MONITORING STUDIES

Approach

The water quality in tributaries to Tillamook Bay currently exceeds water quality standards for fecal coliform bacteria (or alternate parameter, *E. coli*) and temperature. Fecal coliform inputs into the bay have forced periodic closures of the oyster shellfish industry. In addition, impaired water quality may be contributing to reduced salmonid populations in the bay and its tributaries through reduction in the quality of the habitat. Because of these concerns, the Tillamook Bay National Estuary Project (TBNEP) and Tillamook County Performance Partnership (TCPP) have been implementing a long-term water quality monitoring program for the tributary rivers. A primary objective of the monitoring program is to characterize water quality in the lower portions of selected tributaries to Tillamook Bay in order to allow for analysis of long-term trends in general water quality and short-term variations in parameters with significance to regulatory issues.

The Tillamook River consistently has the highest FCB concentrations. TSS concentrations are highest in the Trask and Wilson Rivers, corresponding to the rivers with the largest watersheds and highest flows. Conversely, TSS concentrations tend to be lowest in the Tillamook River, which has the smallest watershed area and lowest flows of the five rivers. Inorganic nitrogen concentrations are similar among sites and low relative to values observed in other parts of Oregon (e.g., Wentz et al. 1998). Total phosphorus concentrations are highest in the Wilson and Trask Rivers, although not particularly high relative to other sites in western Oregon (Wentz et al. 1998). However, during storm events they are frequently higher than the 0.1 mg/L maximum value recommended by U.S. EPA (1986) as a goal for prevention of nuisance plant growth in streams.

Fecal coliform bacteria (FCB) contamination of surface waters occurs downstream of the forest/agriculture interface. Both agricultural and human sources contribute to the observed high bacterial concentrations. From 1996 to 1998, the TBNEP sponsored scoping studies to provide the critical information needed to design a more rigorous water quality monitoring program. Based on the results of those studies, and on monitoring efforts conducted by E&S Environmental Chemistry, Inc. (E&S), Oregon Department of Environmental Quality (ODEQ), Oregon Department of Agriculture (ODA), and the Tillamook County Creamery Association (TCCA), the TCPP is implementing a long-term monitoring strategy in the watershed. The monitoring program focuses on storm sampling for FCB and TSS, weekly sampling for *E. coli*, bimonthly sampling for nutrients, and continuous monitoring for temperature (Sullivan and Eilers 1999).

From November 1996 to March 1998, E&S Environmental Chemistry, Inc., under contract to TBNEP, conducted a water quality characterization and monitoring effort throughout the basin. It included regular monitoring for FCB, TSS, nutrients, and temperature in each of the five rivers that flow into Tillamook Bay. In addition, intensive storm sampling (especially for bacteria) was conducted during six rainstorm events.

There are a variety of possible monitoring objectives, and these can relate to trend detection for a host of potentially important water quality parameters. Based on available data for the five rivers in the watershed, the primary candidate variables for continued monitoring were identified by Sullivan and Eilers (1999) as:

- FCB (or alternative *E. coli*)-currently often in excess of water quality standards in the rivers and the bay.

- temperature - in excess of water quality standards in at least some sections of the lower rivers.

- total suspended solids - associated with degradation of salmonid spawning habitat and possible excessive sedimentation of the lower rivers and the bay.

- nutrients - although currently not excessively high, can have serious ecological consequences if concentrations increase in the future.

Based on available data and the perceived importance of salmonid fisheries, shellfish resources, and sedimentation issues in the watershed, Sullivan and Eilers (1999) constructed a list of potential monitoring objectives. With some modification, these objectives have been incorporated into the on-going monitoring effort (Table 1).

E&S has continued the monitoring of FCB, TSS, and nutrients in some of the rivers in the Tillamook Bay watershed. In addition, ODEQ has continued the temperature monitoring and the TCPP has continued *E. coli* monitoring. These monitoring efforts are intended to answer the kinds of questions outlined in Table 2.

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

TIL-BUR - Tillamook River at Burton Bridge

Table 1. Proposed monitoring objectives for the Tillamook Bay watershed. (Modified from Sullivan and Eilers 1999.)

Bacteria

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

To quantify changes in the percentage of storms which are accompanied by FCB concentrations during part or all of the storm >200 cfu/100 ml in the Tillamook, Trask, and Wilson Rivers.

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

To quantify the frequency of exceedences of *E. coli* water quality criteria throughout the Basin.

Nutrients

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

Total Suspended Solids

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

Temperature

To determine the daily maximum temperatures throughout the lower reaches of the rivers during summer months.

To quantify changes in the number of days per year that daily maximum temperatures in the rivers exceed water quality criteria.

To determine the spatial extent of water temperature exceedences during summer months in the rivers.

TRA-TTR - Trask River at Tillamook Toll Road. This was initially the primary Trask River site. The primary site was changed in 1998 to the 5th St. dock, however, when bridge construction work closed the bridge for an extended period.

TRA-5th - Trask River at 5th St. dock

WIL-SSB - Wilson River at Sollie Smith Bridge

KIL-ALD - Kilchis River at Alderbrook Bridge

Table 2. Recommended monitoring questions
Is the concentration (flow-weighted average concentration and peak concentration) of FCB in the lower reaches of the Tillamook, Trask, and Wilson Rivers increasing or decreasing (and by how much) during typical storm events during the fall, winter, and spring seasons over time scales of years to decades?
Are the storm loads of FCB increasing or decreasing (and by how much) during typical seasonal storm events in the Tillamook, Trask and Wilson Rivers over time scales of years to decades?
Are the concentrations of *E. coli* in the lower reaches of the Tillamook, Trask, and Wilson Rivers, and the frequencies of water quality criteria exceedence, increasing or decreasing (and by how much) over time scales of years to decades?
Is the total nutrient loading (N, P) to Tillamook Bay from the Trask and Wilson Rivers increasing or decreasing (and by how much) over time scales of years to decades?
Is the total suspended solids loading to Tillamook Bay from the Trask, Wilson, and Kilchis Rivers increasing or decreasing (and by how much) over time scales of years to decades?
What is the frequency and duration of temperature excursions above threshold values (expressed as daily maxima) in the lower reaches of the rivers and what is the spatial extent of such excursions?
Are there trends (increasing or decreasing) in the frequency, duration or extent of temperature excursions above threshold values in the downriver sections of the rivers over time scales of years to decades?

Sampling site locations are shown in Figure 1, along with the location of sites that were monitored less frequently during the initial characterization efforts.

Storms are selected for monitoring of FCB and TSS by the expected duration and intensity of rainfall subsequent to a variety of antecedent moisture conditions. The storms are selected in an effort to represent storms of different intensity and differing hydrological response.

Bacteria

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

Within each season and combination of seasons, storms will be classified into a matrix to reflect hydrological conditions. It is planned that, at a later date, data will be analyzed for trends in FCB fluxes associated with specific storm types. Flow-weighted concentrations and storm loads will be compared from year to year by evaluating results obtained for each storm type for which a sufficient number of storms are successfully monitored (? 10). We anticipate that a minimum of eight to ten years of monitoring data will be required for trends analysis.

Cell types are currently planned to be:

Rainfall Intensity
  = high (> .15 in/hr during ? 8 hrs during the course of a storm)
  = low (> .15 in/hr during < 8 hrs during the course of a storm)

Total Storm Size
  = large (total precipitation > 4 in)
  = moderate (total precipitation 2-4 in)
  = small (< 2 in)

Length of Precipitation-Free Period (< 1 in precipitation) Prior to Storm
  = long (> 1 week)
  = short (< 1 week)

These criteria will be further evaluated after additional data are collected and data analyses conducted.

E. coli concentrations are monitored approximately weekly at 7 to 10 sites on four of the rivers (all except Wilson) by the TCPP. Wilson River *E. coli* monitoring is conducted by the TCCA. Geometric mean concentrations, based on the sampling reporting day plus the four previous samples, are tabulated. Results are compared with the water quality standard (126 cfu/100 ml).

Restoration and other BMP-related activities will be underway during the coming years throughout the Tillamook Basin, in conjunction with a variety of other programs and research or restoration efforts. It is recommended that FCB concentrations and loads should be measured above and below these sites, using a storm-based approach as outlined for the primary monitoring sites. Such monitoring will provide critical information regarding BMP effectiveness, and is on-going within the Beaver Creek project discussed below.

Suspended Solids

TSS is measured at the primary downstream sites on the Wilson, Trask, and Kilchis Rivers during each of approximately four to six storm events per year, with an effort to sample high-flow storm events when possible. During each storm, typically six to eight samples (plus QA samples) are collected and analyzed for TSS at each site. Data are analyzed to estimate the flow-weighted average storm concentration and total TSS storm load per river, using observed discharge and measured TSS concentration. In addition, an effort is underway to quantify the relationship between measured TSS and river discharge.

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

Nutrients

Water samples are collected bi-monthly at the primary downstream sites on the Wilson and Trask Rivers and analyzed for the following nutrients: NO_3^-, NH_4^+, TKN, and TP. Data will be analyzed at a later date to test for trends in nutrient concentrations over time in these two rivers.

There is a need to continue monitoring for N and P in the watershed because of the importance of eutrophication as a potential threat to any estuary, including Tillamook Bay. In addition, analyses conducted for the Wilson and Miami Rivers within the context of recent watershed assessments by E&S for the TCPP show historical trends of increasing NO_3^- concentrations in both of these rivers. However, the immediate risk of nutrient-caused degradation of the ecological integrity of the rivers and the estuary appears less than the risk of degradation caused by other issues, such as bacteria, sediment and temperature. We therefore recommend continued monitoring of nitrogen and phosphorous, but at a lower level of intensity compared with the other parameters.

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

Temperature

Temperature data are collected hourly, using continuous temperature monitors that are installed in the spring and removed in the fall each year by TCPP staff. Data are then transmitted to ODEQ. Temperature monitoring is conducted at 11 sites in the Tillamook Basin, including a downstream site on each of the five rivers.

Results

Bacteria

Results of FCB monitoring to date at the primary (downstream) sampling point on each river are shown in Figure 2. Flow-weighted average FCB concentrations are shown in Figure 3, stratified by storm size and length of the period preceding the storm during which substantial precipitation did not occur. Previous research has shown that these two variables, total storm size and length of dry period preceding the storm, are important determinants of storm FCB load.

Fecal coliform bacteria concentrations were variable from river to river, ranging from 0 to about 4,000 cfu/100 ml at the downriver primary sites (Figure 2). The range for the secondary sites representing the forest/agriculture interfaces, sampled by Sullivan et al. (1998a), was much narrower, from 0 to 500 cfu/100 ml.

Seasonal differences in FCB concentrations were observed at all of the rivers included in the monitoring effort. The highest bacterial concentrations were often observed during storm events in early autumn or otherwise preceded by relatively dry weather conditions. Many samples were measured during early autumn storms in excess of 500 cfu/100 ml. Concentrations reaching several thousand cfu/100 ml were not unusual. High bacterial concentrations (>500 cfu/100 ml) also were recorded at other times of the year in the Tillamook, Trask, and Wilson Rivers.

Flow-weighted storm average FCB concentrations show considerable variability throughout the period of record (Figure 3), as do estimated storm loads of FCB (data not shown).

Stratifying storm data by storm size and antecedent hydrology (as relected by length of antecedent period during which 1 inch of precipitation was recorded at Tillamook) removed some of the variability, although early fall storms have the potential to contribute especially high bacterial concentrations and loads. Additional analyses are on-going to determine an appropriate method of stratifying storm bacteria data prior to conducting trends analyses. This will allow year-to-year comparison among storms that are more similar hydrologically.

E. coli monitoring results are shown in Figure 4 for sites on the lower mainstem of the four rivers monitored by the TCPP. The geometric mean *E. coli* concentrations in the Tillamook river were virtually always above the water quality standard of 126 cfu/100 ml, and exceeded 1500 cfu/100 ml throughout the summer of 2000 (Figure 4). Many Tillamook River sample concentrations were measured in excess of 3,000 cfu/100 ml. Analyses are on-going to determine the major sources of *E. coli* to the Tillamook River.

Occasional water quality criterion violations were also noted in the Miami, Trask, and Kilchis Rivers. However, of those, only the Miami River mainstem showed any geometric mean concentrations above 300 cfu/100 ml.

Total Suspended Solids

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

Suspended sediment fluxes are highly episodic in nature. It is therefore necessary to obtain measurements during the times of largest flux (i.e., large storm events).

Highest TSS concentrations and loads are found in the Wilson and Trask, and to a lesser extent, the Kilchis Rivers (Figure 5). Monitoring for TSS is currently only conducted in these three rivers, and only at the primary (downriver) monitoring site on each. This will measure changes over time in the cumulative flux of TSS from both the forested and at the least a large portion of the agricultural lands in each of these watersheds.

TSS values up to, or exceeding, 300 mg/L were encountered during high-flow periods in all three of the monitored rivers (Figure 5). TSS generally increased dramatically with discharge during storm events.

Nutrients

Total inorganic nitrogen concentrations (TIN; NO_3-N + NH_4-N) are generally in the range of 0.4 to 1 mg/L in the rivers (Figure 6). Concentrations of TIN are reduced during summer and higher during winter. This is likely due to greater biological demand for N in the aquatic and terrestrial systems during summer months. Available monitoring data for the Wilson River show a generally increasing trend in NO_3^- concentration since the 1960s (Figure 7). Similar results were found for the Miami river. The cause of this apparent trend is not known, but may be related to continued development of alder stands in the riparian zones of these rivers subsequent to timber harvesting and fires. Nitrogen-fixing bacteria are found in association with alder roots, and can cause elevated streamwater NO_3^- concentrations.

Total phosphorus (TP) concentrations in the rivers are typically less than about 0.1 mg/L, except during storms when the concentrations sometimes exceed 0.5 mg/L (Figure 8). The rivers with largest watersheds (Trask and Wilson), during periods of the highest flows, tend to have the highest TP concentrations and the river with the lowest flows and smallest watershed (Tillamook) has the lowest TP concentrations during high-flow periods.

Temperature

Continuous temperature monitoring of the rivers has been conducted by ODEQ at 11 sites throughout the Tillamook Basin, including at least one site on each river. Results during the 2000 summer season for the Tillamook River at Bewley Creek, Kilchis River at Curl Road, South Fork Wilson River and North Fork and South Fork of the Trask River are shown in Figure 9. Data have been statistically processed to yield the 7-day average of the daily maximum temperature (commonly called the 7-day statistic). These 7-day statistics are used to determine if the stream temperatures violate state water quality standards. Temperatures at all of the sites consistently exceeded the spawning standard (12.8°C), beginning in mid June to early July and extending to about early October.

The statewide criterion for aquatic health (17.8°C) was exceeded for about 4 to 6 weeks in the Kilchis, North Fork Trask, and Tillamook Rivers, but not in the South Fork Wilson or South

Fork Trask Rivers (Figure 9). Daily maximum temperatures in the Trask, Tillamook, and Kilchis Rivers reached in excess of 21.1°C during mid-summer. Five sites showed temperature in excess of 17.8°C for 20 or more days during the summer of 2000: Trask River (2 sites), Wilson River, Kilchis River, and Tillamook River (1 site each).

ODEQ plans to continue summer temperature monitoring of these sites. Trends analysis will require many years of monitoring data. It will be important to continue to monitor temperature to more precisely quantify the frequency, duration, and extent of temperature excursions above threshold values in each of the rivers and to document any improvements that result from riparian restoration efforts in the watershed.

Summary

On-going routine monitoring of water quality by E&S, TCPP, and ODEQ in the rivers that flow into Tillamook Bay is summarized in Table 3. Routine monitoring continues for FCB, *E. coli*, TSS, nutrients and temperature. Two to three rivers have been selected for monitoring of each parameter except *E. coli* and temperature, which are monitored in all five rivers. Monitoring for FCB and TSS continues to be storm-based (four to eight storms per year), for nutrients is bimonthly, for *E. coli* is weekly, and for temperature is continuous. This monitoring strategy will allow the TCPP to answer all of the key monitoring questions posed in Table 2, except the extent of temperature excursions above threshold values (the last part of the last question in Table 2).

This is by no means an exhaustive monitoring strategy, but it will provide important information that will allow determination of trends in policy-relevant and biologically-relevant parameters over a five to ten year time frame and to answer important monitoring questions.

We also believe that a number of other monitoring approaches are advisable, each intended to address a specific issue or question. They include storm-based longitudinal studies of FCB loads in some of the lower rivers every three to five years, site-specific storm-based FCB monitoring of BMP effectiveness, site-specific monitoring of effectiveness of erosion-control efforts, and spatial studies of temperature exceedences. Some of these are planned for, pending funding.

Table 3. Routine monitoring schedule.

Parameter	Temporal Monitoring Approach	Sample Timing	Sites	Logistics
FCB	Storm	Two storms during each of the four seasons; six to eight samples per storm at each site	Primary sites on Tillamook, Trask, and Wilson Rivers	Sterile sample collection at 0.5 m depth
TSS	Storm	Four to six large storms per year; six to eight samples per storm at each site	Primary sites on Trask, Wilson, and Kilchis Rivers	Large storms (Wilson River discharge to ? 6,000 cfs) generally occur during November through January; van Dorn sample collection at 0.5m depth
Nutrients (TP, NO$_3$, NH$_4$, TKN)	Bimonthly	Collect winter samples during high flow periods (Wilson River discharge > 6,000 cfs)	Primary sites on Wilson and Trask Rivers	Van Dorn sample collection at 0.5m depth
Temperature	Hourly	Continuous monitoring throughout the summer season	11 sites total, with at least two sites on each river	Tidbit or HoboTemp; download data quarterly
E. coli	Weekly	Samples collected approximately every 7 days	About 7 sites on each river	Sterile sample collection

STUDIES TO IDENTIFY MAJOR SOURCES AND SOURCE AREAS OF FECAL COLIFORM BACTERIA

Prior to and during the course of the general monitoring efforts, it became increasingly clear that FCB contamination is a widespread problem throughout the watershed, 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 presumed 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.

Water quality monitoring was also conducted by the TCCA at eight sites on the Wilson River during the period late September, 1997 through early March, 1998, from river mile 8.6 to river mile 0.2 near where the river enters Tillamook Bay. Samples were collected approximately weekly by the TCCA during the course of the study, plus at more frequent intervals during two storm events in October, 1997 and March, 1998. Samples were analyzed by TCCA for FCB and *E. coli*.

Subbasins that drained into each of the 38 sampling sites on the Tillamook, Trask, and Wilson Rivers 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 on each river. From these corrected flow values, FCB loads (cfu/sec) were calculated by multiplying the FCB concentration (cfu/100 ml) by the flow (ml/sec). This resulted in load estimates associated with individual sub-basins for the Tillamook, Trask, and Wilson 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 river segments and their associated subbasins that most frequently contributed the largest loads of FCB to the rivers during these two storms (Sullivan et al. 1998b, Bischoff and Sullivan 1999).

Watershed factors thought to influence loading of FCB to surface waters were quantified using coverages produced by Alsea Geospatial 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 development type was then quantified from these coverages for each subbasin that drained into a particular sampling site, including area used for pastureland, rural residential housing, urban development, 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 was 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.

The overall trend for the Trask River 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 the watershed, 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 Road), this was mainly because discharge was only a small component of the discharge at lower sites on the river.

High loads were found at a variety of locations in both the Trask and Tillamook Rivers. There was not one major source area of FCB load; 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 lower portions of the watershed and/or a larger contribution of FCB close to the bay.

Evaluation of the spatial land use patterns within the contributing drainage areas to each of the monitoring sites revealed some interesting patterns. The FCB loads contributed from the watershed to the various monitored sites was not clearly or consistently correlated with any of the identified land use features. However, highest loads were often 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. Findings were similar when FCB loads were normalized by contributing area and by length of river segment. These findings provide strong, albeit circumstantial, evidence that the watershed areas that frequently contribute the largest FCB loads within these two watersheds are primarily influenced by human activities other than, or in addition to, 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 most strongly associated with urban land use, and to a lesser extent rural residential and agricultural land use.

These results suggest that the sites which showed the largest contributions of FCB to the Trask River, at least during the two storms that were intensively monitored, occurred in association with human habitation, especially the urban and rural residential areas of the watershed. Highest loads were often found in the lower sections of the river, which are heavily ditched and where human activity is concentrated, soils are poorly drained, and runoff potential is high. FCB loads were high throughout the watersheds, and appear to originate from a variety of sources.

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.

The monitoring data collected by TCCA were also evaluated relative to major land uses and reported by Bischoff and Sullivan (1999). By far the highest FCB loads to the Wilson River were contributed by the land areas that drain into Site 7 (in the mixing zone just below the TCCA outfall) during the October 1997 and March 1998 storms. This site was the only site in the Wilson River basin that has contributing areas occupied by urban land use. Relatively high FCB loads were also found at a variety of other sites. A consistent relationship was not observed between FCB loads and land use among the other sites sampled in the Wilson River watershed.

A study conducted by Oregon State University estimated the percentage contribution of human, dairy, and wildlife sources of FCB to each of the five rivers in the Tillamook Bay watershed (Moore and Bower 2000). This work was based on the measured resistance of bacteria in water samples from the five rivers to a suite of antibiotics to which humans or dairy cows are routinely exposed. Large differences were observed within and among rivers, both monthly and within a single storm, with respect to the relative importance of inferred human versus dairy sources of bacteria. Wildlife sources were usually less than 25% of total estimated FCB. Human sources dominated most samples collected during September through December. Dairy sources were more commonly approximately equal to, or higher than, human sources during spring and summer months. Overall, human FCB sources exceeded half of the total estimated FCB on 51% of the sample occasions. In contrast, dairy sources equaled or exceeded half of the total estimated FCB on 38% of the sample occasions (Moore and Bower 2000).

Thus, efforts to control FCB sources should focus on the entire lowland area. Controlling either agricultural sources alone or human sources alone is not likely to be successful if the ultimate objective is to achieve water quality standards in the rivers and in the bay.

On-going research is focused on further characterization of FCB source areas in the lower reaches of the Trask and Wilson Rivers, in the areas influenced by urban land use. Frequent (spatial and temporal) interval sampling of the lower reaches of these rivers is taking place during multiple storms and the results integrated with GIS landscape analysis. In addition, a study has recently been initiated by Oregon State University (OSU), working in cooperation with the TCPP, to identify fecal bacteria sources using a genetic marker technique. Samples collected from Tillamook Basin rivers are processed for *E. coli* at TCPP and shipped frozen to OSU, where the sample is processed and DNA identifiers are extracted. These are matched with known DNA identifiers that will classify the sample as human, bovine, equine, porcine, avian, canine, or feline. By identifying the specific amount of each identifier in each sample we will be able to identify the highest known cause for the *E. coli* in each section of the river. This will allow action items to be developed to treat the highest known contributor first in each section.

BEAVER CREEK PROJECT

Dairy farmers in the Tillamook Basin (and elsewhere) feel threatened by the prospect of additional nonpoint source (NPS) pollution regulatory actions and remain unconvinced that management activities on their individual farms make any appreciable difference for water quality in the Basin. Many are skeptical that land use (especially riparian management) impacts water quality/habitat quality issues related to sediment fluxes, temperature, and aquatic biota.

What is needed is a clear and unambiguous demonstration of improvement subsequent to remediation on neighboring farms. Such a demonstration must remove only minor amounts of farmland from productivity, be simple and inexpensive to implement, enhance rather than detract from the aesthetic qualities and economics of the farm, and yield visible improvements in water quality. Several methods are available with which to remediate NPS pollution contributions to river waters from dairy farming and other agricultural activities. Chief among these are constructed or enhanced wetlands, fenced riparian areas, and altered hydrology to route surface water away from areas of concentrated animal use. It is not known, however, how large wetland or riparian filters need to be in order to optimize removal efficiencies for bacteria, sediment, or nutrients. Optimal design features such as buffer widths, hydrologic retention, and plant species mixes are poorly known. These issues are important because farmers are rightfully reluctant to remove large portions of their farms from productivity in order to improve water quality. What is needed is better information regarding the extent to which effective filtration can be provided with minimal loss of productive land.

The ultimate goal of the ongoing Beaver Creek watershed remediation effort is to achieve effective remediation of high water temperature and FCB and sediment load contributions to stream waters from an agricultural subbasin of the Tillamook River in a way that does not diminish the productivity of adjacent farms. Research goals include determination of bacterial and sediment fluxes from relatively undisturbed headwater tributary streams and quantification of the effectiveness of best management practices in remediating bacteria and sediment contributions to the lower river and the bay.

The on-going remediation effort is intended to demonstrate effective reduction of FCB, temperature, and sediment loads contributed to surface waters from an upland agricultural subbasin of the Tillamook Bay Watershed. This is being accomplished by a combination of streamside fencing, water diversion, riparian planting, enhancement of multiple small wetlands, working with farmers to alter management activities, and water quality monitoring before and after implementation of these remediation efforts. Primary objectives are to 1) improve water quality in a subbasin of one of the rivers that flows into Tillamook Bay; 2) improve aquatic habitat quality by reducing sediment transport and water temperatures and reducing the load of bacteria that is transported to the lower river and oyster beds in the bay; 3) quantify the effectiveness of these measures by implementing a long-term monitoring strategy for FCB, turbidity and TSS, and water temperature; and 4) demonstrate the environmental benefits that can be achieved through implementing cost-effective management practices and remediation efforts. The project specifically addresses each of the priority problem areas of the Tillamook Basin initially identified by TBNEP: fecal bacterial contamination, sedimentation, and salmonid habitat degradation. Specific improvements, and associated uncertainty, is being quantified and will be communicated to local stakeholders.

Considerable effort was devoted to selection of an appropriate subbasin in which to conduct the remediation project as well as an appropriate reference (control) watershed. This was done in conjunction with local agency representatives and other knowledgeable stakeholders. Input was provided to the project team from representatives of the TCCA, TBNEP, Oregon State University Extension Service, Oregon Department of Agriculture, Natural Resources Conservation Service, and Tillamook Soil and Water Conservation District. Several candidate subbasins were selected and initial contacts with landowners were initiated.

Two subbasins were selected from among the candidates, and more extensive discussions with landowners and farm managers were conducted. It was determined that either subbasin (Upper Tillamook River mainstem or Beaver Creek, a tributary to the Tillamook River) would be appropriate for the proposed remediation, with the other serving as the reference subbasin. It soon became apparent that landowner cooperation was most likely to occur in the Beaver Creek subbasin, and farm visits to the three upper farms in this subbasin revealed excellent potential for remediation work. Subsequently, a protracted period of discussions and farm visits by members of the project team was required to convince landowners and their family members on two of the farms of the benefits of participating in this project. In December, 1998, the second farm representative agreed in principle to participate. In anticipation of this agreement, some pre-treatment water quality monitoring had been initiated in September, 1998.

The farms selected for remediation are two of the three uppermost farms in the Beaver Creek watershed. Three major tributary streams contribute flow from the forest to the pasturelands on these farms, Bear Creek to the north and the north and south forks of Beaver Creek.

Pre-treatment Site Description and Assessment of Problem Areas

During the year prior to initiation of this project, much of the riparian zone on the uppermost farm was fenced by the landowner. Very small buffer strips were provided between fence and streambank. Much of the streamside area of the middle farm (not participating in this project) was also fenced during that period. Very little fencing had been done in the past on the lower farm; most riparian areas on the lower farm were readily accessible to livestock. Some riparian and wetland areas on the middle and upper farm were also accessible to livestock.

Many areas of streambank erosion were present in the study area; especially on the lower and middle farm. Many of these erosion-prone areas were frequented by livestock during part of the year.

Riparian areas on the lower farm were heavily vegetated with blackberry in many areas. Blackberry thickets were sufficiently dense and extensive as to preclude planting a diversity of native plants (including trees) throughout large portions of the riparian zone. In addition, these thickets obstructed fence line locations in some places.

There were two areas, one on the upper farm and one on the lower farm, where runoff patterns contributed surface runoff during periods of heavy precipitation that flowed directly from areas heavily utilized by livestock into adjacent streams or open drainage ditches. In both cases, these source areas were adjacent to the respective barns on those farms.

There were also many areas on all three farms where the surface contours of the land allowed direct overland flow to enter streams from pasture areas during periods of heavy rainfall. These were generally locations where the pastures sloped abruptly to the edge of the streambank.

Thus, there were many potential source areas for bacteria and sediment contributions to Beaver Creek and its tributary streams. In addition, there was a general lack of trees throughout the riparian zones on all three farms and only a limited amount of shading of the streams was provided by existing riparian vegetation.

Although soils were saturated throughout much of the rainy season in many places, areas of wetland vegetation were scattered. Existing wetlands were grazed by livestock and wetland function appeared to be diminished. An extensive riparian wetland and former stream channel system on the lower farm had been partially isolated from streamflow by prior ditching.

Approach

The environmental restoration approach has involved the fencing of riparian areas, altering hydrological runoff to minimize bacterial input, and enhancing several small wetlands in runoff-contributing agricultural areas. Riparian and wetland areas have been planted with native species. Enhanced wetland systems were designed mainly to filter a portion of adjacent stream flow during high-flow periods.

Surface waters are being monitored above and below the remediation subbasin and in the reference (control) subbasin. Monitoring includes measurement of rainfall, streamflow, and sampling of five to ten storms per year plus some baseline monitoring. Both parameter concentrations and loads will be calculated and expressed on a per-storm basis. Storm results will be normalized by storm type (based on rainfall intensity, maximum discharge, season, and antecedent hydrological conditions) for year-to-year comparisons and statistical analyses.

Monitoring includes temperature, turbidity, TSS on a less frequent basis, and FCB. TSS will be estimated for all sampling occasions from turbidity measurements and observed turbidity/TSS relationships. At two year increments, we will quantify the realized improvements (and associated measurement uncertainties) in the concentrations and loadings of FCB and TSS.

For TSS, the success of the project will be measured as change in the difference (plus or minus) between the reference and the treatment subbasins. This is a straightforward paired-catchment analysis. For bacteria, we also wish to quantify improvement in bacterial concentrations and loads. We will do that using several approaches, in anticipation of a high degree of temporal variability. These will include analyzing for trends within designated storm types, predicted versus observed concentrations and loads, flow-weighted storm average concentrations, and total storm loads.

E&S Environmental Restoration, Inc. is coordinating the effort. Other participants include Oregon State University, Kilchis Dairy Herd Services, Tillamook County Creamery Association, Oregon Streamside Services, and Rees Enterprises. Riparian planting has been accomplished with the aid of volunteers from the local watershed council. Collaborating agencies include the Tillamook County Performance Partnership, Oregon Department of Environmental Quality, OSU Extension Service, Natural Resources Conservation Service, U.S. Environmental Protection Agency, Oregon Department of Agriculture, and Tillamook Soil and Water Conservation District.

On-the-Ground Activities

A preliminary plan was formulated for the remediation actions. It included completing the riparian fencing along all of the stream and ditch areas on the participating farms and rerouting some of the streamflow into a former stream channel. The stream location was previously changed by ditching, and some of the old channel areas provide greater opportunity for removal of sediments and bacteria from the discharge. A series of small wetlands were identified for enhancement through minor excavation and/or placement of sandbags, planting with native vegetation, and fencing.

Ground work completed during the summer of 2000 focused largely on three key issues: 1) diverting the surface water away from areas frequented by animals, 2) providing additional filtration to aid in the removal of fecal bacteria and sediment from runoff, and 3) excluding the animals from the riparian and wetland areas. The type of work conducted in each of these areas is outlined below.

Using the preliminary restoration plan as a base, specific sites were identified for remediation. At these sites, small wetland areas were enhanced to aid in filtration of stormflow runoff. Wetlands are small and situated so as to filter surface runoff from pastureland before it enters permanent stream channels and also to contain runoff, allowing infiltration and retention of both water and bacteria. Wetlands and riparian areas were fenced and planted with a mixture of native wetland vegetation (16 species). Streamside areas on the lower farm were fenced to allow development of riparian vegetation buffers and to reduce bank erosion, enhance stream shading, and provide a biological filter for stormflow runoff. In addition, damaged areas of fencing, mainly in areas that had experienced recent stream erosion, on the upper farm were repaired. In these areas, new sections of fenceline were installed. New Zealand high tension electric fence was used, which has proven superior for use in flood-prone areas. Livestock watering troughs and piping were installed in three locations on the lower farm. Runoff flowpaths from pasture to streams and ditches were modified where necessary to increase detention time and contact with soils and vegetation.

Newly-fenced riparian areas were replanted with a mixture of grasses in eroded areas and native sedges, shrubs, and trees. Species were selected to maximize bank stabilization, shading and development of future streamside coarse woody debris.

A series of small wetlands was enhanced on the lower farm along a former stream channel. This area represents an old stream channel that has been partially bypassed by ditching. The vegetation was characterized by blackberry and a few hydrophytic species. The old channel was reconnected by a pipe and the wetlands restored through minor excavation, increased ponding, and fencing, and they were replanted with native wetland and riparian plant species. The wetlands are small (approximately 6-12 feet wide and 40 to 100 feet long) and are connected by the old stream channel. The wetland series was connected to the stream through an 8 inch pipe used to divert water into the wetlands. The pipe was fitted with a shut-off control valve and a fish screen. Excavated material was used to contour the wetlands in order to increase ponding.

Hydrologic Modifications

Three water diversion systems were installed, two of which were designed to reroute runoff water in areas frequented by cows. The first diversion was installed on the upper farm adjacent to the barn. An open ditch carried runoff and groundwater that originated on the hillslope behind the barn, and the ditch continued for about 450 ft before entering the main stream channel of Beaver Creek. The area around this ditch was heavily utilized by the dairy cows and was judged to be the likely largest single bacteria source area on the upper farm. During rainstorms, the soil in that area often became saturated for prolonged periods and provided extensive areas for direct runoff contributions to the ditch and stream system. The existing runoff pattern thus carried water directly through the portion of the farm that experienced the greatest amount of animal traffic. We determined that the best way to isolate the water from the animals was to install a buried pipe to carry the runoff from behind the barn to the point where the ditch joined the stream. The new pipe (12? corrugated PVC) and an overflow valve were installed in September, 2000, and the existing ditch was filled in.

The second diversion was installed on the lower farm to accomplish essentially the same purpose. In this case, surface runoff during rainstorms flowed directly downhill from the barn to Beaver Creek. The amount of water was much less than was the case adjacent to the upper farm, however, because there was no stream or groundwater source in the area around the barn on the lower farm. In this latter case, the problem was restricted to surface runoff from rainfall that could not infiltrate the compacted soils around the barn. A perforated 4? PVC pipe was buried in coarse gravel that was hauled to the site and the pipe was installed parallel to the stream near the top of the streambank. This pipe was structured to intercept surface runoff that was moving from the barn towards the stream. The runoff, which contains only rather small volumes of (highly contaminated) water was rerouted to the adjacent pasture. Thus, this water will now infiltrate the soil of the pasture prior to moving laterally to enter the stream channel. This movement through soil will aid in the removal of fecal bacteria from the runoff.

The third diversion that we installed was intended to improve water filtration capabilities by diverting a portion of the water in Beaver Creek, which had earlier been ditched near the property line, back into the old stream channel that meandered through the pastures. This old stream channel provided more opportunity to enhance wetland function than the existing (and previously ditched) stream channel. An 8” pipe was installed to connect Beaver Creek to the old stream channel, and a shut-off valve was installed to conform with permit requirements and to allow experimental regulation of water flow through the old stream channel. A culvert was also installed to carry surface runoff from the pasture of the adjacent farm into the top of the old stream channel, and a one-way valve was installed on the culvert to prevent water from flowing from the old stream channel back up to the pasture on the adjacent farm.

The streamside and ditchside areas on both of the farms were surveyed to determine the location of all areas where surface runoff might flow directly from the pasture into the stream or ditch during periods of heavy rainfall. The ground in all such areas was recontoured, by hand shovel work, to construct a shallow trench and adjacent berm, running parallel to the water course. The objective was to force future surface runoff from the pasture to infiltrate soil and pasture vegetation prior to entering the water course. This will help to remove fecal bacteria from the water before it contaminates the stream.

Wetland Enhancement

A series of small wetland areas was enhanced along the length of the old stream channel, which rejoins Beaver Creek further downstream, near the barn on the lower farm. Minor excavation was done on the top wetland area. In addition, six small dams were installed at appropriate locations to create ponded areas. The dams were constructed of sand bags, stacked about 2 ft high, extending across the stream channel.

Similarly, a series of three small ponded areas was created and fenced along the ditch line that runs along the northern edge of the pasture on the lower farm. These ponded areas were also planted with native wetland vegetation, which will enhance bacterial and sediment removal from the runoff water.

Fencing

In order to exclude animals from the riparian and wetland areas, a New Zealand high tensile fence was installed along all water courses on the lower farm during the summer of 2000. Approximately 2.4 mi of fencing was installed, along with 750 ft of buried waterline that supplies three watering troughs. Additional fencing was installed on the upper farm in areas where the previously-installed fence had been damaged by bank erosion. Approximately 550 ft of new fencing was installed in December, 2000.

Blackberry Removal and Planting Efforts

Prior to initiation of this project, many of the streamside areas of the lower farm were inundated with blackberry. Much of this blackberry was hand-cleared to make room for fence construction and to allow for subsequent riparian planting with shade trees and with a greater diversity of native riparian and wetland plant species.

The planting efforts took place during spring, 2000 and 2001. About 8,000 plants were planted, including trees, shrubs, sedges, and wetland species. Most of the trees and some of the shrubs were tubed to minimize animal damage.

Sampling Location and Schedule

Sampling sites were selected at the three forest/agriculture interface locations (both upper forks of Beaver Creek and Bear Creek) and on Beaver Creek just below the lower portion of the lower farm (Figure 1). Less frequent sampling is conducted below the major animal holding area of the upper farm. A precipitation gage was installed at the downstream site. A staff gage and pressure transducer were installed at the bridge crossing below the confluence of Bear and Beaver Creeks to measure discharge. A sampling site was also selected for the reference (untreated) watershed at the Yellow Fir Road crossing of the upper Tillamook River.

Parameters and Measurements

Stream stage has been monitored from December 16, 1998 to the present for Beaver Creek at the intersection of the creek and Ecklhoff Rd. A rating curve to estimate discharge from stage measurements is under current development.

Sample Analysis

Streamwater samples are routinely analyzed for turbidity and FCB. Duplicate and deionized water blank samples are submitted as routine samples to the laboratory as checks on analytical quality. *In situ* measurements are collected for temperature using continuous temperature monitors. A subset of samples is analyzed for TSS by gravimetric 103C analysis.

Results to Date

Hydrology

Hydrological modifications have been successful, based on visual inspection, in routing runoff water away from areas of concentrated animal activity. In addition, recontouring of streambank areas appears to have resulted in increased filtration of direct surface runoff by soils prior to entering open water courses. A portion of Beaver Creek has also been diverted during high flow periods through the series of enhanced wetlands in the old stream channel on the lower farm.

Fecal Coliform Bacteria

FCB concentrations at the Beaver Creek site immediately downstream of the project area frequently exceed 2,000 cfu/100 ml during storm events, occasionally exceeding 6,000 cfu/100 ml. The reference site also exhibits FCB concentrations that frequently exceed 2,000 cfu/100 ml, with highest concentrations > 6,000 cfu/100 ml. Measurements have also been collected at each of the upstream Beaver Creek tributaries, near the point where they exit forest land and enter agricultural land. FCB concentrations were often > 200 cfu/100 ml at these forest/agriculture interface sites, especially during fall storms, when concentrations > 1,000 cfu/100 ml were commonly encountered. FCB concentrations were especially high at the upper site which is situated immediately downstream of extensive beaver activity. The source of the high FCB at this site is not known but is believed to be beavers or other wildlife in the upper, forested watershed.

The results of our water quality monitoring efforts to date illustrate substantial contamination of runoff with bacteria as the streams pass through the study area. The Beaver Creek study area therefore will provide a good opportunity to accomplish improved conditions. Results also show substantial bacterial contamination upstream of agricultural land use. The data collected thus far provide a good baseline against which to measure future improvements.

Total Suspended Solids and Turbidity

Turbidity is measured on all sampling occasions. Turbidity increases dramatically with storm events at all sites, regardless of the size of the storm, and also regardless of season.

TSS is measured less frequently, only on some sampling occasions. Measured TSS values are closely correlated with measured turbidity, and we therefore will use the turbidity measurements to estimate TSS for all sampling occasions that lack TSS measurements. These measured and estimated TSS concentration values will be used as the basis for calculating TSS loads.

Temperature

Temperature data were collected at the five remediation monitoring sites using calibrated tidbit temperature loggers. Temperature is being monitored at the Beaver Creek gaging station using the Solinst Levelogger. Stream temperatures increased from the forest/agriculture interface to the lower end of the project, suggesting that stream warming occurs as a result of a lack of shade in the agricultural portions of the watershed.

Discussion

This project is quantifying achievable reductions in the contributions of bacteria and sediment in agricultural areas over the short-term and long-term (implementation of continued monitoring). It is hoped that such improvements will reduce bacterial contamination of the river and bay, reduce stream bank erosion and erosion from agricultural fields, reduce sediment transport from uplands to the lower river and the bay, reduce stream temperatures, improve the integrity of aquatic biological communities in streams draining agricultural lands, and improve salmonid habitat quality in the upper and lower watershed. Most importantly, these improvements are being measured and quantified.

Results will continue to be quantified, measured, and periodically photographed. Complete documentation of the extent of improvement for each critical parameter will be provided. This information will help state agencies to refine estimates of achievable improvements (i.e., Senate Bill 1010, TMDL process, 303d listings, etc.) and will be communicated to the agricultural community in the Tillamook Basin.

WATERSHED ASSESSMENTS

Draft watershed assessments have recently been completed by E&S, in cooperation with the Tillamook Bay Watershed Council and the TCPP, for the Wilson and Miami Rivers. These assessments have been prepared according to Oregon Watershed Enhancement Board (OWEB) protocols and are intended to provide the technical foundation for development of watershed-specific action plans for future environmental protection, restoration, and enhancement activities.

Highlights from the Wilson River Watershed Assessment are summarized below. Analogous information is also available for the Miami River watershed.

The major objective of each assessment is to summarize current conditions and data gaps within the watershed in order to help to identify how current and past resource management is impacting aquatic resources. Through this summarization, an attempt is made to create a decision-making framework for identifying restoration activities that will improve water quality and aquatic habitats. The primary components of the watershed assessment, include fisheries, fish habitat, hydrology, water use, sediment sources, and water quality.

Fisheries

The OWEB assessment method focuses strongly on watershed processes that affect salmonids and their associated habitats. Understanding the current condition of salmonid populations in the watershed is vital to identifying the effects of the spatial and temporal distribution of key habitat areas. Additionally, salmonids are often used as indicator species under the assumption that they are the most sensitive species in a stream network (WPN 1999, Bottom et al. 1998, Tuchmann et al. 1996). Habitat conditions that are good for salmonids generally reflect good habitat conditions for other species of aquatic biota.

Anadromous salmonid species known to occur in the Wilson River include chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), chum salmon (*O. keta*), steelhead trout (*O. mykiss*), and sea-run cutthroat trout (*O. clarkii*). Although details of their life history and habitat requirements differ substantially, all spawn in fresh water, migrate through the estuary, and rear for varying lengths of time in the ocean before returning to their natal streams to complete their life cycle. Resident cutthroat trout are also present in the Wilson River.

The National Marine Fisheries Service (NMFS) has listed coho salmon as threatened. Coastal cutthroat and steelhead are candidates for listing. Listing for chum and chinook was not warranted as determined by NMFS. Listing occurs for an entire Evolutionarily Significant Unit (ESU) which is a distinctive group of Pacific salmon, steelhead, or sea-run cutthroat trout.

Coho salmon populations along the entire Oregon coast are now considered depressed. According to Hasselman (1995), Tillamook Bay coho abundance and adult spawning escapement have shown significant rates of decline not generally observed for other Oregon coastal river basins in the central and north coast (TBNEP 1998). Coho habitat is distributed throughout the Wilson River watershed (Figure 10).

Numbers of adult coho (mostly age 3) escaping to the spawning grounds have been indexed using the peak count method, which is based on repeated counts on the spawning grounds. Surveys have been conducted by ODFW since 1950 on Cedar Creek, a tributary to the Wilson River; and with the exception of five years (1974–1979), on the Devils Lake Fork of the Wilson River. Peak counts (expressed as number per mile of stream surveyed) were relatively low in the mid-1950s, relatively high from about 1960 through the mid-1970s and since about 1975 have remained low and variable. All-time lows were reached in the early 1990s. These data suggest that either the quality of freshwater habitat has seriously declined since about 1976 or that other factors (*e.g.*, poor ocean survival, over harvesting, influence of hatchery fish, or high estuarine mortality) are limiting the number of returning adults (TBNEP 1998).

A combination of factors, including rearing and spawning habitat degradation, reduction in summer streamflow, passage impacts at dams, decrease in ocean productivity, excessive fishing, and impacts caused by hatchery programs, have been implicated in most of the declines and extinctions of coho salmon populations in Oregon. In coastal rivers and lower Columbia Basin tributaries, low summer flows and the loss of complex instream structure, winter side channels, sloughs, and shade have been identified as predominant problems. Timber harvest in the coastal temperate rain forest belt has contributed to winter habitat loss, particularly in the uplands. Logging has caused the loss of large conifers from riparian areas that would have provided long-lasting instream structure when they fell into streams. Siltation from logging roads, road-failures, and loss of ground cover, along with reduction of water filtering and shade due to the removal of riparian vegetation, have reduced egg and juvenile survival. Historical logging practices also used splash dams that ripped spawning gravel and instream rearing structure out of streams when logs were flushed downstream as a form of transport. Agriculture, industrialization, and urbanization have degraded coho rearing habitat in the lower river and estuary through such actions as diverting water, channelizing streams, diking off-channel and estuary areas, and releasing effluents that elevate temperatures and reduce water quality (ODFW 1995).

The influence of hatchery fish on naturally-spawning populations is not known. However, it appears that the runs of natural spawners are earlier now than they were in the past, suggesting that hatchery fish may have had an influence (TBNEP 1995). Based on observations made during peak count spawning surveys, most Tillamook Basin coho spawned during December in the decades of the 1950s and 1960s. But by the late 1980s, peak spawning had apparently shifted to November. Until recently, it was the practice of hatcheries to take eggs from the first returning spawners. This practice selected for early spawners and over time has resulted in a shift toward earlier spawning runs of most coastal coho hatchery stocks, including the Trask River hatchery.

Both fall and spring chinook salmon are present in the Tillamook Bay Watershed. Mature fall chinook (2 to 6 years of age) return to all five of the major subbasins from early September through mid-February. Peak entry into the rivers occurs in mid-October. Tillamook Bay fall chinook spawn from October to January. Spring chinook salmon occur primarily in the Trask and Wilson Rivers, with a small population in the Kilchis River. Spring chinook enter Bay tributaries from April through June.

The recreational catch of fall and spring chinook salmon has been estimated since 1969 from annual returns of salmon/steelhead punch cards (Nicholas and Hankin 1988, Nickelson et al. 1992, ODFW 1995, Kostow 1996). These catch estimates indicate a generally increasing trend from 1969 through 1993 (period of available data) for fall chinook salmon (TBNEP 1998). The recreational catch of fall chinook averaged about 15,900 fish between 1985 and 1993. When compared with the average annual commercial catch of about 17,000 for the period 1923–1946, the present level of harvest appears remarkably stable. Although hatchery fish contribute to the fall runs, it is believed that most fall chinook are produced from naturally spawning fish (Nicholas and Hankin 1988).

The recreational catch of spring chinook salmon has been small compared to the fall chinook catch, but the catch has remained relatively stable since about 1987. However, ODFW regards spring chinook salmon abundance as depressed when compared with commercial landings during May through July during the 1930s (Nicholas and Hankin 1988). Spring chinook runs are supplemented by hatchery fish produced at the Trask River and Whiskey Creek hatcheries (TBNEP 1998).

Agricultural and logging practices along low gradient river reaches in lower basins have greatly decreased the complexity and productivity of juvenile chinook rearing areas. Wetlands, marshes and braided channels have been straightened, channelized, diked, drained and deforested to create croplands and pastures. Summer flows and water quality have also decreased and summer water temperatures have increased in these areas.

Spring Chinook use the mainstem Wilson River into the headwaters and the lower portion of the Jordan Creek subwatershed. Fall chinook are found more extensively throughout the watershed, including the Little North Fork, Cedar Creek and North Fork subwatersheds. Spring chinook remain in the larger streams where deep holding pools are more abundant. In contrast, fall chinook move directly to spawning areas, reducing the need for these large holding pools.

Less is known about the present status of sea-run cutthroat trout than about any of the other anadromous salmonid species in the Tillamook Bay watershed. Sea-run cutthroat trout, the smallest of the anadromous salmonids present in the watershed, have not been fished commercially. The only attempt to routinely count sea-run cutthroat has been resting pool counts made by ODFW staff since 1965 in conjunction with summer steelhead counts in the Wilson and Trask Rivers. These data suggest that numbers of sea-run cutthroat trout in resting holes may have been somewhat higher before the mid-1970s than they have been since, particularly in the Wilson River.

Tillamook Bay historically supported the Oregon Coast’s largest chum salmon fishery (TBNEP 1998). During the 1930s and 1940s, catches of over 50,000 fish were not uncommon. Oregon is near the southern edge of chum salmon distribution which may, in part, account for the large interannual variability in run sizes that have been observed in Tillamook Bay streams over the years. ODFW has collected peak counts of spawning chum salmon since 1948 in the Kilchis, Miami, and Wilson River watersheds. Peak counts (number per mile) were relatively high through about 1954. Since 1954, the peak counts appear to have declined somewhat and have shown high interannual variability. Due to the very low counts on the spawning grounds since about 1992, concern has been growing that the chum population is experiencing serious problems. Chum salmon use only the lowest portions of the Wilson River watershed, never extending beyond the Lower Wilson or low elevations of the Little North Fork Wilson subwatersheds. Chum salmon in Oregon require typical low gradient, gravel-rich, barrier-free freshwater habitats and productive estuaries. They have not been supplemented by hatchery fish.

Most coastal steelhead in Oregon are winter-run fish and summer steelhead are present only in a few large watersheds, including the Wilson River watershed. The subspecies (*Oncorhynchus mykiss irideus*) includes a resident phenotype (rainbow trout) and an anadromous phenotype (coastal steelhead). Winter steelhead are native to Tillamook Bay streams and are widely distributed throughout the Basin. Summer steelhead were introduced to the Basin in the early 1960s and are supported entirely by hatchery production (TBNEP 1998). Although summer steelhead have been observed in all five subbasins, most occur in the Wilson River and Trask River subbasins. Summer steelhead typically enter Tillamook Bay streams from April through

July and hold in deep pools until they spawn the following winter. Winter steelhead generally enter streams from November through March and spawn soon after entering freshwater.

No reliable information on the historic abundance of steelhead in Tillamook Bay streams is available. Steelhead were gillnetted commercially in Tillamook Bay from the late 1890s through the 1950s. However, harvest data for steelhead were not recorded in a reliable manner until after the fishery had been restricted to the early part of the steelhead run. Rough estimates of total coastwide steelhead run size made in 1972 and 1987 were similar (Sheppard 1972, Light 1987), suggesting that overall abundance remained relatively constant during that period. The only information available for assessing trends in the abundance of steelhead runs to Tillamook Bay streams is angler salmon/steelhead report tags and holding pool counts for summer steelhead. The combined recreational catch of winter steelhead for all five subbasins and Tillamook Bay shows a declining trend since the early 1970s. The recreational catch has declined from a high of more than 20,000 in 1970 to fewer than 2,000 in 1993.

Coastal steelhead abundance follows a similar cycle in all populations from Puget Sound in Washington to California, indicating that factors common to all populations influence trends. The most probable factor responsible for this cycle is ocean condition. Ocean productivity is recognized to undergo long-term cycles that include periods that are relatively favorable or unfavorable to the survival of salmonids. This cycle appears to be a natural process that cannot be affected by management actions. The ocean productivity cycle appears to be unfavorable for steelhead currently and all steelhead population abundance trends are correspondingly low (ODFW 1995).

Steelhead and rainbow trout populations have also been affected by freshwater habitat degradation. Most coastal salmonid freshwater habitats were historically coniferous temperate rain forest ecosystems. Stream systems were structurally complex, with large instream wood, flood plains, beaver ponds, braided channels, and coastal marshes and bogs. Human activities have altered these ecosystems, particularly by reducing their complexity and removing components that were essential to steelhead and rainbow trout production. Logging and road construction in the Coast Range and Cascade Mountains have had the most widespread impact on coastal steelhead, and have affected most populations (ODFW 1995).

Aquatic and Riparian Habitats

Distribution and abundance of salmonids within the watershed varies with habitat conditions such as substrate and pool frequency as well as biological factors such as food distribution. In addition, salmonids have complex life histories and use different portions of the watershed during different parts of their life cycle. There are also differences among salmonid species in their timing and extent of habitat utilization. The interactions of these factors in space and time make it difficult to identify the specific watershed components that most strongly affect salmonid populations. Consequently, entire watersheds must be managed to maintain fish habitats, and not just individual components (Garono and Brophy 1999).

Healthy populations of anadromous salmonids are generally associated with the following freshwater habitat characteristics:

- cool, clean, well oxygenated water;
- unobstructed access to spawning grounds;
- clean, stable spawning gravel;
- winter refuge habitat for juveniles;
- complex stream channel structure with an appropriate mixture of riffles, pools, and glides;
- deep pools;
- stream channels with an abundant supply of large woody debris;
- abundant food supply;
- adequate summer stream flows; and
- diverse, well-established riparian community.

Since 1996, 18 creeks and rivers have been surveyed by ODFW in the Wilson River watershed, totaling approximately one-fifth (78 miles) of the entire stream network (Figure 11). Conditions are variable in time, however, and respond to hydrologic factors. For example, the large flood event of 1996 most likely altered LWD and sediment conditions in the watershed.

Stream morphology describes the physical state of the stream, including features such as channel width and depth, pool frequency, and pool area (Garono and Brophy 1999). Pools are important features for salmonids, providing refugia and feeding areas. Substrate type is also an important channel feature since salmonids use gravel beds for spawning. These gravel beds can be buried by heavy sedimentation, resulting in loss of spawning areas as well as reduced invertebrate habitat. For streams that were surveyed, stream morphology and substrates were compared against ODFW benchmarks to evaluate current habitat conditions (Table 4). In the streams surveyed, the pool frequency for the majority of the pools fell in the moderate category. Less than a quarter of the surveyed stream reaches were either desirable or undesirable. The majority of the stream reaches were also in the moderate category based on the percent of area of the stream reach in pools. However, the percentage of undesirable streams was more than twice the percentage of desirable streams. In general, the depth of pools was sufficient. Residual pool depth was desirable for approximately half of all stream reaches surveyed. Only 15% of surveyed streams had undesirable residual pool depths.

Gravel conditions in riffles demonstrated generally moderate to desirable conditions, although Jordan Creek showed undesirable conditions in 5 of 12 reaches surveyed. The majority of reaches surveyed throughout the Wilson River watershed had moderate gravel conditions, suggesting a need for improvement.

Large woody debris is an important feature that adds to the complexity of the stream channel. LWD in the stream provides cover, produces and maintains pool habitat, creates surface turbulence, and retains small woody debris. Functionally, LWD dissipates stream energy, retains gravel and sediments, increases stream sinuosity and length, slows the nutrient cycling process, and provides diverse habitat for aquatic organisms (Bischoff et al. 2000; BLM 1996). LWD is most abundant in intermediate sized channels in third- and fourth-order streams. In fifth-order and larger streams, the channel is generally wider than the length of a typical piece of LWD, and therefore, LWD is not likely to remain stable in the channel.

In general, LWD conditions in the surveyed streams were less than desirable (Table 5). In particular, the density of key pieces of LWD was predominantly rated as undesirable. In less than one-fifth of the surveyed stream reaches was the density of key pieces rated as desirable. LWD conditions in Deyoe Creek and South Fork of the Wilson were exceptionally good overall, having desirable LWD conditions in terms of the total number of pieces, the volume of the pieces, and the number of key pieces per 100 m of stream. For Devils Lake Fork, Elk Creek, Fall Creek, Idiot Creek, Jordan Creek and South Jordan Creek, all three LWD measures were undesirable. Riparian conditions almost uniformly demonstrated undesirable conditions, with nearly all streams lacking sufficient densities of conifers in the riparian zones.

Table 4. Stream morphology and substrate conditions in the Wilson River watershed as compared to ODFW benchmark values. Data were collected by ODFW.

Stream	Reach	Stream Miles	Gradient (%)	Pool Frequency (Channel Width Between Pools)	Percent Pools	Residual Pool Depth (m)	Gravel in Riffles (%area)
Berry Creek	1	1.0	3.7	7.8	19.5	0.7	33.0
	2	1.4	12.6	72.6	4.3	0.6	18.0
Cedar Creek	1	0.9	1.6	10.7	18.1	0.8	28.0
	2	1.7	1.8	10.4	20.9	0.8	28.0
	3	0.3	1.9	7.1	20.9	0.6	28.0
	4	0.4	2.7	10.2	15.7	0.5	31.0
	5	0.8	4.8	6.3	14.9	0.4	29.0
	6	0.8	23.0	15.9	7.5	0.1	30.0
Devils Lake Fork	1	1.0	6.5	4.6	24.0	0.5	25.0
	2	0.4	1.4	5.5	16.0	0.5	34.0
	3	1.4	2.2	6.8	31.0	0.6	28.0
	4	0.3	4.0	10.1	93.0	0.9	0.0
	5	0.5	3.7	3.1	29.0	0.4	32.0
	6	1.9	1.9	4.3	51.0	0.4	24.0
	7	1.7	1.5	7.5	43.0	0.5	17.0
	8	0.8	0.7	10.6	38.0	0.5	30.0
Deyoe Creek	1	0.9	3.9	27.2	8.2	0.6	25.0
	2	0.4	0.7	2.9	97.3	0.6	16.0
	3	0.2	2.2	47.4	9.5	0.3	24.0
	4	0.8	4.1	98.4	2.8	0.4	23.0
Drift Creek	1	3.0	7.9	21.8	6.5	0.4	66.0
Elk Creek	1	0.8	2.7	7.6	21.1	1.2	13.0
	2	2.3	3.9	18.9	10.8	1.1	16.0
	3	0.7	4.2	28.8	9.9	0.8	37.0
	4	1.5	12.8	98.0	4.5	0.8	53.0
Fall Creek	1	0.2	10.9	19.8	5.7	0.6	5.0
	2	1.7	6.0	14.3	6.4	0.3	44.0
	3	0.7	16.0	20.4	5.6	0.4	54.0
Idiot Creek	1	0.6	4.5	6.2	3.0	0.3	34.0
	2	2.8	8.7	8.3	20.1	0.4	47.0
Jordan Creek	1	0.2	1.7	8.2	40.9	0.8	14.0
	2	1.5	1.6	4.9	34.3	1.0	14.0
	3	1.1	1.7	6.5	27.3	1.0	17.0
	4	2.3	2.4	7.1	43.8	1.3	16.0
	5	0.2	2.5	6.0	32.5	1.2	15.0
	6	1.4	3.3	6.6	28.5	1.0	12.0
	7	0.3	3.2	20.5	5.4	0.4	16.0
	8	0.4	3.3	4.8	32.1	0.7	13.0
	9	0.4	8.5	6.0	13.8	0.8	22.0
	10	0.1	6.4	0.0	0.0	0.0	0.0
	11	1.0	11.7	8.8	12.0	0.6	24.0
	12	1.0	23.4	40.3	4.5	0.5	37.0

Stream	Reach	Stream Miles	Gradient (%)	Pool Frequency (Channel Width Between Pools)	Percent Pools	Residual Pool Depth (m)	Gravel in Riffles (%area)
Kansas Creek	1	0.5	6.3	8.4	20.6	0.4	44.0
	2	0.6	11.4	12.9	19.2	0.4	63.0
Little North Fork Wilson River	1	1.2	0.8	4.0	32.0	0.9	25.0
	2	1.4	1.0	0.0	49.7	0.8	23.0
	3	5.6	2.1	2.7	35.2	0.8	29.0
	4	1.1	4.2	3.1	20.7	0.8	63.0
	5	1.5	2.4	4.6	28.3	0.7	45.0
	6	0.8	9.2	32.7	7.8	0.5	38.0
South Fork Jordan Creek	1	0.7	3.5	24.8	6.8	0.5	25.0
	2	1.6	4.8	15.6	9.1	0.4	34.0
	3	0.7	12.5	171.6	0.7	0.4	43.0
South Fork Wilson River	1	2.6	1.4	7.2	36.0	0.9	21.0
	2	1.6	2.3	8.8	25.0	0.9	33.0
	3	1.6	3.4	12.7	9.6	0.7	22.0
	4	1.5	7.1	104.1	2.2	0.9	21.0
	5	0.6	23.1	0.0	0.0	0.0	35.0
	6	0.5	21.6	0.0	0.0	0.0	30.0
South Fork Wilson River Trib B	1	0.6	4.0	6.1	14.1	0.4	62.0
	2	0.7	13.2	26.1	4.2	0.4	75.0
South Fork Wilson River Trib C	1	0.5	6.5	10.4	12.8	0.4	29.0
	2	0.3	7.6	8.2	16.1	0.5	56.0
	3	0.3	8.2	7.7	18.3	0.5	47.0
	4	1.1	14.6	16.6	17.1	0.3	41.0
W. Fk of North Fk Wilson River	1	2.0	2.2	13.7	21.1	1.1	19.0
	2	1.7	2.8	11.7	25.2	0.6	19.0
	3	2.2	8.9	18.0	19.9	0.6	48.0
West Fork Elk Creek	1	1.1	8.3	33.9	4.3	0.9	30.0
	2	0.6	19.9	0.0	0.0	0.0	20.0
White Creek	1	2.0	5.5	15.8	24.8	0.6	36.0

░ = Desirable ▓ = Undesirable ☐ = Moderate

Table 5. Large woody debris conditions in the Wilson River watershed as compared to ODFW habitat benchmark values. Data were collected by ODFW.

				Woody Debris		
Stream	Reach	Stream Miles	Gradient (%)	# Pieces/ 100m	Vol. (m^3/100m)	# Key Pieces / 100m
Berry Creek	1	1.0	3.7	15.1	28.9	0.50
	2	1.4	12.6	19.8	58.8	1.20
Cedar Creek	1	0.9	1.6	14.0	9.9	0.10
	2	1.7	1.8	12.9	12.4	0.10
	3	0.3	1.9	15.6	10.4	0.20
	4	0.4	2.7	36.1	27.3	0.00
	5	0.8	4.8	30.9	41.7	0.50
	6	0.8	23.0	61.9	115.3	3.00
Devils Lake Fork	1	1.0	6.5	5.0	14.4	0.00
	2	0.4	1.4	4.4	7.1	0.00
	3	1.4	2.2	5.5	15.2	0.00
	4	0.3	4.0	33.0	188.6	0.00
	5	0.5	3.7	3.7	10.8	0.00
	6	1.9	1.9	12.7	37.3	0.00
	7	1.7	1.5	2.1	7.9	0.00
	8	0.8	0.7	7.4	30.2	0.00
Deyoe Creek	1	0.9	3.9	35.4	144.1	6.20
	2	0.4	0.7	20.9	116.8	5.20
	3	0.2	2.2	33.5	153.2	8.90
	4	0.8	4.1	34.9	148.0	7.40
Drift Creek	1	3.0	7.9	24.4	21.3	0.20
Elk Creek	1	0.8	2.7	4.6	7.1	0.10
	2	2.3	3.9	2.2	3.1	0.00
	3	0.7	4.2	17.9	31.8	0.40
	4	1.5	12.8	32.7	62.1	2.10
Fall Creek	1	0.2	10.9	1.3	3.8	0.00
	2	1.7	6.0	1.1	2.9	0.10
	3	0.7	16.0	7.9	11.3	0.10
Idiot Creek	1	0.6	4.5	9.2	13.2	0.30
	2	2.8	8.7	9.2	9.7	0.20
Jordan Creek	1	0.2	1.7	3.2	2.8	0.00
	2	1.5	1.6	6.7	10.5	0.30
	3	1.1	1.7	12.4	15.6	0.30
	4	2.3	2.4	9.1	9.0	0.10
	5	0.2	2.5	7.8	11.2	0.30
	6	1.4	3.3	5.9	7.5	0.00
	7	0.3	3.2	20.6	29.1	0.70

Stream	Reach	Stream Miles	Gradient (%)	Woody Debris		
				# Pieces/ 100m	Vol. (m^3/100m)	# Key Pieces / 100m
	8	0.4	3.3	5.2	6.1	0.50
	9	0.4	8.5	52.3	117.6	3.80
	10	0.1	6.4	3.4	5.1	0.60
	11	1.0	11.7	16.6	33.2	0.80
	12	1.0	23.4	38.3	105.1	4.60
Kansas Creek	1	0.5	6.3	2.2	1.3	0.00
	2	0.6	11.4	16.8	32.6	0.70
Little North Fork Wilson River	1	1.2	0.8	7.4	16.6	0.00
	2	1.4	1.0	9.2	33.4	0.00
	3	5.6	2.1	14.7	36.5	0.90
	4	1.1	4.2	40.5	68.4	1.00
	5	1.5	2.4	21.1	33.7	0.70
	6	0.8	9.2	22.1	28.6	0.00
South Fork Jordan Creek	1	0.7	3.5	2.9	2.3	0.00
	2	1.6	4.8	9.2	14.4	0.10
	3	0.7	12.5	8.3	17.3	0.20
South Fork Wilson River	1	2.6	1.4	4.4	6.8	0.30
	2	1.6	2.3	11.0	14.7	0.50
	3	1.6	3.4	28.9	92.6	3.80
	4	1.5	7.1	22.6	162.6	7.40
	5	0.6	23.1	77.2	594.2	25.10
	6	0.5	21.6	11.4	102.6	4.50
South Fork Wilson River Trib B	1	0.6	4.0	13.4	27.9	1.10
	2	0.7	13.2	31.7	65.3	2.40
South Fork Wilson River Trib C	1	0.5	6.5	8.3	11.6	0.60
	2	0.3	7.6	19.6	57.3	3.20
	3	0.3	8.2	24.2	73.7	3.80
	4	1.1	14.6	22.3	82.4	5.20
W. Fk of North Fk Wilson River	1	2.0	2.2	7.6	18.1	0.30
	2	1.7	2.8	24.1	47.1	0.50
	3	2.2	8.9	26.1	54.9	0.50
West Fork Elk Creek	1	1.1	8.3	43.8	92.4	1.90
	2	0.6	19.9	64.8	137.3	2.90
White Creek	1	2.0	5.5	14.6	33.1	1.60

░ = Desirable
▓ = Undesirable
□ = Moderate

In general, the potential for LWD recruitment in the Wilson River watershed was poor (Figure 12). None of the riparian areas in the watershed demonstrated a high potential to contribute LWD to the stream channel. In seventy percent of the subwatersheds, the majority of LWD recruitment potential was low. The lack of large conifers (>24" dbh) in this watershed is likely a result of the Tillamook Burn, historic vegetation removal along the riparian corridor, and salvage logging.

Riparian vegetation is an important element of a healthy stream system. It provides bank stability, controls erosion, moderates water temperature, provides food for aquatic organisms and large woody debris to increase aquatic habitat diversity, filters surface runoff to reduce the amount of sediments and pollutants that enter the stream, provides wildlife habitat, dissipates flow of energy, and stores water during floods (Bischoff et al. 2000). Natural and human degradation of riparian zones diminishes their ability to provide these critical ecosystem functions. Shade conditions in the streams surveyed were generally rated as desirable (Figure 13). Only the Devils Lake Fork of the Wilson showed a significant proportion of less-than-desirable shade conditions.

Results from E&S's aerial photo analysis of stream shading yielded similar results to the stream reach surveys of ODFW. Stream shading conditions were generally high across the watershed. Shade conditions were high for at least 80% of the stream length in 7 of the 11 subwatersheds. Areas not rated as high generally occurred along the lower mainstem of the river and Hall Slough. Hall Slough was the only subwatershed for which the majority of the stream was not in the high shade category.

Stream channels are often blocked by natural barriers, such as waterfalls, or by human-caused barriers, especially poorly designed culverts at road crossings. This has resulted in significant loss of fish access to suitable habitat. Anadromous fish migrate upstream and downstream in search of food, habitat, shelter, spawning beds, and better water quality. Fish populations can be significantly limited if they lose access to key habitat areas.

Over 211 culverts out of a total 436 road-stream crossings have been surveyed for potential fish passage barriers and 24% of those surveyed were judged to be impassable by ODFW (Figure 14). The Wilson River watershed has an average stream crossing density of 2.3 stream crossings per square mile. Stream crossing densities were highest in the Hall Slough and Lower Wilson River subwatersheds (7.5 and 4.1 crossings/mi^2, respectively). These same two subwatersheds also contained the vast majority (84%) of the surveyed culverts that were judged to be impassable and the lowest subwatershed percentages judged to have high stream shading. The only other subwatersheds found to contain impassable culverts were Cedar Creek/Upper Wilson River and Middle Wilson River (both < 10%). It should be noted, however, that culverts have not been surveyed in four of the subwatersheds.

There are numerous tide gates in the lower reaches of the Wilson, Trask, and Tillamook Rivers, in the southern portion of the Tillamook Basin, including six in the Wilson River watershed. Four of these were identified by TBNEP as impediments to fish passage. An effort has been underway by the TCPP to replace them with fish-friendly tide gates. To date, one has been replaced, two are scheduled for replacement in 2001 (both on Blind Slough), and one is scheduled for replacement at a later date (midway between Blind Slough and the furthest end of the point in the bay). It is believed that, upon completion of this effort, all major tide gate impediments to fish passage in the Wilson River watershed will have been corrected.

Disconnecting the floodplain from the river can lead to reduced physical complexity and channel downcutting due to increased water velocities, resulting in deteriorated habitat conditions. Additionally, disconnection from the floodplain can lead to changes in the biotic structure of the aquatic ecosystem by limiting nutrient and organic material exchanges between the stream and floodplain. Dike and setback levee construction has been extensive throughout the lower reaches of the Wilson River watershed. These structures have had significant effects on flooding, hydrologic function, and fish access to estuarine wetlands. Attempts to control flooding have reduced the natural complexity of the river channel and separated the river from its floodplains. The loss of natural floodplain function has impacted other resources with economic value, such as the fish and shellfish industries. Channelization of the river has also attracted commercial and residential development to the floodplain (Coulton et al. 1996). To some degree the diking has increased streambank erosion by increasing water depth and flow velocity between the dikes (Leopold et al. 1992). In addition, the removal of large woody debris has made streambanks more vulnerable to this type of erosion process.

Wetlands contribute critical functions to watershed health, including water quality improvement, filtration, flood attenuation, groundwater recharge and discharge, and fish and wildlife habitat. The Devils Lake subwatershed, in particular, has a significant amount of higher elevation wetlands. Wetlands constitute an important landscape feature in the Wilson River watershed. The predominant wetland types are palustrine wetlands and tidal salt marshes. Palustrine wetlands are common along many of the stream corridors, although many of these have been disconnected from the stream by flood protection efforts. The Devils Lake subwatershed, in particular, has a significant amount of higher elevation watersheds.

Wetlands play an important role in the life cycles of salmonids (Lebovitz 1992, Shreffler et al. 1992, MacDonald et al. 1987, Healey 1982, Simenstad et al. 1982). Estuarine wetlands provide holding and feeding areas for salmon smolts migrating out to the ocean. These estuarine wetlands also provide an acclimation area for smolts while they are adapting to marine environments. Riparian wetlands can reduce sediment loads by slowing down flood water, allowing sediments to fall out of the water column and accumulate (Mitsch and Gosselink 1993). Wetlands also provide cover and a food source in the form of a diverse aquatic invertebrate community. Backwater riparian wetlands also provide cover during high flow events, preventing juvenile salmon from being washed downstream.

The TBNEP (1998) determined that both tidally influenced wetland habitat and intertidal mud flat habitat have been substantially reduced since the mid-1880s. During the last 50 years, considerable new salt marsh habitat has been created in the south end of the bay due to delta formation associated with high sediment input from the watershed. Recent floods have probably temporarily accelerated this process. The new salt marsh does not replace the quantity of lost marsh and wetlands and probably provides lower quality habitat than the lost mature marsh. In general, the complexity of the estuarine habitat has been reduced. Complex structure provided by large woody debris and associated pools has been removed and the connections between river channels and their flood plains have been severed (except during periodic large floods) through the construction of dikes and levees. Sediment from the watershed appears to be contributing to filling of the upper portion of the estuary and reducing the amount of pool habitat.

The overall condition of aquatic and riparian habitats in the watershed has been dramatically changed. Habitat quality for salmonid fish and other biota has been reduced. On-going and future efforts to restore habitat quality include in particular replacement of culverts and tide gates that have blocked fish access to important habitat, improvement of LWD recruitment potential, and reconnection and restoration of wetlands.

Hydrology

Human activities in the watershed can alter the natural hydrologic cycle, potentially causing changes in water quality and the condition of aquatic habitats. Changes in the landscape can increase or decrease the volume, size, and timing of runoff events and affect low flows by changing groundwater recharge.

Peak flows occur as water moves from the landscape into surface waters. The primary peak flow generating process for the Coast Range and its associated ecoregions is rain events. The Coast Range generally develops very little snow pack. Snow pack that does develop in the coastal mountains is only on the highest peaks and is of short duration. Rain-on-snow events are infrequent in the Coast Range, although these events have contributed to some of the major floods, including the floods of 1964 and 1996. These large floods are rare events, and we have no data to suggest that current land use practices have exacerbated the flooding effects from rain-on-snow events.

Topography in the Wilson River watershed is characterize by steep headwaters that lead quickly into low gradient floodplains (Figure 15). Elevations in the watershed range from sea-level to 3,691 feet it its highest point. Precipitation ranges from 86 inches annually in the lowlands to 157 inches in the highest elevations of the watershed (based on PRISM calculations; Daly et al. 1994).

Flooding is a natural process that contributes to both the quality and impairment of local environmental conditions. Consequently, an ideal flood management strategy attempts to reduce flood hazards and damage while protecting the beneficial effects of flooding on the natural resources of the system. River flooding tends to occur most commonly in December and January during periods of heavy rainfall or snowmelt, or a combination of both. River flooding combined with tidal flooding can magnify impacts. The lowland valleys are the most prone to flooding during these periods.

The Wilson River watershed has the largest floodplain area within the Tillamook Basin, at almost 5,000 acres. One of the primary natural functions of the floodplain is to reduce the severity of peak flows, thereby reducing down-stream impacts and flood hazards. However, much of the floodplain area in the Wilson River watershed has been altered. The floodplain has been largely disconnected from the river and its tributaries through the construction of dikes and levees, reducing floodplain storage of flood waters.

Increased peak flows can have deleterious effects on aquatic habitats by increasing streambank erosion and scouring (ODFW 1997). Furthermore, increased peak flows can cause downcutting of channels, resulting in a disconnection of the stream from the floodplain. Once a stream is disconnected from its floodplain, the downcutting can be further exacerbated by increased flow velocities as a result of channelization.

Although the largest floods are most important from a flood hazard standpoint and are frequently associated with rain-on-snow events, the effects of increases in smaller magnitude peak flows cannot be discounted from a stream channel or ecological standpoint (Naiman and Bilby 1998). High flows constitute a natural part of the stream flow regime and are largely responsible for transporting sediments and forming channels. Consequently, increases in the magnitude of moderate peak flows can lead to channel incision through bank building or erosion. Because forest harvest practices are common in the watershed, there may be effects of forestry on watershed hydrology other than those commonly associated with rain-on-snow events. These might include reduced evapotranspiration, decreased infiltration and subsurface flow, and increased overland flow (Naiman and Bilby 1998). Such changes may result in modified peak and low flow regimes and subsequent effects on instream aquatic habitat quality.

Both the Lower Wilson and Hall Slough subwatersheds have large areas of agricultural land use (9% and 57% respectively; Figure 16). Consequently, there is a potential for agricultural practices to change the infiltration rates of the soil. Additionally, land cover in the Tillamook bottomland has changed significantly since being settled in the early 1900's (Coulton et al. 1996). These factors suggest a potential for hydrologic impacts and warrant further investigation once digital soils data are available.

Road construction associated with timber harvest and rural development has been shown to increase wintertime peak flows of small to moderate floods in Oregon Coast Range watersheds (Harr 1983). This assessment used a roaded area threshold of 8% to screen for potential impacts of roads on peak flows (discharge increase >20%; WPN 1999). Watersheds with a greater than 8% roaded area are considered to have a high potential for adverse hydrologic impact, 4 to 8% have a moderate potential, and less than 4% have a low potential.

According to GIS calculations from the ODF fire roads coverage, all of the subwatersheds in the Wilson River watershed were considered to have a low potential impact on hydrology from the density of forest roads.

Past fires changed the ability of the surface soils to store runoff from forested areas (c.f., Coulton et al. 1996). Burned areas, and especially areas of repetitive burns, typically show a reduced ability to store moisture in surface soils (TBNEP 1998). The Tillamook Burns of 1933, 1939, 1945, and 1956, and especially the repeated burns and construction of salvage logging roads, disrupted the infiltration and water storage capacity of the upland areas.

Screening for land management activities that may be affecting natural hydrologic conditions suggests that roads have little effect on current hydrologic regimes, but other hydrologic impacts may have occurred in response to the Tillamook Burns and/or agricultural practices (especially diking and draining of wetlands) in the valley bottoms. Loss of historical flood plain acreage and land cover (such as wetlands, forested valley bottoms) have likely had significant impacts on hydrologic conditions in the Wilson River watershed. Existing flood control features used to protect floodplain land uses have simplified natural streamflow processes in many places and reduced the complexity of instream habitats that support fish and aquatic organisms.

The documented sensitivity of valley flooding to upstream watershed conditions indicates the need for a strong management focus on restoring natural watershed functions. Future flood management efforts in the valley floodplains may be compromised by the failure to adequately address upland watershed impacts that influence the flow rate and volume of flood waters. However, altered upland processes can be difficult to restore, especially where they are part of a significant disturbance regime such as the Tillamook Burns. There is a clear need for floodplain and wetland restoration to improve flood attenuation and storage.

Water Use

Water that is withdrawn from the stream has the potential to affect instream habitats by dewatering that stream. Dewatering a stream refers to the permanent removal of water from the stream channel, thus lowering the natural instream flows. Instream water rights were established by the Oregon Water Resources Department for the protection of fisheries, aquatic life, and pollution abatement; however, many remain junior to most other water rights in these watersheds.

The largest amount of water appropriated in the Wilson River watershed is for irrigation. Most of this water is appropriated in the lower elevations of the Wilson River watershed and is most likely used for maintaining dairy pastures. Due to rural residential development on the outskirts of the city, there is a also small amount of water appropriated from the Wilson River for domestic water use (3.74 cfs). During very dry seasons, domestic water used combined with irrigation withdrawals in the lower elevations of the Wilson River watershed may have deleterious effects on instream habitats by reducing instream flows. However, appropriated water represents only 12% of modeled instream flows (based on a 50% exceedance) suggesting that the impacts are limited to low flow periods.

Based on current water availability model outputs, there appears to be little concern for dewatering in the Wilson River watershed. None of the subwatersheds demonstrated water loss greater than 2% of the predicted instream flows. Consequently, it is unlikely that water withdrawals from the Wilson River and its tributaries are having a large impact on current instream flows. However, any time water is appropriated for out-of-stream use, there is a potential for some effects on the instream habitats to occur during periods of very low flow.

During the low flow months (July through October), mean daily discharge was below the instream water right almost 50% of the time, with the highest percentage of occurrences in August through October. Assuming that the instream water right is a good indicator of habitat conditions for salmonids, there is a potential for low flow conditions to have a deleterious effect on local salmonid populations. Consequently, any out-of-stream water use during these low flow situations will only exacerbate habitat problems. Instream flow requirements for salmonids need to be further evaluated to determine actual impacts of surface water withdrawals on salmonid populations.

Sediment Sources

Erosion is a natural watershed process in the Oregon Coast Range. The bedrock geology of much of the Oregon Coast is composed of weak, highly erosive rock types. However, most experts agree that land use practices have increased the rate of erosion in many coastal watersheds (WPN 1999, Naiman and Bilby 1998). High levels of sediment in rivers and streams is associated with loss of agricultural lands to bank erosion, and filling of the estuary. Sediment is also negatively impacting many aquatic organisms. Understanding the role of erosion and its interaction with other watershed processes is critical to maintaining a healthy ecosystem. The majority of sediment deposition into the stream system occurs during large storm events. The major floods of February, 1996 focused attention on the sediment accumulating in Tillamook Bay, which is perceived to be blocking rivers and channels.

Upland processes that deliver sediment to the stream system include landslides and surface erosion. In lowland streams and rivers, erosion occurs principally as streambank erosion, which often causes significant losses of riparian agricultural land. Wildfires alter soil conditions, setting the stage for increased rates of erosion. In this watershed, slope instability, road instability, and rural road runoff are the most significant sediment sources. Shallow landslides and deep-seated slumps are common in the Oregon Coast Range. Streamside landslides and slumps are major contributors of sediment to streams, and shallow landslides frequently initiate debris flows. Rural roads are a common feature of this watershed, and many are present on steep slopes. Washouts from rural roads contribute sediment to streams, and sometimes initiate debris flows. The density of rural roads, especially unpaved gravel and dirt roads, indicates a high potential for sediment contribution to the stream network.

Agricultural and pasture land runoff, as well as the history of fire in the Tillamook region are also contributing factors. However, agricultural and pastoral lands occupy only about 2% of this watershed, and are mostly located at the lower elevations of the watershed. Urban runoff is not a major contributor of sediment in this watershed. Developed lands occupy less than 1% of the Wilson River watershed.

Under natural conditions, geology, topography, and climate interact to initiate landslides. With human intervention, natural conditions may be modified in ways that increase the likelihood of landslide initiation. Road-building often creates cuts and fills. In a slide-prone landscape, road-cuts may undercut slopes and concentrate runoff along roads, and road-fills on steep slopes may give way, initiating a landslide. Vegetation removal, such as by logging or wildfire, may also increase the likelihood of landslide and consequent debris flow occurrence. In the short term, a debris flow can scour a channel or remove beneficial prey (benthic macroinvertebrates) and channel structures. Over the long-term, these events deliver woody debris, organic matter, and gravel that could result in the reestablishment of productive aquatic habitat and provide an important reset mechanism to the stream ecosystem.

Agricultural and urban lowlands occupy approximately 8% of the Tillamook Bay watershed (USDA 1978). USDA (1978) estimated that 60,613 tons (54,976 metric tons) of sediment enter Tillamook Bay annually. Of that total, 9,010 tons (8,172 metric), or 15%, were determined to be derived from agricultural lands. As in upland streams, non-organic sediment plays an important role in stream channel morphology. Organic sediment, including wood, contributes to channel structure, and to the aquatic habitat and food resources of the fluvial ecosystem. Human uses of the lowlands have affected the rate and character of lowland sedimentation through changes in flooding frequency and size, and by the diking of floodplains and tidal wetlands. In addition, channel modification, removal of LWD, and streamside grazing have increased streambank erosion. These changes have in turn affected the quantity and quality of riparian and aquatic habitat in the lowlands.

Sediment in the rivers and streams of the Wilson River watershed has been an issue of great concern for many decades. The combination of the wet climate, steep slopes in the uplands, and very erosive soils results in naturally high levels of sediment in the rivers and streams. The historic wildfires in the watershed, as well as resource management practices over the past century are associated with an additional increase in sediment levels. High levels of sediment in the streams have been associated with increased rates of sedimentation in Tillamook Bay. Additionally, high sediment levels are associated with the declining health of salmonid populations.

Based on the landslide inventory conducted in the North Fork of the Wilson subwatershed, as well as studies conducted in nearby areas, landslide frequency in the Wilson River watershed appears to be very high. However, a comprehensive landslide inventory of the whole Wilson River watershed is lacking, so the specific locations of landslide activity are unknown. Previous assessments of sediment in the Tillamook Bay watershed have suggested that landslides and debris flows contribute the majority of the sediment in the watershed.

Roads are the primary source of sediment related to human activity. Contribution of sediment from roads is attributed to two processes: landslides originating from roads, and road runoff. Landslides coming from roads produce the largest proportion of road-associated sediment. The high density of stream-crossing culverts and sidecast dirt and gravel roads indicates that road-associated landslides are of significant concern in the Wilson River watershed. The ODF road inventory will provide detailed road information on ODF lands, which constitute the majority of the gravel and dirt roads in the Wilson River watershed. Additionally, cooperation with private landowners to identify and reduce sediment sources on private roads could further mitigate the impact of sediment in the watershed.

Lastly, streambank erosion is a concern in the Wilson River watershed. While the overall contribution of sediment from streambank erosion is less significant that other sources, erosion from the streambank is associated with a lack of riparian shade. Restoration of riparian vegetation and prevention of livestock grazing near streambanks will lessen sediment contribution from streambank erosion.

Water Quality

The water quality assessment proceeds in steps. The first step is to identify uses of the water that are sensitive to adverse changes in water quality, and identify potential sources of pollution in the watershed. The second step establishes the evaluation criteria. The third step examines the existing water quality data in light of the evaluation criteria. Conclusions can then be made about the presence of obvious water quality problems in the watershed, and whether or not additional studies are necessary. The ODEQ has developed the Oregon Water Quality Index (OWQI) as a water quality benchmark that is keyed to indicator sites monitored regularly by ODEQ. The OWQI integrates measurements of eight selected water quality parameters (temperature, dissolved oxygen, biochemical oxygen demand, pH, ammonia+nitrate nitrogen, total phosphates, total solids, fecal coliform bacteria) into a single index value that ranges from 10 (the worst) to 100 (the best). Land use, geology, hydrology, and water quality vary widely throughout the North Coast basin. Comparing minimum seasonal Oregon Water Quality Index (OWQI) values, water quality ranges from excellent at the upper Wilson River site to fair at the other sites in the watershed. Water quality data were collected by the ODEQ laboratory in 1985-1987 for the Tillamook Bay Tributaries special study, and regular quarterly ambient monitoring of all of the sites began in 1992.

All major tributaries, as well as the Wilson River mainstem were sampled for temperature in either the 1997 or 1998 summertime monitoring season and continuous monitoring data have passed ODEQ quality control protocols. Data have been statistically processed to yield the 7-day average of the daily maximum temperatures. The Wilson River mainstem is temperature limited throughout its entire stream length. In summer months, the Wilson mainstem reaches stream temperatures greater than 20.3°C (68.5°F) and sometimes exceeds 24.0°C (75.2°F) in the lower reaches. These data suggest that the Wilson River is impaired for temperature relative to salmonid rearing and growth.

Of the 398 available dissolved oxygen measurements, 27 (7%) were below 8.0 mg/L, and 175 (44%) were below 11.0 mg/L. These data suggest that at least portions of the Wilson River are moderately impaired with respect to dissolved oxygen to support salmonid spawning and incubation.

Available monitoring data suggest that nitrate concentrations have increased in the Wilson River since the 1960s (Figure 7). The cause of such an increase in nitrate cannot be determined from the available data. It is possible that nitrogen fixation in large alder stands in the Wilson River watershed may be contributing to higher nitrate concentration in the river. The available data suggest, however, that the Wilson River water quality is impaired with respect to nitrogen.

Large changes in both loads and concentrations of fecal coliform bacteria are associated with storm events, especially during the fall season. Based on the available data, water quality in the Wilson River is impaired with respect to bacteria. It has been suggested that prior moisture conditions and amount and intensity of rainfall play important roles in controlling the flux of fecal coliform bacteria into surface waters (Dorsey-Kramer 1995; Jackson and Glendening 1982). Particularly high concentrations have consistently been observed during small summer storm events and the first storms after the summer low flow season (Jackson and Glendening 1982).

The data collected by Sullivan et al. (1998a) can be used in a very limited fashion to examine whether or not the concentrations of fecal coliform bacteria have changed appreciably since the last major study of this type in 1979-1980 (Jackson and Glendening 1982). Although the available data are too limited to allow for a statistical evaluation, they are consistent with the belief that major changes in the extent of bacterial contamination of the rivers have not occurred in recent decades.

Only 3 of 218 measurements exceed the turbidity evaluation criterion of 50 NTU. Turbidity is often directly proportional to TSS. Concentrations of TSS were typically in the range of about 5 to 400 mg/L in the Wilson River, which had consistently higher TSS concentrations than the other rivers. Highest TSS concentrations were observed during large storm events.

There was a general relationship between TSS concentrations and flow, with greater flows resulting in increased TSS concentrations. TSS concentrations were consistently higher in the lower river as compared with the forest/agriculture interface site, suggesting that the agricultural and residential portions of the watersheds do contribute sediment loads to the rivers. However, the difference in measured TSS values at paired upper and lower sites was generally small, less than about 30 mg/L, even at relatively high TSS values (> 50 mg/L). This suggests that most of the TSS is derived from the forested uplands, but that some TSS is also derived from the agricultural lowlands.

At the screening level of this assessment, water quality in the major streams of the Wilson River watershed would be considered impaired because of the frequency of exceedence of the evaluation criteria for temperature, nitrogen, and bacteria. Dissolved oxygen may also be a problem in the lower reaches of the river near the mouth. There is no reason to suspect that the river suffers from impairment with respect to pH, total phosphorus concentration, turbidity, or trace metals. There is not sufficient data to make a determination with respect to organic contaminants.

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