Fluvial Geomorphic Analysis of the Tillamook Bay Basin Rivers

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1. INTRODUCTION

The catastrophic flood events of February 1996 renewed interest in improving flood protection in the Tillamook Bay Basin (Plate 1). This was not the first major flood event; major flooding dates back to the initial settlement of humans on the Tillamook alluvial floodplain. Post-flood reports from the Portland District, U.S. Army Corps of Engineers (Corps) date back to the early 1960s. Report data provides positive information that flood events have had major impacts on the basin. Although the results are visible, the processes and historic, present, and future conditions require additional understanding. Research conducted under the Tillamook Bay National Estuary Project (TBNEP) provides a plethora of information from the early to middle 1990s. The U.S. Environmental Protection Agency (USEPA) coordinated these cooperative research agreements.

Intent and Scope of the Present Study

The purpose of this Tillamook Bay assessment is to inventory and characterize the five river basins (the Miami, Kilchis, Wilson, Trask and Tillamook Rivers) within the study area of Tillamook County, and to provide a foundation in order to undertake a geomorphic assessment. Reviewing and synthesizing existing data, as well as collecting new data during site visits to the study area, were conducted for this assessment.

It is important to understand that there are a number of documents that provide assessment of the individual watersheds. These reports also contain sections dedicated to river basins or subdrainage basins. Summarizing the existing basin conditions will provide a foundation for the geomorphic model and the hydrologic model, which will be developed in the Corps' General Investigation Study of the Tillamook Bay Basin.

The TBNEP recently characterized many of the resources in the Tillamook Basin. These documents provide a fundamental collection of reference material for the existing basin conditions and site references to earlier investigations. The historic and baseline setting is provided in the 1978 report, *Tillamook Bay Drainage Basin Erosion and Sediment Study Oregon,* prepared by the Tillamook Bay Task Force, the Oregon Water Resources Department (OWRD), and the U.S. Department of Agriculture, Soil Conservation Service (SCS). These documents provide a wealth of baseline information, and data for this assessment was taken from some of these reports. Nevertheless, data was logically presented with little geomorphic analysis conducted.

Setting

Tillamook Bay is a small, shallow estuary located on the northern Oregon Coast about 80 miles south of Astoria and 60 miles west of Portland. The bay's current geographic dimension is 6 miles in length and up to 3 miles in width; it averages about 6 feet in depth over its 13 square mile area. The settlement and therefore, the human impact on the Tillamook Bay Basin, started in the 1850s. Small rural/agricultural settlements were established and petitioned the State of Oregon to create Tillamook County.

On December 13, 1853, the State Legislature established Tillamook County, as well as several of the surrounding counties. Shipment of all products was by sea until 1871, when the first road access was completed; however, it was not until some 30 years later that rail service was established. From this early date, humans started to modify the environment to enhance their living conditions.

Today, it appears that the bay and channel network are being loaded with sediment. This reduces boat and access from the bay to the river systems that drain into the bay. There is an apparent perception that at the river-bay interface, channel sedimentation rates have or are increasing; sediments are now plugging channels, reducing in-flow capacity, and increasing flood levels and duration.

This apparent erosion-sediment problem has been combined in part with the devastating forest fires that burned over extensive areas in the basin between 1933 and 1945. The fire history is complex, burning and laying bare over 228,000 acres of highly erodible volcanic material to winter storms. These intense precipitation events saturated the soil, and coupled with steep slopes and highly weathered rock material, increased the sediment loading of basin channel systems for many years after the last fire.

Geomorphic processes from these events have formed larger channel systems. Sediment transport also was accelerated downslope by numerous mass movement types of processes. During storm events, high discharges can transport higher volumes of sediment out of the mountain reaches and to the alluvial/delta complex and the bay/river interface zones. This process causes sediment loading of the complete channel system, which increases temporary sediment storage from the mountain reaches to the lower channel/bay reach.

A summary of the erosion-sediment problem in the Tillamook Basin is provided below.

- Channels in the bay are impassable to most shipping because of sediment.
- Sediment carried down the rivers and into the bay has built up at rapid rates, filling former channels south of Garibaldi.
- The drastic erosion-sediment problem has been traced in part to the devastating forest fires between 1933 and 1945. These fires have exposed over 228,000 acres of highly erodible material to severe winter storms.
- As these channels became larger, more soil particles and debris were carried down the slope and accelerated erosion problems.

- The lower river channels were choked with sediment; as a result of reduced channel capacity, flooding was often aggravated during storms.
- Commercial activities such as farming, logging, road construction, and uncontrolled cattle movement across streambanks increased the erosion-sediment problem.
- The general problem is obvious: too much sediment.
- The problems are complicated and oversimplification is a hazard.

Previous Geologic and Geomorphic Work

The study area was relatively far from population centers (Willamette Valley) and lacking in significant mineral wealth; as such, it has been the focus of very few geologic investigations. The area was covered in general terms in regional reconnaissance studies by Warren and others (1945) and Wells and Peak (1961). Early geologic investigations were conducted by Layfield (1936) and Baldwin (1952), and were related to the study of volcanic rocks.

The majority of geologic studies are related to flood data along the five major rivers within the Tillamook Bay Basin (post-flood reports by the Corps in 1966, 1972, 1978, and 1999). The flood events of the early 1960s energized an expansion of general investigations, which included the impacts of logging and agricultural activities in the basin. Waananen and others (1971) also generated documentation of the 1964 and 1965 flood events. The Oregon Department of Geology and Mineral Industries (DOGAMI) published two reports that considered environmental geology and flood events in Tillamook and Clatsop Counties (DOGAMI 1972, 1973). These reports provide the foundation and the bulk of the geologic investigations in the study area.

The erosion and sediment study prepared by the Tillamook Bay Task Force and others (1978) appears to present the view that a serious sediment problem exists in the Tillamook Bay Basin. In addition, it appears that all impressions and actions related to the sediment-erosion problem in the basin are linked to this document. Some information about the study and its conclusions are provided below.

- The study used 1975 as a baseline date.
- Sampling sites and suspended sediment samples were collected from the five rivers.
- Sediment samples from the bay floor were collected.
- The five river basins were subdivided into agriculture or forestlands.
- Erosion on agricultural lands was divided into two major groups (29,490 acres): streambank erosion or sheet and rill erosion on croplands.
- Forestland erosion was divided into seven major groups (323,050 acres): roads, trails, landslides, streams, clearcuts, forested areas, and burns.
- The study found that sediment enters the bay at the rate of 61,000 tons annually.
- The study found that forestlands in the upper watershed comprise over 90% of the area and contribute about 85% of the sediment.

Tables 1 and 2 provide data from the study on the erosion and sediment production from agricultural and forestland, respectively. Tables 3 and 4 provide data from the study on the sediment delivery from agricultural and forestland, respectively. The data in the tables show that 61% of the mean annual erosion and 86% of the mean annual sediment is on agricultural land, and that 17% of the mean annual erosion and 52% of the mean annual sediment is on forestland (Plate 1).

In 1992, the USEPA established a National Estuary Project; the Tillamook Bay/Estuary was added into the program, which allowed funding for the TBNEP.

Table 1. Stream System Erosion and Sediment Production for Agricultural Land

Subbasin	Stream System Mean Erosion (tons per year)	Stream System Mean Sediment (tons per year)	Percent
Miami	1,211	1,114	16
Kilchis	1,414	1,300	17
Wilson	1,973	1,874	24
Trask	2,479	2,355	30
Tillamook	1,152	1,071	16
TOTAL	8,229	7,714	---

Source: Tillamook Bay Task Force et al., 1978.

Table 2. Stream System Erosion and Sediment Production for Forest Land

Subbasin	Stream System Mean Erosion (tons per year)	Stream System Mean Sediment (tons per year)	Percent
Miami	3,026	760	2
Kilchis	1,760	1,378	5
Wilson	15,198	7,720	29
Trask	25,295	13,846	50
Tillamook	3,500	2,929	11
TOTAL	48,799	26,633	---

Source: Tillamook Bay Task Force et al., 1978.

Table 3. Sediment Delivery from Agricultural Lands in the Tillamook Bay Basin

Total Acres	Mean Annual Gross Erosion - Acres	Percent and Tons of Sediment Reaching the Stream
Miami Subbasin 1,260 acres	220.2 tons from 1,205.6 acres	27% or 59.0 tons/year
Kilchis Subbasin 3,600 acres	1,211.2 tons from 10.9 acres	92% or 1,114.3 tons/year
Wilson Subbasin 4,430 acres	634 tons from 4,090.2 acres	25% or 144 tons/year
Trask Subbasin 11,900 acres	1,896.4 tons from 10,651.7 acres	95% or 2,355 tons/year
Tillamook Subbasin 9,570 acres	1,868 tons from 9,340 acres	20% or 370 tons/year

Source: Tillamook Bay Task Force et al., 1978.

Table 4. Sediment Delivery from Forest Lands in the Tillamook Bay Basin

Total Acres	Mean Annual Gross Erosion - Acres	Mean Annual Gross Fluvial Sediment	Bedload	Sediment Delivery to Fluvial Sediment
Miami Subbasin 24,290 acres	20,492.0 tons or 540.0 tons/sq. mile	2,041.4 tons or 53.7 tons/sq. mile	47.0%	10.0%
Kilchis Subbasin				
Upper Kilchis 21,400 acres	12,040.0 tons or 360.05 tons/sq. mile	1,070.0 tons or 32.0 tons/sq. mile	47.0%	8.8%
Lower Kilchis 15,010 acres	11,704.7 tons or 578.5 tons/sq. mile	2,310.7 tons or 98.5 tons/sq. mile	64.0%	19.7%
South Fork Kilchis 6,910 acres	10,466.1 tons or 967.2 tons/sq. mile	1,001.1 tons or 92.6 tons/sq. mile	17.0%	9.5%
Wilson Subbasin				
Lower Wilson 47,720 acres	41,535.4 tons or 557.0 tons/sq. mile	8,514.8 tons or 114.2 tons/sq. mile	20.5%	20.5%
Upper Wilson 56,960 acres	28,833.3 tons or 324.0 tons/sq. mile	4,325.4 tons or 46.8 tons/sq. mile	41.0%	15.0%
North Fork Wilson 16,430 acres	7,103.44 tons or 276.72 tons/sq. mile	416.1 tons or 16.2 tons/sq. mile	41.0%	16.0%
Trask Subbasin				
Main Trask 69,920 acres	78,504 tons or 718.6 tons/sq. mile	16,485.8 tons or 150.9 tons/sq. mile	19.0%	21.0%
East Fork Trask 18,830 acres	29,002 tons or 985.8 tons/sq. mile	7,250.5 tons or 246.5 tons/sq. mile	11.0%	25.0%
South Fork Trask 13,190 acres	4,995.7 tons or 240.45 tons/sq. mile	1,090.27 tons or 52.9 tons/sq. mile	48.0%	22.0%
Tillamook Subbasin 33,570 acres	41,628.7 tons or 703.7 tons/sq. mile	7,097.6 tons or 135.3 tons/sq. mile	7.6%	17.0%

Source: Tillamook Bay Task Force et al., 1978.

Sediment Problem

Brown and others (1958), Terich and Komar (1974), Percy and others (1974), Komar and Terich (1976), and Schubek and Meade (1977) indicate that the extensive farming and logging that followed settlement of estuarine drainage basins, as well as construction of jetties to facilitate navigation at estuary mouths, contributed to shoreline erosion and/or deposition.

Tillamook Bay Sediment

Analysis by Glenn (1978) found a mixture of sediment from various sources in some parts of Tillamook Bay. The tidal rivers of Tillamook and Tillamook-South Trask have sediments from both river and shoreline sources, as in parts of the southwestern and eastern margins. The almost total dominance of sediments from the river source in the combined Tillamook-Trask tidal rivers and in the eastern margin south of Kilchis Point, indicates that the rate of sediment supply from the shoreline source far exceeds the river source in much of Tillamook Bay. Komar and others (1997) found that currently, 60% of the total bay sediment has a shoreline source. This could indicate that the rate of supply and/or transport has undergone modifications over the last 50 years.

According to Glenn (1978), sedimentation in Tillamook Bay during the Holocene shows two rates of infilling: the period between 9,000 to about 7,000 years ago was the most rapid, and the period from 5,000 to 3,000 years ago was at a slower rate. During this earlier period, a structural ridge between northern and southern Tillamook Bay appears to have developed. The structural ridge divides the bay along a south to north axis. Sedimentation patterns and bathymetric surveys date back to 1867. The 1957, 1995, and 2001 data sets are of major significance. Depositional patterns and trends indicate bay aggradation east and limited erosion west of the structural high (Corps of Engineers, Portland District, internal working documents, 2001). Tillamook Bay has a complex sedimentary history, which is outside the scope of this analysis. The governing investigative factor for this assessment is the aggradation of the eastern bay/river zones.

Methods and Limitations

There are extensive data gaps in the knowledge of the geomorphology and geology of the Tillamook Bay Basin. However, it was beyond the scope of this effort to undertake any geologic field investigations or to develop additional geomorphic data sets. New interpretations are offered, and geomorphic processes are combined with resolving inconsistencies in existing data sets and problems normally encountered when data from multiple sources are synthesized into a single fluvial geomorphology format.

It is acknowledged that perceptions and factual data sometime initially conflict. This report presents material that combines these factors to present the current geomorphic conditions leading to possible predictions of future geomorphic conditions. The geomorphic analysis involved identifying the physical processes actively reshaping the alluvial deposits and determining the importance of each one to long-term sediment production. Aerial photographs taken of the alluvial plain deposits in 1939, 1965, and 2000 were studied to identify historic and current geomorphic processes. The processes identified were depositional and erosional in nature. Geology, geomorphology, hydrology and forest events were combined with aerial photography and analyzed to provide a processes driven explanation of current and future landscape developments of the Tillamook Bay Basin.

Map and Aerial Photo Interpretation

Maps of the Tillamook Basin by the Tillamook Bay Task Force and others (1978) provide a wealth of geologic, hydrologic, erosion and sediment, and slope data to serve as baseline data sets. Basic geologic quadrangle-scale mapping by the U.S. Geological Survey (USGS) and other researchers provides the geology of the area. Bostrom and Komar (1997) documented the rock types in the Tillamook Bay Basin for the TBNEP.

Due to the large area and scale of the alluvial sediment plain, aerial photographs constitute an indispensable tool for initial landform and drainage identification and delineation. Subsequently, photo interpretation is typically refined using subsurface data, topographic and hydrologic information, soils maps, land use patterns, and field reconnaissance. Multiple aerial photo coverage flown at different dates has become essential. It provides opportunities to observe geomorphic basin modifications over time. Some limitations were encountered, however, due to the vast quantity of photos and the lack of total basin coverage.

The most used coverage has been individual frames and index mosaics of vertical, black and white photography at a scale of 1:20,000 obtained from the Corps. Coverage from this source is available at various intervals and area coverage; however, study area coverage of the Kilchis, Wilson, and Trask Rivers from 1939, 1965, and 2000 mosaics were compiled and reproduced digitally and geographically rectified. These photos are of exceptional quality and allowed interpretation of geomorphic and cultural condition modification over time. Discharge variations occur between the photos based on gauge data from the Wilson and Trask Rivers (Table 5). These data sets aided in mapping river pattern changes, and processes such as gravel bar development, erosion, and basic fluvial changes. Topographic and basin delineation analyses were undertaken based on USGS topographic maps.

Table 5. Wilson and Trask Rivers Discharge Data During Aerial Photograph Flights

Flight Date	Wilson River Discharge	Trask River Discharge
May 12, 1939	183 cfs	184 cfs
April 26, 1965	625 cfs	470 cfs
Sept. 29, 1999	54 cfs	76 cfs
March 24, 2000	1,270 cfs	1,080 cfs

Field visits were made to each river basin to verify the processes, conclusions, and to define smaller scale features. Both visual methods and geo-positioning systems were used to locate major sites. Spot measurements were made of active channels, channel slopes, terrace formations, and on the alluvial plain. During the field visit, specific investigations included channel descriptions, comparative differences in surface and channel conditions based on data analysis of the historic photographs and current conditions. Upper basin terrain, geologic rock type, and slope were analyzed in order to understand sediment yield.

Subsurface Investigations

The lack of outcrops on the alluvial plain complex or massive bank exposures of more than a few feet led to an interest in obtaining water well log information. It was hoped that well log data would provide clues to alluvial plain deposits, development, and deltaic formation, as well as answers to the thickness and geographic distribution of the alluvial plain deposits. However, although well log information was abundant, it provided limited data.

In the alluvial plain area, less than 10% of all borings are more than 200 feet deep and do penetrate through or into the major of the alluvial sequence. Holocene alluvial deposits are reached. The effect of these sections created with the well log data in depth and geographical subsurface variations are discussed in later sections. By combining these items and analyzing the well log data, a basic geomorphic model was developed. The model was used to couple historic geomorphic activity to predict future processes and impact along the alluvial plain and deltaic area.

Sediment Transport and Sediment Forecast

The overall objective of the sediment transport analysis was to develop a sufficient understanding of the processes in order to identify historic conditions and to be able to forecast future trends. Standard methods of analysis, such as streamflow, sediment transport measurements and computer modeling were generally not used in the study. The lack of detailed sediment transport models and limited scope of this study did not allow for data collection. However, the magnitude and mechanics of the sedimentation processes allowed for a more generalized approach based on field investigation and aerial photography.

The significant transport processes in gravel and steep-sloped terrain have been described by a number of researchers. Sediment transport assessments were made for some basins to estimate long-term potential erosion/deposition conditions in the study area. After an understanding of the historic and current geomorphic processes were developed, the next step was to prepare a geomorphic forecast. The key element in the future forecast or trends is the sediment available for erosion, transport and deposition.

The geomorphic analysis determined that the extremely high historic sediment supply was the result of rapid sediment delivery to the channel network, and that the constant hydrology to transport those high loads would continue until the sediment load would reach a “stable” longitudinal profile and cross-sectional geometry. Judgments were made about the main channel systems crossing the alluvial plain as to the idea of “stable” conditions. The idea of “stable” conditions is based on geomorphic analysis, pre-fire conditions, hydrology, and local geologic conditions.

Longitudinal Profile Comparison

Longitudinal profiles for the study reaches of the Miami, Kilchis, Wilson and Trask Rivers were constructed using data from 1978 and 2000. A Tillamook River profile was not constructed because the study reach is only 2 river miles, and is at or below the sea level datum plain. The 1978 elevation data is based on NAVD 1929 (FEMA 1978) and was compared with 2000 elevation data from the Corps (2001), with a datum of NGVD 1988. Mathematical corrections were completed to superimpose the profile elevation data from each river. Survey information indicates that there is an elevation correction between these two base elevation data sets.

Constructing longitudinal profiles with differing datum plains could induce a degree of elevation error. Using the standard geodetic correction factor of 3.1 feet, the numerical error should be minimal. Regardless, it was decided that a 1 foot plus or minus allowance would be used. Based on these allowances, the longitudinal profile data provided important information linking geomorphic processes and current fluvial conditions. The plotted profiles use raw elevation points for ease of comparison. Data analyses of the constructed longitudinal profiles indicate an increase in bed elevations for the majority of the rivers plotted. Each river has both degrading and aggrading reaches. There appear to be limited reaches that are in a state of pseudo-equilibrium.

2. REGIONAL GEOLOGIC SETTING

Geologic Units

Bostrom and Komar (1997) provide an update, review, and summary of the geologic rock formations found within the Tillamook Bay Basin. The Siletz River Volcanics (Tsr) are the oldest rock unit identified in the basin about 50-62 Ma (mega-annum or millions of years), making them early Eocene. The typical suite of volcanics consists of aphanitic to porphyritic flows, tuff breccias, and some massive lava flows. Tectonic activity created sills of thoeleiitic alkolic basalt. The upper units are interbeds of basltic siltstone, sandstone, tuff, and conglomerate. The origin for most of the unit is marine with seafloor deposits interbedded (Walker and MacLeod 1991).

There are six additional formations found within the basin ranging in age from Eocene to Miocene. Rock type consists of massive- to thin-bedded marine sedimentary units with volcanic material interbedded. These rock types are eroded by the drainage system of the basin. The weathering effect on the geologic column (volcanic and marine units) provides a constant sediment supply. Additional impacts generate fluctuations in the sediment supply but not the transport capacity. Bostrom and Komar (1997) base their detailed descriptions of the rock types in each river system (Miami, Kilchis, Tillamook, Wilson, and Trask) on the basic geologic map of Walker and MacLeod (1991).

Tectonics

The eastern uplands of the Tillamook Bay Basin are a broad northeast-plunging structural arch in Tertiary volcanic and sedimentary strata. Eocene basalt and interbedded marine strata constitute the core of this structural feature. The major fault zones are northwest trending, and locally truncate the southwest-striking Siletz River Volcanics. The major river systems flow westward cutting across the northwest-trending fault systems.

Engineering Characteristics of Geologic Units

The engineering characteristics of the geologic units in the Tillamook Bay Basin are discussed by DOGAMI (1972, 1973) and only a cursory review is presented here. Six quadrangle maps in a section of the DOGAMI reports delineate the geologic units. Plate 2 provides the fundamental basin geology.

The volcanic material in the basin is constantly undergoing attack by both chemical and physical weathering agents, and by the interrelated processes of mass wasting and erosion. The chemical and physical weathering breaks down the unstable volcanic bedrock material and a variety of gravel-induced mass wasting processes transport the sediment downslope to the fluvial system, which is ultimately transported to the bay.

The basin geology creates areas of steep slopes, landslide or mass movement topography, weak or no-cohesive strength sediment, and sedimentary rocks that result in a landscape that favors slope failure, which is inherently unstable and especially sensitive to modification and slope loading during storm events. Slope failures under the influence of gravity and water weight have occurred throughout the geologic history of the Tillamook Bay Basin. Shallow slumps, rapid earthflows, rockfalls, and debris flows characterize the upper basin sediment delivery processes.

The factors of mass movement or slope failure of regional scope include climate and rock type. The climate of the basin is moist marine and is typified by heavy winter storm events that produce high amounts of precipitation. This water increases the weathering processes of these non-cohesive rocks, increases pore pressure, decreases shear strength within the basin rock types, and initiates slope failure in the upper basin area. The weathering of the volcanic rocks the marine sediments, which are composed of high clay, are prone failure under the basin's climatic conditions.

Engineering and Habitat Restoration Sites

Projecting geomorphic response to predict the impact of engineering actions is a predictive tool based on historic geomorphic patterns and processes combined with current events. Due to the risk and uncertainty of predicting channel processes from engineering actions, only three general types of actions are modeled in this assessment: (1) realign, deepen, and/or widen the channel, (2) remove revetments/levee systems, and (3) take no action.

3. GEOGRAPHIC AND PHYSIOGRAPHIC SETTING

Tillamook Bay Basin

Some general information about Tillamook Bay is provided below.

- The bay is about 6 miles long, up to 3 miles wide, and covers about 12 square miles at high tide.
- In 1978, average depth in the bay was about 6 feet.
- The watershed that drains into Tillamook Bay measures 550 square miles and consists mostly of steep forested terrain.
- Climate is dominated by strong marine storms off the Pacific Ocean, with wet winters and moderately dry summers; temperature ranges are narrow. Frequent southwest storms between November and March bring heavy rainfall over short periods of time.
- Average annual precipitation for the basin is 115 inches, ranging from 90 inches at Tillamook to 150 inches at higher elevations.

Sediment and Landscape

Geomorphic evolution of the Tillamook Bay Basin has changed or moved the dynamic equilibrium conditions resulting in a landscape in flux. Noticeable modifications have occurred in the upper watershed, along the rivers and floodplains, and to the river/bay/estuary environments.

Flooding and sedimentation patterns have impacted the Tillamook Bay Basin watershed from its minor tributary streams to its five major river systems. High sedimentation volume is acknowledged in a Corps' internal document from the early 1900s. The quantities were not defined, but it was stated that, "considerable quantities of gravel, sand, and mud is annually deposited in the bay and channels."

The DOGAMI (1973) documented the sediment sources in the basin as stream bank erosion, landslides and debris flows. The report of the Tillamook Bay Task Force and others (1978) analyzed the five watersheds and concluded that landslides (natural or man-induced) are numerous in all basins. The Wilson and Trask watersheds produced a significant occurrence of landslides; the steep and highly weathered volcanic bedrock combined with ample hydrology produced slope failures in all basins within the watershed.

Subsurface Geologic Analysis of the Tillamook Bay Alluvial Plain

The Tillamook alluvial plain is underlain by fine-grained marine sedimentary rocks and associated volcanic rocks. The DOGAMI (1972) concluded the material is of low porosity and permeability, and that water yield in the study area is low. The groundwater movement is oriented down gradient (west to northwest). Discharged groundwater provides much of the fluvial network base flow during the summer dry season.

The majority of subsurface data was extracted from water well logs. In 1972, DOGAMI analyzed 61 well logs for water yield, but little subsurface geology analysis had been completed. From published well log sections (DOGAMI 1972), a geologic fence diagram was constructed, and illustrates the complex nature of riverine and deltaic sedimentation patterns and/or processes (Plate 3). Well number 81, Trask River Bridge at Highway 101, and well number 65 (at Tillamook County fairgrounds) illustrate transgression and regression sedimentation patterns. Data indicates that the marine sediments are progressively transgressed by terrestrial (alluvial plain) sediments. Coupling current sea level elevation and sediment delivery patterns shows that bay infilling will continue. Deltaic zone growth and riverine transgression sedimentation will fill the eastern bay area. Initially the eastern section (east of the tectonic ridge) will fill and low volumes sediment will pass the ridge and deposit in the bay proper.

Flooding

Preliminary investigations by DOGAMI (1972) revealed that clogging of the lower streams and bay by silting was not the primary cause of flooding in the floodplain areas. The effect of high ocean tides driven farther ashore by gale force winds was a far greater cause of flooding. The report concluded that any advantage in getting floodwaters to the ocean as quickly as possible by dredging would depend on the simultaneous occurrence of flooding conditions and the ebb and slack tide. Such an occurrence would be purely coincidental and not dependable. Commonly, the high ocean tides would combine with stream flooding to overflow the deepened channel ways regardless of the dredging effort.

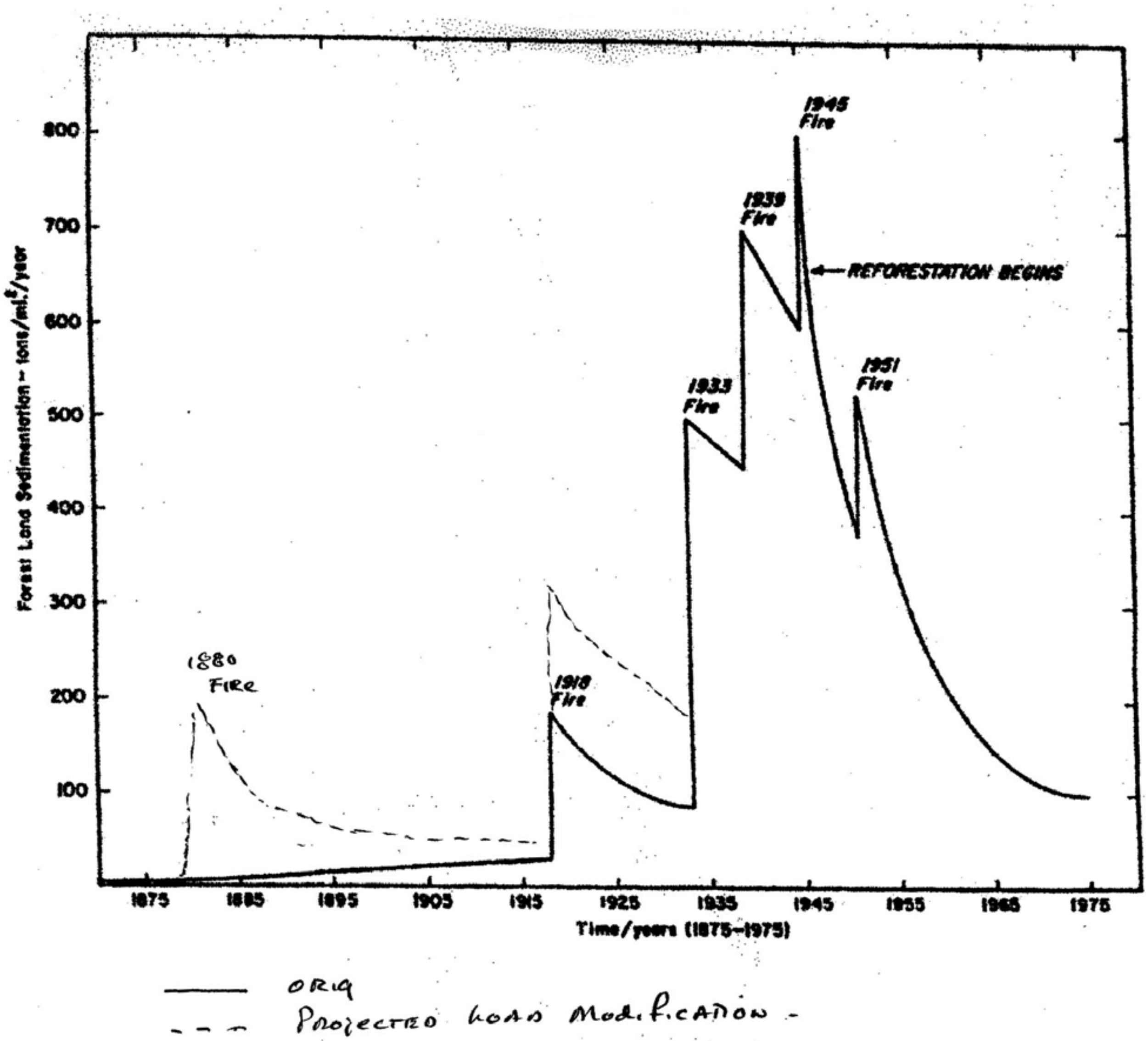
Basin Forest Fire History

Fire history in the Tillamook Bay Basin can be traced to the late 1800s. The earliest identified fire affecting the watershed was in 1845 (Johannessen 1961; PWA 1996); this fire was an intentional fire started in the Willamette Valley (Marion County), which crossed over the Coast Range Mountains and burned large sections of the upper watershed.

Minor fires occurred in the lower mountain area between 1845 and 1880. The Soil Conservation Service (1978) provides a conceptual diagram of historic major fires in 1918, 1933, 1939, 1945, and 1951 (Figure 1). Based on documented fire events, sediment delivery rates and volume are qualitatively produced. Understanding the complex fire history of the Tillamook Bay Basin provides vast knowledge about the history of the sediment problem in the basin. The timing and fire patterns provide an understanding of sediment supply and the delivery of sediment to the basin channel network.

A fire map produced by the Tillamook Bay Task Force and others (1978) illustrates the complex fire sequence in the basin. Mapping by the Oregon Department of Forestry (1990) and imagery analysis of the 1933 fire called the “Tillamook Burn” shows that this fire burned a total of 239,695 acres. As shown in Table 6, the total acreage burned by subsequent fire events decreased to about 32,700 acres in 1951.

Figure 1. Estimated Sediment Rates from Major Fires, 1875 to 1975



Modified after data provided by Soil Conservation Service (1978). The solid line indicates sediment rate and volume based on the SCS data (1978). The dashed lines indicate the revised sediment rate and volume based on analysis completed during this study.

Table 6. Burn Acreage for the Tillamook Fires in 1933, 1939, 1945, and 1951

Year	Perimeter Area of Fire (acres)	Unburned Area in Perimeter (acres)	Previously Burned (acres)	Burned Area (acres)
1933 Fire	261,222	21,527	---	239,696
1939 Fire	209,690	19,030	15,527	189,660
1945 Fire	182,370	2,240	10,899	180,130
1951 Fire	32,700	N/A	N/A	32,700
Fires Combined	360,882	5,946	---	354,936

Source: Modified after Oregon Department of Forestry 1990

The following findings can be linked to sediment production in the river network of the Tillamook Bay Basin (Plate 1).

- Large portions of the Tillamook Basin had been burned by turn of the 20th century.
- The first major fire in the Tillamook Basin in the 1900s was in 1918.
- In 1933, the first and largest in a series of fires burned large sections of the basin, including the Miami, Kilchis, and Wilson River drainages and minor areas of the Trask River drainage.
- Fires in 1939, 1945, and 1951 reburned the northern sections of the basin as well as burning unburned forested areas in the western sections of the upper watershed. The fire pattern extended to the southern basin.

After the Tillamook Burn in 1933. salvage of fire-killed timber resulted in a rapid increase in timber harvest. Harvest peaked in 1952 at about 610 million board feet after the last major fire in 1951. The fires and salvage logging left thousand of acres bare to coastal winter storms. Erosion processes were accelerated and thousands of tons of sediment were washed into the streams to eventually be deposited in the river systems and bay. However, the amount of sediment and its rate in reaching the bay has been reduced since the reforestation program became effective (Tillamook Bay Task Force et al. 1978).

Figure 2 provides a qualitative sediment load in tons per square mile per year for the fire noted. Based on the fire history, the 1918 fire sediment load appears to be under represented. The 1918 fire was the first major fire in the 1900s and its large geographic extent would indicate sediment load to be higher than presented by the Tillamook Bay Task Force (1978).

Figure 2 provides a modification to the sediment load volume, based on additional fire history analysis. The 1880 fire would have increased the sediment delivery to the channel network. The volume of the 1918 fire sediment load has been increased to reflect the geographic extent and the time period between the earlier 1880 fire. This graphic shows qualitative values combined with some numerical values. Regardless, the fire process will increase sediment supply, and an increase in sediment supply will produce modifications to the channel network.

The Tillamook Bay watershed is 89% forested uplands (TBNEP 1998); based on data presented in Tables 1 to 4 (Tillamook Bay Task Force et al., 1978), the current forest conditions account for almost 85% of the sediment yield. During a 29-year period (1918-1951), fire exposed over 70% of the upper basin to the direct impact of winter rains and storm systems. Under "natural" conditions, the Tertiary volcanic rocks lack a high degree of competence. Combining geology with topography, climate, and fire would increase the occurrence of slope failures. As the number of slope failures increased, the total sediment supply also increased.

Sea Level Variations

Modern deposition and erosion of river-borne sediment in the Tillamook Bay estuary began about 9,000 years ago when rising ocean levels entered the river valley (which had been formed by earlier ocean fluctuations). People who watch the recording fathometer in a fishing boat often see it trace the profile of a submerged shoreline as the boat passes a water depth of about 300 feet. This submerged shoreline was the coast when the last ice age was at its maximum, about 15,000 years ago. Dry land extended seaward (west). As the last ice age ended, melting glaciers shed great torrents of meltwater into the oceans, rapidly raising the sea to about its present level (Kraft 1971).

The rising ocean submerged the lower courses of the coastal rivers and then flooded into their new mouths, which converted them into tidewater estuaries and bays. Nearly every large stream becomes an estuary as it approaches the coast. Waves sweeping sediment along the beaches built sand spits across the mouths of the estuaries, converting them into nearly enclosed bays now shoaled with deep fills of trapped river mud. River water flowing out through the bar maintains an inlet connecting the bay to the open ocean. In short, this describes the last 15,000 years of geologic history of the Tillamook Bay Basin.

Following the natural progression of geologic events, the Tillamook Bay estuary will fill with sediment delivered by short drift and headland erosion and stream transport to the bay. Stratigraphic and radiocarbon analyses show that the Holocene fill in Tillamook Bay began to accumulate sometime before about 9,000 years ago (Glenn 1978) in deep parts of refill river valleys. According to Glenn (1978), the rate of accumulation generally coincides with the rates of worldwide sea level rise at a faster rate (greater than about 3 meters per 1,000 years) up to about 7,000 years ago, and at a slower rate (less than 2 meters per 1,000 years) since that time.

Effects of Sea Level Change

Komar and others (1997) analyzed the bathymetric data and concluded that the bay volume has risen 1.5 millimeters per year. From 1887 to 1954, they calculated the rate of bay sediment accumulation at 68 centimeters per 100 years. Core data found sediment deposits that correlate with the fire history in the western sections of the bay. Calculation based on this data indicates that sedimentation rates could exceed 79 centimeters per 100 years when coupled with sea level fluctuations. Currently, the Corps is revisiting this issue. Combining these conditions, the calculations show that sediment deposition is an active process in the bay-deltaic river zone.

Upper Watershed Segment

The five major rivers chiefly drain areas of volcanic and associated sedimentary rocks of Eocene age in the Oregon Coast Range (Walker and MacLeod 1991). Small streams and tributaries, and parts of the lower Tillamook and Miami Rivers, drain areas of sedimentary rocks of Oligocene to Miocene age in the rolling hills adjacent to the southern and northern margins of the Tillamook Bay area. Quaternary age gravels, sands, silts, and clays underlie terraces and floodplains in the lowlands around the City of Tillamook (Plates 1 and 2).

In the upper Tillamook Basin, landslide/mass movement topography is extensive. These mass failures are developed primarily in the soft and weathered Oligocene-Miocene sedimentary rocks, and in the sandstones and siltstones of the Astoria Formation. Relatively stable areas do occur in the Miocene volcanic rock units at Cape Meares and in the undifferentiated Eocene volcanic rocks in the southeastern section of the study area. The southern shoreline area of Tillamook Bay in the Tillamook River Basin also appears stable. The sandstone in these areas is assigned to the Astoria Formation. The lack of topographic relief aids in the stability factor. The Wilson River foothills area is dominated by mass movement features, which generate a knob and swale topographic pattern.

Major Watersheds

<u>Miami River</u>. The Miami River is the northern-most watershed in the Tillamook Bay Basin and in the study area. The total drainage basin covers about 36 square miles. The headwaters are about 14 miles to the east in the Coast Range. The highest point elevation in the drainage is approximately 1,700 feet above sea level. Only the lower 2 miles of the Miami River are included in the study area. According to the Corps (1972, 1977), this section has an average slope of 16 feet per mile. In the upper reaches, flows through Coast Range Tertiary volcanic rock have eroded deeply incised gorges and narrow canyons before opening to a wider alluvial plain. The alluvial plain and deltaic morphology dominate the 2-mile study reach.

<u>Kilchis River</u>. The Kilchis River is just south and east of the Miami River. The total drainage basin covers about 87 square miles and is 21 river miles long. The geology and terrain of the Kilchis is similar to that of the Miami watershed; its headwaters are in Coast Range Tertiary volcanics and have eroded a deep, narrow canyon before exiting onto the alluvial plain and flowing into the bay. Although a long river, the Kilchis River has slopes in its upper reaches exceeding an average of 50 feet per mile. The study reach is from river miles 5 to 0, and has a slope of about 8 feet per mile. Alluvial plain and deltaic morphology are dominant in the study reach.

<u>Wilson River</u>. The Wilson River flows about 44 river miles before entering Tillamook Bay. Only the lower 9 river miles are in the study area. The total drainage area is 193 square miles. The highest elevation is near Round Top Mountain at nearly 2,200 feet above sea level. The river’s average slope though the study area is about 6 feet per mile. Upland geology is again mainly Tertiary volcanics forming narrow steep gorges with rock-lined reaches. At the mountain apex, the alluvial plain becomes unconfined. Sedimentation processes control the western fluvial slope. The lower most portion flows across a wide but confined floodplain to the bay. The history of the Wilson River watershed is comparable to

the other drainages in the study area; high erosion, impacts from several forest fires between 1930 and the early 1950s, and logging operations were common.

<u>Trask River</u>. The Trask River watershed encompasses about 176 square miles and the river is approximately 31 miles long. When combined with the Wilson, these rivers form the majority of the alluvial plain of the Tillamook Bay Basin. The Trask River is to the south of the Wilson River and northeast of the Tillamook River. Ten river miles comprise the study area with an average slope of 6 feet per mile. Both the Trask and Wilson Rivers are comparable; Tertiary volcanics and deep rock-lined gorge sections are evident before reaching the mountain apex. A large complex alluvial plain develops and slopes to the bay.

<u>Tillamook River</u>. The Tillamook River is the southern-most watershed. The headwaters drain a small upland valley at about 400 feet above sea level. Although it has a total river length of 17 miles, only river miles 0 though 2 are in the study area. The lower 8 river miles have a slope of 3.8 feet per mile; the slope in the study area appears to be less. The river flows through flat broad terrain and margins with the Trask River on the southern side of the bay. The total drainage area is 61 square miles but during major flood events, flood water can cover more than 2,300 acres. Geomorphically, the Tillamook River is a minor contributor of sediment, although it has a major impact during floods.

Deltaic – Bay Segment

Deltaic Setting and Processes

The concept of the delta is one of the oldest in geology, dating back to 400 B.C. when Herodotus observed that the alluvial plain at the month of the Nile was similar to the Greek letter Δ. The term has been used for this geographic feature ever since. The basis of the modern three-fold classification of deltas was established by Fisher and McGrowen (1969; also see Galloway 1975), who proposed a subdivision into river-, wave-, and tide-dominated types.

A delta is a body of sediment laid down by dynamic sedimentary processes in a zone of interaction where a river (fluvial system) enters a deeper and less turbulent body of water. When the fluvial system is large or a multi-river system (like the five rivers of the Tillamook Basin and the body of water of Tillamook Bay), the resulting sediment body is a product of complex sequences involving multiple environments ranging from fresh to saline water. The precise nature, horizontal and vertical distribution, and relative importance of the environment are determined by the characteristics of the river regime, coastal processes at work, the structural geologic setting, and climate factors (Fairbridge and Bourgeois 1978).

In the Tillamook Basin delta, the rivers regime involves a large load of fine-grained sediment; an appreciable range between high and low river stages; low wave energy, littoral current (if one), and tidal ranges in Tillamook Bay; active regional or local coastal submergence by rising sea level (Vincent 1989); and a climate that allows a variety and density of different vegetation. These variables have interacted within the context of cyclic and progressively slowing sea level modifications produced from the Holocene time. Both depositional and erosional processes have been involved.

There have been few, if any, attempts to provide basic interpretations and to illustrate the distribution and sequence of Tillamook Bay delta complexes; those that do exist have been frequently modified. One of the most widely referenced basic models is that of Kolb and VanLopik (1958) who initiated the much-copied “lollipop” diagram approach. Their model was used to define the Mississippi River delta complex and illustrates the complexity of these environments, the impact on river sedimentation processes, and other events.

Deltaic distributions are the most conspicuous of the subaerial environment and are evident because of the natural levee ridges that flank the stream channels. The pattern of distributions forms the skeletal framework of this multi-river delta complex. As long as distributary channels actively receive sediment, the mouth of the rivers will progress seaward at a rate directly related to the amount of discharge and sediment load, as well as the depth of the receiving body of water, Tillamook Bay. Distributary natural levee formation essentially involves the same fluvial processes that are generated to produce those in the alluvial plains and upland areas of the Tillamook Basin; however, a few differences in morphology and lithology do occur. The levees are more uniform in height and width, because far less meandering takes place in the distributary channels. Mean sea level is the dominant elevation-controlling factor. Rather than being laterally gradational with backwater, natural levees of the lower deltaic plain grade into and/or are interfingered with interdistributary deposits and bay-river deposits.

A variety of depositional environments occur in the deltaic plain. However, it is not within the scope of this report to provide a detailed deltaic analysis.

4. Geomorphic Sedimentation and Transport Concepts

River systems and tributary channels are important avenues of sediment transport that deliver eroded material from the upper hill slopes to the low agricultural lands. Variability in sediment delivery, hydraulic discharge, and channel slope give rise to spatial and temporal variations in channel morphology and response. Analysis and time-scale relationships provide an overview of channel response to changes in discharge and sediment supply from both land use and climatic conditions.

The river system of the Tillamook Bay Basin ranges in size from small ephemeral rivulets to the five major rivers draining the basin. Over decades to centuries, channel morphology has been influenced by both local and systematic downstream variation in sediment supply from upper basin hill slope processes, the ability of the channel network to transport these loads downslope and down-basin, and the effects of vegetation on channel processes.

Channel adjustments that altered discharge and sediment supply include changes in width, depth, velocity, slope, sediment size and roughness (a hydraulic element). The basic keys to understanding or describing the physics governing channel processes and to illustrate control on channel processes include the conservation of energy; sediment transport; flow of water through the channel network and at any point along a channel; energy dissipation by channel features; and geometry of the active channel zone.

The frequency and magnitude of precipitation events are documented for the Tillamook Bay Basin; these events cause both erosion and maintain channel geometry. Topographic relief of the upper basin provides the potential energy that drives these processes. Downslope movement of water converts the potential energy into kinetic energy, which is dissipated by friction and turbulence generated by the channel bed and bank.

Channel Response

Channel confinement influences channel response. Channel migration and avulsion are typically rare in confined channels. All upper watershed areas of the Tillamook Bay Basin are bedrock controlled. Channel geometry or migration and avulsion are linked to the geologic time scale. At the upland-to-valley transition area, channel configuration is unconfined. These unconfined channels form floodplains. Over time, out-of-channel bank events widen the floodplains and aggradation occurs.

Debris flows are a primary sedimentation agent of channel disturbance in the upland or mountain areas of the basin. Debris flows tend to be pulsed disturbances, the effects of which vary with slope and position in the watershed. Sediment transport of debris flow material can scour the steep channel to bedrock, depositing large volumes of sediment in the lowlands or floodplain areas. Benda and Cundy (1990) assess the potential impacts of debris flows, and differentiate areas of potential debris flow initiation, scour, and deposition.

The relatively simple set of channel processes noted above results in a wide array of possible channel responses to changes in sediment supply, discharge, and external influences such as woody debris flow obstruction. In response to changes in sediment supply or discharge, altered bed forms, or particle size, the channel system may widen, deepen, and/or change its slope through aggradation, degradation or modifications to channel sinuosity.

Channel Changes and Sediment Supply

There is extensive literature using both empirical evidence and conceptual models that show channel changes and common responses. The basic physics of channel change reveal a wide range of responses to changes in sediment supply; channel change can induce channel widening and aggradation, decrease channel features through pool filling, and decrease bed sediment size. Increased discharge can cause channel widening, incision, and bed armoring. The response of a river system to increased sediment supply depends on the ratio of transport capacity to the sediment supply. Significant aggradation, channel widening, bed filling, pool filling, or braiding occurs where the amount of introduced sediment overwhelms the local transport capacity. Pulse- or slug-type sediment delivery combined with mass movement or hill slope failures are the major cause of sediment supply to a river system. This generates spatial and temporal variability in sediment supply that will govern channel morphology in different reaches of the channel network.

5. LANDFORMS AND GEOMORPHIC PROCESSES

Erosional and Depositional Landscapes

The shape of a river channel is a consequence of the interaction of discharge or flow and the bed and bank boundary conditions. Flow in the river reacts to the bed and bank conditions or topographic features, such as bank roughness, gravel bars, pools and riffles, and sediment supply, as well as the boundary shear stress fields that control the sediment movement patterns. These processes adjust the channel morphology to maintain equilibrium by combining flow conditions, boundary shear stress fields, and cross-sectional patterns of sediment transport. Simply stated, if one process fluctuates, there will be a response in the other two processes. For example, an increase in sediment without an increase in flow or discharge conditions will result in deposition. On the other hand, erosion could occur with an increase in flow/discharge without modification of the other components.

Fluvial Environments and Processes

Mountainous sections in the Tillamook Bay Basin are volcanics of Tertiary age, which are highly weathered and subject to mass movements and other types of slope failure processes. Little, if any, consideration of geomorphic processes has occurred, other than slope failures with respect to logging actives. All investigators in the last several decades agree that upland slope failure is the major contributor to the current sediment loading process, which is currently passing through the basin. Watershed analysis in the early 1970s (DOGAMI 1972, 1973; Tillamook Basin Task Force et al. 1978) illustrate the variety and extent of slope failures and their linkage to weathering, erosion, and winter storms impacting the volcanic rocks in the upper basin. Harr (1983) and Hicks (1991) couple logging road construction, winter storms, and slope failure with increased sediment loading. Analyses in 2000-2001 (Bischoff et al. 2000, 2001) assessed watersheds with and without roads and concluded that there was a greater hydrologic impact to watersheds with roads. Again, slope failure was the dominant geomorphic process delivering sediment slugs to the current channel networks. The upper basin areas supply both sediment and hydrologic energy. All of the river basins have a rock “gorge” which increases the fluvial energy and transport capacity (Plate 4). Downslope, the river networks pass the mountain apex on to the alluvial plain. The Wilson and Trask Rivers dominate the main Tillamook Bay Basin to form an alluvial fan complex. The Tillamook and Kilchis Rivers add to the complex lower in the system and closer to the deltaic-bay zone. The Miami River has no geomorphic linkage.

The alluvial fan complex created by the rivers of the Tillamook Bay Basin has a complex depositional and erosion history. Alluvial fans have been recognized and investigated by geologic and geomorphologists since the mid-19th century, but mostly in arid climates where fans are exceptionally well developed. In the Tillamook Bay Basin, fans have not been delineated or are indefinite as a dominant landscape feature. From analysis of the basin and associated landforms, alluvial fans appear as the major geomorphic feature.

Alluvial fans typically occur at the mouths of drainage basins and are large-scale morphological features built up by bedload streams and in humid climates, by streams with high-suspended loads. Fans of all types develop where the stream emerges from the confines of a valley or gorge area into a basin. Exiting the confinement, degrees of freedom are obtained allowing for the horizontal expansion of the flow, deceleration, and deposition of some or the entire sediment load. The emergence from the valley or mountainous region into a basin will commonly be associated with a reduction in gradient, and this further favors deceleration and deposition (Plate 4). This geographic setting defines the Tillamook Bay study area. Basins into which fans build are quite variable (Knight 1975). The Tillamook Basin is adjacent to the Pacific Ocean in a tectonically active zone. Although vertical elevation is a function of many geomorphic processes, sediment supply, hydrology, and tectonics normally dominates.

The typical fan shows a decrease in slope from the apex, close to the point of emergence, to the toe giving a concave upwards profile. The Wilson/Trask fan complex illustrates the classic slope with the distal reaches entering the bay complex. This simple profile is commonly broken into a series of segments. Each slope segment has a roughly even slope; however, the slope of the segments decreases sharply at deposition or erosion zones along the profile in a proximal to distal traverse (Bull 1964) and ending in the bay. These segments can be attributed to pulses of tectonic activity, climatic or catastrophic events with the upper basin. Short-term catastrophic events illustrate sedimentation pattern changes on a human time scale. They may be associated with episodes of fan incision and/or growth where the main channel will migrate across the fan complex inducing erosion or deposition (Photo X).

The down-fan reduction in slope is commonly associated with a reduction in grain size, particularly the maximum particle size; data from the Gravel Harvest Study (Stinson and Stinson 1998) illustrates that size reduction is a process acting on the Wilson, Miami, and Kilchis Rivers. Tillamook Basin fans are classified as humid fans (dominated by a major stream channel). Historic records and subsurface data sets are lacking because of drill/well depth and geographic position in the basin. Gole and Chitale (1966) indicate that a time period of 250 years may be required for major channel migration (without human impact upon the landscape). A time period of this length is not possible in the Tillamook Basin.

Where coarse sediment is supplied from the upper watershed areas, as exemplified by the massive forest fires of the 1930s to early 1950s, fan development and channel modifications are common. Modifications include a downstream change from a meandering stable channel system, to a channel complex with upstream sheet bar complexes, to large or numerous individual gravel bar complexities. This progression from a highly developed gravel sheet bar complex is illustrated by the comparison of aerial photographs from 1939, 1965, and 2000 (Plates 4 to 14). Downstream bar complexities change to longitudinal/lateral bars and point bars; as gravel supply reduction occurs, bars die out or acreage and number is reduced.

Channel Pattern

Investigating the change in channel pattern or plan form is a major method used to study various aspects of changing river channels; it can be used to determine the impact on fluvial landforms and development on the alluvial plain created by sedimentation processes.

Changes to a channel's plan form can take place by bank erosion, deposition within the channel, and by chute development or avulsion involving a channel switching positions and gravel bar complex development. For streams in the Tillamook Basin that had an abundant sediment supply until the mid 1950s, the material in the channel is apt to be "overloose" and easily entrained. With the decline in total sediment supply since the mid 1950s, gravel transport has declined and fine-grained sediment transport has continued.

Each river basin has a dominant channel system and typical floodplain morphology. Relict channel (sloughs) are clearly visible in the lower reach of the fans/alluvial plain (Plates 4 to 14). The sloughs in the lower reach still function as passages during high water events. Human activities and apex channel stabilization have reduced access and function during high flow events. By 1939, the sloughs in the upper alluvial plain have been separated from the active channel. Geomorphically, main channel distributary separation generates an increase in bed aggradation and gravel bar erosion, and sediment supply is reduced by reforestation after the early 1950s. Bed aggradation should induce flooding on the upper alluvial plain, and fine grain deposition with an increase in alluvial plain in the upper reach near the apex. Flooding and floodwaters concentrate in the depressions of the relict channel/slough segments along the alluvial plain. Bed aggradation and distributary separation appear to present a drainage pattern that is an underfit system within the confines of the dominate channel on the alluvial plain.

In-channel Features: Form and Function

Depositional features occur when and where the flow velocity is insufficient to carry the sediment size or amount of material in the fluvial area. There are typical locations within a channel where deposition occurs, and the coupling of these sites and depositional shapes are classified as bar. The dominate type of bars or bar complexes found on gravel-bed rivers of the Tillamook alluvial plain will be presented to aid in understanding the geomorphic function.

Point Bar-Gravel Bar Types

Point bars are characteristic of meandering river systems (regardless of the sediment load) and tend to extend in the channel direction and downstream. They generally form parallel to the eroding bank line. The gravel unit will occur near the convex bank, and it often possesses a steep outer slope and a high water chute or secondary channel landward from the water. Sediment gradation is common in the up and down stream direction on the bar, along with a vertical grading. Gravel bars can grade into the floodplain if sediment loading is greater than transport capacity.

Mid-Channel Bars. These are single bar units that are common features in river systems that have received too much sediment. They are more numerous than point bars. Based on sediment load and hydrology, evolution to small island complexes may develop. Their diamond shape directs flow to the river banks causing bank line flow impingement, which can induce bank erosion or sequence vertical accretion and bank line attachment.

<u>Lateral Bars</u>. These are bars which occur as an attached bar with the bank line or terrace complex and are most commonly found in straight reaches of the channel. Based on form and function, they are sediment storage sites in a gravel or sand river. Their number and acreage appears to correspond to sediment load.

<u>Diagonal or Transverse Bars</u>. Diagonal bars form obliquely across the channel system and are not parallel to the flow. At full development stage, the complex will be attached to both banks. The bar slopes upward in a downstream direction with an avalanche face at the downstream end. Diagonal bar complexes were identified during this assessment.

Bars are established where material is deposited from the bedload. This occurs where the traction force of the stream declines. Typical locations for bars are at the apex of the channel fan and channel reaches where resistance to flow increases and slack water may occur along the convex bank; at places where the channel widens; and at channel junctions where the less powerful contributory may be in backwater. No formal criterion will be presented for the occurrence of bars in light of flow and sediment characteristics. Bars strictly defined as accumulations of sediment grains cannot occur if the flow depth (d) is approximately equal to the mean grain size (D).

Four major bar types were analyzed during the gravel bar investigation. Smith (1974) and Church and Jones (1982) identified gravel bar and/or gravel complex geomorphic development and sedimentation implications. Table 7 presents a gravel bar classification combined with morphology, function and sediment impact. The sediment storage function provided by Table 7 is the key function and method used to interpret the geomorphic process controlling the fluvial landform of the alluvial plain and distal deltaic reaches.

Table 7. Classification of Gravel Bar Formation and Function

Morphology	**Function**		
	Hydraulic Resistance	**Sediment Storage**	**Equivalent Bar Unit**
Attached			
Asymmetrical	Diagonal riffle	Lateral bar Point bar	Diagonal bar
Symmetrical	Transverse riffle	Transverse bar Channel junction bar	Transverse bar
Detached			
Asymmetrical	------	Point Bar or river bend spur	Longitudinal bar Transverse bar
Symmetrical	Longitudinal riffle	Medial bar	Longitudinal bar Transverse bar
Formation	River-bed: deformation by erosion/deposition; Non-fluvial: emplacement	Channel size: adjustment by deposition	Simple deposition

Source: Modified after Church and Jones, 1982

The bar surface is composed of lag concentrations of relatively coarse materials one grain thick which, at the proximal bar end, may be as coarse as those found in the adjacent channel. Both point bars and some detached bars will have a high water chute or channel landward of the main bar. In mature gravel bar complexes, this feature is active in high flow events. This zone is a non-aggrading channel and aids in island and mid-channel bar formation. Sediment storage bars become more prominent in channel systems as traction load sediment increases in abundance. As sediment supply/load normalizes, the geomorphic processes reverse. Analysis of the Wilson, Trask, and Kilchis Rivers demonstrate these processes. After the 1950s, sediment supply processes were declining due to reforestation in the Tillamook Burn areas.

Backswamp/Floodbasin

A backswamp/floodbasin in geomorphic terms is a flat, shallow, poorly drained, typically swampy or marshy floodplain area bounded by natural levees and other topographic high features. Some of these topographic high features are engineered for river stabilization. During overbank flood events, fine-grained sediment accumulation is the dominant geomorphic process. Some researchers may class this zone as intra-tidal marsh. The geomorphic environment is coupled to the deltaic and riverine zones and will not be discussed separately.

Crevasse splays are discrete mini-delta or thin lobes of sediment deposited on the distal side of natural levees and at the river-bay interface. A splay becomes a slight topographic rise or feature. These depositional features are coarser than the average natural or deltaic sediment because channelized floodwaters have a higher sediment transport capacity than floodwaters occurring as sheet flow. An increase in total sediment load coupled with high flow events also will produce crevasse splay deposits (cover photo of Kilchis River, 1939).

6. FLUVIAL AND GEOMORPHIC ANALYSIS

The Miami River has very limited aerial photographic data. While the Kilchis, Wilson, and Trask Rivers have historic and current aerial photographs (1939, 1965, 2000), only the 2000 photos had complete coverage of the study area. Longitudinal profiles were constructed from 1978 data sets from the Federal Emergency Management Agency (FEMA), and 2000 data sets from the Corps and Tillamook County. Field observations during high and low water periods provided first hand information, qualitative in nature.

Miami River Geomorphology

The Miami River Basin is dominated by gravel storage. Currently, no sediment source areas appear visible in the basin. Fine-grained sediment deposition is the controlling geomorphic process at the river-bay zone. The Miami River is the smallest of the watersheds in the Tillamook Basin. It drains heavily wooded steep terrain and appears to have a moderate slope to the bay. Geographically, the Miami River Basin is narrow and lacks major human development. The study reach is 2 miles in length, from river miles 0 to 2 (Plates 5 and 6).

The basin showed less sign of hill slope erosion or slope failure than the other river basins. Sediment storage sites are dominant in the basin. There were no identified long transport reaches. Numerous temporary storages sites indicate that this river is transport limited. Being transport limited means that high volumes of sediment can and are normally transported only during high flow or flood events. Flow would appear to be flashy and short in duration. Alder is the main riparian vegetation, and there is a lack of large woody debris within the active channel of the river. In the transition reach between the uplands and the lowlands (agricultural lands), the gravel bar complexes increase both in spatial and temporal occurrence. The large silt and sand bar-delta near the river's mouth indicates that a high volume of fines is transported out of the basin. The relationship of fines to gravels constituting the bar complexes should be analyzed.

<u>River Miles 2-1</u>. The Miami River is a gravel-rich system based on the high number of small lateral and point bar complexes; there appears to be a substantial supply of sediment to the river. Thalweg pattern appears to be stable and a riparian zone is present throughout the reach. Floodplain and riverbed elevations are within 4 to 6 feet in elevation difference. The channel appears stable and at high flow or flood events, it easily leaves its banks flowing onto the surrounding floodplain. Bed elevation data indicates minor bed aggradation averaging from 2 to 4 feet. The data sources and their differences may create a minor elevation difference, which could be plus or minus 1 foot based on professional judgment (Plate 6). Nevertheless, bed elevation data tends to indicate a net gain from 1978 to 2000. This net gain supports the analysis of a channel system laden with sediment. Based on the fire history, the system is adjusting to historic sediment loading and transport capacity.

<u>River Miles 1-0</u>. Bed aggradation appears to be dominant in the upper 0.5 mile. Erosion or degradation appears to be the dominant geomorphic process in the lower reach until just upstream of the Southern Pacific Railroad/Highway 101, where bed aggradation again is dominant. Although few gravel bar complexes occur in the reach, those that do occur are geographically small. Downstream of the Southern Pacific Railroad/Highway 101,

deposition/bed aggradation is dominant. Riparian development appears equal in density and acreage as described for river miles 2 to 1.

In summary, bed aggradation is the dominant geomorphic process for the Miami River. Reduction of sediment delivered pre-1960 is still being passed through the system. Complexity and channel narrowing also could have occurred, based on findings on the Trask, Wilson, and Kilchis Rivers. It appears that minor amounts of engineering actions have been undertaken on this river. The Miami River could represent the prototype for the Tillamook Bay Basin: a system in transition from sediment rich and transport low, to one that is now moderate in sediment load but with the same hydrology. As the bed aggrades, this could lead to channel migration or a catastrophic channel relocation across the alluvial plain (Plate 5 and 6).

Kilchis River Geomorphology

The upper reaches of the Kilchis River appear limited in sediment supply. The fluvial processes are competent to transport the volume of material supplied. At the transition zone, deposition with minor bank erosion are the controlling geomorphic processes. Transport is the controlling process on the Kilchis River (Plates 7 to 10).

Channel morphology from the bay to the upland displays a channel system competent to transport a full range of sediment. The steep upper basin provides energy and sediment. Normal riffle pool morphology is dominant in the upper reaches in this bedrock-controlled channel. During storm events, hill slope failure and mass movement result in debris torrents cascading through the system. The November 1999 storm event is just one example. High sediment loading occurs and transport continues until transport energy is reduced or sediment supply depleted. At the transition zone, transport energy is reduced resulting in gravel deposition. This process occurs basin wide. Bank cavitation appears to constitute a major geomorphic process in the upper watershed. The amount of sediment generated by these processes would not compare to that generated by hill slope failures. Fine-grained sediments are passed to the bay. Overbank flooding occurs in the lower basin and appears to flow in “old” channels that cross the lower valley area and cause aggradation. Floodplain aggradation could induce active channel erosion and transport a higher volume of sediment to the bay.

<u>River Miles 5-4</u>. Between 1939-1965, the active channel appears to have undergone widening along with a reduction in the number and type of gravel bars (Tables 8 and 9). This reduction is coupled to an area reduction. There is a reduction in riparian zone area and density from 1939 to 1965. Basic channel morphology shows no significant modification. The increase in channel width in this reach could explain the loss or reduction in the riparian zone. Overall bar number is constant but total area appears to have decreased. This reduction can be accounted for by the development of a mid-channel island just up-channel from river mile 4. A new channel has developed along the right descending bank line in a high water chute across the 1939 point bar (Plate 7).

Table 8. Kilchis River Channel Features, 1939

River Mile (RM)	Channel Feature Acreage						Total
	Island	BD	LL	LR	HWC	PT	
RM -1 to 0	---	---	---	---	---	---	---
RM 0 to 1	---	---	0.36	1.8	---	---	---
RM 1 to 2	---	---	7	0.82	---	0.51	---
RM 2 to 3	---	2.1	0.55	1.59	---	9.82	---
RM 3 to 4	---	2.82	5.63	7.84	---	0.36	---
RM 4 to 5	---	0.01	4.34	1.16	---	6.78	---
RM 5 to 6	---	0.03	3.28	0	---	---	---
TOTAL	0.00	4.96	21.16	13.21	0.00	17.47	**56.80**

Key: Island = Vegetated Island; BD =Mid Channel Bar; LL = Lateral Bar, Left Bank; LR = Lateral Bar, Right Bank; HWC = High Water Channel; PT = Point Bar

Table 9. Kilchis River Channel Features, 1965

River Mile (RM)	Channel Feature Acreage						Total
	Island	BD	LL	LR	HWC	PT	
RM -1 to 0	---	---	---	---	---	---	---
RM 0 to 1	---	---	---	---	---	---	---
RM 1 to 2	---	0.13	3.23	---	---	1.47	---
RM 2 to 3	---	0.05	0.31	1.05	---	2.87	---
RM 3 to 4	---	0.7	0.94	5.46	---	0.18	---
RM 4 to 5	2.43	0.88	2.01	1.44	1.65	0.05	---
RM 5 to 6	---	---	2.13	---	---	---	---
TOTAL	2.43	1.76	8.62	7.95	1.65	4.57	**26.98**

Channel Feature Change Factor from Previous Photo Date

River Mile (RM)	Island	BD	LL	LR	HWC	PT
RM -1 to 0	---	---	---	---	---	---
RM 0 to 1	---	---	---	---	---	---
RM 1 to 2	---	---	0.5	---	---	2.9
RM 2 to 3	---	---	0.6	0.7	---	0.3
RM 3 to 4	---	0.2	0.2	0.7	---	0.5
RM 4 to 5	---	88.0	0.5	1.2	---	---
RM 5 to 6	---	---	0.6	---	---	---

Note: Change factor represents magnitude of acreage change of gravel deposits from 1939 to 1965 as observed from aerial photographs. For each respective river mile, a factor of 10.0 represents a ten-fold increase in the acreage of gravel bars from 1939 to 1965. A factor of 0.5 represents that the acreage of gravel bars was reduced to one half from 1939 to 1965.

Key: Island = Vegetated Island; BD =Mid Channel Bar; LL = Lateral Bar, Left Bank; LR = Lateral Bar, Right Bank; HWC = High Water Channel; PT = Point Bar

From 1965 to 2000 (Plates 8 and 9), there was a two-fold increase in total gravel bar number, coupled to a reduction in total gravel bar area (Table 10). This bar development displays no major impact on the morphological pattern of the channel reach. Some engineering features were constructed in this reach over the last 5 years. Sediment trapping and bar growth is appears to be the resulting short-term development. These actions appear to have induced a degree of stability to the reach and the riparian zone has redeveloped in both area and density since 1965. Comparison of longitudinal profile data is not possible due to the lack of data above river mile 4.

Table 10. Kilchis River Channel Features, 2000

River Mile (RM)	LL	LR	HWC	PT	Total
RM -1 to 0	---	---	---	---	---
RM 0 to 1	0.35	0.45	---	0.45	---
RM 1 to 2	2.75	0.86	---	1.25	---
RM 2 to 3	2.1	0.44	---	1.78	---
RM 3 to 4	3.61	1.77		2.57	---
RM 4 to 5	2.21	2.95	0.65	0.01	---
RM 5 to 6	0.05	0.18	0.33	2.52	---
TOTAL	11.07	6.65	0.98	8.58	**28.82**

Channel Feature Change Factor from Previous Photo Date

River Mile (RM)	LL	LR	HWC	PT
RM -1 to 0	---	---	---	---
RM 0 to 1	---	---	---	---
RM 1 to 2	0.9		---	0.9
RM 2 to 3	6.8	0.4	---	0.6
RM 3 to 4	3.8	0.3	---	14.3
RM 4 to 5	1.1	2.0	0.4	0.2

Key: LL = Lateral Bar, Left Bank LR = Lateral Bar, Right Bank
HWC = High Water Channel PT = Point Bar

River Miles 4-3. This reach of the Kilchis River has undergone the highest degree of geomorphic modification. In 1939, large point bars and mid-channel bar complexes had developed. These gravel complexes were serving as temporary in-channel sediment storage locations or zones. High sediment supply was generated as a result of the massive forest fires in the Tillamook Basin during the summer of 1932. The bare and highly decomposed material in the upper basin was laid bare to the winter rains. The coupling of these processes is the major factor in development of a channel system highly laden with sediment. By 1965, these gravel complexes were still dominating the channel geomorphic processes. Gravel bar consolidation reduced the total number of gravel bar complexes. There were still large point and mid-channel bars within the reach, however.

With the reforestation of the upper watershed, sediment supply has been reduced. During storm events, however, “natural” slope erosion processes would still be on going. These processes would still deliver sediment to the channel network. Channel data from 2000 indicates an increase in stability and an additional reduction in sediment supply. The profile slope shows an increase in slope. With the reduction in the number of mid-channel gravel bar complexes, there was a shorting of channel length resulting in the increase in slope. Bar size was reduced with the increase in slope and the reduction in total sediment supply. Combined with these processes, the large bar complexes were divided by erosion resulting in an increase in the development of lateral bar complexes. This reach was a sediment storage reach in 1939 and 1965. By 1965, the volume of sediment in temporary storage in this reach was on the decline. Longitudinal profile data from 1978 and 2000 indicate that the upper half was an erosion and transport zone, whereas the lower half was in pseudo-equilibrium. The riparian zone appears simpler in 1939 and 1965. Density and area show no major variations. Increased channel stability between 1965 and 2000 also provided for an increase in the riparian zone area and density.

<u>River Miles 3-2</u>. Channel complexity and gravel bar development show a marked decline from 1939 to 2000 (Plates 7 to 10). Gravel bar growth appears to have stopped, whereas erosion and transport of the gravel deposited from 1939 to 1965 was underway. In 1939, there were seven main gravel bar complexes; by 1965, the number was reduced to five and they were smaller in area. By 2000, the number of gravel bars had increased again to seven as in 1939, whereas the area of gravel storage was four-fold less. Channel stability also increased based on the area distribution and density of the riparian zone.

During the 1965 period, gravel harvesting occurred on one of the major point bars within the reach. The duration of this activity and the long-term geomorphic impact are unknown; the short-term impact would have been minor. This reach converted from a sediment storage reach in 1939 to a transport reach by 2000. Analysis of the longitudinal profile data from 1978 and 2000 provides proof that the reach slope increased and degradation dominated. Degradation indicates a shortage of sediment supply in this reach plus a reduction in total sediment supply/input in the system.

<u>River Miles 2-1</u>. Sediment in temporary storage was reduced from 1939 to 2000. Large lateral gravel bar complexes were reduced in size and complexity by a combination of fluvial processes. Fluvial erosion in conjunction with a developing riparian zone contributed to increasing the channel stability and bar erosion. The riparian zone though river mile 2 increased in area and density. Temporary sediment storage sites remained geographically constant from 1939 to 2000. The number appears to have maintained a constant value. The channel width appears to have been reduced. Channel stabilization has increased with a reduction in gravel bar size and an increase in riparian zone development.

Slope data indicates a flattening and some aggrading. Erosion is dominant in the upper reach while aggrading and slope reduction control the lower half of the reach. Combining these conditions results in a channel reach that is less complex. The stable channel morphology increases the transport processes reach-wide. During the period of record, there appears to be little channel modification, resulting in a reach that is transgressing to greater stability and sediment transport efficacy.

River Miles 1-0. This reach shows very little geomorphic modification from 1939 to 2000 (Photograph 1). Channel width and plan-view pattern have remained constant. Gravel bar development throughout the time period also appears constant (less than 3 bars). The lower quarter of the reach is subject to minor mounts of narrowing. Controlling factors appear to be coupled to delta processes in the inertial zone and flushing of gravel sediment to the bay. Bar erosion or development shows no variance from 1939 to 2000. Riparian zone reduction is the norm, which is opposite riparian development upstream of river mile 1.

Aerial photographic analysis for 1939,1965, and 2000 indicate splay deposits along the lower half of the reach. A major deposit is present on 1939 imagery and can still be detected on 2000 imagery. There is no longitudinal profile data, so analysis is not possible. The geologic setting and ongoing processes in the river/bay transitional zone are predominately aggrading. Field observations indicate gravel has been and is being deposited in this lower zone. Large flow events serve as the conveyance element.

In summary, Tables 8-10 show gravel bar data for the Kilchis River in 1939, 1965, and 2000. Analysis of this data indicates that the total number of gravel bars decreased from 1939 to 1965; the number then increased to 1939 values in 2000. Gravel bar acreage decreased from 56.8 acres in 1939 to 22.9 acres in 1965, and to 26.7 acres in 2000. The large acreage in 1939 could be linked to the massive forest fires occurring in the upper basin in 1932. Subsequent fires from 1932 to 1950 aided sediment supply to all rivers within the basin. Reforestation and lack of massive forest fires after 1950 has reduced sediment supply. Hydrologic conditions have not changed over the last 100 years (Corps 2001).

Discharge data is only available for the Wilson River. High flow events occurring throughout the basin generally have similar conditions and hydrologic conditions appear to have maintained basic values. Based on this assumption, only sediment supply and/or input values have undergone modification. High sediment supply was generated as a result of the massive forest fires during the summer of 1932. The bare and highly decomposed material in the upper basin was laid bare to winter rains. The coupling of these processes is the major factor in development of channel system highly laden with sediment. By 1965, gravel complexes were still dominating the channel geomorphic processes. Gravel bar complexes, both in aerial extent and number, were reduced from 1939 to 1965, which reworked and redistributed the temporarily stored sediment.

Analysis indicates the Kilchis River is less complex, more stable, and has larger and denser riparian zones. Sections of the lower river from river miles 2-3 are aggrading in areas from river miles 2-3 that are dominated by transport; the reach from river miles 3-5 appears to be stable. Input and output could be relatively equal. The dominant river process in 1939 was sediment input and temporary storage. There was a greater supply of sediment than energy to transport the sediment load. By 1965, the Kilchis River was still sediment rich and transport poor. Gravel development was still high, but transport was reducing the volume (number and size) of gravel bar complexes. A state of pseudo-equilibrium was becoming dominant. In 2000, the Kilchis River appears to be sediment poor. Sediment reduction along with no major fluctuation in hydrologic conditions is creating a high energy/transport system. The inverse, which occurred from 1939 to 2000, created a river system that can transport a high amount of sediment during major flow events. Sediment movement terminates in Tillamook Bay, at the river/bay transition zone. Sedimentation is resulting in aggradation at the river mouth (river mile 0 and into the bay), (Plates 7 to 10).

Kilchis River Overlap Analysis

Six river miles of the Kilchis River under went continuity or overlay analysis. River patterns based on 1939, 1965, and 2000 aerial photographs produced spatial and temporal river pattern data. Table 11 presents this data. Based on the analysis, 48.5% of the Kilchis River is non-congruent. Only 4.0% or 3.7 acres are congruent between 1939 and 2000. This indicates that a long-term degree of river freedom exists. Continuities increased to 13.0% or 21.5 acres by comparing river continuity or overlay for 1965 and 2000 (Plate 10).

Table 11. Kilchis River Channel Overlap Analysis, 1939-1965-2000

Length	Overlap	Kilchis River	Acreage	% of Total
5.26 miles	0	No Overlap	44.1	48.5
	2	1939/2000 Overlap	3.7	4.0
	3	1965/2000 Overlap	11.9	13.0
	4	1939/1965/2000 Overlap	21.5	23.6
	Total Acreage (for all 3 years)		90.9	---

Note: “Overlap” is the attribute in the Arc/View shape files.

This data shows that the Kilchis River Basin hydrology has remained constant during the period of record resulting in a constant transport capacity and a non-steady sediment supply. Variations in sedimentation rates and in channel geomorphic processes have induced channel pattern modifications; gravel bar complexes and bed aggradation and degradatation indicates A system that is still out of phase or a river system that is in non-quasi-equilibrium is generated. (Tables 8, 9, and 10, Plate 10). High sediment supply and sediment in transport prior to the early 1950s have impacted fluvial processes. After the 1950s, sediment supply and sediment in transport have progressed to a new quasi-equilibrium condition, a system dominated by bed aggradation and a reduction in gravel bar complexes. Channel slope conditions have modified as bed aggradation reaches impact the channel processes (Plate 10).

Comparing 1965 and 2000 channel positions, overlap percentage has increased (Table 11 and Plate 10). As overlap or congruence increases, channel freedom decreases and stability appears to increase. Increased channel stability appears coupled to a reduction in transport capacity and an increase in out-of-channel flow higher on the alluvial plain. Human impacts are currently not measurable. Nevertheless, they have reduced channel freedom and appear to add to a sense of channel stability.

Sediment supply is the controlling geomorphic process in the upper drainage of the Wilson River. Debris flows and erosion sites are numerous in the upper area. The river is sediment driven and high sediment supply feeds the upper system. Erosion and transport are dominant in the uplands. At the transition zone, deposition and floodplain aggradation are dominant. The river appears rich in sediment within the active channel and in the lowest terraces associated with the active channel. The upper river is bedrock controlled with a veneer of sediment stored in the active channel area. Numerous locations occur that indicate historic and current mass movement events in the upper watershed. Hill slope failure is the main geomorphic process currently delivering sediment to the channel. The river also appears to have a large volume of sediment in temporary storage within the active channel. The size of this sediment deposition is unknown. No estimations are present of possible volumes of transport, other than to say there is a high possibility that a large volume of sediment is available for transport during major flow events. The amount of woody debris on channel bar complexes and terrace deposits appears high. This could increase channel blockage and increase possible erosion/sediment transport to the lowlands (Plates 11 to 14).

River Miles 8-7. These upper river miles represent a major temporary sediment storage reach. From 1939 to 2000, there was a reduction in total acreage from 10.31 to 7.97 acres Tables 12 to 14). Temporary storage appears to be dominant. Riparian density and acreage show a similar increase. Channel stability shows an increasing tendency and conversely, channel complexity appears to decrease. Thalweg migration was normal during the period. Combining these conditions shows a channel reach with high transport and in-phase with the sediment supply entering and exiting the reach. Development of a stable riparian zone aids channel bank stabilization. Flood photographs show that floodwater exits the channel in this reach. This energy reduction reduces sediment transport and bank erosion. Bed elevation data illustrates minor bed aggradation for the period of record (1978 to 2000, Plate 14).

Table 12. Wilson River Channel Features, 1939

River Mile (RM)	**Channel Feature Acreage**						**Total**
	Island	**BD**	**LL**	**LR**	**HWC**	**PT**	
RM -1 to 0	4.49	---	---	0.28	---	0.4	---
RM 0 to 1	2.58	---	0.07	0.01	---	---	---
RM 1 to 2	---	0.26	---	---	---	---	---
RM 2 to 3	---		0.8	0.26	---	0.88	---
RM 3 to 4	---	0.04	2.03	1.05	---	---	---
RM 4 to 5	---	3.79	9.9	10.42	---	3.12	---
RM 5 to 6	1.13	---	1.32	3.71	---	8.32	---
RM 6 to 7	1.54	---	2.65	3.19	2.6	8.23	---
RM 7 to 8	3.63	---	1	1.47	4.03	---	---
TOTAL	13.37	4.09	17.77	20.39	6.63	20.95	**83.2**

Key: Island = Vegetated Island; BD =Mid Channel Bar; LL = Lateral Bar, Left Bank; LR = Lateral Bar, Right Bank; HWC = High Water Channel; PT = Point Bar

Table 13. Wilson River Channel Features, 1965

River Mile (RM)	Channel Feature Acreage						Total
	Island	BD	LL	LR	HWC	PT	
RM -1 to 0	---	0.75	0.25	---	---	---	---
RM 0 to 1	---	1.65	---	0.76	---	---	---
RM 1 to 2	---	---	0.34	0.05	---	---	---
RM 2 to 3	---	0.03	0.46	0.06	---	0.23	---
RM 3 to 4	---	0.43	---	0.22	---	1.19	---
RM 4 to 5	---	0.38	0.7	0.69	---	5.73	---
RM 5 to 6	---	0.05	0.1	0.53	---	9.15	---
RM 6 to 7	---	12.01	10.64	4.5	1.03	---	---
RM 7 to 8	---	---	3.03	2.81	2.16	0.84	---
TOTAL	0	15.3	15.52	9.62	3.19	17.14	**60.77**

Channel Feature Change Factor from Previous Photo Date

River Mile (RM)	Island	BD	LL	LR	HWC	PT
RM -1 to 0	---	---	---	---	---	---
RM 0 to 1	---	---	---	76.0	---	---
RM 1 to 2	---	---	---	---	---	---
RM 2 to 3	---	---	0.6	0.2	---	0.3
RM 3 to 4	---	10.8	0.0	0.2	---	
RM 4 to 5	---	0.1	0.1	0.1	---	1.8
RM 5 to 6	---	---	0.1	0.1	---	1.1
RM 6 to 7	---	---	4.0	1.4	0.4	---
RM 7 to 8	---	---	3.0	1.9	0.5	---

Note: Change factor represents magnitude of acreage change of gravel deposits from 1939 to 1965 as observed from aerial photographs. For each respective river mile, a factor of 10.0 represents a ten-fold increase in the acreage of gravel bars from 1939 to 1965. A factor of 0.5 represents that the acreage of gravel bars was reduced to one half from 1939 to 1965.

Key: Island = Vegetated Island; BD =Mid Channel Bar; LL = Lateral Bar, Left Bank; LR = Lateral Bar, Right Bank; HWC = High Water Channel; PT = Point Bar

River Miles 6-7. Temporary sediment storage in this reach peaked in 1965 with 28.18 acres of gravel bar complexes. Channel width and complexity also peaked during this period. The riparian zone was under attack by bank erosion and gravel deposition. Although there was nearly 10 additional acres in 1965 than in 1939, both years had five gravel complexes. A three-fold decrease in gravel bar array occurred by 2000, but there was no significant reduction in bar count. Riparian density and acreage shows a major increase by 2000 (Plates 11 to 14). Bed elevation data for 1978 and 2000 indicate that the complete reach was aggrading. Coupling this process to complexity, an increase in riparian zone, and gravel storage indicates a channel in pseudo-equilibrium with the hydrologic and sediment conditions. Stabilization of the riparian zone and bed aggradation indicates a possible reduction in channel discharge capacity. Floodwaters appear to exit the channel system upstream of river mile 7.

Table 14. Wilson River Channel Features, 2000

River Mile (RM)	Channel Feature Acreage						Total
	Island	BD	LL	LR	HWC	PT	
RM -1 to 0	0.04	0	---	1.88	---	---	---
RM 0 to 1	0.09	---	0.38	---	---	---	---
RM 1 to 2	---	---	---	---	---	0.18	---
RM 2 to 3	---	0.29	0.26	0.86	---	---	---
RM 3 to 4	---	0.51	1.08	0.26	---	---	---
RM 4 to 5	---		1.99	0.07	0.13	2.35	---
RM 5 to 6	---	0.04	1.79	0.67	0.27	3.26	---
RM 6 to 7	---	0.37	4.13	1.28	---	2.55	---
RM 7 to 8	---	0.96	5.13	---	---	1.88	---
RM 8 to 9	---	---	---	0.31	---	---	---
TOTAL	0.13	2.17	14.76	5.33	0.4	10.22	**33.01**

Channel Feature Change Factor from Previous Photo Date

River Mile (RM)	Island	BD	LL	LR	HWC	PT
RM -1 to 0	---	---	---	---	---	---
RM 0 to 1	---	---	---	---	---	---
RM 1 to 2	---	---	---	---	---	---
RM 2 to 3	---	9.7	0.6	14.3	---	---
RM 3 to 4	---	1.2	---	1.2	---	---
RM 4 to 5	---	---	2.8	0.1	---	0.4
RM 5 to 6	---	0.8	17.9	1.3	---	0.4
RM 6 to 7	---	---	0.4	0.3	---	---
RM 7 to 8	---	---	---	0.0	---	2.2
RM 8 to 9	---	---	---	---	---	---

Key: Island = Vegetated Island
BD =Mid Channel Bar
LL = Lateral Bar, Left Bank
LR = Lateral Bar, Right Bank
HWC = High Water Channel
PT = Point Bar

River Miles 5-6. Over the study period, major changes to the channel thalweg have modified this reach. From 1978 to present, the lower half of the reach has undergone the brunt of the thalweg perturbations along with bed degradation. In 1939, there was 14.48 acres of temporary storage in 5 major gravel complexes; the number of gravel complexes has decreased to 4 with only 6.03 acres. An increase in acreage and density in the riparian zone also occurred, inducing a stability increase and a reduction in complexity.

River Miles 4-5. In 1939, this reach was highly complex and was dominated by massive areas and numbers of temporary gravel sites (Photograph 2 and Plate 11). Lateral gravel bars were dominant (Table 12). Lateral gravel bar complexes indicate high sediment transport rates plus a high degree of channel complexity. High flow or storm events increase the occurrence of bank erosion and general aggrading in association with the large lateral gravel bar complexes. The resulting process is a reduction in riparian zone, an increase in temporary sediment storage, and aggrading. By 2000, temporary storage sites decreased from 27.23 to 4.54 acres. Analysis of bed elevation data from 1978 to 2000 shows that bed elevation has increased. Coupling this data with channel thalweg data supports a reduction in both complexity and acreage of temporary sediment storage locations.

River Miles 3-4. Channel stability in this reach increased from 1930 to 1965. Bar area and number of temporary gravel complexes also decreased and are coupled to the increase in stability. Sediment reduction in bar number and area produced a decrease in channel complexity. Bank erosion resulted in minor degrees of channel path/thalweg migration. From 1939 to 1965, riparian vegetation is comparable, and by 2000, the density and acreage of the riparian zone showed a marked increase (Plates 11 to 13).

River Miles 2-3. During the study period, this reach was in pseudo-equilibrium with hydrology and sediment supply. Temporary sediment volumes declined in 1965 and 2000, reflecting increasing stability and sediment production in the upper watershed. Channel narrowing is the dominant geomorphic process occurring from 1965 to 2000. Riparian zone area and density increased from 1939 to 2000. Channel path stabilization resulting from sediment supply supported the increases in these zones along the reach.

River Miles 1-2. No major geomorphic channel modification occurred from 1939 to 2000. Engineering operations have restricted major channel perturbations. Gravel bar complexes also reflect minor sedimentation process within this reach. Lack of gravel storage locations indicates a transport section. Discharge and sediment supply are in pseudo-equilibrium and long profile data support this position. Slope appears stable during the study period. Channel complexity is not a factor (there is none) (Plates 11 to 14).

River Miles Below 1. This reach has islands and a minor number of gravel bars. The presence of an island below river mile 1 indicates a high influx of sediment reaching the lower river bay/interface reach. Normal wave and tidal action could redistribute sediment delivered if this reach was in geomorphic equilibrium. The basin fire history supports high sedimentation. Constant hydrologic conditions will move sediment bayward mainly during storm/high-flow events. Island and bar development declined by 30% from 1939 to 1965, and declined another 10% from 1965 to 2000 (Tables 13 and 14). Factors controlling sediment transport can be coupled to reforestation of the upper watershed. Engineering operations in this reach have been undertaken, resulting in only minor sediment redistribution and minor river perturbations in the delta/bay dominant geomorphic zone.

In summary, the Wilson River is an aggrading system, and 7 of the 9 river miles analyzed are aggrading. Geomorphic data indicate the river is storing less sediment and developing a denser and wider riparian zone. Bed aggradation may be caused by a combination of natural and man-induced narrowing. Construction of revetments, levees, and other channelization features may be factors coupled to the aggrading nature of the Wilson River. A reduction in sediment supply or loading with no reduction in hydrology also appears to be factors. Bed aggradation may induce floodwater to exit the channel system at lower discharges.

Sediment supply/loading appear less based on fire and reforestation history. High sediment supply/load occurred from 1933 to the early 1950s. Fires laid bare the highly erosive volcanic material to winter storm events resulting in massive sediment delivery to the channel system. The lack of major forest fires during the last fifty years has resulted in a major reduction of sediment yield. During 1933-1951, the Wilson River was sediment rich and transport capability poor, resulting in a massive period of sediment transport from the upper basin to the bay. The reduction in acreage and number of gravel bar complexes from 1939 to 2000 indicates the river is transferring from sediment rich back to sediment normal, while maintaining the same hydrology. Bed aggradation appears coupled to riparian zone development and complexity reduction. Long profile data indicate pseudo-equilibrium of sediment introduced to the system and sediment in temporary storage (Plate 14). Riparian zone development reduces bank/bed erosion, only if high flow or flood events exit onto the floodplain near the valley apex. Observations of flooding during 1996 and 1999 indicate that this occurs. In-channel energy is reduced and sediment transport is reduced resulting in bed aggradation. Minor flood events appear to remove the gravel bar complexes and/or reduce their acreage and total number.

Wilson River Overlap Analysis

Table 15 shows a spatial and temporal discontinuity in the Wilson River geographic positioning for the study dates (1939, 1965, 2001). Total overlap or congruence is 24.4% or 58.8 acres from a total of 240.9 acres. Analysis of the data indicates a congruence increase over time. Coupling basin sediment supply and transport processes, end erosion events continuity will increase if sediment supply and delivery remain in the current state of quasi-equilibrium. Continuity overlap comparisons from 1939 to 1965 illustrate major spatial variations; data for 1965-2000 illustrate a reduction in the discontinuity, 7.9% to 12.2%. Channel freedom and in-channel transport capabilities appear reduced, resulting in reaches of bed aggradation (Plate 14).

Table 15. Wilson River Channel Overlap Analysis, 1939-1965-2000

Length	Overlap	Kilchis River	Acreage	% of Total
8.60 miles	0	No Overlap	127.5	52.9
	1	1939/1965 Overlap	19.1	7.9
	2	1939/2000 Overlap	6.0	2.5
	3	1965/2000 Overlap	29.5	12.2
	4	1939/1965/2000 Overlap	58.8	24.4
	Total Acreage (for all 3 years)		240.9	---

Note: "Overlap" is the attribute in the Arc/View shape files.

Basin hydrology has remained constant during the period of record, resulting in a constant transport capacity and a non-steady sediment supply. Variations in sedimentation rates and in-channel geomorphic processes have induced channel pattern modifications; gravel bar complexes and bed aggradation and degradation. This generated a river system that is out of phase or in non-quasi-equilibrium. High sediment supply and sediment in transport prior to the early 1950s have impacted fluvial processes. After the 1950s, sediment supply and sediment in transport have progressed to a new quasi-equilibrium condition, a system dominated by bed aggradation and a reduction in gravel bar complexes (Tables 12,13, and 15). Channel slope conditions have modified as bed aggradation reaches impact the channel processes.

Comparing 1965-2000 channel positions, overlap percentage has increased (Table 15 and Plate 14). As overlap or congruence increases, channel freedom decreases and stability appears to increase. Human impacts are currently not measurable. Nevertheless, they have reduced channel freedom and appear to add to a sense of channel stability. Combining geomorphic processes with the human impact shows that the Wilson River has lost a high degree of freedom or sinuosity, and ability to transport bed sediment. Bed aggradation is the effect, resulting in a reduction in channel cross-sectional area to convey discharge or the high flow events.

The gravel harvesting events of the 1990s are not distinguishable based on the type and temporal variables. No implied conclusion is stated as to the status of gravel harvest activities on the Wilson River.

Trask River Geomorphology

Sediment supply in the upper basin, by debris flow events, is the controlling geomorphic process in the Trask River. Transport and supply appear equal in the upper basin. Deposition controls the lower basin area. Fine grain deposition is aggrading the floodplain in the lower basin. Upper basin sediment supply and transport capacity appears in balance. This river appears to be the major sediment production basin in the Tillamook Bay Basin (Table 4).

The upper Trask River (upland reach) is bedrock controlled. Degradation and lateral movement are minimal and channel geometry is bedrock controlled (Plate 4). Sediment delivery appears to be coupled to hill slope failures (mass movement events), which could bulk to debris flows. The forested upland hills appear to supply a relatively small amount of large woody material (tree material). Lag deposits of this material are stranded along the high flow line or locked in the eroded cuts within in the bedrock bed. At the transition from uplands to valley, in-channel sediment storage increases. Lateral and point bar complexes are present. This reach has incised about 5 to 10 feet. Incision decreases bayward and transport of fine silts and sand volume increases. From the transition zone to the bay bank (river miles 0-3) section, bank erosion zones increase. The volume and size of sediment produced by this geomorphic process is unknown. The occurrence of tributary debris flow or blow out channels appears to increase the higher in the basin one proceeds. The steep hill slope failure occurrence requires additional analysis. The sediment bulking or loading in the upper watershed creates a channel system that is transport-limited during storm events (Plates 15 to 18).

<u>River Mile 8-7</u>. A zone of temporary storage is the controlling sediment process in this reach. Point bar features dominated sediment storage in 1939; by 2000, no point bar complexes existed (Tables 16 to 18 and Plates 15 to 17). Lateral bar occurrence trends decline in both acreage and number by 2000. The riparian zone shows a marked increase from 1939 to 2000, indicating a reduction in sediment load and channel plain view migration. The combination of these geomorphic processes indicates an increase in channel stability, which aids in the development of the riparian zone. Analysis of flood event photographs show that floodwaters are exiting onto the alluvial plain and inducing flooding. Aggradation processes are supported by the bed elevation increase data between 1978 and 2000.

Table 16. Trask River Channel Features, 1939

River Mile (RM)	Channel Feature Acreage						Total
	Island	**BD**	**LL**	**LR**	**HWC**	**PT**	
RM -1 to 0	---	18.63	---	---	---	---	18.63
RM 0 to 1	---	---	0.05	0.18	---	---	0.23
RM 1 to 2	---	0.41	---	---	---	---	0.41
RM 2 to 3	---	---	---	---	---	0.26	0.26
RM 3 to 4	---	---	---	1.32	---	0.08	1.40
RM 4 to 5	---	1.41	0.78	3.92	---	6.11	12.22
RM 5 to 6	---	0.18	8.38	13.30	---	---	21.86
RM 6 to 7	---	0.05	9.18	6.79	---	---	16.02
RM 7 to 8	---	---	6.51	---	0.32	12.27	19.10
TOTAL	---	20.68	24.90	25.51	0.32	18.72	**90.13**

Key: Island = Vegetated Island; BD =Mid Channel Bar; LL = Lateral Bar, Left Bank; LR = Lateral Bar, Right Bank; HWC = High Water Channel; PT = Point Bar

<u>River Mile 6-7</u>. Lateral bar complexes dominate the temporary sediment storage features in 1939, and the trend continues although acreage has been reduced (50.41 acres in 1939, 25.98 acres in 1965, and 14.72 acres in 2000; Tables 16 to 18). Channel pattern migrations declines and bed aggradation continues. Point bar development remains constant between 1965 and 2000. Bed aggradation and channel narrowing stability appears to increase. The riparian zone area and density also continues to increase. Stabilization of the riparian zone and bed aggradation indicates a possible reduction in channel discharge capacity. Floodwater exits the channel system to the alluvial plain in this reach (Photograph3). Return flow occurs in this reach, and data indicates that this is a major channel bank erosion process. The result is an increase in fine-grained sediment supply. Out-of-channel flooding deposits fine-grained sediment on the alluvial plain and induces minor alluvial plain elevation increases.

<u>River Mile 5-6</u>. Gravel bar complex area and number show a marked decrease form 1939 to 2000 in this reach. The trend is coupled with the geomorphic processes acting upon the

lower basin (alluvial plain) by those events in the upper basin (mountain reaches). In 1939, gravel bar features accounted for 21.86 acres of sediment storage elements. Channel stability appears to have increased where temporary storage site areas have decreased. Riparian area and density are increasing because of slower migration and gravel transport. Longitudinal profile data indicates that bed degradation has occurred in the upper most section from 1978 to 2000 (Plate 18). Bed aggradation still dominates the reach, inducing channel cross-section reduction and increasing out-of-channel flood flows.

Table 17. Trask River Channel Features, 1965

River Mile (RM)	Channel Feature Acreage						Total
	Island	BD	LL	LR	HWC	PT	
RM -1 to 0	29.28	---	---	---	---	---	---
RM 0 to 1	---	---	0.61	0.32	---	0.1	---
RM 1 to 2	---	0.28	---	---	---	---	---
RM 2 to 3	---	---	---	---	---	0.13	---
RM 3 to 4	---	---	0.22	---	---	0.86	---
RM 4 to 5	---	---	0.67	1.83	---	3.23	---
RM 5 to 6	1.79	0.92	7.74	3.29	---	---	---
RM 6 to 7	---	0.31	8.1	2.71	---	0.82	---
RM 7 to 8	---	4.14	0.05	0.44	---	---	---
TOTAL	31.07	5.65	17.39	8.59	0	5.14	**67.84**

Channel Feature Change Factor from Previous Photo Date

River Mile (RM)	Island	BD	LL	LR	HWC	PT
RM -1 to 0	---	---	---	---	---	---
RM 0 to 1	---	---	12.2	1.8	---	---
RM 1 to 2	---	0.7	---	---	---	---
RM 2 to 3	---	---	---	---	---	0.5
RM 3 to 4	---	---	---	---	---	10.8
RM 4 to 5	---	---	0.9	0.5	---	0.5
RM 5 to 6	---	5.1	0.9	0.2	---	---
RM 6 to 7	---	6.2	0.9	0.4	---	---
RM 7 to 8	---	---	---	---	---	---

Note: Change factor represents magnitude of acreage change of gravel deposits from 1939 to 1965 as observed from aerial photographs. For each respective river mile, a factor of 10.0 represents a ten-fold increase in the acreage of gravel bars from 1939 to 1965. A factor of 0.5 represents that the acreage of gravel bars was reduced to one half from 1939 to 1965.

Key: Island = Vegetated Island; BD =Mid Channel Bar; LL = Lateral Bar, Left Bank; LR = Lateral Bar, Right Bank; HWC = High Water Channel; PT = Point Bar

River Mile 4-5. Analysis of the gravel bar complex indicates a high volume of sediment was still in temporary storage in this reach. The trend shows a decline of 50% from 1939 to

2000. Gravel bar number also trended lower and channel migration and cross-sectional area show similar results (Tables 16 to 18, Plate 15 to 18). Longitudinal profile analysis indicates the lower 0.5-mile is trending to bed degradation, as compared to upstream aggradation. Meander pattern modification has decreased and stability appears to be increasing. Coupled to these geomorphic processes and sediment supply history, in-channel sedimentation processes have changed from depositional to erosional. Water well log number 81 (Highway 101 and the Trask River Bridge) shows that the Trask River is currently flowing through historic deltaic sediment (Plate 3). The fine-grained sediment requires less hydraulic energy for transport. During the dry period, bank dry raveling occurs and is then transported during higher flow event. The combination of up-area streambed armoring and lower reach bank erosion could increase fine grain sedimentation in the bay.

Table 18. Trask River Channel Features, 2000

River Mile (RM)	Channel Feature Acreage						Total
	Island	**BD**	**LL**	**LR**	**HWC**	**PT**	
RM -1 to 0	35	4.32	1.31	---	---	---	---
RM 0 to 1	---	0.3	0.97	0.35	---	0.07	---
RM 1 to 2	---	0.49	0.1	0.43	0.22	---	---
RM 2 to 3	---	---	0.34	---	---	0.09	---
RM 3 to 4	---	---	0.14	0.11	---	0.13	---
RM 4 to 5	---	---	0.79	1.55	---	2.01	---
RM 5 to 6	---	---	0.95	0.54	---	0.28	---
RM 6 to 7	---	0.14	0.77	3.59	---	0.94	---
RM 7 to 8	---	0.19	2.5	0.27	---	---	---
TOTAL	35	5.44	7.87	6.84	0.22	3.52	**58.89**

Channel Feature Change Factor from Previous Photo Date

River Mile (RM)	Island	BD	LL	LR	HWC	PT
RM -1 to 0	1.2	---	---	---	---	---
RM 0 to 1	---	---	1.6	1.1	---	0.7
RM 1 to 2	---	1.8	---	---	---	---
RM 2 to 3	---	---	---	---	---	0.7
RM 3 to 4	---	---	0.6	---	---	0.2
RM 4 to 5	---	---	1.2	0.8	---	0.6
RM 5 to 6	---	---	---	0.2	---	---
RM 6 to 7	---	0.5	0.1	1.3	---	1.1
RM 7 to 8	---	---	50.0	0.6	---	---

Key: Island = Vegetated Island; BD =Mid Channel Bar; LL = Lateral Bar, Left Bank; LR = Lateral Bar, Right Bank; HWC = High Water Channel; PT = Point Bar

River Mile 3-0. In a reversal of sediment processes, 1965 and 2000 sedimentary features are more numerous and have more acreage than this reach had in 1939 (Plates 16, 17 and 18).

Bed degradation dominates river miles 2.5 to 4 and sediment transport exceeds deposition. This reach has been channelized by levees and other structures. The narrow and channelized section creates increased velocity resulting in a transport-dominated reach. Below river mile 0 to river mile 2.5, the deposition of fine-grained sediment is dominant. This deposition results in the development of island and bar complexes (Table 16 to 18, Plate 16 and 17). This depositional process occurs in all the Tillamook Bay Basin Rivers. Reduction in hydraulic energy results in deposition and the development of a sediment wedge.

In summary, the Trask River is an aggrading system with minor reaches of degradation. High sediment loads resulted from the forest fires of the 1930s to 1950s. The Trask is no different than the other rivers in the basin; during the 1930s to early 1950s, sediment supply exceeded transport capacity, which resulted in channel bed aggradation and a perceived increase in channel stability. The reduction in channel cross-sectional area and bed elevation resulted in an earlier out-of-channel flow with no increase in discharge rates. These geomorphic processes are "normal" and represent a channel system returning to a state of quasi-equilibrium. Observations during the 1996 and 1999 flood events indicate out-of-channel flow in the upper alluvial plain area. The reduction in gravel bar and island complexes from 1939 to 2000 support the findings that sediment supply is returning to "normal." Nevertheless, these "normal" volumes may be high and are a function of basin geology and climatic conditions.

Trask River Overlap Analysis

The Trask River overlap analysis (Table 19 and Plate 18) shows that only 23.7% of the total active river channel area occupies the same geographical location. A total of 116 acres or 48.8% of the total channel show no correlation in channel positions during the study period (Table 19). Years 1965 and 2000 show the highest degree of location correlation, 13.6% or 56.3 acres. Spatial and temporal discontinuities or continuities directly couple to channel stability. The higher the degree of discontinuity, the higher the degree of channel freedom, or channel migration (meandering). This geomorphic process is influenced by sediment supply, sediment in transport, basin discharge events or frequency of high flow events, channel slope, and human impact. Data presented indicates that basin hydrology has remained constant. Sedimentation processes have undergone a period of flux, impacting the quasi-equilibrium condition of the river system. High sediment supply and sediment in transport prior to the early 1950s impacted fluvial processes. After the 1950s, sediment supply and sediment in transport have progressed to a new quasi-equilibrium condition, a system dominated by bed aggradation and a reduction in gravel bar complexes (Tables 16 to 18). Channel slope conditions have been modified as bed aggradation reaches impact the channel processes.

Table 19. Trask River Channel Overlap Analysis, 1939-1965-2000

Length	Overlap	Kilchis River	Acreage	% of Total
8.20 miles	0	No Overlap	116.1	48.8
	1	1939/1965 Overlap	22.3	9.4

	2	1939/2000 Overlap	10.7	4.5
	3	1965/2000 Overlap	32.4	13.6
	4	1939/1965/2000 Overlap	56.3	23.7
	Total Acreage (for all 3 years)		237.7	---

Note: "Overlap" is the attribute in the Arc/View shape files.

Comparing 1965-2000 channel positions, overlap percentage has increased to 13.6% or 32.4 acres (Table 19 and Plate 18). As overlap or congruence increases, channel freedom decreases and stability appears to increase. Human impacts are currently not measurable. Nevertheless, they have reduced channel freedom and appear to add to a sense of channel stability. Combining geomorphic processes and human impact indicates that the Trask River has lost a high degree of freedom or sinuosity, and an ability to transport bed sediment. Bed aggradation is the effect, resulting in a reduction in channel cross-sectional area to convey discharge or high flow events.

Tillamook River Geomorphology

Deposition and aggradation are the dominant geomorphic processes in the Tillamook River. The river appears to have the lowest gradient of all rivers in the Tillamook Bay Basin. Only minor areas of gravel sediment are evident (Plate 19). The system generates a high volume of fine sediment. The river lacks the similar geomorphic forms of the other rivers in the basin. Upland reaches are non-descript forms; there is a low gradient channel and well-defined riparian zone. Bank cavitation is the primary sediment providing process. This type of bank failure supplies small woody material to the channel. The impact of this woody material to the overall system has not been quantified. However, the low channel gradient likely would not provide the sediment or discharge velocity for any channel impact associated with the woody debris. No transition reach appears within the system, which results in a lack of any major reach having temporary sediment storage. The lower river is confined by a set of low levees of unknown composition and engineering quality. During high flow events, water will overtop these structures resulting in lowland flooding. Tillamook County has identified these locations and has installed gravel ramparts to reduce erosion of the road prism. The lower river flows into the bay and may provide mostly fine-grained material.

Sinuosity and Longitudinal Profile

Meandering rivers are those having a sinuosity index of 1.5 or greater (Leopold et al, 1964). The sinuosity index is a ratio of channel length to down valley straight-line distance. Rivers with a sinuosity index below 1.5 are classified as straight or sinuous. However, this does not imply these rivers are lacking in symmetric curvature. Leopold et al. (1964) used this index to classify river channel morphology and stability. Assessment of sinuosity shows fluvial geomorphic processes and modifications over time. River patterns show no distinct boundaries but a continuum from one pattern type to another. Basin geomorphic events along with human activities will impact results of sinuosity analysis in the alluvial plain, as is the case for the Tillamook Bay Basin alluvial plain.

Nevertheless, the sinuosity index shows reaches that are confined or unconfined across the alluvial plain. Sediment supply, transport rates and slope combine to impact the sinuosity index and interpretations. The lack of sediment yield and transport volumes in the basin are unknown with the exception of the 1978 general erosion volumes. Linking basin history, longitudinal profile, and sinuosity analysis indicates that a number of reaches are still responding to geomorphic events occurring in the early half of the century. Analysis completed by Philip Williams and Associates and others (PWA et al. 2001) for 1955 and 1985 show minor modifications in the sinuosity index. A sinuosity index analysis for 1939, 1965 and 2000 was completed for this assessment and a comparison analysis performed. Sinuosity analysis was completed for the five rivers of the Tillamook Bay Basin (Miami, Kilchis, Wilson, Wilson, and Trask Rivers), as well as a longitudinal profile analysis for all rivers except for the Tillamook River. This is because the study reach composites for the lower 2 river miles are at or below mean tidal range. Analysis would fail to provide useable data sets. The concepts of stability and sinuosity show sediment supply declining from those of the pre-1950s. Bed aggradation is still a dominant geomorphic process, which increases channel bed and bank instability. Bed aggradation results in channel area reduction, allowing high flow events of decreasing discharge to exit the mainstem channel area. Systems that are sediment rich and manipulated by human activities (revetment-levee construction) respond by aggradation and down valley sediment transport. During major flow events, sediment slugs will phase through the river system.

Aggregating the individual river sinuosity, longitudinal profile, and gravel bar complex analysis to a basin model indicates channel adjustments are proceeding. Bed aggradation processes have reduced channel cross-section area and hydraulic energy. Channel stability appears to be increasing, along with an increase in riparian zone area and density (Plates 6, 10, 14, and18). The reduction in cross-section area appears to induce out of channel flooding at discharges that historically (pre-1950s) could be retained within the channel cross-section area. Gravel bar complex acreage and bars numbers have declined, indicating a basic reduction of sediment supply from the upper basin areas to a “normal” volume or rate. Quantifying the volume or rate currently is not possible without a detailed basin sediment budget study.

In select reaches, bed armoring will develop and induce additional gravel sediment trapping, which could increase fine grain sediment transport bayward. A reduction in gravel transport could increase bank erosion in the lower alluvial plain (river miles 0 to 4). Bank and bed erosion in the upper alluvial plain will remain low during channel forming discharges. Bank erosion will occur and couple with reach geomorphic conditions. Major periods of bank erosion or channel preparation will increase as aggradation continues. Combining these geomorphic processes could generate a major channel alignment from the mountain/upland apex and the upper alluvial plain. Gravel harvest activities along the upper channel reaches could prolong major channel migration. These activities could increase gravel size sediment transport rates though the system to the bay, and reduce the current stability conditions.

Miami River

The Miami River is a low sinuosity river and data indicates that river mile 4 and above have sinuosity indexes greater than 1.50, resulting in a classification of a meandering river reach. Sinuosity index values have remained constant (Table 20). Channel bed aggradation occurred between 1978 and 2000 (Plate 5). Channel migration across the alluvial plain during the last +100 years appears minimal. Bed aggradation appears to have induced a degree of channel stability. Coupling hydrology conditions and bed processes, there appears to be an increase in out-of-channel flow. This is a location and discharge event function. The increase in out-of-channel flow reduces the erosion impacts to bed and bank conditions. Less in-channel hydraulic energy equals to lower rates of bed and bank erosion, and in-channel sediment transport.

Table 20. Sinuosity Indices for the Miami River from 1939 to 2000

River Mile	1939	1955	1965	1985	2000
0.0-1.0	1.08	1.25	1.24	1.24	1.25
1.0-2.0	1.05	1.18	1.10	1.08	1.07
2.0-3.0	1.10	1.29	1.30	1.32	1.30

Note: Data for 1955 and 1985 is taken from PWA et al. 2001; data for 1939, 1965, and 2000 was developed for this assessment.

Kilchis River

Sinuosity and longitudinal profile analyses (Table 21 and Plate 10) illustrate the relationship between channel meandering and bed aggradation. Five different years of sinuosity data and two different years of longitudinal profile data show that the reach from river miles 2.0 to 3.2 is a meandering (sinuosity index >1.5) and aggrading reach. Gravel bar complexity, acreage, and development has declined from 1939 to 2000 (Tables 8 to 10). The analysis shows that:

- River mile <1: an increase in sinuosity, the long-term trend is downward.
- River mile 2-3: a meandering channel reach.
- River mile 2-3: an aggradation reach.
- River mile 1-2: a degrading reach and transport dominated reach.
- River mile <0-1: sinuosity increase and bed aggradation.
- Bed aggradation is occurring.
- A reduction in gravel bar complexes, in acreage and number.

Sediment deposition is dominant from river mile 1.0 and below. Deposition in this reach has formed a sediment wedge at the delta and river interface. Analysis of 1939 aerial photographs show that a large amount of gravel type material was deposited before 1939. Additional sedimentation has continued, but at a slower rate. Nevertheless, the rate is not quantifiable, and recent deposition has not completely obscured the 1939 deposition. Coupling this analysis and basin history, the Kilchis River is trending to a new condition of quasi-equilibrium. The reduction in sediment supplies and bed aggradation decreases the transport rate to the bay. Bed aggradation from river miles 2 to 3 increases out-of-channel flow and alluvial plain flooding.

Table 21. Sinuosity Indices for the Kilchis River from 1939 to 2000

River Mile	1939	1955	1965	1985	2000
0.0-1.0	1.27	1.37	1.40	1.43	1.38
1.0-2.0	1.05	1.15	1.10	1.06	1..04
2.0-3.0	1.62	1.82	1.81	1.81	1.78
3.0-4.0	1.11	1.21	1.20	1.21	1.20
4.0-5.0	1.09	1.08	1.05	1.02	101

Note: Data for 1955 and 1985 is taken from PWA et al. 2001; data for 1939, 1965, and 2000 was developed for this assessment.

Wilson River

Combining the five data sets of sinuosity analysis with the two longitudinal profile data sets shows that the Wilson River is trending to a new phase of quasi-equilibrium. The reduction in sediment supply from the upper basin, the constant hydrology and channel cross-sectional area reduction indicates a stable channel (Table 22 and Plate 14). The analysis shows that:

- River mile 0-3: a transport dominated reach.
- River mile 2-4: a low sinuosity-straight, engineered reach.
- River mile 4-6: a degradation dominated reach; sediment transport > deposition.
- River mile 5-6+: meandering channel; aggradation processes dominate; deposition is greater than erosion.
- A reduction in gravel bar complexes, in acreage and number.

Sinuosity index analysis indicates that from 1939 to 1985, the trend increased; the period from 1985 to 2000 illustrates an index reduction, but is still higher than the 1939 levels. Reaches of low sinuosity (river miles 1 to 4) appear to establish a balance between sediment supply, hydrology and is a transport dominated reach. River miles <0 to 1 is dominated by sediment deposition. A sediment wedge has developed and has increased in area, and illustrates an up-channel growth pattern. A reduction in channel cross-section and bed aggradation induces a factor of stability by a reduction of in-channel energy. This reduction is linked with sediment transport and channel cross-section erosion to reduce channel capacity. The reduction in channel capacity could increase deposition of large gravel material and a winnowing of the fine-grained material. This assessment is qualitative and will remain so until a basin sediment budget is developed.

Table 22. Sinuosity Indices for the Wilson River from 1939 to 2000

River Mile	1939	1955	1965	1985	2000
0.0-1.0	1.16	1.21	1.20	1.19	1.19
1.0-2.0	1.25	1.32	1.32	1.32	1.32
2.0-3.0	1.09	1.09	1.10	1.09	1.09
3.0-4.0	1.10	1.10	1.10	1.10	1.10
4.0-5.0	1.37	1.48	1.50	1.51	1.54
5.0-6.0	1.53	1.70	1.71	1.25	1.70
6.0-7.0	1.24	1.17	1.19	1.25	1.28
7.0-8.0	1.80	1.08	1.08	1.08	1.05

Note: Data for 1955 and 1985 is taken from PWA et al. 2001; data for 1939, 1965, and 2000 was developed for this assessment.

Trask River

Compiling the sinuosity analysis data conducted by PWA et al. (2001) and the data from analysis in this assessment shows that:

- In the study reach, sinuosity index is below 1.5.
- Sinuosity index analysis indicates an increase of less than 0.10.
- Minor sinuosity index values increase up-channel.
- River mile 7-8: lowest index values.
- River mile <0-1: no significant variations.
- River mile 2-4: 1939, 1955 and 1965 show minor increase in index values.
- 1985-2000: reduction in index values.

The sinuosity index (Table 23) and channel overlay and longitudinal profile (Plate 18) coupled with basin sedimentation pattern and processes appear to support an increase in channel stability. River miles 2-4 is a transport dominated reach where river mile 0-1 is dominated by finer-grained sediment deposition. Bar and island channel forms have developed and analysis indicates they have increased in size during the last 35 years. Above river mile 5, deposition processes dominate. Channel bed aggradation occurs from 1978 to 2000. This results in a reduction in channel cross-sectional area and a perceived increase in channel stability that could be linked with out-of-bank flooding at lower discharges.

Table 23. Sinuosity Indices for the Trask River from 1939 to 2000

River Mile	1939	1955	1965	1985	2000
0.0-1.0	1.07	1.08	1.10	1.12	1.10
1.0-2.0	1.09	1.09	0.09	1.12	1.11
2.0-3.0	1.11	1.21	1.24	1.18	1.15
3.0-4.0	1.14	1.15	1.15	1.19	1.20
4.0-5.0	1.06	1.05	1.05	1.08	1.12
5.0-6.0	1.09	1.14	1.12	1.18	1.15
6.0-7.0	1.13	1.15	1.12	1.16	1.15
7.0-8.0	1.02	1.03	1.01	1.11	1.10

Note: Data for 1955 and 1985 is taken from PWA et al. 2001; data for 1939, 1965, and 2000 was developed for this assessment.

Tillamook River

Only river miles 0 to 2 are included in the study reach. The Tillamook River is at or within the tidal range of Tillamook Bay. Because of this and the short study reach, no longitudinal profile was constructed; however, a sinuosity analysis of the reach was constructed. Data from years 1939, 1965 and 2000 were combined with that from PWA et al. (2001). The analysis shows that no sinuosity modifications have occurred during the study period (Table 24 and Plate 19).

Table 24. Sinuosity Indices for the Tillamook River from 1939 to 2000

River Mile	1939	1955	1965	1985	2000
0.0-1.0	1.12	1.12	1.11	1.10	1.10
1.0-2.0	0.04	0.04	0.03	0.03	0.03
2.0.3.0	1.12	1.08	1.09	1.08	1.09

Note: Data for 1955 and 1985 is taken from PWA et al. 2001; data for 1939, 1965, and 2000 was developed for this assessment.

7. FUTURE GEOMORPHIC LANDSCAPES

Controlling Geomorphic Processes by River Basin

The river systems in the Tillamook Bay Basin are attempting to return to a state of quasi-equilibrium. Abnormally high sediment supply occurred from 1930 to the mid-1950s. Slope failure events in the upper basin areas dominated the geomorphic processes that were overloading the fluvial system. Deforestation resulting from the devastating forest fires between 1933 and 1951, the climatic conditions of the area, and the highly erodible volcanic and marine sediments combined to form the abnormally high sediment supply. Tables 25 and 26 summarize the controlling geomorphic processes for each river basin. Although the tables reflect the geomorphic processes occurring in each river basin, they are not site specific nor do they provide a numerical inventory solely as method of classification of these controlling processes (Photograph 4). Table 25 combines in-channel processes and sediment supply, and Table 26 links to external channel sediment supply and in-channel processes. Tables 25 and 26 represent a qualitative rating for the controlling geomorphic processes for each basin, and the values of high, moderate and low are used. This is only the initial phase for constructing a total basin analysis, which would consist of a basin-wide geomorphic framework and sediment budget.

Table 25. Internal Channel Sediment Supply Processes

River Basin - Geomorphic Processes ID for River Basins

River Basin	Cut Back Cavitation	Bar Erosion (Accretion or erosion)	Bed Movement (Aggradation or degradation)	Woody Debris in Channel or on Terrace
Miami River	Low	Low	Moderate	Low
Kilchis River	Moderate	Moderate	Moderate	Low
Wilson River	Moderate	Moderate	Moderate	Low
Trask River	Moderate	Moderate	High	Low
Tillamook River	Low	Low	Moderate	Low

Table 26. Basin Controlling Geomorphic Processes

River Basin - Controlling Geomorphic Process Degree/Rating

River Basin	Sediment Supply	Deposition/Aggradation	Erosion/Degradation
Miami River	Low	Moderate	Moderate
Kilchis River	Moderate	Moderate	Moderate
Wilson River	High	Moderate	Moderate
Trask River	High	High	High
Tillamook River	Low	Low	Low

This information provides an understanding of the controlling fluvial geomorphic processes shaping the Tillamook alluvial plain. The combination of external and internal geomorphic processes result in limiting the channel response. Hydrology data for the Wilson River (period of record 1930 to date; see Appendix A) indicates a constant energy source and/or stream power. During the high sediment supply period, in-channel energy and/or stream power capacity was overwhelmed by the sediment supply. After the mid 1950s to date, sediment supply reduction has occurred. Analysis shows channel freedom and migrations combined with major gravel complex development and migration. As the river systems exit the upper basin areas flow onto the upper Tillamook alluvial plain, a reduction of channel energy and/or stream power occurs, which results in gravel deposition and gravel bar development for several miles downstream of the valley apex on to the alluvial plain. With reforestation in the upper basin areas, the abnormally high sediment supply and delivery rates have declined. With this decline, or a return to a more "normal" sediment supply from the upper basin area, the transport capacity has increased (Photographs 5 and 6).

In-channel sediment transport has increased and the acreage and number of gravel bar complexes have declined. Gravel bar analysis (Tables 8-10, 12-14, and 16-18) shows a 2-fold reduction of gravel bar acreage and a reduction in bar number. Channel overlap analysis (Tables 11, 15, and 19) from 1939 to 1965 show that channel migration across the upper alluvial plain had a high degree of freedom. High volumes of gravel in transport or in temporary storage in the upper channel areas aided in increasing channel freedom (Plates 5 to 19). With the reduction in sediment supply, a corresponding reduction in channel freedom appears to have occurred.

Erosion of the gravel bar complexes occurred after the mid-1950s. The channels on the upper alluvial plain was still sediment rich resulting in unilateral bar development and erosion. Fine and medium grain sediment transport increased down the alluvial plain, channel dynamics were modified and resulted in bed aggradation in the upper and middle channel reaches of the Tillamook alluvial plain. The natural widening processes or increase in cross-sectional area was denied. This is a natural process in channel network development. This function is required to transport the combination of increased water volume and sediment. Channels on the lower alluvial plain have a larger cross-sectional area than that those on the upper alluvial plain or headwater areas. Cross-sectional areas of the channels on the lower and upper Tillamook alluvial plain have similar geometry (Plates 5 to 19). The channels of the Tillamook alluvial plain create a dichotomy in the pyramid concept of fluvial geomorphology. This means that the channel cross-sectional area will generally increase from the headwaters to the sink. The failure to allow the channel cross-sectional area to increase impacts the linkage between cross-sectional area, sediment transport, and discharge. Human activities also are coupled to the failure in allowing this geomorphic process to develop. The narrowing or failure to increase channel area in the lower alluvial plain results in the disruption of normal geomorphic events and/or processes.

Erosion and reduction in gravel bar complexes in the upper alluvial plain supports bed aggradation, an apparent increase in channel stability, and is associated with an increasing riparian zone (Photographs 5 and 6). The lack of cross-sectional area and migration freedom in the lower alluvial plain reduces the amount of sediment and the size of the sediment that can be transported through the lower channels to the bay. The lower few river miles of each river are transport high zones. The reduction of cross-sectional area increases the in-channel energy resulting in the high transport. Sediments supplied to these reaches passes to the bay and are deposited at the river/bay interface. A depositional wedge has developed that increased channel narrowing and reducing channel depth. The impact of the reduction in channel migration freedom and narrowing on the mid-alluvial plain is a reduction in gravel movement and bar development. The reduction in migration freedom increases the development of the riparian zone. The increasing riparian zone aids in stabilizing temporary storage gravel and decreases channel cross-sectional areas. Gravel that was confined in massive gravel bars or temporary sediment storage sites was populated with riparian vegetation (decreasing the mobility and increasing energy requirements for entrainment). This appears to allow high flow or flood event to exit the current channel at lower stage elevations (Plate 20 and Photographs 7, 8 and 9).

The reduction in channel area also reduces in-channel energy. Combined, these processes culminate in bed aggradation, bed armoring, and a reduction in gravel transport quantities at historic discharge levels. As gravel sediment transport decreases, an increase in fine-grained sediment transport occurs. The removal of the fine-grained sediment matrix creates a framework of interlocked gravel that increases the armor layer depth. This requires high in-channel stream energy to dislodge and induce gravel transport. The channel reaches downstream of the aggrading zone show a historic increase in bank erosion. The geomorphic processes controlling this bank erosion are return flow from the alluvial plain and the change in cohesive strength of the finer-grained bank sediment.

Comparing the 1939, 1965, and 2000 photographs shows that bank protection actions have reduced the migration freedom and failed to allow the natural channel widening processes to proceed. These actions have stopped the development of the fluvial pyramid (Plates 5 to 19).

Table 27 provides a geomorphic framework explaining these channel character by reach and the resulting geomorphic output. Based on the data collected during this study, the rivers in the Tillamook Bay Basin are attempting to return to a quasi-state of equilibrium. This trend is hindered by the reduction of the channel area on the alluvial plain. Analysis of historic aerial photographs shows a reduction of the channel net on the alluvial plain by the removal of sloughs from the channel network (Dougherty, Hall, and Hoquarten Sloughs).

An evaluation of the 1939 period shows that the Tillamook Bay Basin rivers are ones of massive erosion and sediment yield from the upper watershed. With constant hydrology, all systems were overloaded with sediment and massive sediment transport though the basin to the bay. The high sediment supply increased the degree of channel freedom in the upper alluvial plain. The gravel introduced into the system created major gravel bar complexes and induced bank erosion and major sediment deposition at the mouth of the rivers.

By 1965, there was a major reduction in sediment supply from the upper basin. As reforestation continued in the upper basin, the constant hydrology increased the in-channel erosion of the gravel bar complexes. Bed and bank erosion appears to have decreased resulting in an increase in the riparian zone. High volumes of fine-grained sediment still were depositing in the bay. During high flow or flood events, gravel slugs were delivered to the bay interface. However, the channel still was unable to pyramid and move to a quasi-equilibrium condition. The sloughs of the basin were undergoing additional reduction in conductivity. The wedge at the river month areas on the Kilchis, Wilson, and Trask Rivers continued to develop.

Future Channel Dynamics

An analysis of imagery from 2000 and field investigations show that the rivers are trending to a state of quasi-equilibrium. The migration freedom decreases as the riparian zone area increases in size and density. The reduction in gravel sediment transport continues to result in an increase to the amount of fine-grained sediment deposited in the bay. The major sloughs on the upper alluvial plain were still disconnected from the channel network, while the lower alluvial plain (below Highway 101) sloughs maintain hydrologic conductivity. The disconnection from the upper alluvial plain impacts the sediment transport and high flow or flood routing. Fine-grained sediment deposition at the mouth area continues and may show indications of transgression up to the lower channel area.

Based on the historical and current geomorphic processes, bay sedimentation will continue allowing gravel transport to occur during major flow or flood events. Sediment supply will continue at current volumes. These rates will maintain constant unless another catastrophic event occurs, such as a forest fire and/or a sea floor tectonic event. Over time, riparian zone development and the reduction of in-channel cross-sectional area may generate catastrophic channel relocation on the upper alluvial plain. Gravel sediment transport will continue to slow as channel narrowing and riparian zone development advances. Bank and bed erosion will continue through the middle section of the alluvial plain generating high volumes of fine-grained sediment to the bay. This increased trend in bed and bank erosion is an attempt by the channel system to reconstruct a fluvial pyramid. If these processes are left unchecked, the fluvial system will complete this reconstruction.

At the mouth of the rivers, the sediment wedge will continue to grow and could advance upstream or impact the structural features that have restricted channel freedom, resulting in erosion and/or failure. Over geologic time, Tillamook Bay will fill and a larger delta complex will result. The geographic areas east of the tectonic high in the bay will fill first; the results of infilling already have been identified (as early as the 1940s). Unless channel freedom and cross-sectional area is not reestablished, selective bay filling will continue along with flooding in the lower and middle reaches of the Tillamook alluvial plain.

Table 27. Geomorphic Changes along the Kilchis, Wilson and Trask Rivers Projected for the Entire Tillamook Basin

Channel Character	Reach	Imagery Date 1939	Imagery Date 1965	Imagery Date 2000
General Basin	Upper Basin-Tribs.	Slope Failure Rate: high-tributary yield sediment to mainstem.	Slope Failure Rate: reduction-tributary yield sediment to mainstem.	Slope Failure Rate: level off-tributary yield sediment to mainstem.
	'Rock gorge'	Transport zone	Transport zone	Transport zone
	Alluvial Plain Apex	Transport and deposition rates - high	Transport < Deposition >	Transport = Deposition =
Fine grain sediment deposition occurs on alluvial plain. In-channel deposition may cause high flows to exit channel.	Upper Alluvial Plain	Increased sediment supply. Increased bar development. Increased bank erosion. Increased channel instability. Channel width increases. **Channel Aggrading**	Moderation in sediment supply. Decrease in bar development. Decrease in bar acreage. Decreased bank erosion. Channel narrowing increased.	Continued reduction in sediment supply. Decrease in bar development. Decrease in bar acreage. Decreased bank erosion. Increased channel narrowing continues. Channel/bank stability.
Alluvial plain-floodplain flood common during high flows. Fine grain sediment deposition on floodplain.	Middle Alluvial Plain	Increase sediment supply. Increase bar development. Increase bank erosion. Increase channel instability. **Channel Aggrading**	Moderation in sediment supply. Decrease in bar development. Decrease in bar acreage. Decreased bank erosion.	Continued reduction in sediment supply. Decrease in bar development. Decrease in bar acreage. Decreased bank erosion. Increased channel narrowing continues. Channel/bank stability.
Alluvial plain-floodplain flood common during high flows.	Lower Alluvial Plain	Numerous gravel bars/acreage small. Bank erosion minor. Channel pattern stable. Transport > Deposition <	Moderation in sediment supply. Decrease in bar development. Acreage declines. Decrease in bar number. Decreased bank erosion. Channel stable. Transport > Deposition <	Continued reduction in sediment supply. Decrease in bar acreage & number. Decreased bank erosion. Continued channel narrowing. Increase in riparian zone. Channel/bank increased stability. Transport > Deposition <
Flood during all flood events	River-Deltaic	Natural levees & splay deposits dominant. Deposition > Constructed levees aid sediment accumulation & river mouths. **Channel/Bay Aggrading**	Natural levees & splay deposits dominate. Deposition > Constructed levees aid sediment accumulation and river mouths. **Channel/Bay Aggrading**	Natural levees & splay deposits dominate. In-channel sediment wedges are a dominant sedimentary structure. Deposition > Constructed levees aid sediment accumulation and river mouths. **Channel/Bay Aggrading**

8. CONCLUSIONS AND RECOMMENDATIONS

In summary, positional landscapes prevail in the Tillamook Bay Basin area. Erosion is the dominant geomorphic process occurring in the upland/mountain regions. Mass movement or slope failure supply the bulk of the sediment yield available for transport to the lower watershed. Coupling the Tillamook Basin fire history and hydrology support and aids the mass movement processes.

Given the scale of the rivers in the Tillamook Bay Basin, with the floodplain and the long relaxation time involved in fluvial processes, it appears unlikely that the river-floodplain and river-bay zones are in equilibrium. This is not to say that these systems are not coupled, but that erosion and sedimentation events and location adjust on different time-scales and to a different frequency distribution. It appears that the major forest fire events of the 1930s and 1950s were the most significant sediment producers from the upland/mountainous regions in the basin. The fire events and burn patterns appear to have produced pseudo-cycles in which periods of high quantities of sediment were generated and then delivered to the channel networks of the Tillamook Bay Basin. During initial sediment generation from the uplands, areas the floodplain and river/bay zones could have been in a stable geomorphic state or equilibrium.

Due to changing sediment supply and transport location, the geometry of the channel system and related floodplain has quite different effects on the bay or river/bay transition zone. The partial uncoupling of the river-floodplain and river/bay transition zones has been greatly increased by human actions. These include deliberately increasing flood deposits on some floodplain locations, reducing flood deposits through the constructions of "embankments" and some dredging, the prevention of avulsion and migration by embankments and revetments, and filling or blocking secondary channels and sloughs in the basin.

The recommendations for controlling or reducing the flooding impact can be presented with two perspectives: the geologic and the geomorphic. The geologic perspective is strictly based on geomorphic processes and events of geologic time. The channel system within the Tillamook Bay Basin is attempting to return to an equilibrium state by way of tectonics, climatic conditions, and basin geology. Left alone, the alluvial plain will reestablish connectivity with the sloughs in order to regain the fluvial geomorphic pyramid. Bank and bed erosion is direct evidence that this process is evolving. Sediment wedge development at the rivers' mouths is the first phase to increasing sinuosity and channel freedom. The lower half of the alluvial plain could become a more complex alluvial fan and delta environment resulting from sedimentation processes. Failure to remove or modify a large percentage of structures that reduce channel freedom would preclude the natural process occurring. However, removal or modification of these structures is currently being analyzed. Nevertheless, the channel system will evolve to one of equilibrium and continuing human intervention will attempt to manage this evolution. Flooding is a process nature uses to maintain balance and advance the return of an equilibrium state.

The geomorphic perspective is a mix of geologic, geomorphic, and human intervention. Human actions, including engineering elements, will attempt to manage the Tillamook river systems to enhance geomorphic and geologic processes. The following recommendation may appear to be oversimplified; nevertheless, the basic elements are provided. The reestablishment of hydrologic conductivity between upper alluvial plain to the Tillamook Bay is needed. This could be completed by the reconnection of the sloughs and the mainstem channel systems. This would allow some fluvial pyramid development to proceed, as well as increase the degree of channel freedom in the deltaic area. However, the total removal of levees or other structural elements retarding channel freedom is not an acceptable solution. Allowing some set back of these structures would allow natural channel processes to develop. The increase in channel cross-sectional area would reduce high flow or flood events. There must be a combination of restoring natural channel processes, while at the same time controlling the degree of freedom of the channels with some engineering elements. The mix and location becomes a political situation; however, without some combination, there will be no reduction of flood events in the Tillamook Bay Basin.

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APPENDIX A: FIRE AND FLOOD RELATIONSHIPS

Data is based on the discharge record for the Wilson River and the major fire events in the Tillamook Basin.

River Flood and Major Fire Events			
Tillamook Bay Basin, Wilson River			
Year	**Flood Date/Peak Flow (cfs)**	**Fire Date**	**River Maps/Photos**
1887	Unknown		
1914	Unknown		
1915	1/14/15 = 7,500		
1916	Unknown		
1918		Fire	
1921	Unknown		
1931	Unknown		
1932	1/18/32 = 16,700	August 1933	
1933	12/19/32 = 12,900		
1934	12/12/33 = 30,000		
1935	1/22/35 = 14,300		
1936	1/12/36 = 19,500		
1937	12/22/36 = 16,600		
1938	12/27/37 = 21,200		
1939	2/14/39 = 15,800	August 1939	May 1939
1940	12/15/39 = 17,000		
1942	12/19/41 = 18.700		
1943	11/23/42 = 17,800		
1945	2/7/45 = 22,800		
1946	12/28/45 = 17,100		
1947	12/13/46 = 18,100		
1949	2/17/49 = 24,500		
1950	11/27/49 = 20,200		
1951	12/23/50 = 10,900	August 1951	
1954	12/9/53 = 20,300		
1955	11/18/54 = 14,800		
1956	12/21/55 = 21,100		
1957	12/9/56 = 17,500		
1958	12/19/57 = 16,400		
1959	11/18/58 = 15,000		
1961	11/24/60 = 19,900		
1962	11/22/61 = 21,700		
1963	2/3/63 = 21,700		
1964	1/25/64 = 25,000		
1965	12/22/64 = 32,100		April 1965
1966	1/5/66 = 17,100		

Year	Flood Date/Peak Flow (cfs)	Fire Date	River Maps/Photos
1967	12/13/66 = 20,100		
1968	2/4/68 = 15,900		
1969	12/3/68 = 11,300		
1970	1/18/70 = 12,600		
1971	12/6/70 = 18,800		
1972	1/20/72 = 36,000		
1973	12/21/72 = 22,000		
1974	1/15/74 = 20,600		
1975	1/13/75 = 14,100		
1976	12/4/75 = 29,400		
1977	3/7/77 = 6,680		
1978	12/13/77 = 32,000		
1979	3/5/79 = 13,300		
1980	1/12/80 = 16,300		
1981	12/26/80 = 25,100		
1982	1/24/82 = 19,200		
1983	12/3/82 = 18,700		
1984	2/12/84 = 8,450		
1985	11/2/84 = 7,800		
1986	2/23/86 = 15,500		
1987	2/1/87 = 18,900		
1988	12/9/87 = 26,100		
1989	1/10/89 = 10,000		
1990	12/4/89 = 31,000		
1991	4/5/91 = 25,800		
1992	1/28/92 = 13,000		
1993	11/21/92 = 11,600		
1994	2/24/94 = 8,180		
1995	11/30/94 = 20,000		
1996	2/8/96 = 35,000		
1997	12/29/96 = 15,400		
1998	10/30/97 = 21,900		
1999	12/27/98 = 35,350		
2000	11/25/99 = 25,400		March 2000

APPENDIX B: DETAILED GRAVEL ANALYSIS AT SELECTED SITES ON THE MIAMI RIVER

Gravel Size Data for Selected Rivers in the Tillamook Bay Basin

Data is from the Tillamook County Soil and Water Conservation District in cooperation with the U.S. Department of Agriculture, Natural Resource Conservation Service analysis and as reported by Randy Stinson and Sheila Stinson (February 20, 1998). Sediment samples were collected from the Miami, Kilchis, and Wilson River systems within the Tillamook Bay Basin. Samples were collected and particle size distribution of the substrate and armor layer. The finding of the study indicated that the effect of gravel bar harvesting has had no apparent impact to the particle size distribution or volume of gravel recruited annually in the stream. Taking this as a given, this indicates that the channel processes are at or near equilibrium. The analysis illustrates channels that fine downstream and can be couples to slope and basic energy conditions.

Miami River

Armor Layer:

- 3-inch gravel is less than 5% of through out sample reach (RM 1-3.75).
- 1½-inch gravel is greater than 10% from RM 1 and up the system.

Substrata:

- At Moss Creek, 3-inch gravel appears and this is a common situation from most tributaries.
- There was no information for the mainstem.

Kilchis River

Armor Layer:

- No 3-inch gravel below RM 3, except in 1995-1996, both of which were major flood years.
- 1½-inch gravel appears greater than 10% from RM 3 and up system.

Substrata:

- 3-inch gravel is less than 10% of the sediments sample until RM 5 and above.

Wilson River

Armor Layer:

- 3-inch gravel appears greater than 5% at or above RM 7.95
- 1½ inch gravel is greater than 10% from RM 4.2

Substrata:

- No samples were collected from the mainstem, only tributaries.

The 3-inch samples were the largest size sampled this analysis. The Armor Layer Toe Count counted all gravel larger than 3 inches in size. No gravel larger than 3 inches was found below the following river miles:

Miami River: river mile 3.75
Kilchis River: river mile 3.4
Wilson River: river mile 6

Analysis of this data indicates that the sampled rivers display normal grading and that major flow events (large floods) will pulse or slug gravel sediment down the system.

PHOTOGRAPH PLATES

Photograph Number 1: Kilchis River 1939; River mile 0-1.

Large sediment deposit at the river – delta interface, it is still visible on the 2000 Photograph. The presents of the sedimentary element are an indication that recent sediment rates have slowed.

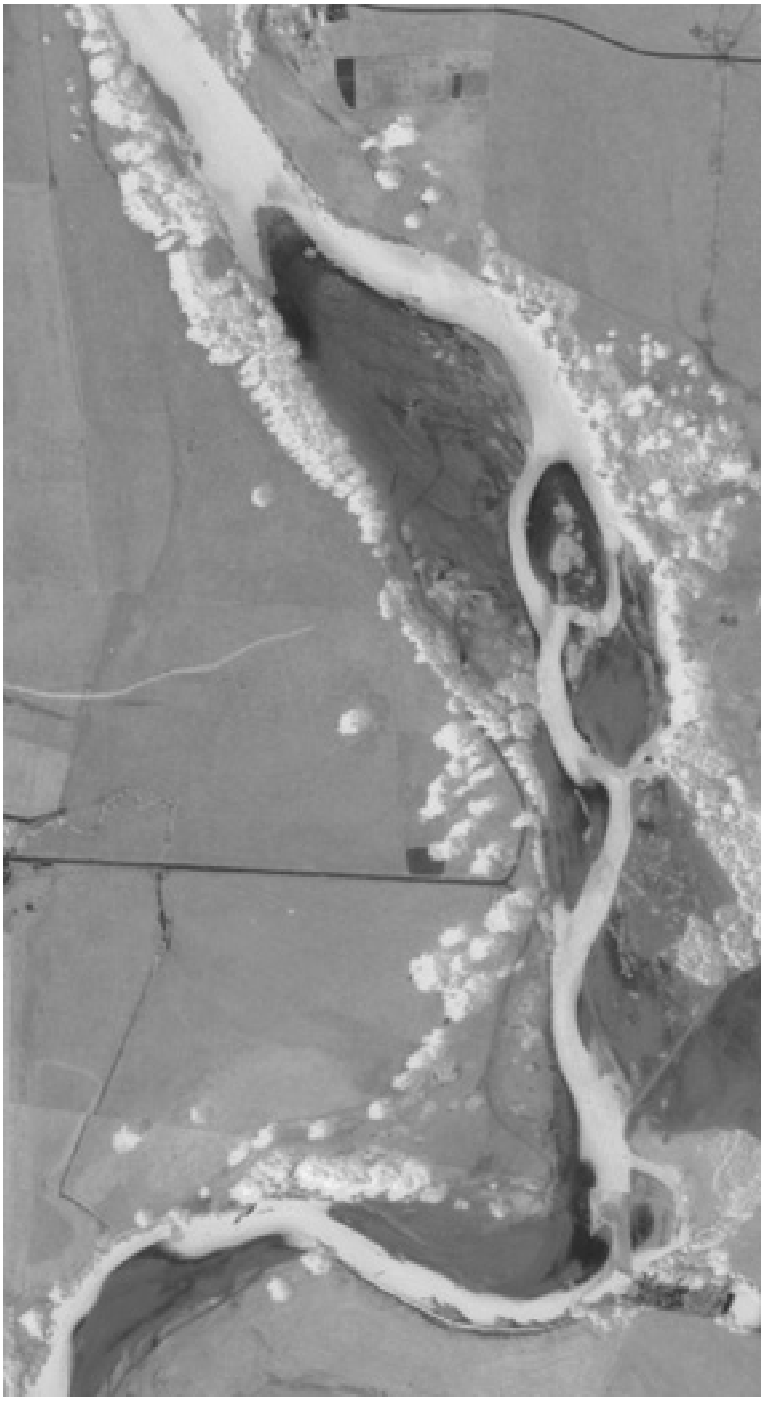

Photo 2: Wilson River 1939; River mile 4 to 5.

Extensive Gravel Bar complexes with limited riparian development. Gravel deposition occurring resulting in bed aggradation. High sediment loading associated with basin fire history. This large gravel bar complex is just up stream of Daugherty Slough.

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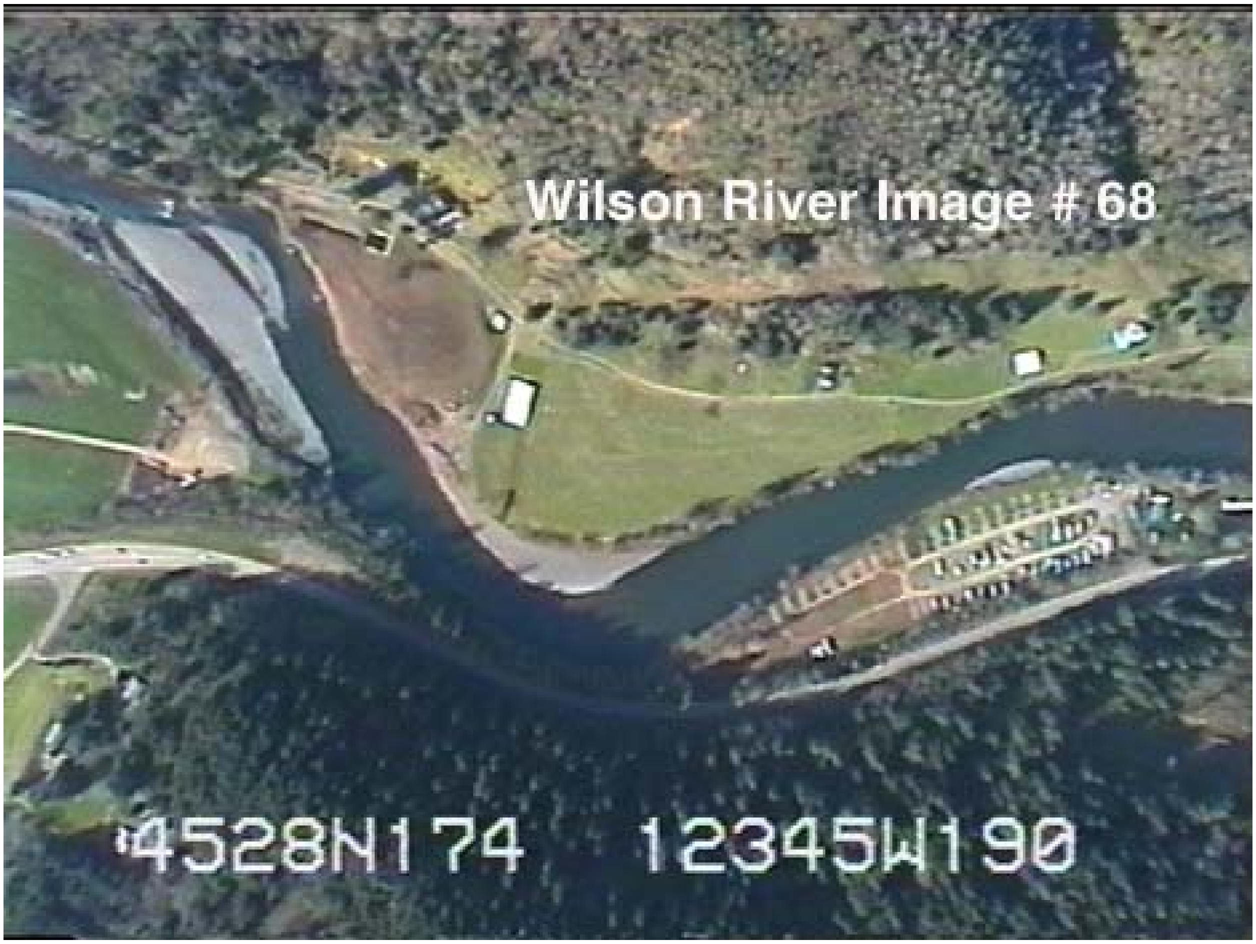
Photography Number 3: Trask River 1939; River mile 6 –7.

Extensive Gravel Bar complexes with limited riparian development. Gravel deposition occurring resulting in bed aggradation. High sediment loading associated with basin fire history

Photography Number 4: Wilson River November 1999.

Upper Basin Area; illustrating the slope Failures in the Upper Wilson Basin resulting from the November 1999 winter. (Wilson River Image 92)



Photography Number 5: Wilson River November 1999.

Upper Basin and Alluvial Plain Apex. Gravel Bar Complex indicates refreshment from storm related gravel transport. (Wilson River Image 68)

Photography Number 6: Wilson River November 1999, Middle Alluvial Plain.

Fine grain sediment deposited on agricultural land after flood event. Notice the large riparian zone and minor gravel bar complexes.
(Wilson River Image 73)

Photography Number 7: Wilson River.

Alluvial Plain at Flood Stage and Out of Channel Flow.
(Wilson River Image 50)

Photography Number 8: Trask River November 1999.

Lower Alluvial Plain at Flood Stage and Out of Channel Flow. (Trask River Image 7)

Photography Number 9: Trask River November 1999.

Upper Alluvial Plain at Flood Stage and Out of Channel Flow. Fine grain sediments are depositing on the agricultural lands. (Trask River Image 5)