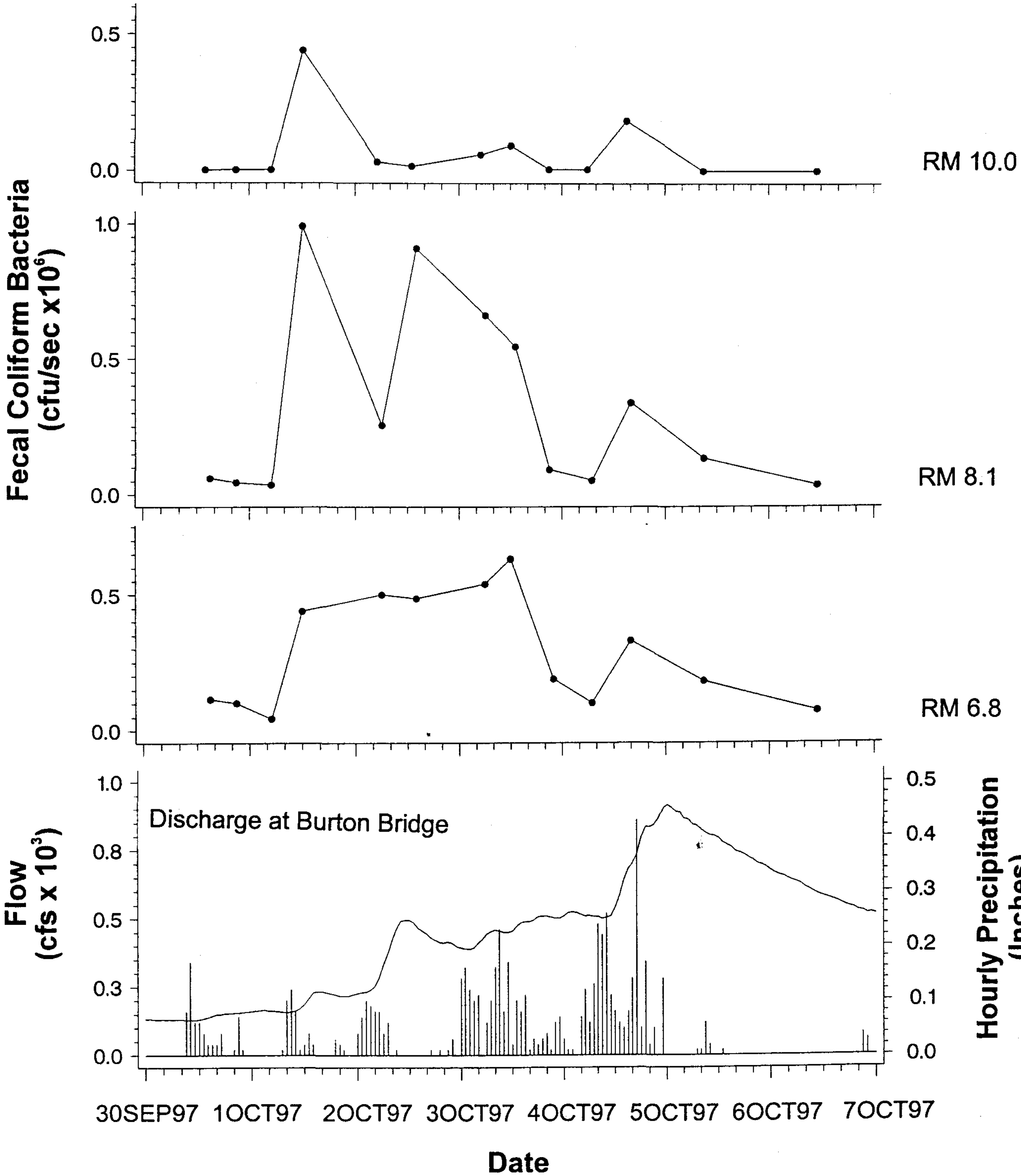
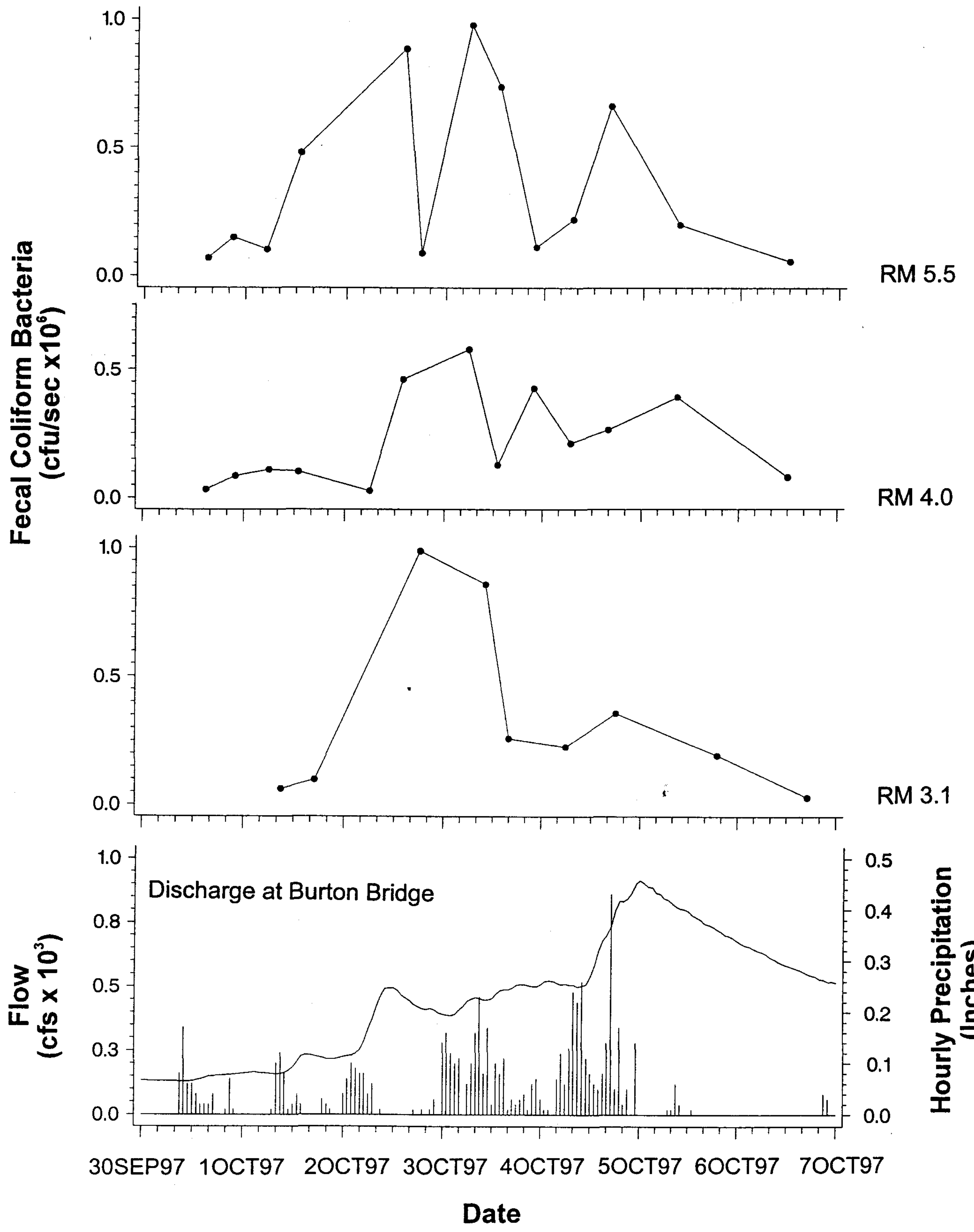


Figure 32. Load of fecal coliform bacteria (cfu/sec x 10^6) at all sites measured along the mainstem Tillamook River during the October 1997 storm. Sites are indicated by river mile (RM), with the uppermost panel (RM 10) being at the Yellow Fir Rd bridge crossing and the lowermost panel (RM 0.9) being at the last bridge before the Tillamook River enters the bay. Also shown are the hourly precipitation amounts and the discharge throughout the storm at the primary monitoring site.



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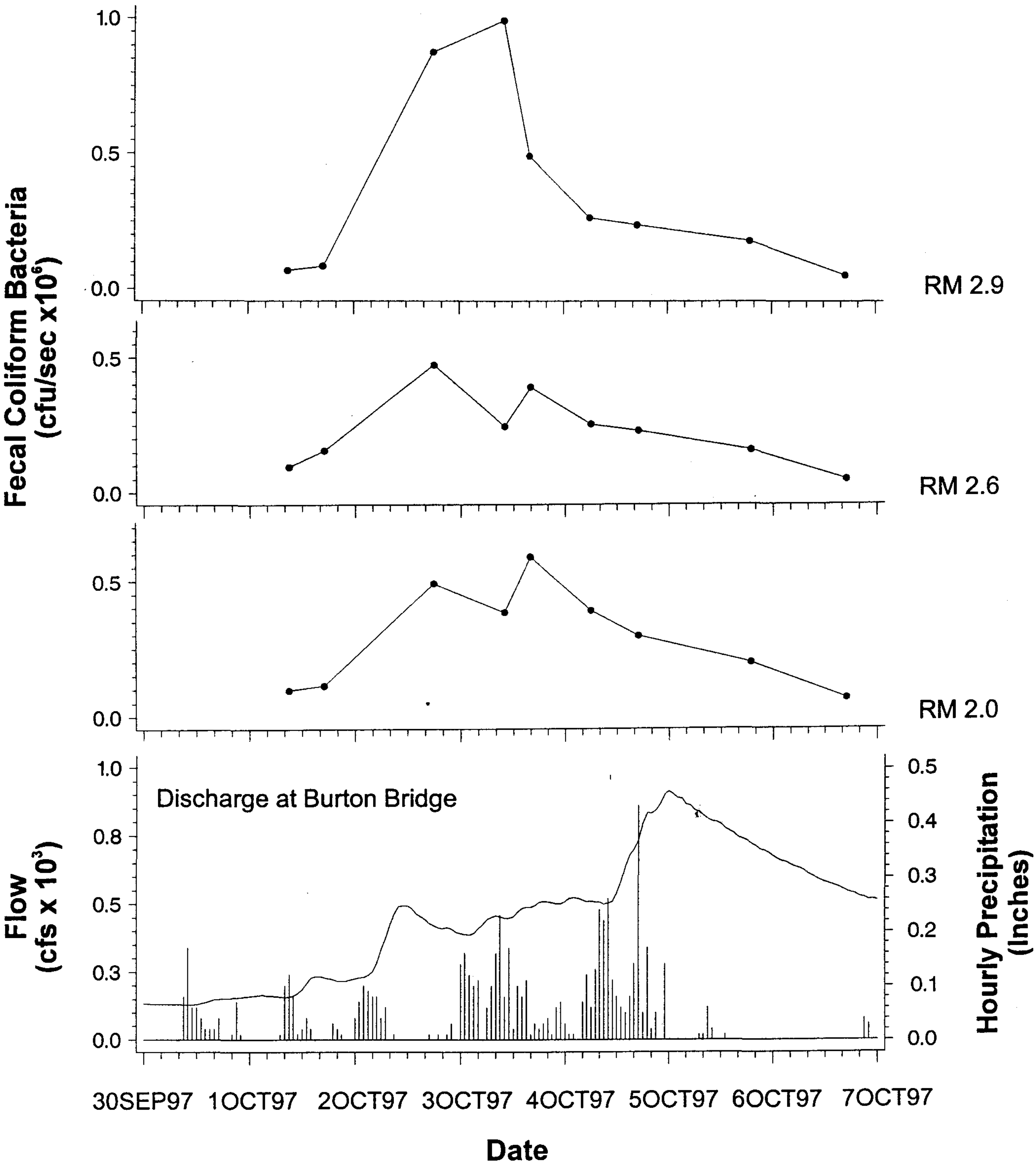

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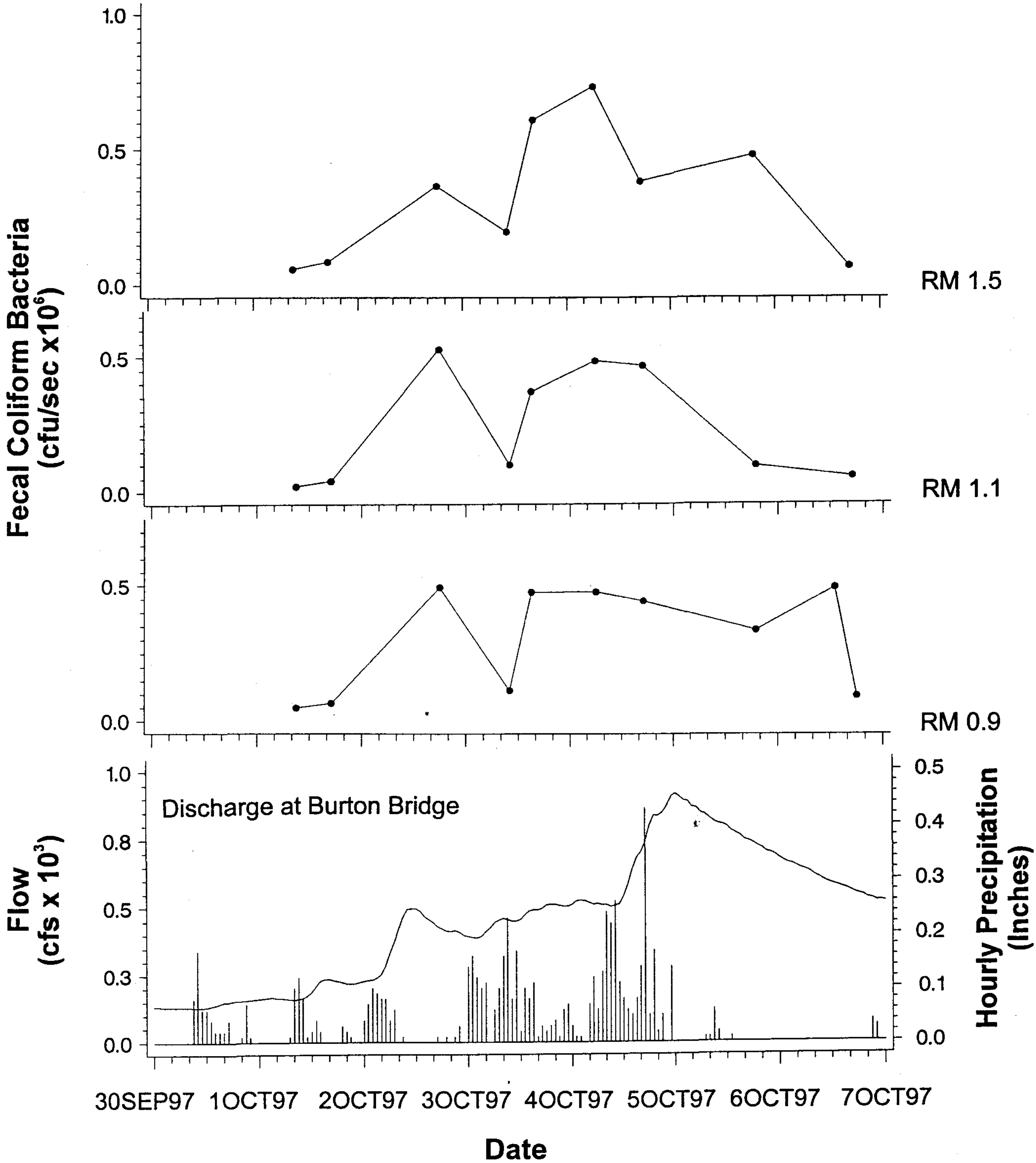


Figure 32 Continued.

corresponded to a rather significant lull that occurred in precipitation inputs (even though discharge was actually increasing at that time). The largest loads were frequently at the rest area and in the mid-section of the river between RM 2.9 and RM 5.5.

The bacterial fluxes measured at each site on the Tillamook River throughout the duration of the second intensive monitoring effort (Storm 6) are shown sequentially in Figure 33. At the uppermost site (RM 10), the FCB load remained low throughout the storm. FCB concentrations were actually relatively high at this site (generally above 200 cfu/100 ml and as high as 1300 cfu/100 ml on one sampling occasion during this storm), but the discharge is low at the Yellow Fir Rd site, only about 9% of the discharge at the primary site on this river. The various panels shown in Figure 33, as you move down to RM 4.5, show some areas with load increases (e.g., RM 8.1, 6.8 and 4.5), but the changes from site to site were small relative to the changes throughout the storm at a given site. The highest loads (> 0.25×10^6 cfu/sec) were observed in the lower reaches of the river, for example at sites RM 2.0, 1.5, and 1.1. The most downriver site (RM 0.9) did not exhibit the high peaks seen at a few of the other sites (e.g., > 0.5×10^6 cfu/sec at RM 1.5 and 1.1), but it had substantially higher loads throughout almost the entire storm than did any of the upper sites. The exception to this was very early in the storm, when some of the upper sites exhibited somewhat higher loads than did RM 0.9. This pattern observed in the Tillamook River suggests that the major sources of FCB load are many and that they are scattered throughout the agricultural portions of the basin. However, largest loads were often reached in the mid-section of the Tillamook River during the October storm and in the lower 2 miles of the river during both storms.

FCB concentrations and loads were also measured in two tributary streams to the Tillamook River that flow into it near the rest area at about RM 8 to 8.3. Some measurements were taken during the first intensive storm (Storm 4) and additional measurements were taken during the last storm (Figures 34 through 37). The concentration of FCB was generally low in Simmons Creek during the October 1997 storm. On most sample occasions the concentration was less than 100 cfu/100 ml, although one high value (>600 cfu/100 ml) was measured (Figure 34). The FCB load in Simmons Creek was always low (<0.05 cfu/sec). In contrast, the other tributary stream to the Tillamook River that was sampled during the October 1997 storm (Fawcett Creek) contained quite high concentrations of FCB. Concentrations were generally >500 cfu/100 ml and exceeded 2,000 cfu/100 ml on two sample occasions (Figure 35). Nevertheless, the discharge rate for Fawcett Creek is relatively modest, and the FCB loads were well under 0.25×10^6 cfu/sec throughout the fall storm (Figure 35). FCB concentrations in both of these tributaries during the March 1998 storm were consistently less than 200 cfu/100 ml and were generally less than 100 cfu/100 ml. FCB loads were very low (< 0.1×10^6 cfu/sec). Thus, these tributaries were not important contributors to the observed high FCB loads in the Tillamook River during the spring intensive storm, although Fawcett Creek was a significant contributor to Tillamook River loads during the fall storm.

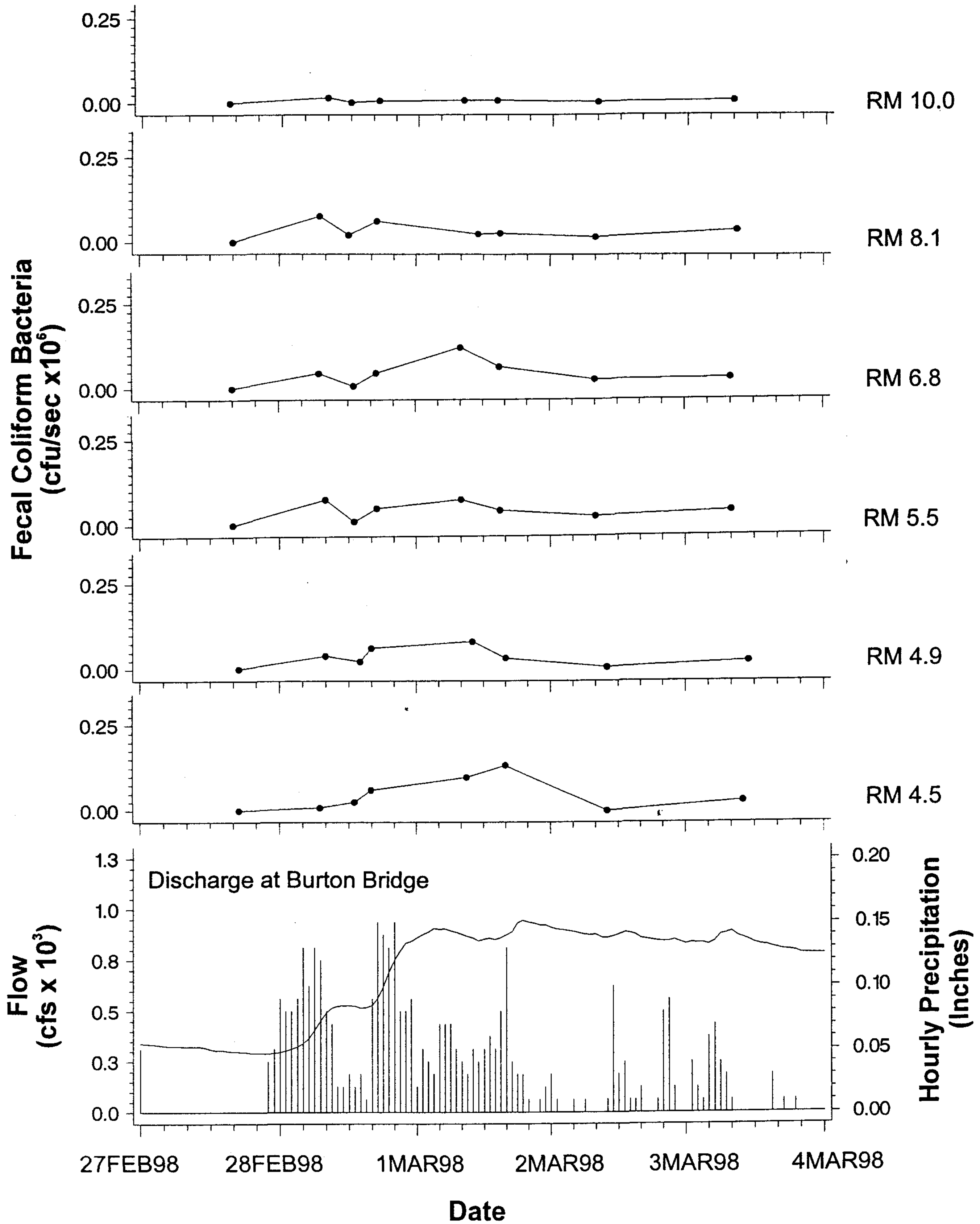
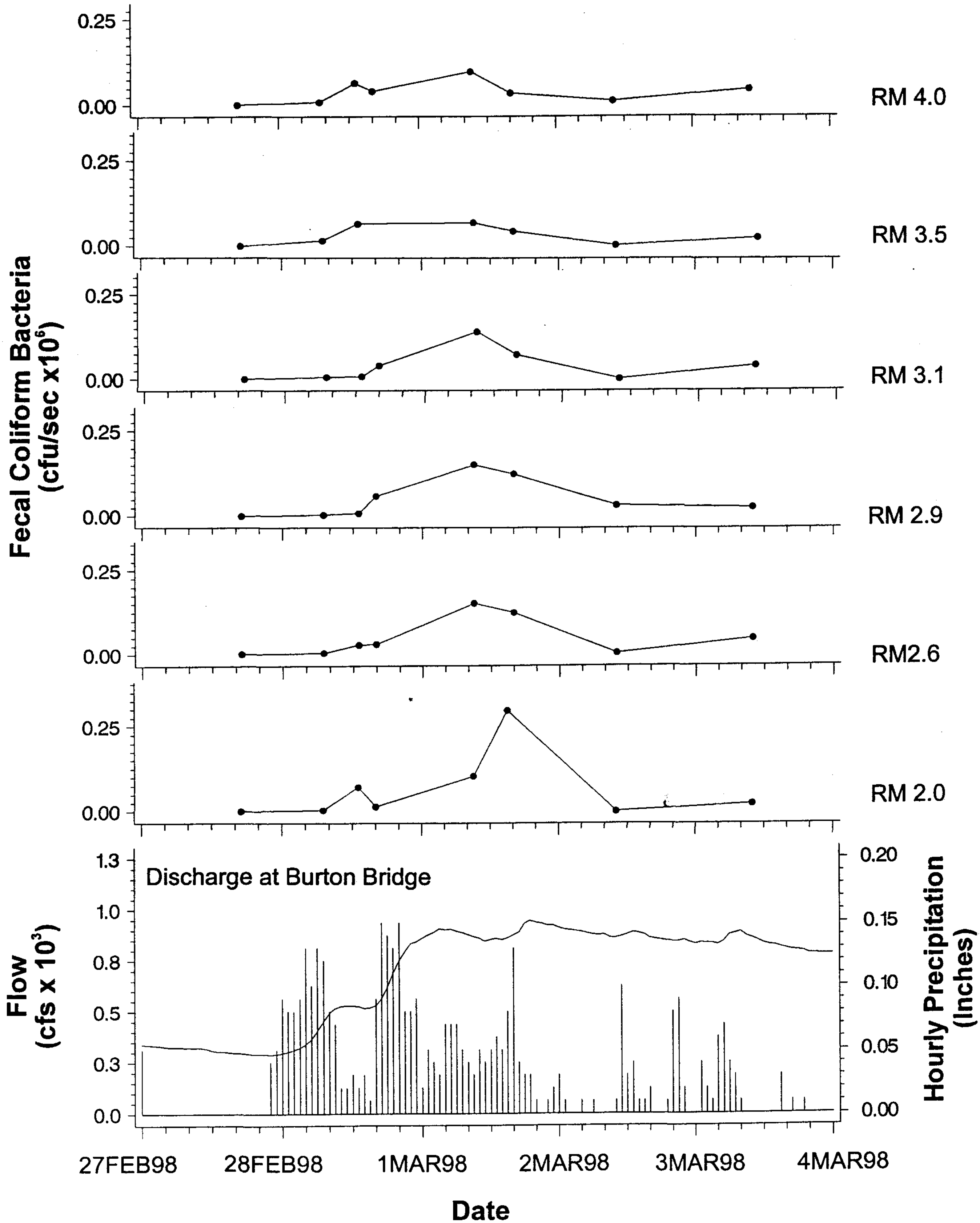


Figure 33. Load of fecal coliform bacteria (cfu/sec x 10^6) at all sites measured along the mainstem Tillamook River during the March 1998 storm.



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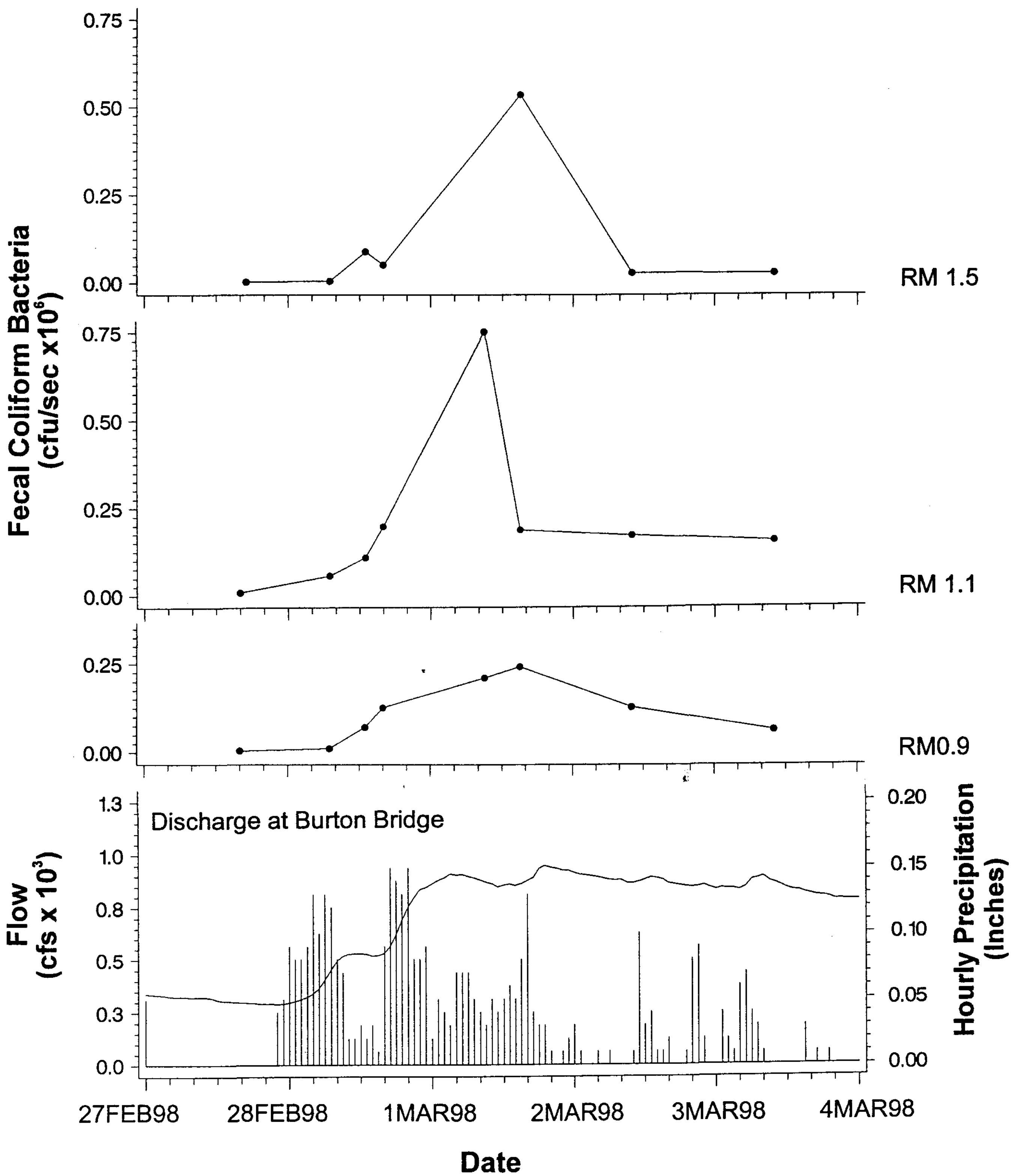

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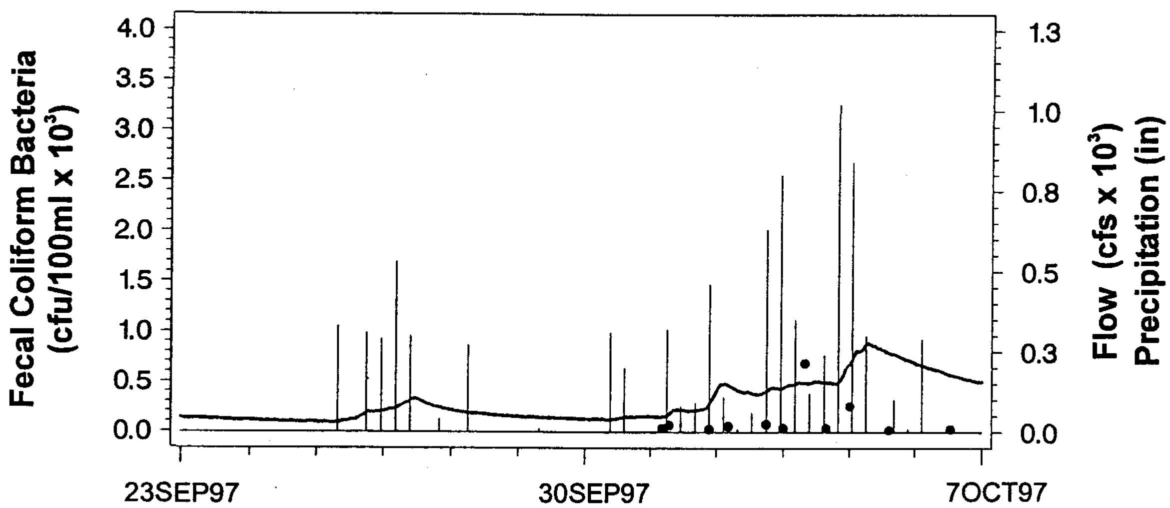
Simmons Creek



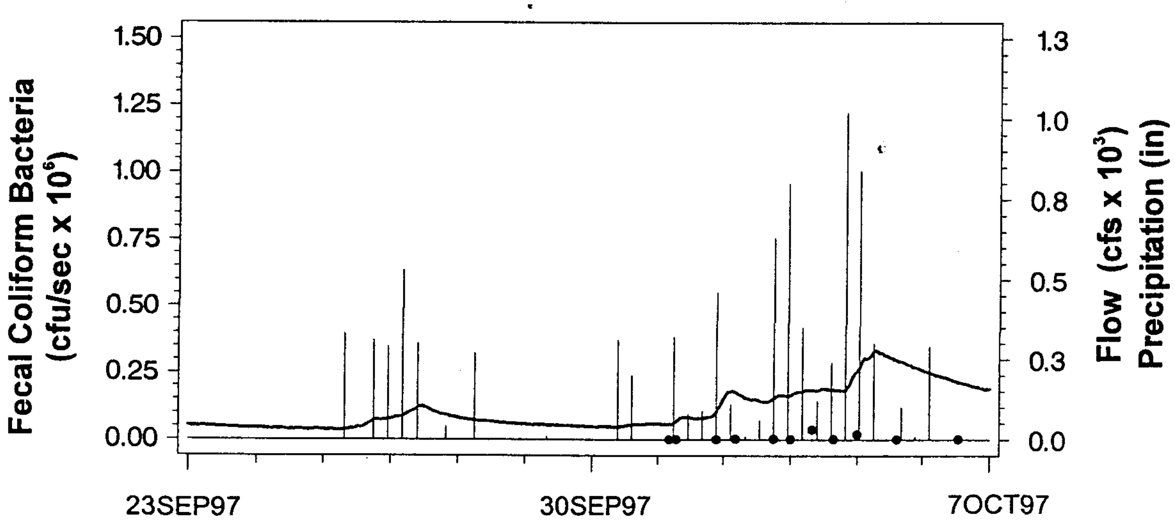
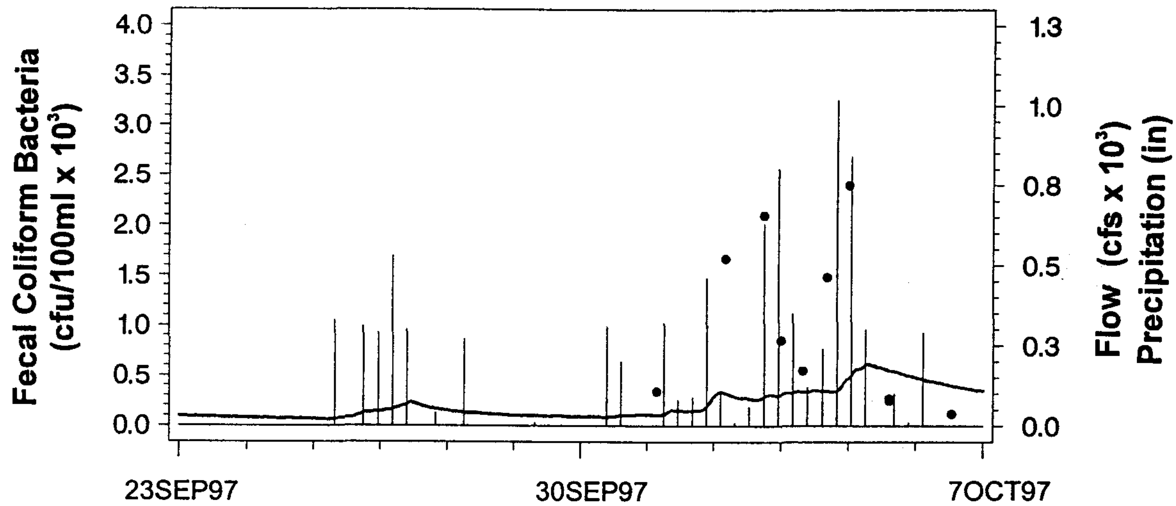


Figure 34. Fecal coliform bacteria concentration (top panel) and load (bottom panel) in Simmons Creek, at its point of entry into the Tillamook River, during the October 1997 storm.

Fawcett Creek



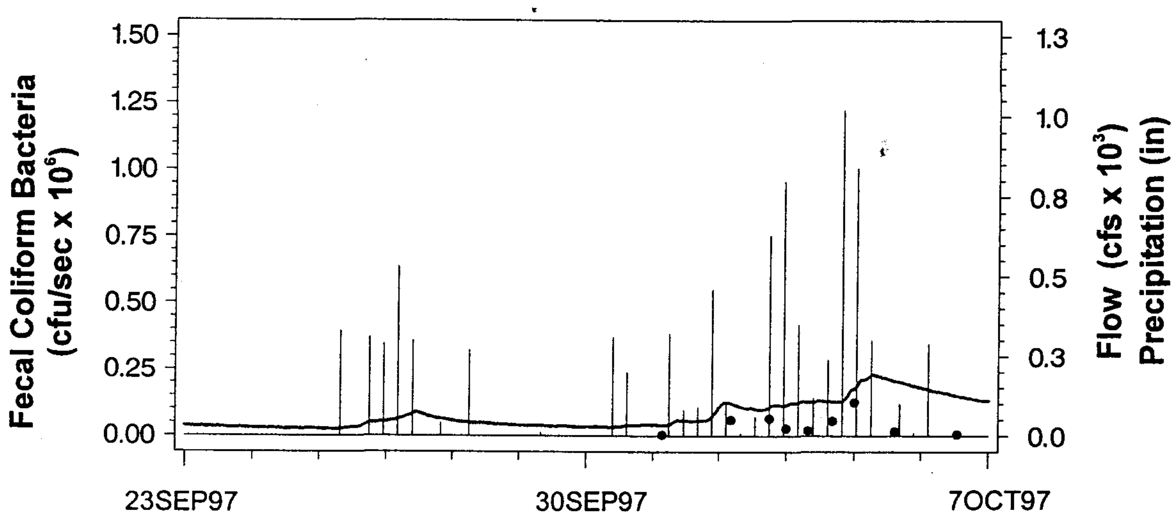


Figure 35. Fecal coliform bacteria concentration (top panel) and load (bottom panel) in Fawcett Creek, at its point of entry into the Tillamook River, during the October 1997 storm.

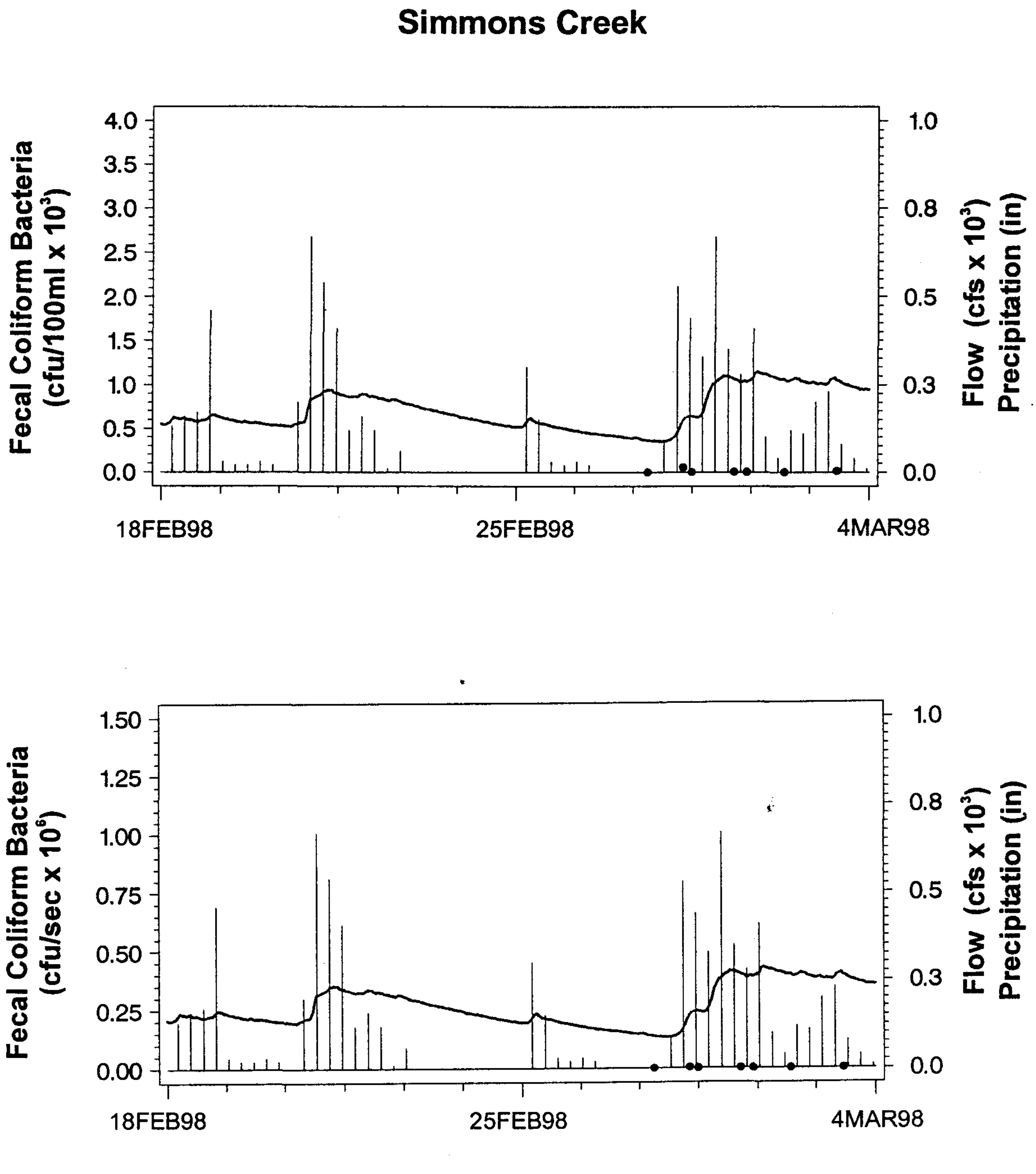
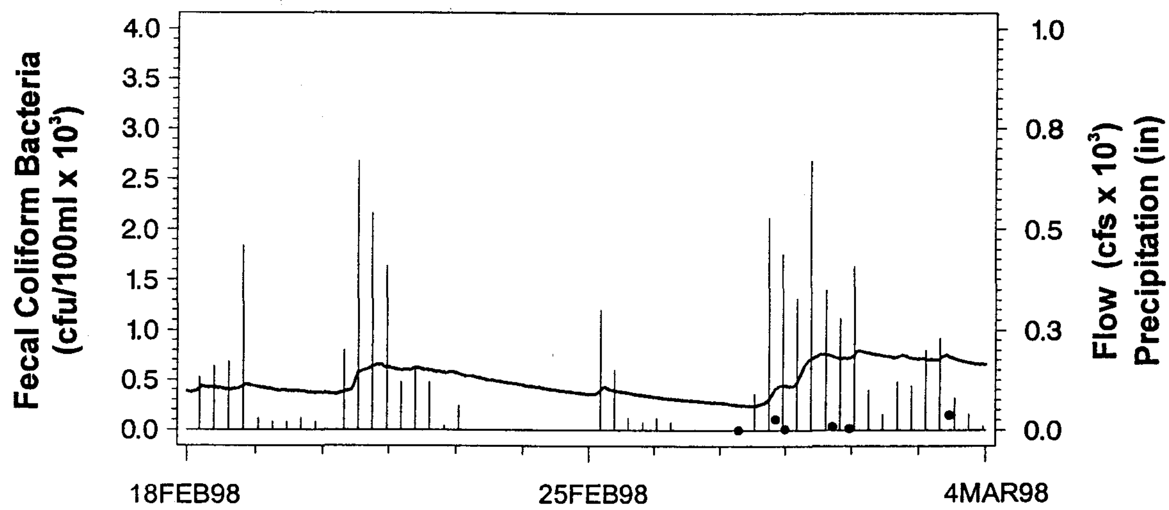


Figure 36. Fecal coliform bacteria concentration (top panel) and load (bottom panel) in Simmons Creek, at its point of entry into the Tillamook River, during the March 1998 storm.

Fawcett Creek



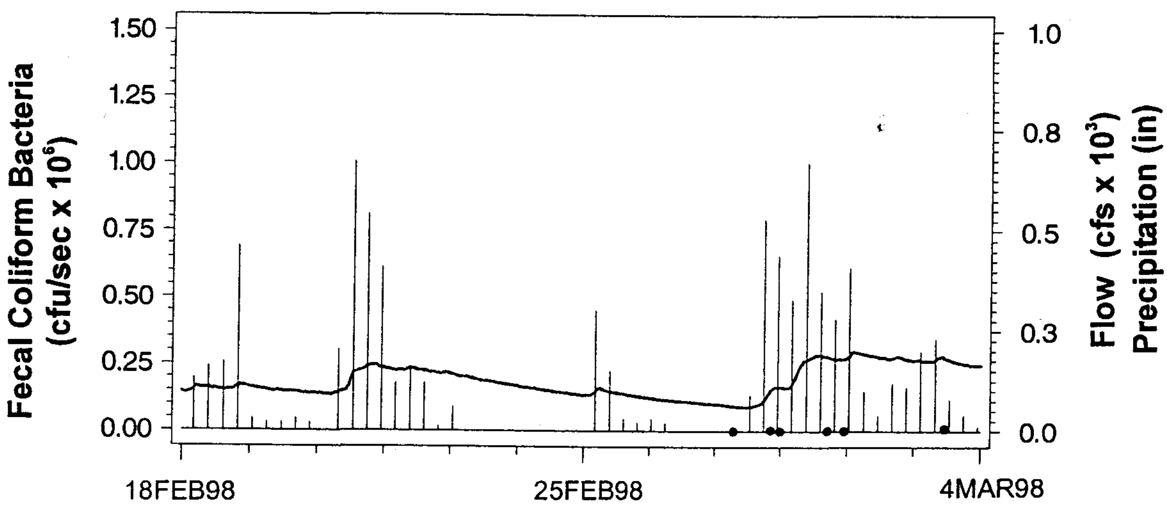


Figure 37. Fecal coliform bacteria concentration (top panel) and load (bottom panel) in Fawcett Creek, at its point of entry into the Tillamook River, during the March 1998 storm.

In the Trask River, the FCB loads during the October storm were highly variable from site to site, and among sampling occasions at all except one of the sites. At the uppermost site (Loren's Landing, RM 9.0), FCB loads remained relatively constant and and low (less than about 0.25 x 10^6 cfu/sec). All other sites showed pronounced variability during the course of the storm. All sites exhibited relatively low loads (less than about 0.25 x 10^6 cfu/sec) on the first day of sampling (September 30 or October 1) and again on the last day of sampling (October 6). Loads at most of the sites exceeded 1 x 10^6 cfu/sec during portions of the storm, however, especially around the time of the most intense rainfall (October 4th). Two sites in the mid-section of the study area exhibited loads in excess of 1.5 x 10^6 cfu/sec, at RM 4.3 and 3.7. All three of the lowest sites (RM 1.2, 0.2 and 0.0) exhibited loads greater than 2 x 10^6 cfu/sec. At RM 0.0, a fairly smooth response was found, with gradually increasing loads throughout the course of the storm, to a peak of over 2 x 10^6 cfu/sec on October 4th, and then a decreasing load to about 0.25 x 10^6 cfu/sec on October 6th, the last day of sampling (Figure 38).

FCB loads at the sampling sites on the Trask River during the March 1998 storm (Storm 6) are shown sequentially in Figure 39. At the uppermost site (RM 9.0, Loren's Landing), FCB loads remained very low throughout the storm (less than about 0.025 x 10^6 cfu/sec). At RM 7.0, the next downriver site, a small increase in FCB load was observed early in the storm, but the FCB load at this site remained below about 0.05 x 10^6 cfu/sec. The first site to show significant increases in FCB flux during the storm was at RM 4.3, where FCB loads increased markedly on the second day of sampling (February 28, 1998), and gradually decreased to near the pre-storm baseline over the next three days. Several high peaks in FCB load (>0.25 x 10^6 cfu/sec) were observed at RM 3.7, and these occurred slightly after the major pulses of precipitation. From site RM 3.6 down to site RM 2.4, there were rather small differences from site to site, except for one high peak measured at site RM 3.2. The largest loads found in the Trask River during this storm were often observed at the six lowest sites, from RM 2.3 to RM 0.0. At all six of these sites, FCB loads reached peak values around 0.5 x 10^6 cfu/sec. At several of the lowest sites, FCB loads remained between about 0.25 and 0.50 x 10^6 cfu/sec throughout much of the duration of the storm. Sampling of the March 1998 storm was discontinued while the discharge was still relatively high in both rivers. In fact, there was no peak discharge during this storm, but rather a plateau of elevated discharge. At the time of cessation of sampling, FCB loads in the upper portions of the sampling area on the Trask River had declined to near pre-storm levels. In the lower reaches of the Trask River (RM 1.7 and below), however, FCB loads were still high (~0.5 x 10^6 cfu/sec) on the last sampling occasion.

The principal sites on the Tillamook and Trask Rivers that contributed FCB loads to the respective rivers during the October 1997 storm are listed in Tables 5 and 6. The major load contributing sites (compared to their neighboring upriver sites) on the Tillamook River were scattered across much of the portion of the basin (lowlands) that was sampled. High load

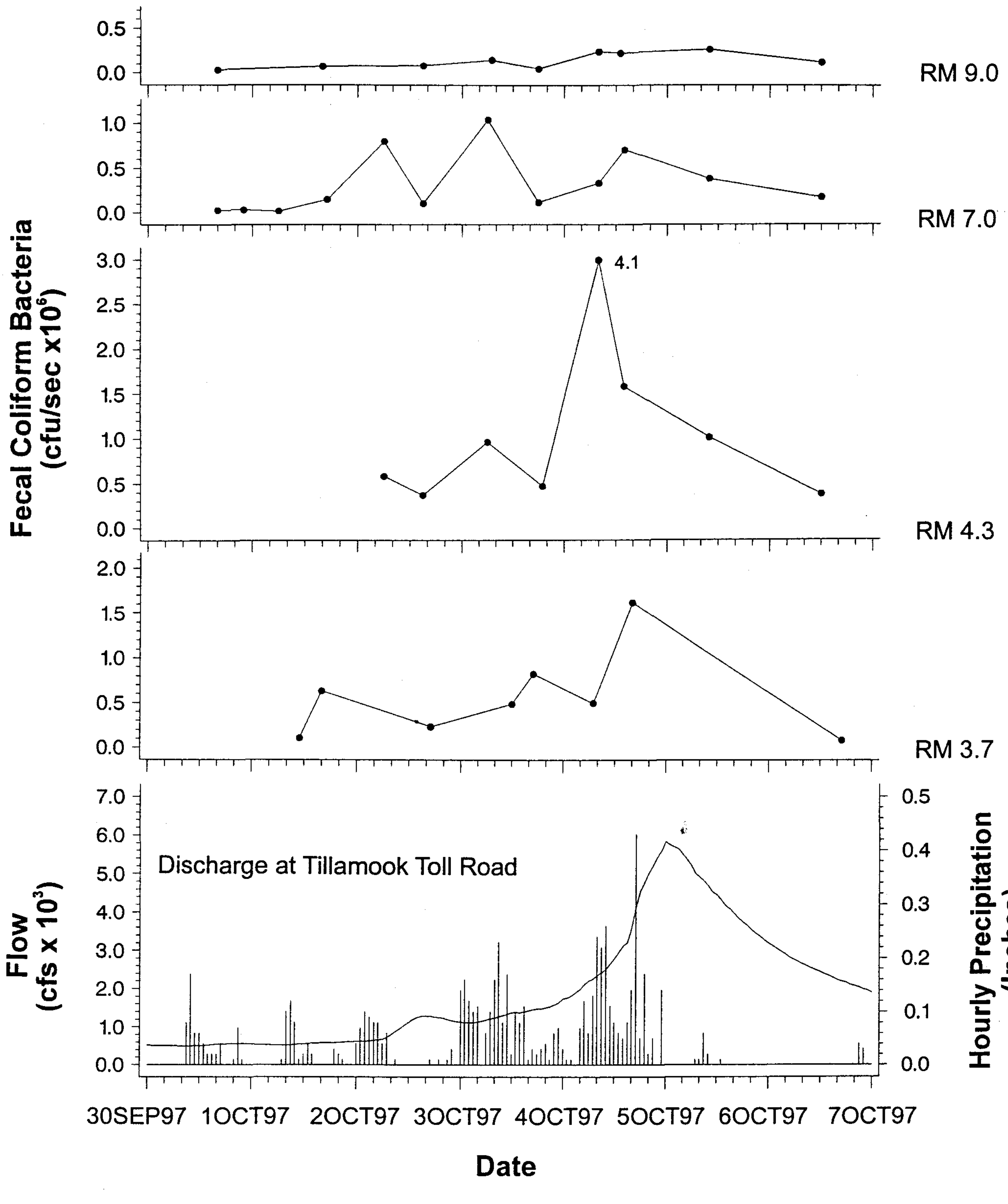
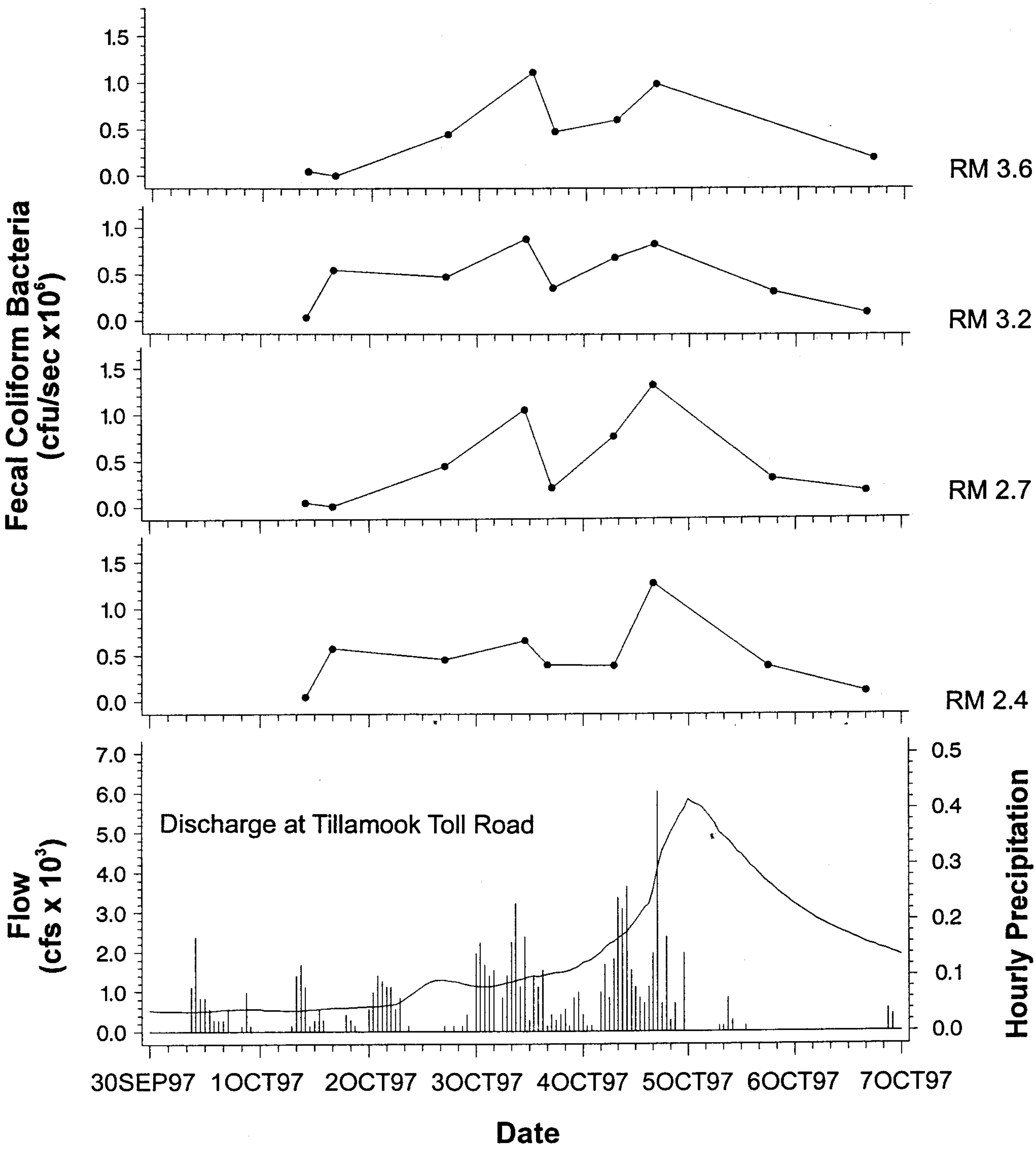


Figure 38. Load of fecal coliform bacteria (cfu/sec x 10^6) at all sites measured along the Trask River during the October 1997 storm.



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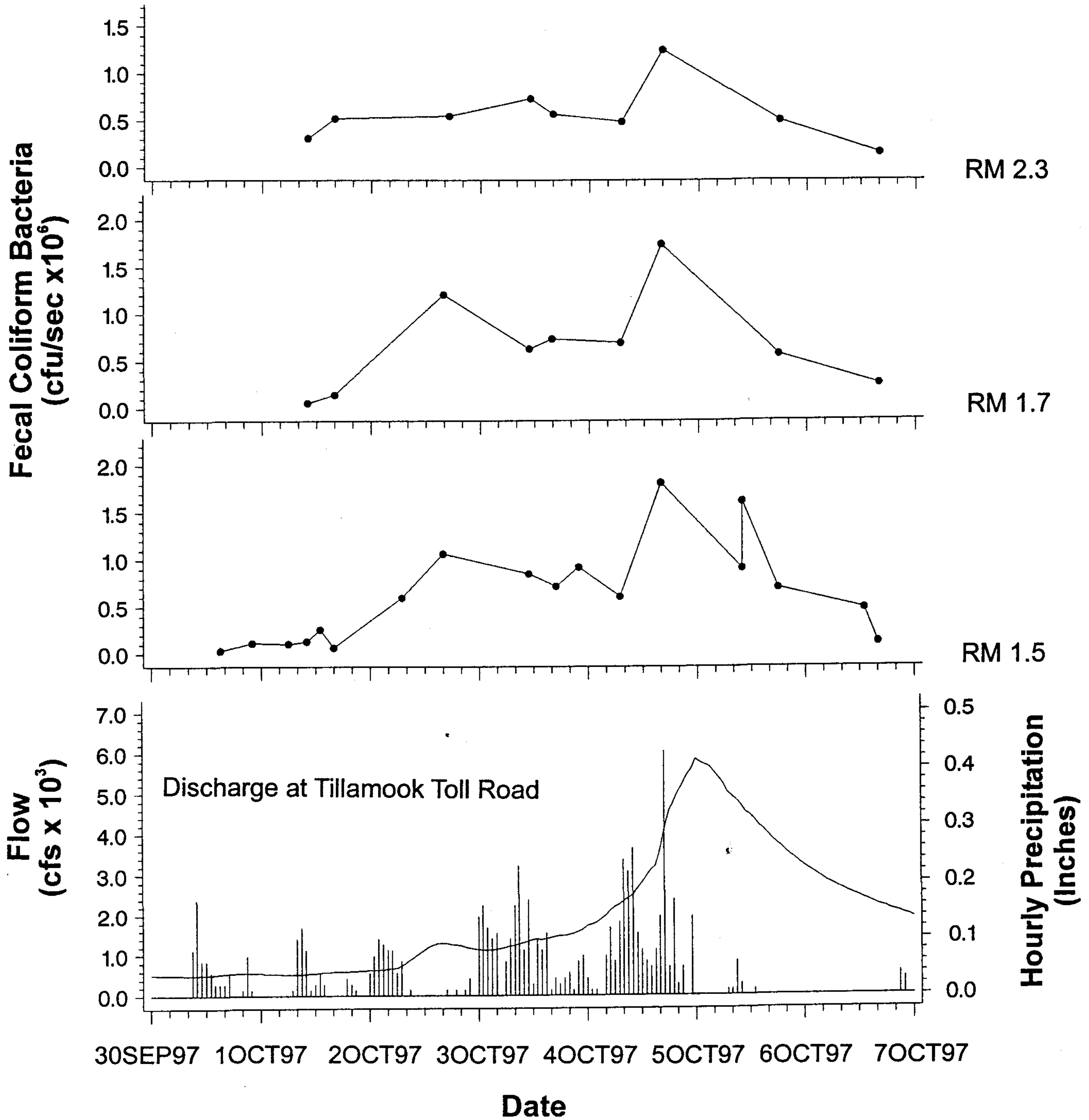

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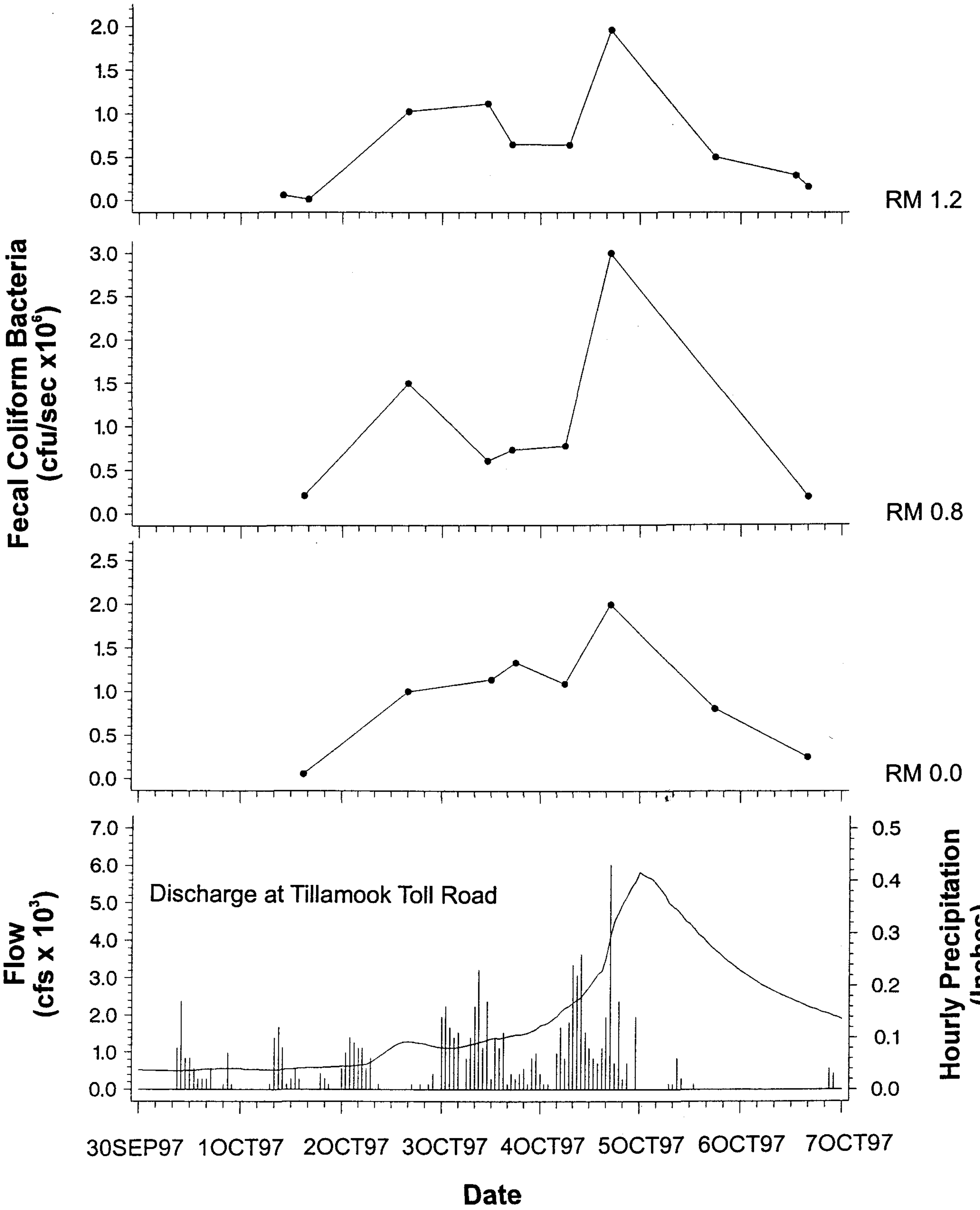


Figure 38 Continued.

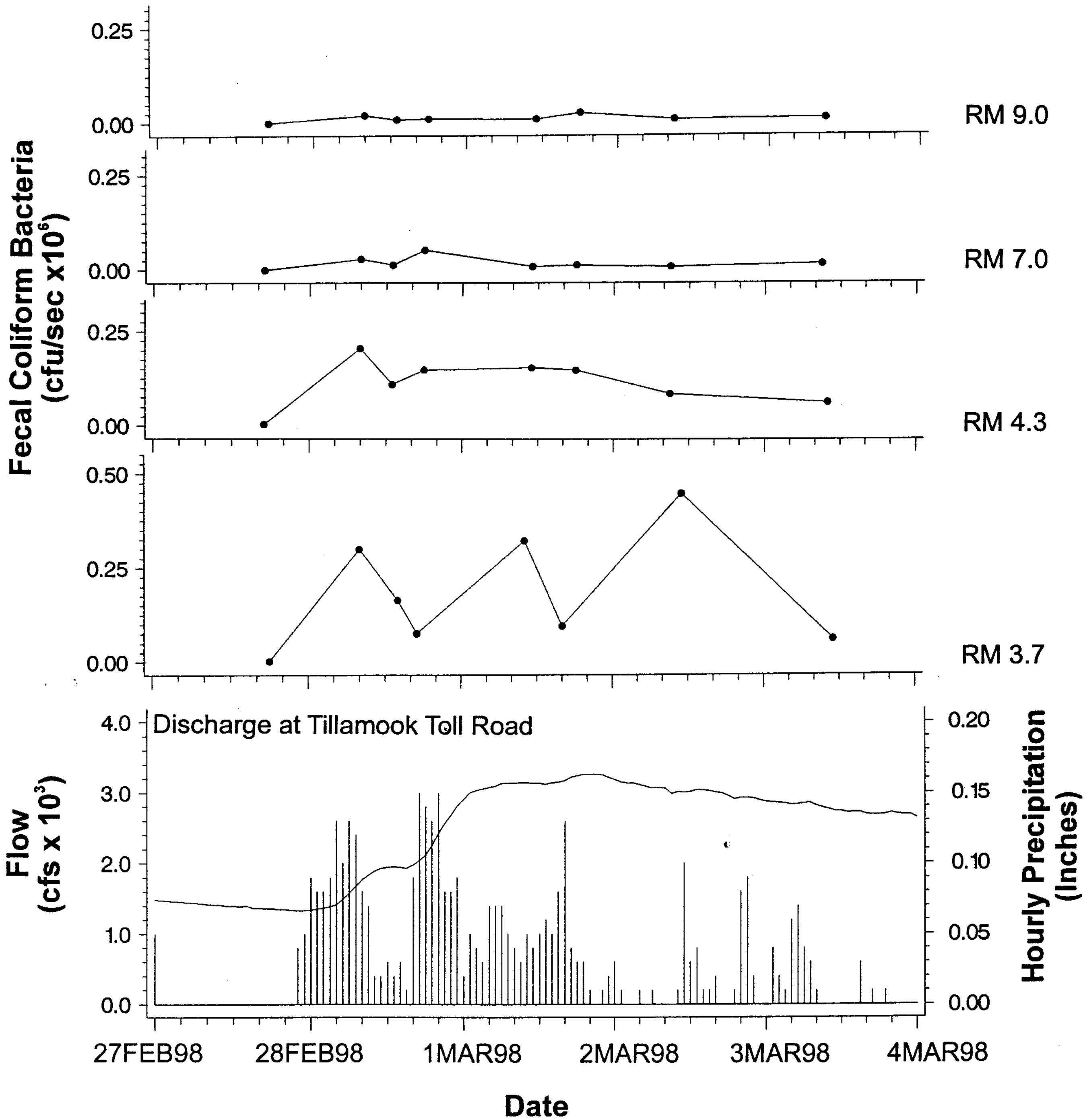


Figure 39. Load of fecal coliform bacteria (cfu/sec x 10^6) at all sites measured along the Trask River during the March 1998 storm.

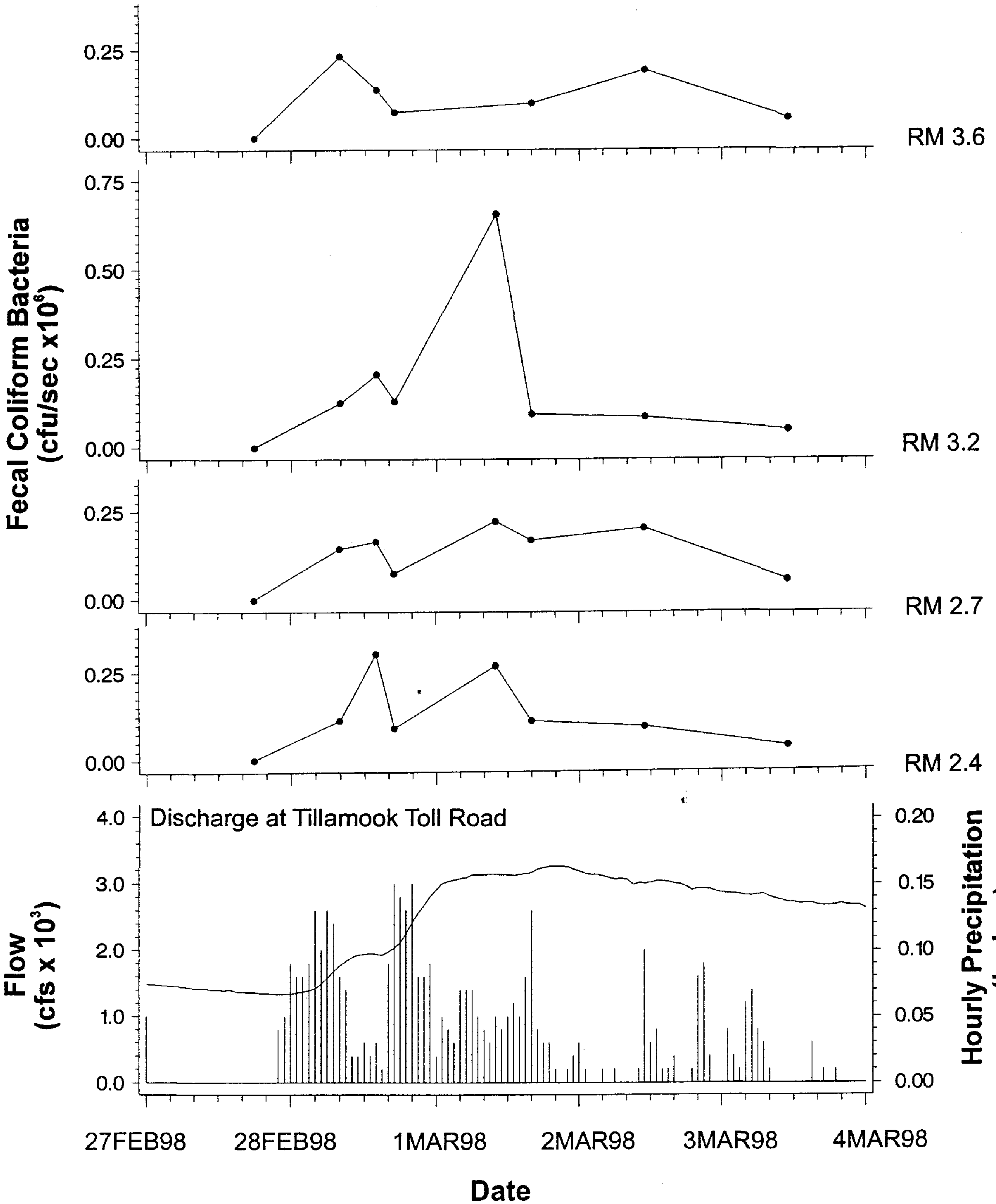


Figure 39 Continued.

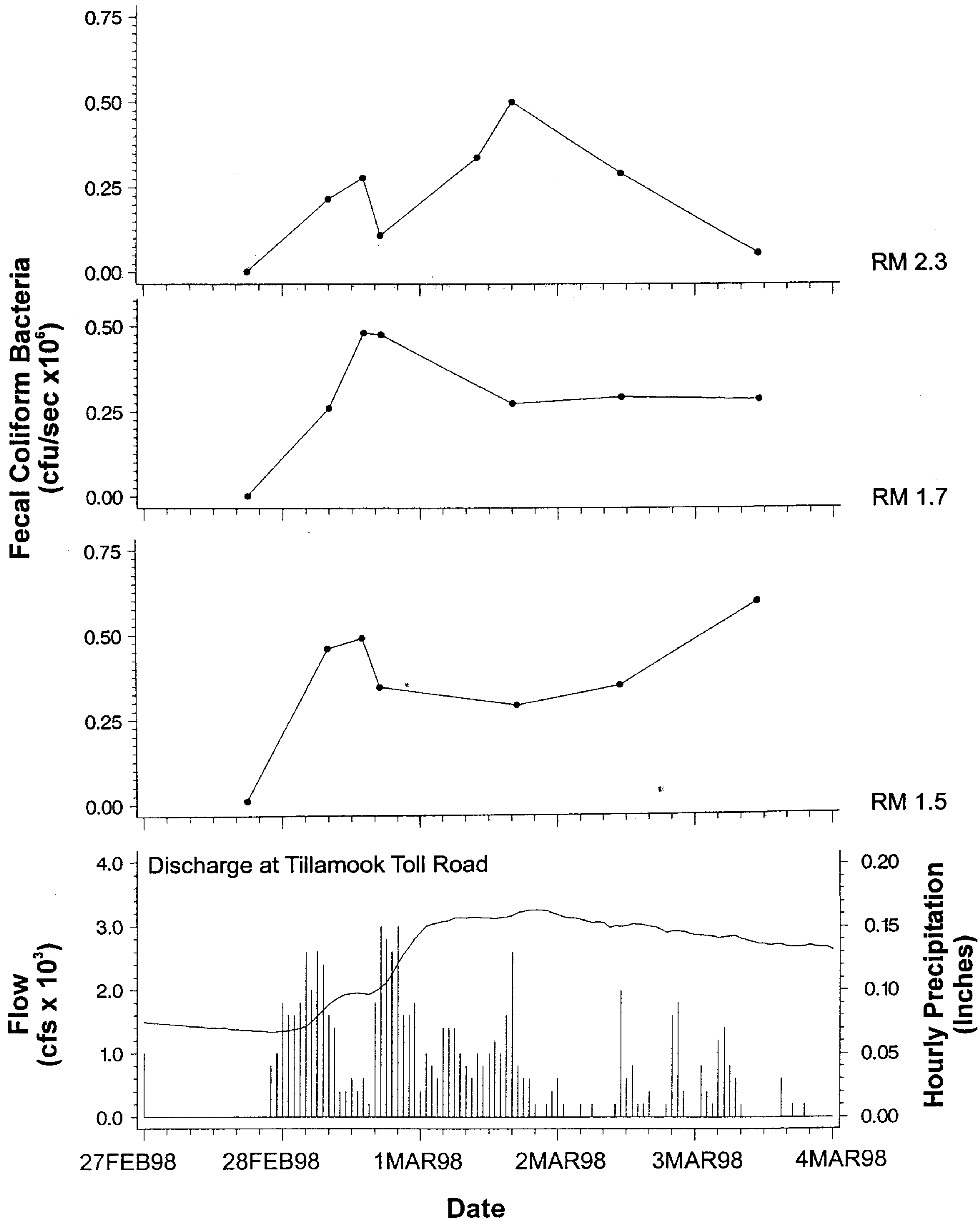


Figure 39 Continued.

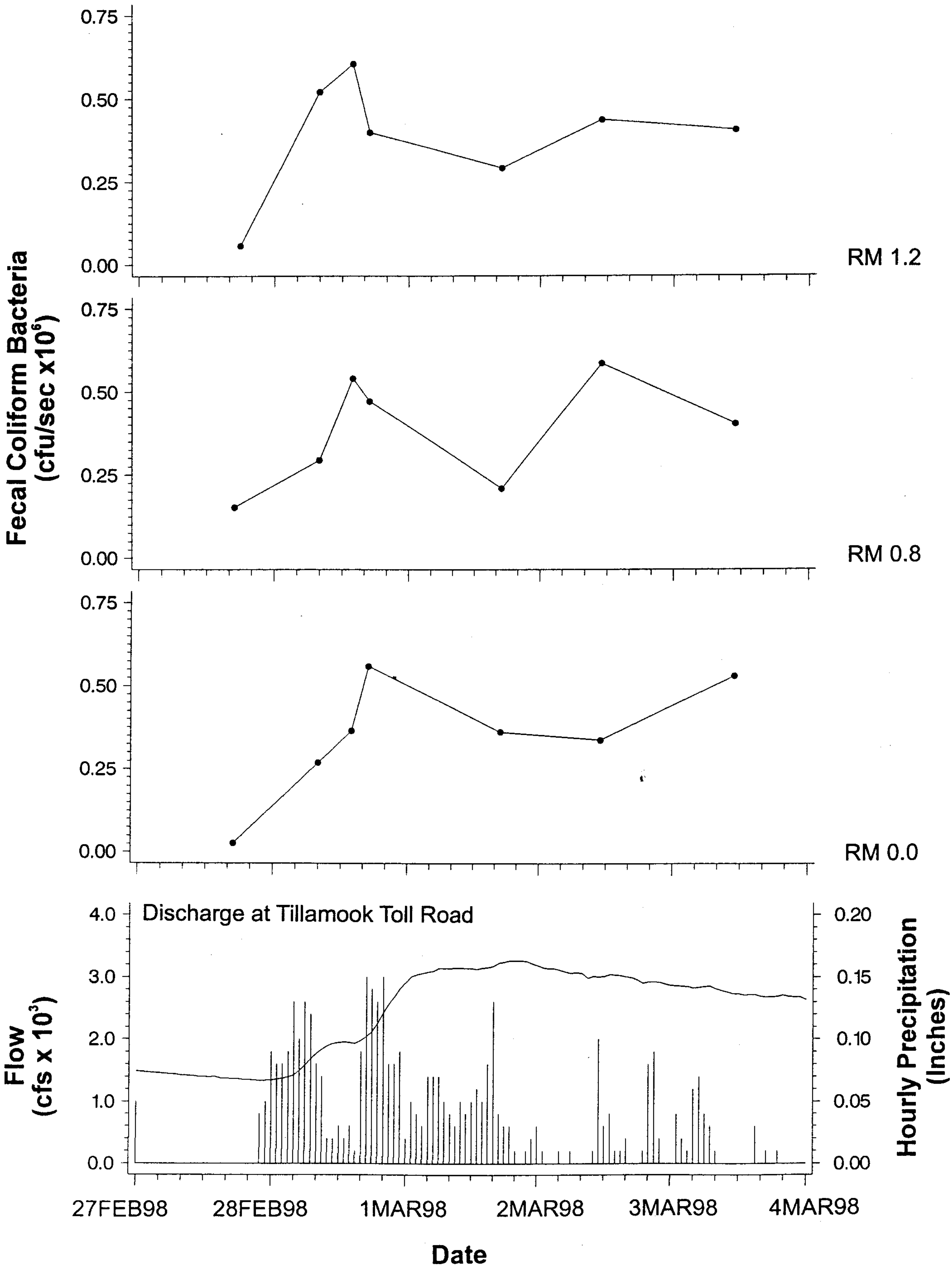


Figure 39 Continued.

Table 5. Rank order bacteria load contributions at specific monitoring sites sampled 7 or more times on the Tillamook River during all 12-hr time slices for which 6 or more sites were sampled during the October 1997 storm. The top five load contributing sites are listed.

Ordered by Load[1]			Ordered by Load Per Contributing Area[2]			Ordered by Load Per River Miles to Upriver Site[3]		
Site	R.M.	Total Score	Site	R.M.	Total Score	Site	R.M.	Total Score
RES	8.1	32	FRA	2.0	25	NET	0.9	22
WEB	5.5	21	BTG	2.9	20	BTG	2.9	19
NET	0.9	15	NET	0.9	16	FRA	2.0	18
FRA	2.0	14	WEB	5.5	14	WEB	5.5	17
TDI	1.5	12	AWT	2.6	10	RES	8.1	15

[1] Scores for each time slice were calculated as the load within that time slice at a given site, minus the load at the site immediately upriver. Total score is the sum of scores for each site across the time slices sampled in sufficient number (≥ 6 sites sampled) during the storm. The site which contributed the largest load within a time slice was assigned a score of 5; the site contributing the second largest load was assigned a score of 4; and so on to the fifth largest load (score=1). The maximum possible total score would be 40 (largest load in each of eight time slices).
[2] Before calculating the score, the load difference between each pair of sites was divided by the contributing area (ha) of the watershed that drained into the river between those two sites.
[3] Calculated as above, except the loads were divided by the number of river miles between each pair of sites.

Table 6. Rank order bacteria load contributions at specific monitoring sites sampled 7 or more times on the Trask River during all 12-hr time slices for which 6 or more sites were sampled during the October 1997 storm. The top five load contributing sites are listed.

Ordered by Load[1]			Ordered by Load Per Contributing Area[2]			Ordered by Load Per River Miles to Upriver Site[3]		
Site	R.M.	Total Score	Site	R.M.	Total Score	Site	R.M.	Total Score
10L	4.3	17	HOQ	0.8	19	TEF	2.3	23
ASF	1.7	14	5TH	1.5	19	5TH	1.5	17
TTR	2.4	14	TTR	2.4	19	TTR	2.4	14
HOQ	0.8	13	DST	3.2	13	BTR	3.6	13
TEF	2.3	12	BTR	3.6	12	HOQ	0.8	12
5TH	1.5	12	BPS	2.7	12			

[1] Scores for each time slice were calculated as the load within that time slice at a given site, minus the load at the site immediately upriver. Total score is the sum of scores for each site across the time slices sampled in sufficient number (≥ 6 sites sampled) during the storm. The site which contributed the largest load within a time slice was assigned a score of 5; the site contributing the second largest load was assigned a score of 4; and so on to the fifth largest load (score=1). The maximum possible total score would be 40 (largest load in each of eight time slices).
[2] Before calculating the score, the load difference between each pair of sites was divided by the contributing area (ha) of the watershed that drained into the river between those two sites.
[3] Calculated as above, except the loads were divided by the number of river miles between each pair of sites.

contributing areas were found as high upriver as the rest area (RM 8.1) and as low as RM 0.9 (Table 5). The major load-contributing sites on the Trask River were less well-distributed across the basin, and tended to be clustered to some degree around the portions of the river that receive drainage from the City of Tillamook and the site downriver from the Port of Tillamook STP discharge point (10L, Table 6). The largest load-contributing site on the Trask River during both storms was site 10L, which drains the area approximately between Chance Road and Highway 101. This same section of the Trask River exhibited a rapid rise in FCB concentration in 1979 and 1980 (Jackson and Glendening 1982).

The principal load-contributing sites during the March 1998 storm were generally similar to those found for the October 1997 storm (Tables 5 and 7). However, the largest loads of FCB were contributed during the March 1998 storm to the Tillamook River at site TIL-SFT, a site in the lower reaches of the river with a very small watershed contributing area (Figure 3). Other major load contributing sites were similar between the two storms on both the Tillamook and Trask Rivers (Tables 5 through 8).

Thus, the overall trend for both the Tillamook and Trask Rivers during both the fall and spring storms was as follows. FCB loads were low at all sites at the beginning and generally at the end (depending on when sampling was discontinued) of the storms. At the uppermost sites, located in the upper section of the agricultural portions of these watersheds, FCB loads remained low. At the

Table 7. Rank order bacteria load contributions at monitoring sites on the Tillamook River during all 12-hr time slices sampled during the March 1998 storm. The top five load contributing sites are listed.

Ordered by Load[1]			Ordered by Load Per Contributing Area[2]			Ordered by Load Per River Miles to Upriver Site[3]		
Site	R.M.	Total Score	Site	R.M.	Total Score	Site	R.M.	Total Score
SFT	1.1	24	SFT	1.1	25	SFT	1.1	30
RES	8.1	19	BTG	2.9	15	BTG	2.9	13
TDI	1.5	14	MID	4.5	14	TDI	1.5	10
AWT	2.6	6	TDI	1.5	10	AWT	2.6	7
FRA	2.0	6	AWT	2.6	8	BUR	4.0	7
BTG	2.9	6	FRA	2.0	8	ATG	3.1	7

[1] Scores for each time slice were calculated as the load within that time slice at a given site, minus the load at the site immediately upriver. Total score is the sum of scores for each site across the time slices sampled in sufficient number (≥ 6 sites sampled) during the storm. The site which contributed the largest load within a time slice was assigned a score of 5; the site contributing the second largest load was assigned a score of 4; and so on to the fifth largest load (score=1). The maximum possible total score would be 35 (largest load in each of seven time slices).

[2] Before calculating the score, the load difference between each pair of sites was divided by the contributing area (ha) of the watershed that drained into the river between those two sites.

[3] Calculated as above, except the loads were divided by the number of river miles between each pair of sites.

Table 8. Rank order bacteria load contributions at monitoring sites on the Trask River during all 12-hr time slices sampled during the March 1998 storm. The top five load contributing sites are listed.

Ordered by Load[1]			Ordered by Load Per Contributing Area[2]			Ordered by Load Per River Miles to Upriver Site[3]		
Site	R.M.	Total Score	Site	R.M.	Total Score	Site	R.M.	Total Score
10L	4.3	16	TEF	2.3	22	5TH	1.5	21
5TH	1.5	15	5TH	1.5	17	HOQ	0.8	14
TEF	2.3	14	ASF	1.7	14	BPS	2.7	14
ASF	1.7	14	HOB	1.2	13	ASF	1.7	11
HOB	1.2	10	ATR	3.7	8	HOB	1.2	8
ATR	3.7	10						

[1] Scores for each time slice were calculated as the load within that time slice at a given site, minus the load at the site immediately upriver. Total score is the sum of scores for each site across the time slices sampled in sufficient number (≥ 6 sites sampled) during the storm. The site which contributed the largest load within a time slice was assigned a score of 5; the site contributing the second largest load was assigned a score of 4; and so on to the fifth largest load (score=1). The maximum possible total score would be 35 (largest load in each of seven time slices).
[2] Before calculating the score, the load difference between each pair of sites was divided by the contributing area (ha) of the watershed that drained into the river between those two sites.
[3] Calculated as above, except the loads were divided by the number of river miles between each pair of sites.

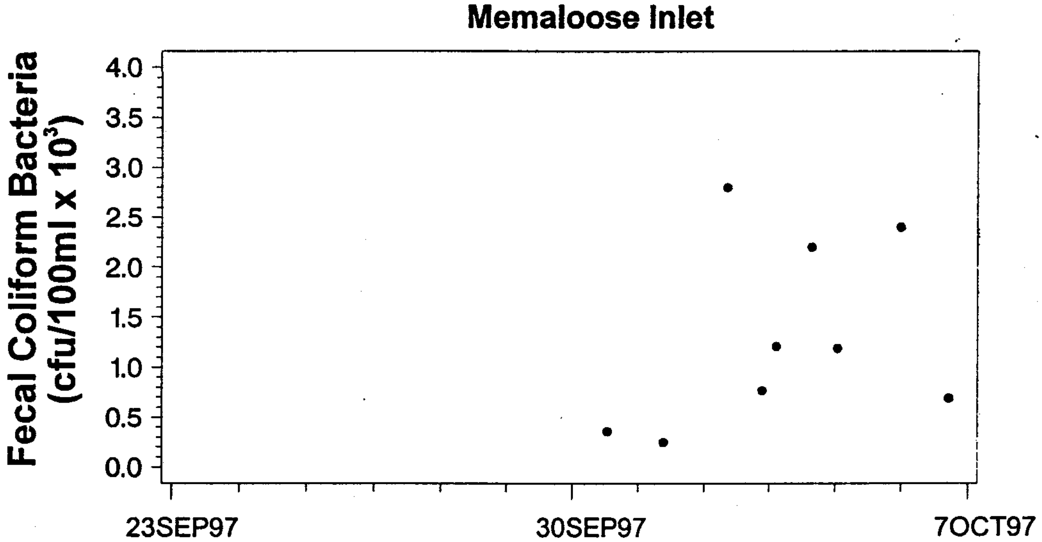
uppermost Trask River site (Loren's Landing), this was mainly because FCB concentrations remained low. At the uppermost Tillamook River site (Yellow Fir Rd.), this was because the discharge is low compared to the lower reaches of the Tillamook River (FCB concentrations were frequently high). High loads were found at a variety of locations on both rivers. There was not one major source area of FCB load on either river; the source areas were many and widely scattered. The largest loads in both rivers were generally achieved in the lower two miles or so of river reach. This suggests the cumulative effect of a large number of source areas within the agricultural portions of the watersheds and/or a larger contribution of FCB close to the bay.

Jackson and Glendening (1982) found fairly uniform concentrations of fecal coliform bacteria along the Tillamook River from the Yellow Fir Rd. bridge crossing down to the boat dock near the last bridge crossing during two storms, in December 1979 and March 1980. Concentrations were similar for the two storms, generally in the range of about 500 to about 1500 cfu/100 ml. The sample site just above the rest area exhibited the highest concentrations during the July 1980 sampling and also the December 1979 and October 1980 storm samplings. Results of our analyses confirm that this section of the Tillamook River remains one of the sections with highest FCB loading.

A site in the bay was monitored during the two intensive storm monitoring efforts. It was adjacent to Memaloose Boat Launch, just north of where the Tillamook and Trask Rivers enter Tillamook Bay. During high-discharge periods, a substantial amount of water flows past this point from south to north. In some respects, this portion of the bay behaves more like a river than a bay during significant storm events. The FCB concentration data for Memaloose Inlet are presented in Figures 40 and 41. Wilson River discharge and precipitation at Tillamook are depicted in the lower panel on each figure as a reference to hydrological conditions during the storm. During Storm 4, FCB concentrations exceeded 1,000 cfu/100 ml on over half of the sampling occasions, with a peak concentration of nearly 3,000 cfu/100 ml (Figure 40). These are extremely high concentrations given that the bacterial standard for protecting the oyster beds located just north of this sampling location is only 14 cfu/100 ml. Even during the spring storm (Storm 6), which resulted in much lower FCB loads in the Tillamook and Trask Rivers, the FCB concentration at Memaloose Inlet was about 500 to 1,000 cfu/100 ml on half of the sampling occasions (Figure 41).

Jackson and Glendening (1982) also found quite high concentrations of fecal coliform bacteria at locations throughout the bay in 1979 and 1980. Maximum values exceeding 900 cfu/ 100 ml were found at 12 of 14 by sites during a 6 day storm event in December 1979. Highest concentrations were found in the southern portion of the bay, especially near Rock Point along the southwestern shore (median, 974 cfu/100 ml, n=9). Concentrations above 900 cfu/100 ml were also measured in the bay at 4 sites during a 4-day storm in March, 1980. Again, highest concentrations were found along the southwestern shore of the bay (median concentrations at Rock Point, 670 cfu/100 ml, n=9). Bay samplings in July and October 1980 yielded much lower concentrations, although median concentrations in the southern (upper) portions of the bay were consistently higher than 20 cfu/100 ml.

During a fall storm, October 24-26, 1980 (40 hrs), the fecal coliform load to the bay was estimated to be highest in the Tillamook River, followed closely by the Wilson and Trask Rivers, with somewhat smaller load contributions from the Miami, and especially the Kilchis River (Tillamook SCD 1981). Our fall storm analyses in 1997, however, suggested much higher FCB loads in the Trask, as compared with the Tillamook, River. Loading patterns were quite different in the other seasons during 1979 and 1980. A winter storm, December 2-6, 1979 (91 hrs) yielded largest loads in the Wilson and Trask Rivers, followed by the Kilchis, Tillamook, and finally Miami Rivers. During a spring storm, March 10-13, 1980 (60 hrs), the Wilson, Trask, and Kilchis Rivers again had the largest loads, followed by the Tillamook and finally the Miami Rivers (Tillamook SWCD 1981). Our analyses suggested that FCB loads in the Kilchis River were nearly an order of magnitude lower than FCB loads in the Tillamook River. Thus, there is some indication that the relative importance of the various watersheds may have changed since 1980 regarding their contribution of FCB to the bay.



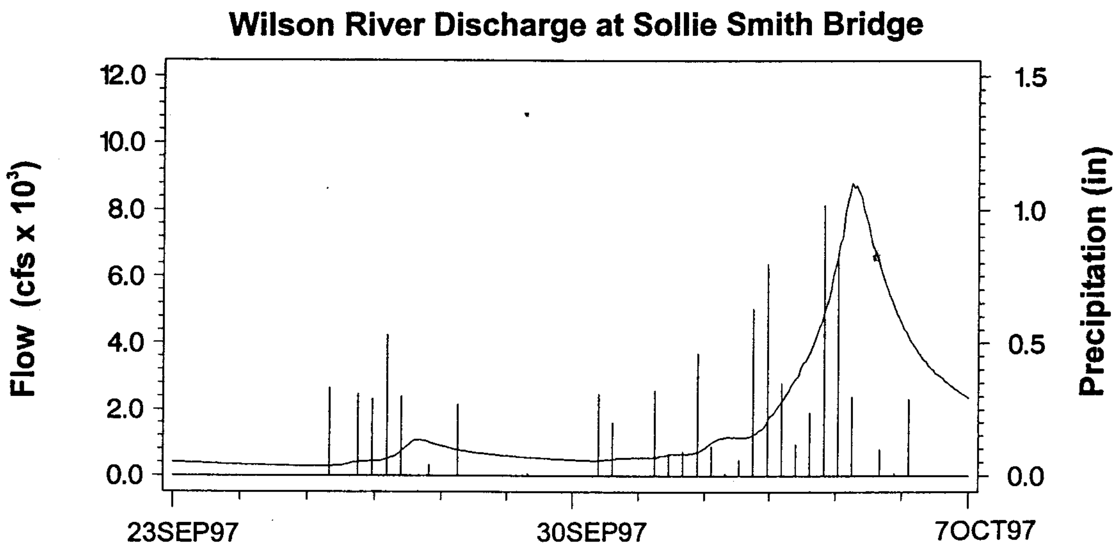
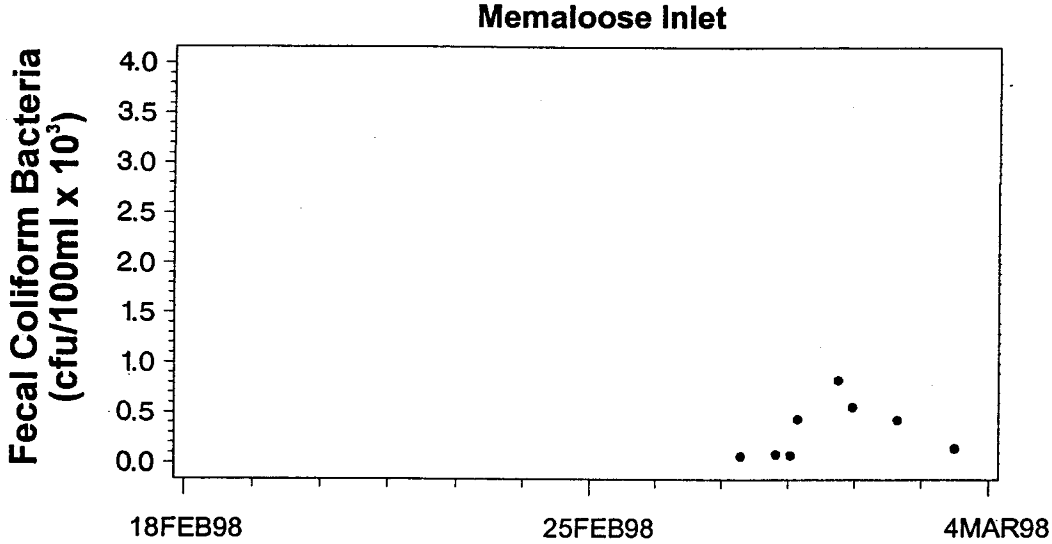


Figure 40. Concentration of fecal coliform bacteria measured at Memaloose Inlet, in the southern portion of Tillamook Bay, during the October 1997 storm. Wilson River discharge and precipitation at Tillamook are given in the lower panel for hydrologic reference.



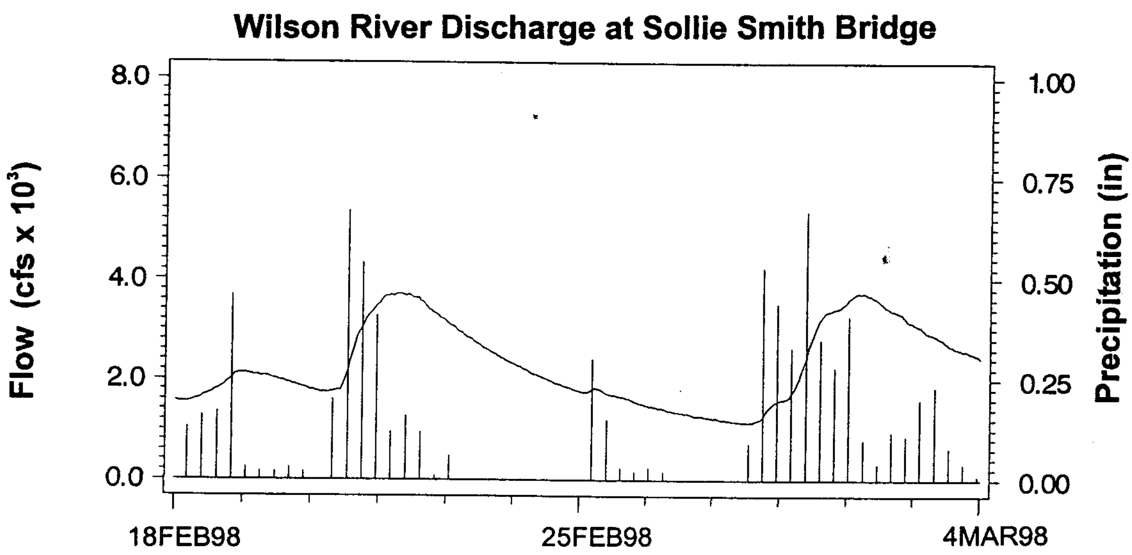


Figure 41. Concentration of fecal coliform bacteria measured at Memaloose Inlet, in the southern portion of Tillamook Bay, during the March 1998 storm. Wilson River discharge and precipitation at Tillamook are given in the lower panel for hydrologic reference.

Relationship Between FCB Loads and Land Use

Jackson and Glendening (1982) hypothesized that the primary sources of fecal coliform bacteria to the rivers may require saturated ground. Source types that fit this pattern include field application of manure, barnyards located some distance from the river, and inadequate on-site sewage disposal systems. We evaluated the relationship between the segments of the Tillamook and Trask Rivers that contributed the largest FCB loads and the land uses that were associated with the lands that drained into those river segments. The objective was to look for land use patterns associated with high FCB loading rates.

Evaluation of the spatial land use patterns within the contributing drainage areas to each of the monitoring sites revealed some interesting patterns. The percentage of each drainage area within agricultural, riparian, rural residential and urban land use categories is given in Table 9. Percentages for a few of the sites on the Tillamook River were somewhat different between storms because three new sites (TIL-AWT, TIL-TTR, and TIL-ATG) were added for the second intensively-monitored storm. The frequency of farm building clusters and rural residential building clusters within each drainage area are listed in Table 10.

During the October 1997 storm, the three sites on the Tillamook River that contributed the largest FCB loads, compared to the neighboring upstream sites were TIL-RES, TIL-WEB, and TIL-NET. These were also the three sites with the highest frequencies of rural residential building clusters (65, 70, and 27, respectively; Table 10). During this same storm, the three sites on the Trask River that contributed the largest FCB loads were sites TRA-10L, TRA-ASF, and TRA-TTR. Site TRA-10L also had the highest frequency of rural residential building clusters of the Trask River sites (55; Table 10) and is the first site downriver of the discharge point from the Port of Tillamook STP. Site TRA-ASF had only two rural residential building clusters (Table 10), but 66% of the drainage area to this site was in urban land use (Table 9, third highest of the Trask River sites). Site TRA-TTR had the second highest percentage of its contributing area in rural residential land use (14%, Table 9).

Very similar results were found for the March 1998 storm. The three largest load contributors on the Tillamook River were sites TIL-SFT, TIL-RES, and TIL-TDI (Table 7). Of these, only one (TIL-RES) was high in rural residential building clusters (65), but the other two were within the top four sites in terms of percentage of drainage subbasin in rural residential land use (4.3% and 5.0%, Table 9). On the Trask River, the March 1998 storm yielded highest loads at sites TRA-10L, TRA-5th, and TRA-TEF. These were second highest in terms of percent urban land use (TRA-5th, 88%) and the highest (TRA-10L, 55) and third highest (TRA-TEF, 26) in terms of frequency of rural residential building clusters (Table 10).

Table 9. Land use types by sample site subbasin in the Tillamook and Trask River watersheds.

Sub-basin	Area (ha)	%Agricultural	%Riparian	%Rural Residential[1]	%Urban	%Forested Upland and Other
Subbasins Sampled during the October 1997 Storm						
TIL-BTG	109	80.0	1.1	3.0	0	18.9
TIL-FRA	133	56.5	3.5	0.6	0	40.0
TIL-BEW	529	46.3	4.4	6.2	0	49.4
TIL-ATG	90	40.9	0.0	3.0	0	59.1
TIL-SFT	15	39.5	0.1	4.3	0	60.4
TIL-TDI	632	36.9	0.4	5.0	0	62.7
TIL-RM0	272	30.6	0.7	0.1	0	68.7
TIL-NET	539	28.2	1.5	4.4	0	70.2
TIL-BUR	2079	25.3	4.4	0.7	0	70.3
TIL-AWT	148	21.5	2.9	1.1	0	75.5
TIL-RES	5058	10.0	1.5	2.8	0	88.5
TIL-WEB	2366	9.6	4.0	2.1	0	86.4
TIL-YEL	1063	7.3	0.0	0.7	0	92.7
TIL-FAW	1606	3.4	0.7	2.5	0	95.8
TIL-SIM	1095	2.0	0.3	0.5	0	97.7
Subbasins Sampled during the March 1998 Storm[2]						
TIL-BTG	109	80.0	1.1	3.0	0	18.9
TIL-BUR	78	74.5	3.7	1.4	0	21.8
TIL-MIB	52	62.4	0.0	5.2	0	37.6
TIL-FRA	133	56.5	3.5	0.6	0	40.0
TIL-BEW	529	46.3	4.4	6.2	0	49.4
TIL-MID	622	45.3	10.6	1.6	0	44.1
TIL-SFT	15	39.5	0.1	4.3	0	60.4
TIL-TDI	632	36.9	0.4	5.0	0	62.7
TIL-RM0	272	30.6	0.7	0.1	0	68.7
TIL-NET	539	28.2	1.5	4.4	0	70.2
TIL-AWT	148	21.5	2.9	1.1	0	75.5
TIL-TTR	1379	13.4	1.7	0.3	0	84.9
TIL-ATG	38	10.9	0.0	0.0	0	89.1
TIL-RES	5058	10.0	1.5	2.8	0	88.5
TIL-WEB	2366	9.6	4.0	2.1	0	86.4
TIL-YEL	1063	7.3	0.0	0.7	0	92.7
TIL-FAW	1606	3.4	0.7	2.5	0	95.8
TIL-SIM	1095	2.0	0.3	0.5	0	97.7

Table 9. Continued

Sub-basin	Area (ha)	%Agricultural	%Riparian	%Rural Residential[1]	%Urban	%Forested Upland and Other
Subbasins Sampled in the Trask River during Both Storms[2]						
TRA-ATR	64	93.7	1.4	7.0	0.0	5.0
TRA-DST	4	89.6	0.0	0.0	10.7	10.4
TRA-RM0	95	87.3	1.2	0.4	0.0	11.5
TRA-TTR	11	86.9	0.0	14.3	8.0	13.1
TRA-TEF	953	84.9	4.0	5.8	13.9	11.0
TRA-BTR	10	84.6	0.0	32.8	0.0	15.4
HOQ-CON	1160	83.8	4.5	3.6	13.8	11.6
TRA-BPS	19	80.8	2.8	4.8	0.0	16.5
TRA-HOQ	13	67.1	0.0	0.0	2.6	32.9
TRA-10L	1895	48.8	2.4	10.9	0.0	48.8
TRA-CHA	865	44.1	7.3	10.7	0.0	48.6
TRA-ASF	105	30.3	1.1	1.6	65.7	68.6
TRA-HOB	124	4.5	0.0	0.0	96.5	95.5
TRA-5TH	21	2.7	9.0	0.0	87.7	88.3
TRA-LOR	39673	0.1	0.0	0.1	0.0	99.9

[1] Some areas were classified as both rural residential and as agricultural.
[2] Three additional sites were added in the Tillamook watershed for the March 1998 storm that were not sampled during the October 1997 storm.

These findings were unexpected and are very important. They provide very strong, albeit circumstantial, evidence that the largest FCB loads within these two watersheds may in fact be provided by human activities other than dairy farming. Urban areas appear to be significant contributors, as do rural residential areas. The latter, however, may also contain intensive dairy farming activities in some cases.

Sites on the Tillamook River that were important FCB load contributors, when expressed as per unit area or per length of river were for the October 1997 storm:

TIL-NET
TIL-FRA
TIL-BTG
TIL-WEB
TIL-AWT, and
TIL-RES

Two were high in agricultural land use (TIL-BTG, and TIL-FRA); one was high in percent rural residential land use (TIL-NET); and three were high in frequency of rural residential building clusters TIL-WEB, TIL-RES, TIL-NET (These were actually the three highest sites in terms of rural residential building clusters) (Table 10).

Table 10. Number of farm and rural residential building clusters within each of the sample site drainage areas included in the October 1997 and March 1998 intensively-sampled storms.

Farm Building Clusters						Rural Residential Building Clusters					
Tillamook 97 Storm		Tillamook 98 Storm[1]		Trask Storms		Tillamook 97 Storm		Tillamook 98 Storm		Trask Storms	
Site	#Centroids	Site	#Centroids	Site	#Centroids	Site	#Centroids	Site	#Centroids	Site	#Centroids
TIL-BUR	17	TIL-MID	10	TRA-TEF	16	TIL-WEB	70	TIL-WEB	70	TRA-10L	55
TIL-NET	8	TIL-NET	8	TRA-10L	15	TIL-RES	65	TIL-RES	65	TRA-LOR	27
TIL-RES	7	TIL-RES	7	HOQ-CON	12	TIL-NET	27	TIL-NET	27	TRA-TEF	26
TIL-TDI	6	TIL-TDI	6	TRA-CHA	10	TIL-BUR	23	TIL-BEW	22	TRA-CHA	25
TIL-WEB	6	TIL-WEB	6	TRA-ATR	6	TIL-BEW	22	TIL-FAW	16	HOQ-CON	21
TIL-RM0	3	TIL-TTR	6	TRA-RM0	5	TIL-FAW	16	TIL-TDI	11	TRA-BTR	6
TIL-YEL	2	TIL-RM0	3	TRA-LOR	4	TIL-TDI	11	TIL-SIM	10	TRA-BPS	5
TIL-BEW	2	TIL-YEL	2	TRA-HOB	3	TIL-SIM	10	TIL-TTR	10	TRA-ATR	4
TIL-BTG	2	TIL-BEW	2	TRA-ASF	2	TIL-BTG	10	TIL-BTG	10	TRA-RM0	2
TIL-SIM	1	TIL-BTG	2	TRA-HOQ	1	TIL-YEL	7	TIL-MID	9	TRA-TTR	2
TIL-FAW	1	TIL-SIM	1	TRA-DST	0	TIL-SFT	4	TIL-YEL	7	TRA-ASF	2
TIL-FRA	1	TIL-FAW	1	TRA-5TH	0	TIL-AWT	2	TIL-BUR	7	TRA-DST	0
TIL-ATG	0	TIL-FRA	1	TRA-BPS	0	TIL-RM0	2	TIL-SFT	4	TRA-5TH	0
TIL-AWT	0	TIL-BUR	1	TRA-BTR	0	TIL-FRA	1	TIL-AWT	2	TRA-HOQ	0
TIL-SFT	0	TIL-ATG	0	TRA-TTR	0	TIL-ATG	0	TIL-RM0	2	TRA-HOB	0
		TIL-AWT	0					TIL-FRA	1		
		TIL-SFT	0					TIL-MIB	0		
		TIL-MIB	0					TIL-ATG	0		

[1] Three additional sites were added in the Tillamook watershed for the March 1998 storm that were not included in the October 1997 storm sampling.

Many of these same sites had the largest FCB loads per unit area or per length of river during the March 1998 storm. A couple of additional sites also emerged as important during the March intensive storm:

TIL-SFT
TIL-MID
TIL-TDI
TIL-BUR, and
TIL-ATG

Site TIL-SFT was unusual in that it so clearly dominated the FCB loading per unit area and per river length during this storm. It was relatively high in percent agricultural land use (40%). In fact, four of these five sites were high in percent agricultural land use (37% to 75%, Table 9).

On the Trask River, the sites that contributed the largest FCB loads per unit area and per river length were during the October 1997 storm:

TRA-5th
TRA-TEF
TRA-HOQ
TRA-ASF
TRA-BPS
TRA-HOB, and
TRA-ATR

Four of these sites (TRA-HOB, TRA-5th, TRA-ASF, and TRA-TEF) were the four highest in the watershed in terms of percent urban land use. Three of the other four had percent agricultural land use greater than 67% (Table 9). During the March 1998 storm, the same Trask River sites were highest in FCB load per unit area and per river length as was found during the October storm.

These same land use analyses were repeated for a set of drainage areas (subbasins) defined in a different way. For this second set of land use analyses, the drainage areas contributing to each sampling site were restricted to those within 100m on either side of waterways (river, tributary streams and/or drainage ditches). These buffer zones are shown in Figures 42 and 43 for the Tillamook and Trask Rivers, respectively. The percentages of the area within the various land use types that occurred in the buffered streamside portion of the sample site drainage area subbasins are listed in Table 11. The numbers of farm building and rural residential building clusters within each of the buffered subbasins are listed in Table 12

On the Tillamook River, during the October storm, the three highest load-contributing sites (RES, WEB, and NET) were also the three highest sites in number of rural residential building clusters within the buffered streamside areas (Table 12). Four of the top five load-contributing sites were also four of the top five sites in number of farm building clusters within the streamside buffer zones (NET, WEB, RES, TDI). During the March storm, only the RES site was high in both FCB loads (Table 7) and number of rural residential building clusters (Table 12). Half of the top six load-

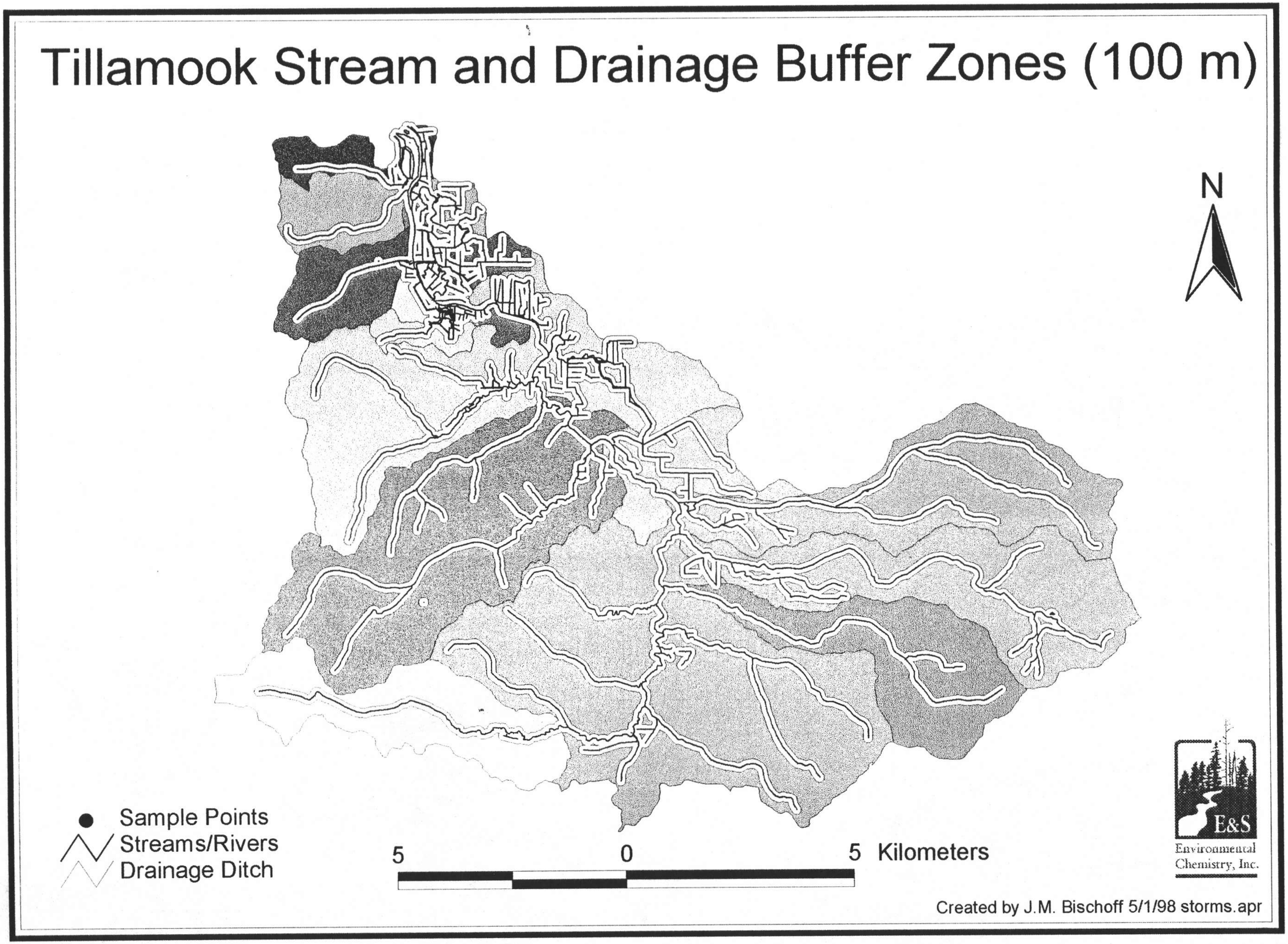


Figure 42. Buffer zones delineated on the basis of distance from waterways (100m on each side of river, tributary streams, drainage ditches) in the Tillamook River watershed.

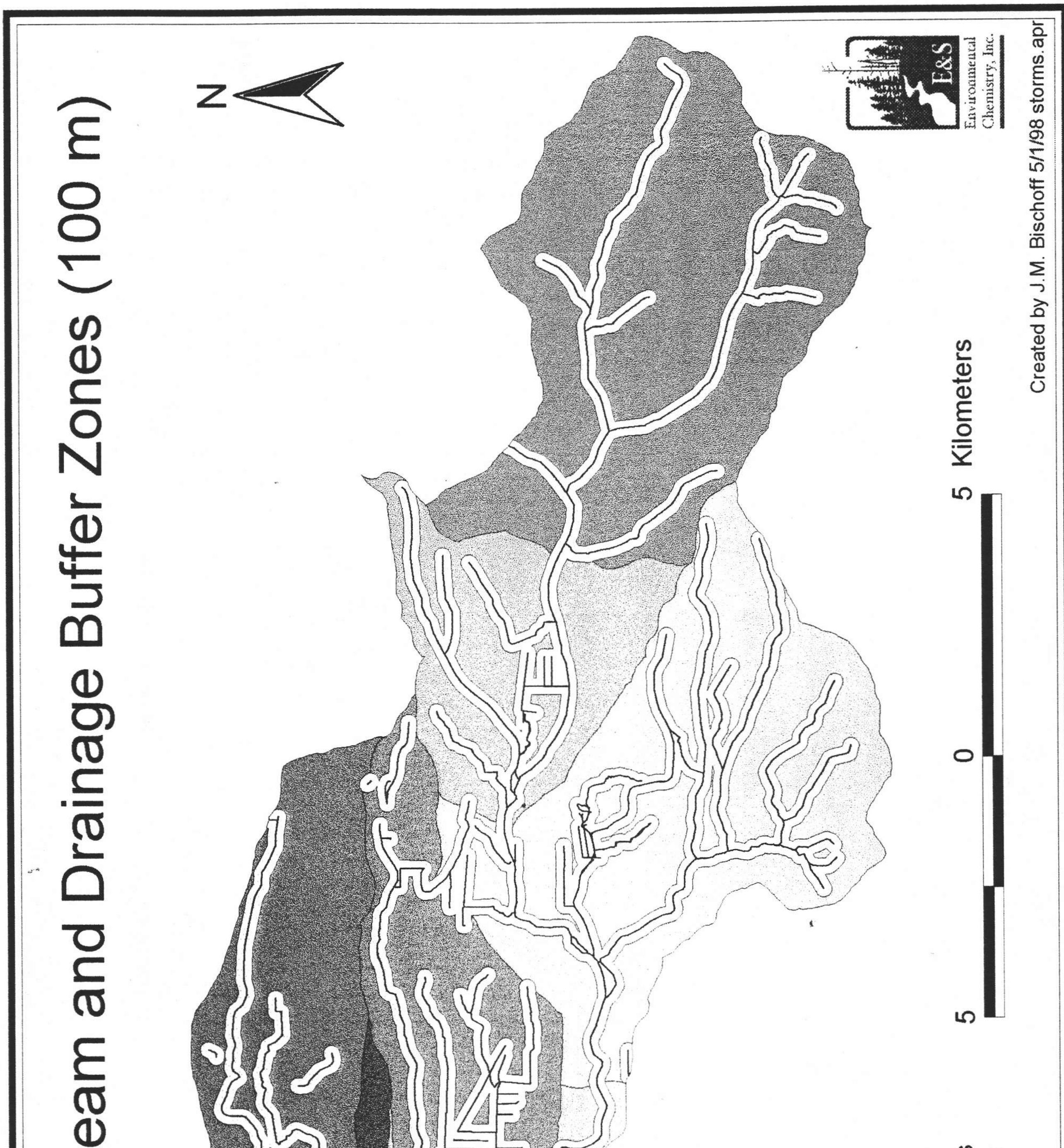


Figure 43. Buffer zones delineated on the basis of distance from waterways (100m on each side of river, tributary streams, drainage ditches) in the Trask River watershed.

Table 11. Land use types by sample site subbasin within a 100 m buffer zone on either side of the river plus all tributary streams and drainage ditches.

Sub-basin	Area (ha)	%Agricultural	%Riparian	%Rural Residential	%Urban	%Forested Upland and Other
Subbasins Sampled during the October 1997 Storm						
TIL-BTG	63	84.4	1.9	1.8	0.0	13.7
TIL-TDI	229	81.6	1.1	1.4	0.0	17.3
TIL-FRA	93	79.9	5.1	0.9	0.0	15.0
TIL-ATG	47	67.8	0.0	0.0	0.0	32.2
TIL-BEW	197	65.6	8.6	9.7	0.0	25.8
TIL-NET	202	60.0	3.4	7.5	0.0	36.6
TIL-SFT	10	55.2	0.1	1.1	0.0	44.7
TIL-RM0	137	55.0	1.3	0.1	0.0	43.7
TIL-BUR	573	53.7	13.0	0.9	0.0	33.3
TIL-AWT	69	46.1	6.3	2.3	0.0	47.5
TIL-YEL	155	33.2	0.0	0.8	0.0	66.8
TIL-RES	1192	23.1	4.4	4.6	0.0	72.5
TIL-WEB	531	21.5	15.7	4.4	0.0	62.7
TIL-FAW	409	9.8	2.5	4.9	0.0	87.7
TIL-SIM	199	5.0	1.7	2.8	0.0	93.3
Subbasins Sampled during the March 1998 Storm						
TIL-BTG	63	84.4	1.9	1.8	0.0	13.7
TIL-MIB	33	83.7	0.0	0.0	0.0	16.3
TIL-BUR	36	82.5	7.7	0.6	0.0	9.8
TIL-TDI	229	81.6	1.1	1.4	0.0	17.3
TIL-FRA	93	79.9	5.1	0.9	0.0	15.0
TIL-BEW	197	65.6	8.6	9.7	0.0	25.8
TIL-MID	230	63.0	23.6	1.0	0.0	13.5
TIL-NET	202	60.0	3.4	7.5	0.0	36.6
TIL-SFT	10	55.2	0.1	1.1	0.0	44.7
TIL-RM0	137	55.0	1.3	0.1	0.0	43.7
TIL-AWT	69	46.1	6.3	2.3	0.0	47.5
TIL-TTR	308	43.4	5.7	0.8	0.0	50.8
TIL-YEL	155	33.2	0.0	0.8	0.0	66.8
TIL-ATG	14	29.7	0.0	0.0	0.0	70.3
TIL-RES	1192	23.1	4.4	4.6	0.0	72.5
TIL-WEB	531	21.5	15.7	4.4	0.0	62.7
TIL-FAW	409	9.8	2.5	4.9	0.0	87.7
TIL-SIM	199	5.0	1.7	2.8	0.0	93.3

Table 11. Continued

Sub-basin	Area (ha)	%Agricultural	%Riparian	%Rural Residential[1]	%Urban	%Forested Upland and Other
Subbasins Sampled in the Trask River during Both Storms						
TRA-RM0	92	86.9	1.2	0.0	0.4	11.9
TRA-TEF	404	84.2	6.6	12.4	4.8	9.1
TRA-DST	3	84.1	0.0	16.4	0.0	15.9
TRA-ATR	23	82.5	3.8	0.0	7.2	13.8
TRA-BTR	8	81.2	0.0	0.0	26.1	18.8
TRA-TTR	7	77.4	0.0	14.0	4.4	22.6
TRA-BPS	16	77.2	3.3	0.0	5.7	19.5
HOQ-CON	385	76.7	9.0	10.4	0.7	14.3
TRA-HOQ	13	67.2	0.0	2.6	0.0	32.8
TRA-10L	678	51.6	5.4	0.0	13.3	43.0
TRA-ASF	20	49.2	5.0	30.2	1.9	45.8
TRA-CHA	292	47.0	10.5	0.0	4.8	42.5
TRA-HOB	5	38.7	0.0	41.1	0.0	61.3
TRA-5TH	9	6.3	14.3	71.9	0.0	79.4
TRA-LOR	5740	0.2	0.1	0.0	0.3	99.7

[1] Some areas were classified as both rural residential and as agricultural.

contributing sites (TDI, FRA, BTG) were also high (>80%) in percent of buffer zone in agricultural use (Table 11).

On the Trask River, during the October storm, the six highest load contributing sites (Table 6) included four of the six buffered drainage areas having highest percentage of rural residential lands plus the site having the second highest percentage of urban land. During the March 1998 storm, the six highest FCB load contributing sites included the three sites having the highest percentage of their buffered drainage area in rural residential land use plus three of the five sites having the highest percentage of their buffered drainage area in urban land use (Table 11). Also, two of the top three load-contributing sites contained two of the three highest numbers of rural residential building clusters (Table 12). Two sites (10L and TEF) contained large numbers of both farm building clusters and rural residential building clusters.

The results of our analyses suggest that the largest FCB loads were contributed by urban and rural residential land use activities especially during the fall storm, when loads were very high. These high loads were particularly evident in the lower reaches of the Trask River. The high load contribution from the lower sections of the Trask River can easily be seen by comparing results obtained at the primary Trask River site (Tillamook Toll Rd.) with results obtained at the 5th St. dock during the two storms that were sampled at both sites. Although these two sites are only 0.9 mi.

Table 12. Farm buildings and rural residental centroids occuring within 100 meter buffer of streams and drainage ditches.

Farm Building Clusters						Rural Residential Building Clusters					
Tillamook 97 Storm		Tillamook 98 Storm[1]		Trask Storms		Tillamook 97 Storm		Tillamook 98 Storm		Trask Storms	
Site	#Centroids	Site	#Centroids	Site	#Centroids	Site	#Centroids	Site	#Centroids	Site	#Centroids
TIL-BUR	11	TIL-MID	9	TRA-TEF	16	TIL-WEB	39	TIL-WEB	39	TRA-10L	38
TIL-NET	7	TIL-NET	7	TRA-10L	15	TIL-RES	33	TIL-RES	33	TRA-LOR	22
TIL-WEB	5	TIL-WEB	5	HOQ-CON	5	TIL-NET	21	TIL-NET	21	TRA-TEF	16
TIL-TDI	2	TIL-TDI	2	TRA-RM0	4	TIL-BEW	18	TIL-BEW	18	TRA-CHA	6
TIL-RES	2	TIL-TTR	2	TRA-CHA	4	TIL-FAW	13	TIL-FAW	13	TRA-BPS	5
TIL-YEL	2	TIL-RES	2	TRA-ATR	4	TIL-BUR	10	TIL-SIM	10	TRA-BTR	5
TIL-RM0	1	TIL-YEL	2	TRA-HOQ	1	TIL-SIM	10	TIL-MID	7	TRA-ATR	3
TIL-FRA	1	TIL-RM0	1	TRA-HOB	1	TIL-BTG	6	TIL-BTG	6	HOQ-CON	2
TIL-BEW	1	TIL-FRA	1	TRA-LOR	1	TIL-TDI	3	TIL-TTR	4	TRA-RM0	2
TIL-FAW	1	TIL-BEW	1	TRA-DST	0	TIL-SFT	2	TIL-TDI	3	TRA-ASF	1
TIL-SIM	1	TIL-FAW	1	TRA-5TH	0	TIL-AWT	2	TIL-SFT	2	TRA-TTR	1
TIL-ATG	0	TIL-SIM	1	TRA-BPS	0	TIL-RM0	1	TIL-AWT	2	TRA-DST	0
TIL-AWT	0	TIL-ATG	0	TRA-BTR	0	TIL-FRA	1	TIL-RM0	1	TRA-5TH	0
TIL-SFT	0	TIL-AWT	0	TRA-TTR	0	TIL-YEL	1	TIL-FRA	1	TRA-HOQ	0
TIL-BTG	0	TIL-SFT	0	TRA-ASF	0	TIL-ATG	0	TIL-BUR	1	TRA-HOB	0
		TIL-MIB	0					TIL-YEL	1		
		TIL-BUR	0					TIL-MIB	0		
		TIL-BTG	0					TIL-ATG	0		

[1] Three additional sites were added in the Tillamook watershed for the March 1998 storm that were not included in the October 1997 storm sampling.

Table 13. Comparison of results obtained for fecal coliform bacteria concentrations and loads between the primary site on the Trask River (Tillamook Toll Rd. Bridge, TTR) and the 5th St. dock, which is 0.9 miles downriver from TTR, during the two intensively-sampled storms.

Site Comparison for 5th Street Dock and TTR									
Storm	Dates	Peak River Discharge (cfs x 10^3)		Peak FCB (cfu/100 ml)		Water Volume (m^3 x 10^6)		Total FCB Load (cfu x 10^{12})	
		5th	TTR	5th	TTR	5th	TTR	5th	TTR
4	9/30/97 - 10/8/97	5.9	5.8	2300	2800	37.9	37.2	330	225
6	2/27/98 - 03/8/98	3.3	3.3	880	440	50.4	49.6	190	34

apart, the peak FCB loads achieved and the cumulative storm loads were quite different between the sites (Table 13). For example, the total storm FCB load at the downriver site (5th St. dock) was almost 50% higher during the October storm and over 400% higher during the March storm as compared with the upriver site. Relatively large loads were also associated with high percentage of drainage contributing area in agricultual land use, especially when load estimates were expressed on a per unit area or per river length basis and when land use was evaluated within streamside buffer zones. Agricultural contributions appeared to be proportionately higher during the March storm than during the October storm.

Earlier research by Jackson and Glendening (1982) also concluded that most of the fecal contamination in the Tillamook River subbasin occurred below the forest/agriculture boundary in the area that contains homes and dairy farms. They were unable to make definitive statements regarding the extent of the contribution that might have been coming from homes having inadequate on-site subsurface sewage disposal systems. However, based on a comparative analysis of the Munson Creek and Bewley Creek subbasins, Jackson and Glendening (1982) hypothesized that the most likely source was farms with barnyards near the creeks. The results of our analyses do not dispute Jackson and Glendening's hypothesis that dairy farms and associated barnyards are important sources of FCB contamination of drainage waters in the Tillamook River watershed. However, the results of our analyses suggest that FCB sources associated with human activities other than dairy farming (e.g., urban land use in the Trask River watershed and rural residential dwellings in both the Tillamook and Trask River watersheds) are likely more important FCB sources.

CONCLUSIONS

A number of conclusions can be drawn from the storm sampling that was conducted in the rivers of the Tillamook Bay watershed. Key conclusions include the following:

- The largest loads of FCB to Tillamook Bay are contributed by the Trask River, followed by the Wilson and then the Tillamook River. FCB loads in the Miami and Kilchis Rivers are lower than the other three rivers by about an order of magnitude.

- The largest loads of nitrogen to Tillamook Bay are contributed by the Trask River, followed by the Wilson River.

- The largest loads of TSS and TP (which are likely both primarily from erosional materials) are contributed by the Wilson River, followed by the Trask River.

- FCB loads in a given river differed markedly from storm to storm, with highest loads (by a substantial margin) contributed by the early fall storm.

- The highest concentrations of FCB were generally achieved well before the time of peak river discharge, and generally occurred during the period of most intensive rainfall.

- The largest FCB storm loads were reached in the mid-section of the Tillamook River and in the lower sections of both the Tillamook and Trask Rivers. However, FCB contributions were substantial throughout both watersheds.

- The land areas that contributed the largest FCB loads to the Trask River were those containing urban land use. Other land uses associated with areas that contributed large FCB loads were rural residential and agricultural land use. The land uses that contributed the largest FCB loads to the Tillamook River (whose watershed does not include urban land use) were rural residential and agricultural land uses.

These results suggest that the largest contributions of FCB to the Tillamook and Trask Rivers, at least during the two storms that were intensively monitored, occurred in associated with human habitation, especially the urban areas of the Trask River watershed and the rural residential areas of the Tillamook River watershed. Agricultural land use was also an important FCB contributor in the Tillamook River watershed. Highest loads were generally found in the lower sections of the rivers, which are heavily ditched and where human activity is concentrated, soils are poorly drained, and runoff potential is high.

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