Tillamook Bay

Environmental Characterization

A SCIENTIFIC AND TECHNICAL SUMMARY

Final Report
July, 1998

Tillamook Bay National Estuary Project

Tillamook Bay National Estuary Project
“Tillamook Bay Environmental Characterization: A Scientific and Technical Summary”

Garibaldi, Oregon
July, 1998

Cover photo by Don Best

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FOREWORD

Tillamook Bay exemplifies the type of estuary found in the Pacific coast range ecoregion of the Pacific Northwest. The Bay and Watershed support diverse living resources including shellfish, salmon, trout, bottomfish, and numerous bird species. Some species have been listed as endangered or threatened and declining numbers of salmon have become the focus of state, regional, and federal governments. Natural resources remain the backbone of local and regional economies which depend on fishing, timber, and agriculture to support a diverse and growing population.

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

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

This **Tillamook Bay Environmental Characterization Report** summarizes relevant facts and figures to describe the natural features of this coastal watershed. After a brief overview of local geography and human activities in the Watershed in Chapters 1 and 2, the report focuses on the priority problems identified by the program, including:

- Chapter 3, Biological Resources;
- Chapter 4, Water Quality;

- Chapter 5, Sedimentation; and
- Chapter 6, Flooding.

We hope these technical characterizations will allow TBNEP citizens and managers to make sound and practical decisions based on the best available science. However, we also recognize the limits to our understanding of ecosystem function and the uncertainties associated with various anthropogenic impacts to our biological, chemical, and physical environment. We hope the results of numerous TBNEP-initiated scientific studies will add to our understanding of ecosystem structure and function and help managers make better decisions. Several scientific studies were recently completed and relevant findings are included in this completed **Tillamook Bay Environmental Characterization Report,** which summarizes and evaluates the best available science to support our objectives. Garibaldi, Oregon. July, 1998

AUTHORS

Chapter 1: Introduction

Steve Nelson
Bruce Follensbee
Roxanna Hinzman

Chapter 2: Human Uses

Jason Kruckeberg
Jessica Miller

Chapter 3: Biological Resources

Robert Ellis

Chapter 4: Water Quality

Avis Newell

Chapter 5: Sedimentation

Jay Charland
Frank Reckendorf

Chapter 6: Flooding

Kevin Coulton

EDITORS

Technical editors

Roxanna Hinzman
Steve Nelson

Copy editor

JoAnne Booth

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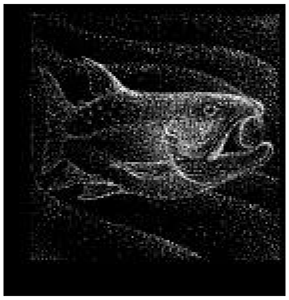
TABLE OF CONTENTS

Chapter 1
Introduction: A Diverse and Dynamic Coastal Landscape

Chapter 2
Human Uses: Economic Contributions and Environmental Impacts

Chapter 3
Biological Resources: Our Heritage and Future

Chapter 4
Water Quality: Measuring Health and Progress



Chapter 5
Sediment: Sources and Impacts

Chapter 6
Flooding: Causes, Impacts, and Choices

Appendices

Appendix 3-A
Salmonid habitat requirements for Northern Oregon coastal streams

Appendix 3-B
Common and scientific names of fish recorded for Tillamook Bay, Oregon

Appendix 4-A
Summary of selected studies and management plans regarding Tillamook Bay and its watershed

Appendix 4-B
303(d) list. Detailed text describing the water bodies in the Tillamook Bay Watershed that are on the State's list of Water Quality-Impaired Waters

Appendix 4-C
Maps of the waters listed, and the water bodies of concern for bacteria, temperature, flow modification, habitat modifications, sedimentation, nutrients, pH, and dissolved oxygen

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

ASCE	American Society of Civil Engineers
B.P.	Before present
BFE	base flood elevation
BLM	(U.S.) Bureau of Land Management
BMPs	best management practices
CAFO	Confined Animal Feeding Operation
CCMP	Comprehensive Conservation and Management Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund)
COE	(U.S. Army) Corps of Engineers
CRMP	Coordinated Resource Management Plan
CRS	Community Rating System
CSRI	Coho Salmon Restoration Initiative
DEQ	(Oregon) Department of Environmental Quality
DO	dissolved oxygen
DSL	Department of State Lands
EPA	(U.S.) Environmental Protection Agency
ESA	Endangered Species Act
FC	fecal coliform
FDA	(U.S.) Food and Drug Administration
FEMA	Federal Emergency Management Administration
FHMP	Flood Hazard Mitigation Plan
FMA	Flood Mitigation Assistance
FTU	Formazin turbidity unit
GIS	Geographic Information System
GLO	General Land Office
ICC	Increased Cost of Compliance
LWD	large woody debris
MEAD	Methane Energy and Agricultural Development (Project)
MLLW	mean lower low water
N	nitrogen
NAS	National Academy of Sciences
NEP	National Estuary Project
NFIP	National Flood Insurance Program
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Service
OCI	Oyster Condition Index
ODA	Oregon Department of Agriculture
ODF	Oregon Department of Forestry
ODLCD	Oregon Department of Land Conservation and Development

ODSL	Oregon Department of State Lands
ONRC	Oregon Natural Resources Council
ORV	off-road vehicle
OSU	Oregon State University
P	dissolved phosphorus
PNI	Pacific Northwest Index
POM	particulate organic matter
SAV	submerged aquatic vegetation
SSWCC	State Soil and Water Conservation Commission
TBNEP	Tillamook Bay National Estuary Project
TCCA	Tillamook County Creamery Association
TCSWCD	Tillamook County Soil and Water Conservation District
TCWP	Rural Clean Water Program
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USLE	Universal Soil Loss Equation
UV	ultra-violet

CHAPTER 1

INTRODUCTION: A DIVERSE AND DYNAMIC COASTAL LANDSCAPE

There is no final ecological truth. All knowledge is a current approximation, and each addition to that knowledge is but a small, incremental step toward understanding. For not only are ecosystems more complex than we think, they are more complex than we can think.

—Jack Ward Thomas
from “Wildlife in Old Growth Forest” in *Forest Watch* (Jan.-Feb. 1992):15

CHAPTER 1

INTRODUCTION:
A DIVERSE AND DYNAMIC COASTAL LANDSCAPE

Overview

The Tillamook Bay is a small, shallow estuary about 60 miles west of Portland on the Oregon Coast. Approximately 6.2 miles (10 kilometers) long and 2.1 miles (3.4 km) wide, the Bay averages only 6.6 feet (2 meters) in depth over a total area of 13 mi^2 (34 km^2), or 8,400 acres (3,400 hectares). At low tide, about 50% of the Estuary bottom is exposed as intertidal mud flats and presents navigational hazards similar to those facing the first European explorers who entered the Bay in 1797. Several deep channels, running roughly north-south, represent the geologic signatures of river mouths drowned by the rising Pacific Ocean about 9,000 years ago.

Since the first European settlements in the 1850s, humans have altered the Estuary and surrounding Watershed. Anxious to improve ocean-borne commerce, citizens and governments dredged and modified the Estuary's main navigational channels in the late 1800s. Heavy sediment loads convinced the U.S. Army Corps of Engineers (COE) to abandon its activities in the southern end of the Bay shortly after the turn of the century. The last ocean-bound ship left the town of Tillamook in 1912 and today only the Port of Garibaldi at the northern end of the Estuary serves deep water traffic. Like many small, West Coast ports in timber growing areas, Tillamook Bay continues to face sedimentation problems and subsequent impacts on navigation and fish habitat.

Five rivers enter Tillamook Bay from the south, east, and north. Salmon fishermen still recognize the Bay and its five rivers - the Tillamook, Trask, Wilson, Kilchis, and Miami - as some of the West Coast's most productive fishing spots. Yet their bounty of chinook, chum, coho, and steelhead pales compared with earlier harvests. Today the North Coast coho salmon is listed as a threatened species and chum and steelhead fish populations have been declining. Scientists point to the dramatic loss of spawning and rearing habitat as a principal reason for the decline of

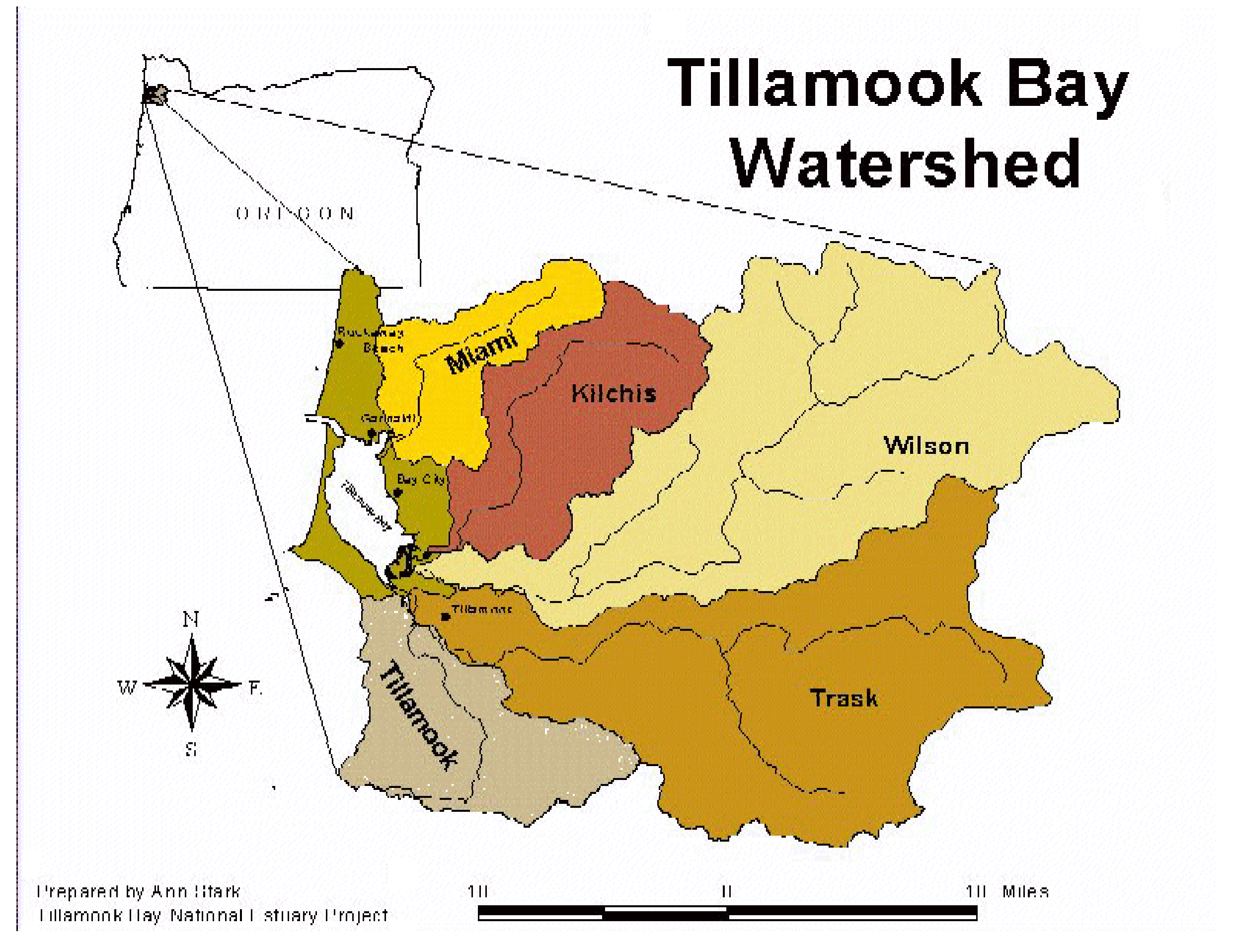


Figure 1-1. Map of the Tillamook Bay Watershed in Tillamook County, Oregon. It includes the watersheds of five rivers: the Miami, Kilchis, Wilson, Trask, and Tillamook. *Source:* Produced by Ann Stark, Tillamook Bay National Estuary Project, Garibaldi, OR.

Tillamook Bay salmonids. Today's salmon rivers drain a 560 mi^2 (1,451 km^2) Watershed (**Figure 1-1**) that includes some of North America's richest timber and dairy lands. Forestry, agriculture, and Fishing activities - although essential to the economy and character of Tillamook County - have taken a high toll on salmon and other living resources dependent on the aquatic environment.

Like most Pacific Northwest estuaries, Tillamook Bay is part of a coastal, temperate rainforest ecosystem. The Bay is surrounded by rich forests that blanket the rainy Coast Range. With mean annual precipitation around 90 inches (229 cm) per year in the lower basin and close to 200 inches (510 cm) per year in the uplands, the Watershed's coniferous forests - trees such as Douglas fir, true fir,

Temperate rainforest:
Woodland of temperate but usually rather mild climatic areas with heavy rainfall, usually including numerous kinds of trees, but dominated by a particular species.

Alluvial:
Deposited by running water.

Figure 1-2. Waves carry sediment through Bayocean Spit into Tillamook Bay in this May 1954 photo, 1 1/2 years after the breach.
Source: Tillamook County Pioneer Museum historic photo collection.

spruce, cedar, and hemlock - cover about 89% of the total land area. Hardwood species such as alder and maple also grow throughout the region, especially as second growth in riparian areas. Most of the older trees have been lost to fire and timber areas. Most of the older trees have been lost to fire and timber harvest. Today, Douglas fir is the dominant species. Foresters describe this environment as a highly productive ecosystem – from both biological and commodity perspectives.

In the lower Watershed, forest gives way to rich alluvial plains used primarily for dairy agriculture. Early settlers recognized the rich agricultural potential of the lowlands and drained the area with numerous dikes, levees, and ditches. Once characterized by meandering rivers and networks of small channels that provided Fish habitat, woody debris, and organic matter; today's 40 mi^2 (104 km^2) lowland supports about 28,600 dairy cattle (calculated in 1,000- pound units, including calves, heifers and dry stock) (Pedersen, B. pers. com. 1998) and produces 95% of Oregon’s cheese. Cattle also produce hundreds of thousands of tons of manure annually and much of the bacteria that washes into the Estuary.

The Estuary

Tillamook Bay is a drowned river estuary. Several deep channels wind through intertidal mud flats that rise above the water surface at low tide. The Bay receives fresh water input from five rivers and exchanges ocean water through a single channel in the Northwest corner. Despite large freshwater inflows, especially during the rainy winter months, heavy tidal fluxes dominate the system; extreme diurnal tides can reach 13.5 ft (4.1 m), with a mean tidal range of 5.6 ft (1.7 m) and diurnal range of 7.5 feet (2.3 m). Tidal effects extend various distances up the rivers, ranging from 0.4 miles (0.6 km) for the Miami River, to 6.8 miles (11 km) for the Tillamook River (Komar 1997). The volume of water entering the Bay due to tides has been estimated at 1.63 x 109 cubic feet (4.63 x 107 cubic meters) (Perch et al. 1974). The Bay experiences the full range of estuarine circulation patterns, from well-stratified to well-mixed, depending on the season and variations in river discharge. During heavy rain winter months, November through March, researchers describe a stratified system, but during low precipitation summer months, the Bay shifts to a well-mixed estuarine system (Camber 1997). Salinity ranges from around 32 ppt near the ocean entrance to around 25 ppt at the upper (southern) end of the Bay near the river mouths. Water temperature ranges from around 47-66^{o}F (8-19^{o}C) over the year. The Estuary maintains relatively high levels of dissolved oxygen (DO) throughout the year and ranges from about 6.0 ppm to 12.0 ppm. Eutrophication and low DO do not appear to be problems for Tillamook Bay. However the Bay experiences high levels of bacteria, especially after storms and associated agricultural runoff and point source overflow. Chapter 4, Water Quality provides a detailed look at water pollution problems in Tillamook Bay.

Geologists describe Tillamook Bay as a river mouth that drowned about 9,000 years ago when the rising Pacific Ocean inundated the lower reaches of the Trask, Wilson, Tillamook, Kilchis, and Miami Rivers (Camber 1997). Rising sea levels brought large amounts of marine sediments into the Bay until about 6,000 years ago when the Estuary reached a dynamic equilibrium between sediment deposition and resuspension. (Coulton et al. 1996). A predominant northern longshore drift deposited sands to create the elongated north-south peninsula known today as Bayocean Spit. The spit generally protected the Estuary from ocean intrusion until 1952, when the sea breached the eroding spit (Figure 1-2) and deposited additional marine sediments in the southwestern corner of the Bay.

Corps of Engineers have documented a decrease in Bay water volumes from 40,677,030 yd^3 (31,051,168 m^3) in 1867 to 32,531,336 yd^3 (24,833,081 m^3) in 1995. Most observers identify upland sediments as the primary source of current sediment load to the Bay. Forestry practices, road building, forest fires, and landslides are considered the major sediment contributors to Tillamook Bay. Smaller amounts of sediment come from lowland areas, mostly from eroding or unstable river banks (Komar 1997). Moreover, the winding network of river channels and natural floodplains characteristic of the pristine system has been modified by dikes, levees, channels, tide gates, and riprap. The resulting modern ecosystem presents different characteristics in terms of water flow, sedimentation patterns, and salmonid habitats than the natural system which evolved over the previous 9,000 years. Sedimentation and erosion are described in Chapter 5.

The Estuary provides habitat for numerous fish, shellfish, crabs, birds, seals, and sea grasses. A 1973 survey identified 53 species of fish in the Bay at various times of the year. Five species of anadromous salmonids use the Estuary at some point in their life cycle. A prolific benthic community includes rich clam beds and dense areas of eelgrass. Dungeness crabs provide an important recreational fishery and the Bay provides an important habitat for many birds migrating on the Pacific flyway. After earlier declines, the seal population has grown in recent years due to measures to protect marine mammals. Today, groups of these marine mammals can be seen sunning themselves on intertidal mud flats at low tide. Chapter 3, Biological Resources, offers a detailed characterization of the status and trends of important Bay species and their habitat.

From a management perspective, the Oregon Department of Land Conservation and Development (ODLCD) classifies Tillamook Bay as a "shallow draft development" estuary under Goal 16 of the Statewide Planning Goals. This classification categorizes Tillamook Bay as an "estuary with maintained jetties and a main channel (not entrance channel) maintained by dredging at less that 22 feet (6.7 m); these estuaries have development, conservation, and natural management units." (ODLCD 1987).

State and local planners define management units according to biological and physical features and allow particular activities and uses in those areas, while prohibiting others. For Tillamook Bay, management units define shellfish growing regions as prohibited, conditional, and restricted to limit human consumers’ exposure to water-borne pathogens. These closures represent an important problem for local oyster growers. Although not native to Tillamook Bay, oysters grow well under aquaculture methods and historically represented a significant income source for the region. Other management activities include dredging and channel maintenance and protection of neighboring wetland areas. For a more detailed overview of human activities related to the Estuary, see Chapter 2, Human Uses.

Climate

Tillamook County receives a lot of rain. A typical year brings almost 100 inches (254 cm) of precipitation, mostly in the form of rain, but also snow in the upper Watershed. In 1996, however, 126 inches (320 cm) of lowland rain (and very heavy upland rain and snow) led to severe flooding throughout the Basin and caused significant economic and environmental damages. From 1961 through 1990, The City of Tillamook averaged 90 inches (229 cm) of rain per year with 76% of total precipitation occurring from October through March. The highest precipitation and rainfall events occurred during November, December, and January. Tillamook County averaged more than 23 days per year in which precipitation exceeded 1 inch (2.54 cm). Chapter 6, Flooding and Waterway Modification, provides an overview of flood problems and trends.

The seasonal, episodic nature of precipitation defines the natural system. Fall chinook migrate upstream with the first heavy rains in late autumn. Big storms cause major landslides in the steeply sloped upland regions. Although heavy storms have characterized the natural system for thousands of years, human activities have exacerbated the impacts and consequences of high rainfall (Coulton et al. 1996). Westerly winds predominate and carry the temperature-moderating effects of the ocean over all of western Oregon. Summers are cool and dry; winters wet and moderate (USDA 1964). Winds blow nearly continuously throughout the year and often reach gale force in the winter. Prevailing winds come from the northwest during the summer and from the south and southwest during the winter.

Temperatures in Tillamook County are moderate. The mean annual temperature is 50.4^{o}F (10.2^{o}C), with yearly mean and mean minimum temperatures documented at 59.3^{o}F (15.1^{o}C) and 41.6^{o}F (5.4^{o}C), respectively. Those 30 years averaged less than one day per year with a temperature over 90^{o}F (32^{o}C). September had the greatest number of extreme temperatures while July and August recorded the highest temperature of 102^{o}F (38.89^{o}C).

Soils and Geology

Tillamook Bay and its Watershed are situated in typical Pacific Northwest coastal terrain. A relatively straight coastline consists of miles of sandy beaches punctuated with cliffs of igneous rock and small inlets such as the Bay. East of the Pacific Coast, the high, steep ridges of the Coast Range climb up to 3,500 feet (1,064 m). These upland areas consist mostly of volcanic basalt base material with overlying soils formed from basalt, shale, and sandstone material. Primarily an Astoria-Hembre association, moderately deep upland soils cover the gently sloping to very steep terrain of the forested uplands.

In the Tillamook Bay Basin, five river valleys dissect the steep slopes of the uplands and bring sediment and organic material to the rich alluvial plain and Estuary below. In this setting, a discontinuous coastal plain separates the coast and the mountains. Derived from basalt and sandstone-shale bedrock, these deep, level floodplain soils have been deposited over thousands of years by the streams and rivers. They range in width from a few hundred feet to more than a mile and can extend upstream up to seven miles along broad stream channels. Known as the Nehalem-Brenner-Coquille association, these are among the most fertile soils in the area, but require drainage for maximum productivity. Originally, these soils were almost all forested; but most have been cleared and are used for hay and pasture. Most farmers irrigate their soils in the dry summer months. Between the bottom-land floodplain and the forested regions, extensive alluvial terraces extend up to 80 feet (24 meters). Referred to as the Quillayute-Knappa-Hebo association, these soils have high to medium organic content, but are less fertile than soils on the bottom lands. Alluvial terrace soils make up about 50% of the Tillamook Basin's tillable lands.

Tillamook Basin Vegetative Communities

Human activities have greatly altered the vegetation of the Tillamook Bay Watershed (See historic reconstruction map, Figure 6-6). Since the 1850s, European-Americans have cleared and harvested trees, drained wetlands, and established pastures for dairy cattle. In addition, a series of forest fires beginning in the 1930s burned much of the natural vegetation of the upland forests. Today, most of the mixed conifer upland forests have been replanted in Douglas fir trees. But the natural, or potential vegetation of the Tillamook Basin is evenly distributed between the Sitka spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla) vegetation zones. These two vegetation zones extend from British Columbia to Northern California, running roughly parallel to the coast with the hemlock zone also enclosing the Willamette Valley (Franklin and Dryness 1973).

The spruce zone covers the lower regions of the Watershed and normally occurs at elevations below 450 feet (150 meters). It is a wet zone with annual precipitation ranges between 118 inches (300 cm) and 78 inches (200 cm). The nearby ocean adds frequent summer fogs and moisture to otherwise dry months and distinguishes the spruce zone from the higher elevation hemlock zone. The temperature averages 51^{o}F (10.6^{o}C) annually with an average January minimum of 40^{o}F (4.7^{o}C) and a July maximum of 70^{o}F (20.6^{o}C) at Astoria. The soils are deep, fine textured, typically acid (pH 5.0 to 5.5) and high in organic matter (15-20%).

Dense, tall stands of Sitka spruce, western hemlock, western red cedar (Thuja plicata), Douglas fir (Pseudotsuga menziesii), and grand fir (Abies grandis) dominate the spruce zone. In dune areas close to the ocean, shore pine (Pinus contorta contorta) is locally common. Hardwood species occurring in the zone include red alder (Alnus rubra), bigleaf maple (Acer macrophyllum), and occasional California bay (Umbellularia californica) with red alder dominating recently disturbed sites and some riparian areas. Understory vegetation is generally composed of a dense growth of shrubs, herbs, ferns, and crytograms. Common native species include sword fern (Polystichum munitum), wood sorrel (Oxalis oregona), red and evergreen huckleberry (Vaccinium parvifolium and V. ovatum), salal (Gaultheria shallon), red elderberry (Sambucus racemosa), and western rhododendron (Rhododendron macrophyllum).

Seral:
Relating to the complete successional sequence of ecological communities that have occupied a specific area, from first species to colonize the area to the final climax vegetation.

Successional patterns in the spruce zone following fire or logging are often dominated by a dense shrub community composed of salmonberry (Rubus spectabilis), sword fern, elderberry, and huckleberry, with the relative dominance varying with the site conditions. The shrub community can persist for quite some time due to the excellent growing conditions, but at some point it yields to one of two types of seral forest stands. The conifer type is a mixture of spruce, hemlock, and Douglas fir and the hardwood type is a monotypic, dense stand of red alder. Replacement of the alder stands can be very slow, due to the dense shrub understory. The resulting communities are either semipermanent brush fields, spruce stands, or red cedar and hemlock that grew on downed logs.

The hemlock zone normally extends in elevation between 450 feet (150 meters) and the subalpine zone of the Coast Range. With less ocean influence and summer fog, the upland hemlock zone still receives heavy precipitation. In fact, the upland regions average up to 142 inches (360 cm) of rain each year with very little precipitation in the late spring to fall period. The zone temperature averages 50^{o} F (9.6^{o} C) annually with a January minimum of 30^{o} F (-0.7^{o} C) and a July maximum of 78^{o} F (25.6^{o} C) at Valsetz. The soils are derived from sedimentary and basalt parent materials, of moderate depth and medium acidity, with a high infiltration rate.

In the hemlock zone the dominant vegetation is dense conifer forest. Forest stands are dominated by Douglas fir, western hemlock, and western red cedar, with other conifers mixed in, such as grand fir, Sitka spruce, and Pacific yew (Taxus brevifolia). Hardwood species occurring in the hemlock zone include red alder, bigleaf maple, black cottonwood (Populus trichocarpa), and Oregon ash (Fraxinus latifolia). Understory vegetation varies with moisture regimes, but in the moist coastal portion of the hemlock zone, sword fern, wood sorrel, vine maple (Acer circinatum), and Oregon grape (Mahonia nervosa) are the most common species.

Successional patterns in the hemlock zone following fire or clearcut logging bring the first year residual species and invading herbaceous species from the genera Senecio and Epilobium. This community is replaced during years two to five by one dominated by fireweed (Epilobium angustifolium), thistle (Cirsium vulgare), and bracken fern (Pteridium aquilinum). The next community is dominated by shrubs such as vine maple, Oregon grape, salal, and blackberry species (Rubus spp.). Eventually the shrubs are overtopped by conifers such as Douglas fir.

Midden:
Refuse heap. An excellent source of information about a population’s food, tools, and other everyday objects.

Native Americans of the Tillamook Basin

European Americans first came to live near Tillamook Bay in 1851 when Joe Champion landed a whaling boat on the banks of the Estuary and lived for the winter in a tree stump. But Native Americans lived very well on the area’s fish, mammals, and plants for about 3,000 years before Mr. Champion arrived.

Native American habitation of the northern Oregon Coast began by about 1000 B.C. with a period called the Early Marine, lasting until approximately 500 A.D. The Late Marine period lasted from about 500 A.D. to 1856 A.D., followed by the Historic period lasting up to the present. Elsewhere on the Oregon Coast, initial habitation is believed to have occurred around 3000 B.C. and possibly as early as 6000 B.C. (Ross 1990).

The first human inhabitants of the coast relied on hunting and gathering of upland terrestrial resources. By the beginning of the Early Marine period, the people had adapted to the marine and riverain environment and food sources. The shell middens from this period include several types of clams, as well as the bones of harbor seals, sea lions, sea and river otters, numerous types of water birds and fish, and a number of land mammals.

The Late Marine was a period of changing culture patterns, with most of the villages located on the coast at the mouths of rivers or on estuaries at freshwater sources. The resource base included marine, riverain, estuarine, and terrestrial sources for a broad-ranging diet and stable food supply. Introduction of the bow and arrow around 500 A.D. changed the hunting patterns for land mammals. Although much of the archeological evidence was gathered on the south coast, it is assumed that the settlement patterns on the north coast are similar (Ross 1990).

The Native Americans inhabiting the Tillamook Basin at the time of European contact were known as the Nehalem band of the Killimuck (also known as Tillamook) tribe (Seaburg and Miller 1990). The Killimuck occupied the coastal area between Tillamook Head to the north and the Siletz River to the south. Four Killimuck bands each spoke a different dialect of a shared Salish group Killimuck language. During the Late Marine period, the Killimuck lived in groups of rectangular, semi-subterranean houses built of split cedar planks. Usually four families lived in each house, with the number of houses proportional to the river or bay supporting the group. Cooking was done indoors at a row of cookfires down the center of the house and the walls were lined by sleeping platforms and storage.

Primarily a marine people, they traveled mostly by canoe. These craft, made from large cedar trunks, could hold 4-30 people, depending on the size and type. Overland transportation was by walking, but the dense forests limited this to a few trails through the mountains for hunting and trade purposes.

Seasons were named for important food items that became available at those times. The primary foods and gathering seasons were: salmonberry sprouts in April; salmon berries in May and June; camas bulbs and lamprey in June and July; and salal berry, huckleberry, and strawberry in July and August. The first chinook salmon arrived in September, chum in October, and coho in November. Elk moved down from the high country in the fall. Natives gathered fern, lily roots, and kinnikinnick berries in December; caught winter steelhead from December to April; and hunted beaver, muskrat, and bear (Seaburg and Miller 1990).

Lewis and Clark estimated the Killimuck population at 2,200 in 1806, but this figure does not represent the Late Marine population. Europeans visiting Tillamook on the sloop Lady Washington reported that the Killimuck had smallpox in 1788, which would indicate that disease had already reduced the population by that time. By 1849, the Killimuck population was estimated at only 200, following measles and other epidemics. Additional information on the Killimuck can be found in Vaughn (1890), Boas (1923), Jacobs

(1959), and Sauter and Johnson (1974). For a more detailed look at subsequent human activities in Tillamook Bay Watershed, see Chapter 2, Human Uses.

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CHAPTER 2

HUMAN USES:
ECONOMIC CONTRIBUTIONS AND ENVIRONMENTAL IMPACTS

The river carries a history of the land and the people who live on the land, stories collected from a thousand feeder streams and recorded in pockets of sand, in the warm and cold currents, the smells of the water, the mayflies.

—Kathleen Dean Moore
River Walking *Reflections on Moving Water*
Harvest Books, NY, NY. 1995.

The Tillamook Burn

These mountains have heard God;
they burned for weeks. He spoke
in a tongue of flame from sawmill trash
and you can read His word down to the rock.

In milky rivers the steelhead
butt upstream to spawn
and find a world with depth again,
starting from stillness and water across gray stone.

Inland along the canyons
all night weather smokes
past the deer and the widow makers —
trees too dead to fall till again He speaks,

Mowing the criss-cross trees and listening peaks.

—William Stafford
Oregon Poet Laureate
“The Tillamook Burn” copyright 1962, 1998 by the Estate of William Stafford.
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CHAPTER 2

HUMAN USES:

ECONOMIC CONTRIBUTIONS
AND ENVIRONMENTAL IMPACTS

Introduction

The Tillamook Bay Watershed's extensive forests, lowlands, and the Bay itself have always shaped the region's human uses and economic growth. Based on geographic imaging, 89% of the Watershed's 358,450 acres (145,172 hectares) is considered forest land, 6.5% is used for agriculture, 1.5% is taken up by urban or rural development, and 3% is covered by water (Oregon Department of Environmental Quality (DEQ) 1992). This landscape, along with the region's environmental characteristics, proved ideal for dairy farming, forestry, and commercial fishing. Historically, job availability in these industries drove the region's population trends.

Eighty-nine percent of the Watershed is considered forest land, 6.5% is used for agriculture, 1.5% is taken up by urban or rural development, and 3% is covered by water.

In recent years, other income sources have substantially affected job growth and population trends. For example, recent studies have shown that income commonly attributed to retirees, such as investments and transfer payments, comprises nearly 50% of the annual personal income of Tillamook County residents (Radtke 1995). The number of retirees moving into the County is expected to continue to increase, and this will result in increases in service sector jobs and dependence on non-earned income sources (Radtke 1995). Also, tourism is expected to grow in the Tillamook Bay Watershed as vacationers continue to "discover" the area.

This chapter traces the economic contributions and environmental impacts of the major human uses of the Tillamook Bay Watershed. The chapter includes a historical overview of each of the major economic sectors and a look at current demographic characteristics of the Tillamook County population. Each major economic sector (or human use) is analyzed independently with relation to its current economic status, projected trends, and associated environmental impacts. Also included is a discussion on managing the human uses of the Watershed for both economic growth and environmental protection. The chapter concludes with a list of research efforts recommended to better understand current and future economic conditions and trends in the Watershed.

A Historical Overview of the Major Human Uses of the Tillamook Bay Watershed

Prior to the 1850s, the Killimuck Indians were the only humans living in the Tillamook Bay Watershed.

Prior to the 1850s, the Killimuck[1] Indians were the only humans living in the Tillamook Bay Watershed (Jensen, W. pers. com. 1997). Because of the vast resources of fish, game, shellfish, berries, and roots, the Killimuck had no need to cultivate crops or to hunt or gather in the upper Watershed (Taylor 1974, Coulton *et al.* 1996). Extensive food gathering was limited to the tidewater area and along the rivers in the lower Watershed. There are no records of any major impacts or alterations to the landscape caused by the Killimuck, other than periodic burnings of the lowlands to encourage growth of grains and produce pasturage for horses (Coulton *et al.*1996). This burning typically took place in the fall and kept some lowlands open and clear of stands of large trees.

The earliest known Killimuck village site is carbon-dated at 1,000 years old.

Archaeological investigations in the 1950s identified 10 Native American villages along the shoreline of the Bay and the river delta areas (U.S. Army Corps of Engineers 1975). The earliest known Killimuck village site is carbon-dated at 1,000 years old. The Killimuck population declined rapidly in the first half of the nineteenth century. Smallpox disease apparently first occurred on the central Oregon coast before 1789, probably as a result of contact with Euro-American explorers. In 1806, Lewis and Clark estimated the Killimuck population at around 2,200; by 1849, their population had dropped to 200, largely due to disease (Coulton *et al*. 1996).

The first white settler in the region, Joseph Champion, came to the Tillamook area for six months in 1851. One year later, Henry W. Wilson brought the first cattle into the area, laying the foundation of the dairy industry.

The first white settler in the region, Joseph Champion, came to the Tillamook Bay area for six months in 1851. One year later, Henry W. Wilson brought the first cattle into the area, laying the foundation of the dairy industry. In the spring of 1852, Elbridge Trask filed the first land claim for 640 acres (259 hectares). By the close of 1852, three families and six bachelors were living in the area. In 1853, Tillamook County was established and by 1854, 80 settlers had moved into the County (Coulton *et al.* 1996).

Early settlers came to the Tillamook Bay Watershed primarily to farm. The combination of climate and soils prompted steady growth in dairy farming. Immediately after settlement, much of the lowland forest was cleared, diked, and drained to increase the amount of land available for agriculture. A significant portion of the lower intertidal and freshwater wetland areas was converted to pasture by the early 1900s (Coulton *et al*. 1996). By 1900, Tillamook County had one of the highest numbers

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[1] Over time, the Killimuck became referred to as the Tillamook. We will refer to the tribe using what is believed to be the original pronunciation.

of owner-operated farms in the State. The Tillamook County Creamery Association (TCCA) was established in 1909 as a cooperative of 10 smaller cheese producing cooperatives (Schild, H. pers. com. 1997).

The forested lands in Tillamook County have provided timber harvest for wood products industries since the 1880s.

The forested lands in Tillamook County have provided timber harvest for wood products industries since the 1880s. While the extensive stands of timber were originally viewed as a hindrance to farming, by 1894 the timber industry was considered the County's most important industry (Levesque 1985). As demand for timber products increased and technology evolved, the number of timber workers and amount of harvested timber increased dramatically. Through the Donation Land Act of 1850, the Homestead Act of 1862, and the Timber and Stone Act of 1878, private timber companies acquired much of the County's valuable timber (Levesque 1985). Large scale logging began in the early 1900s with no effort to reforest cleared lands.

The Tillamook Burn, a series of forest fires from 1933–1951, profoundly affected the use of forest lands in the region. The fires killed most (about 200,000 acres) of the old-growth timber in the Wilson and Trask River watersheds, burning some areas repeatedly.

The Tillamook Burn, a series of forest fires from 1933–1951, profoundly affected the use of forest lands in the region. The fires killed most (about 200,000 acres) of the old-growth timber in the Wilson and Trask River watersheds, burning some areas repeatedly. The fires were followed by road building for salvage logging, fire protection and replanting (Levesque 1985). Reforestation of the burned acreage began in 1949. Since salvage logging ended in 1959, timber harvest in the Tillamook Burn area, now the Tillamook State Forest, has been mainly commercial thinning. However, remaining private timberlands have been intensively clear-cut in recent years (Labhart, M. pers. com. 1997).

Fish and shellfish were historically plentiful in Tillamook Bay and it did not take long for residents to begin a commercial fishing industry.
In 1961, the gillnet fishery in Tillamook Bay was closed, and commercial salmon fisheries moved to sea.

Fish and shellfish were historically plentiful in Tillamook Bay and it did not take long for residents to begin a commercial fishing industry. A small export fish cannery was constructed in Hobsonville in 1885 and its products were shipped to San Francisco (Coulton *et al.* 1996). Commercial gillnet fishing in the Bay began in the late 1800s. The large historic populations of chinook, coho, and chum salmon in the basin have been well documented. Commercial fishing of coho salmon was regulated as early as 1892. Fish hatcheries were established in the early 1900s, with the current Trask River hatchery in operation since 1914 (Coulton *et al.* 1996). In 1961, the gillnet fishery in Tillamook Bay was closed, and commercial salmon fisheries moved to sea (Tillamook System Coho Task Force 1995). Tillamook Bay continues to support a thriving charter fishing service, with paid guides hosting recreational anglers. Despite restrictions on certain species, processing of seafood and fish products has remained a local industry. The Port of Garibaldi leases property for anchorage, services, and seafood processing facilities for commercial fishing boats, which harvest a variety of species, including salmon, bottomfish, tuna, shrimp, and crab. Historic information on the shellfish industry in Tillamook Bay is limited prior to the 1960s because harvests were rarely documented. Oysters are not native to Tillamook Bay, but were first planted in the

Bay in 1928. Conditions in Tillamook Bay are very good for oysters and the Bay dominated Oregon's oyster production for many years (Oregon Department of Agriculture (ODA) 1995). The Bay has long been a major clam producer, harvesting more and more of the State's total since the mid-1980s (Johnson, J. pers. com. 1995).

Conditions in Tillamook Bay are very good for oysters and the Bay dominated Oregon's oyster production for many years.

Natural resource-based industries require efficient and reliable transportation and shipping networks to succeed. Port activities (from Tillamook and Garibaldi) such as importing and exporting, shipping, and navigational improvements have long been a part of the local economy. Historical accounts document the importance of deep water channels for boats to transport logs and lumber to West Coast markets (Levesque 1985). Before 1913, the Port of Tillamook maintained a shallow draft channel as far as the City of Tillamook for ocean-going ships (Coulton *et al*. 1996). Regular dredging of the main navigation channel began in the late-1880s, with dredging near the City of Tillamook ending in the 1920s. By the 1970s, main channel dredging was limited to the mouth area. Most of the dredge spoils were disposed of at sea. Construction of the north jetty, completed in 1918, was intended to aid navigation but may have had the opposite effect by accelerating sand accretion in the Bay (Coulton *et al.* 1996). Logistical improvements and cost reductions over the past few decades have made road transportation much more viable than marine shipping options.

Although natural resource extraction industries have historically supported the Tillamook Bay region, the Watershed has also been a tourist destination since the turn of the century (Coulton *et al.* 1996). Hiking, beach combing, wildlife viewing, sport fishing, off road vehicle use, crabbing, and clamming are all popular recreational activities which draw numerous tourists. Many people, especially retirees, are also finding that the Tillamook Bay Watershed is an attractive place to live. The past decade has brought an influx of retirees to the Watershed, and to the entire Oregon Coast (Davis and Radtke 1994). **Table 2-1** tracks human use of, and impacts on, the Tillamook Bay Watershed and its resources.

Although natural resource extraction industries have historically supported the Tillamook Bay region, the Watershed has also been a tourist destination since the turn of the century.

Table 2-1. Selected events time line

Year	Event
1000	Earliest known native Killimuck settlement along Bay and deltas.
1806	Lewis and Clark estimate the Killimuck population at about 2,200.
1849	Killimuck population estimated at approximately 200, reduced largely by disease.
1851	First European settler, Joseph Champion, arrives in Tillamook.
1852	Henry W. Wilson brings the first cattle to the area. Elbridge Trask applies for the first land claim of 640 acres.
1853	Tillamook County established. Three dairy operations begin exporting butter.
1863	Three sawmills open in Watershed (all would close by 1870).
1880s	Permanent logging and lumber operations begin in Tillamook Bay Watershed. Regular dredging begins in Bay.
1885	First cannery built for export at Hobsonville.
1886	Regular ship service begins.
1892	Extensive diking and draining of the lowlands begins. Commercial fishing for coho salmon regulated in the Bay.
1909	Tillamook County Creamery Association formed.
1911	Railroad around Bay reaches Tillamook.
1912	Bayocean resort hotel opens, with 1,600 lots sold on Bayocean Spit by 1914.
1918	Army Corps construction of north jetty completed.
1923	20 sawmills operating in the County.
1928	Oysters first planted in Tillamook Bay.
1933	First of the Tillamook Burn forest fires. Subsequent fires in 1939, 1945, 1951.
1941	Wilson River Road constructed as state highway.
1940s	Salvage logging begins on a large scale.
1949	Oregon Department of Forestry begins re-forestation of Tillamook Burn.
1952	Bayocean Spit breached.
1953	610 million board feet harvested from Tillamook Watershed. Salvage logging peaks.
1956	Corps of Engineers repairs Bayocean Spit breach and creates Cape Meares Lake.
1961	Oregon Fish Commission closes Tillamook Bay to gillnet commercial salmon harvest.
1963	Highway 101 rebuilt along Bay from Tillamook north.
1971	Oregon Department of Forestry adopts the Forest Practices Act.
1974	Corps of Engineers says sedimentation makes dredging of upper Bay infeasible.
1979	South jetty construction completed.
1981	Rural Clean Water Program begins addressing County farm wastes; ends in 1996.
1991	Corps of Engineers repairs the end of the north jetty.
1993	Tillamook Bay National Estuary Project begins work in the Watershed.

Sources: Coulton, K.G., Williams, P.B., and Benner, P.A. 1996. An environmental history of the Tillamook Bay Estuary and Watershed. Phillip Williams & Associates and Oregon State University, prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.
Levesque, P. 1985. A chronicle of the Tillamook County Forest Trust Lands, Volume 1. Published for Tillamook County, Tillamook, OR.

Tillamook County Demographic Characteristics

This section provides selected demographics of the Tillamook County population. Data are provided on population trends, age structure, employment characteristics, and income characteristics. Because very few statistics are available at the watershed level, most demographics included in this report are given for Tillamook County.

Population Trends

Since 1950, the population of Oregon has doubled and Tillamook County's population has increased by approximately 20% (U.S. Bureau of Census 1990). The Tillamook County population declined in the 1960s and rose sharply between 1970 and 1980, largely as a result of fluctuations in the timber industry (Coulton *et al.* 1996). The County population stabilized during the 1980s and has risen steadily in the 1990s **(Table 2-2)**. Population growth in Oregon, especially Tillamook County, historically depended on fluctuations in the natural resource industries. In recent years, population growth has been less a reaction to natural resource industries and more a function of living conditions and quality of life concerns.

Population is expected to continue to increase at a rate of 1.5–2% per year.

Although Tillamook County's population has continued to grow, birth rates have decreased and death rates have increased since 1990 (Center for Population Research and Census 1997). Population growth can be attributed primarily to in-migration, which is expected to continue to increase at a rate of 1.5–2% per year (Garvasi, M. pers. com. 1998).

Table 2-2. Population change since 1950: Oregon and Tillamook County

Year	Oregon	avg. annual % change	Tillamook County	avg. annual % change
1950	1,521,341	N/A	18,606	N/A
1960	1,768,687	1.63	18,955	0.19
1970	2,091,385	1.82	18,034	-0.49
1980	2,633,156	2.59	21,164	1.74
1990	2,842,321	0.79	21,570	0.19
1995	3,132,000	1.94	23,300	1.53

Source: U.S. Bureau of Census 1990. Center for Population Research and Census, Portland State University. 1997.

Age Structure

The continued influx of retirees and the aging of the "baby boom" generation virtually guarantees an older population profile for both Oregon and Tillamook County.

Since 1960, the older population of the United States (65 years and older) has been expanding at almost twice the rate of the total American population (Davis and Radtke 1994). In addition, much of this older population is migrating to new areas (Davis and Radtke 1994). Tillamook County has become a popular destination for older migrants, who are attracted to its rural, uncrowded conditions and proximity to nature-based recreation. Tillamook County's median age increased from 34.2 years in 1980 to 40.9 in 1990. Comparatively, the median age in Oregon in 1990 was 34.5 years. Additionally, nearly 21% of Tillamook County's population was 65 or older in 1990, compared with 14% statewide (U.S. Bureau of Census 1990). The continued influx of retirees and the aging of the "baby boom" generation virtually guarantees an older population profile for both Oregon and Tillamook County.

Employment Characteristics

Tillamook County's unemployment rate has historically fluctuated with trends in natural resource industries.

Tillamook County's unemployment rate has historically fluctuated with trends in natural resource industries. During the 1970s and 1980s, declining jobs in the timber and fishing industries in Tillamook County caused higher unemployment rates than state and national figures. As of 1995, however, Tillamook County's unemployment rate (4.8%) was comparable to state (4.4%) and national (5.4%) figures (Oregon Employment Department 1996). The Oregon Employment Department (1996) has projected that the non-manufacturing sector will account for nearly 95% of all new jobs in northwest Oregon from 1995–2005. Tourist-related sectors of retail trade and services will provide the most jobs. Manufacturing is expected to grow slightly, but projections are uncertain because it is difficult to predict the future of the region's forest products and fishing industries (Angle *et al*. 1996).

Income Characteristics

Tillamook County lags behind the State and the nation in average annual covered wage rates.

Tillamook County lags behind the State and the nation in average annual covered wage rates (Radtke 1995). This may be due to the fact that many jobs are in low paying industries, such as service/tourism industries, or are seasonal or part-time. Growth in these employment sectors, and continued decreases in the availability of family wage jobs, may combine to keep covered wage rates lower than state or federal rates. Covered wage refers to all workers covered by unemployment insurance, including federal employees **(Figure 2-1)**.

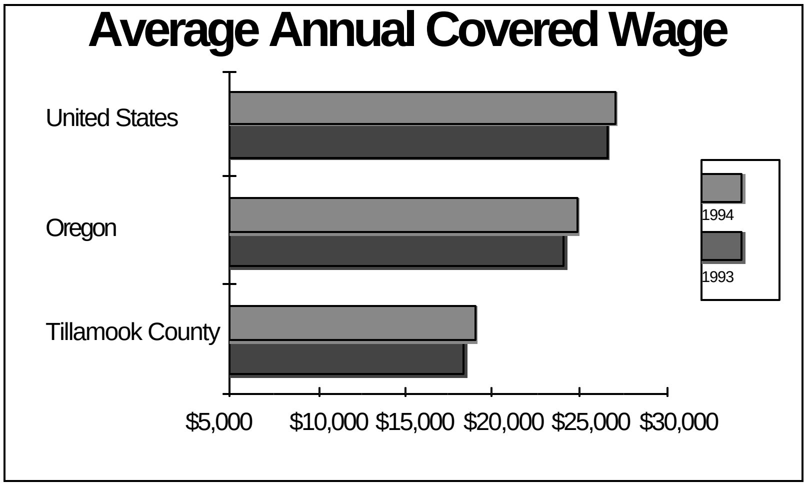

Figure 2-1. Average annual covered wage for Tillamook County, the State of Oregon, and the United States, 1993 and 1994.
Source: U.S. Bureau of Labor Statistics. Adapted from a graphic by Radtke, H.D. 1995. Economic trends in the northern coastal regional economy. Report prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

Radtke (1995) calculated the total personal income of Tillamook County residents in 1993 generated by each of the major industries in the County. Natural resource-based industries such as timber, fishing, and agriculture continue to be important sources of personal income for Tillamook County residents. Income from agriculture, the timber industry, and commercial fishing accounted for approximately 32% of the Tillamook County total **(Figure 2-2)**. Non-earned income such as investments and transfer payments makes up 48% of personal income in the County. Comparatively, investments and transfer payments make up 34% of statewide personal income and 38% of neighboring Clatsop County's personal income (Radtke 1995). The large percentage of investments and transfer payments in Tillamook County reflects the large number of retired and elderly residents. The number of retirees moving into the County is expected to rise, further increasing the overall contribution of transfer payments and investments to the local economy (Davis and Radtke 1994).

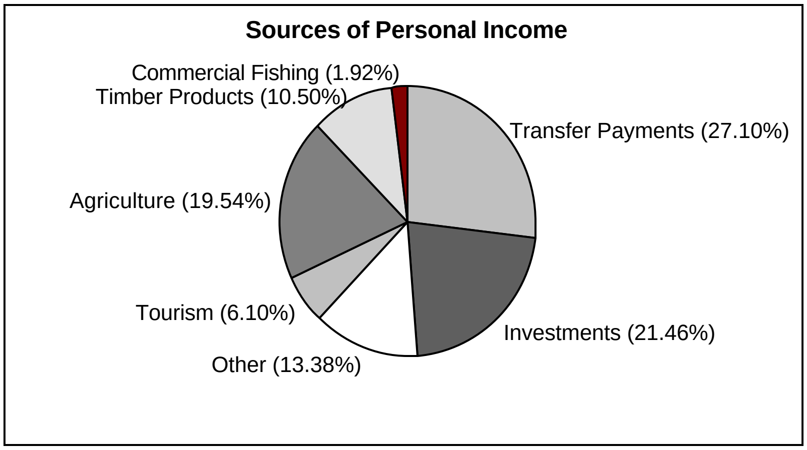

Figure 2-2. Sources of personal income in Tillamook County, 1993. *Source:* Radtke, H.D. Economic trends in the northern coastal regional economy. Report prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

Description of the Major Economic Sectors in the Tillamook Bay Watershed

In this section, each of the major economic sectors in the Tillamook Bay Watershed is characterized relative to the personal income it generates. This includes direct wages and benefits as well as the "multipliers" associated with each industry. Multipliers are used to estimate total contribution by quantifying the transactions associated with earned income. For example, the timber products industry provides wages to workers which, in turn, are used for food, housing, entertainment, and many other transactions. The timber products industry also supports numerous businesses and agencies that maintain and repair equipment, provide social services, etc. All of these secondary transactions generate income. Economic analysts such as Davis and Radtke (1994) have developed models that estimate the magnitude of multiplier effects at the scale of regional economies.

In addition to personal income generated, the status and trends of each of the economic sectors is discussed. Economic sectors included in this analysis are:

- agriculture, primarily dairy farming;
- timber products;
- commercial fisheries, including shellfish;
- recreation/tourism;
- "non-earned" income sources such as investments and transfer payments; and
- port activities and gravel mining (no economic data included).

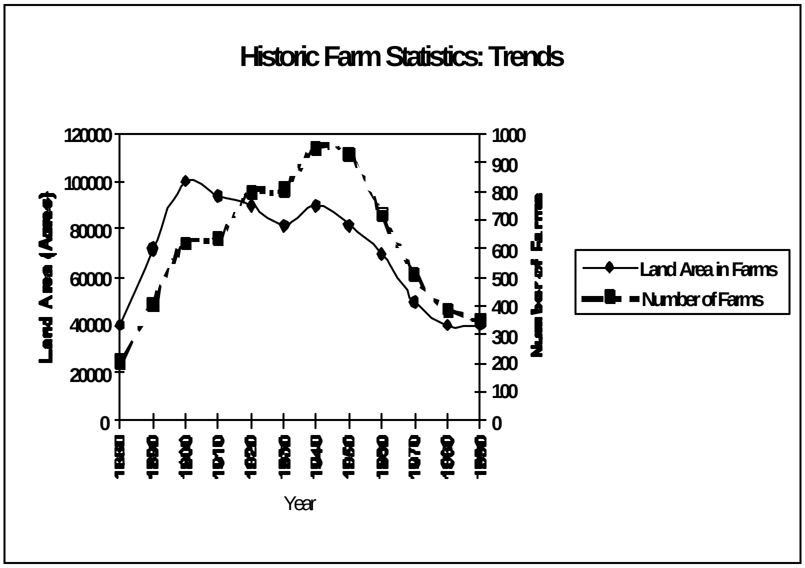

Figure 2-3. Historic farm statistics: trends.
Source: U.S. Census of Agriculture, data provided by Tillamook County Creamery Association.

None of the other sources of income for Tillamook County residents is large enough to make up more than 1% of the total personal income of County residents.

The environmental impacts associated with each economic sector are also briefly discussed.

Agriculture

Dairy products generated 82% of the County’s agricultural income in 1995.

Agriculture in Tillamook County has contributed significantly to the coastal economy since Euro-American settlement. The production of dairy products began in 1852, just one year after the first white settler arrived. During periods of low productivity for timber products and fishing industries, agriculture has provided a valuable, steady income source (Coulton et al. 1997) (Figure 2-3). The number of farms and the land area used for farming have decreased since the 1950s due to conversion and combination of small farms to larger commercial farms (Coulton et al. 1997).

In 1995, agricultural commodity sales from Tillamook County totaled $75.8 million (OSU Economic Information Office 1996) **(Figure 2-4)**. Dairy products generated 82% of the County’s agricultural income in 1995. The only other major agricultural commodities in the County were small woodlots, and cattle and calves, which generated 11% and 5% of the total income, respectively (OSU Economic Information Office 1996). Because dairy products represent the vast majority of agricultural production in Tillamook County, our analysis of agriculture will focus on the dairy industry.

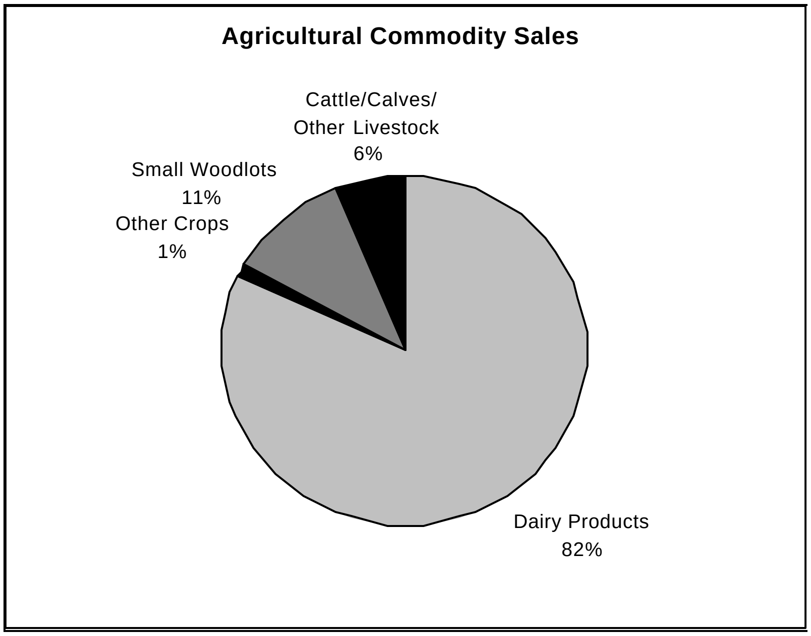

Figure 2-4. Agricultural commodity sales in Tillamook County, 1995. *Source:* Oregon State University Economic Information Office, 1996. Oregon county and state agricultural estimates, 1996 special report 790, Corvallis, OR.

Economic Status

Most Tillamook area farms are concentrated into a 35 mi.^{2} (91 km^2) tidewater floodplain pasture area (Little 1989). The area's high rainfall, mild winters, and good soils support abundant grass for pastures year-round. The development of the Tillamook County Creamery Association (TCCA) has also played a major role in establishing the County's successful dairy industry. Over the years, a trend toward fewer, larger dairy farms can be observed in the County. The total number of dairy farms declined 66% from 1940 to 1977 and declined another 30% from 1977 to 1993 (McMullen, J. pers. com. 1996).

Most Tillamook area farms are concentrated into a 35 mi.^{2} tidewater floodplain pasture area.

Milk was Oregon's fifth-ranking commodity in 1994. Tillamook County produces more milk than any other county in the State. In 1994, Tillamook County accounted for 26%, or 25,600, of the State's milk cows (OSU Economic Information Office 1996). Overall milk production in the County has increased steadily as a result of more cows and more effective and efficient milk production methods. Milk production among TCCA members increased over 60% between 1984 and 1995, going from roughly 291 million to 460 million lbs (132 million to 209 million kg) during that period. Production peaked in 1992 at 480 million lbs (218 million kg) and has declined each year since (McMullen, J. unpublished data 1996).

Milk was Oregon's fifth-ranking commodity in 1994. Tillamook County produces more milk than any other county in the State.

The TCCA also purchases milk from Willamette Valley farmers and other outside sources for production at the Tillamook County Creamery. Purchases outside the TCCA represented 17% of the milk used in production in 1995 and approximately 30% in 1996 (Schild, H. pers. com. 1997).

Most of the County's milk goes into production of Tillamook’s famous cheese. Tillamook cheese is sold throughout the western United States and exported to various markets around the world. While cheese dominates product sales, the TCCA also markets milk, whey, butter, ice cream, and other products. The Portland metropolitan area is the primary consumer of Tillamook dairy products. The high population growth rate in the Portland area over the last two decades has been a major reason for steep increases in milk production (Schild, H. pers. com. 1997). Despite decreasing milk value, TCCA sales have increased steadily in the past decade (McMullen, J. unpublished data 1996).

Environmental Impacts Associated With Agricultural Production
The most obvious impact of dairy product production is the impact on water quality. Fecal coliform bacteria from manure enters rivers, streams, sloughs and drainage ditches, either directly from the cows or via runoff from pastures on which manure has been spread. A typical dairy cow can produce 7–20 tons (6–18 metric tons) of manure annually (Dorsey-Kramer 1995). With approximately 90 inches (213 cm) of rainfall each year and about 28,600 dairy cattle (calculated in 1,000-pound units, including cows, calves, heifers, and dry stock) (Pedersen, B. pers. com. 1998) in the County, there is obviously a high risk of bacterial contamination in the region (Dorsey-Kramer 1995).

The most obvious impact of dairy product production is the impact on water quality. A typical dairy cow can produce 7-20 tons of manure annually. With so many cattle, there is obviously a high risk of bacterial contamination in the region.

One of the County’s most publicized environmental issues is the closure of Tillamook Bay’s shellfish beds due to the risk of bacterial contamination. Water quality testing and shellfish testing have led to strict regulations on oyster harvest and closure of various portions of the Bay. Some years, shellfish beds are closed to harvest for more than 100 days (DEQ 1994). While the dairy industry has long been viewed as the major cause of bacterial contamination in the Bay, no comprehensive study of the relative contribution of bacteria sources has been completed. Other potential sources include sewage treatment facilities and on-site septic systems. Bacterial contamination will be discussed in greater detail in Chapter 4, Water Quality.

In part because of the dairy farming/shellfish connection, the Rural Clean Water Program (RCWP), a national effort to help clean up agricultural wastes, picked the Tillamook Bay area in 1981 as one of its primary test sites. The RCWP covered 23,540 acres (9,160 hectares) of pasture/range lands in the Watershed and provided funding in 10-year contracts to implement best management practices (BMPs) on agricultural lands. The RCWP made major strides in installing manure storage facilities, roofing, guttering, fencing, and other management practices on farms. Water quality monitoring conducted during the 10 years of the project showed a 40–50% reduction in mean fecal coliform (DEQ 1994). The last RCWP contracts expired in 1996 and many questions remain about the contribution of dairy farms to the Bay's fecal coliform problem. One main objective of the TBNEP's workplan is to identify the various sources of fecal coliform in the Watershed. The TBNEP is currently conducting studies to assess the contribution of the various sources of bacterial contamination.

Water quality monitoring showed a 40–50% reduction in mean fecal coliform (DEQ 1994).

In addition to bacterial contamination problems, cattle grazing and trampling in and around streams can cause streambank erosion and destroy habitat. Some landowners have constructed off-channel watering systems for livestock, but many others allow direct access to riparian areas and waterways. Numerous streamside fencing projects in the County are keeping cattle out of streams. Some of these projects are voluntary, with farmers paying for their own materials. Other fencing projects are sponsored by the DEQ, the Oregon Department of Fish and Wildlife (ODFW), the TCCA, and by participants in the Hire-the-Fishermen program seeking to improve in-stream and riparian habitat.

One main task in the TBNEP's workplan is to identify the various sources of fecal coliform in the Watershed. The TBNEP is currently conducting studies to assess the contribution of the various sources of bacterial contamination.

Timber Products

Forested land makes up approximately 89% of the Tillamook Bay Watershed (DEQ 1992). These lands have supported profitable timber harvest and wood products industries in Tillamook County since the 1880s. Most forested land in the Watershed was owned by private timber companies from eastern states in the 1930s at the time of the first of the Tillamook Burn fires (Levesque 1985). Tillamook County eventually acquired most of the Watershed's burned forest lands by foreclosing on lands with taxes delinquent for more than three years. The County then deeded most of this land to the State to be held in trust for the County and its taxing districts (Levesque 1985). The volume of timber harvested from State Trust lands, managed by the Oregon Department of Forestry (ODF), peaked in the early 1950s during salvage logging of the Tillamook Burn area, exceeding 610 million board feet in 1953 (ODF 1995). Since 1960, most timber harvesting has occurred on private and federal lands because the state trust lands replanted after the burns are still developing into mature, harvestable stands **(Figure 2-5)**.

Forested land makes up approximately 89% of the Tillamook Bay Watershed.

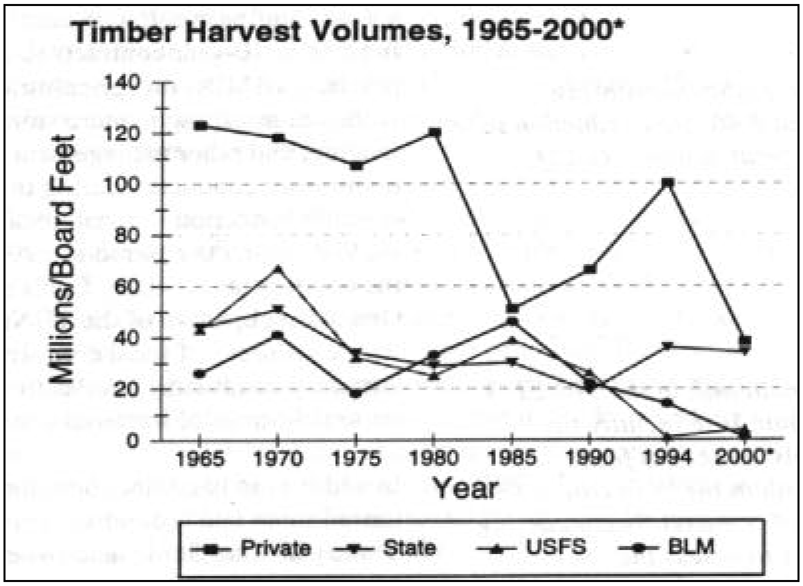

Figure 2-5. Timber harvest volumes, 1965–2000.
***ODF has projected figures for the year 2000**
Source: Oregon Dept. of Forestry, 1995. ODF Timber harvest report, Tillamook, OR.

Economic Status

Although Tillamook County's timber-related employment has declined substantially from historic levels, the timber industry has shown small increases recently (Angle *et al*. 1996). "Timber industry" refers not only to tree harvesting, but also to the managing and processing of timber. Employment increases in Tillamook County are directly attributable to jobs in timber processing (sawmills/planing mills). New jobs in timber processing have offset steady declines in available logging jobs. In 1994, approximately 7% of Tillamook County's workforce was employed in the timber industry in some fashion. This is roughly twice the rate of the State of Oregon as a whole (Angle *et al*. 1996). The timber products industry generated 11% ($37 million) of Tillamook County personal income in 1993 (Radtke 1995).

In Tillamook County, forest land ownership is 46% State Trust, 23% private, 14% U.S. Forest Service, and 8% Bureau of Land Management (ODF 1995). The remaining 9% of forest lands are owned by private non-industrial or other public owners **(Figure 2-6)**. For the Tillamook Bay Watershed, a higher percentage, approximately 64%, is State Trust forest land (DEQ 1992). Timber harvest in the County has varied substantially by land owner **(Figure 2-7)**. Over the past 30 years, private lands have yielded almost half the timber harvested in Tillamook County (ODF 1993, 1995).

In Tillamook County, forest land ownership is 46% State Trust, 23% private, 14% U.S. Forest Service, and 8% Bureau of Land Management. The rest is owned by private non-industrial or other public owners.

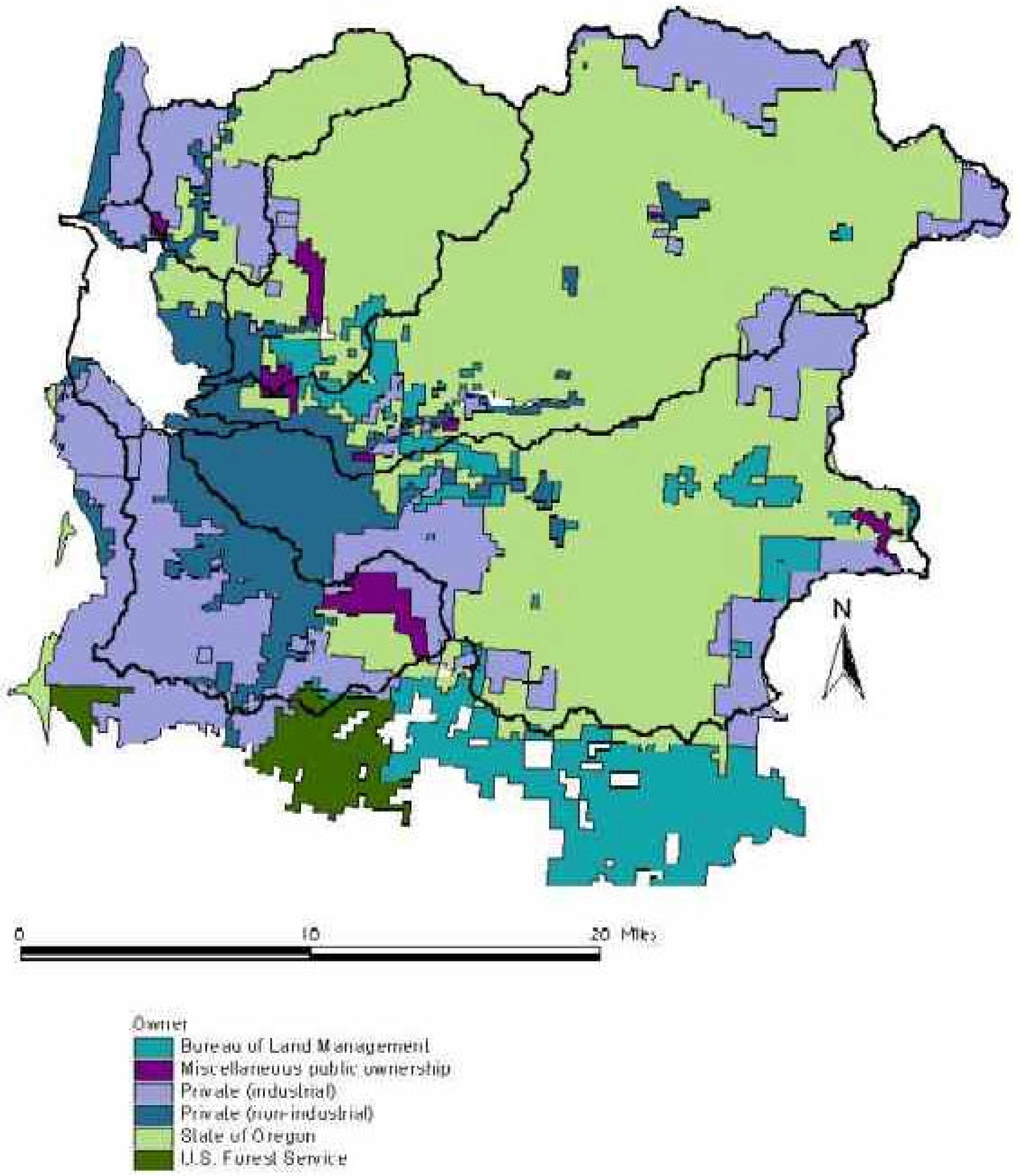

Figure 2-6. Ownership of Land in the Tillamook Bay Watershed.
Source: Tillamook Bay National Estuary Project Geographic Information System, October 1997, version 2.

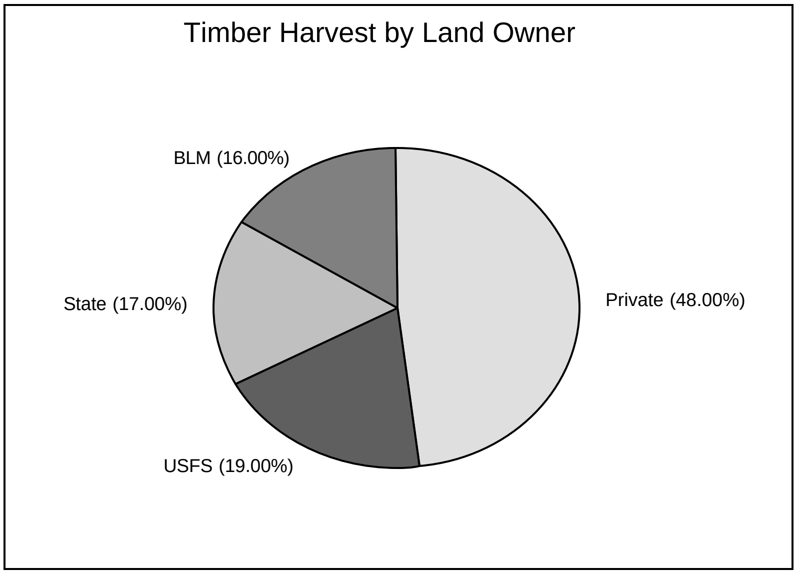

Figure 2-7. Percent of total timber harvest in Tillamook County by land owner, 1962–1994.
Source: Oregon Department of Forestry, 1995. ODF Timber harvest report, Tillamook, OR.

Timber inventories on State Trust lands have been increasing substantially as replanted timber grows toward harvestable size. Even with the low harvest rate, the Tillamook State Forest still contributed 21% of the County's total timber harvest in 1994 (Angle *et al.* 1996). Statewide, timber harvested from state-owned or trust lands comprised less than 3% of overall timber harvest. Harvest rates and employment levels in Tillamook County are expected to rise over the next 25 years as State Trust stands reach harvestable age. In the Economic Overview of the Northwest Oregon State Forest Management Plan (Angle *et al.* 1996), the ODF compares recent timber harvests in Tillamook County with a reference period of 1983–1987. Overall, harvests in 1994 decreased by 29% from 1983–1987 levels, mostly due to declining harvest from federal lands in the County. In fact, harvests from state lands have increased by 7% and harvests from private lands have increased by 50% since 1987 (Angle *et al.* 1996).

Harvest rates and employment levels in Tillamook County are expected to rise over the next 25 years as State Trust stands reach harvestable age.

Projected trends show private harvest levels decreasing and state harvests increasing substantially. Private owners could increase harvest levels above projected levels, but unless they also increase management intensities, any harvest increase would be temporary. Any increase would likely come from harvesting younger, faster growing stands of timber, and the result would be reduced harvest levels later (Angle *et al.* 1996). Currently, most private forest land is at

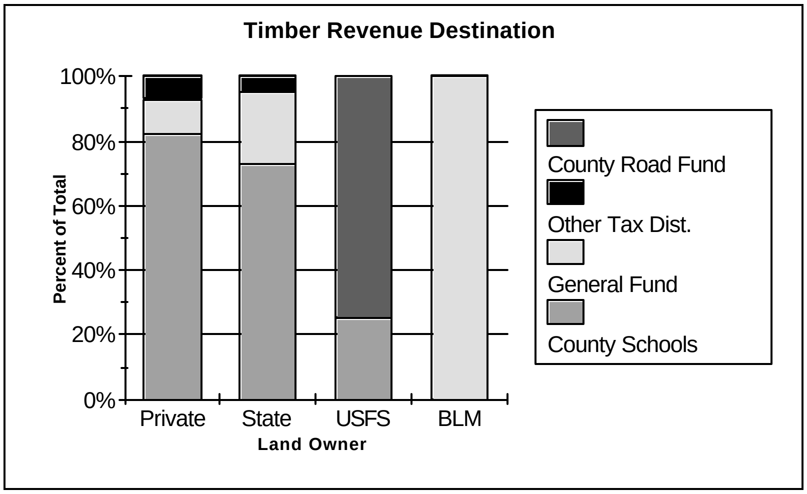

Figure 2-8. Destination of timber tax/payment revenue.
Source: Oregon Department of Forestry *et al*. 1993. Tillamook County timber supply analysis. Prepared by Forestry Subcommittee, Tillamook County Economic Development Committee.

or below projected rotation age of 35–60 years (Angle *et al*. 1996). Under the current federal Northwest Forest Plan, which governs federal land management in the area, most Bureau of Land Management (BLM) lands are managed for the restoration and maintenance of aquatic resources and late successional forest habitat ("old growth"). None of these lands will be managed for timber production, and timber harvest levels will be essentially zero.

Most of the tax revenue garnered from private timber sales goes to county schools while the rest is distributed to the County General Fund and other taxing districts.

Most of the tax revenue garnered from private timber sales goes to county schools while the rest is distributed to the County General Fund and other taxing districts **(Figure 2-8)**. Two-thirds of the proceeds from State Trust land timber harvesting is distributed among county schools (73%) the general fund (22%) and other taxing districts (5%). State school funding to county schools is reduced by the amount of timber revenues they receive. In lieu of tax revenue, the USFS gives the County approximately 25% of timber revenue, split between the County Road Fund and county schools. Fifty percent of timber revenue from BLM lands is given to the County and all of this revenue goes to the County General Fund (Labhart, M. pers. com. 1996).

Environmental Impacts Associated With Timber Harvest and Processing

Widespread clear-cutting of timber stands and salvage logging after the Tillamook Burn led to serious erosion and sedimentation of the Watershed.

Log drives and splash dams as early as the 1870s on Tillamook Bay rivers damaged riparian areas and may have caused excessive erosion (Coulton *et al*. 1996). In addition, widespread clear-cutting of timber stands and salvage logging after the Tillamook Burn led to serious erosion and sedimentation of the Watershed (Coulton *et al*. 1996). Prior to extensive regulations on timber harvest, clear-cutting was

Roads built in the 1950s to salvage the burn timber are still the largest potential cause of erosion and sedimentation on State Forest lands.

conducted with little regard for slopes and proximity to streams and rivers. The Tillamook Burn fires also destroyed vegetative cover and seriously accelerated erosion during rainfall events. Roads built in the 1950s to salvage the burn timber are still the largest potential cause of erosion and sedimentation on State Forest lands (Labhart, M. pers. com. 1996). Many miles of roads were constructed to improve access to timber lands and provide fire breaks. Roads built since the 1971 Forest Practices Act meet stricter erosion control standards. Many older roads and associated culverts need major improvements to prevent further erosion and sedimentation. During severe storm events, old culverts and roads may fail, possibly leading to significant erosion and major sedimentation. In recent years, ODF has put a good deal of effort into improving roads in the Tillamook State Forest. For example, in 1995 ODF spent a record $3.6 million on road improvements, primarily on bringing old roads up to current construction standards (Labhart, M. pers. com. 1996).

In 1995 ODF spent a record $3.6 million on road improvements, primarily on bringing old roads up to current construction standards.

Some potential environmental impacts of timber harvest and associated roads and culverts include:

- culverts barring the return of anadromous fish;
- sedimentation, pesticide, or herbicide damage to wildlife resources and habitat; and
- habitat and ecosystem changes due to clear-cuts.

While each of these is a potential impact of the timber industry, regulations have been developed to mitigate the environmental impact of harvesting. The Forest Practices Act, enacted by the ODF in 1971, regulates harvest practices and protects riparian areas, fish and wildlife habitat, and steep slopes. The ODF coordinates actively with the ODFW, the U.S. Fish and Wildlife Service (USFWS), and other agencies to regulate forest practices and environmental impacts on fish and wildlife (Labhart, M. pers. com. 1996).

Commercial Fisheries

The Tillamook Bay ecosystem has historically supported extensive populations of anadromous fish. Coho, chinook, and chum salmon have supported river, estuary, and open ocean commercial fisheries (Coulton *et al*. 1996). In fact, Tillamook Bay supported the Oregon Coast's largest chum salmon fishery (Coulton *et al*. 1996). Although commercial fishing in local rivers and Tillamook Bay was regulated and restricted as early as 1892, catch totals and returning spawners decreased steadily. By 1961, the Bay and rivers were closed to commercial fishing entirely and the industry shifted to sea (Tillamook System Coho Task Force 1995).

The Tillamook Bay ecosystem has historically supported extensive populations of anadromous fish.

In addition to ocean-based commercial fishing, small commercial shellfish industries have long been a part of Tillamook County's economy.

In addition to ocean-based commercial fishing, small commercial shellfish industries have long been a part of Tillamook County's economy. Tillamook Bay has consistently produced Oregon's largest commercial harvest of clams and small local clamming operations have come and gone over the years (Johnson, J. pers. com. 1996). Since oysters were planted in the Bay in 1928, Tillamook Bay has been one of Oregon's top oyster-producing bays. Despite this, current oyster harvest levels are far below historic levels (Hayes, J. Proceeds TBNEP Human Uses Forum 1996).

Economic Status

Although ports such as Newport and Astoria claim the majority of the Oregon coast's ocean-bound fishing boats, the fishing industry generated $4.9 million of personal income for Tillamook County in 1994 (Radtke 1995) **(Table 2–3)**. Traditionally, large populations of chinook, coho, and chum made up most of the salmon catch. For the last several years, only fall chinook populations have been listed as stable or healthy. All other species are listed as depressed or declining (Klumph and Braun 1995b). Because of declines in the salmon fishery, commercial operations have turned to other fish species, primarily bottom fish such as rockfish, whiting, sole, and flounder.

Table 2-3. Personal income generated by the Tillamook County fishing industry, 1994

Species Landed	Income Generated
Salmon	$118,010
Crab	$588,570
Shrimp, Pink	$385,234
Tuna	$551,108
Bottom fish	$1,330,136
Other	$209,211
Distant/Offshore*	$1,708,800
TOTAL	$4,891,068

*** Includes revenue generated and returned by distant or offshore fisheries.**

Source: Radtke, H.D. 1995. Economic trends in the northern coastal regional economy. Report prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR. Table adapted from data included in Angle, B. *et al*. Coordinator, Lettman, F. 1996. Northwest Oregon State Forest management plan: An economic overview. Oregon Department of Forestry, Forest Resource Planning Program, Salem, OR.

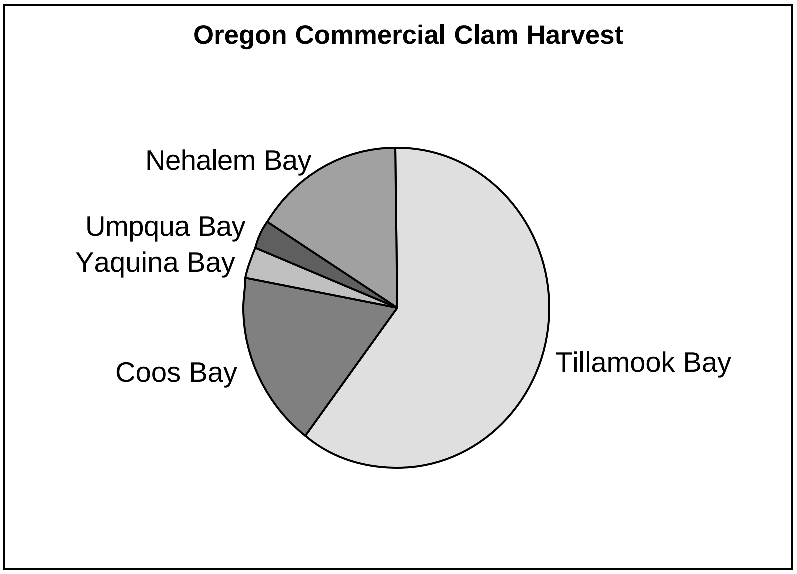

Figure 2-9. Origin of clams harvested in Oregon, 1984–1994.
Source: Johnson, J. 1996. Personal communication. Oregon Department of Fish and Wildlife, Newport, OR.

Total personal income generated from commercial fishing ($4.9 million in 1994) is down 67% from $15 million in 1987.

Total personal income generated from commercial fishing ($4.9 million in 1994) is down from approximately $7 million in 1993 and $15 million in 1987 (Davis and Radtke 1994). This represents a 67% decrease in less than 10 years in Tillamook County commercial fisheries income (Radtke 1995). Commercial fisheries generated less than 2% of Tillamook County's total personal income in 1993, and this percentage is decreasing (Davis and Radtke 1994).

Tillamook Bay is the State's largest commercial producer of clams, accounting for 60% of the statewide harvest.

Tillamook Bay is the State's largest commercial producer of clams, accounting for 60% of the statewide harvest (Johnson, J. pers. com. 1996) **(Figure 2-9)**. The harvest of clams, and mud and ghost shrimp, from Tillamook Bay generated approximately $95,000 in personal income in 1994 (Radtke 1995). Clam species commonly harvested in Tillamook Bay include the cockle, littleneck, butter, and gaper. The cockle clam dominated both the commercial, 82%, and recreational, 41%, harvest in Tillamook Bay from 1984–1994 (Johnson, J. as cited in Miller and Garono 1995). Commercial clam harvest in Tillamook Bay has fluctuated over time due to changes in harvest methods and the number of harvesters. Although the number of commercial harvesters in the Bay had declined to 10 by 1994 from a high of 20 in 1985, the harvest level has been increasing since 1992 (Johnson, J. pers. com. 1996). Prior to 1992, commercial clam harvest remained at or below 50,000 lbs (22,650 kg) annually but in 1994 the commercial clam harvest topped 150,000 lbs (67,950 kg) (Johnson, J. pers. com. 1996). Mechanical harvest of clams was discontinued in 1985. Almost all of the commercial clam harvest is done by divers in the subtidal

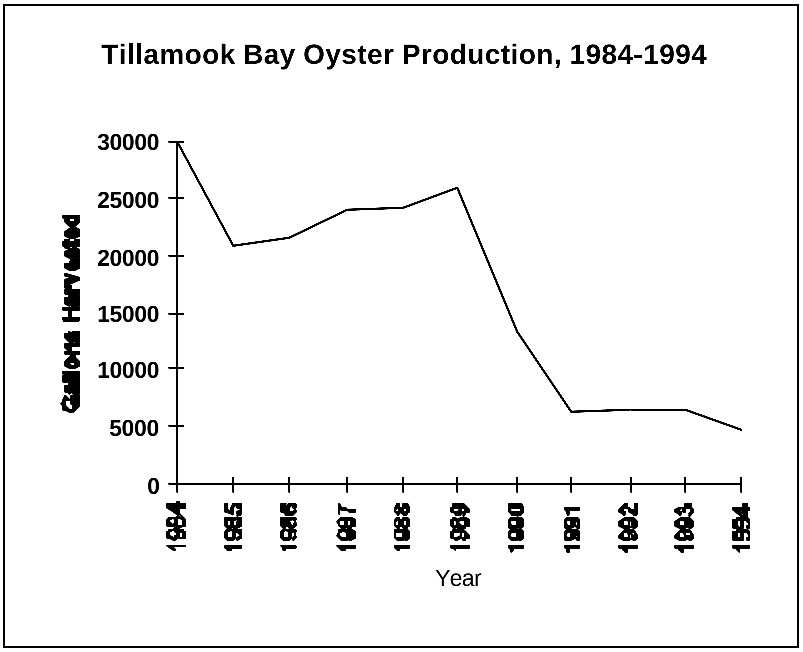

Figure 2-10. Tillamook Bay oyster production, 1984–1994.
Source: Oregon Department of Agriculture Shellfish Program. 1995. Shellfish harvest statistics. Oregon Department of Agriculture, Salem, OR.

portions of the Bay.

Oyster production in Tillamook Bay has fluctuated over time, ranging from approximately 30,000 gallons in 1982 to a low of approximately 4,000 gallons in 1994.

The cultivation of oysters in Tillamook Bay began in the 1920s when a local resident acquired Pacific oyster seed originally brought from Japan to Canada. Oyster production in Tillamook Bay has fluctuated over time, ranging from approximately 30,000 gallons in 1982 to a low of approximately 4,000 gallons in 1994 (Cannon, D. pers. com 1995) **(Figure 2-10)**. The personal income generated by oyster production in 1994 was estimated at $161,000 (Radtke 1995).

Water quality, oyster growth, mortality, burrowing shrimp numbers, and meat quality play large roles in the overall biological and economic production of the oyster industry. Additionally, harvest of shellfish grown for interstate commerce is strictly regulated to protect human health. Bacterial contamination of shellfish growing waters and subsequent shellfish harvesting closures have resulted in economic hardship for oyster culturists and contributed to the production trends. Many of the Bay harvesting closures coincide with the highest demand periods, such as Christmas and New Year’s (Hayes, J. Proceeds TBNEP Human Uses Forum 1996).

Bacterial contamination of shellfish growing waters and subsequent shellfish harvesting closures have resulted in economic hardship for oyster culturists.

Future projections for ocean-based commercial fisheries are difficult due to changing regulations and ocean conditions, and shifts in species sought. Bottom fish harvesting and long-range fleets have provided an alternative all along the coast to depressed or restricted salmon fisheries. However, increases in income from alternative fisheries may not be felt as strongly in Tillamook County as in other coastal ports because of the lack of a large local fleet. Recently, a commercial crabbing operation began in Garibaldi, attempting to ship live crab to California markets. Based on the ODFW's 1996 "Pounds and Value of Commercially-Caught Fish and Shellfish in Oregon," statewide income has increased from Dungeness crab landings (ODFW 1996). Income generated from bottom fish such as sole and rockfish has remained static while income generated from salmon landings continues to decrease (ODFW 1996).

Environmental Impacts Associated With Commercial Fisheries
The effect of commercial harvests on salmonid population decline over the years is difficult to quantify. Based on existing information, with the exception of fall chinook, all species of salmon and trout in the Watershed have shown sharp decreases in harvest levels. The chum, coho, and winter and introduced summer steelhead stocks are listed as declining in the Tillamook Basin (Klumph and Braun 1995b). It is nearly impossible to measure the impact of commercial fishing on the decline of any of these stocks, and to what extent other factors are responsible. The status and trends of anadromous salmonid populations are discussed in detail in Chapter 3, Biological Resources.

Recreation and Tourism

Tillamook County showed the highest tourism growth rate of all Oregon's counties between 1987 and 1991.

Tillamook Bay and its surrounding forests and rivers have long been a popular tourist destination. The region's natural resources support recreational fishing, clamming, crabbing, and hunting throughout the year. Recently, non-harvest recreational activities, such as wildlife viewing, hiking, beachcombing, birdwatching, boating, and simply "driving through" have increased in popularity. The Watershed's proximity to Portland, the largest metropolitan area in the State, creates potential for further development of the tourism industry. Tillamook County showed the highest tourism growth rate of all Oregon's counties between 1987 and 1991 (Davis and Radtke 1994).

The economic impact of recreation and tourism is difficult to assess for several reasons.

- It is difficult to define who is a tourist. Is every visitor to Tillamook County a tourist, including those visiting on business?

Tourism generated $21.6 million dollars, or 6%, of total personal income in Tillamook County in 1993.

- If business travelers are also tourists, it is even more difficult to differentiate between dollars spent by business travelers and pleasure travelers.
- It is difficult to differentiate between dollars spent by tourists living outside the Watershed and dollars spent by resident recreators.

- No consistent data is available which tracks visitor days or tourist expenditures in Tillamook County.

The Oregon Employment Department obtains payroll and expenditure information from eating and drinking establishments, accommodations, and other retail businesses to gain an idea of tourists' contribution to local economies. Davis and Radtke (1994) used this data, along with projection models, to get a general idea of the personal income generated by tourism.

Economic Status

Regardless of definition, visitors to Tillamook County contribute to the local economy by purchasing goods and services. Tourism generated $21.6 million dollars, or 6%, of total personal income in Tillamook County in 1993 (Radtke 1995). Tourism related retail, sleeping, eating and drinking establishments collected most of the tourist dollars (Radtke 1995).

As many as 1,000 boats a day can be seen on the Bay and local rivers.

Obviously, many of the tourists who come to the Watershed focus on Tillamook Bay. Radtke (1995) estimated the income generated by "Bay-dependent" commercial and recreation pursuits **(Table 2-4)** Ocean recreational salmon and bottom fishing generated a combined $1.1 million while Bay and Estuary recreational salmon and steelhead fishing generated $3.3 million in personal income in 1994. Most of this money is generated in the fall during the chinook salmon run, when as many as 1,000 boats a day can be seen on the Bay and local rivers. Many of these boats belong to guides who charge up to $175 per person per day of fishing. About 60 guides belong to the Tillamook Guides Association and many others come from the Portland metropolitan area to lead trips (Juarez, T. Proceeds TBNEP Human Uses Forum 1996).

The Tillamook Bay Watershed ranked second to the Rogue River system in the amount of income generated by recreational fishing in coastal watersheds.

The Tillamook Bay Watershed ranked second to the Rogue River system in the amount of income generated by recreational fishing in coastal watersheds. For recreational boaters, Tillamook Bay is the most widely used bay in the State, and the sixth most-used water body statewide (Oregon State Marine Board 1994). Virtually all of the boating visitor-days are spent fishing.

Table 2-4. Marine dependent recreational use and estimated economic contribution, 1994

Recreational Use	Estimated Economic Contribution
Wildlife Viewing	$4,744,700
Bay recreational salmon/steelhead fishing	$3,263,534
Ocean recreational bottom fishing	$622,586
Clamming	$508,250
Ocean recreational salmon fishing	$441,375
Waterfowl hunting	$360,400
Crabbing	$198,380

Source: Radtke, H.D. 1995. Economic trends in the northern coastal regional economy. Report prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

Wildlife viewing, including birdwatching, generated about $4.7 million in income (Radtke 1995). Radtke derived this figure based on ODFW estimates of 279,100 visitor days in the area and $17 per visit day (Radtke 1995). The Tillamook Bay Watershed and Malheur National Wildlife Refuge are the two top birdwatching spots in the State (Roberts, C. Proceeds TBNEP Human Uses Forum 1996).

Recreation in the upper Watershed also contributes economically to the County. Hunting for deer and elk and other game brings a number of individuals into the County. Based on harvest surveys and a 1991 USFWS analysis, hunters spent over $2.2 million on deer and elk hunting in the Tillamook Bay Watershed in 1991. Big game hunting levels are expected to remain static and deer and elk populations are steady (Biederbeck, H. Proceeds TBNEP Human Uses Forum 1996).

Off road vehicle (ORV) use is a popular activity on Tillamook County forest lands and is growing rapidly (Angle *et al*. 1996). The Tillamook State Forest represents one-third of the acreage available for riding in the entire State. It is the only designated riding area within two hours of Portland (ODF 1996). Numerous ORV groups use the State Forest and an average of 25 organized events are held there each year, attracting nearly 3,000 people annually (ODF 1996). The BLM also has ORV trails on some of its forest land in the County, although not in the Tillamook Bay Watershed. Other forms of recreation in the upper Watershed are more difficult to quantify. Hiking and mountain biking organizations commonly use the State Forest, and many individuals come to hike or explore. Hiking, mountain biking, hunting, and ORV use are all expected to gain popularity in the Watershed (Angle *et al*. 1996).

Environmental Impacts Associated With Recreation/Tourism

Each of the Watershed's popular recreational activities has associated environmental impacts.

Each of the Watershed's popular recreational activities has associated environmental impacts. Sport fishing, like commercial fishing, is one of the many factors that has contributed to declining Tillamook basin salmonid populations. Besides harvest concerns, sport fishing is controversial for its dependence on hatcheries. The main purpose for fish hatcheries is to maintain a reliable number of fish for harvest by sport anglers. Hatcheries have been under scrutiny for years because hatchery-raised stocks mix with wild stocks. Interbreeding between wild and hatchery fish may weaken the genetics of wild fish, possibly weakening their instincts and making them less hardy. Hatchery trout and salmon may also eat wild fry and crowd wild fish out of prime spawning habitat (Klumph and Braun 1995b). If they do harm wild stocks, hatcheries and sport fishing, like commercial fishing, are only partly responsible for their declines.

Interbreeding between wild and hatchery fish may weaken the genetics of wild fish, possibly weakening their instincts and making them less hardy.

Other forms of recreation/tourism also affect the upland environment. Off road vehicle use in the State Forest and on beaches can cause erosion and noise pollution and destroy habitat. However, ORV groups are active in trail improvement projects and ORV user fees go toward trail maintenance. Non-motorized forms of upland recreation such as hiking and mountain biking have not been identified as substantially impacting the local environment. Hunting could reduce big game and waterfowl stocks, but hunter numbers are not viewed as a problem and game populations have shown no significant decreases (Biederbeck, H. Proceeds TBNEP Human Uses Forum 1996).

"Non-Earned" Income
(i.e., investments and transfer payments)

Non-earned income sources, primarily investments and transfer payments, represent a major and increasing source of economic growth in Tillamook County.

Non-earned income sources, primarily investments and transfer payments, represent a major and increasing source of economic growth in Tillamook County. Investment income includes money made from dividends, interest, and rents. Transfer payments include Social Security payments and other specific retirement programs, medical payments, and government assistance programs. Income derived from investments and transfer payments has historically been high for the Oregon Coast, primarily as a result of the high number of retiree residents (Davis and Radtke 1994). Older populations rely on Social Security and Medicare payments, investment income, and savings far more than the overall population (Davis and Radtke 1994).
The figures Davis and Radtke (1994) used to estimate investments and transfers represent only the direct payments. Little information is available on the spending patterns of county residents dependent on non-earned income. Without this information, the total contribution of

non-earned income sources to the local economy may not be fully realized. Most economic studies and valuations conducted on coastal economies focus on the traditional industries of timber, agriculture, and fishing. Multiplier effects associated with these industries account for where the money goes once it is earned, for example: food, gas, and necessity items. While the multiplier effect has been studied and computed for some economic sectors, information is lacking on individuals dependent on non-earned income sources.

Economic Status

Non-earned income sources generated approximately 48% of the total personal income in Tillamook County in 1993 (Davis and Radtke 1994). The amount of money garnered from transfer payments has increased every year since 1989. In fact, transfer payments alone represent more of the County's personal income than agriculture and commercial fishing combined and Tillamook County is substantially more dependent on non-earned income than the rest of Oregon or the nation **(Figure 2-11)**. With in-migration of retirees expected to continue increasing, dependence on non-earned income sources should also continue to rise.

Non-earned income sources generated approximately 48% of the total personal income in Tillamook County in 1993.

Environmental Impacts Associated With Non-Earned Income Sources

Potential environmental impacts associated with increases in non-earned income dependence are consequences of the Watershed's increasing population. Current residents may have fears about overcrowding and lowered quality of life. Large scale developments planned for retirees and second home owners can change the environment and character of the area, and could increase runoff and potential pollution from on-site sewage treatment or overloaded municipal systems. This type of growth and development should be carefully planned.

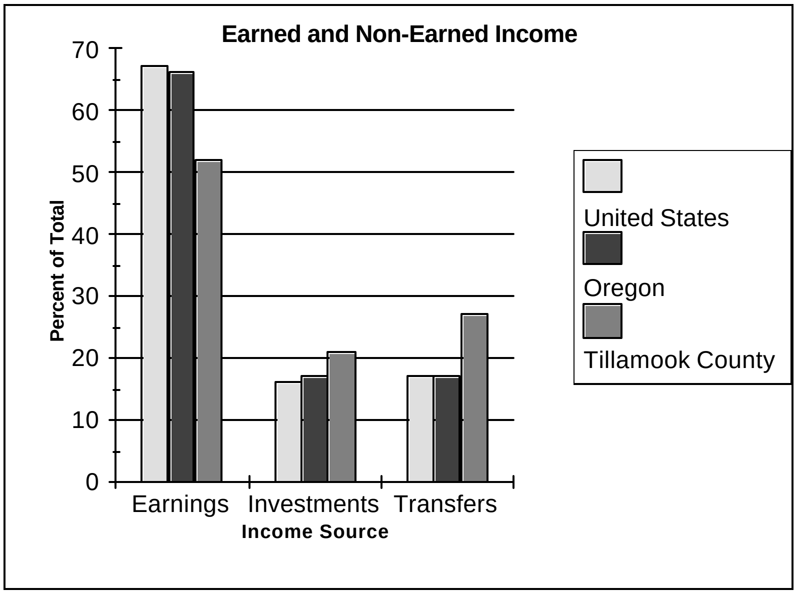

Figure 2-11. Comparison of dependence on earned and non-earned income, 1993.
Source: U.S. Department of Commerce Bureau of Economic Analysis. 1994. General statistics. U.S. Department of Commerce, Wash. D.C.
Adapted from Radtke, H.D. 1995. Economic trends in the northern coastal regional economy. Report prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

Port Activities and Gravel Mining

Port activities such as dredging, shipping, and gravel mining are human uses of the Watershed worth mention more for their potential environmental impacts than their economic contribution. Most economic data on Tillamook County is collected for the larger money industries, so no data is available describing the income generated by dredging or gravel mining. Revenue earned from shipping and exporting is attributed to the natural resource industries. For example, the export of timber products is counted as part of the timber industry rather than the shipping industry. Because of this, “port activities” does not register as a primary source of income in the County, although marine shipping and exporting was an important economic sector in the past. Although several commercial gravel removal businesses operate in the County, gravel mining generates no more than 1% of residents’ total personal income.

In the 1970s, however, the Army Corps of Engineers determined that dredging of the upper Bay channels was not economically feasible due to rapid sediment deposition.

Dredging for navigational purposes was a common port activity in the early 1900s. In the 1970s, however, the Army Corps of Engineers (COE) determined that dredging of the upper Bay channels was not economically feasible due to rapid sediment deposition (COE 1972). Currently, dredging activity in Tillamook Bay is limited to maintenance dredging in several locations (Bacon, D. pers. com. 1996). The Port of Garibaldi holds permits for maintenance dredging in Bay City and Garibaldi boat basins, and the Old Mill Marina in Garibaldi holds a permit for dredging its boat basin (Bacon, D. pers. com. 1996). Because dredging may have a substantial impact on the local economy (and the environment), the costs and benefits of various dredging options should be analyzed and well-publicized before any new dredging. The environmental impacts of dredging are discussed in Chapter 5: Sedimentation.

In-stream gravel mining deserves mention because of a recent decision to phase out commercial in-stream gravel removal in the County. While this may not have a substantial impact on the economy, it certainly has environmental ramifications. Under a 1992 agreement by several Tillamook County departments, ODFW, the Division of State Lands (DSL), the COE, and various aggregate producers, commercial in-stream gravel removal was phased out by Oct. 1, 1997. The agreement was directed at protecting in-stream chum salmon habitat and preventing soil erosion. Mining more gravel than the system replenishes can degrade the streambed, increase water velocities and subsequent bank scouring, and lead to bank erosion (Reiter, M. as cited in Miller and Garono 1995). Conversely, curtailing commercial in-stream gravel removal may lead to increased gravel build-up, especially at the mouths of local rivers. In-stream gravel mining is discussed in greater detail in Chapter 5, Sedimentation.

Summary of Key Economic Trends

- The timber products industry is projected to increase in importance in the next 20–25 years as stands replanted after the Tillamook Burn fires grow to a harvestable age.

- The income generated by the commercial fishing industry to Tillamook County has declined 67% since 1989, largely as a result of the collapse of salmon populations, and will probably continue to decline as a result of reductions in bottom fish harvest limits.

- The tourism/recreation industry is expected to grow, although some recreational fisheries may be restricted.

- Agriculture, primarily dairy farming, is expected to continue to be a steady source of income to Tillamook County residents.

- In-migration of retirees will continue to shift the County’s economic base toward further dependence on non-earned income sources. Growth in the number of elderly persons will also result in greater need for service industry businesses.

- The non-manufacturing sector will create most of Tillamook County’s new jobs. However, these jobs tend to be lower paying than jobs in natural resource industries and also tend to be seasonal or part-time.

Managing Human Uses

Each of the Tillamook Bay Watershed’s major human uses has been discussed in terms of its historical development, current economic contribution to personal income, and projected trends. The human uses are all connected by the productive capacity of the Watershed. Management measures are necessary to ensure the long-term viability of both the industries and the resources they depend upon.

Management of land use in Tillamook County has evolved dramatically since agricultural production and timber harvest first began in the 1800s. Restrictions of various human uses have become more numerous as environmental impacts and industry competition have grown. Perspectives differ on the equity and usefulness of many of these regulations in managing human uses. This section highlights these perspectives on land use management and discusses methods of evaluating management measures.

The Government Agency Perspective

Restrictions and regulations of human uses have long been a necessary part of economic growth and development. Rather than working as a preventive technique, regulations have historically been enforced as a response to environmental or ecological problems. For example, forest practices were restricted very little until the Tillamook Burn fires created extreme erosion problems. Likewise, commercial fishing in the Bay and local rivers was not restricted until it became apparent that salmon stocks had been drastically reduced. Many natural resource-based businesses have maximized short-term profits at the expense of the long-term viability of the resource.

Management measures (*i.e.*, regulations and restrictions) are typically implemented to protect the long-term viability of an industry by protecting the productive capacity of the system upon which the industry relies. Additionally, management measures are adopted to safeguard the environment and ensure that one industry does not compromise others by depleting the resource base. The concepts of sustainability and watershed management, usually used in an ecological context, can be viewed in economic terms just as easily. Collectively, watershed management measures attempt to keep all human uses of the Watershed economically viable. Each of the Watershed’s economic sectors is dependent on the same productive system, and all must be viewed as connected and managed accordingly. While management

Management measures are implemented to protect the long-term viability of an industry by protecting the productive capacity of the system upon which the industry relies...

measures may restrict a certain use, other valuable uses are typically protected.

The concepts of sustainability and watershed management, usually used in an ecological context, can be viewed in economic terms just as easily.

Most ecological and economic problems, including the TBNEP's priority problems, involve a variety of factors and many actions are required before changes are evident. For example, the RCWP and subsequent best management practices on farms have reduced bacterial contamination of the Watershed. However, these programs alone cannot "solve" bacterial contamination problems. Additional manure management measures on farms, sewage treatment plant improvements and monitoring, and septic tank maintenance are all needed to manage the bacterial contamination problem. To use another example, the Forest Practices Act and subsequent logging regulations have emphasized protecting habitat and riparian areas. While this regulation undoubtedly has a positive affect on fish habitat, many other programs and regulations for riparian protection and habitat development must also be considered. The entire bundle of existing management measures must be relied upon to influence human uses.

Most ecological and economic problems, including the TBNEP's priority problems, involve a variety of factors and many actions are required before changes are evident.

The Private Property Perspective

Many landowners in Tillamook County view regulations and management differently, believing that landowners have always managed their lands for both economic benefit and to sustain the environment on which they depend. Many landowners refer to a long history in Tillamook County of natural resource production on private lands that has both earned a profit and maintained the environment. As was mentioned previously, many factors have combined to lead to the TBNEP's priority problems. It may be difficult for individual landowners to view the use of their land as a cause of these environmental problems. Regulations which restrict certain landowners from pursuing their trade are often viewed as unfair and discriminatory.

Partly as a response to public vs. private property concerns, new policies are attempting to promote collective management among landowners rather than specific restrictions. One important example of this is The Oregon Plan, which grew from the 1997 Governor's Coastal Salmon Restoration Initiative. The Oregon Plan works to restore Oregon stocks of coho salmon. Acting in lieu of a federal listing of the coho salmon as an endangered species, the plan avoids large scale land use restrictions. A federal listing of the coho would substantially affect all natural resource dependent industries in the Tillamook Bay area. Landowners have a chance to prove that collectively managing their own land is as effective as government restriction and regulation. In Tillamook County, much of the land along waterways is privately owned by agricultural producers, residential landowners, small woodlot owners, and others. Ideally, The Oregon Plan will foster an understanding among all landowners that active management of all land uses is important for both environmental and economic benefit.

Evaluating Management Measures

The TBNEP's Base Programs Analysis (Kruckeberg, J. 1996) provides an initial inventory and evaluation of the existing regulations for managing the Watershed's three priority problems. Additional work is needed, however, to calculate the effects of various management measures and monitor these effects over time.

One method used to judge the economic value of a management measure is to conclude that net benefits are greater with the management measure than without. For example, the Forest Practices Act restricts timber harvest on steep slopes and in riparian areas. These restrictions limit timber harvest but also minimize erosion and safeguard fish and wildlife habitat, which could benefit the commercial and recreational fishing industries and the agricultural industry. Thus the Forest Practices Act could be viewed as a policy which restricts one industry, but provides net social benefit. Net social benefit is a subjective concept that all segments of society rarely agree upon. Perspectives on benefits and costs vary widely among landowners, agencies, and decision makers, especially when a measure strongly impacts a single use or stakeholder group.

Net social benefit is a subjective concept that all segments of society rarely agree upon. Perspectives on benefits and costs vary widely among landowners, agencies, and decision makers, especially when a measure strongly impacts a single use or stakeholder group.

All management measures and regulations create tradeoffs and raise questions about equity within industries: Does the regulation unfairly hinder one industry while allowing another to flourish? Does the regulation accurately estimate the contribution of the natural environment and natural processes? To address these questions, new management measures should be subject to cost/benefit analyses or economic valuation. Solid scientific research is a critical component of evaluating economic impacts. For example, bacterial contamination from local farms has long been targeted as the reason for the closing of the shellfish beds. It is unrealistic, however, to view this problem as simply a dairy farmer vs. shellfish harvester debate. In terms of the income generated by these industries, there is no comparison: In 1994, agricultural commodities generated $65 million in personal income while shellfish harvesting generated approximately $160,000 in personal income (Radtke 1995). Stricter regulations to control dairy industry wastes are for the protection of the entire Watershed, however, not just the shellfish industry. Water quality concerns are worth far more than $160,000 a year, but no study has yet estimated the economic costs and benefits of manure management measures. Policy analysis and economic valuation studies (described in more detail below in Research Recommendations) can attempt to answer such questions.

Another method of measuring the effects of management measures is to set benchmarks or indicators to evaluate progress. Many current regulatory programs have elements of internal review or periodic evaluations. Unfortunately, due to financial or temporal constraints, these reviews do not occur as often as they should. The Oregon Progress Board has for many years published statewide indicators for success. Many smaller jurisdictions and interest groups also track their progress toward broad goals, and more specific objectives, using benchmarks. Regulatory programs should be reviewed in the same manner. As management measures are adopted and enforced, benchmarks should be set to evaluate what the measure is attempting to achieve. The public may be more willing to support regulations with proven, positive results.

As management measures are adopted and enforced, benchmarks should be set to evaluate what the measure is attempting to achieve.

Research Recommendations

Based on the review of the social and economic information available on economic sectors in the Tillamook Bay Watershed, several research needs have been identified. Most of the economic data for Tillamook County is incomplete or included with statewide or region-wide statistics. Solid economic analysis requires updated and reliable information. The following recommended studies and research efforts collectively address existing data gaps and, if conducted, would provide helpful information for economic decision-making. TBNEP or other local agencies are already considering some of these recommendations. We recognize that several of these recommended studies should be statewide, or even national.

- **Gather and update locally relevant economic, social, and demographic data**

Economic analyses done on Tillamook County must rely on statewide data collection agencies and periodic data gathering events (*i.e.* Census). There is no local source for consistent and reliable economic data on Tillamook County. Collecting locally-relevant data is crucial for successful economic development planning on any scale (Davis and Radtke 1994). A local group (or contractor) could conduct surveys and provide economic information to track patterns and trends in the local economy. This includes the establishment of benchmarks and indicators of progress. Updated information is necessary on virtually all economic sectors in the County before serious valuation studies can be conducted.

- **Conduct an economic valuation study**

The TBNEP is sponsoring a consulting firm to conduct an economic valuation of proposed CCMP actions. This study will use a model to evaluate all of the inputs associated with an economic/environmental issue or problem. Such a study will be extremely useful because it can provide a means to assess certain industries' value relative to natural resources. While many current models can assess the monetary contribution of various industries, monetary value is not typically placed on the natural resources that support the industries. For example, the sport fishing industry may generate $4–5 million annually in personal income but clean water is not viewed as having an economic value. The additional value (quality of life benefits and aesthetics) of natural capital such as clean air, clean water, and open space is not included in most economic valuations. Although some studies have assigned dollar values to natural resources, these assigned values are still not commonly accepted as valid in economic analysis.

Estimating the monetary value of estuary resources would provide a means of deciding whether investments in the protection, conservation, mitigation, restoration, or enhancement of these resources will improve the welfare of society. For example, in a 1995 TBNEP survey, respondents ranked clean water, clear air, and a variety of fish and wildlife as the three most important characteristics of the Watershed (TBNEP Public Attitude Questionnaire 1995). An economic valuation model should be able to place a value on these characteristics and include them in the valuation process.

Many different valuation studies could be conducted. The most effective way to use a valuation study would be to frame an economic question and identify as many of the inputs as possible for inclusion in the model. For example, the relationship between bacterial contamination and the closing of the shellfish beds could be evaluated. A question could be: What would be the cost of keeping the Bay open to shellfish harvest for xx days annually? Many inputs would be needed, such as the average number of days the Bay is closed each year, rainfall estimates, sewer treatment plant outfall levels, total potential for income per day open, potential income lost because of closures, cost of implementing best management practices, cost of fencing streams, cost of manure management, and more. Costs for all potential sources on all land uses would need to be estimated and included in the model. Economic valuation models are only as useful as the data that go into them. Thus a great deal of reliable data would be required. This methodology could be applied to other economic/environmental issues in the Watershed.

- **Study job growth in the service sector and the real benefits of this growth**

More than 90% of all new jobs in Tillamook County are projected to be in non-manufacturing sectors (Oregon Employment Department 1996). Most of these positions will be in the service sector, including government jobs. While increasing jobs in the service sector have helped lower the unemployment rate, these positions have not improved county residents' per capita income. The local economic effects of growth in the service sector should be researched.

- **Study local business development/investment opportunities**

To create family wage jobs in the Tillamook Bay Watershed, the community should promote local business development opportunities and investment strategies which may capitalize on — but not consume — natural resources. The Economic Development Council of Tillamook County, or business development center could hire a consultant to research and review the feasibility of non-service sector business opportunities. One such opportunity is the Methane Energy Agricultural Development (MEAD) project, which would bring a number of family wage jobs into the County.

- **Study the multiplier effect of non-earned income sources**

The multiplier effect is used to assess the value of various industries to the overall economy. While the multiplier effect has been computed for most industries in the County, revenue from non-earned income sources is harder to track. More information is needed on where the revenue comes from and how it is used. With nearly 50% of the County’s total personal income derived from these investments and transfer payments, we should have a better understanding of how this money moves through the economy. Although a comprehensive study of this nature is needed statewide, or even nationally, the findings would be particularly useful for Tillamook County. With the County so dependent on non-earned income, it would be useful to track how it is distributed.

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CHAPTER 3

BIOLOGICAL RESOURCES:
OUR HERITAGE AND FUTURE

In the Northwest, a river without salmon is a body without a soul. From the Sacramento to the Yukon, every waterway pulled by gravity to the Pacific has, at one time, been full of the silver flash of life. During certain times of the year, you could walk under any rain-country waterfall and get hit over the head by a leaping forty-pound fish. Lakes ran red with sockeye, streams were crowded with coho ... It was a bounty that tested the limits of greed....

—Timothy Egan. 1990.
from *The Good Rain, Across Time and Terrain in the Pacific Northwest.*
Vintage Books, New York, NY.

Salmon have returned through thousands of life cycles. At times landslides, drought, and fire have blocked their passage. At other times nets, dams, pollution, and lack of water prevented salmon from reaching the spawning grounds. Our quest to learn enough to control salmon through their life cycle continues. Perhaps, now and then, reflection is as important as active research and restoration.

—Courtland Smith. 1996.
From "What have Northwest residents learned?" in *The Northwest Salmon Crisis, A Documentary History.*
edited by Joseph Cone and Sandy Ridlington.
Oregon Sea Grant.

Fish aren't the most important thing watersheds produce. Water is. And if we produce lots of good, cold, clean, clear water, we will have salmon.

—Jim Martin, Governor's Natural Resources Office
Speaking at the Governor's Watershed Enhancement Board 1996 Conference, Seaside, Oregon.

CHAPTER 3

BIOLOGICAL RESOURCES:

OUR HERITAGE AND FUTURE

Introduction

Tillamook Bay supports a variety of biological resources, valued for their economic, recreational, aesthetic, and ecological importance. To ensure that these resources are maintained for future generations, management decisions for the Estuary and Watershed must be based on sound scientific information. This chapter provides an overview of what is known about the status and trends of several of the most valued biological resources of the Bay. Problems and data gaps are identified for each of the valued resources. Some possible solutions to the resource problems also are discussed and recommendations for additional research and/or management actions are presented as initial input for the Tillamook Bay Comprehensive Conservation and Management Plan.

To ensure that biological resources are maintained for future generations, management decisions for the Estuary and Watershed must be based on sound scientific information.

The anadromous salmonids are emphasized because they have been selected as a focal point for the TBNEP. However, the status, trends, and problems of non-anadromous fish resources of the Bay — as well as bay clams, Dungeness crab, and oysters — are also reviewed. The status of ecologically valuable resources such as salt marsh habitat, eelgrass beds, phytoplankton, zooplankton, and epibenthic and benthic invertebrate communities are discussed relative to the habitat requirements for anadromous salmonids and other valued resources. Invasive species, such as spartina and the green crab, are not discussed in this document, but will be handled in fact sheets being developed jointly by the South Slough National Estuarine Research Reserve and TBNEP.

Anadromous:
Assending rivers from the sea at certain seasons for breeding.

Benthic:
Occurring on the bottom underlying a body of water.

Epibenthic:
Flora and fauna occurring from the low water mark to the benthos.

Status and Trends

Our goal in this section is to objectively analyze the available data regarding the status and trends of several of the most valued biological resources of the Tillamook Bay Estuary and Watershed. For each resource, we first discuss the status and trends of the populations and then what is known about the status and trends of their habitat. Data that have been developed according to scientifically sound sampling methods and that allow the assignment of statistical confidence limits are the most useful for evaluating status and trends. Unfortunately, as will be discussed below, much of the available information is based on data that do not meet these basic criteria.

Anadromous Salmonids

Pacific salmon are recognized as an icon of the way of life in the Pacific Northwest and are one of the region's most valued natural resources.

Pacific salmon are recognized as an icon of the way of life in the Pacific Northwest and are one of the region's most valued natural resources. Tillamook Bay and its five major tributaries historically supported large runs of salmon and steelhead trout (Coulton *et al*. 1996). During the past several decades, the number of adult salmonids returning to Tillamook Bay tributaries has declined. Similar declines have been noted in other watersheds along the Washington, Oregon, and northern California coastline.

Surveys conducted by the TBNEP indicate that citizens within Tillamook County are concerned that degraded habitat conditions may have contributed significantly to the decline of anadromous salmonid populations. Several state and federal resource agencies, including the Oregon Department of Fish and Wildlife (ODFW), share these concerns. The TBNEP selected anadromous salmonid resources as one focal point for the program because they are so important to the economy and quality of life in Tillamook County.

Salmonid life stages:
Roe, or eggs, are laid and fertilized in gravel nests called *redds*. *Fry* emerge after the eggs incubate and the egg sac is absorbed. After the fry feed and grow in freshwater, they migrate to the estuary, where they adapt as *smolts* to the brackish water, preparing for entry into the ocean. The juvenile salmonids then go to sea, where they feed and grow to maturity. Return age varies, with the fish that return to spawn earlier referred to as *jacks*.

Population Status and Trends

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

The most useful kinds of information for assessing the present status and trends of anadromous salmonid populations include the following:

- numbers of adults returning to spawn (escapement);
- numbers of fish harvested;
- distribution and abundance of juvenile fish within the freshwater and estuarine environments;
- smolt production (chinook, coho, steelhead, cutthroat trout); and
- the influence of hatchery fish on the naturally spawning populations.

We found that data relating to numbers of adult spawners, numbers of fish harvested, and some rough estimates of the contribution of hatchery fish to the spawning runs are available for some, but not all of the runs. Information regarding the distribution and relative abundance of juvenile salmonids in tributary streams is only beginning to be developed and is not yet adequate to provide a comprehensive overview of status of juvenile salmonids in the Watershed. Information on the estuarine distribution and abundance of juvenile salmonids is dated and incomplete. No information is available on smolt production.

Of the five species present in the Watershed, only fall chinook salmon appear to be healthy and relatively abundant.

Table 3-1 summarizes our findings relative to the general health and trends in abundance of the Tillamook Bay anadromous salmonid species and races. Health was considered poor if the naturally spawning population appeared to be heavily supported by hatchery fish and/or if the population is severely depressed compared with historic conditions. Of the five species present in the Watershed, only fall chinook salmon appear to be healthy and relatively abundant. The rationale for the conclusions shown in Table 3-1 is described in the following species-by-species summary of available information relating to status and trends for the Tillamook Bay salmonids. More detailed information on anadromous salmonid spawning, incubation and rearing needs is collected in **Appendices 3-A and 3-B**.

Chinook salmon. Both fall and spring races of chinook salmon are present in the Tillamook Bay Watershed. Mature fall chinook (2 to 6 years of age) return to all five of the major subbasins from early September through mid-February. Peak entry into the rivers occurs in mid-October. Tillamook Bay fall chinook spawn from October to January.

Spring chinook salmon occur primarily in the Trask and Wilson Rivers, with a small population in the Kilchis River. Spring chinook enter Bay tributaries from April through June. River entrance probably peaks in May (Nicholas and Hankin 1988). Spawning begins as early as the first week in September and peaks during the last week of September or first week of October.

Chinook salmon were fished commercially by gillnetting in Tillamook Bay from about 1893 until 1961, when the fishery was permanently closed.

Chinook salmon were fished commercially by gillnetting in Tillamook Bay from about 1893 until 1961, when the fishery was permanently closed. As many as 28,000 chinook salmon (both races) were packed annually on Tillamook Bay from 1893 through 1919. The pack of chinook salmon was very erratic during this period and was frequently less than 5,000 fish or not reported. From 1923 through 1946, commercial landings remained relatively stable ranging from 12,000 to 31,000 fish and averaged about 17,000 fish (Nicholas and Hankin 1988). The commercial catch declined from 1947 through 1961. The decline may have been related, at least in part, to increased regulatory restrictions on the fishery.

Table 3-1. Status and recent population trends of Tillamook Bay anadromous salmonids

Species/race	Status	Recent population trends
Chinook salmon		
fall	**healthy**	**stable or increasing**
spring	**heavily supported by hatchery fish, depressed compared with historic abundance**	**possibly declining**
Coho salmon	**heavily influenced by hatchery fish, severely depressed compared with historic abundance**	**declining**
Chum salmon	**depressed compared with historic abundance**	**declining**
Steelhead trout		
winter	**heavily influenced by hatchery fish, numbers appear low**	**declining**
summer	**introduced, supported entirely by hatchery fish**	**declining**
Sea-run cutthroat trout	**depressed**	**possibly declining**

Source: Based on data in Nicholas, J., and D. Hankin. 1988. Chinook salmon populations in Oregon coastal river basins: Description of the life histories and assessment of recent trends in run strengths. Oregon Department of Fish and Wildlife informational report no. 88–1. 359 pp

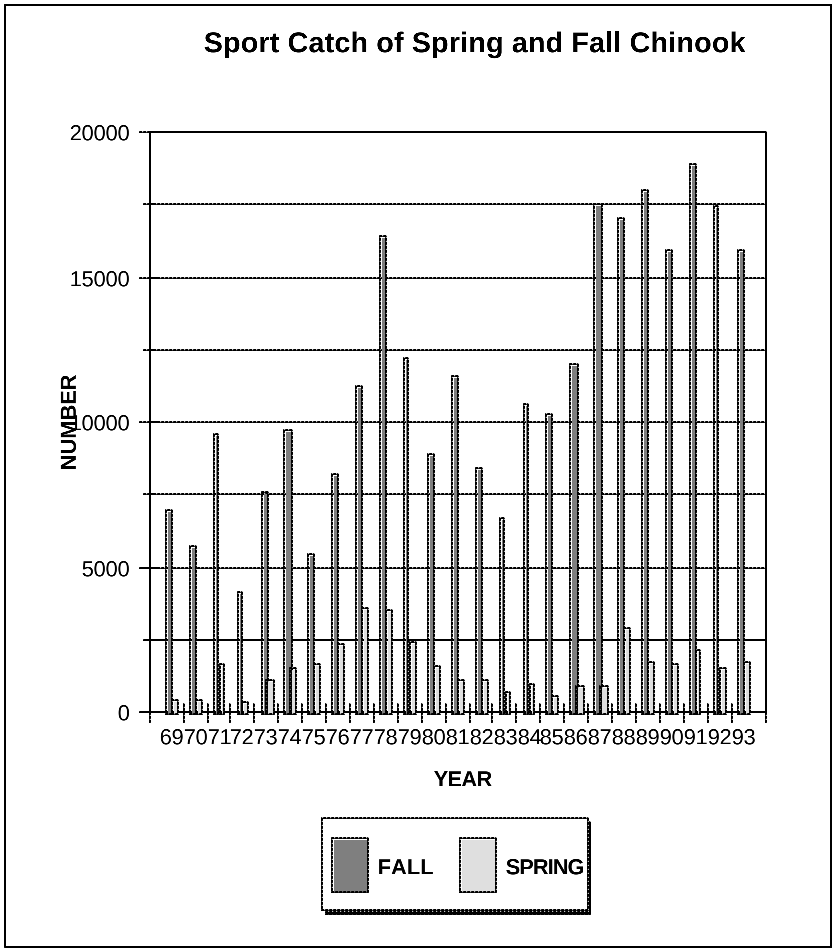

Figure 3-1. Tillamook Bay Basin sport catch of fall and spring chinook salmon.
Source: Pacific States Marine Fisheries Commission, StreamNet Report, 1997.

The recreational catch of fall and spring chinook salmon has been estimated since 1969 from annual returns of salmon/steelhead punch cards (Nicholas and Hankin 1988, Nickelson *et al.* 1992, ODFW 1995, Kostow 1996). These catch estimates indicate a generally increasing trend from 1969 through 1993 (period of available data) for fall chinook salmon **(Figure 3-1)**. The recreational catch of fall chinook averaged about 15,900 fish between 1985 and 1993. When compared with the average annual commercial catch of about 17,000 for the period 1923–1946, the present level of harvest appears remarkably strong and stable. Although hatchery fish contribute to the fall runs, it is believed that most fall chinook are produced from naturally spawning fish (Nicholas and Hankin 1988).

The recreational catch of spring chinook salmon has been relatively small compared to the fall chinook catch; however, the catch has remained relatively stable since about 1987.

The recreational catch of spring chinook salmon has been relatively small compared to the fall chinook catch; however, the catch has remained relatively stable since about 1987 (Figure 3-1). The ODFW regards spring chinook salmon abundance as depressed when compared with commercial landings during May through July during the 1930s (Nicholas and Hankin 1988). Spring chinook runs are supplemented by hatchery fish produced at the Trask River and Whiskey Creek hatcheries.

The only **long-term** direct counts of the number of adult chinook salmon reaching the spawning grounds (fish that have "escaped" the fishery) are "peak" count data collected on the spawning grounds. Peak counts are made during the spawning season by individuals who walk along the shore and count the number of spawners a number of times during the spawning season. The ODFW began peak counts of fall chinook on the Kilchis, Wilson, and Tillamook Rivers about 1950 and with a few exceptions has conducted them annually since.

It should be noted that the peak count method of estimating spawning escapement has some serious limitations. Bodkin *et al.* (1995) reviewed the underlying assumptions in the peak count method, concluding that peak counts, as conducted by ODFW, are biased both in time and space and are often modified by a correction factor. One of the biggest problems with the peak count method was the selection of stream segments for monitoring. Instead of selecting stream segments randomly, the counts were routinely collected on those stream segments known to be more heavily utilized for spawning. Therefore, use of the peak count data for estimation of total numbers of spawners would result in an overestimation of the total numbers. The ODFW recognized the weakness in the peak count method, and since 1990 has randomized its sampling approach to spawning surveys. They have continued to collect peak count data at the standard survey reaches to allow comparison of the two methods.

The combined results for the three rivers for the period 1950–1996 are presented as adult fish per mile of stream surveyed in **Figure 3-2**. Although highly variable from year to year, no obvious upward or downward trend is apparent in the data.

Coho salmon populations along the entire Oregon coast are now considered depressed and are being considered by the National Marine Fisheries Service (NMFS) for threatened status ... Tillamook Bay coho abundance and adult spawning escapement have shown significant rates of decline.

Coho salmon. Coho salmon populations along the entire Oregon coast are now considered depressed and are being considered by the National Marine Fisheries Service (NMFS) for threatened status under the Endangered Species Act (ESA) (58 FR 57770; 27 October 1993). According to Hasselman (1995), Tillamook Bay coho abundance and adult spawning escapement have shown significant rates of decline not generally observed for other Oregon coastal river basins in the central and north coast.

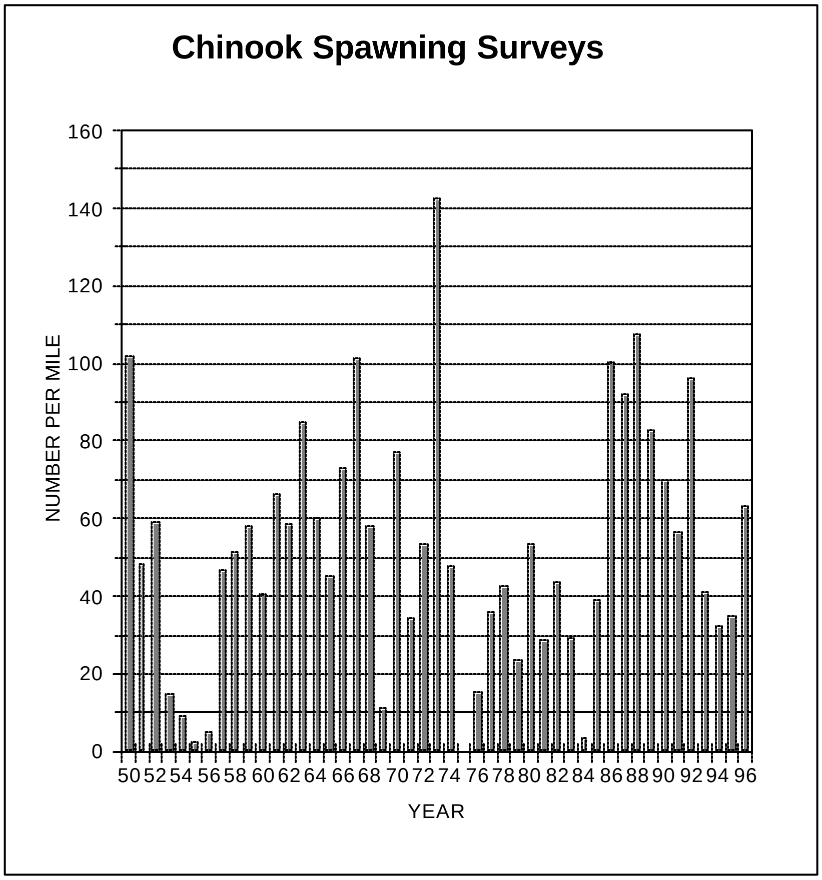

Figure 3-2. Tillamook Bay Basin peak count estimates for chinook salmon.
Source: Oregon Department of Fish and Wildlife spawning survey count data, 1997.

Historically, the Tillamook Bay Watershed was an important producer of coho salmon. Coho were harvested intensively in the Bay with gill nets from the late 1800s through 1961 when the gill net fishery was permanently closed. The annual gill net catch during the 1930s ranged from 24,590 to 73,974 and averaged about 46,000 fish. After 1940, the gill net fishery declined while the ocean fishery increased. The decline in the gill net fishery may have been related, in part, to increased regulatory restrictions on the fishery. During the late 1980s, most of the harvest occurred in the ocean fisheries off Oregon and California. The total combined harvest of naturally produced Tillamook Bay coho in the ocean (commercial and sport fisheries), Estuary (sport fishery), and fresh water (sport fishery) during the late 1980s was estimated to average 3,500 coho annually (Bodenmiller 1995).

The recreational catch of coho in Tillamook Bay and its tributaries has been estimated since 1975, based on angler salmon/steelhead reporting tag returns. Harvest rates averaged 1,785 fish annually and

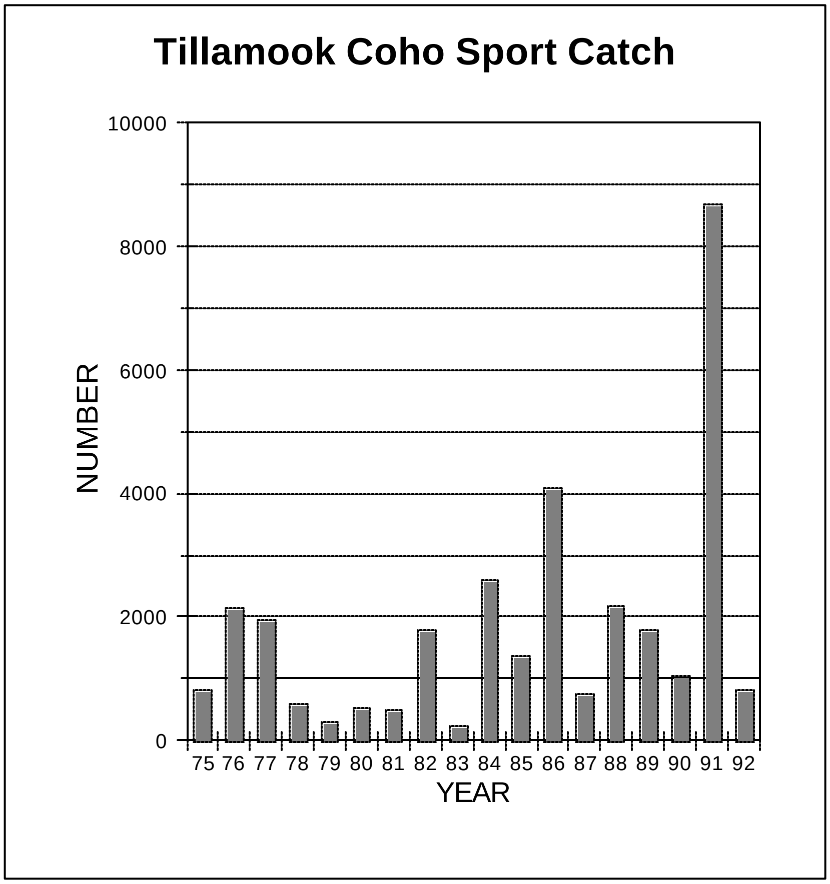

Figure 3-3. Tillamook Bay Basin sport catch of coho salmon.
Source: Oregon Department of Fish and Wildlife spawning survey count data, 1997.

have shown wide interannual variation **(Figure 3-3)**. Note that the high catch in 1991 was an anomaly, in that relatively large numbers of non-Tillamook Bay coho were caught just inside the mouth of the Bay during the latter part of the summer. These fish may have temporarily entered the Bay due to localized abundance of prey species near the mouth of the Bay (Klumph, R. pers. com. February 1997).

Data suggest that either the quality of freshwater habitat has declined badly since about 1976 or that other factors (e.g., poor ocean survival, over harvesting, influence of hatchery fish, or high estuarine mortality) are limiting the number of returning adults.

Numbers of adult coho (mostly age 3) escaping to the spawning grounds have been indexed using the peak count method described above for chinook salmon. Surveys have been conducted by ODFW since 1950 on Cedar Creek, a tributary to the Wilson River; and with the exception of five years (1974–1979), on the Devils Lake Fork of the Wilson River. Additional survey reaches were added in 1981 on Sam Downs Creek in the Kilchis River basin and on Simmons Creek in the Tillamook River basin. Peak counts (expressed as number per mile of stream surveyed) were relatively low in the mid-1950s, relatively high from about 1960 through the mid-1970s and since about 1975 have remained low and variable

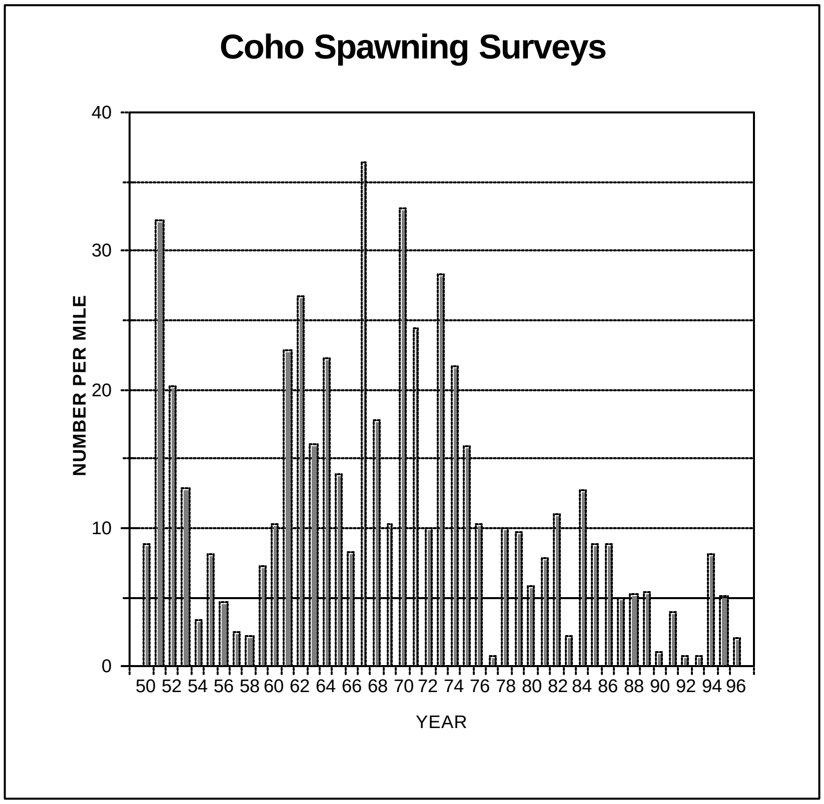

Figure 3-4. Tillamook Basin peak count estimates for coho salmon. ***Source:*** Oregon Department of Fish and Wildlife spawning survey count data, 1997.

(Figure 3-4). All-time lows were reached in the late 1980s and early 1990s. These data suggest that either the quality of freshwater habitat has declined badly since about 1976 or that other factors (*e.g.*, poor ocean survival, over harvesting, influence of hatchery fish, or high estuarine mortality) are limiting the number of returning adults. As will be discussed later, some areas of the Watershed (*e.g.*, the Tillamook River basin) have probably experienced continued freshwater habitat degradation, but the majority of the Watershed has been relatively undisturbed by human activities during the past 20 years.

Hatchery coho have been stocked in the Tillamook system, practically without interruption, since 1902. Returns of hatchery fish to the Trask River hatchery for the period 1985–1992 ranged from 1,245 to 10,174 with an average of 5,231 fish.

The influence of hatchery fish on the naturally spawning populations is not known.

The influence of hatchery fish on the naturally spawning populations is not known. However, it appears that the runs of natural spawners are earlier now than they were in the past, suggesting that hatchery fish have had an influence. Based on observations made during peak count spawning surveys, most

Tillamook basin coho spawned during December in the decades of the 1950s and 1960s. But by the late 1980s peak spawning had apparently shifted to November. Until recently, it was the practice of hatcheries to take eggs from the first returning spawners. This practice selected for early spawners and over time has resulted in a shift toward earlier spawning runs of most coastal coho hatchery stocks, including the Trask River hatchery.

During the 1960s and 1970s, hatchery fish were released only into the Trask River and little change in spawn timing was noted. In the early 1980s, hatchery fish were released throughout the Tillamook basin (Miami, Kilchis, Wilson, and Tillamook). Chilcote and Lewis (1995) suggested that this event was responsible for the shift in spawn timing among the natural spawners. However, they recommended additional studies before making a definitive statement regarding cause and effect. If hatchery stocks have largely displaced the wild, naturally spawning coho in the basin, the population could be in a very precarious situation. A shift to early spawning could increase mortality by subjecting more of the incubating embryos in the gravel to bedload movements caused by early winter storms. Reducing variability in their life stage schedule may also increase competition for food and habitat.

Tillamook Bay historically supported the Oregon Coast's largest chum salmon fishery.

Chum salmon. Tillamook Bay historically supported the Oregon Coast's largest chum salmon fishery. During the 1930s and 1940s, catches of over 50,000 fish were not uncommon. Oregon is near the southern edge of chum salmon distribution which may, in part, account for the large interannual variability in run sizes that have been observed in Tillamook Bay streams over the years. The gill net fishery in Tillamook Bay held up longer than any of the other Oregon chum fisheries but was permanently closed in 1961.

In 1988, due to apparent declines in returning adults, the ODFW restricted chum salmon to catch and release on the Miami and Kilchis Rivers and closed all other streams to chum salmon fishing.

Since chum salmon are not taken in the ocean troll fishery, the only recent catch data available for evaluating population trends are the estimates of recreational catch. The recreational catch of chum salmon has been estimated since 1969 based on salmon/steelhead reporting tag returns. Unfortunately, these data were not useful for estimating trends in the population because both fishing effort and regulations changed substantially over the period of record. Fishing for chum salmon with fly fishing equipment became popular in the 1980s on the lower Miami and Kilchis Rivers and fishing pressure increased greatly. In 1988, due to apparent declines in returning adults, the ODFW restricted chum salmon to catch and release on the Miami and Kilchis Rivers and closed all other streams to chum salmon fishing.

The ODFW has collected peak counts of spawning chum salmon since 1948 in the Kilchis, Miami, and Wilson sub basins **(Figure 3-5)**. Peak counts (number per mile) were relatively high through about 1954. Since 1954, the peak counts appear to have declined somewhat and have shown high interannual variability. Due to the

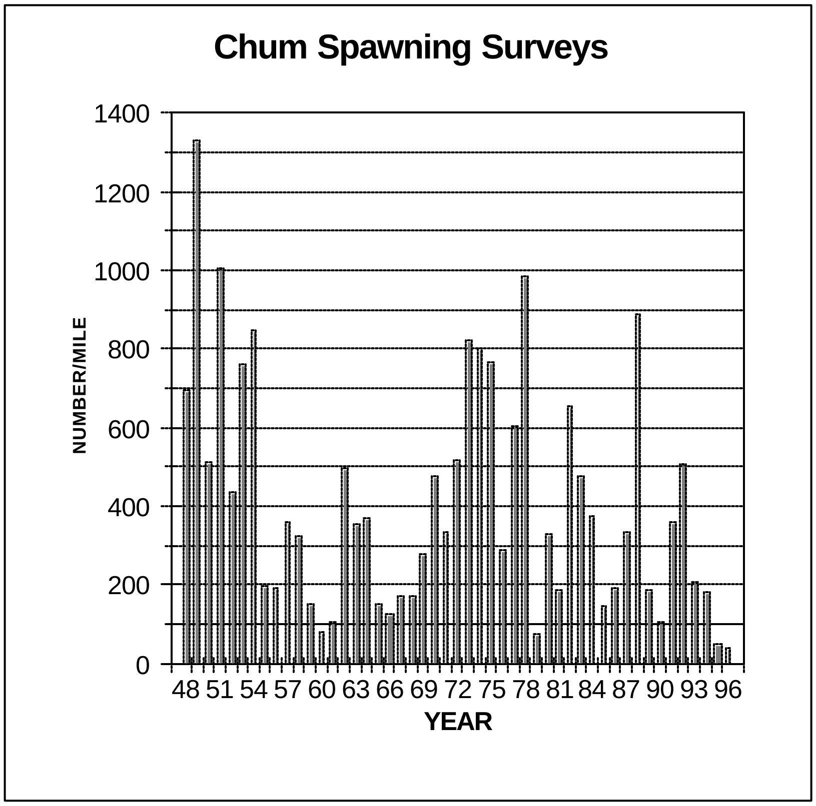

Figure 3-5. Tillamook Bay Basin peak count estimates for chum salmon.
Source: Oregon Department of Fish and Wildlife spawning survey count data, 1997.

very low counts on the spawning grounds since about 1992, concern has been growing that the chum population is experiencing serious problems. The ODFW is watching the situation closely and if numbers do not increase in the near future may find it necessary to recommend closure of the catch and release fishery on the Miami and Kilchis Rivers (Klumph, R. pers. com. 1997).

Chum salmon populations in the Tillamook Watershed have not been supplemented by hatchery fish. However, early egg taking operations for other purposes required payback to Coal Creek and other donor sites. Chum adults return to spawn at ages 2 to 7 with most returning at ages 3 to 5 (Emmett *et al.* 1991). Most of the spawning occurs in the lower reaches of the main river channels or in small flood plain streams tributary to the lower river channels. Recent habitat trend information for these areas is not available.

Survival of both wild and hatchery steelhead trout has declined recently.

Steelhead trout. The NMFS is considering listing steelhead trout along the Oregon Coast as threatened under the ESA, based on concerns that hatchery fish heavily supplement many of the runs and that survival of both wild and hatchery fish has declined recently (Busby *et al.* 1996). The listing petition (ONRC *et al.* 1994) requested ESA protection for the winter runs of steelhead in the Miami, Kilchis, Wilson, and Trask Rivers.

Two races of steelhead — “summer” and “winter” — live in the Tillamook Watershed. Winter steelhead are native to Tillamook Bay streams and are widely distributed throughout the Basin. Summer steelhead were introduced to the Basin in the early 1960s and are supported entirely by hatchery production (Braun, K. pers. com. 1997). Although summer steelhead have been observed in all five subbasins, most occur in the Wilson River and Trask River subbasins. Summer steelhead typically enter Tillamook Bay streams from April through July and hold in deep pools until they spawn the following winter. Winter steelhead generally enter streams from November through March and spawn soon after entering freshwater. Age at the time of spawning ranges from 2 to 7 years with the majority returning at ages 4 and 5 (Emmett *et al.* 1991).

Two races of steelhead — “summer” and “winter” — live in the Tillamook Watershed. Winter steelhead are native to Tillamook Bay streams and are widely distributed throughout the Basin. Summer steelhead were introduced to the Basin in the early 1960s and are supported entirely by hatchery production.

No reliable information on the historic abundance of steelhead in Tillamook Bay streams is available. Steelhead were gillnetted commercially in Tillamook Bay from the late 1890s through the 1950s. However, harvest data for steelhead were not recorded in a reliable manner until after the fishery had been restricted to the early part of the steelhead run. Rough estimates of total coastwide steelhead run size made in 1972 and 1987 were similar (Sheppard 1972, Light 1987), suggesting that overall abundance remained relatively constant during that period. However, the proportion of hatchery fish in the runs appeared to have increased between the two estimates. Light (1987) estimated total run size for the major stocks on the Oregon Coast (including areas south of Cape Blanco) for the early 1980s at 255,000 winter steelhead and 75,000 summer steelhead. With about 69% of winter and 61% of summer steelhead of hatchery origin, Light estimated the naturally produced runs totaled 79,000 winter and 29,000 summer steelhead (note that most of the Oregon coastal summer steelhead are in the Umpqua and Rogue River systems).

The only information available for assessing trends in the abundance of steelhead runs to Tillamook Bay streams is angler salmon/steelhead report tags and holding pool counts for summer steelhead. The combined recreational catch of winter steelhead for all five subbasins and Tillamook Bay shows a declining trend since the early 1970s **(Figure 3-6)**. As indicated in Figure 3-6, the recreational catch has declined from a high of more than 20,000 in 1970 to fewer than 2,000 in 1993. The trend in the combined catch reflects the trends seen in each of the individual subbasins.

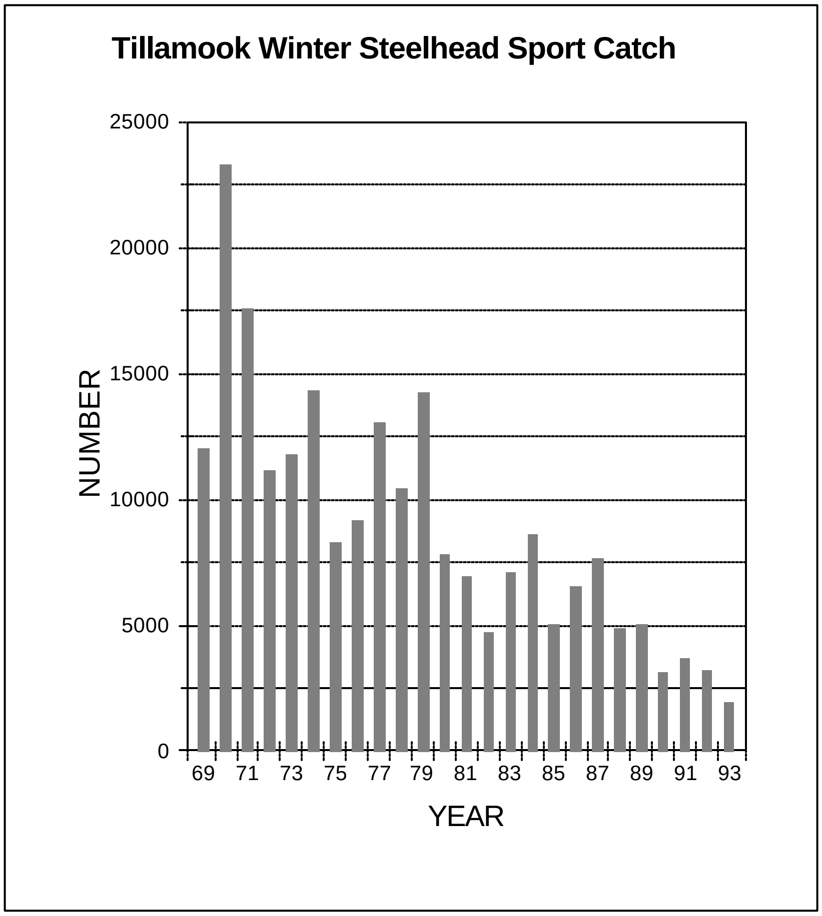

Figure 3-6. Tillamook Bay Basin sport catch of winter steelhead trout. *Source:* Pacific States Marine Fisheries Commission, StreamNet Report, 1997.

The combined recreational catch of summer steelhead for the five subbasins and Tillamook Bay is shown in **Figure 3-7**. Although numbers have varied considerably from year to year over the period of record, visual interpretation of the data suggests that there may be a declining trend in the catch, particularly since about 1980.

However, counts of summer steelhead in resting pools in the Wilson and Trask Rivers since 1965 **(Figure 3-8)** suggest that numbers of fish in resting pools were at least as high in the late 1980s as they were during much of the 1970s when catches were relatively higher. The resting pool counts can vary from year to year due to differences in viewing conditions, survey personnel, and viewing techniques. Therefore, caution should be used in interpreting resting pool counts for trend analysis.

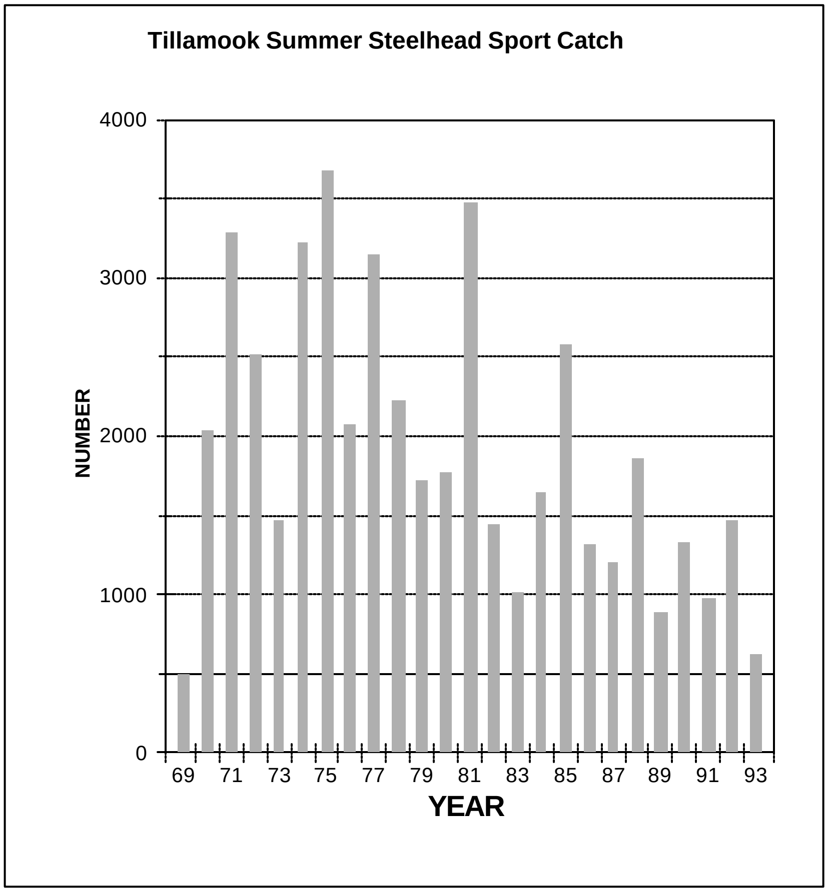

Figure 3-7. Tillamook Bay Basin sport catch of summer steelhead trout.
Source: Pacific States Marine Fisheries Commission, StreamNet Report, 1997.

Less is known about the present status of sea-run cutthroat trout than about any of the other anadromous salmonid species in the Tillamook Watershed.

Sea-run cutthroat trout. Less is known about the present status of sea-run cutthroat trout than about any of the other anadromous salmonid species in the Tillamook Watershed. Sea-run cutthroat trout, the smallest of the anadromous salmonids present in the Watershed, have not been fished commercially. Although sea-run cutthroat trout are harvested in the recreational fishery, their numbers are not recorded on salmon/steelhead report tags. Therefore, determination of trends in abundance cannot be made on the basis of catch data. Beginning in 1997, sea-run cutthroat trout angling regulations were changed to “catch and release” only (Klumph, R. pers. com. 1997). Cutthroat trout spawn in small headwater tributaries in late winter and early spring when water conditions are generally poor for viewing. Age at spawning is highly variable (2 to 10 years) and individual adults may spawn more than once during their lifetime (Emmett *et al.* 1991).

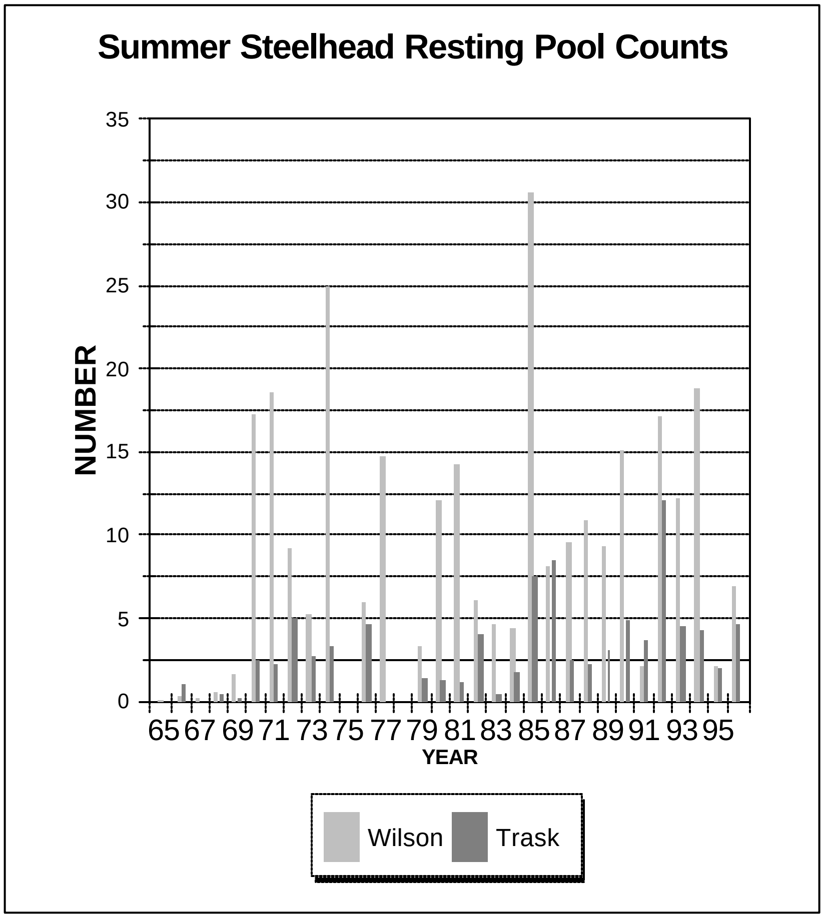

Figure 3-8. Resting pool counts of summer steelhead trout.
Source: Pacific States Marine Fisheries Commission, StreamNet Report, 1997.

The only attempt to routinely count sea-run cutthroat has been resting pool counts made by ODFW staff since 1965 in conjunction with summer steelhead counts in the Wilson and Trask Rivers. Note that holding pool surveys were not conducted on the Wilson River in 1975 or 1978 or on the Trask River in 1975, 1977, or 1978. The resting hole count results are presented as average number of fish per hole to allow comparison from year to year due to differences in the number of holes surveyed **(Figure 3-9)**. These data suggest that numbers of sea-run cutthroat trout in resting holes may have been somewhat higher before the mid-1970s than they have been since, particularly in the Wilson River. No further interpretation of the data is warranted.

Beginning in 1997, sea-run cutthroat trout angling regulations were changed to "catch and release" only.

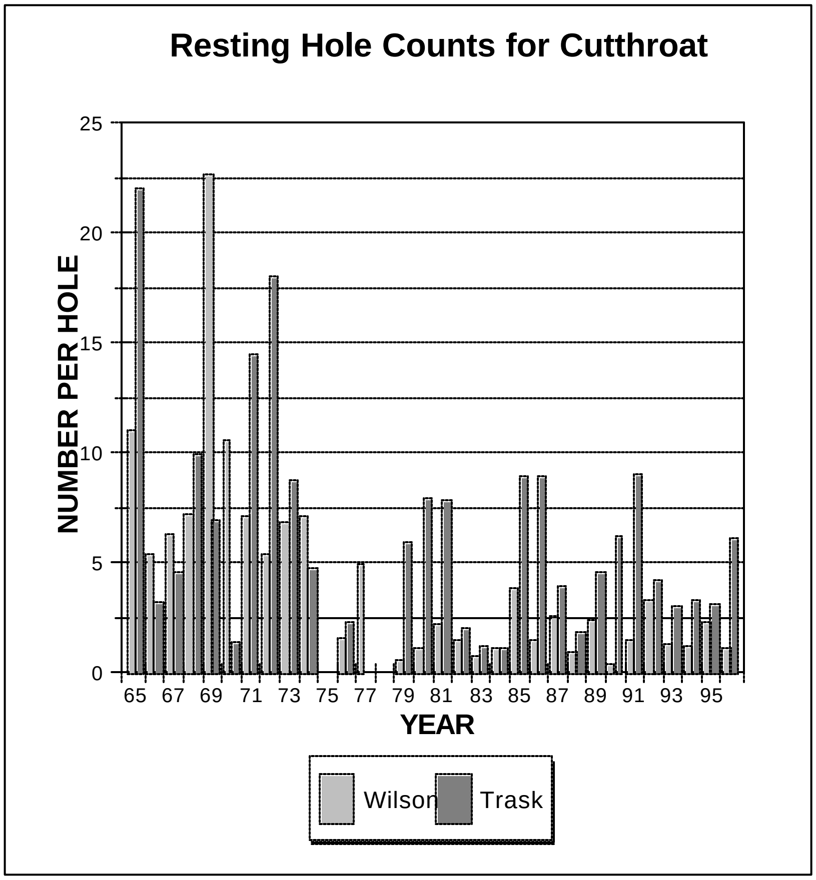

Figure 3-9. Resting pool counts of sea-run cutthroat trout, Wilson and Trask Rivers.
Source: Oregon Department of Fish and Wildlife resting pool count data, 1997.

Habitat Status and Trends

Anadromous salmonids utilize rivers and streams for migration, spawning and rearing; estuaries for adaptation to salt water conditions, refuge from predators, and for rearing; and the marine environment for rearing and maturation. Each of these environments plays a key role in the life cycle of the salmonid species that occur in the Tillamook Bay Watershed. This section presents an overview of the status and trends in habitat conditions for anadromous salmonids within each of these environments.

Pool:
A quiet place in a stream.

Riffle:
A shallow extending across a stream over which water flows so swiftly that the water is broken into waves.

Glide:
A calm stretch of shallow water flowing smoothly and gently.

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

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

Many of these habitat elements as well as some additional species-specific habitat criteria have been evaluated in the Tillamook Basin during the last six years as part of the ODFW Aquatic Inventory Project. Although not yet complete, these surveys provide the best source of information for assessing the present status of the freshwater habitat. A preliminary summary of survey data from the Kilchis, Wilson, Trask, and Tillamook subbasins was available at the time this chapter was prepared (Moore *et al.* 1995). These data, representing surveys on 15–18% of the stream miles in the Tillamook Basin, were collected in 1990–1993. The surveyed streams were selected to represent the range of conditions found throughout the Basin, especially within anadromous fish production areas.

Based on the survey data, more than 60% of stream segments surveyed were rated poor for those habitat criteria that relate directly to the presence of large woody debris (LWD) **(Table 3-2)**. Large woody debris adds complexity to stream channels, helps in the retention of spawning gravel and organic detritus, provides cover and refuge for rearing juvenile salmonids, and reduces the chance that fish will be flushed from the system during peak flow events by creating more low velocity areas within the stream channel (Hicks *et al.* 1991, Naiman *et al.* 1992). Streams flowing through confined valley floors that lack LWD generally have relatively straight, uniform channels with little habitat diversity. According to the ODFW survey results, these conditions are typical of many stream segments in the Tillamook basin. No remedy for the lack of LWD appears to be close at hand.

Table 3-2. Qualitative rating* of key fish habitat characteristics for Tillamook Basin streams

Characteristic	**Rating (% of stream length)**		
	Poor	**Fair**	**Good**
Pool area (% total stream area)	34.8	34.2	31.0
Pool frequency (channel width/pool)	9.5	16.7	73.8
Pool complexity (woody debris)**	67.0	26.5	6.5
Gravel availability (% gravel in riffles)	15.3	54.6	32.1
Gravel quality (% fines in riffles)	24.3	40.2	35.5
Large woody debris (LWD) pieces	63.4	20.6	16.0
LWD volume	61.0	14.4	24.6
LWD recruitment (riparian conifers)	98.7	1.3	0.0
Stream shade (% canopy closure)	6.5	22.6	70.9

***Qualitative rating is expressed as percent of total length surveyed. Qualitative benchmarks of habitat quality were developed from regional summaries of survey data compared with reference surveys of streams with high quality habitat.**

****Pool complexity based on LWD influence as percent of total pools.**

Source: Moore, K., J. Boechler and K. Braun. 1995. Section 3, Freshwater habitat. As cited in: Tillamook Bay Coho Task Force, ed., Tillamook Bay coho status report, Oregon Department of Fish and Wildlife.

Large conifer trees make the best LWD in streams because when they fall into a stream they tend to form relatively stable, long-lasting habitat (Andrus *et al.* 1988). Red alder, which now dominates the riparian corridors in the Basin, is more easily moved by the force of high water and decomposes much faster than conifers (Grette 1985). According to the survey results, conifers, particularly conifers over 24 in (61 cm) in diameter, are in very low abundance in the riparian corridors of the fish-bearing streams. Recruitment of new conifers for LWD production could take well over 100 years. In the meantime, it appears that mature alder will be the primary source of LWD.

Large conifer trees make the best LWD in streams.

The steep topography of much of the Basin combines with the mix of weathered volcanic soils for a high risk of mass failure processes. Many streams in the Basin have extensive reaches within the debris flow initiation and scour zones, and lack the large woody debris structure to trap and sort sediments mobilized by mass failures. During the surveys, landslides and debris avalanches were frequently encountered. Some evidence of mass movement was reported in 27% of the reaches surveyed. This contrasts with 16% of reaches surveyed in the Nehalem basin and 5% in the Alsea basin (Moore *et al.* 1995).

The surveys also identified a general lack of off-channel refuge habitat such as alcoves, side channels, and connected wetland areas. These areas are particularly important in the over-winter survival of coho salmon and sea-run cutthroat trout and steelhead trout. Off-channel sites provide refuge from high sediment loads and high water velocities which occur in most larger stream channels during frequent winter rain events. Lack of off-channel refuge areas can be partially compensated for if in-channel refuge habitat (*e.g.*, root wads, debris jams, deep pools with complex cover) is abundant. However, as discussed above, LWD is usually necessary for creation of such habitat in Coast Range streams.

Periphyton:
Organisms that live attached to underwater surfaces.

About one-third of the stream segments were rated “good” for gravel abundance and gravel quality and about one-half of the stream segments were rated “fair” for gravel abundance and gravel quality. Considering the amount of erosion and sediment transport that occurs annually in the Watershed (See Chapter 4, Water Quality), these ratings are encouraging. Another encouraging finding was that shade was good in more than 70% of the stream segments surveyed and poor in only 6.5%. From review of the same data set, Moore *et al.* (1995) hypothesized that some segments of streams may be overshaded, and low light levels may be limiting production of periphyton which in turn may be limiting aquatic invertebrates. If this is the case, then the shade rating system should be revised to lower value at high shade levels.

As discussed in Chapter 4, water quality in Tillamook Basin rivers and streams is generally satisfactory for maintenance of cold water fish populations. However, bacterial concentrations and water temperatures exceeding state standards have been identified as problems in the lower reaches of some rivers and are being evaluated by the Oregon Department of Environmental Quality (DEQ) and the TBNEP.

The present condition of freshwater habitat in the Tillamook Watershed has been influenced by human activities and natural phenomena that have occurred over an extended period of time. Several major events and practices have disturbed the Watershed.

- Log drives during the late 1880s and early 1900s on the Wilson, Trask, and Tillamook Rivers caused long-term damage to the channels due to sluicing effect of the log drives and the clearing of obstacles in preparation for the drives (Sedell and Duval 1985).
- Forest fires burned extensive parts of the Watershed in 1868, 1878, 1902, 1918, and periodically from 1933 to 1951 (the Tillamook Burn), exposing the soil to heavy erosion.
- Salvage logging followed the Tillamook Burn fires and continued into the 1970s. It opened many new roads, removed essentially all riparian conifers, and generally worsened the already extreme erosion in the burned-over areas.
- Major floods of 1964, 1972, 1979, 1990, and 1996 resulted in widespread restructuring of the stream channels, damage to riparian buffers, and exportation of woody debris.
- Thousands of miles of roads and hundreds of stream crossings constructed in the Basin since the turn of the century have contributed increasing amounts of sediment through erosion of road banks and mass failures. In addition, improperly designed culverts have caused numerous passage problems for migratory fish.
- Agricultural development, beginning in the mid-1880s, has resulted in loss of riparian habitat along stream banks. Drainage characteristics and hydrology of tributary streams and adjacent wetlands have been altered through channelization and construction of dikes and riprap fills on the gentler flood plain areas of the basin.

The landscape change study revealed two distinctly different landscape histories, divided by the western edge of the historic fire line.

Habitat data ODFW collected during the past six years is the only comprehensive data set available for description of recent habitat conditions in the Tillamook Watershed. However, a TBNEP-sponsored study of landscape-level changes in the Watershed (Strittholt and Frost 1995) provides some insight into recent (during the last 20 years) changes in the Watershed that potentially could affect salmonid habitat. The study revealed two distinctly different landscape histories, divided by the western edge of the historic fire line. The land east of this line (approximately 60% of the total Watershed) demonstrated an overall maturing of recovering vegetation largely replanted after the massive forest fires. The land west of this line has been substantially influenced by clearcutting, particularly heavy in several subwatershed basins. The subwatershed most impacted by logging between 1974–1975 and 1992 (in area) was the Tillamook River Basin. Logging has affected one-third of its land area, with more than half of its remaining forest as of 1974–1975 harvested (*ibid.*). Most of this recent logging was conducted on private lands and regulated under the Oregon Forest Practice Rules. These rules require protection of riparian buffer strips along the fish-bearing stream channels as well as a number of other precautions to limit the effects of logging activities. Whether these rules adequately protect salmonid habitat has not yet been determined in the Tillamook Bay Watershed.

A number of positive management actions taken over the years are likely to improve anadromous fish habitat in the Watershed over the long term.

Moore *et al.* (1995) suggested that Tillamook Basin habitat conditions, at least for coho salmon, may be at a low point. They believe that recovery will be a slow process because key elements for recovery, such as development of conifer communities in riparian zones, are only getting started. A number of positive management actions taken over the years are likely to improve anadromous fish habitat in the Watershed over the long term. Some of the most important positive actions are listed below.

- Reforestation of the historic burned and logged areas of the Watershed began in 1949 and was completed in 1970. This management measure is acknowledged as successfully improving hydrologic response in the burned areas and has significantly reduced soil loss from these areas (OWRD and USDA-SCS 1978)

- Unregulated timber harvest in the riparian zone of fish bearing streams ended in 1972 when the 1971 Oregon Forest Practices Act took effect. Forest practice rules have been modified over the years since that time to provide greater protection to streams and their riparian zones. It is anticipated that they will continue to be modified and improved in the future.

- Tillamook Basin has been identified as a priority area for implementation of the Oregon Plan, which succeeds the Governor’s Coastal Salmon Restoration Initiative, developed in 1996.

In summary, all four of the subbasins surveyed have substantial habitat that can be classified as fair to good, according to the ODFW benchmark criteria. Habitat has made substantial recovery from the heavy sediment loading that preceded reforestation, particularly since the early 1970s. For some species such as coho salmon, which require specific overwinter rearing and refuge habitat, habitat conditions may be near a low point. For other species such as the fall chinook salmon, which spawn and rear in main stem and larger tributary habitat and do not spend long periods of time in the freshwater environment, habitat conditions appear to be satisfactory. One of the biggest problems in the Watershed is the general lack of LWD in the small- to medium-size tributary streams. The generally poor ratings for LWD recruitment from riparian areas indicate that recovery of habitat complexity in many areas will be a long process due to the lag time required to reestablish conifer communities in the riparian zone. Better management practices have eliminated a number of the man-caused disturbances that have contributed to the present condition of the freshwater habitat. A watershed approach to stream habitat restoration is needed to ensure continued recovery.

One of the biggest problems in the Watershed is the general lack of LWD in the small- to medium-size tributary streams.

Current status of estuarine habitat. Studies conducted in other Pacific Northwest estuaries (Healey 1982, Simenstad and Salo 1982, Iwamoto and Salo 1977) have shown that the general behavior of anadromous salmonid species is quite consistent from estuary to estuary, although there are differences in detail. We relied on these general descriptions of juvenile behavior for identifying important habitat components in the Tillamook Bay Estuary because reliable site-specific information is lacking.

Chum salmon migrate seaward as fry, 30–40 mm in length, and enter the estuary within a few days after emerging from the gravel spawning beds. Juvenile chum salmon were present in Tillamook Bay between March and June in monthly samples collected by the ODFW (Forsberg *et al*. 1975) between May 1974 and April 1975 **(Table 3-3)**. Residence time of individual chum fry in the estuarine environment is variable (range 4–32 days) with the majority staying about 30 days (Simenstad and Salo 1982).

The general behavior of anadromous salmonid species is quite consistent from estuary to estuary.

Healey (1982) found that chum salmon typically disperse several kilometers from the river mouth upon entry into the estuary, favoring the shoreline and eelgrass beds. The first habitat occupied includes tidal creeks and sloughs high in the delta area, but other intertidal areas are also quickly colonized. During high tide, chum salmon fry congregate in the upper intertidal at the fringe of marshes, and penetrate deep into the marshes along tidal creeks. At low tide, the fry retreat into tidal creeks that retain flowing water at low tide and into delta channels. Eelgrass beds appear to be important both as a refuge from predators and as an area rich in invertebrate prey.

Table 3-3. Juvenile salmonids present at all sampling stations in the Estuary combined*

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Chinook		18	266	1010	733	691	299		9	2	2	
Chum	169	7									14	310
Coho	12	1	2	2			12	2			3	16
Steelhead	1	7	3									
Cutthroat	2	3	1	4		5	1	1	1			

***Total number of juvenile salmonids present at all sampling stations in the Estuary combined during the period May 1974 through April 1975**

Source: Adapted from Forsberg, B., J. Johnson and S. Klug. 1975. Identification, distribution, and notes on food habits of fish and shellfish in Tillamook Bay, Oregon. Fisheries Commission of Oregon, contract report no. 14–16–0001–5456 RBS. 85 pp.

Benthic:
Occurring on the bottom underlying a body of water.

Epibenthic:
Flora and fauna occurring from the low water mark to the benthos.

Neritic:
The relatively shallow waters of the continental shelf; roughly the region from low tide to a depth of 600 feet.

Food availability in the estuarine environment may be an important limiting factor for chum salmon (Simenstad and Salo 1982, Gallagher 1980). Compared with the array of zooplankton potentially available as prey, juvenile chum salmon food choices in other estuaries have been found to be highly size and taxa specific (Simenstad *et al.* 1980, Simensted and Eggers 1981). They preferentially consume large, relatively rare harpacticoid (*Harpacticus* spp.) and calanoid (*Calanus* spp.) copepods from available epibenthic and neritic zooplankton, respectively. Although food habit studies of Tillamook Bay chum salmon have not been conducted, it is possible that fluctuations in the abundance of preferred prey species could play an important role in determining estuarine survival rates and subsequent run size.

Chinook salmon, because of their many juvenile life history patterns, have the most varied pattern of estuary utilization. Chinook, which migrate seaward as fry, colonize the estuary in much the same way as chum, first occupying tidal creeks high in the marsh area, and later the outer estuary. Unlike chum, chinook fry don’t appear to occupy high salinity nursery areas. Some chinook fry may occur in the Tillamook Bay Estuary but previous sampling efforts (Cummings and Berry 1974, Forsberg *et al.* 1975) did not distinguish between fry and underyearling smolts. Most chinook in Oregon estuaries appear to enter as underyearling smolts in May and June (Reimers 1973). Forsberg *et al.* (1975) reported juvenile chinook present in Tillamook Bay from June through November with a few collected in January through March. Underyearling smolts are generally found in salt marsh habitat but mud flat, foreshore areas can be utilized for some time by larger underyearlings before they move into open water habitats (Stober *et al.* 1973, Simenstad and Eggers 1981). Yearling chinook (mostly from the spring run) move directly into neritic habitat without much

Chinook salmon, because of their many juvenile life history patterns, have the most varied pattern of estuary utilization.

utilization of salt marsh or other shallow habitat (Simenstad and Salo 1982).

Prior to entering the ocean, coho salmon may rear within the estuary for a short time.

Coho salmon smolts generally migrate seaward from April to June with peak movement usually occurring in May (Emmett *et al.* 1991). Prior to entering the ocean, coho salmon may rear within the estuary for a short time. However, the actual use of the estuary by this species is not fully understood (Moore *et al.* 1995). During monthly sampling in Tillamook Bay between May 1974 and April 1975, Forsberg *et al.* (1975) caught a few juvenile coho during the period May through August, and in November, December, February, and March. Cummings and Berry (1974) sampled six locations along the main channel in Tillamook Bay from June through early September 1972 and found a few coho on all sampling dates.

Steelhead trout smolts appear to spend little time in estuaries and move quickly into the open ocean environment.

Steelhead trout smolts appear to spend little time in estuaries and move quickly into the open ocean environment after migrating downstream in March, April, and May. Forsberg *et al.* (1975) reported finding a few steelhead smolts in May, June, and July catches of their 1974–1975 survey of Tillamook Bay fishes. None were caught during the June through early September 1972 sampling conducted by Cummings and Berry (1974). Utilization of the Tillamook Bay Estuary by underyearling steelhead has not been documented. However, downstream movements of underyearling steelhead during summer and early autumn have been observed in other estuaries (Zedonas 1992). It has been suggested that these movements may be in response to density dependent factors, indicating that the carrying capacity of the freshwater habitat has been exceeded (Zedonas 1992).

Cutthroat trout probably utilize open water, channel, eelgrass, and mudflat habitat in estuaries.

Most wild cutthroat trout smolts enter Pacific Northwest estuaries during April and May at age 2 to 4 years (Nicholas and Hankin 1988). Although not well documented, cutthroat trout probably utilize open water, channel, eelgrass and mudflat habitat in estuaries. Studies of oceanic distribution of juvenile salmonids off the Oregon Coast indicate that juvenile cutthroat trout are present in off-shore waters from about May through August, but disappear from the catches in September (Pearcy *et al.* 1990). Apparently most cutthroat trout return to the estuarine or freshwater environment from mid to late summer (Gieger 1972, Loch 1982). Historically, sport fisheries targeted sea-run cutthroat trout in the Estuary and tidal reaches of rivers from about July through September. Present sport fishing occurs mainly in the rivers.

In addition to physical habitat, juvenile salmonids depend on the estuary for production of food organisms.

In addition to physical habitat, juvenile salmonids depend on the estuary for production of food organisms. Estuarine food webs are largely detritus-based systems. The watershed contributes particulate and dissolved organic matter, and salt marsh vegetation, eelgrass, and other types of submerged vegetation are important sources of detritus within the estuary. Juvenile salmonids (*e.g.* fall chinook) which rely heavily on detritus-feeding epibenthic invertebrates such as amphipods, isopods, and copepods therefore depend indirectly on eelgrass beds, salt marshes, and other areas of vegetation for their food supply.

Detritus:
Material resulting from the decomposition of dead organic remains (plants, animals, or excrement), or small particles from weathered rock, such as sand or silt.

Available information suggests that ample estuarine food resources may be partly responsible for declines in some natural salmon runs over the last century, as well as the organic matter is available to supply animal populations in Northwest estuaries (Simenstad *et al.* 1984, Wissmar and Simenstad 1984, Wissmar 1986). However, in situations where populations are very abundant, local food resources may be limiting. It has been proposed that limited lack of complete success of some hatchery stocks. When many juveniles at once reach the estuary (such as during a heavy natural outmigration or following release from a hatchery), they may reduce the size of the local invertebrate populations drastically. Prey resources are further limited, and recovery of the prey population is protracted, in areas where shallow flats, marshes and quiet channel habitat have been removed by dredging and channelization. Simenstad *et al.* (1982) hypothesized that in this situation the salmon may spend less time in the estuary. As smaller outmigrants to the ocean, they would then be more susceptible to open water predators. This is probably not a problem in Tillamook Bay now but should be considered for future salmonid management.

Table 3-4 summarizes the habitat types and juvenile residency information for the five salmonid species. Of the five species, chinook salmon and chum salmon depend most on the estuary, followed by cutthroat trout. Most coho salmon and steelhead trout appear to use estuaries primarily as a migratory route and as a physiological transition zone for ocean residency.

With the exception of water quality, little is known about the present status of Tillamook Bay's rearing habitat for juvenile salmonids. Water quality in the Bay remains good, relative to the requirements of anadromous fish. The major concerns regarding future water quality in the Bay are related to its capacity to absorb increased levels of nutrients and possibly toxic substances as the human population density in the Watershed increases.

Table 3-4. Primary estuarine habitats utilized by juvenile anadromous salmonids and approximate period of residency of individual fish

SPECIES	PRIMARY HABITAT UTILIZED					RESIDENCY (approximate range for individual fish)
	Salt marsh	Eelgrass	Mud flat	Tidal channel	Open water	
Chinook	X	X	X	X	X	weeks to months
Chum	X	X		X		days to about 1 month
Coho			X(?)	X	X	days to months
Steelhead			X(?)	X	X	days to a few weeks
Sea-run cutthroat		X	X(?)	X	X	weeks to months

Sources: Healey, M. 1982. Juvenile salmon in estuaries, the life support system. In: V.S. Kennedy, ed., Estuaries Comparisons. Academic Press, New York, N.Y.
Simenstad, C., and E. Salo. 1982. Foraging success as a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon, *Oncorhynchus keta*, in Hood Canal, Washington. In: B.R. Miteff and R.A. Nevè, ed., Proceedings of the North Pacific Aquaculture Symposium Report 82-2. Alaska Sea Grant Program, University of Alaska, Fairbanks, AK.
Iwamoto, R. and E. Salo. 1977. Estuarine survival of juvenile salmonids: A review of the literature. Report to Washington Department of Fisheries, Fisheries Resources Institute, University of Washington, Seattle, WA.

Information on benthic and epibenthic invertebrate community structure and abundance would be helpful in evaluating present food resources for juvenile salmonids. A TBNEP-sponsored benthic and epibenthic invertebrate survey was conducted in 1996 (Golden *et al.* 1997). Preliminary results of the study indicate a diverse benthic community (154 taxa from grab samples collected throughout the Bay) with species richness (number of species) slightly higher in the lower Bay. Lower, middle, and upper portions of the Bay had similar ranges of species diversity, as did channels and flats. Conspicuously absent in the benthic samples was *Corphium salmonis*, an important prey species for juvenile salmonids in other estuaries (Golden *et al.* 1997). No good explanation for this has been found. Detailed information on the density of benthic and epibenthic invertebrates at various locations in the Estuary will be available in the final report for the invertebrate inventory.

Trends in important salmonid habitats within the Estuary can be seen by tracing changes in some of the key habitats through time.

Trends in important salmonid habitats within the Estuary can be seen by tracing changes in some of the key habitats through time. Historic maps and photographs of the Bay perimeter and bathymetric studies of the Bay morphology provide insight into some of the important changes that have taken place since settlement of the region by Euro-Americans in the mid-1850s. A detailed account of historic changes in the Bay shoreline and bathymetry is included in the environmental history of the

Tillamook Bay and Watershed prepared by Coulton *et al.* (1996) for the TBNEP. The following important changes have likely altered the quality and/or quantity of salmonid habitat.

- Shoreline fills between 1867 and 1977 reduced intertidal habitat by about 11%. Most of the filling occurred on Bayocean Spit (57%), and around the river deltas (33%), with the remaining 10% used for the City of Garibaldi.

- Extensive tidally influenced brackish and freshwater wetlands have been lost. Large areas of tidal wetlands connected with the Trask, Wilson, Kilchis, and Tillamook Rivers to the south and west of the City of Tillamook were present when the Bay was first mapped in the mid-1850s. Construction of levees and dikes in the late 1890s and early 1900s converted most of these wetlands to pasture for dairy cattle.

- Delta growth at the mouths of the Kilchis, Wilson, Trask, and Tillamook Rivers created most of the existing tidally-influenced wetlands over the past 50 years. Shorelines have extended up to 3,000 feet (914 m) beyond the conditions present in the 1930s. The delta has been colonized primarily by salt marsh vegetation. No studies have been conducted to determine whether rearing juvenile salmonids are directly utilizing the newly created salt marsh habitat.

- The new delta formations at the mouths of the Kilchis, Wilson, Trask, and Tillamook rivers have developed at the expense of mud flat habitat.

- Periodic bathymetric mapping of the Bay since 1887 indicates that many areas of the Bay are becoming shallower and the structural complexity of the Bay bottom has been lost. However, between 1957 and 1995, the major channels became deeper and the channel network became somewhat more extensive and interconnected. Juvenile salmon rely on the network of tidal channels for access to the remaining intertidal salt marsh habitat and for cover during low tide. There is no evidence that filling of the upper Bay has reduced the connectivity between intertidal salt marsh habitat and subtidal channel habitat.

- Large woody debris was abundant in the upper half of the Estuary and in the tidally-influenced portions of river channels when the region was first settled in the mid-1880s. Juvenile anadromous salmonids use LWD in the estuary as cover and refuge from predators, particularly during low tide. Much of the LWD in Bay tidal channels and lower river channels was actively removed between the late 1800s and 1920.

- The Bay entrance and main channels for navigation have been dredged periodically since the mid-1890s. Before dredging began, four main tidal channels cut through the 6-mile long Bay. During the late 1890s, three dikes were constructed and dredging connected two of the channels. This reduced the natural channels to two main tidal channels, each wider and deeper than the original four. A secondary result was the shoaling of the western half of the Bay. The main navigation channel was dredged regularly up to the 1970s. Most of the dredged sediment was disposed of in the ocean, but some was used for some of the shoreline fills discussed above. In 1974, the COE determined that dredging of the upper Bay channels was economically infeasible due to rapid sediment deposition. Thus the upper Bay has not been dredged since the 1970s. Impacts of dredging on salmonid habitat in the Bay include temporary loss of benthic macroinvertebrate food organisms, changes in the tidal prism and salinity intrusion, and modifications to the natural sediment dynamics of the Bay.

From the above review and our analysis of historic maps of the area, it is clear that both tidally influenced wetland habitat and intertidal mud flat habitat have been substantially reduced since the mid-1880s. During the last 50 years, considerable new salt marsh habitat has been created in the south end of the Bay due to delta formation associated with high sediment input from the Watershed. Recent floods have probably accelerated this situation. The new salt marsh does not replace the quantity of lost marsh and wetlands and probably provides lower quality habitat than the lost mature marsh. In general, the complexity of the estuarine habitat has been reduced. Complex structure provided by large woody debris has been removed and the connections between river channels and their flood plains have been severed (except during periodic large floods) through the construction of dikes and levees. These losses are probably permanent. Sediment from the Watershed appears to be filling the upper portion of the Estuary and reducing the amount of deeper channel habitat. It should be noted that in 1974 state environmental experts advocated dredging the upper Bay and rivers in order to restore marine life in these areas following changes caused by the 1972 floods (Wick 1972). However, the COE determined that dredging of the upper Bay channels was economically infeasible because the channels would probably have to be dredged each year and dredging would not prevent tidal flooding (Gilkey 1974). Today, environmental experts no longer advocate dredging as a viable alternative for reducing the effects of sediment on estuarine biota.

Tidally-influenced wetland habitat and intertidal mud flat habitat have been substantially reduced since the mid-1880s. Today, environmental experts no longer advocate dredging as a viable alternative for reducing the effects of sediment on estuarine biota.

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In addition to providing food and shelter for juvenile anadromous salmonids, the Tillamook Bay Estuary also provides a migratory route and physiological transition zone for adult salmonids returning from the ocean. Adult salmon, steelhead, and sea-run cutthroat trout spend varying lengths of time in the Estuary prior to river entry. Adults often hold in the deep holes in the Estuary or the tidal zone of the rivers. Coho salmon, and spring and fall chinook salmon may spend from a few days to several weeks in the estuarine and brackish water environment. Low flow conditions in the rivers during the fall migratory period of coho and fall chinook salmon can delay their upstream migration. Chum salmon generally enter the Estuary later in the fall when river flows are higher and move relatively quickly to the spawning grounds. Steelhead trout also enter the Estuary during periods when river flow is relatively high and move quickly into fresh water (Dawley *et al.*1986). Cutthroat trout spend varying lengths of time in the Estuary and tend to utilize the tidal freshwater areas of the lower rivers prior to upstream migration.

In addition to providing food and shelter for juvenile anadromous salmonids, the Tillamook Bay Estuary also provides a migratory route and physiological transition zone for adult salmonids returning from the ocean.

Adult anadromous salmonids are subject to mortality from sport fishing (discussed previously) and from predation by marine mammals, including harbor seals and sea lions. Harbor seal (*Phoca vitulina richardsi)* and California sea lion (*Zalophus californianus californianus*) populations in the Northwest have increased dramatically since they became protected under the Marine Mammal Protection Act of 1972 **(Table 3-5)**. Seals and sea lions are known to prey on salmonids and on species that are important salmonid prey (Olesiuk and Bigg 1988, Olesiuk *et al*. 1990). The literature includes few estimates of harbor seal annual consumption. Harvey (1987) addressed the question of harbor seals' total consumption of fish and particular prey eaten. Based on previously reported food habit studies, he estimated that salmonids numerically comprised fewer than than 1% of the fish consumed, but accounted for 11% of the total biomass. A comparative study of the diets of harbor seals and California sea lions in Puget Sound indicated that salmonids comprise a higher percentage of the diet of California sea lions than of harbor seals (NMML 1996). Salmonid remains were found in only 2% of harbor seal scats but 15% of sea lion scats. The California sea lion diet included adult, jack, and juvenile salmonids, whereas only adult salmonid remains were found in the harbor seal scat (NMML 1996). The remaining diet of these pinnipeds is primarily bait fish (*e.g.*, herring, smelt, and anchovy) and invertebrates (squid).

Table 3-5. Recent increases in Pacific Northwest marine mammal populations

Species/location	Past Date	Abundance	Recent date	Abundance
Harbor seals				
British Columbia	1970	9,000–10,500	1988	75,000–88,000
Washington	1972	2,000	1992	38,000
Oregon	1984	4,000–5,000	1992	9,500–12,200
Tillamook Bay	1973	250	1993	600
California sea lion				
United States	1978	36,000	1988	67,000

Sources: Palmisano, J., R. Ellis and V. Kaczynski. 1993. The impact of environmental and management factors on Washington's wild anadromous salmon and trout. Report prepared for: Washington Forest Protection Association and the State of Washington Department of Natural Resources, Olympia, WA. 369 pp.
Kaiser, R., R. Lowe and R. Brown. 1995. Tillamook Bay coho stock status rep. Section 7, Nonhuman predation on salmonid stocks. Tillamook Bay Coho Task Force, Oregon Department of Fish and Wildlife.

Predation rates of harbor seals and sea lions on anadromous salmonids in and near Tillamook Bay have not been studied. However, harbor seal seasonal abundance and food habits were investigated in Tillamook Bay and Netarts Bay between June 1978 and November 1981, with results indicating that harbor seal predation was probably not very high, at least at that time (Brown and Mate 1982). Harbor seals were most abundant in the Bay from June through August, the pupping and molting period. Numbers of harbor seals declined to annual low levels from September through December, when most of the adult salmon were passing through the Estuary. Analysis of the seals' feces indicated that they were feeding mainly on abundant smaller fishes such as surf smelt, northern anchovy, shiner perch, English sole, and Pacific herring.

Analysis of the seals' feces indicated that they were feeding mainly on abundant smaller fishes such as surf smelt, northern anchovy, shiner perch, English sole, and Pacific herring.

Current status and trends in oceanic habitat. It is becoming increasingly clear that a better understanding of the relationship between ocean productivity and anadromous salmonid production is needed to manage these resources. Many natural and hatchery runs of anadromous salmonids began declining along the northern California, Oregon, and Washington coasts in the mid-1970s, persisting into the 1990s. Declining ocean survival appears to be the major factor responsible for this general decline.

A better understanding of the relationship between ocean productivity and anadromous salmonid production is needed to manage these resources.

Anadromous salmonids generally reach sexual maturity and gain roughly 95% of their weight in the marine environment. Rates of survival in the marine environment are related to availability of food organisms and interactions with predator species. Therefore, factors that influence the marine food web supporting anadromous salmonids or that affect predation can have a major influence on salmonid abundance. During the past decade and particularly within the past five years, we have learned much about the linkages between atmospheric conditions, ocean currents, ocean temperature conditions, and biological productivity (Fisher and Pearcy 1992, Cooper and Johnson 1992, Jacobs *et al.* 1994, Fisher 1994). Several interrelated phenomena appear to significantly influence the food and predator-prey relationships important to Tillamook Bay anadromous salmonid populations. These include climatic warming and subsequent warming of sea surface temperature, inter- and intra-annual changes in upwelling along the coast, El Nino events, and shifts in ocean currents.

Ocean warming. Changing offshore water temperatures affect Tillamook Bay salmonids several ways.

- Recent increases in sea surface temperatures in parts of the North Pacific Ocean have reduced the abundance of zooplankton, which forms the basis of the food web for all salmonid species.
- Temperature increases are apparent in both near-shore and offshore waters. Therefore, they affect juvenile salmonids feeding in near-shore environments and adults feeding offshore.
- The current warming trend appears to extend at least into the near future. Thus, reduced ocean productivity may continue to be a problem.

Ocean upwelling. Upwelling along the coastline brings nutrient-rich water to the sea surface, supporting high productivity of phytoplankton and zooplankton. Upwelling has historically been relatively high along the northern Oregon Coast, but El Nino conditions have changed ocean current patterns, reducing upwelling in recent years. Reduced upwelling decreases the basic productivity of the area.

Upwelling:
A persistent and rising cold water current in an oceanic circulation system.

El Nino events. The El Nino ocean conditions bring warm nutrient-poor and low salinity southern-ocean surface waters and easterly winds to the west coast of the Americas. El Nino events have become increasingly common, with drastic impacts.

- The strongest El Nino event of this century occurred in the North Pacific during 1982 and 1983. Its effects were still apparent more than a decade later (Kerr 1994). The 1997–98 El Nino event appears to be of similar magnitude.

- Large declines in salmon production off the Oregon coast were observed in 1993 during the El Nino.
- Predator fish such as jack mackerel, typically associated with more southern distribution patterns, tend to extend their distribution northward during El Nino events.

Ocean currents. Salmonids' success is also profoundly affected by ocean currents.

- The strength of the southerly flowing California Current is important to salmonid production along the Washington, Oregon, and northern California coasts because it carries nutrient-rich waters and affects upwelling conditions.

Pelagic:
The division of the ocean that includes the whole mass of water. It is divided into the neritic zone (water depth 0–600 feet) and the oceanic zone (water deeper than 600 feet).

Primary production:
The creation of organic matter through photosynthesis or *chemosynthesis*.

Secondary production:
The creation of organic matter by consumption of other organic matter.

- From the mid-1940s through the mid-1970s the California Current had a strong southward flow. Productivity along the coast from northern Washington to northern California was relatively high and growth and survival of ocean stocks of salmon were good.
- Since 1976, the California Current has become weaker, upwelling has been weaker, and survival and growth of salmonids from southern Washington through northern California has been relatively poor.

Fish abundance in temperate climates has always cycled and probably always will. Ware and Thompson (1991) demonstrated that the biomass of pelagic fish in the coastal upwelling domain off the West Coast of North America decreased by a factor of five in the first half of the 1900s. To determine whether similar declines had occurred in the past, they tracked individual biomasses of the dominant pelagic fish species through the sediment record off southern California, showing that the populations rise and fall in response to a 40–60 year oscillation in primary and secondary production. As discussed above, anadromous salmonids are closely tied to phytoplankton and zooplankton production and probably have undergone similar oscillations through time. The present decline in the abundance of many Oregon Coast salmonid populations, including Tillamook Bay's, may therefore be explained, at least in part, by these natural cycles.

Non-Salmonid Fish Species

The Tillamook Bay Estuary provides food, shelter and nursery habitat for a wide variety of marine and estuarine fishes.

In addition to its importance in the life cycles of anadromous salmonids, the Tillamook Bay Estuary provides food, shelter and nursery habitat for a wide variety of marine and estuarine fishes. This section presents an overview of what is known about the species diversity, seasonal occurrence, and general distribution patterns of the Bay's non-salmonid fish fauna. Since the fish fauna have not been surveyed recently, the information presented in this section is based on data collected more than 20 years ago. Estuarine conditions have changed since the data were collected. Therefore, the information should be viewed as providing a general picture of fish use of the Estuary, with the understanding that the present status of the non-salmonid fish fauna could be somewhat different.

Population Status and Trends
The information presented in this section is based on the results of two studies conducted in the 1970s. The earlier study involved monthly fish sampling from June to early September 1972 along the main channel in Tillamook Bay (Cummings and Berry 1974). Most of the sampling was conducted at low tide with a seine. This study's objective was to determine whether and where juvenile salmon rear in the Estuary. The occurrence of non-salmonid fishes in the catch was also recorded. The more comprehensive second study, lasting from May 1974 through November 1976, was designed to provide basic biological information relevant to planning and management of the Tillamook Estuary. Results of that study were published as two interim reports (Forsberg *et al.* 1975, 1977) and a final summary report (Bottom and Forsberg 1978). Fish were sampled at 28 locations throughout the Bay. Two types of sampling gear were used: an otter trawl for studying the deeper areas of the Bay, and a beach seine for the shallower and near-shore areas. Twenty-five of the 28 stations were sampled regularly with the trawl and 12 were sampled regularly with seine. Nine stations were sampled with both types of gear.

A total of 63 species of fish (including salmonid species) have been identified in Tillamook Bay.

A total of 63 species of fish (including salmonid species) have been identified in Tillamook Bay **(Appendix 3-B)**. Of the total, 59 were collected in the 1974–1976 seine and trawl samples. The species composition of the Tillamook Bay catch was similar to those reported from other Oregon estuaries (Cummings and Swartz 1971, Mullen 1977, Pearcy and Meyers 1974). A few of the rarer species captured in Tillamook Bay were not listed for the other estuaries, including red gunnel, pricklebreast poacher, smoothhead sculpin, and sablefish. In addition, several species commonly reported in other estuaries were not present in Tillamook Bay seine or trawl catches. Bay goby (*Lepidogobius lepidus*) has been reported in Coos Bay and was among the most common larval fishes in Yaquina Bay. Gear selectivity may explain its absence in Tillamook Bay. Speckled sanddab (*Citharichthys stigmaeus*) was also found in Coos and Yaquina Bays but absent from the Tillamook Bay collections.

Three species — surf smelt, northern anchovy, and shiner perch — represented more than 70% of the entire catch.

The fish community was dominated by a few abundant species **(Table 3-6)**. The 11 most abundant species caught accounted for 97% of the total catch. Three species — surf smelt, northern anchovy, and shiner perch — represented more than 70% of the entire catch. Nineteen of the species captured were represented by fewer than 10 individuals. Similar fish community structure (*i.e.*, numerical dominance by a few relatively abundant species) also has been found in Yaquina Bay (Pearcy and Meyers 1974) and Coos Bay (Hostic 1975).

Abundance of species and individuals showed pronounced seasonality in the 1974–1976 survey (Bottom and Forsberg 1978). Changes in abundance resulted from the loss or gain of transient marine species rather than large scale changes in a resident population. Catch per effort of most species and the number of species per seine and trawl effort generally peaked from May to July. The increase in the number of juvenile herring, surf smelt, English sole, and saddleback gunnel in Tillamook Bay in the spring and summer was consistent with observations of maximum larval abundance of these species in Yaquina Bay (Pearcy and Myers 1974) in the winter or spring.

During the summer, many species were not only more abundant, but more widely distributed throughout the Bay. Emigration from the Estuary in the fall and winter caused a greater decrease in the catch and number of species per unit effort in the upper Bay relative to other Bay sections. The decreasing abundance of shiner perch, staghorn sculpin, and saddleback gunnel in the upper Estuary in the fall or winter also corresponded to the movements of older individuals into the lower Estuary or ocean.

During the summer, many species were not only more abundant, but more widely distributed throughout the Bay.

Superimposed over the broad seasonal pattern are several variables that may have influenced species distribution and abundance in the Tillamook Estuary. These included substrate and the presence or absence of eelgrass beds. Substrate type may have been important for a number of species. The seine, for example, caught the most species per haul at the two shoreline cobble stations in the lower Bay. Pacific herring, saddleback gunnel, starry flounder, and English sole were often found at sandy shoreline areas, while staghorn sculpin and shiner perch were frequently caught in seine hauls over the finer sediment areas in the upper Estuary. More species were caught in mid-Bay trawl catches where eelgrass was abundant.

Table 3-6. Numbers, cumulative percentage and seasons caught per species, 1974–1976*

Species	Total #	Cumulative %	Seasons primarily caught			
			winter	spring	summer	fall
Surf smelt	39442	26.5	X	X	X	X
Northern anchovy	35639	50.5			X	X
Shiner perch	31625	71.8		X	X	X
Pacific herring	17114	83.3			X	X
Chinook salmon	6355	87.6			X	X
English sole	6231	91.7	X	X	X	X
Pacific staghorn	3063	93.8	X	X	X	X
Starry flounder	1722	95.0	X	X	X	X
Rockfish spp.	1267	95.8			X	X
Chum salmon	1081	96.5		X		
Saddleback gunnel	1020	97.2	X	X	X	X
Pacific sandlance	765	97.7		X	X	
Buffalo sculpin	740	98.2	X	X	X	X
Threespine	461	98.5	X	X	X	X
Greenling sp.	252	98.7		X	X	X
Bay pipefish	218	98.9	X	X	X	X
Top smelt	192	99				X
Striped seaperch	170	99.1			X	X
Tube-snout	164	99.2	X	X	X	X
Cabezon	159	99.3		X	X	X
Sand sole	125	99.4	X	X	X	X
Coho salmon	114	99.5		X	X	X
Padded sculpin	93	99.5	X	X	X	
Pile perch	80	99.6			X	X
Cutthroat trout	79	99.6		X	X	X
Steelhead trout	75	99.7		X	X	
Prickly sculpin	68	99.7		X	X	
Pacific tomcod	66	99.8			X	
Snake prickleback	61	99.8		X	X	
Lingcod	44	99.9		X	X	
Sharpnose sculpin	29	99.9	X			X
Penpoint gunnel	28	99.9		X	X	
Pacific sanddab	27	99.9			X	X
Tubenose poacher	24	99.9			X	
Red Irish lord	15	99.9		X	X	
Ringtail snailfish	15	99.9+	X	X	X	
American shad	15	99.9+			X	
Walleye surfperch	8	99.9+			X	X
Longfin smelt	8	99.9+		X	X	
White seaperch	7	99.9+			X	X
Tidepool sculpin	6	99.9+	X			X

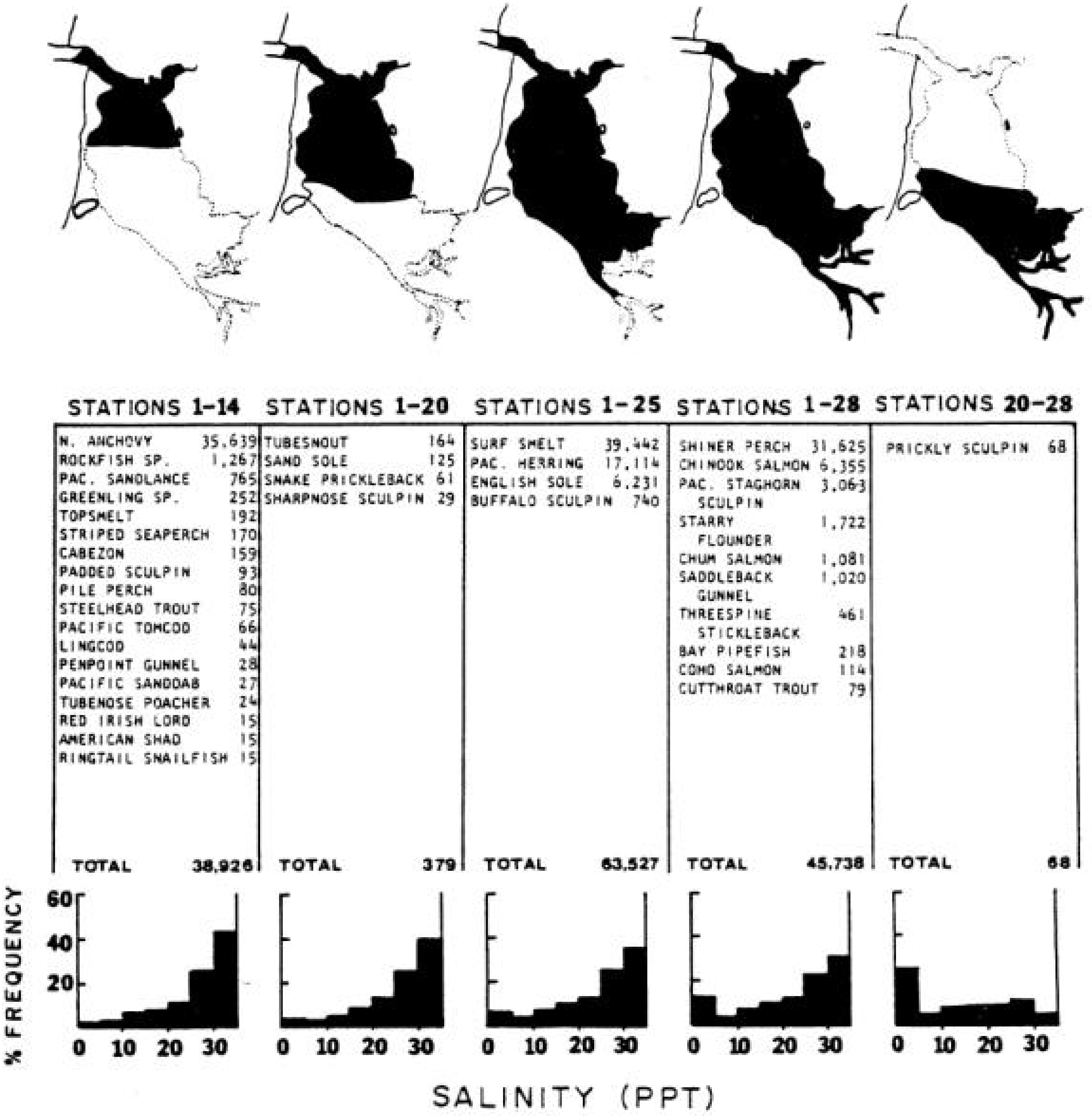
Species	Total #	Cumulative %	Seasons primarily caught			
			winter	spring	summer	fall
Redtail surfperch	4	99.9+			X	X
Arrow goby	3	99.9+	X	X		
Silverspotted sculpin	3	99.9+			X	X
Red gunnel	2	99.9+		X		
Silver surfperch	2	99.9+				X
Butter sole	2	99.9+		X		X
Brown Irish lord	2	99.9+		X		
Warty poacher	2	99.9+			X	
Slipskin snailfish	1	99.9+				X
High cockscomb	1	99.9+			X	
Pacific lamprey	1	99.9+	X			
Longnose skate	1	99.9+				X
Pricklebreast poacher	1	99.9+	X			
Smoothhead sculpin	1	99.9+		X		

***Total numbers, cumulative percentage and seasons caught for species collected in all seine and trawl sets in Tillamook Bay, 1974-1976.**
Source: Adapted from: Bottom, D. and B. Forsberg. 1978. The fishes of Tillamook Bay. Oregon Department of Fish and Wildlife, project no. F–100–R. 56 pp.

Although these factors may influence local distribution and abundance of the various species, salinity may be more important in defining broader zones of horizontal distribution. The abundance of several major groups of species appears to be related to broad salinity zones **(Figure 3-10)**. The observed decline in the total number of species and individuals with distance upriver in Tillamook Bay was presumably a typical pattern, where salinity was too low for a community dominated by strictly marine species.

A number of species occurred throughout all stations in Tillamook Bay, including a small group of euryhaline species that were most abundant in trawl sets in the upper Estuary. It has been observed in other estuaries that smaller and younger organisms are most often distributed in the lower salinity water, migrating toward the sea as they grow larger (Gunter 1961). This was seen in Tillamook Bay for shiner perch, staghorn sculpin, and starry flounder. Presumably, there is a survival advantage for juveniles that can utilize upper Bay areas for feeding and as a sanctuary from marine predators (McErlean *et al.* 1973).

Euryhaline:
Organisms that can tolerate a wide range of salt levels or salinity in either water or soils.



STATIONS 1-14	
N. ANCHOVY	35,639
ROCKFISH SP.	1,267
PAC. SANDLANCE	765
GREENLING SP.	252
TOPSMELT	192
STRIPED SEAPERCH	170
CABEZON	159
PADDED SCULPIN	93
PILE PERCH	80
STEELHEAD TROUT	75
PACIFIC TOMCOD	66
LINGCOD	44
PENPOINT GUNNEL	28
PACIFIC SANDDAB	27
TUBENOSE POACHER	24
RED IRISH LORD	15
AMERICAN SHAD	15
RINGTAIL SNAILFISH	15
TOTAL	38,926

STATIONS 1-20	
TUBESNOUT	164
SAND SOLE	125
SNAKE PRICKLEBACK	61
SHARPNOSE SCULPIN	29
TOTAL	379

STATIONS 1-25	
SURF SMELT	39,442
PAC. HERRING	17,114
ENGLISH SOLE	6,231
BUFFALO SCULPIN	740
TOTAL	63,527

STATIONS 1-28	
SHINER PERCH	31,625
CHINOOK SALMON	6,355
PAC. STAGHORN SCULPIN	3,063
STARRY FLOUNDER	1,722
CHUM SALMON	1,081
SADDLEBACK GUNNEL	1,020
THREESPINE STICKLEBACK	461
BAY PIPEFISH	218
COHO SALMON	114
CUTTHROAT TROUT	79
TOTAL	45,738

STATIONS 20-28	
PRICKLY SCULPIN	68
TOTAL	68

Figure 3-10. Predominant distribution of species captured in seine and trawl in Tillamook Bay, 1974-1976. Graphs show which of the relatively abundant species were found within the blacked out portion of the estuary. Those fish listed in 1-14 were found in the lower third of the Estuary, but only those listed in 1-20 were found from the middle through the lower portion of the Bay.

Source: Bottom, D., and B. Forsberg. 1978. The fishes of Tillamook Bay. Oregon Department of Fish and Wildlife project no. F-100-pp.

Since the 1974–1976 fish survey, no additional fish surveys have been conducted in the Bay that allow comparison with present conditions. Therefore, it is not possible to determine whether species composition, relative abundance, or distribution patterns have changed.

Bay Clams

Population Status and Trends

The bay clam populations in Tillamook Bay provide a valuable resource for recreational and commercial users. Twelve species of bay clams have been collected from Tillamook Bay **(Table 3-7)** but

Table 3-7. Scientific and common names of clams known to occur in Tillamook Bay

Scientific name	Common name
Clinocardium nuttallii	cockle clam
Cryptomya californica	California softshell clam
Macoma balthica	baltic clam
Macoma irus	irus clam
Macoma nasuta	bentnose clam
Macoma secta	sand clam
Mya arenaria	eastern softshell clam
Saxidomus giganteus	butter clam
Solen sicarius	jackknife clam
Tellina bodegensis	Bodega tellin clam
Tresus capax	gaper clam
Venerupis staminea	native littleneck clam

Sources: Griffin, K. 1995. Identification and distribution of subtidal and intertidal shellfish populations in Tillamook Bay, Oregon. Report submitted to the Tillamook Bay National Estuary Project, Garibaldi, OR. 68 pp.
Hancock, D., T. Gaumer, G. Willeke, G. Robart and J. Flynn. 1979. Subtidal clam populations: Distribution, abundance, and ecology. Oregon State University Sea Grant College Program.

The most important commercial and recreational species are the gaper, cockle, butter, and native littleneck clams.

the most important commercial and recreational species are the gaper, cockle, butter, and native littleneck clams. Cockle clams comprise approximately 90% of the commercial fishery.

The first comprehensive survey of the clam population in Tillamook Bay, conducted between 1974 and 1975, first identified areas of the Bay that had clam population densities that could support commercial harvest (Hancock *et al.* 1979). The pre-determined density that could support commercial harvest was greater than five clams per ft^2 ($54/m^2$). Areas that met this criterion then were surveyed further to assemble information such as biomass estimates, composition of the populations (age, size, species, etc.), and habitat characteristics. Additional surveys in 1984 and 1985 covered the same area, and again derived biomass estimates, population composition, and habitat characteristics (Gaumer 1986 and 1986). The data from these two surveys are becoming dated but ODFW still uses them for management of the resource.

Two recent surveys of the clam populations have been conducted.

Two recent surveys of the clam populations have been conducted. In 1995, a partial survey (94 stations) of the lower Estuary was conducted to identify those areas of the Estuary that support relatively dense populations of commercially and recreationally important species of clams (Griffin 1995). This study was followed in 1996 by a more comprehensive inventory of the entire Estuary (Golden *et al.* 1997). Preliminary data summaries were available for the 1996 study at the time this report was prepared. In both studies, sampling methods were designed to be consistent with those of the previous ODFW surveys so that data could be directly comparable.

Table 3-8 tracks the densities of the four most important clams in the Hobsonville Channel (an area of high subtidal clam density) over the period 1974–1975 to 1996. Between 1974–1975 and 1996, butter clam abundance appears to have increased dramatically, littleneck clam increased substantially, and cockle clam increased slightly. Gaper clam numbers showed a major decline. The State banned mechanical harvesting in 1985 after the 1984 and 1985 surveys revealed poor recruitment of gaper clams. The differences for cockle, littleneck, and butter clam density estimates between 1995 and 1996 appear to be substantial, and could reflect actual changes in density between the two sampling dates. Anecdotal reports of mass die-offs of intertidal cockles during the floods of 1995/96 could explain the decline for cockles, which do not burrow well and might be smothered by sediment more easily than other species. But the increases for butter and littleneck clams are probably due to sample variability, since the 95% confidence limits for the individual means in both sets were generally as large or larger than the estimated numbers per square meter.

Golden et al. (1997) found substantial differences in the size distribution of clams between intertidal and subtidal areas.

Table 3-8. Density of clams (no./m^2) in Hobsonville Channel

Species	1974–75	1984	1985	1995	1996*
Cockle	18.6	21.6	28.0	30.7	17.3
Littleneck	15.7	28.1	25.8	12.1	24.4
Gaper	16.4	3.2	4.3	1.7	4.4
Butter	7.9	19.4	31.2	23.9	53.1
Average	14.7	18.1	22.3	17.1	24.8

*** Computed as the average of Golden *et al.* sampling sites S1 and S3.**

Sources: Griffin, K. 1995. Identification and distribution of subtidal and intertidal shellfish populations in Tillamook Bay, Oregon. Report submitted to the Tillamook Bay National Estuary Project. 68 pp.
Golden, J., D. Gillingham, V. Krutzikowsky, and J. Johnson. 1997. A biological inventory of benthic invertebrates in Tillamook Bay. Oregon Department of Fish and Wildlife, Newport, OR. 40 pp. + appendices.

The 1997 Golden *et al.* inventory also compared 1996 biomass data from similar subtidal areas (overlapping sample sites) sampled in 1974–1975. In those areas, total biomass of clams in 1996 (129,545 lbs/acre, 144,898 kg/ha) was substantially higher than total biomass in 1974–1975 (54,443 lbs/acre, 60,895 kg/ha). Cockle clams for areas of overlap had a biomass of 15,139 lbs/acre (16,934 kg/ha) in 1996, compared with 10,573 lbs/acre (11,826 kg/ha) in 1974–1975. Golden *et al.* (1997) believed the increase in biomass between 1974–1975 and 1996 is largely due to the growth in weight of cockle clams and increased butter clam densities, but added that different survey methods could contribute to the increase.

Golden *et al.* (1997) found substantial differences in the size distribution of clams between intertidal and subtidal areas. Larger clams of all species were found in the subtidal areas than in the intertidal areas. The researchers attributed this to heavy recreational harvest, especially in the Garibaldi Flat area. Anecdotal reports of weather-related clam die-offs in intertidal areas could also explain some of the difference.

Harvest information for the commercial fishery between 1978 and 1994 shows a recent rapid increase in the harvest of cockle clams in

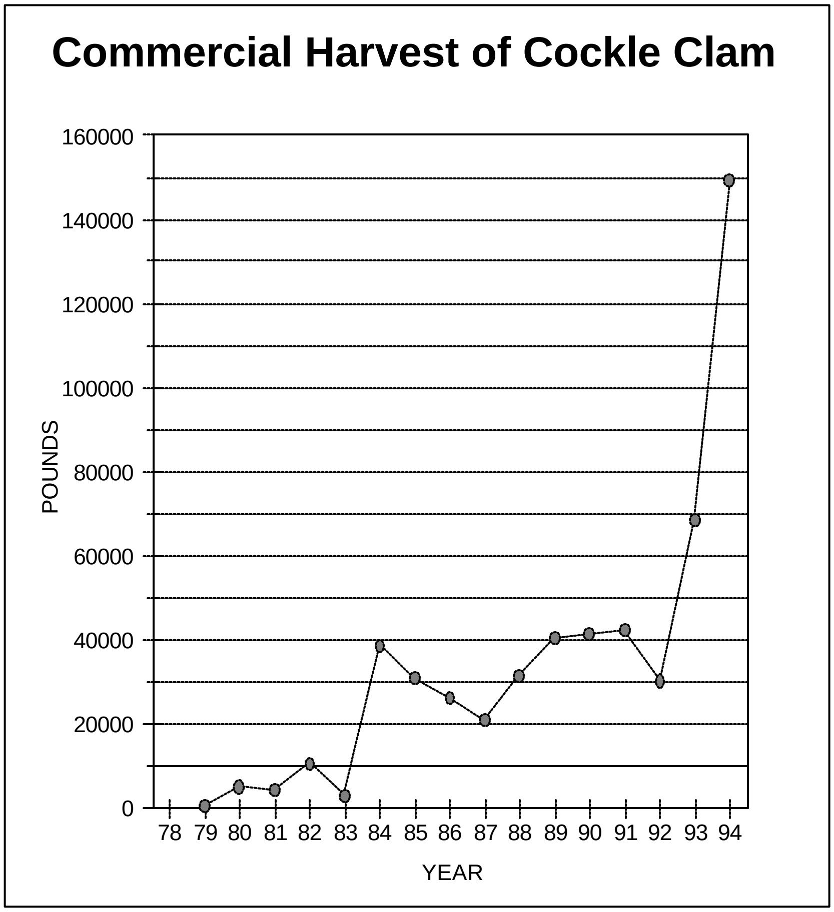


Figure 3-11. Commercial harvest of cockle clam in Tillamook Bay, 1978-1994.
Source: Griffin, K. 1995. Identification and distribution of subtidal and intertidal shellfish populations in Tillamook Bay, Oregon. Report submitted to the Tillamook Bay National Estuary Project, Garibaldi, OR. 68 pp.

Tillamook Bay **(Figure 3-11)**. Commercial harvest of the three other commercially important species (littleneck, gaper, and butter) remained relatively constant over the same period. Due to concern over the rapid increase in the commercial harvest of cockle clams, the ODFW placed a commercial quota of 90,000 pounds per year beginning in 1995. This quota represents about 10% of the estimated biomass of market-sized clams in the areas that have been surveyed in the past. A quota of 10% is considered a conservative management tool, since the biomass estimate only applies to a limited, albeit productive, portion of the Bay. Data collected during the 1995 and 1996 surveys indicated that substantial numbers of cockle clams live in other parts of the Bay (Griffin 1995, Golden *et al.* 1997).

Recreational harvesting of bay clams has not been monitored very closely, thus the number of reliable data points for trend analysis is limited.

Recreational harvesting of bay clams has not been monitored very closely, thus the number of reliable data points for trend analysis is limited. A detailed study, conducted in 1971, indicated that the total recreational catch for the period March–October 1 was about 60,750 clams from Garibaldi Flat (Gaumer *et al*. 1973–74). Estimates for 1993–1995 on the same area (Griffin 1995), indicate an average of about 13,700 clams. The bag limit in the early 1970s was 36 bay clams versus the present 20 clams, which may account for part of the difference. However, there is little doubt that recreational use of the clam resource was considerably higher in the early 1970s than it has been in recent years. From 1993 through 1995, the harvest increased steadily from 8,183 pounds to 21,759 pounds (3,052 to 8,116 kg), suggesting a possible resurgence in recreational clamming, at least at Garibaldi Flat.

Survival and growth at a given location are determined by a variety of habitat factors, including availability of food, salinity, substrate composition and stability, current velocity, inter- and intra-specific competition, predation, and water quality.

Habitat Status and Trends

The life cycle of bay clams, although variable in length, is generally similar. Female clams release millions of eggs into the water column, where they are fertilized by sperm released by nearby males. The fertilized eggs soon hatch into free-swimming larvae. The larval period varies from species to species but one to two weeks is common. The larvae are usually carried many miles by the tidal currents and therefore become widely distributed throughout the estuary. At the end of the free-swimming stage the larvae develop an embryonic shell and a siphon and gills appear. The young clams settle to the bottom. This is known as a clam "set" and the young clams are known as "seed" clams. At this stage they are about the size of a grain of sand. After a variable period of growth, the seed clams begin digging and bury themselves in the substrate. Survival and growth at a given location are determined by a variety of habitat factors, including availability of food, salinity, substrate composition and stability, current velocity, inter- and intra-specific competition, predation, and water quality.

Substrate composition appears to be an important limiting factor for cockle, gaper, littleneck, and butter clams. None of these species is found in any abundance in mud or mud-silt substrates. This factor basically restricts these four species to the lower half of the Bay. Based on 92 samples collected in 1995, Griffin (1995) plotted the density of cockle, gaper, littleneck, and butter clams on a variety of substrates where measurable densities were found in the lower Estuary. His results indicated that all four species occurred in substrates consisting of mixtures of the following: (1) rock and sand; (2) sand and silt; and (3) rock, sand, shell, and silt. Gaumer (1977) noted that substrate in the Garibaldi area of Tillamook Bay consisted of gravel and rock with some shell and sand. This area supported some of Oregon estuaries' heaviest concentrations of intertidal and subtidal bay clams.

Substrate composition appears to be an important limiting factor for cockle, gaper, littleneck, and butter clams.

Species of clams that are not as commercially or recreationally important generally occur in shallow or intertidal areas characterized by muddy, silty substrate (Griffin 1995). These species include the eastern softshell, bentnosed, irus, and baltic clams. These clams, especially the softshell and bentnosed, can withstand significantly different conditions than the four economically important species, including low salinity, foul substrate, and anaerobic conditions.

Clam populations appear to be negatively affected by the presence of burrowing shrimp. Tillamook Bay hosts two species of burrowing shrimp: the ghost shrimp (*Callianassa californiensis*), and the mud shrimp (*Upogebia pugettensis*). Griffin (1995) found burrowing shrimp in 26 of the 92 total stations sampled in 1995 for clams. Of those 26 sites, only three also had clams, and in the lowest densities of any of the stations sampled. Gaumer and McCrae (1990) reported that an increase in the abundance of mud and ghost shrimp on Bayocean Spit in Tillamook Bay during the interval 1975 to 1986 virtually eliminated cockle clams from this once productive area. Similar impacts of burrowing shrimp on clam populations have been observed in other estuaries (*ibid.*). The factors responsible for increases in burrowing shrimp populations are poorly understood.

Eelgrass and clams may also be incompatible. Griffin (1995) found that of 21 stations where eelgrass was present, only five had clams as well. Those five had only gapers and cockles, and always in densities less that 10.8/m^2. Additionally, at the five stations where eelgrass and clams coexisted, the density of eelgrass was low (always less than 50% cover). Griffin noted that his survey was limited in scope and that additional work would be necessary to confirm or refute his findings regarding the influence of eelgrass. It also should be noted that Gaumer and McCrae (1990) reported that gaper clam densities were often highest near eelgrass beds in Oregon estuaries. Eelgrass beds, however, provide critical habitat for many other aquatic species.

The influence of changing suspended sediment input rates on clam populations is poorly understood.

The influence of changing suspended sediment input rates on clam populations is poorly understood. As discussed in Chapter 5, the dynamics of sediment deposition and erosion in the Bay have not been studied in any detail. However, bathymetric surveys conducted sequentially since the mid-1880s clearly demonstrate that the Estuary is filling in with sediment and that the rate of filling has accelerated since the mid-1800s. Golden *et al.* (1997) noted that the southern channel areas of the Bay were affected most by recent flooding, with clam beds covered by silt more than one foot (30 cm) deep in some places. As discussed above, the commercially and recreationally important clam species avoid substrates consisting of mud or mud and silt. As the Estuary fills with mud and silt, the amount of substrate suitable for production of important clam species may decline.

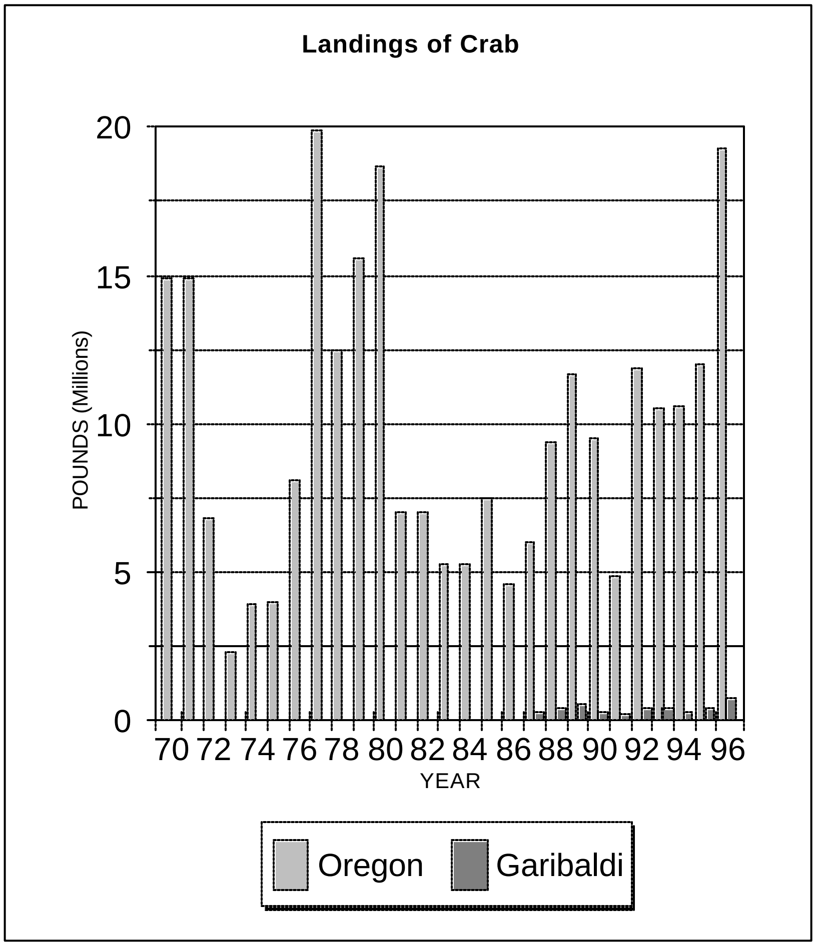


Figure 3-12. Commercial landings of Dungeness crabs for the entire Oregon Coast and for the Port of Garibaldi.
Source: Oregon Department of Fish and Wildlife commercial fisheries statistics, 1997.

Dungeness Crabs

Population Status and Trends

Dungeness crabs are an important biological resource of Tillamook Bay, harvested both for commercial and recreational uses. Most commercial harvesting of Dungeness crabs occurs along the open coast in shallow near-shore waters. The recreational harvest of Dungeness crabs in Oregon takes place in the estuaries. Catch statistics (pounds landed) for commercial crab landings are available for the Oregon Coast and since 1987 for the Port of Garibaldi **(Figure 3-12)**. Cycles in crab abundance have been observed in the northern California, Oregon, and Washington crab catch statistics, with a nine- to ten-year frequency of relatively high catches alternating with low catches (Berryman 1991). It is assumed that the catch reflects the general abundance of harvestable size

Cycles in crab abundance have been observed, with a nine- to ten-year frequency of relatively high catches alternating with low catches.

crabs. However, because fishing effort varies from year to year due to weather conditions, crab price, and regulatory constraints, population trend analysis based on catch could be misleading.

The population status of Dungeness crabs in Tillamook Bay has not been monitored. The only biological survey data available for Tillamook Bay crab is distribution and relative abundance data collected by ODFW in 1974–1975 (Forsberg *et al*. 1975). During the 12-month study, 5,031 crabs were captured. Crabs were present throughout the entire Estuary but most were captured in the lower third. Legal-size crabs were caught only in the lower and mid-Bay, while sublegal crabs where caught throughout the Bay. The furthest intrusion of crabs into the upper Estuary occurred during the summer and fall, probably associated with low fresh water inputs and subsequent higher estuarine salinity. Most crabs (59%) were captured during the summer and very few (5%) in the winter. The ODFW monitors and regulates the commercial crab harvest. Only male crabs with a carapace width of 5.75 inches (16.5 cm) may be harvested. Most Dungeness crabs mature at age 2 and can spawn before reaching harvestable size at age 3 or 4 (Emmett *et al*. 1991). In the Estuary, the daily recreational catch is limited to 12 legal size crabs. The length of the commercial fishery has been lengthened or shortened based on projected abundance of harvestable crabs in coastal waters. No seasonal restrictions have been placed on the recreational crabbing in Tillamook Bay.

In summary, insufficient data are available to evaluate either the present status of Dungeness crabs in the Estuary or trends in their abundance.

The population status of Dungeness crabs in Tillamook Bay has not been monitored.

Habitat Status and Trends

Although Dungeness crabs have been harvested commercially and recreationally along the Pacific Northwest Coast and in its estuaries for many years, relatively little research has been conducted to identify the important habitat parameters necessary for the success of the various life stages. Much of what is presently known regarding habitat requirements, larval dispersal patterns, and migration patterns of the juvenile life stages has been developed within the last 15 years. The need to understand the effects of estuarine dredging operations on crab resources has been the impetus for much of the recent research. Most of the research relevant to Tillamook Bay has been conducted on the Washington Coast in Grays Harbor and Willapa Bay.

Crab surveys conducted between 1983 and 1987 in Washington’s Grays Harbor and Willipa Bay and adjacent areas of open coast have shown that coastal crab populations rely heavily on both estuaries as nursery areas (Gunderson *et al*. 1990). Although not documented for the coastal populations adjacent to Tillamook Bay, a similar relationship likely exists. It was found in Washington that

Megalops:
A larval stage in crabs in which the legs and abdominal appendages have appeared, the abdomen is relatively long and the eyes are large.

mating and spawning take place in coastal waters. Mating takes place primarily in March and April but may extend as late as July. After mating the spermatophores remain viable in the female for many months and fertilize the eggs upon extrusion (Wild 1983). Each female carries as many as 1.5 million eggs. The eggs hatch in the spring into larvae which remain pelagic for four to five months. The larvae undergo a series of molts and transformations and by May or June are abundant in coastal and estuarine waters as megalops. After the last molt of the megalops stage, the young crabs settle to the bottom in both coastal and estuarine environments. Crabs that initially settle in estuaries grow substantially faster than those that settle along the open coast. Juveniles remain in the areas of settlement over their first winter and then most coastal 1-plus crabs immigrate to estuaries to join siblings that settled there the previous year. By September of the second year, many crabs at about 4 inches (10 cm) carapace width emigrate to the open coast, where they reach maturity. Another study conducted in Grays Harbor (Stevens and Armstrong 1984) found that there is a secondary emigration to coastal waters when crabs that remain in the estuary reach sexual maturity. Thus it appears that estuaries play a critical role in the maintenance of crab populations along the Washington coast and probably along the Oregon coast as well.

Estuarine habitats utilized by Dungeness crabs vary considerably by age. Early juvenile crabs have been shown to prefer eelgrass beds and intertidal substrate with a high content of clam or oyster shell (Stevens and Armstrong 1984, Eggleston and Armstrong 1995). McMillian *et al.* (1995) found that post settlement mortality of crab in northern Puget Sound correlated inversely with habitat complexity. Survival was highest in a mixed sand and gravel substrate with an overstory of attached drift algae, intermediate in eelgrass, and lowest on open sand. These studies suggest that eelgrass beds and areas with complex substrate conditions such as are found in oyster beds and the shell-dominated substrates in lower Tillamook Bay may be very important refuge habitat for early juvenile crab.

Estuarine habitats utilized by Dungeness crabs vary considerably by age.

Because of the importance of eelgrass beds to early juvenile crab and many other estuarine species, it is important to determine whether the extent and density of eelgrass habitat in Tillamook Bay has changed significantly through time. The earliest map of eelgrass beds and other vegetation in Tillamook Bay was produced in 1975 as part of 1974–1975 fish surveys (Forsberg *et al.* 1975). The map **(Figure 3-13)** showed the general distribution of eelgrass but did not provide estimates of density. A partial map of eelgrass beds was prepared and mapped on the transects sampled for clams in 1974–75 (Gaumer 1977). This map **(Figure 3-14)** provided only partial coverage of the Estuary but did distinguish between sparse, moderate, and dense eelgrass beds. Until recently no additional attempts had been made to map the location or density of eelgrass beds.

Multispectral airborne video of Tillamook Bay during the lowest tide of the month. The major emphasis of this work was to map eelgrass distributions while getting a more detailed picture of the Bay's various substrates.

In July 1995, the TBNEP contracted to acquire multispectral airborne video of Tillamook Bay during the lowest tide of the month. The major emphasis of this work was to map eelgrass distributions while getting a more detailed picture of the Bay's various substrates. **Figure 3-15** shows the classified imagery, which was field verified. Dense and sparse eelgrass beds could be distinguished but some eelgrass may also occur in areas designated as mixed algae because separation of species in these areas was not possible. Due to the uncertain accuracy of the 1975 mapping, quantitative assessment of changes in the real extent of eelgrass beds is probably not warranted. However, some qualitative observations regarding changes in distribution can be made.

Eelgrass bed distribution in Tillamook Bay may have changed during the past 20 years.

In comparing the 1995 imagery map (Figure 3-15) with the maps developed in the mid-1970s (Figures 3-13 and 3-14), it can be seen that in the mid-1970s most eelgrass beds were located in the following areas: (1) the mid-section of the Bay, (2) along the northeastern edge of the Bay, (3) bordering both sides of the main outlet channel at the northern end of the Bay, and (4) on the Miami River delta near Garibaldi. In 1995, only sparse eelgrass beds were present in the mid-section of the Bay. Eelgrass was still present on the Miami River delta and along the edges of the main channels at the northern end of the Bay. Also, substantial expanses of dense eelgrass were present on portions of several tidal flats at the northern and southern ends of the Bay. The beds at the southern end of the Bay were not identified on the mid-1970s maps. These comparisons indicate that eelgrass bed distribution in Tillamook Bay may have changed during the past 20 years.

As juvenile Dungeness crab grow larger, they move from eelgrass beds and other protective shallow water habitat into deeper water and prefer the lower half of the estuary where salinity is generally higher. A study comparing densities of crab in subtidal and intertidal habitats (Stevens *et al.* 1984) suggests that adult crabs may be sensitive to high light levels and are generally found during the day in relatively deep water where light intensity is low. Movements of crab from subtidal areas to intertidal areas during darkness have been recorded. These movements appear to be related to greater food availability on the intertidal flats (Stevens *et al.* 1984). Thus it appears that subtidal channel habitat is important for the larger size classes of crab. As discussed above for the clams, sediment from the Watershed is filling in areas where relatively deep subtidal habitat previously occurred. This loss of channel habitat, particularly if it extends into the lower Bay could shrink the amount of living space for the larger size classes of Dungeness crab.

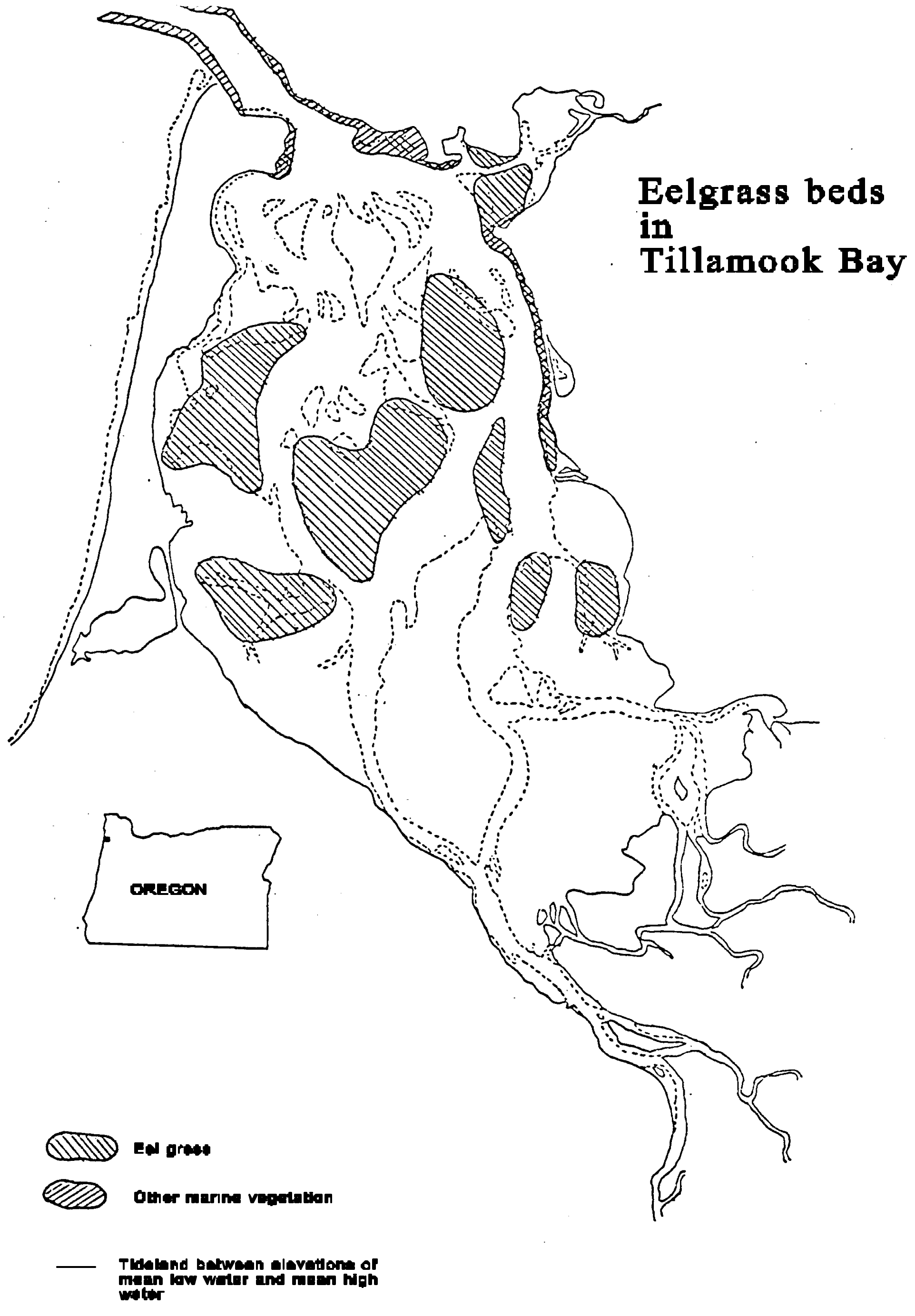


Figure 3-13. Eelgrass beds in Tillamook Bay in 1975.
Source: Forsberg, B., J. Johnson, and S. Klug. 1975. Identification, distribution, and notes on food habits of fish and shellfish in Tillamook Bay, Oregon. Fisheries Commission of Oregon, contract report no- 14-16-0001-5456 RBS. 85 pp.

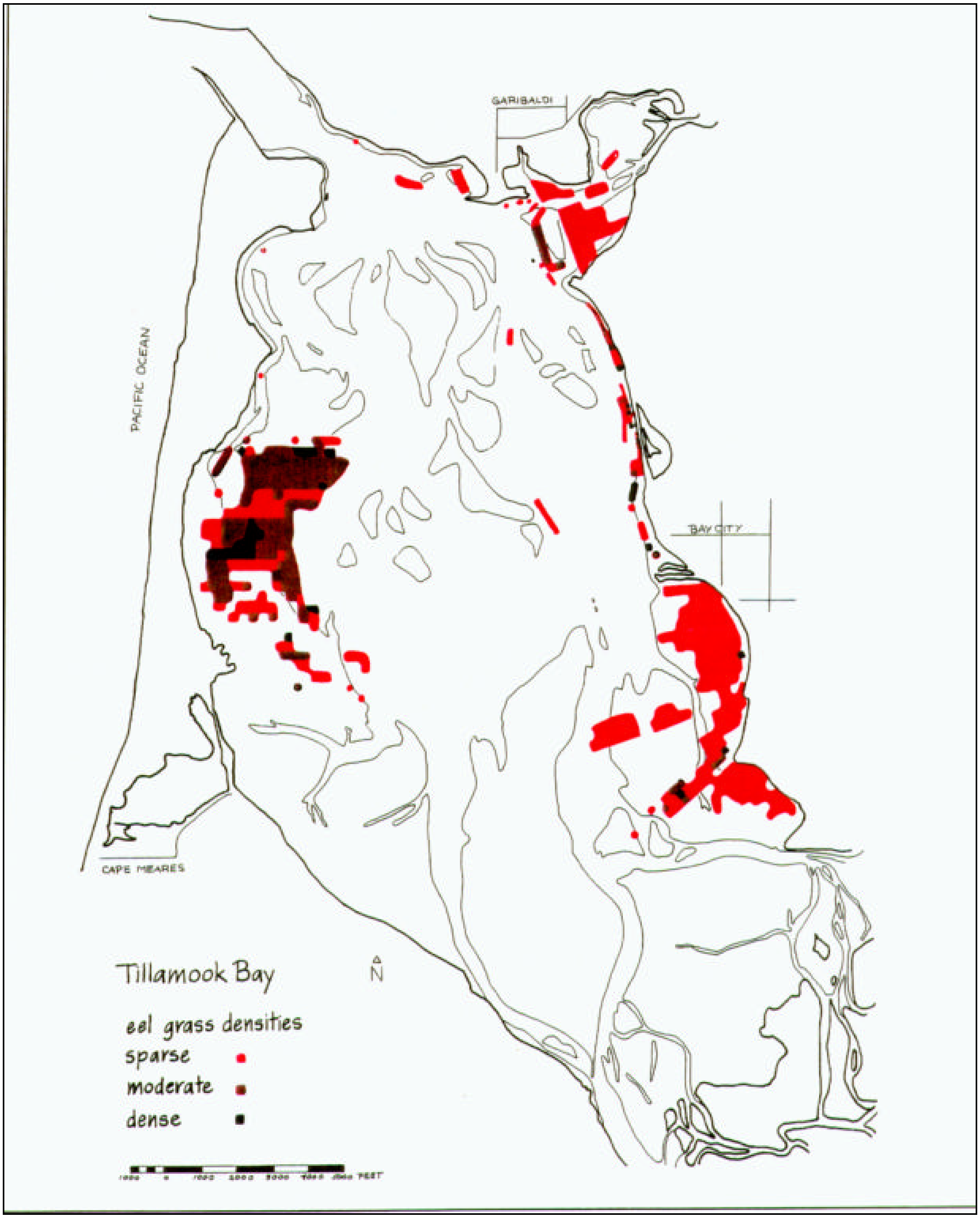


Figure 3-14. Eelgrass beds identified on transects sampled during 1967-1977 clam surveys.
Source: Gaumer, T. 1977. Oregon bay clam distribution, abundance, planting sites and effects of harvest. Annual rep. NOAA, National Marine Fisheries Service project no. 1-122-R Segment 1. 38 pp.

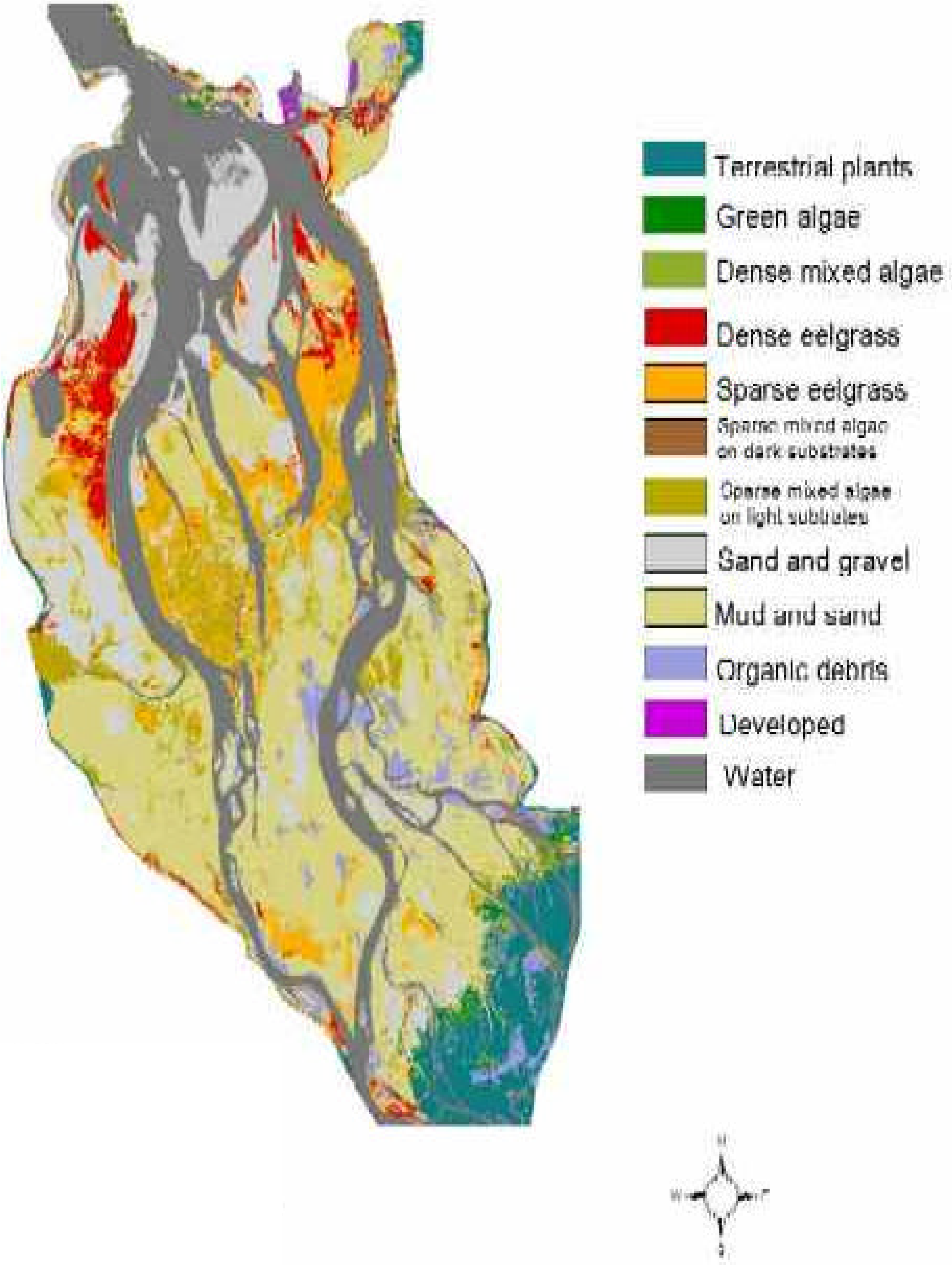


Figure 3-15. Eelgrass beds, other plants, and substrates of Tillamook Bay, July 1995.
Source: Earth Design Consultants. 1996.Corvallis, OR. Prepared for Tillamook Bay National Estuary Project, Garibaldi, OR

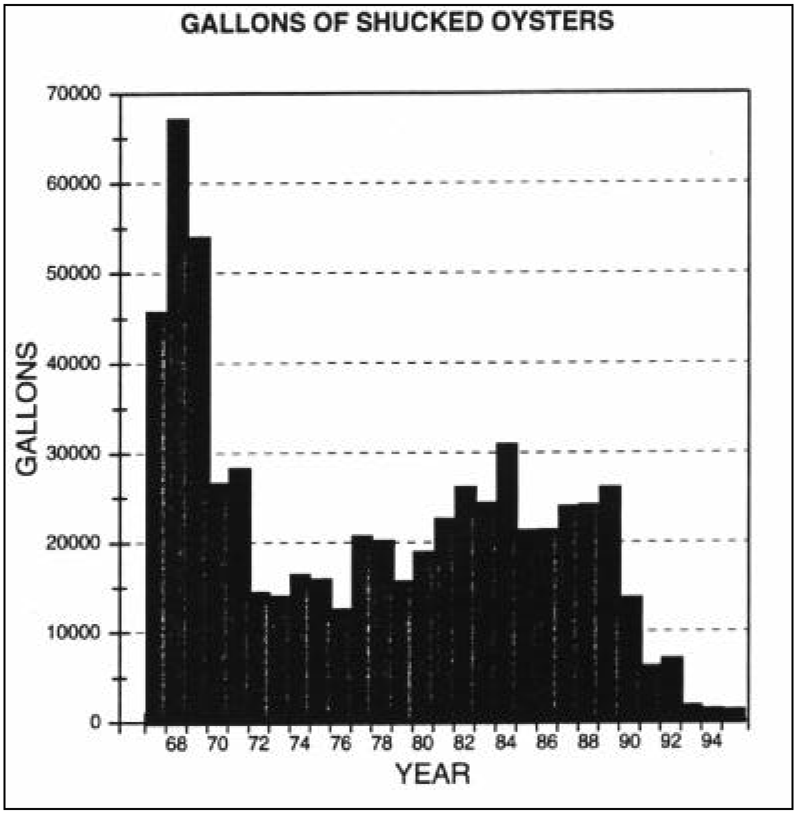


Figure 3-16. Commercial oyster production in Tillamook Bay between 1967 and 1995.
Source: Oregon Department of Agriculture. Agricultural statistics.

Oysters

Population Status and Trends

Oysters have been grown commercially in Tillamook Bay since the 1930s. Most of the production has been from culture of the Pacific oyster (Crassostrea gigas) that was introduced to the United States from Japan in the early 1900s (Quayle 1988). A smaller variety of Crassostrea, the Kumamoto oyster (C. sikamea) was introduced in the late 1940s and early 1950s. The Kumamoto oyster's flavor is considered better than the larger Pacific oyster but it is more difficult to raise. Kumamoto oysters have been grown in Tillamook Bay but they are a small percentage of total production.

Between 1970 and 1989, total oyster production in Tillamook Bay remained relatively constant (Figure 3-16) with an average annual production of about 21,200 shucked gallons. This level of production made Tillamook Bay the leader among the oyster producing estuaries on the Oregon coast. However, beginning in 1990, production dropped off sharply and has remained very low since that time. Much of the drop in production since 1990 is due to drastically reduced production by the Hayes Oyster Company, which holds leases on 1,700 of the 2,500 acres (689 of 1,012 hectares) of state tidelands leased for oyster production in Tillamook Bay. Also, Olson Oyster Company and Tillamook Oyster Company have ended their operations.

Within the last few years, several new plats near the northern end of the Bay have been leased from the State of Oregon and begun production. If the old leases are successfully brought back into full production and the new leases prove successful, oyster production could surpass the 1970s and 1980s levels. However, as will be discussed later, growth of the oyster industry in Tillamook Bay will probably continue to be limited by a number of factors — some natural and some directly related to human activities.

The oyster industry in Tillamook Bay will probably continue to be limited by a number of factors — some natural and some directly related to human activities.

Habitat Status and Trends

In Tillamook Bay, tideland oyster plats for rearing oysters are leased from the State of Oregon. As previously discussed, Tillamook Bay has approximately 2,500 acres (1,012 ha) of leased oyster plats. Most of these plats are located west of Bay City in the mid-region of the Estuary.

The Pacific oyster is cultured in lower intertidal areas in mesohaline-euhaline waters (usually 10–35 ppt) (Barrett 1963, Berg 1971, and Quayle 1988). It usually grows best on firm bottoms but can be found on mud or mud-sand bottoms. It tolerates air temperatures of 25° F (4° C) during low tides and water temperatures of 40–97° F (4–36° C). Adults will continue to feed down to 38° F (3° C), but growth stops when temperatures drop below 50° F (10° C) (Quayle 1988). Best conditions for somatic growth are 63° F or 17° C (range 60–65° F or 15–18° C); salinities >24 ppt (range 10–35 ppt); food suspensions of 120 mg/l; and pH levels above 7.8 (Bernard 1983, Brown and Hartwick 1988). Growth rates correlate primarily with suspended particulate organic material levels and secondarily with temperature, but are mediated by salinity (Malouf and Breese 1977, Brown 1988).

Salinity levels:

saline	
hyperhaline	40 ppt
euhaline	30–40
brackish	
polyhaline	18–30
mesohaline	5–18
oligohaline	0.5–5
fresh	<0.5

Somatic growth:
Growth of the body of an organism rather than the reproductive tissue.

The ODFW monitored salinity and water temperature on the Estuary bottom monthly between May 1974 and April 1975 at several mid-Bay locations (Forsberg et al. 1975). Water temperature ranged from 45° F (7° C) in January to 60° F (15° C) in August but was less than 55° F (13° C) throughout most of the year. No information on the daily fluctuations in water temperature was collected. Salinity ranged from about 34 ppt during October to about 5 ppt in January. During most of the year salinity ranged between 20 and 30 ppt. These data indicate that Tillamook Bay waters are typically cooler than optimum, whereas salinity is generally in the preferred range for Pacific oyster. DEQ Storet data don’t suggest any major changes in these water quality parameters.

Water quality affects oyster marketing, as well as growth and survival. One of Tillamook Bay oyster growers' biggest problems is fecal coliform bacteria in the water column.

Water quality affects oyster marketing, as well as growth and survival. One of Tillamook Bay oyster growers' biggest problems is fecal coliform bacteria in the water column, which periodically exceed state health standards, as discussed in Chapter 4, Water Quality. Since oysters remove bacteria from the water column, they may represent a health hazard if consumed raw. High bacteria levels result in temporary shutdowns of the Bay's oyster harvesting. Chapter 4 includes a detailed discussion of the coliform bacteria problem, its regulation, and effects on oyster operations.

Siltation and increased turbidity over oyster beds resulting from sediment carried into northwest estuaries from tributary rivers and streams can result in high oyster mortalities (Pauley et al. 1988, Quayle 1988). This problem represents a continuous threat to Tillamook Bay oyster growers and has caused recurring damages during flood events such as those in 1952, 1965, 1972, and 1996. If siltation is severe during floods, it can take several years to get back to full production. In 1952, Bayocean Spit, the narrow peninsula that separates the ocean from the Bay, breached near the oyster beds. The resulting catastrophic sediment event covered the beds with sand, killing most of the oysters. The breach was repaired in 1956 and oyster production was reestablished.

Oysters need an adequate supply of phytoplankton for food, which must be composed of usable species. Generally, anything that interferes with adequate light and nutrient supplies could reduce phytoplankton production, but it is not known to what extent nutrient or light availability may limit phytoplankton production in Tillamook Bay. Changes in water conditions also could foster production of phytoplankton species that are less suitable as oyster food. Little is known about phytoplankton species composition in Tillamook Bay.

Oysters need an adequate supply of phytoplankton for food, which must be composed of usable species.

Changes in ocean productivity could influence oyster production in estuaries along the Pacific Northwest coast. A possible correlation between oyster condition and ocean productivity has recently been suggested for Willapa Bay oysters (Ebbesmeyer and Strickland 1995). Scientists at the Washington State shellfish laboratory on Willapa Bay evaluate oyster condition by calculating an Oyster Condition Index (OCI), the average ratio of dry weight of meat (in grams) to the volume of the oyster shell cavity (in milliliters). In calculating OCI, this ratio is usually multiplied by 100. A high value of OCI is desirable because it means more meat and higher price per oyster. The OCI values in Willapa Bay typically range from 4 to 12. Data have been collected since 1954. From 1955 though 1977 the OCI averaged 9.0. From 1978 through 1993, OCI decreased about 28% to an average of 6.5. When the OCI was plotted against the Pacific Northwest Index (PNI), a composite weather condition index based on long-term climatic data for the Pacific Northwest, researchers found a correlation between the two. Under the cool, wet conditions that prevailed from the 1950s to the mid-1970s (negative PNI), oyster condition was good (OCI was high). Under the warm, dry conditions (positive PNI), oyster condition has declined (OCI is lower). Oceanic conditions could be responsible because the direction from which the water reaches the Washington Coast affects water temperature, nutrient supplies, and phytoplankton production off the coast. Under cool, wet conditions (negative PNI), currents bring more cold, nutrient-rich subarctic ocean water from the north to the Washington Coast. Under warm, dry conditions (positive PNI), the subarctic water off Washington's coast is replaced by warmer, lower nutrient water from farther south. The researchers pointed out that although oyster condition and ocean productivity may be related, the observed correlation does not imply a cause-effect relationship and could involve a variety of other factors not considered.

Other environmental variables have also been shown to influence the survival and production of the Pacific oyster. For example, juveniles and adults are affected by storms and associated waves that can displace individuals and bury them in sediment (Cheney and Mumford 1986). Diseases and algal blooms that inhibit feeding can also reduce population size and growth.

The researchers pointed out that although oyster condition and ocean productivity may be related, the observed correlation does not imply a cause-effect relationship and could involve a variety of other factors not considered.

Other estuarine species also reduce Pacific oyster growth or indirectly affect oyster viability. For example, mud and ghost shrimp cause very serious problems for oyster growers in Tillamook Bay. These burrowing shrimp damage oyster beds by making them too soft for culture or by smothering the oysters. Beginning in the early 1960s, some growers managed this problem through the use of the pesticide Sevin (carbaryl). Sevin was shown to reduce mud and ghost shrimp populations by more than 90%, which subsequently improved substrate conditions and survival rates for the oysters. However, Sevin is a non-specific pesticide and also killed substantial numbers of other estuarine invertebrates. Due to growing concern regarding the effects of Sevin on the ecology of the Estuary, growers were ordered to seek ODFW permits in 1982 for Sevin use. Lawsuits over these permits led to a court decision (Oregon Court of Appeals 1984) which effectively terminated the practice. However, Washington growers still use Sevin under very strict application guidelines.

Oysters are often grown in association with eelgrass beds because eelgrass beds are typically located on relatively firm, stable substrate. The few studies that have investigated the effect of oyster culture on eelgrass beds indicate that the presence of an active oyster site results in decreased eelgrass abundance (Rumrill and Christy 1996, Pregnall 1993, Waddell 1964, Everett et al. 1995). These studies have documented decreased shoot density and percent cover, as well as poor natural recovery after oyster culture ceases in a given area. However, most of these studies concern rack or stake culture, which may have very different mechanisms and effects than ground culture. The only study to investigate the impact of ground culture on eelgrass also found that ground culture causes a decrease in eelgrass abundance (Rumrill and Christy 1996). There is some evidence that the presence of oysters in eelgrass beds can be beneficial. Oysters remove food particles from the water column and deposit the undigested component as feces on the substrate. The fecal material may provide additional plant nutrients for eelgrass growth (Langdon, C. pers. com. 1997). No carefully designed research to evaluate this effect has been conducted in Pacific Northwest estuaries.

The uncertainties associated with oyster production, especially the burrowing shrimp and water quality problems, have made oyster growers anxious about risking capital on large quantities of spat, which may help explain why the oyster industry in Tillamook Bay has not significantly increased over the years.

A variety of predators are known to eat juvenile and adult Pacific oysters, including: crabs (C. magister, C. productus, and C. gacilis), the common oyster drill (Urosalpinx cinerea), starfish (Pisaster spp., Evasterias troschlii, and Pycnopodia helianthoides), and ducks and scoters. However, crabs are the only significant oyster predator in Tillamook Bay.

In summary, many variables influence the success of oyster production in Tillamook Bay. Problems associated with flooding, siltation, bacterial contamination, and burrowing shrimp are relatively obvious. Effects of changes in other variables such as ocean productivity, phytoplankton composition, light penetration, and water temperature are poorly understood. The uncertainties associated with oyster production, especially the burrowing shrimp and water quality problems, have made oyster growers anxious about risking capital on large quantities of spat, which may help explain why the oyster industry in Tillamook Bay has not significantly increased over the years.

Resource Problems and Information Gaps

In this section we attempt to identify major data gaps and develop a list of problems relating to the valued biological resources. This information will be used as input for development of the scope for the Tillamook Bay CCMP.

Tools for evaluating the variables that control valued resources in the freshwater environment are better developed than those for the estuarine environment.

From an overview perspective, several general observations can be made, based on the above review of the status and trends of the valuable resources. First of all, it appears that tools for evaluating the variables that control valued resources in the freshwater environment are better developed than those for the estuarine environment. For example, specific habitat characteristics in the freshwater environment have been identified as important for the freshwater life stages of anadromous salmonids. Stream habitat is routinely surveyed and results compared against benchmark criteria that allow evaluation of whether the habitat is good, fair or poor. This information is extremely useful in helping managers identify problem areas and sources of problems. In the Estuary, we recognize sensitive habitat types (e.g., eelgrass beds and salt marsh) but analytical tools analogous to the steam survey technique have not been developed for the Estuary's valuable biological resources.

Second, we found that very little of the population information was developed from statistically designed sampling programs. Inferences regarding population status were often based on potentially biased data. This can be a serious problem, particularly if management decisions such as harvest quotas are based on what may be inaccurate information. It is critical, therefore, that scientifically designed sampling schemes be built into any short-term or long-term sampling programs used for the management of the Bay's valued resources.

Third, reliable long-term monitoring data was generally unavailable for all of the valued resources. Without long-term data sets, it is impossible to evaluate trends through time or to separate out effects of natural phenomena from man-induced changes.

Finally, there have been no comprehensive studies relating the condition of the Watershed to conditions in the Estuary for valued resources. We know that many of the changes that have taken place in the estuarine environment are related closely to disturbances in the Watershed that have altered flow, sediment input rates, and water quality. Monitoring and research directed at tying conditions in the Watershed to conditions in the Estuary are lacking.

Without long-term data sets, it is impossible to evaluate trends through time or to separate out effects of natural phenomena from man-induced changes.

In addition to these broad observations, a number of resource-specific problems should also be considered priorities. They are listed here.

Anadromous Salmonids

Tillamook basin coho salmon, chum salmon, steelhead trout, and sea-run cutthroat trout populations are depressed. At least part of these species' decline can be attributed to recent changes in oceanic conditions that, since about 1975, have been less favorable for the survival of anadromous salmonids along the northern California, Oregon, and Washington coasts. Coho salmon have been particularly hard hit by the poor ocean conditions because they rear off the northern California and Oregon coasts and do not migrate into the more productive waters of the Gulf of Alaska. Overharvesting of coho salmon when ocean conditions were poor exacerbated the problem. Harvest management has been changed recently to adjust for the poor ocean conditions.

Freshwater habitat surveys conducted in the Tillamook Watershed since the early 1990s indicate that habitat conditions for anadromous salmonids are generally degraded compared with ODFW standard benchmark criteria. The major problems identified were the general lack of channel complexity, off-channel habitat and in-channel large woody debris (LWD). It was also determined that recruitment of LWD from large conifers will take a very long time. Excessive fine sediment in the spawning gravel was identified as a persistent problem in many of the stream reaches surveyed.

Hatchery fish spawning with wild fish may be causing genetic introgression, a significant problem for both coho salmon and steelhead trout in the Tillamook Basin. An observed shift in the spawning timing of naturally spawning coho salmon represents a potentially serious problem that could be contributing to the observed population decline.

Insufficient information is available to determine whether estuarine conditions are now limiting coho salmon, chum salmon, steelhead trout, and sea-run cutthroat trout. However, the primary concerns for salmonid habitat in the Estuary are long-term changes in the quantity and quality of habitat due to activities in the Watershed and the effects of increasing human population densities.

Genetic introgression:
The introduction of one or more genes of one species into the gene pool of another species through hybridization (natural or artificial) between the species. Introgression also occurs between distinct populations of the same species, through repeated backcrossings (as is the case with wild and hatchery stocks of salmonids).

To summarize, resource problems for anadromous salmonids include:

- lack of off-channel habitat for winter refuge and rearing of coho salmon and cutthroat trout;
- general lack of LWD and associated channel complexity; and
- persistent sources of sediment loading.

Information gaps for salmonids in the freshwater environment include:

- scientifically designed long-term monitoring programs to measure changes in key habitat variables through time;
- biological measures of habitat conditions such as smolt production, density of juveniles per unit area of rearing habitat, and benthic macroinvertebrate abundance; and
- understanding of the amount of genetic mixing that has occurred between hatchery and wild stocks.

Information gaps for salmonids in the estuarine environment include:

- information on the quantity or quality of juvenile salmonid rearing habitat in the Estuary;
- information on present use of various major estuarine habitats by juvenile salmonids; and

- long-term monitoring designed to evaluate effects of changes in Watershed inputs of sediment, plant nutrients, large woody debris, and toxic substances on estuarine habitat conditions and estuarine biological communities.

Non-Salmonid Estuarine Fishes

The available information suggests that Tillamook Bay represents an important nursery area for a wide variety of marine and estuarine fish species. Eelgrass habitat contained the largest number of species per trawl and appears to be especially important for the juvenile life stages. However, rocky intertidal areas appeared to be the most diverse of the habitats sampled by seining. The information base used for evaluation of the non-salmonid fishes is more than 20 years old and needs updating.

Tillamook Bay represents an important nursery area for a wide variety of marine and estuarine fish species.

Resource problems for non-salmonid estuarine fishes can’t be accurately determined without long-term data that can be used to determine trends in the fish populations or to evaluate effects of changes in the estuarine environment on species composition, distribution, and abundance.

Information gaps for non-salmonid estuarine fishes include:

- recent information on species composition, relative abundance or habitat utilization; and
- long-term monitoring that relates changes in the estuarine habitat to the species composition, relative abundance, and distribution of the non-salmonid fish community.

Bay Clams

Harvest information for the commercial clam fishery in Tillamook Bay showed a rapid increase in the take of cockle clam during the last few years. Similarly, the recreational catch of bay clams nearly tripled from 1993 to 1995. Golden et al. (1997) found that recreationally important clams on intertidal areas were consistently smaller than clams in subtidal areas. They attributed the lack of large clams in the intertidal areas to effects of heavy recreational harvest. It is possible to overharvest bay clams to the point that their populations crash. The ODFW, which manages these resources, recently placed a conservative upper limit on the commercial harvest of cockle clam in the Bay but has not changed the recreational bag limits.

Heavy recreational digging in the 1970s appeared to reduce intertidal clam numbers. Since divers began harvesting subtidal areas, cockle and butter numbers appear to have increased for unknown reasons.

The long-term health of the bay clam populations in Tillamook Bay depends on maintaining good water quality conditions and retaining appropriate substrate.

Clam surveys in 1995 and 1996 indicate that gaper clam populations have declined in lower Tillamook Bay by as much as 90% from levels present in the mid-1970s. If this is the case, then the reasons for the decline should be determined.

The long-term health of the bay clam populations in Tillamook Bay depends on maintaining good water quality conditions and retaining appropriate substrate. Increased sediment deposition in the Bay could threaten some clam beds and should be monitored.

One resource problem for clams may be overharvesting of large clams in the intertidal areas by recreational clam fisheries.

Information gaps for bay clams include:

- identification of the factors responsible for the decline of gaper clam populations;
- long-term information on the effects of changes in Bay bathymetry and substrate conditions on the distribution and abundance of bay clams; and
- an understanding of the interrelationships among eelgrass, clams, oysters, and other organisms.

Dungeness Crab

The Tillamook Bay Estuary is an important nursery area for Dungeness crab. Crab reared in the Estuary probably contribute substantially to the ocean adult crab populations. At present, information is lacking regarding the abundance of the various life stages of crab in the Estuary. Long-term monitoring has not been conducted to allow assessment of trends in populations. The studies conducted in the mid-1970s indicated that eelgrass was a preferred habitat for early juvenile Dungeness crab. Later studies showed survival was highest on beds with high content of clam or oyster shell and/or attached drift algae. Whether there is a direct correlation between the amount of eelgrass present and the number of crab produced in the Estuary is not known. Large Dungeness crab appear to prefer deeper water habitats and are generally found in subtidal channels during the daylight hours. Much of the channel habitat in the mid and upper Bay areas has been silted in and is getting shallower through time. How these kinds of changes influence the carrying capacity of the Bay for Dungeness crab is not known.

The Tillamook Bay Estuary is an important nursery area for Dungeness crab. Long-term monitoring has not been conducted to allow assessment of trends in populations.

Information gaps for Dungeness crab include:

- recent information on the distribution and abundance of the various life stages of crab within the Estuary, to permit evaluation of the present status of the crab population; and
- long-term information on crab abundance and preferred habitat, which would improve our ability to predict how future changes in estuarine conditions may affect local crab populations.

Oysters

Oyster production in Tillamook Bay has been low for the last several years due to reduced production by the major leaseholder and departure of two other oyster growers. Oyster growers' chief problems are periodic shutdowns due to coliform bacteria and the detrimental effects of burrowing shrimp on oyster beds. Unpredictable periodic flooding and associated heavy sedimentation also cause recurring damage. Little is known about the factors that limit growth of oysters in the Bay, such as phytoplankton density and species composition, water temperature, turbidity, and suspended sediment concentrations, or the effect of changes in nearshore ocean environment on oyster production. A variety of predators and diseases can also affect the survival of rearing oysters. Our analysis of the current situation identifies resource problems, as well as research needed to help ensure continued success of the Bay oyster industry.

Oyster growers' chief problems are periodic shutdowns due to coliform bacteria and the detrimental effects of burrowing shrimp on oyster beds.

Resource problems for oysters and oyster growers include:

- unpredictable shutdowns of oyster harvesting due to coliform bacteria contamination; and
- reduced production levels due to impacts of burrowing shrimp on oyster survival and growth.

An information gap for oysters is:

- long-term information on the condition of oysters relative to conditions in their environment, such as phytoplankton composition and density, light penetration, eelgrass distribution, suspended sediment loads, etc.

Recommendations

General

Long-term data sets are necessary to sort out effects of natural variation from man-induced changes.

Long-term data sets are necessary to sort out effects of natural variation from man-induced changes. Some changes, for example river flow variations and marsh development, occur at the decade scale (Levings 1980), which is much longer than most research projects cover. Management and research projects which integrate activities in the drainage basin with those in the Estuary are clearly needed for Tillamook Bay. Habitat surveys are being conducted in the Watershed for assessment of salmonid habitat but little effort has been made to develop long-term data sets that tie conditions in the Watershed to conditions in the Estuary. Flow characteristics, suspended sediment loads, and water quality of the rivers entering the Estuary have important long-term implications for the health of the Estuary. Monitoring programs that tie these variables to activities in the Watershed and to conditions at selected audit reaches in the Estuary could be used for hypothesis testing. For example, does long-term recovery in salmonid habitat in the freshwater environment translate to long-term benefits to salmonid habitat in the Estuary? Information that could be collected in the Estuary for tests of specific hypotheses for anadromous salmonids include salmon growth and survival in major habitats, productivity at several trophic levels and gain/loss of vegetated habitat. Techniques to explore food webs, such as stable isotope investigations, could also be tested. Data from audit reaches could be reviewed periodically to see if the sampling scheme is valid for management and research. If managers and scientists can compromise and agree on joint sampling as a way of improving data bases for habitat management, knowledge would be continually updated in a timely manner. This strategy could maintain or improve conditions in some of the key habitats in Tillamook Bay and lead to a better understanding of the relationship between the freshwater portion of the Watershed and the Estuary.

Trophic level:
A stage in a food web occupied by organisms that feed on the same general type of food, used in diagramming the energy flow within an ecosystem. Carnivores, herbivores, and plants constitute different trophic levels.

All long-term monitoring should be designed to provide statistically reliable results. Data should be collected at geo-referenced locations and stored in a central Geographic Information System (GIS). The use of the GIS would allow rapid retrieval of information, improve the accuracy of the data base and allow future hypothesis testing by running “what if” scenarios.

Resource-Specific

Recommendations are listed below for each resource discussed in this chapter.

Anadromous Salmonids

- Efforts to inventory anadromous salmonid habitat throughout the Watershed should continue.
- Areas of good habitat should be identified and protected. This should include an analysis of the watershed upstream from the good habitat to locate potential problems that could result in future degradation to the habitat.
- Where feasible, habitat should be improved through the creation of off-channel winter habitat and introduction of LWD. Efforts should focus first on locations where the target fish species are known to be present.
- The issue of genetic introgression of hatchery fish into the wild populations of coho salmon and steelhead trout needs to be carefully addressed. According to R. Klumph (pers. com. 1997), December spawning coho are still present at a few locations within the Watershed. These fish may represent the only remaining source of genetic material for bringing back December runs of coho salmon. The habitat where these fish occur should be protected and enhanced.
- Long-term monitoring in the Watershed is needed to evaluate changes in habitat and system productivity for juvenile salmonids through time. One approach might be to select representative reaches in upper, mid, and lower sections of the five major drainages as monitoring sites. Parameters to monitor would need to be carefully selected to provide the most information with the least expenditure of time and money.
- In the Estuary, information is needed on the relative importance of various major habitat types to the various anadromous salmonid species. We would need focused sampling of specific habitat types when the various salmonid species are present.
- Integrated long-term monitoring (discussed above under general recommendations) should be designed to provide the input needed to test hypotheses regarding the effects of changes in estuarine conditions on juvenile salmonid rearing habitat in the Estuary.

- Development of quantitative or semi-quantitative measures of estuarine habitat quality — similar to those used in the freshwater environment to classify stream habitat — would help us monitor long-term trends in habitat quality.

- Eelgrass bed monitoring should continue, due to the beds' importance as fish and wildlife habitat.

Non-Salmonid Estuarine Fishes

- Using the information developed in the 1974–1976 surveys, a focused, cost-effective fish survey of the Tillamook Bay Estuary should be conducted. No information is now available to determine whether estuarine fish populations have changed significantly since the mid-1970s.
- Long-term monitoring of fish populations at selected audit reaches should be part of the Estuary's general, integrated monitoring program.

Bay Clams

- The 1996 clam surveys indicated that gaper clam populations have declined drastically since 1974–1975. Research is needed to identify the factors responsible for the decline.

- Research is needed to better understand the relationship between subtidal and intertidal clam populations.

- The recreational fishery appears to selectively harvest larger clams. Catch, effort, and size of clams harvested should continue to be monitored.

- At present, the best prospect for new commercial fisheries appears to be for butter clams. Any future expansion of commercial fisheries to other species should be coupled with creation of subtidal reserves to assure adequate spawning biomass.

- Long-term monitoring of the bay clam populations in specific audit reaches should be included in the general, integrated monitoring program for the Estuary.

Dungeness Crab

- Distribution and seasonal abundance of Dungeness crab in representative habitat types throughout the Estuary should be surveyed to evaluate the relative importance of the major habitat types in the life cycle of the crabs and to assess the present status of the crab population.

- Long-term monitoring of the Dungeness crab population in specific audit reaches should be included as part of the Estuary's general, integrated monitoring program.

Oysters

- The Tillamook Bay oyster industry should consider monitoring oyster condition, using the Oyster Condition Index developed for the Willapa Bay oyster industry. This would provide growers with a way to measure any long-term changes in the productivity of the Bay for oysters.

- Some of the steps needed to reduce coliform bacteria levels in the Bay are discussed in Chapter 4: Water Quality.

- Research is needed to better understand the factors that control burrowing shrimp abundance, densities, and population distribution, and the interactions between oysters, eelgrass, and burrowing shrimp.

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CHAPTER 4

WATER QUALITY:

MEASURING HEALTH AND PROGRESS

Water is medicine. It is different. It gives everything life.

—Louie Dick, Confederated Tribes of the Umatilla Indian Reservation
Speaking at the Governor's Watershed Enhancement Board 1996 Conference, Seaside, OR.

Consider this water which flows toward the city .... See how pure and fine it is! But when it enters the city ... people wash their hands and faces and feet and other parts in it, and their clothes and carpets, and the urine of all the quarters and dung of horses and mules are poured into it and mixed up with it. Look at it when it passes out the other side of the city! Though it is still the same water, turning the dust to clay ..., making the plain verdant ... disagreeable things have been mingled with it.

—Rumi
as translated by W.S. Merwin, 1979, from "When the Heart Bursts in Flame...," by Rumi.
In *Selected Translations, 1968–1978*.
Atheneum Publishers, New York, NY.

Oregonians love water. Tell them that 42.5 cubic miles of water descends on their hapless state every year and they'll probably shout hooray. They know that the water will enrich their lives in ways that non-Oregonians don't always understand: through the tranquilizing effect of rain on the roof, through the euphoric feeling brought by watching a creek tumble down a mountainside, through the reverence for nature's power that emerges when you witness roaring river rapids or the thundering ocean surf. But ... not all of Oregon's water announces its presence by clatter, roar, and thunder. Much of it speaks softly, like snow floating down onto the Cascade Mountains.

—Ken Metzler
author of *The Best of Oregon*
in foreword to *Oregon's Quiet Waters*, by Cheryl McLean and Clint Brown. 1987.
Jackson Creek Press, Corvallis, OR.

CHAPTER 4

WATER QUALITY:
MEASURING HEALTH AND PROGRESS

National Estuary Program and Tillamook Basin Background

Tillamook Bay has a long history of bacterial pollution problems (Blair and Michener 1962, Jackson and Glendening 1982, Musselman 1986, DEQ 1994). Bacterial concentrations in the Bay have historically been high during the wet seasons of the year: fall, winter, and early spring. Due to the Bay's unpredictable water quality, the proximity of five wastewater treatment plants, and many non-point sources of bacteria and viruses, oyster culture is allowed only in specified areas of the Bay, and harvesting is allowed only under conditions identified in the shellfish management plan for Tillamook Bay (ODA 1991). Bacterial problems often close harvesting in Tillamook Bay, which was historically one of Oregon's leading producers of shellfish.

Bacteria sources include waste treatment plants, livestock operations, septic systems, and domestic and wild animals.

Bacteria can enter the Bay directly or via the Basin's many rivers and streams. Sources include municipal and private wastewater treatment plants, dairy and other livestock operations, onsite septic systems for homes not served by sewer systems, and both domestic and wild animals, among others. Bacterial concentrations are highest in the Bay when fresh water inputs are highest, so the shellfish plan regulates oyster harvesting according to river levels and rainfall intensity, as well as occasional spills at local wastewater treatment plants.

Bacteria problems often close harvesting in Tillamook Bay, which was historically one of Oregon's leading producers of shellfish.

Pathogen contamination is the single water quality parameter identified as a priority problem by the National Estuary Project. Bacterial contamination has been the subject of numerous studies and management plans, several of which are summarized in **Appendix 4-A.** However, Tillamook Basin waters have other water quality problems. Temperatures in the lower reaches of the Trask, Tillamook, and Wilson rivers exceed water quality standards and may affect salmonid habitat in those reaches during part of the year. Extensive information bout nutrient levels has not been collected, but existing data suggest that nutrient levels are moderate in the Tillamook Basin. These are of concern, since estuarine eutrophication is an increasing problem nationwide (NOAA 1996).

Buffer strips along streams can improve riparian habitat and decrease overland runoff of nutrients and bacteria.

Fortunately, the causes of many of these problems are related. Nutrients accompany human and animal wastes, as do bacteria, so controlling bacteria will likely affect nutrient loads as well. Stream temperature is related to the loss of shade, the loss of riparian habitat and possibly thermal pollution from point sources. Buffer strips along streams can improve riparian habitat and decrease overland runoff of nutrients and bacteria.

The bacteria and temperature water quality violations relate directly to the Tillamook National Estuary Project's priority problems. Flow modification, habitat modification, and sedimentation — listed as parameters of concern along many river miles in the Tillamook Watershed — also relate directly to salmonid habitat, one of the three priority problems. By addressing all of these topics in the Comprehensive Conservation and Management Plan (CCMP), the TBNEP will meet state and federal requirements, as well as address the identified priority problems.

This chapter will cover both the history and current status of the bacteria problems in the Tillamook Watershed. It will also discuss water temperatures in Tillamook Watershed streams, and nutrient and dissolved oxygen (DO) conditions in fresh and saline waters.

Tillamook Basin Water Quality Standards

Bacteria Criteria

Water quality standards for recreatio nal contact and shellfish growing waters differ; but allowable levels in both fresh water and the Bay have long been exceeded in the Tillamook Watershed.

Pathogens such as hepatitis and typhoid, which present the greatest risk to human health from water contact or ingestion of raw shellfish, are not easily detected. Intestinal bacteria are more easily quantified, and are used as indicators of pathogen contamination, since both are present in the waste of warm-blooded animals. Water quality standards for recreational contact and shellfish growing waters differ; but allowable levels in both fresh water and the Bay have long been exceeded in the Tillamook Watershed (Jackson and Glendening 1981). The bacteria standard for recreational contact applies to both fresh and saline waters and is intended to protect people in contact with water, such as swimmers. The shellfish standard is much more stringent, as it is designed to protect people from pathogens which might be consumed with raw shellfish.

Water quality criteria for shellfish growing areas and for surface waters used for recreational contact appear in **Table 4-1.** No shellfish harvest standard has been adopted for bacteria levels in oyster meat. However, some states limit oyster meat for processing and interstate commerce to no more than 230 counts per 100 g of meat. The U.S. Food and Drug Administration (FDA) uses this standard to evaluate shellfish management plans. Both the water and oyster meat bacteria levels from Tillamook Bay have often exceeded these standards during the rainy months of the year.

Before 1996, the state water quality standard for recreational contact was based on fecal coliform (FC), differing from the shellfish growing water standard only in the number of fecal coliform colonies allowed (Table 4-1). This standard was revised in 1996, and is now based on *E. coli.* Both standards are commonly exceeded in the Tillamook Basin. As described later in this report, freshwater values occasionally exceed 12,000 FC/100 mls, and estuarine values reach 1,600 FC/100mls.

Other Water Quality Criteria

The water quality standard for temperature in the Tillamook Basin is 64° F. The method for determining compliance with the water quality standard is described in Table 4-1. The State does not have numeric criteria for nutrient concentrations in the Tillamook Basin. However nutrients can cause eutrophication of water bodies, which may raise pH and cause large swings in DO, both of which can harm aquatic life. State regulations for pH and DO in the North Coast Basin are described in Table 4-1. None of the pH or DO data collected in the Tillamook Basin exceeded these standards, although there are anecdotal reports of algal blooms in the lower reaches of streams and sloughs.

A Review of Historical Data

Prior to 1979, studies by universities and state or federal agencies identified the concern about water quality in Tillamook Basin, but the reports did not specifically identify the causes and location of the bacterial pollution. In 1979, the Tillamook Bay Bacteria Study was initiated to specifically identify the sources and extent of fecal pollution occurring in the Bay and Watershed.

The Oregon Department of Environmental Quality (DEQ) (Jackson and Glendening 1981) reviewed existing reports on water quality in Tillamook Bay Basin. DEQ completed a sampling program to quantify the bacterial problems in the Basin and to identify sources. During 1979–1980, DEQ sampled along

Table 4-1. Selected water quality standards of interest in the Tillamook Basin

Parameter	Reference	Description
Bacteria in shellfish waters	Oregon Administrative Rules 340-41-(North Coast) (2)(e and f) Oregon Administrative Rules 603-100-(000-030)	A median fecal coliform concentration in water overlying shellfish areas shall not be greater than 14 colonies per 100 mls, and no more than 10% of the samples shall exceed 43 colonies per 100 mls. A geometric mean of 15 or more samples shall not exceed 14 colonies per 100 mls, and no more than 10% of the samples shall exceed 43 colonies per 100 mls.
Recreational contact in water	Oregon Administrative Rules 340-41-(North Coast)(2)(e and f)	Through March 1996: a geometric mean of five fecal coliform samples should not exceed 200 colonies per 100 mls, and no more than 10% should exceed 400 colonies per 100 mls. Effective March 1996 through present: a 30-day log mean of no less than five samples of *E. coli* shall not exceed 126, and no single sample shall exceed 406 organisms per 100 mls of sample.
Water temperature	Oregon Administrative Rules 340-41-(North Coast)(2)(b)	A 7-day moving average of the maximum daily temperature shall not exceed 55° F (12° C) in waters and during seasons that support salmon spawning, egg incubation, and fry emergence, or 64° F (18° C) otherwise.
pH	Oregon Administrative Rules 340-41- (North Coast)(2)(d)	pH shall not be lower than 6.5 nor higher than 8.5 standard pH units
Dissolved oxygen (DO)	Oregon Administrative Rules 340-41-(North Coast)-(2)(a)	During salmonid spawning periods DO must not be lower than 11 mg/L unless intergravel DO exceeds 8.0, or where altitude and temperature conditions preclude attainment of the standard, when DO must be at least 95% of saturation. In water bodies that support cold water aquatic life (such as salmonid species), DO must be at least 8 mg/L, or if diurnal monitoring data are available, the minimum shall not fall below 6.5 mg/L. For estuarine waters, DO concentrations must exceed 6.5 mg/L.
Habitat modification	Oregon Administrative Rules 340-41-027	Habitat is classed as impaired when any of several biologic community status scores are below 76% of that for an appropriate reference site, and habitat conditions that limit fish or other aquatic life have been documented.
Flow modification	Oregon Administrative Rules 340-41-027	Flow modification is classed as impaired when any of several biologic community status scores are below 76% of that for an appropriate reference site, a water right has been applied for, there is documentation that minimum flows are insufficient, and the impaired flows are due to human use.
Sedimentation	Oregon Administrative Rules 340-41-(North Coast)(2)(j)	Sedimentation is a problem when any of several biologic community scores are lower than 76% of that for an appropriate reference site, and the impairment is attributed to appreciable deposits of any organic or inorganic material deleterious to fish or aquatic life or to public health, recreation, or industry.

Source: Compiled by Avis Newell. 1997. Oregon Department of Environmental Quality.

the five tributaries to Tillamook Bay; in selected creeks and sloughs and within the Bay itself. Jackson and Glendening (1982) identified bacterial sources including discharge from wastewater treatment plants, runoff from agricultural areas, discharge from malfunctioning or improperly designed or constructed septic systems, and direct inputs from animals in the basin.

Based on analysis of the data, Jackson and Glendening concluded that the majority of fecal contamination occurs in the lower subbasins where the dairy farms and homes are located. This trend can be seen in **Figure 4-1** where F/A represents the boundary between forest and agricultural land uses.

Jackson and Glendering concluded that the majority of fecal contamination occurs in the lower subbasins where the dairy farms and homes are located.

Similar trends were seen in all of the five tributaries. Additionally, Jackson and Glendening concluded that the forested areas were not a significant contributor of fecal coliform bacteria when compared to downstream fecal sources. Elk herds were not found to significant source of bacteria to Tillamook Bay, although they may have a localized impact not identified in the study.

To aid in determining the type of fecal sources contributing to the river contamination, fecal coliform data for the sample sites were plotted against time. This analysis showed that the fecal coliform levels would rise shortly after rainfall began. The rapid response time suggested that the available fecal coliforms are on the ground surface and ready to move when it rains. At some low point in the descending limb of the hydrograph, the bacterial level begin to climb again, without rainfall occurring.

Jackson and Glendening (1982) hypothesized that the fecal source concentrations were increased for a time by the rain, and the concentrations were then diluted by additional rain or were depleted. After the rain ended, the fecal material accumulated and began discharging again without additional rainfall. To test this hypothesis, additional sampling was conducted on Illingsworth Creek, which flowed through a barn area. Fecal bacteria counts rose from 270/100mL upstream of the barn to 20,000/100mL downstream of the barn and loafing area. Based on the data from Illingsworth Creek, Jackson and Glendening concluded that a large portion of the fecal contamination in the subbasin was most likely occurring in the ditches and streams adjacent to or in the barnyards of the dairy farms. This situation would also account for the high fecal coliform concentrations observed during the dry weather in the summer.

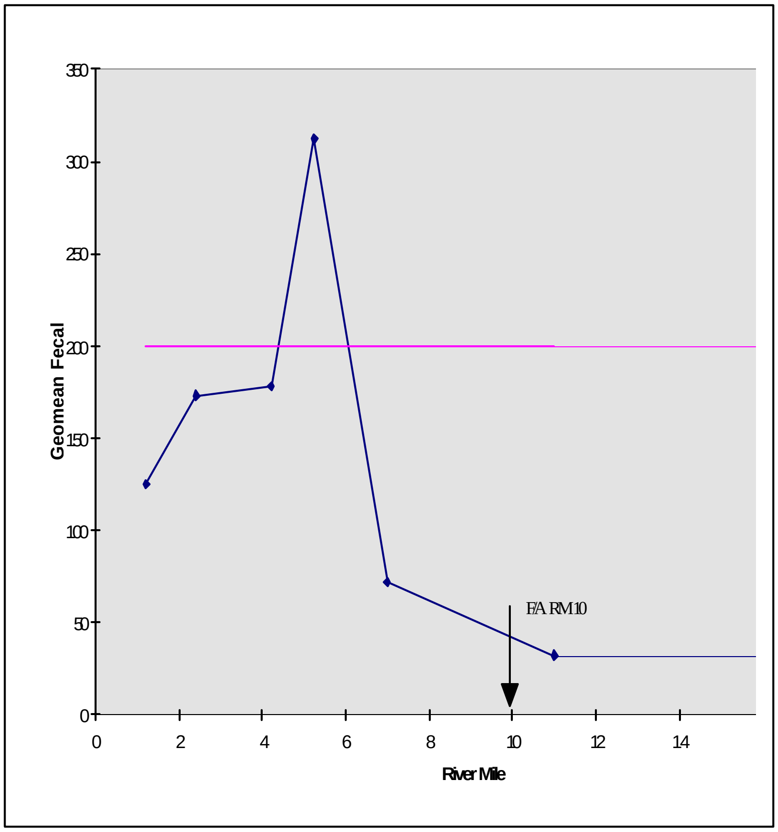


Figure 4-1. The geometric mean of fecal coliform plotted by Trask River mile. The majority of fecal contamination occurs in the lower subbasin, where farms and homes are located. Similar trends were observed in other basins. F/A=forest/agriculture interface.
Source: Jackson, J., and E. Glendening. 1982. Tillamook Bay bacteria study fecal source summary report. Oregon Department of Environmental Quality, Portland, OR.

Jackson and Glendening (1982) identified critical areas within the watershed where leaky septic systems could pollute surface waters. Tillamook County Health Department surveys conducted between 1974 and 1979 found that 20% of 184 onsite systems inspected were failing (Jackson and Glendening 1982; DEQ 1981). Using this failure rate, Jackson and Glendening predicted that 580 of the estimated 2,900 onsite systems in Tillamook County would exhibit similar problems. However, they were unable to make any definite statement about the fecal coliform that may have been contributed by homes with inadequate on-site sewage disposal systems.

Only 8% of the on-site disposal systems were functioning improperly, and just 2% were polluting surface waters.

Subsequent sanitary surveys in Tillamook County demonstrated that the 20% failure rate was not basin-wide. Far fewer (8%) were actually functioning improperly, and few of these (2%) were polluting surface waters (Arnold *et al.* 1989).

Sewage treatment plants were not considered a significant fecal coliform contributor when the plants operated as designed.

The wastewater treatment plants perform better now than they did in the mid-1970s and early 1980s, when the FDA implicated them as hazards to the shellfishing industry.

Monitoring and alarm systems were upgraded at wastewater treatment plants so that malfunctions could be identified and reported immediately. The wastewater treatment plants perform better now than they did in the mid-1970s and early 1980s, when the FDA implicated them as hazards to the shellfishing industry andJackson and Glendening (1981) completed their assessments (Musselman 1986). Since the early 1980s the plants have been required to report malfunctions within the hour so damage can be assessed and shellfish harvesting closed if necessary. Specific details about each wastewater treatment plant are presented later in this chapter.

Jackson and Glendening were unable to quantify loads from each of the sources, but did identify management measures to be taken for the wastewater treatment plants, septic systems, and farms.

The DEQ also produced a management plan to decrease bacteria inputs to the Bay and provided input to a shellfish management plan that would outline the conditions under which shellfish could be harvested (Jackson and Glendening 1981, 1982; Glendening and Jackson 1981; DEQ 1981). This work included a review of the background information, a summary of current field work, and a manure management plan for the Rural Clean Water Program (RCWP), which was implemented between 1982 and 1992. This series of reports is the most comprehensive review of existing data and of bacterial sources prior to 1982 in the Tillamook area.

Management Plans

Tillamook Bay Drainage Basin Agricultural Non-point Source Pollution Abatement Plan

Under Section 208 of the Clean Water Act, the EPA received federal funds for distribution to designated planning agencies to develop water quality management plans to abate pollution from non-point sources. The Oregon Soil and Water Conservation Commission (SWCC) was designated as the implementing agency for Oregon’s 208 Agricultural Non-point Source Pollution Water Quality Program. The Tillamook Bay Drainage Basin Agricultural Non-point Source Pollution Abatement Plan addresses only agricultural related pollution with the Tillamook Bay Drainage Basin. The plan, which was prepared by the Tillamook County Soil and Water Conservation District (TCSWCD) and Tillamook Bay Water Quality Committee, was designed to reduce agricultural pollution in Tillamook Bay through a voluntary program. The plan was coordinated with DEQ's Tillamook Bay Bacteria Management Plan. Stream sampling data was used to identify critical agricultural related water quality problem areas.

The planning process identified solutions to improve water quality. Three criteria were the basis for developing the best management practice (BMP) alternatives listed in the plan:
(1) they must improve water quality,
(2) they must be economically feasible, and
(3) they must have local support.

Water quality monitoring results indicated that animal confinement areas adjacent to open water courses have the greatest potential impact on water quality. Pollution abatement problems and alternative solutions were listed in the plan for animal confinement areas, field application of manure, and water course areas. The BMPs are described in layman's terms below.

Situation A: Animal Confinement Areas
Problem 1. Runoff from animal confinement area enters open water course.

- BMP1: Relocate confinement area.
- BMP2: Regrade and slope confinement area away from open water course.
- BMP3: Divert clean water away from confinement area.
- BMP4: Construct a barrier.
- BMP5: Enclose open water course.
- BMP6: Redirect open water course around confinement area.

Problem 2. Manure pile runoff enters open water course.

- BMP1: Construct a roofed solid waste storage facility.
- BMP2: Construct a liquid manure tank or lagoon.

Problem 3. Silage installation seepage enters open water course.

- BMP1: Minimize silage seepage.
- BMP2: Divert silage seepage.
- BMP3: Roof the silage installation.

Problem 4. Flood water entering animal confinement area.

- BMP1: Construct confinement area above the flood plain.
- BMP2: Construct a dike around the confinement area.

Situation B: Field Application of Manure
Problem 1. Animal waste runoff from fields having saturated soil conditions or ponded water for extended periods.

- BMP1: Install a tile drainage system in these fields.
- BMP2: Install adequate storage facilities that can store manure until soil conditions are favorable for spreading manure.

Problem 2. Manure from fields entering open water courses.

- BMP1: Use grass filter strips.
- BMP2: Convert open ditches to closed systems where practical.
- BMP3: Use good manure application techniques.

Situation C: Water Course Areas
Problem 1. Sedimentation resulting from streambank erosion along a water course.

- BMP1: Preventive maintenance.
- BMP2: Protect eroding streambanks by structural and/or vegetative methods.

Problem 2. grazing animals along streams causing water pollution, bank destabilization and sedimentation.

- BMP1: Fence the streambank top.
- BMP2: Construct a streambank entrance ramp to control animal access.

The Rural Clean Water program

RCWP Activities

Through the RCWP during the 1980s, major bacterial sources were identified and various measures taken to decrease bacterial pollution. The RCWP provided over $6 million in cost-share money to improve manure management facilities on dairy farms. Many wastewater treatment plants and septic systems were also upgraded during this period. Over the last 10 years, the Tillamook County Creamery Association (TCCA) spent $4.3 million, Bay City $2.6 million, Garibaldi $1.0 million, and the City of Tillamook $5 million on upgrades to their wastewater treatment plants. The City of Tillamook, Port of Tillamook Bay, and City of Garibaldi planned to spend more than $1 million each between 1997 and 1998.

While these efforts resulted in improved management practices in the region (Arnold *et al.* 1989, Dorsey-Kramer 1995), bacterial contamination still causes water quality violations in Tillamook area streams and elevated bacteria counts in Tillamook Bay after storms. Continuing bacterial contamination in Tillamook Bay and its tributaries triggers additional management activities.

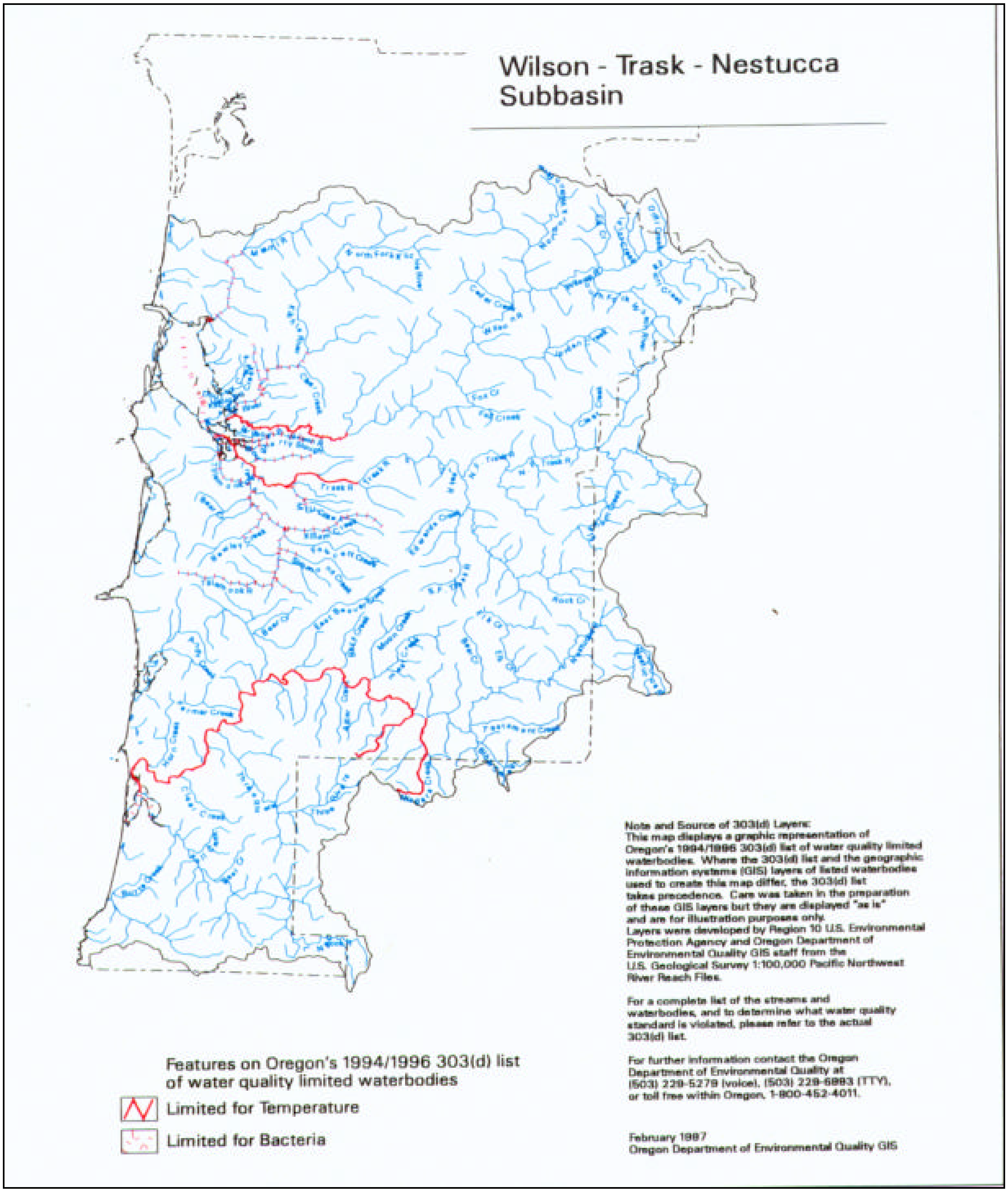
Total Maximum Daily Loads

The Clean Water Act requires the State to list (the 303(d) list) those water bodies that are "water quality limited."

The Clean Water Act requires the State to list those water bodies that are "water quality limited." Water bodies are considered water quality limited when technology based controls are inadequate to achieve State water quality standards. In the Tillamook Bay area, sufficient documentation for listing exists only for fecal coliform and water temperature. Fecal coliform levels commonly exceed the recreational contact criteria in the streams and rivers and exceed both the recreational criteria and the shellfish harvest criteria in the Bay. Summer water temperatures get too high in the lower reaches of both the Trask and Wilson Rivers. **Figure 4-2** shows the locations of water quality limited streams in the Tillamook area, and **Appendix 4-B** and **Appendix 4-C** include the text and maps for the Tillamook Basin 303(d) list.

Several stream reaches in the Tillamook Basin were evaluated as being "of concern" for aquatic habitat, flow modification, and sediment. This evaluation was based on data from state and federal agencies, described in the 1988 Oregon Statewide Assessment of Nonpoint Sources of Water Pollution (DEQ 1988). For the Tillamook Basin, most reaches classified as "of concern" for these parameters were selected by observation only. Quantitative data describing the problems is needed to describe the extent of the problems. The DEQ has not listed these waters as water quality limited (the 303(d) list), but classified them as needing more information.

While reviewing data for water quality limited status, the DEQ also compiled a list of "waters at risk." At these locations, existing data are insufficient to document impairment but pollutant levels are of concern. Maps showing the location of these for various parameters are also included in Appendix 4-C. More data are needed to determine whether nutrients are a problem in Tillamook waters.



Note and Source of 303(d) Layers:
This map displays a graphic representation of Oregon's 1994/1996 303(d) list of water quality limited waterbodies. Where the 303(d) list and the geographic information systems (GIS) layers of listed waterbodies used to create this map differ, the 303(d) list takes precedence. Care was taken in the preparation of these GIS layers but they are displayed "as is" and are for illustration purposes only.
Layers were developed by Region 10 U.S. Environmental Protection Agency and Oregon Department of Environmental Quality GIS staff from the U.S. Geological Survey 1:100,000 Pacific Northwest River Reach Files.

For a complete list of the streams and waterbodies, and to determine what water quality standard is violated, please refer to the actual 303(d) list.

For further information contact the Oregon Department of Environmental Quality at (503) 229-5279 (voice), (503) 229-6993 (TTY), or toll free within Oregon, 1-800-452-4011.

February 1997
Oregon Department of Environmental Quality GIS

Figure 4-2. Map of the Tillamook and Nestucca watersheds, showing the stream reaches that are on Oregon's list of water quality impaired surface waters (the 303d list) for poor water quality in relation to temperature and fecal coliform bacteria.
Source: Oregon Department of Environmental Quality GIS layer, February 1997.

The State is required to develop a Total Maximum Daily Load (TMDL) for these water quality limited water bodies. A TMDL must include:

- a discussion of applicable water quality standards;
- a summary of available data;
- source identification and source load estimates;
- analysis of data, including model development and discussion of variability and uncertainty;
- a description of the loading capacity of the water body for the pollutant of concern;
- an identification of the allocation strategy;
- a margin of safety to account for the uncertainty about the relationship between the pollutant loads and the quality of the receiving water body;
- an implementation plan which includes the responsible agency and time schedule;
- an analysis to demonstrate that the implementation plan will achieve water quality standards; and
- a description of the public participation process.

The TMDL is submitted to EPA for review and EPA must approve or disapprove the TMDL within 30 days of submission. For agricultural lands in Tillamook Basin, the controls will be identified and implemented via water quality management plans created under Senate Bill 1010.

Senate Bill 1010

According to a 1995 Oregon state law, Senate Bill 1010, agricultural water quality management area plans must be created for water bodies included on the 303(d) list. Under this process, the Oregon Department of Agriculture (ODA) must first delineate the geographic area to be included in the plan. ODA then identifies the agricultural issues to be addressed and appoints a Local Advisory Committee to develop a local agricultural water quality management area plan. The Committee recommends strategies to necessary to meet water quality goals and objectives. ODA prefers to designate a local management agency, typically a Soil and Water Conservation District, to implement the plan after its approval.

Coastal Zone Management Plans

The EPA and the National Oceanic and Atmospheric Administration (NOAA) required the development of Coastal Zone Management Plans for Non-Point Sources (DEQ and DLCD 1996). The Oregon Department of Land Conservation and Development (DLCD), in conjunction with the DEQ, developed a Coastal Non-point Source Management Plan that was conditionally accepted by the federal EPA and NOAA in 1996. This plan outlines several agricultural management actions, and also requires the development of agricultural plans under Oregon Senate Bill 1010.

Shellfish Management Plan

In response to oyster-related typhoid outbreaks in 1924 and 1925 elsewhere in the country, the U.S. Public Health Service established guidelines for shellfish growing areas and certifying interstate distribution. States that chose to follow the guidelines received U.S. Public Health Service endorsement, but no enforceable standards were set. The FDA took over the program in 1968, and by 1975 had adopted enforceable standards for shellfish growing waters and marketed shellfish meats. Oregon has participated in the relevant shellfish program since the late 1940s, and its program has adapted to changes in both the federal and state authorities.

The current shellfish management plan was adopted in 1991 in response to the FDA. The FDA conducted three different studies of water column bacteria and oyster meat during the 1970s (Glendening and Jackson 1981) and, based on these results, threatened to disallow interstate shipping of Tillamook oysters. In a 1977 study, of 44 oysters sampled, 16 exceeded the FDA’s recommended shellfish meat level of 230 fecal coliform counts per 100 g of tissue. The highest of these values was 3,300 fecal coliform per 100 g of oyster meat (Glendening and Jackson 1981). In response to the threat of shellfish harvest closure, the Oregon Health Division formed a task force of agency and industry members to address the problems. The current management plan evolved from these efforts, as well as the State’s recognition of the need to fund a program and employ a state shellfish sanitarian.

Bay shellfish harvesting is closed in all conditionally approved areas when the Wilson River rises to 7 feet, or due to sewage spills, toxic spills, or marine biotoxins.

Tillamook Bay is now divided into five shellfish management areas (Figure 4-3). No oyster harvesting is allowed from prohibited areas and harvest is allowed from conditionally approved areas only when those zones are “open”. The Cape Meares area is closed when it rains more than one inch in 24 hours. All of the conditionally approved areas are closed when the Wilson River rises to 7 feet (2,500 cubic feet per second). The Main Bay and Lower Bay areas are re-opened five days after Wilson River peaks. The Cape Meares area is re-opened seven days after the Wilson River peaks, or seven days after the most recent rainfall event that exceeds one inch in 24 hours. Bay shellfish harvesting is also closed occasionally due to sewage spills, toxic spills, or marine biotoxins. The ODA announces these closures and subsequent re-openings.

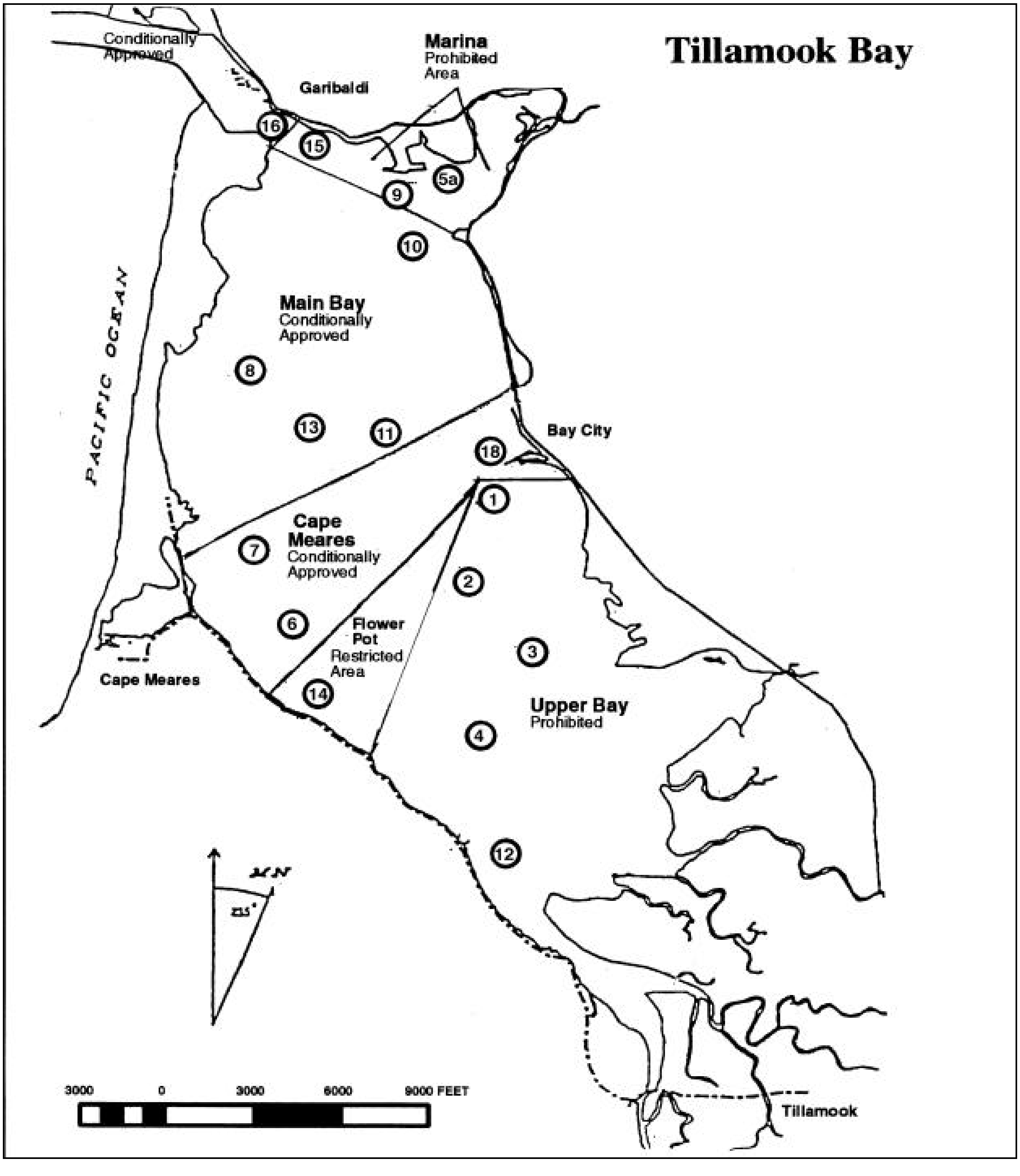


Figure 4-3. Shellfish management areas for Tillamook Bay and locations of monthly water quality monitoring sites.

Source: Tillamook Bay National Estuary Project Geographic Information System, October 1997, version 2.

The shellfish management plan is based on rainfall intensity and river discharge because bacterial concentrations in the Bay are high under these conditions. However, Tillamook Bay is also closed, infrequently, due to spills or bypass conditions at local wastewater treatment plants. Because these are more rare than heavy rainfall, most closures are related to climatic events, which are used to predict high bacterial levels in the Bay. Closures do not directly indicate water quality conditions, since Bay closures are based on river discharge, and not on measures of bacterial contamination. River discharge, although an indirect measure of bacterial levels in the Bay, can be measured instantaneously. Measures of bacterial concentration require 36 to 48 hours for incubation and sometimes longer for confirmatory results. Each year the ODA, working with the FDA, assesses the shellfish management plan. If the relationship between bacteria concentrations and rainfall or river discharge changes significantly, then the shellfish management plan can be modified accordingly.

TBNEP Activities

Despite progress in these efforts to restore water quality, both fresh and saline waters in the Tillamook Basin often don’t meet water quality standards. The 1993 National Estuary Project grant to Tillamook County provides financial resources to develop a Comprehensive Conservation Management Plan (CCMP) to further address these issues. To be truly comprehensive, Tillamook Bay’s CCMP should include all of the existing and required management plans in its development.

Despite progress in these efforts to restore water quality, both fresh and saline waters in the Tillamook Basin often don’t meet water quality standards.

Tillamook Basin Water Quality Trends

Trend Analysis

Arnold *et al*. (1989) reviewed the data collected between 1979 and 1987 to determine if the many management changes in Tillamook County had affected water quality. They found that bacterial concentrations in the Bay sites and in freshwater streams were indeed lower, although water quality violations were still occurring **(Figure 4-4)**. They looked at the data in several ways; comparing geometric mean and quantiles among three distinct time periods, before (1979–1980), during (1982–1984) and after (1985–1987) major implementation phases; and using the FDA criteria for the same three time periods to demonstrate that more of the Bay monitoring sites achieved conditional or acceptable water quality, where they had previously been classified as prohibited. They also identified some factors which may have biased these results, including the

Figure 4-4. Installation rate of five Best Management Practices (BMPs). BMPs including waste storage, roofing, gutters, curbing, and areas of field application of manure are plotted from 1980 to 1989, along with the annual geometric mean of fecal coliform at shellfish growing areas in Tillamook Bay (monitoring sites 6, 7, 8, 11, 13, and 14, identified in Figure 4-2).
Source: Arnold, G., S. Schwind, and A. Schaedel. 1989. Tillamook Bay Watershed bacterial analysis water years 1979–1987. DEQ internal report, Portland, OR.

fact that water years differed among the three time periods that were compared, and the fact that more storm events were included in the 1979–1981 pre-implementation period than in either of the two later time periods. These two factors combined may have resulted in a data set where earlier data were biased high, and later data were biased low, resulting in perceived, but not necessarily real improvements in water quality.

Trend tests were later performed by Wiltsey (1990), looking at data collected from 1979 through 1990 at Bay and tributary sites. These data may have been biased by the inclusion of storm chases early in the dataset. However, even with the high storm chase values at the beginning of the record, no significant trends were observed in fecal coliform concentrations over the period of record, either at sites in the Bay or in the tributaries. When appropriate, the trend tests included river discharge or Bay salinity, to account for some of the variation among sampling periods. The trend test applied was the non-parametric

Seasonal Kendall Tau, a robust test when data are non-normally distributed, and when sampling records are not evenly distributed in time.

Dorsey-Kramer (1995) used a different statistical approach that minimized some of the potential bias present in the Arnold *et al.* (1989) analysis. She identified and grouped together data from sites below the forested areas, and upstream of urban areas, in an attempt to concentrate on the effects in the agricultural areas, and increase the sample size included in the analysis. This approach applied a general linear model to data collected over 30 years, from the early 1960s through 1992, and included an estimate of five day antecedent precipitation for each sampling date. Dorsey-Kramer's analysis showed that fecal coliform concentrations decreased in all seasons, with the greatest decreases occurring in winter **(Table 4-2).** Decreasing trends were observed throughout the period of record, but the decreases became more pronounced after 1984, once a significant percentage of BMPs had been installed (Figure 4-4).

Fecal coliform concentrations decreased during the 1980s, even though herd sizes increased dramatically.

The studies by Dorsey-Kramer (1995) and Arnold *et al.* (1989) conclude that fecal coliform concentrations improved during the 1980s. While the trend tests by Wiltsey (1990) do not confirm this finding, the approaches were sufficiently different that they do not conflict with findings from the other studies. The Dorsey-Kramer approach involved a longer time period, and combined data from many sites, all the while comparing data over time only to the same site, and thus greatly increased the sample size for the analysis, which in turn may lead to trend detection. Another confounding fact is that between 1980 and 1990, the number of dairy cows in Tillamook increased. Dorsey-Kramer (1995) reported a doubling of the cow population, based on membership increases in the Dairy Herd Improvement Association. Numbers of milking cows in 1980 and 1990 (Commodity Data Sheets) indicate a smaller increase (37%) from 18,700 in 1980 to 22,900 in 1990. Since the data suggest that water quality improved while herd sizes increased dramatically, the management practices adopted in agricultural areas of the basin appear to have been very effective. Although conditions may have improved, water quality violations still occur in the tributaries and in the Bay monitoring sites.

The management practices adopted in agricultural areas appear to be very effective.

A few upstream/downstream studies were conducted during the mid-1980s. Dorsey-Kramer (1995) evaluated these data to describe the effect of BMPs installed on two farms in the mid-1980s during the RCWP. Comparing water samples taken during the mid-1980s at sites upstream and downstream of two farms revealed higher bacterial concentrations downstream of the farms, despite recent implementation of new management practices. However, since no pre-implementation data are available, there is no way to determine whether the changes in management practices improved water quality. Although bacterial concentrations were higher downstream of the farms, pre-implementation status may have been much worse. Arnold *et al.* (1989) found similar results for sites along the Wilson and Tillamook Rivers, and along Murphy, Bewley, and Mill Creeks. Downstream bacteria were at much higher concentrations than upstream. Again, these data were collected during the RCWP, so not all new management practices were fully operational and no pre-project data were available to assess improvements.

A comparison of fecal coliform data from (Musselman) 1986 and 1977 **(Table 4-3)** also supports a trend of decreasing fecal concentrations over time. Geometric means were reduced at all but one site. All sites with observations greater than 400 FCU showed a reduction in the percent of observations above this value.

Only one recent study has looked at the bacterial sources along a river gradient. Alexander and Koretsky (1996) sampled six sites along the Trask River, from the forested land down into the Bay near the river mouth during a dry summer period, and at the end of a significant fall rain event **(Figure 4-5)**. During the summer sampling the only site with elevated bacteria concentrations was Hoquarten Slough, a slow moving water body that commonly experiences water quality problems. All other sites along the mainstem of the Trask had bacteria concentrations within the water quality standards and were at similar levels, even in the forested area. During the wet sampling event the upstream-downstream differences were greater. Bacterial concentrations at the three downstream sites exceeded 2,000 colonies per 100 mls while levels at the upstream sites were greater than the dry season values, but still below 500 colonies per 100 mls, with gradual increases as the river flowed downstream. The Hoquarten Slough site was again the worst. Urban runoff is implicated as a significant source in this sampling event, as well as the downstream dairy operations, failing septic systems, and possible wastewater treatment plant malfunction.

The status of many of the potential sources Jackson and Glendening (1981) identified has changed in the 15 years since the report was written. Many dairies have adopted BMPs including increased manure storage capacity, streamside fencing, and gutters to direct rainfall away from animal holding areas. The local wastewater treatment plants have upgraded various aspects of their facilities and should have fewer polluting episodes. Many malfunctioning septic systems have been identified and repaired or replaced. However, the number of cows in the area has increased significantly since 1980

Table 4-2. Reductions in fecal coliform bacteria at stream sites in agricultural areas

Precipitation level	Summer	Autumn	Winter	Spring
Low	24.3%	29.1%	35.4%	30.6%
High	30.6%	40.3%	45.6%	41.6%

Table depicts reductions in fecal coliform bacteria at stream sites in agricultural areas of the Tillamook Bay Basin between 1980 and 1992.
Data are from 14 stream stations in the Tillamook Bay Watershed with monitoring data before and after 1984, the date used by Dorsey-Kramer to define pre and post best management practice implementation. The magnitude of the decreases changed over seasons and with the level of precipitation. The table shows percent decrease among seasons, and for low and high antecedent precipitation.
Source: Dorsey-Kramer, J. 1995. A statistical evaluation of the water quality impacts of Best Management Practices installed at Tillamook County Dairies. Master's Thesis, Oregon State University, Corvallis, OR.

Table 4-3. Fecal coliform concentration changes in Tillamook Bay tributaries

Tributary station	Designation		FC MPN*/100 mL geometric mean		% > 400		# Samples	
	1977	1986	1977	1986	1977	1986	1977	1986
Miami River	M-1	M-1	300	171	65	25	17	8
Vaughn Creek	V	V-3	3300	421	91	60	11	5
Kilchis River	K-1	K-4	34	18	0	0	11	9
Wilson River	W-1	W-13	66	18	11	0	19	10
Wilson River	W-3	W-13A	95	37	15	0	13	5
Hoquarten Slough	HQ	HQ-2	2300	344	100	50	11	8
Trask River	T-1	TR-9	190	72	21	0	19	10
Trask River	T-2	TR-8	42	46	0	0	17	5
Tillamook River	TL-1	T-6	240	60	29	0	17	4
Tillamook River	10	T-BR	250	110	40	10	15	10

Data collected Dec. 2–13, 1977 and Dec. 1–5, 1986. Wilson River mean flow: 6170 CFS/1150 CFS.
* Most Probable Number.
Source: Musselman, J. 1986. Sanitary survey of shellfish waters, Tillamook Bay, Oregon, December, 1986. U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Shellfish Sanitation Branch.

(Dorsey-Kramer 1995; Commodity Data Sheets 1980,1990) and, more than a decade after installation, not all manure storage tanks are properly maintained. The Natural Resource Conservation Service estimates 1998 dairy stock populations within the Tillamook Watershed at about 28,600 milk 1,000-pound units, including cows, calves, heifers, and dry stock (Pedersen, B. pers. com. 1998). While bacteria concentrations may have decreased since the early 1980s (Dorsey-Kramer 1995, Arnold *et al.* 1989), water quality violations still occur, and bacterial concentrations in the Bay are still high enough to warrant closure of oyster harvesting during storm events. A review and follow-up of the earlier work is the best place to start identifying current sources.

Monitoring Efforts in Tillamook Basin

Water quality monitoring programs for the Bay and its rivers are summarized in **Table 4-4.**

The DEQ, in conjunction with the ODA Food Safety Program, samples 15 sites in the Bay **(Figure 4-6)** in order to determine whether Bay water quality meets the requirements of the shellfish management plan for the Tillamook Bay Basin. Samples are collected monthly at outgoing tide, in order to collect data under the highest bacteria levels to which oysters are exposed. This water, with its high ratio of fresh water, has higher bacteria concentrations (Jackson and Glendening 1982, Arnold *et al.* 1989). Freshwater bacteria concentrations are high for two reasons: major sources of bacteria located near fresh water wash into the Bay, and bacteria survive longer in fresh than salt water.

The current extent and schedule of regular sampling in fresh water is much more limited. Five sites, one on each major river (Figure 4-6), are sampled quarterly for bacteria and 16 other parameters, including nutrients, turbidity, dissolved oxygen, etc. These sites are part of the DEQ's ambient monitoring network to characterize water quality statewide. From 1979 through 1989, data were collected intermittently at various freshwater sites, in order to identify the sources of bacteria to the Bay.

Data for the following analyses and diagrams was obtained from Storet, the federal water quality database, and the DEQ between 1961 and the present. Nutrient data were collected in the Bay and at some of the freshwater sites in the early 1990s. Bacteria and other chemistry are available for earlier dates as well. The analyses presented below are intended to supplement the previous, more intense investigations discussed previously. The more recent studies (Dorsey-Kramer 1995, Wiltsey 1990, and Arnold *et al.* 1989) emphasized trend analysis and

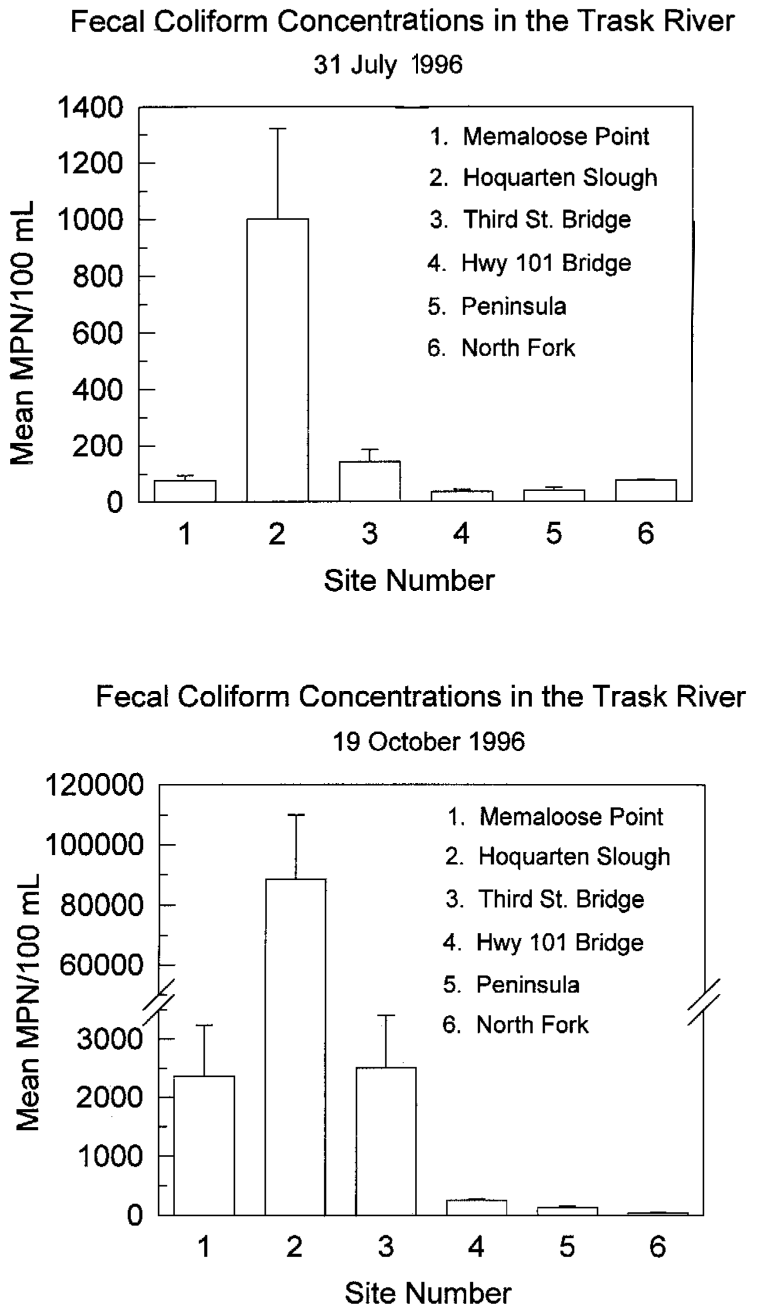


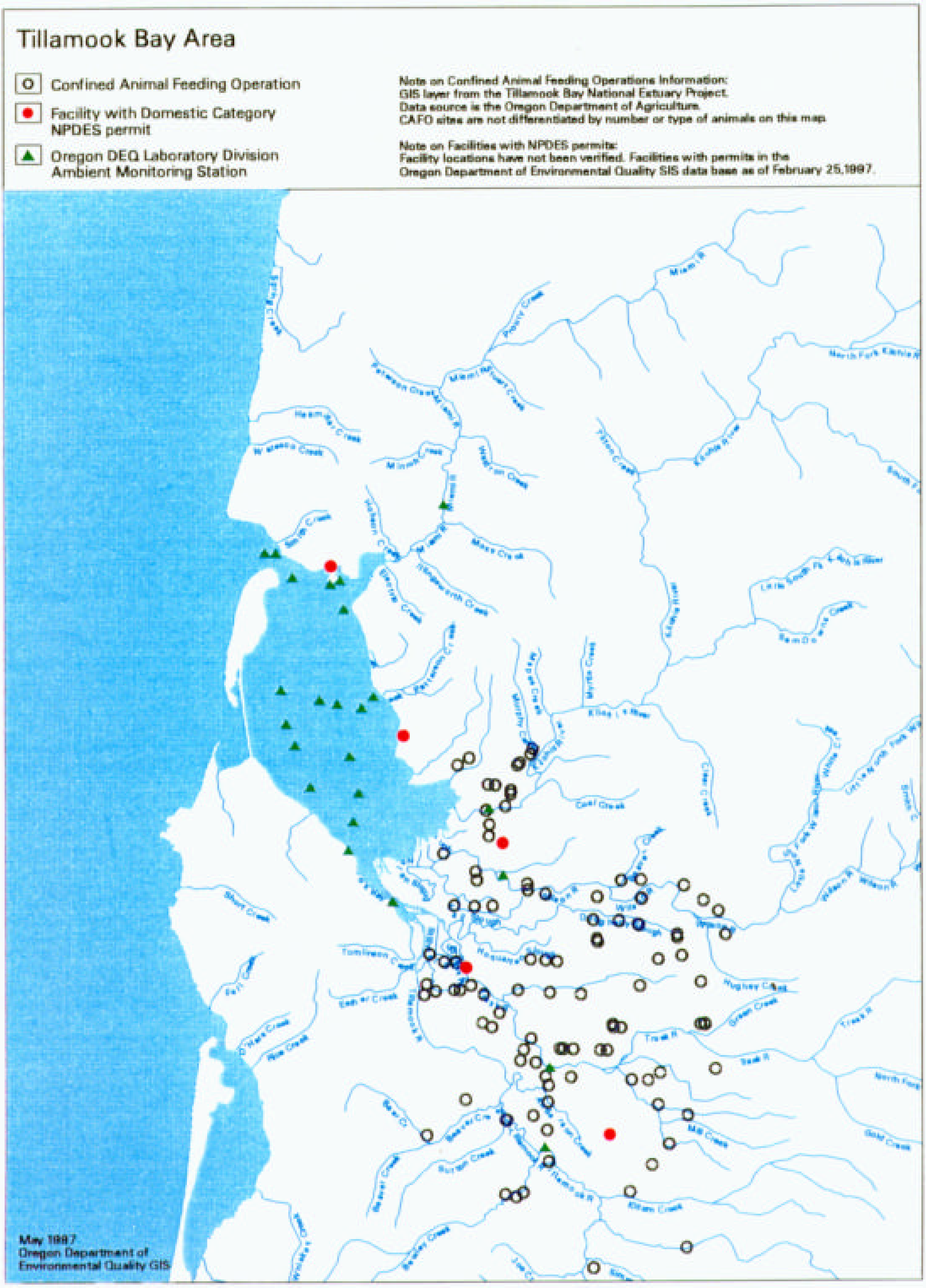
Figure 4-5. Trask River fecal coliform concentrations.

Expressed in concentrations per 100 mls, fecal coliform was measured at six Trask River sites on two sampling dates: after an extended dry weather period on July 31, 1996, and near the end of a substantial rainstorm, Oct. 19, 1996. Site locations extend from the Bay (station 1 at Memaloose Point, .8 miles downstream of the Trask River mouth) to the North Fork Trask River (at river mile 20.2) in forested land.
Source: Alexander, D. and Koretsky, T. 1996. "Seasonal comparison of fecal coliform concentrations in the Trask River and a study of the survival of Escherichia coli in Tillamook Bay water." Final report to the Tillamook Bay National Estuary Project, Garibaldi, OR.

Table 4-4. Monitoring summary

Agency	Program	Monitoring frequency	Monitoring sites	Sampling design	Period of record
DEQ	Ambient Monitoring	quarterly	mouths of rivers	periodic	1980–1986 (monthly 1986–1990)
DEQ		monthly	Bay (about 20 sites)	periodic	1986–-present (quarterly 1980–1986)
DEQ	Tillamook Bay Bacteria Study	every 8 hours at tributary sites, and daylight high and low tides	Bay and sites along all 5 tributaries	episodic (storm events and dry weather)	1979–1980
DEQ	Tillamook Special Survey	N/A	sites along 5 tributaries and creeks, treatment plant effluent	episodic	March 1997
DEQ	Tillamook Special Survey	N/A	sites along 5 tributaries and creeks, treatment plant effluent	episodic	April 1997
DEQ	Tillamook Special Survey	N/A	Miami and Kilchis River mouths, about 20 sites in the Bay	episodic	October 1997
DEQ	Tillamook Dissolved Oxygen Study	N/A	sloughs, Wilson River, Tillamook River, Kilchis River, and Lower Trask River	episodic	September 1997
FDA (with Oregon Officials)		N/A	Bay and tributaries	comprehensive sanitary survey	November 1974
FDA (with Oregon Officials)		N/A	treatment plants	dry weather — pollution source evaluation	May 1976
FDA (with Oregon Officials)		N/A	treatment plants	wet weather — sanitary survey of shellfish waters	November–December 1977
FDA (with State of Oregon and Tillamook County Officials)	Shellfish Sanitation Program	N/A	Bay, tributaries, shellfish and sediments	sanitary survey	December 1–12, 1986

Source: Compiled by M. Fonseca, Oregon Department of Environmental Quality, from listed sources.



Note on Confined Animal Feeding Operations Information:
GIS layer from the Tillamook Bay National Estuary Project.
Data source is the Oregon Department of Agriculture.
CAFO sites are not differentiated by number or type of animals on this map.

Note on Facilities with NPDES permits:
Facility locations have not been verified. Facilities with permits in the
Oregon Department of Environmental Quality SIS data base as of February 25,1997.

Figure 4-6. Map of lower Tillamook Basin, depicting sampling sites discussed in text, permitted point source locations, and locations of Confined Animal Feeding Operations (CAFOs).
Source: Oregon Department of Environmental Quality GIS database. February 1997.

assessments of BMP implementation. The work presented here simply characterizes seasonal distribution of bacteria and nutrients, and looks superficially at recent trends of bacteria at selected Bay sites.

Bacterial Contamination in the Tillamook Basin

Fecal coliform concentrations in Tillamook Bay surface waters differ from season to season. For the freshwater sites in rivers, bacterial concentrations are highest during the low flow months of summer **(Figures 4-7, 4-8, and 4-9)**. Although freshwater bacterial concentrations are likely to be lower during the winter, river discharge then is so much greater that the total amount of bacteria delivered to the Bay during winter is much greater than during summer. In addition, the larger contribution of fresh water to the Bay during winter reduces Bay salinities and salt water intrusion, so waterborne bacteria survive longer. As a result, bacterial concentrations in the Bay during winter are higher than during the summer months (Figure 4-9**)** even though the reverse is true of the freshwater systems.

Time series plots and trend tests of bacteria data from one mid-Bay site (Station 11, see Figure 4-3 for location) are presented in **Figure 4-10**. The results of the non-parametric Seasonal Kendall Tau trend test on untransformed bacteria data show no evidence of decreases in bacteria over the period of 1981 through 1996. Fifteen-sample running geometric averages, conforming to the calculation for the FDA shellfish bacteria standard, are also presented in Figure 4-10. No obvious monotonic trends are observed in this plot.

Bacterial concentrations were below the 14 colonies per 100 mls standard between 1984 and 1988, but these were years when only four to five data points were available. In contrast, monthly sampling was available for the previous and following time periods. In addition, the mid-80s were drought years, which may have contributed to lower bacterial concentrations. Neither approach shows obvious or large changes in Bay bacteria concentrations. Similar analyses at other Bay monitoring sites show the same results, so only data from this site are presented.

The Tillamook Basin rivers are the major source of bacteria to the Bay.

The Tillamook Basin rivers are the major source of bacteria to the Bay. Two observations lead to this conclusion: bacteria levels show a decreasing gradient from the southern Bay near the river mouths to the northern Bay and ocean inlet; and wintertime Bay bacteria concentrations are higher when freshwater inputs are largest. Therefore, in order to address the bacterial problems in the Bay, it may help to understand which rivers contribute the largest loads of bacteria. Given the small amount of data available for both bacterial concentrations and river stage or discharge, it is hard to get accurate figures to address the question. However, a general understanding of bacterial conditions can be gained from the data at hand.

Box and whisker diagrams

Box and whisker diagrams are used in several of the figures in this report to depict the distribution of collected data from several sites for several variables. They look unusual, but their interpretation is straightforward. The upper corners of the box show the 75th percentile of the sample data, and the lower corners show the 25th percentile of the data. The horizontal line extending across the box is the median value for that sample data set. The vertical lines above and below the box show the 90th and 10th percentile, respectively. Any circles above and below the lines show actual data points that lie beyond the 90th or 10th percentile. An easy way to interpret the percentiles is that at the 25th percentile (the bottom of the box) 25% of the values are below that level, while 75% had higher values. The fact that the median value is not always in the middle of the box and whisker shows that the data are not normally distributed (following a bell-shaped curve). Bacteria data often consist of many low numbers and occasional high values, so the upper portion of the box and whisker diagram may be much longer than the lower portion.

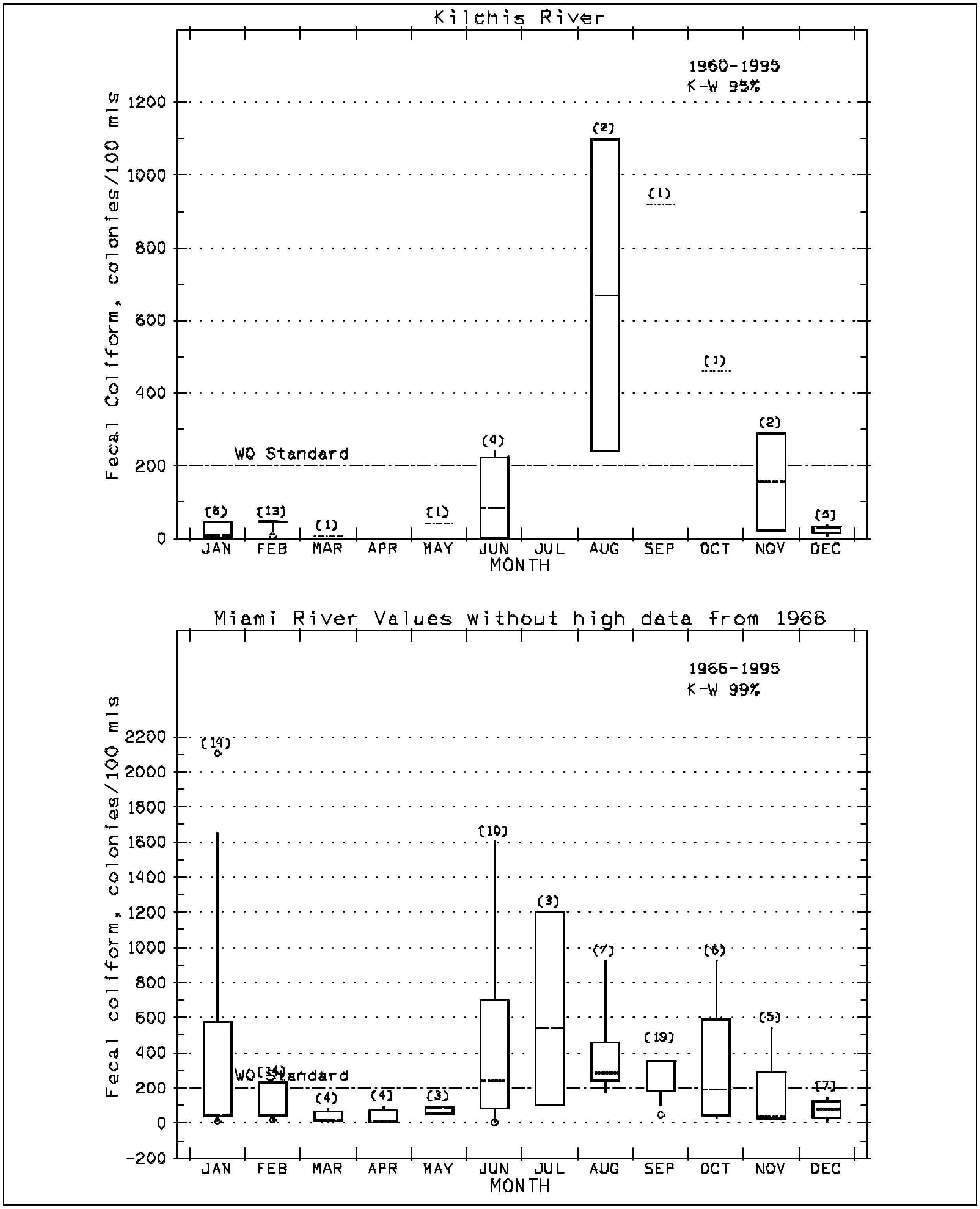


Figure 4-7. Box and whisker diagrams for monthly distributions of fecal coliform bacteria from 1960 through 1995, at sites along the Miami River (river mile 0.3) and Kilchis River (river mile 6.8).
The water quality standard indicated is for recreational contact, 200 fecal coliform colonies per 100 mls.
Source: Analysis by Avis Newell of the Oregon DEQ, based on data collected by DEQ and available on Storet.

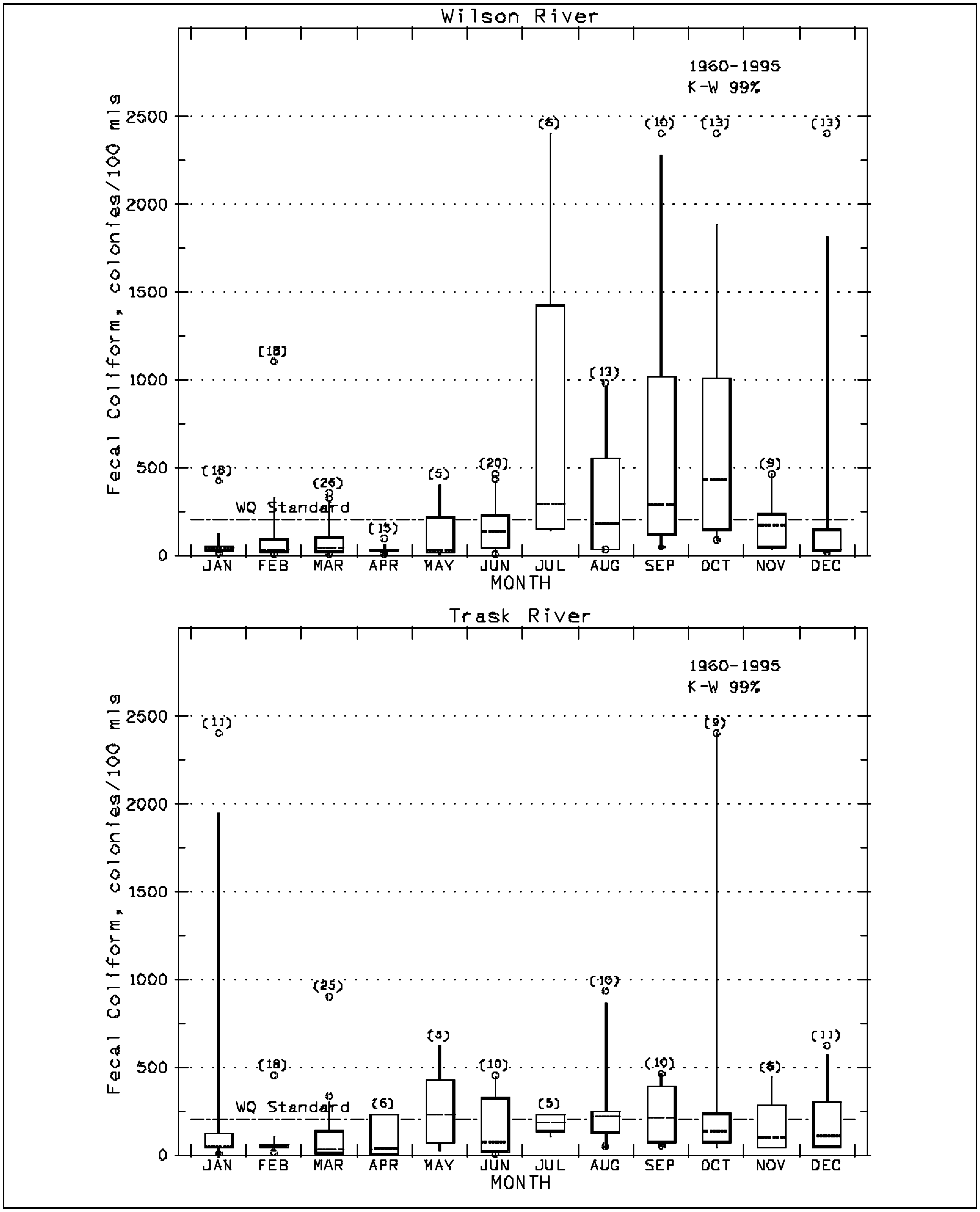


Figure 4-8. Box and whisker diagrams for monthly distributions of fecal coliform bacteria over the years of 1960–1995, at sites along the Wilson River (river mile 1.8) and Trask River (river mile 4.2). The water quality standard indicated is for recreation contact, 200 fecal coliform colonies per 100 mls.
Source: Analysis by Avis Newell of the Oregon DEQ, based on data collected by the DEQ between 1960 and 1995, available on Storet.

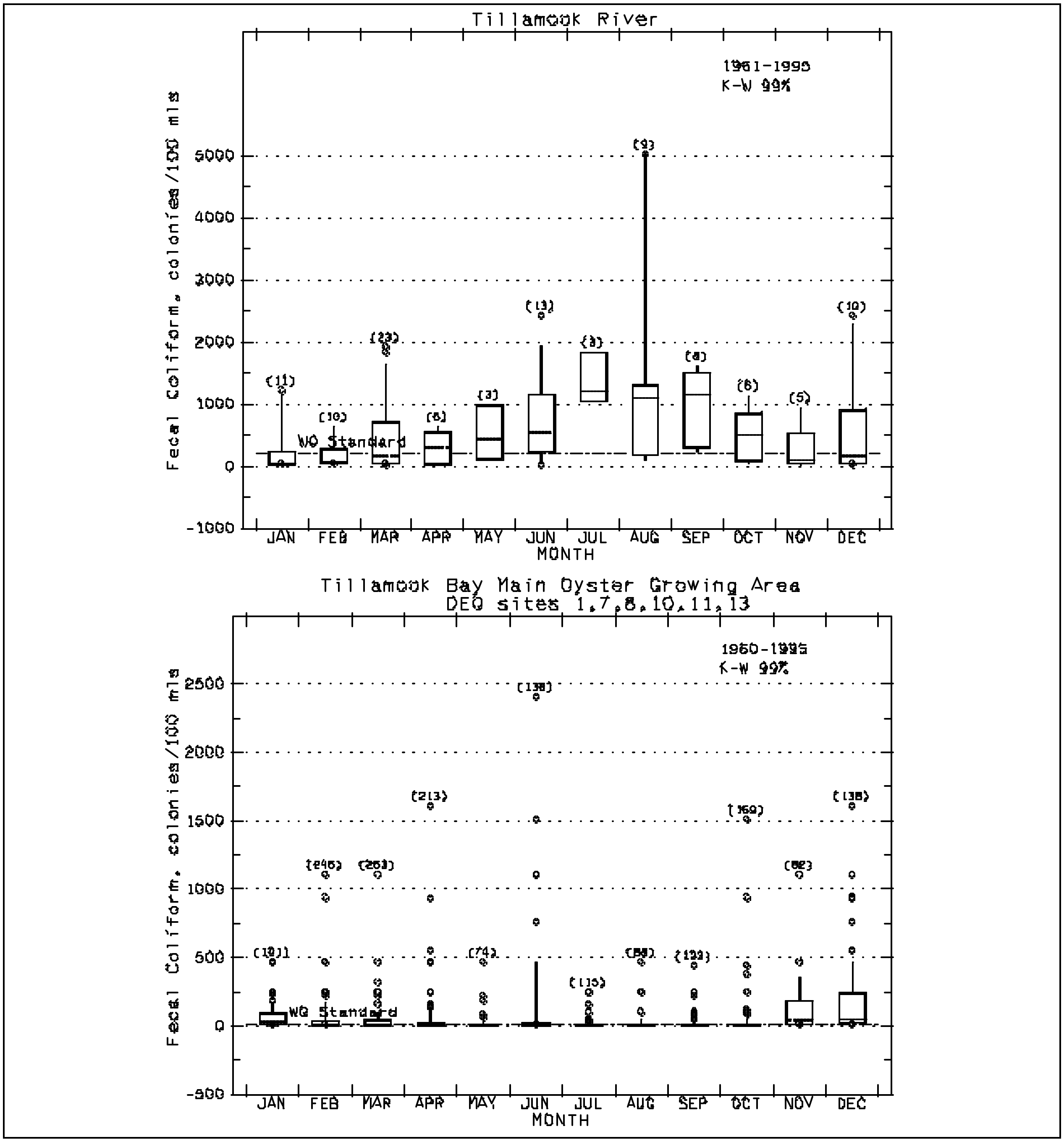


Figure 4-9. Box and whisker diagrams for monthly distributions of fecal coliform bacteria over the years of 1960–1995, at sites along the Tillamook River (river mile 6.8) and at 6 sites in the Main Shellfish Zone of Tillamook Bay (sites 1, 7, 8, 10, 11, and 13, Figure 4-3). The water quality standard indicated is for recreation contact, 200 fecal coliform colonies per 100 mls.

Source: Analysis by Avis Newell of the Oregon DEQ, based on data collected by the DEQ between 1960 and 1995, available on Storet.

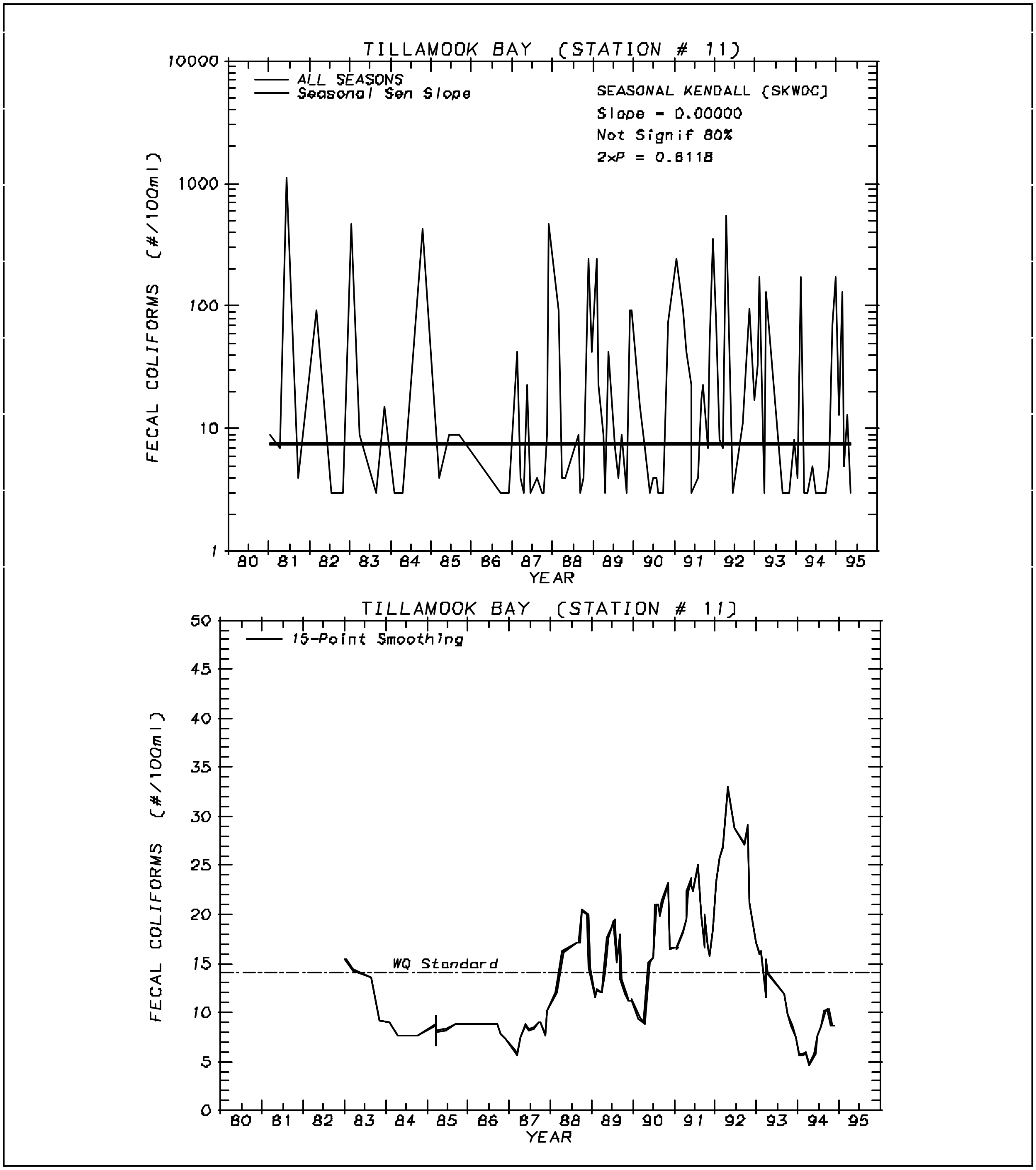


Figure 4-10. Main Bay raw data plotted on a log scale, accompanied by the results of a Seasonal Kendall Tau trend test.

The line through the data represents the zero value trend calculated by the trend test. Below that is a graph of the 15 sample running geometric mean, also plotted on a log scale, with the horizontal line indicating the 14 fecal coliform colonies per 100 mls National Shellfish Sanitation Standard. The 15 sample running average is the statistic compared with the critical level for this standard.

Source: Analysis by Avis Newell of the Oregon DEQ, based on data collected by the DEQ between 1960 and 1995, available on Storet.

Table 4-5. Geometric mean fecal coliform levels per 100 mls in Tillamook Basin rivers

Station name	No. of observations	Geometric mean fecal coliform per 100 mls
Miami River @ river mile 0.3	58	102
Wilson River @ river mile 1.8	126	88
Trask River @ river mile 4.2	71	71
Tillamook River @ river mile 6.8	81	263

The Kilchis River site is omitted from the table because not enough data is available to determine the average bacteria level. Averages are calculated as the geometric mean.
Source: Based on 1985–1996 data DEQ collected at Storet sites.

The Tillamook River site at Bewley Creek consistently has the highest bacterial concentrations of the five river sites included in the ambient monitoring program **(Table 4-5)**. Looking at data collected since 1981 in the Tillamook River, the median monthly values for fecal coliform exceed the recreational water quality standard of 200 colonies per 100 ml every month from March through October, and violations occur every month except February (Figure 4-9). In contrast, median fecal coliform values are below the recreational contact standard on the remaining rivers during most of the year (Figures 4-7, 4-8, and 4-9), although some violations are observed throughout the year at all of the ambient monitoring sites. Median values describe the 50th percentile of the sample distribution, so when a median value exceeds the water quality standard at least half the data collected exceeds the standard. High summer concentrations in the rivers are somewhat confusing. If manure is being applied to the land properly, and animals are kept out of stream channels, then high summer concentrations may indicate constant levels of bacteria reaching the steams (such as failed onsite systems), combined with less dilution during low summer flows.

To determine which river delivers the highest load of bacteria to the Bay, one must consider the volume of water flowing to the Bay as well as the bacterial concentration. Although the Tillamook River generally has higher bacterial concentrations, and more water quality violations, it is smaller than either the Wilson or Trask, so these two may be significant contributors as well. Historically, river discharge has only been monitored on the Wilson River. Staff gauges have been in place at various times on the other four rivers, so estimates of relative discharge are

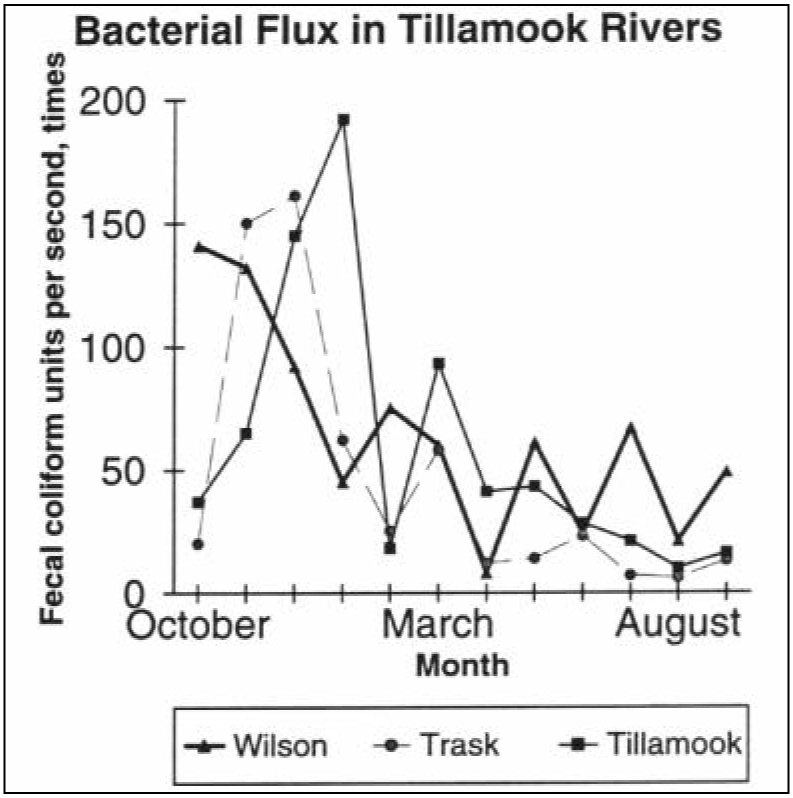


Figure 4-11. Percentage of annual bacteria delivered monthly by Tillamook Bay's three largest rivers: the Wilson, Trask, and Tillamook.

Source: Dr. Jim Moore and Wendy Church, pers. com. 1997. Oregon State University Bioresource Engineering Department, Corvallis, OR. Moore and Church obtained the figures using the monthly median values at each river and estimates of relative flow of the three rivers, obtained from the U.S. Geological Survey.

available (Dorsey-Kramer 1995). Using these discharge estimates with median monthly bacteria concentrations as shown in Figures 4-7, 4-8, and 4-9, monthly bacterial loads for the three largest rivers were estimated **(Figure 4-11)**. From this figure, it is difficult to tell which river contributes the most bacteria. The TBNEP has had river gauges installed in all five Tillamook Bay rivers and is funding a sampling study that will allow more precise estimates of bacterial loads from each river, as well as nutrients and suspended sediments. From the estimates in Figure 4-11, we can see that bacterial loads to the Bay are roughly equal from all three rivers, but there may be some seasonal differences among the rivers. The Trask and Tillamook Rivers appear to contribute much more in winter than in summer months, while the Wilson River's autumn contributions are only moderately higher than in summer (Figure 4-11).

Knowing that the Trask, Tillamook, and Wilson Rivers are the largest contributors of bacteria to the Bay does not help us to identify specific sources. A comparison of upstream and downstream sites along the Tillamook, Trask, and Wilson Rivers shows that bacterial loads increase substantially in the lower, inhabited reaches of the rivers. Point sources are located on the Trask River (City and Port of Tillamook wastewater treatment plants at river miles 1.9 and 5.2, respectively), and Wilson River (Tillamook Creamery at river mile 1.7 of the Wilson River and Pacific Campground eventually entering the Wilson River at river mile 1.5). All three river drainages have dairies, stormwater runoff, and houses with onsite systems. The Tillamook River has no point sources on it, but is a significant contributor of bacteria to the Bay, so the point sources are clearly not the sole sources of bacteria to surface waters in the Watershed.

Nutrients in the Tillamook Watershed

Eutrophication is a problem in many U.S. estuaries and will continue to be a concern nationwide as the coastal population increases (Day *et al*. 1989). High nutrient loads to surface waters may result in increased plant growth, either of algae suspended in the water column or attached to plants and sediments, or of submerged aquatic vegetation in rivers or the Bay. Dense algal growth may impede light penetration in the water column, which may in turn limit the growth of submerged aquatic vegetation that provides important habitat in the Bay. Increased nitrogen inputs have been found responsible for the demise of eel grass in Chesapeake Bay, with related habitat loss for fish nurseries and blue crab (Burkholder *et al*. 1992a). High loads of phosphorus have been found to stimulate blooms of dinoflagellates that are toxic to finfish (Burkholder *et al.* 1992b). These blooms are implicated in several fish kills in the Neuse and Pamlico estuaries of North Carolina, and may be responsible for fish kills in other locations as well. Stevenson *et al.* (1993) have observed the recovery of submerged aquatic vegetation (SAV) in selected areas of the Chesapeake system. They were able to relate water quality parameters to SAV recovery, and demonstrated that SAV recovered in locations where nitrogen and phosphorus had declined due to changes in nutrient input and hydrology.

Dense plant growth can impact water quality as well. In freshwater systems, blooms of algae and dense aquatic vegetation cause large swings in dissolved oxygen concentrations. During daylight hours while plants are actively growing, they take up carbon dioxide and release oxygen to the water column. Oxygen concentrations can become so high that the water is supersaturated with oxygen, which can stress aquatic organisms. As plants metabolize at night, and after the plants have died and begun to decay, the lush growth uses large amounts of oxygen, depleting the oxygen in the water column and again stressing aquatic organisms, if not resulting in complete anoxia. Data that precisely describe these conditions in the Tillamook Basin do not exist. However, anecdotal reports of algal blooms in the lower reaches of the basin suggest that high productivity occurs occasionally. This may affect chum and chinook habitat, as these fish spend more time in the salt marsh and tidal flats than do other salmonid species. (See Chapter 3, Biological Resources, for more information on fish and water quality.)

Since nutrients and bacteria have the same sources, if enough bacteria are reaching surface waters to cause water quality problems in Tillamook Watershed, it is reasonable to question whether nutrients are at levels of concern in Tillamook Bay. Data presented here are from the Bay and ambient freshwater sampling sites shown in Figure 4-6. Nutrient data have only been collected at sites in Tillamook Bay and the ambient network (freshwater sites) since 1994; too short a time period to assess trends in nutrient concentrations in the Bay.

The State has only established nutrient standards for specific surface water bodies where Total Maximum Daily Loads for a given nutrient have been set. None of these are in the Tillamook Basin. The National Oceanic and Atmospheric Administration has conducted a survey of the nation's estuaries (NOAA 1996) and the NOAA office of Ocean Resources Conservation and Assessment has established guidelines for classifying the trophic level of estuarine waters. The parameters include turbidity, suspended solids, biological community characteristics, and concentrations of chlorophyll a, nutrients, and dissolved oxygen. Data for most of these parameters are not available for Tillamook Bay. However, limited data for nutrients and dissolved oxygen can be compared **(Table 4-6)** with these guidance values. Unfortunately, similar guidance values have not been developed for rivers.

Table 4-6 Trophic level guidance values for estuaries

Parameter	High	Medium	Low
Total N	> 1 mg N/L	0.1–1 mg N/L	< .1 mg N/L
Total P	> 0.1 mg P/L	0.01–0.1 mg P/L	< 0.01 mg P/L

Source: National Oceanic and Atmospheric Administration. 1996. Estuarine Euthrophication Survey.

Nitrogen
Gaseous element. In its elemental form it exists as a diatomic molecule, N_2.

Nitrite
The ion NO_2. Unlike the nitrate used in fertilizers, nitrite is toxic to plants in large concentrations.

Nitrate
The ion NO_3. Nitrates are important as concentrated sources of nitrogen in fertilizers. They are very soluble and easily leached from soils, resulting in the contamination of surface waters.

Total Kjeldahl Nitrogen
A method used to determine the otal amount of nitrogen in a sample, regardless of its form.

In-Bay Nutrient Concentrations

At the Main Bay sites (sites 1, 7, 8, 10, 11, 13; Figure 2) analysis of nitrate and nitrites plus total Kjeldahl nitrogen places levels of total nitrogen between 0.1 and 1.0 milligrams per liter, somewhat higher during the winter months **(Figure 4-12**). The NOAA estuary trophic classification (1996) would place Tillamook Bay at a moderate to high trophic level. Nitrate concentrations are higher both during the winter months and at sites in the southern end of the Bay, closer to the river mouths, suggesting that nitrate in the Bay comes largely from fresh water sources. **Figure 4-13** charts phosphorus and nitrogen levels for the Wilson River for comparison. Limited data are available for total Kjeldahl nitrogen, so seasonal patterns for the organic form are not discernable. Applying the same guidance (NOAA 1996), phosphorus concentrations in Tillamook Bay are also in a moderate trophic range. Monthly median phosphorus values rarely exceed 0.025 mg/l in the southern Bay (prohibited shellfish zone), or 0.035 in the main Bay (Figure 4-12). The available data do not show seasonal patterns for total phosphorus.

When high nutrient concentrations result in dense phytoplankton growth, turbidity measures may increase. However, turbidity data for Tillamook Bay are limited, with monthly median values generally below 10 FTU, again decreasing as river water flows north toward the ocean. No discernable seasonal patterns are apparent. Also, no data are available for chlorophyll *a*, so it is not possible to conjecture whether turbidity is due to suspended sediment or to algal blooms. Tillamook Bay is shallow and wind often visibly increases turbidity, so considerable turbidity can be attributed to resuspension of Bay sediment.

Dissolved oxygen is often depleted in eutrophic systems (Day *et al.*1989). Data from the surface water of Tillamook Bay indicate that DO concentrations rarely dip below 6 ppm, and are generally greater than 8 ppm. Dissolved oxygen is lower in summer than in winter months, corresponding to seasonal water temperatures. No data from other depths are available to indicate whether anoxia occurs near the sediment layer.

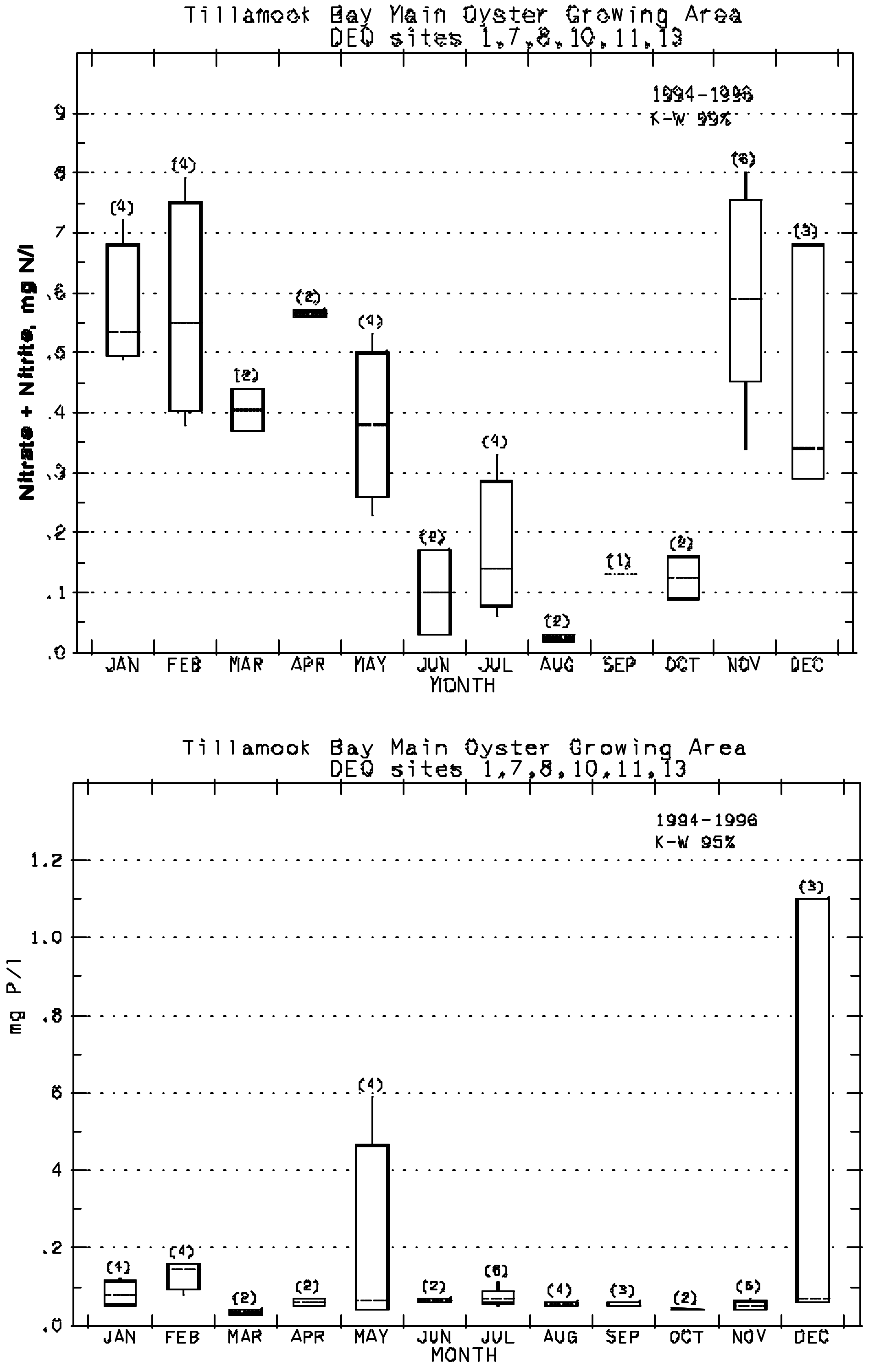


Figure 4-12. Box and whisker diagrams depict the monthly distribution of total phosphorus (mg P/l) and nitrate + nitrite (mg N/l) at Tillamook Bay monitoring sites (1,7, 8, 10, 11, and 13, as identified in Figure 4-3). The Wilson River was selected for demonstration because seasonal patterns among all river sites were similar, and the most data were collected at the Wilson site.

Source: Analysis by Avis Newell of the Oregon DEQ, based on data collected by DEQ, available on Storet.

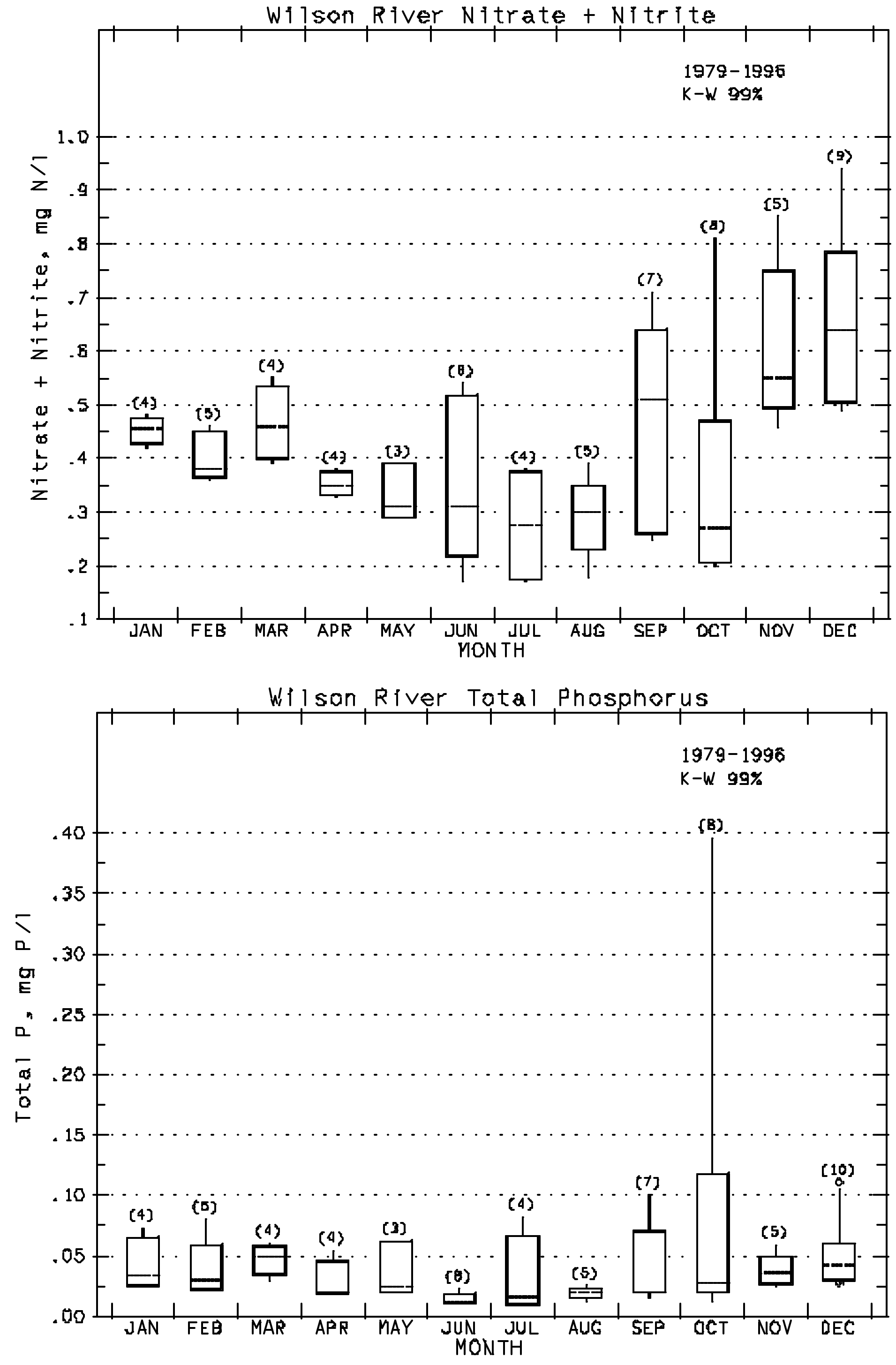


Figure 4-13. Box and whisker diagrams depict the monthly distribution of total phosphorus (mg P/l) and nitrate + nitrate (mg N/l) at the Wilson River site (river mile 1.8). The Wilson River was selected for demonstration because seasonal patterns among all river sites were similar, and the most data were collected at the Wilson Site.

Source: Analysis by Avis Newell of the Oregon DEQ, based on data collected by the DEQ, available on Storet.

No phytoplankton samples or measures of phytoplankton abundance such as chlorophyll *a* have been taken from Tillamook Bay, so it is difficult to assess whether eutrophication is a problem in Tillamook Bay. While the disappearance of eelgrass and other submerged aquatic vegetation has been used as an indicator of eutrophication in other U.S. estuaries (Stevenson 1993, Day *et al.* 1989), Tillamook Bay has a healthy population of eelgrass so eutrophication is not evident. However, the extent of anoxia in sediments, characterization of the phytoplankton community, and changes in the submerged aquatic vegetation have not been investigated, so recent trends regarding eutrophication are not available. The TBNEP recently initiated a study to assess biovolumes for phytoplankton and zooplankton at four locations in the Bay.

Freshwater Nutrient Concentrations

In the freshwater systems, nutrient concentrations differ only somewhat among the five rivers **(Figure 4-14)**. No data are available for the Kilchis River site, so it cannot be compared with the other rivers. Median nitrate plus nitrite concentrations are higher in the Miami River (about 0.7 mg/l) than in the Tillamook (0.55 mg/l), Trask (0.4 mg/l) and Wilson Rivers (0.4 mg/l). Seasonal patterns are similar among all four rivers (Figure 4-13). Winter concentrations exceed summer, with December concentrations generally the highest.

In contrast, median values for both total and dissolved phosphorus (P) are slightly lower at the Miami site than at the Tillamook, Trask, or Wilson River sites (Figure 4-14). All values are relatively low; all median values for total P are lower than 0.05 mg/l, and for dissolved P are lower than 0.01 mg/l. The 75th percentile of total P on the Tillamook, Trask, and Wilson Rivers is generally about 0.05 mg/l, and for dissolved P is about 0.01 mg/l. Seasonal distribution of total P in the river sites is similar to nitrogen but less apparent. Concentrations are somewhat higher during the wet winter seasons than during the dry summer months.

Median chlorophyll *a* concentrations in all four rivers are below 2 µs/L, as are most of the quartile values for chlorophyll *a*. This is far below the water quality standard of 15 µs/L. Once or twice in the past 15 years of sampling (unpublished data, available on EPA's Storet database), chlorophyll *a* concentrations have been high, 10–15 µs/L, on each river. Sampling during an algal bloom would explain these rare, high numbers. Quarterly sampling will not characterize the frequency and intensity of periodic blooms well.

Eutrophication problems are not obvious in the Tillamook Bay Watershed, partly because available data do not cover enough

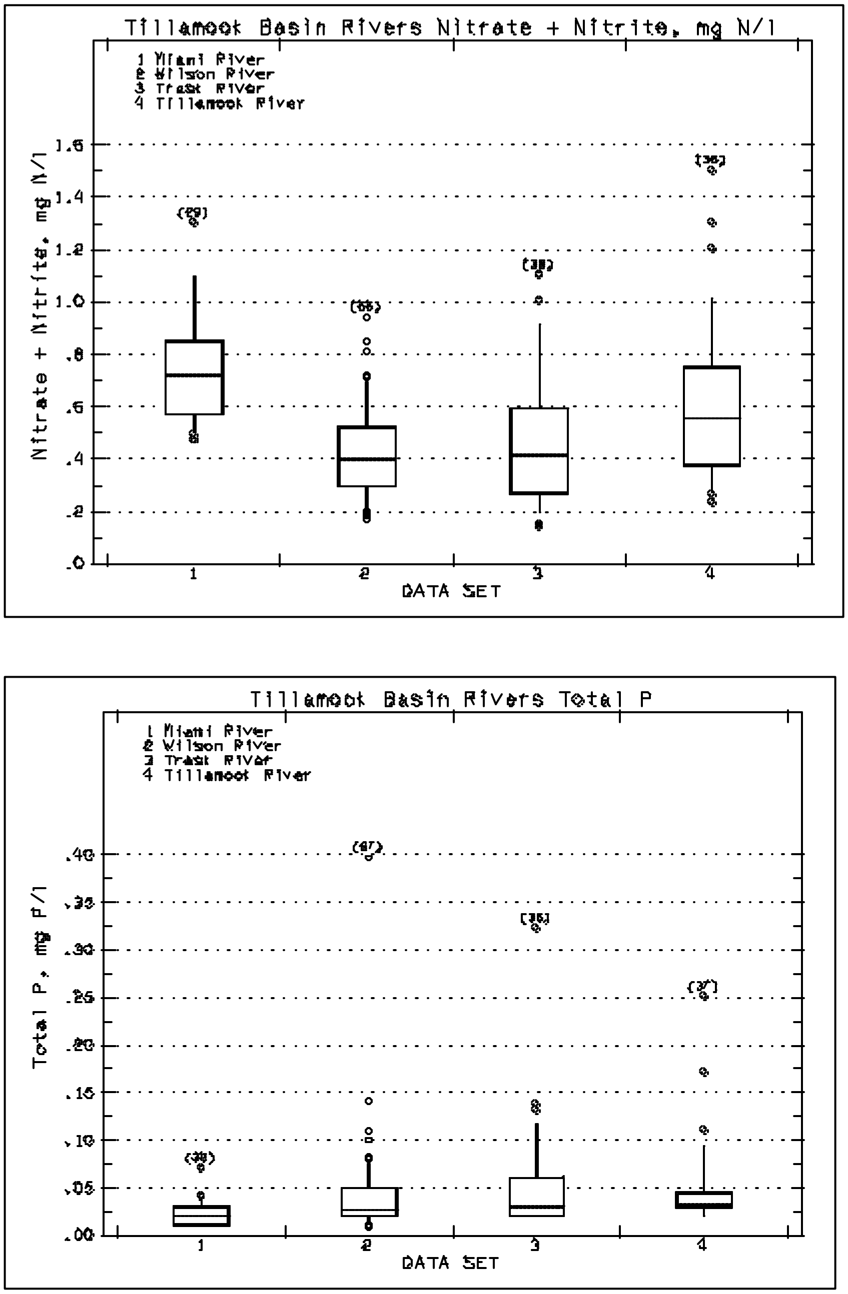


Figure 4-14. Box and whisker diagrams of total phosphorus (mg P/l) and nitrate + nitrate (mg N/l) concentrations at he monitoring sites for four of the five Tillamook Rivers. Only one datum is available for the Kilchis River, so it is not included here.

Source: Analysis by Avis Newell of the Oregon DEQ, based on data collected by the DEQ, available on Storet.

time or parameters to demonstrate eutrophication. Nutrient concentrations in the Tillamook systems are somewhat high, compared with other estuarine systems, and the high levels of bacteria also suggest nutrient sources. However, nutrient concentrations in the Bay are high during winter months when the system is rapidly flushed and Bay productivity is not high. While eutrophication in the Bay itself is not a severe problem, algal blooms have been reported in the lower river reaches. Decreasing non-point sources of nutrient loading may improve water quality in these areas, resulting in improved fish habitat.

Water Temperature

During the summer of 1995, continuously recording thermometers were deployed in each of the five Tillamook tributaries, as well as Patterson Creek, a small stream flowing through Bay City directly into Tillamook Bay. Thermometers were left in place for time periods ranging from 83 to 144 days, through the warmest season of the year, in order to measure the “worst case” conditions for temperature. The monitoring equipment was stolen from the Tillamook River site, so no recent continuously collected data are available from this river. However, the 1988 Nonpoint Source Assessment identified temperature as a concern in the Tillamook River, so it should be evaluated further.

Stream reaches in the watershed have been listed for exceeding water temperature standards.

As a result of this monitoring, two stream stretches in the Watershed have been listed for exceeding water temperature standards. These are the Trask River from the mouth to Gold Creek, and the Wilson River from the mouth to the Little Fork of the Wilson River. These listings are based on data collected during 1995 by the Oregon DEQ. In the Trask River, a maximum seven day average temperature of 70.8° F (21° C) was observed in 1995, with stream temperatures above the standard (64° F, 17° C) for 84 days in 1995. Two of 24 values collected between 1986 and 1995 also exceeded the 64° standard. The Wilson River was slightly cooler. Its seven day average of maximum daily temperatures during 1995 was 69.5° F (21° C), and only 69 days exceeded the temperature standard in 1995. Three of 24 samples collected between 1986 and 1995 also exceeded the 64° standard. While these data may appear to show increases in water temperature over the last decade, little 1986–1994 data is available, so trend analysis is not appropriate.

Toxics

Toxic chemicals can enter surfacewater and groundwater through many pathways, including point discharges from industrial and municipal sources, urban or agricultural runoff, and waste disposal sites. These chemicals can impact human health and the environment. Because of its largely rural atmosphere, toxic chemicals are not the primary water quality issue in the Tillamook Bay Watershed. However, hydrocarbons and metals are common constituents in runoff from roads and parking lots. Pesticides and herbicides from agricultural and residential use, as well from road maintenance, can enter rivers and the Estuary during storm events. Discharge of commercial and residential wastewater directly into storm or sanitary sewers also occurs. Several commercial sites have the potential to discharge toxic chemicals to the rivers or Bay. These include small businesses that are located near waterways (e.g., marinas, auto salvage yards, etc.), the Port of Tillamook Bay, and the Old Mill Marina site.

Many small businesses which use toxic chemicals are located near streams, sloughs, or the Estuary. Most of these businesses do not discharge toxic chemicals as part of their normal operations and thus are not regulated by DEQ or local agencies. However, in the event of an accidental spill, or in incidences of illegal discharge, the appropriate local, state, or federal regulatory agencies can administer enforcement options and oversee cleanup.

Because the Port of Tillamook Bay site is a past military base, it was automatically identified as a CERCLA site. The federal government hired contractors to review documentation and conduct sampling for toxic chemicals on the site. As a result, concrete aviation tanks were removed from service and PCB-contaminated transformers were removed. Further investigation determined that the site could be removed from the list, and that EPA would defer to DEQ for any further actions the state or local authorities deem necessary. Because most of the runoff leaving the site discharges to Anderson Creek, Port authorities intend to conduct bioassays on Anderson Creek waters to ensure that current Port activities are not discharging chemicals at toxic levels.

An assessment conducted on the Old Mill Marina site identified contaminants in soil and groundwater samples, primarily hydrocarbons and wood treating solutions and their breakdown products, from past activities. The site is currently listed as medium priority for cleanup by the DEQ Site Assessment Program. The owners have been invited to join DEQ’s Voluntary Cleanup Program. However, DEQ is not actively managing projects.

Pollutant Sources

Waste Water Treatment Facilities

Six wastewater treatment plants in the Tillamook Basin have National Pollution Discharge Elimination System (NPDES) permits **(Table 4-7)**. Four are solely municipal discharge (the City of Garibaldi, Bay City, the City of Tillamook, and the Port of Tillamook). The TCCA operates a combined wastewater treatment and industrial waste processing plant and the Pacific Campground facility is a combination treatment plant and onsite system. The campground discharges to an onsite system during the low water summer months and to Boquist Slough, which flows into Smith Creek and subsequently the lower Wilson River (river mile 1.5) during the winter. The TCCA plant discharges into the Wilson River (river mile 1.7 from the mouth). Bay City and the City of Garibaldi discharge directly into Tillamook Bay, and the City of Tillamook and the Port of Tillamook discharge into the Trask River (1.9 miles and 5.2 miles from the mouth, respectively). These facilities are required to sample effluent on a schedule determined by the DEQ and described in the permit. The frequency of sample collection and the tests required of these samples vary among facilities. The monthly geometric mean of effluent samples must be below 200 FC/100 mls, and no more than 10% of samples may exceed 400 FC/100 mls.

When the effluent mixes with ambient stream water at lower concentrations, downstream concentrations would be more dilute. Effluent sampling must be conducted to capture a variety of conditions and the DEQ permit officer oversees this when reviewing the monthly reports. Samples are collected from the plant effluent, prior to discharge, so the concentrations reported may differ from those observed downstream of the mixing zone in the receiving water.

The effluent from six wastewater treatment facilities must not exceed a monthly mean of 200 FC/100 mls, and no more than 10% of samples may exceed 400 FC/100 mls .

Most municipal systems are designed to treat both storm water runoff and sewage in their wastewater treatment plants, so flows to these plants may be very high during storm events. When inflows exceed plant capacities, water is either bypassed from the plant, or overflows through the plant. Overflows differ from wastewater treatment plant bypasses. Bypass refers to the practice of diverting untreated sewage from entering the plant, sometimes directly to surface water. Overflows occur when too much water passes through a treatment plant too quickly for adequate treatment. Partially treated water is either released from the plant or directed to a storage area where it can be treated later.

Only one of the four plants, the City of Garibaldi, currently experiences bypasses that discharge untreated water into the Bay. Problems are caused by infiltration of rain water to the sewer system during intense rainfall, generally 3 to 4 inches in a 24-hour period. When flows exceed the hydraulic pumping capacity at the main pump station, excess backs up in the sewer line, and overflows at a city manhole. An alarm notifies the plant operator,

Table 4-7. Tillamook Basin wastewater treatment plant characteristics

Wastewater treatment plant	Collection/ treatment system history	Discharge location	Inflow capacity (mgd)	Average flow/peak flow (mgd)	Common problems
City of Garibaldi	1973—activated sludge/sand filtration; 1946—collection system	Tillamook Bay	0.5	0.4/0.9	Infiltration and inflow in winter; over-capacity flows are bypassed from treatment
City of Bay City	1996—Sequential Batch Reactor (SBR); 1972—two cell waste stabilization lagoon; 1972—collection system	Tillamook Bay	0.3	0.24/1.45	Peak flows in excess of installed capacity are stored in original lagoons
Tillamook County Creamery Association	1995—2 stage activated sludge; 1969—activated sludge package plant; 1948—separator basin with trickling filter	Wilson River, mile 1.7	0.5	0.25	No problems—controlled waste flows do not have variable inflows like municipal systems
Pacific Campground	dispose to onsite system June-October; settling and Bio-Pac reactor, October–May	Wilson River, mile 1.5	0.003		
City of Tillamook	1980—rotating biological contractor; 1969—trickling filter, secondary clarifier, disinfection; 1950—collection system	Trask River, mile 1.9	2.0	0.6 summer/ 4.5 winter	Infiltration and inflow in winter; motels can overload in summer months; over-capacity flows go through system at reduced level of treatment, or overflow into parking lot and evaporate Currently adding new clarifiers which will increase capacity to 5.6 mgd; other planned upgrades will improve water treatment
Port of Tillamook Bay	1968—lagoon systems; 1942—collection system	Trask River, mile 5.2	0.56	0.77/1.7 (no flow in summer)	Collection system built during WWII. Extreme infiltration/inflow in winter. New septic tank effluent pressure system completed in 1998 Bypass potential exists, but has not been used in last 8 years

Source: Oregon Department of Environmental Quality, Northwest Region who then allows a bypass gate to discharge water into the Bay. Garibaldi is under a Mutual Agreement and Order to upgrade its facility, and is scheduled to meet all permit requirements by 2001. Infiltration and inflow problems, which allow large volumes of storm water into the sewage system, exceeding the treatment plant volume, will be addressed by the fall of 1998. Alleviating this problem will enhance both treatment plant operation and treatment quality.

The Port of Tillamook recently upgraded its facility to correct a problem with shallow ground water and runoff inflow into its system. The Port of Tillamook plant has a bypass line designed into the system to divert high flows, but the Port has not had to use the bypass for the past eight years.

The City of Tillamook has experienced two fecal coliform violations in the past five years, one of which was associated with extremely high flows. The plant capacity of 2 million gallons per day (mgd) is often exceeded during winter months. Total dissolved solids and biochemical oxygen demand are high during these times. The City expected to finish upgrading the plant to handle 5.6 mgd by May 31, 1998. The new upgrades will be evaluated before additional anticipated upgrades are implemented. When flows exceed the capacity at the City of Tillamook facility, overflows of partially treated water pool up in the parking lot until the area can be properly cleaned. Thus, bacteria discharges from this facility exceeding permit limits are uncommon, and will become more rare with the upgrades.

Bay City has an overflow lagoon where excess flows can be held until flow at the treatment plant recedes and it can handle the additional waste. This plant, only one year old, is working well.

The TCCA cannot bypass its wastewater treatment plant. Because its wastewater collection system was upgraded in 1992 and is relatively small, weather events do not usually affect the volume of influent. The plant was under scrutiny during 1993, but bacterial reports since that time have all complied with the permit levels. Chlorination has been a greater concern for this plant than bacteria levels. In 1992, the TCCA wastewater treatment plant permit included an effluent criterion for chlorine for the first time. In order to disinfect adequately and meet this standard, the plant installed a dechlorination chamber to decrease chlorine concentrations in the treated effluent. While chlorine is often used to kill bacteria prior to discharge from a treatment plant, discharge of excess chlorine will harm biota in a receiving stream. Thus treatment plant permits limit disinfectant as well as bacteria in effluent.

Pacific Campground’s small Bio-pure Batch Reactor with chlorine and UV disinfection serves the 28-space RV park and one permanent residence. During the dry summer months, the system discharges to an onsite system, but during the wet winter months it discharges to the Wilson River. The treatment performs well for bacteria, but occasionally fails to clarify the water of all dissolved solids.

The Tillamook Basin wastewater treatment plants perform reasonably well. All have either been upgraded recently or are undergoing major upgrades. Monitoring reports show fewer problems than in the past (Musselman 1986, Schnurbusch, S. pers. com. 1997). However, population growth rates on the coast are high, and not easily predicted. Municipalities must constantly anticipate growth rates over the next 20–30 years, in order to account for growth as they maintain and upgrade facities. The fact that major upgrades may be paid off over 20–30 years may impede local ability to upgrade treatment plants before previous upgrades have been paid off.

Land Application of Biosolids

DEQ approves biosolids application management plans and authorizes land application sites.

In addition to discharging treated liquid waste, wastewater treatment facilities must periodically dispose of wastewater solids. The treated solids, referred to as biosolids, are applied to agricultural land. In Tillamook County, solids are a beneficial soil amendment, applied primarily to land used to grow grass silage. More than 99% of the biosolids are applied to sites in the Tillamook River drainage near the Port of Tillamook Bay Industrial Park, or just south of there at South Prairie or Pleasant Valley. Approximately 900 dry tons are applied yearly to 180 acres in the Tillamook River Basin **(Table 4-8)**.

Biosolids consist of biomass that has been removed from the treatment process and stabilized by aerobic or anaerobic digestion, and/or addition of lime. This process reduces both the pathogen content and odor potential. The nutrient content, as plant available nitrogen, is also reduced during stabilization, through the release of ammonia gas. For biosolids to be land-applied, DEQ must approve each wastewater treatment facility’s biosolids management plan and authorize each land application site. Department personnel visit the site before it is authorized. Both general and specific limits and requirements are then specified in the facility's water quality permit, biosolids management plan, and the site authorization letter. These specifications include minimum setbacks from surface waters, minimum vertical separation distances to groundwater, weather conditions at the time of application, minimum time intervals between solids application and crop harvesting, and restricted public and livestock access to the area. Biosolid application rates

Table 4-8. Tonnage of biosolids applied in Tillamook County, and the acreage to which it is applied

Wastewater facility	Dry tons applied per year	Acreage applied per year	Basin
Tillamook County Creamery	782	156	Tillamook River
City of Tillamook	92	18	Tillamook River
Netarts—Oceanside	25	5	Tillamook River
City of Rockaway Beach	2	<1	Miami River
City of Garibaldi	<1	<1	Garibaldi Area
Total	**902**	**181**	

Source: Data are from 1994 or 1996 for each source of biosolids. Information from the Oregon DEQ, Northwest Region.

are matched to the agronomic needs of the crop for nitrogen. In addition, concentrations of nine potentially polluting metals are monitored to assure that the biosolids are suitable for land application. Currently biosolids generated by the City and Port of Tillamook, the Netarts-Oceanside Sanitary District, and the Tillamook County Creamery Association are applied to the DEQ approved application sites in the Tillamook River Basin. The City of Garibaldi, City of Rockaway Beach, and City of Bay City apply biosolids to sites near the City of Garibaldi and in the Miami River Basin.

Sand filters reduce septic system nitrogen output by about 40 percent and bacteria by 90–97%.

Onsite Systems

Septic systems, also known as onsite systems, are common throughout the Watershed in areas outside the urban areas of Garibaldi, Bay City, and Tillamook. Their efficacy depends partly on soil type. Tillamook soils have moderate to poor drainage, and are thus not always ideal for septic systems. Older homes may have metal storage tanks, which corrode in wet soils, leading to system failures. Much of the development in the County is along roads adjacent to rivers. These soils are often poorly drained, so sand filters may be used for both new systems by about 40% and bacteria by 90–99%, may thus provide better performance in Tillamook soils. Sewer lines and centralized treatment are prohibited for residences outside the urban growth and repairs to older systems. Sand filters, which reduce nitrogen boundary. However, current densities for residential

Table 4-9. Results of onsite system inspections in Tillamook Basin between 1988 and 1996

	Tillamook River 1988	Trask River 1989	Wilson River 1989	Kilchis River 1991	Miami River 1991	Bayocean Road 1996	Totals
Properties surveyed	467	529	491	172	38	32	1729
Operational	431	519		119	27	20	
Direct failures	6	10	28	9	3	1	57
Indirect failures	29			11	5		45
Marginal	1			14	1	5	
Unknown				10	2	6	
Unspecified failure				9			9

The failure rate among those systems inspected was between 6 and 7%.
Source: based on information from the Oregon Department of Environmental Quality, Northwest Region.

development do not consider the soil carrying capacity. Cumulative impacts from these areas can result in increased nutrient loading to surface waters, even though bacteria may be significantly controlled.

The ODA, in cooperation with the Tillamook County Health Department, inspects onsite systems every 12 years as part of the shellfish management program. Inspection programs have included house-to-house surveys and dye studies to determine if discharge from failing systems is reaching surface waters. More than 1,700 systems have been inspected since 1988 **(Table 4-9)**. Notices of failing systems are delivered to landowners, who are required to repair their systems. Modifications to onsite systems may also be required if landowners are modifying their property to house more people by adding bedrooms or bathrooms. System failures are observed in about 6–7% of those investigated. This rate is common in other coastal communities, and is much lower than the 20% failure rate Jackson and Glendening (1981) originally estimated. A survey of onsite systems will be completed in summer of 1998.

Confined Animal Feeding Operations

Evapotranspiration:
The combined water loss from a biotic community or ecosystem caused by evaporation of water from the soil, plus the transpiration of plants.

Volatization:
Conversion of a liquid or a solid into a vapor.

Confined animal feeding operation regulations specify that manure must be applied to crop land, with similar specifications to those for biosolid application. Manure should be applied at agronomic rates for nitrogen, and should not exceed the rate of evapotranspiration for liquid. Bacteria and other pathogens are assumed to die off in the surface layers of the soil to which they are applied, thus avoiding discharge to waters of the State. Manure must not be applied where it may seep into or run off to ground or surface water. Since this is a no-discharge permit, all waste should either be taken up by plants, lost to the atmosphere through volatilization, or remain in the surface layers of the soil. Unlike biosolid application, manure is not required to be stabilized before land application, sites are not inspected during the permitting process, and there are no guidelines for the amount of waste that may be applied to a particular site, other than an instruction to apply wastes at the agronomic rate for nitrogen.

Jackson and Glendening (1981) ranked the relative contribution of bacteria to surface waters from farms with various operating characteristics. They identified barnyards with poor manure management practices adjacent to streams as the primary contributors of agriculturally derived-bacteria, and proper manure spreading on pastures as one of the least important sources of agricultural pollution. Since many new management techniques were implemented during the RCWP, contributions from agricultural land should be reviewed again to determine if Jackson and Glendening’s findings are still applicable.

Tillamook Watershed Rivers

The three major contributors of bacteria identified in 1981 – cattle, onsite systems, and wastewater treatment plants – are likely still major bacteria sources.

Rivers in the Tillamook Basin provide substantial loads of bacteria to Tillamook Bay, as shown in Figure 4-11 and reported in Jackson and Glendening (1981). Data collected over the years suggest that the rivers pick up most of the bacteria in the downstream reaches affected by a variety of human uses. During the 1980s and into the present decade, many efforts have been made to decrease bacterial pollutants to surface waters. However, bacterial concentrations in the rivers and Bay still exceed water quality standards, and major bacteria sources still border the lower reaches of the rivers. Dairy cow herd densities have increased significantly over the past decade, as have the human population and housing developments along Tillamook Basin rivers. So, the three major contributors of bacteria Jackson and Glendening (1981) identified — cattle, onsite systems and wastewater treatment plants — are likely still major bacteria sources.

Recommendations

Bacteria

Both the ambient monitoring data and older, more intensive studies indicate that the inhabited lowlands of the Tillamook Basin are major bacterial sources for Tillamook Bay. These include both point and non-point sources from human habitation and agricultural land use, but potential sources have not yet been characterized more specifically. Jackson and Glendening (1981) characterized many sources of bacteria from point sources and septic systems, and ranked the potential of various situations on agricultural land. A review of their findings should be used to design a study to characterize current sources. Many dairy farms have addressed runoff from barnyards and pasture lands, many failing onsite systems have been repaired or replaced, and the wastewater treatment plants have been upgraded. However, at the same time, both human and animal populations have increased. New monitoring approaches that can delineate between bovine and human bacteria should be used in the Tillamook Basin. This information, combined with an evaluation of current management practices and bacterial sources, will tell us which and where further changes are needed. Management practices can be changed without more specific information on bacterial sources, but these changes may be targeted more effectively if the major bacterial sources are specifically identified.

Agricultural Lands

Best management practices (BMPs) for manure storage facilities have been developed and implemented at most dairies in Tillamook County. These BMPs are developed for specific facilities with given herd sizes. Whenever the herd size of a dairy increases by more than 10% or 25 cows, the CAFO permit and BMPs for the facility are reevaluated and modified as necessary. Dairy cow numbers have increased significantly since 1980 (Dorsey-Kramer 1995; Commodity Data Sheets 1980, 1990) and new criteria are used to determine the amount of manure storage required, but it may be necessary to find better ways of disposing of manure. Current facilities and practices need to be examined to determine which sources are most critical, and which management changes would be most cost-effective.

The MEAD Project proposes to collect manure from farms, digest it for energy, use the solid by-product to produce potting soil, and return liquid nutrient to farms for land application. The digestion process, followed by heat treatment, will eliminate parasites and pathogens. However, the treated liquid would be recontaminated if it is hauled out to farm application sites in the same trucks that were used to haul untreated waste in from the farms without disinfecting between uses. Therefore, while such innovative programs should be promoted, participating farmers should still follow recommendations to decrease bacterial runoff.

Implementation of a more proactive compliance program should better protect the environment by focusing energy and resources on pollution prevention. If a dairy fails to meet its CAFO permit conditions or fails to properly implement BMPs, the ODA or another regulatory agency may take corrective action. In the past, this was complaint-driven. Boosting assistance with both dairy and water quality management issues is a necessary step toward establishing a proactive pollution prevention program in Tillamook County. The recent addition of an ODA CAFO inspector and SB 1010 planner and an OSU Extension Service dairy agent will continue and improve the existing programs for both enforcement and educational outreach are essential to improving water quality in the Tillamook Basin.

Not all pollution prevention and bacterial management in agricultural lands should target dairy and CAFO operations. Tillamook County’s rural character and fine grazing support beef operations and other farms not regulated under the CAFO program. These farmers should also receive technical assistance with managing their land to reduce bacteria and nutrients in runoff.

Wastewater Treatment Plants

Three of the six local wastewater treatment plants are currently upgrading their facilities (City of Garibaldi, City of Tillamook, and Port of Tillamook Bay), and one other facility has recently been replaced (Bay City). While problems occur from time to time, these plants appear to be working much better than they were prior to the Jackson and Glendening report (1981, Musselman 1986). However, as the population in Tillamook County continues to grow, constant vigilance is required to keep the plants performing according to their permit guidelines. In addition, communities designing upgrades should consider future population trends.

Biosolids Application

Most biosolids are applied to land in the Tillamook River drainage, which is also one of the rivers with the highest bacterial concentrations and loads to Tillamook Bay. Lime stabilization destroys bacteria and pathogens and reduces odor and vector attraction. Bacterial and phosphorus concentrations are also decreased by the stabilization process, so runoff is less likely to contaminate water to the same degree as would raw waste. Biosolids are applied to sites that are reviewed for suitability by the DEQ and under strict conditions, which reduce or eliminate the transport of nutrients and bacteria to the State's waters. Sampling for bacteria along waterways adjacent to application sites would identify the contribution of bacteria and nutrients from biosolid application in the Tillamook Basin and allow managers to determine if further treatment or management is necessary.

Onsite Systems

Onsite systems are inspected every decade or so during periodic shellfish plan reviews. The conditionally accepted Coastal Zone Non-point Source Management Plan, also known as the 6217 plan (DEQ and ODLCD 1996), requires the inspection of onsite systems during property sales. Owners of failed or poorly functioning onsite systems must pay for repairs or upgrades themselves. In contrast, homeowners on sewage systems have the advantage of public funding to spread payments for improvements over several years. Low-cost State Revolving Fund loans could greatly increase the opportunity and incentive to improve private facilities. In addition to increased onsite inspections and low-interest loans to cover repairs and upgrades to appropriate technology, an educational program for onsite system owners would increase system maintenance and result in a lower percentage of failing onsite systems, decreasing the potential for surface water pollution.

Nutrients

Although nutrient levels are problematic in other estuaries throughout the United States, nutrient concentrations in Tillamook Bay are moderate. Without historical data it is difficult to assess whether the region is developing a eutrophication problem. Statewide population projections and recent growth trends indicate that Oregon's coastal zone will experience significant growth over the next 20 years. Therefore, increased monitoring for indicators of eutrophication in both fresh and saline waters is recommended. In addition to sampling for nutrient levels, dissolved oxygen and chlorophyll *a* should be monitored regularly, preferably more often than quarterly in freshwater systems.

Many management practices that decrease bacterial runoff to surface waters — such as excluding animals from waterways, nurturing buffer strips in riparian zones, and adhering to BMPs — will also decrease nutrient inputs to surface waters. In addition, scheduling application of liquid manure and biosolids to actively growing forage crops at agronomic rates on non-saturated soils will ensure that nutrients are used by plants and will not run off to surface waters or seep into shallow groundwater. Assessing local agronomic needs and educating landowners to manage manure and biosolids to meet those needs will ensure that these nutrient goals are met.

Temperature

Water temperature is a critical habitat element for successful salmonid recovery. Warm water impairs important habitat for young fish, inhibits adult fish passage through critical river segments, and decreases dissolved oxygen levels. Water temperatures may increase due to reduced shade from the riparian zone, reduced water volume, or widening of the stream bed due to landslides and unstable banks. The key to cooling down rivers and streams is to keep them from heating up in the first place. Upstream reaches of the Tillamook Basin Rivers and their tributaries should be evaluated, and riparian zones fenced off or planted as necessary to restore streamside shading and improve streambank stability. Over the last few years, several programs such as Jobs for Fishers and Jobs in the Woods have fenced many miles of streams in the Tillamook Basin. These efforts should be continued throughout the lower Watershed.

Summary

This study provides background information that supports several recommendations for the TBNEP. Bacteria cause water quality problems and impair use of the Bay for shellfishing. However, the relative contributions of the various sources of bacteria in the Tillamook Watershed are poorly understood, and further investigation would help develop a cost-effective management plan. New monitoring methods have been developed that allow the identification of specific animal sources (human, bovine, etc.). These methods should be used to quantify the bacterial sources at various sites in the Basin. Bacterial monitoring results should be combined with information on management practices to determine which practices are effective and where management practices need to be changed.

Financial incentives may accelerate improvements of facilities to improve water quality. Cost-sharing programs and low-interest loans will provide some of the resources landowners need to make management changes that will improve water quality in the Basin. Low-interest loans should be made available to landowners to repair or replace failing or poorly functioning onsite systems. The State Revolving Loan fund is not now available for private landowners. Changing this policy would make low-interest loans available.

Outreach programs for farmers and other landowners can inexpensively improve management practices. Regular maintenance of onsite systems may improve system performance. Outreach programs may help dairy and other farmers improve pasture productivity by changing manure application rates and timing. Hiring a dairy/water-quality Extension agent is a positive step. Other outreach programs should be developed wherever they are appropriate and helpful.

The guidelines currently used to predict agronomic rates for manure and biosolid application were not developed specifically for the Tillamook County environment. High rainfall and mild winters may translate to differing rates and seasons in which nutrients are utilized by plants. More specific identification of nutrient uptake in the Tillamook climate, combined with increased manure nutrient testing, will make the existing manure and nutrient management policy more effective.

Temperature problems in streams must be addressed at a watershed level. Improving riparian habitat will not only reduce water temperatures, but improve stream habitat, decrease flooding impacts, and provide buffer zones, decreasing pollution in overland runoff.

Improving Tillamook Basin water quality is a big job, but the people of Tillamook County have shown that they are willing to do it. The efforts of the past decade should not go unrecognized. Even though population and resultant pressure on Tillamook's water resources have increased, water quality has improved slightly, due to local efforts. Fine-tuning the changes that have been made over the last decade will likely improve conditions further.

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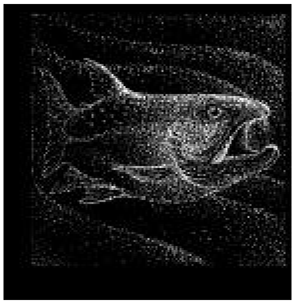

CHAPTER 5

SEDIMENT:

SOURCES AND IMPACTS

River Teeth: Definition

When an ancient streamside conifer falls, finally washed or blown from its riverbank down into the water, a complex process of disintegration begins. The fallen tree become a naked log, the log begins to lead a kind of afterlife in the river, and this afterlife is, in some ways, of greater benefit to the river than was the original life of the tree.

A living tree stabilizes riverbanks, helps cool water temperatures, provides shade and cover for fish, shelter to mammals and birds. But fallen trees serve some of the same purposes, and other crucial ones besides. The gradual disintegration of the log in a streambed creates a vast transfusion of nutrients — a slow forest to river feast reaching from the saprophytic bottom of the food chain to the predatory, fly-casting, metaphor-making top. Downed trees are also part of a river's filtration system: working in concert in logjams, they become flotsam traps; mud, leaf and carcass traps; Styrofoam, disposable diaper and beer-can traps. And they're a key element in river hydraulics: a lot will force current down, digging a sheltering pocket or spawning bed for trout or salmon; over, creating a whitewater spill that pumps life-giving oxygen into the stream; or around, sometimes digging the salmonids version of a safe room with a view, the undercut bank.

On the forest streams I know best — those of the Oregon Coast Range clearcuts, "tree farms" and remnant strips of rainforest — the breakdown of even a five- or six-hundred-year-old river log takes only a few decades. Tough as logs are, the grinding of sand, water and ice are relentless. Within a decade or two and drowned conifer but cedar turns punk, grows waterlogged and joins the rocks and crayfish as features of the river's bottom. I often glance down at my feet while fishing and see that the "rock" I'm standing on is really the top of a gigantic log sunk and buried in gravel and sand. And even after burial, decomposition continues. The log breaks down into filaments, the filaments become gray mush, the mush becomes mud, washes downriver, comes to rest in side channels, The side channels fill and gradually close. New trees sprout from the fertile muck. The cycle goes on ....

—David James Duncan. 1995.
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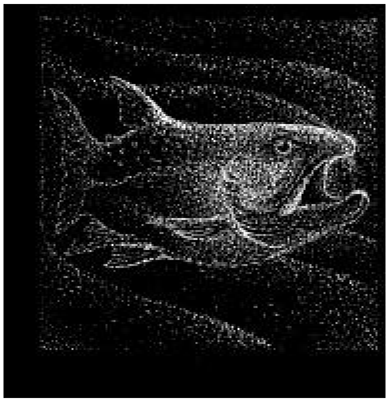
A river revealed in a flash of lightning is as thick and quivering as gelatin. And yet measured against a millennium, a mountain melts down the sides of the valley and pours into the sea.

—Kathleen Dean Moore. 1995
River Walking *Reflections on Moving Water*
Harvest Books, NY, NY



CHAPTER 5

SEDIMENT:
SOURCES AND IMPACTS

Introduction

High rates of sediment input and accumulation have altered the ecological and economic value of the Tillamook Bay Estuary. Some research has suggested that erosion and sedimentation in the Bay's tributaries have increased during this century (TBNEP Nom. Pkg. 1994). Sedimentation has affected the Bay's habitats, bathymetry, and navigability. Estuarine habitats have been altered by changes in the amount of submerged and intertidal land at different depths, in salinity patterns, in the relationship between substrate depth and salinity, and by a reduction in the amount of wood transported to the Estuary. Numerous species are potentially affected by losses of estuarine habitat, notably Chinook salmon and Dungeness crab, which depend on estuarine habitat early in their life cycle. Changes in substrate may also have led to an increase in the population of burrowing shrimp. Although indigenous to Tillamook Bay, burrowing shrimp populations appear to have risen in recent decades, adversely affecting commercial oyster production and eelgrass beds. Navigation on the Bay, both commercial and recreational, is also affected by the accumulation of sediment in the Bay.

Sedimentation has affected the Bay's habitats, bathymetry, and navigability.

Erosion and sedimentation are important processes in a healthy watershed and estuary. The material transported down the fluvial system includes not only the mineral components of soil, but also large woody debris and other organic material. Changes in the amount or make-up of sediment at any point along a fluvial drainage system can disrupt the ecosystem in ways which are often slow to materialize and are unpredictable. The TBNEP is investigating changes in sedimentation in the Tillamook Bay Watershed as they relate to declines in aquatic habitat, disruption of navigation on the Bay and rivers, and flooding.

Fluvial:
of, or relating to rivers; conforming to the changing course of a stream.

The TBNEP is examining sedimentation from a number of angles. Is the rate or type of sediment production and transport through the upland fluvial system adversely affecting fresh water flows or living resources? Has sediment accumulated within the Bay so quickly that the organisms in the Bay cannot tolerate the change? Key questions for subsequent management decisions are whether the economic uses of the Watershed are being damaged by land use patterns in the upland or lowland areas, and whether some corrective action is required to enhance the economic or ecological value of the Bay. To address these issues, the sources and characteristics of the sediment will be discussed, as well as the impact of sediment throughout the Watershed.

We will examine erosion and deposition in three broadly defined regions: the Estuary, the forested uplands, and the agricultural and urbanized lowlands. If the rate of sedimentation has increased, land use and changes in land cover — and alterations of critical habitats — are likely to be responsible. Urbanization, cattle grazing, channelization of streams, loss of riparian areas and floodplains, and road building and other forest management practices all contribute to the current and historical rate of sedimentation.

Sediment Sources

Sediment is deposited rock, soil, or organic material which has been dislodged by erosion, or the physical or chemical processes of wind, water, glacial ice, or gravity.

Sediment is deposited rock, soil, or organic material which has been dislodged by erosion, or the physical or chemical processes of wind, water, glacial ice, or gravity. Sediment organic matter includes tree branches and trunks, leaves, small plants, and algae, as well as solid animal waste. All of this material is collected and transported by the Watershed's fluvial system or through water bodies such as the ocean.

In the uplands, sediment is generated by landslides, defined as "the movement of a mass of rock, debris, or earth down a slope" (National Research Council 1996). The many types of landslides are classified by their movements and type of material, such as rock topple, debris flow, or earth slide. **Table 5-1** provides an abbreviated classification of slope movements. Many of these types, such as debris flows, often meet the fluvial channel as alluvial fans and debris torrents. Upland and boulders, shaped by flowing water into the pools and riffles needed

Table 5-1. Abbreviated classification of slope movements

Type of movement	Type of material		
	Bedrock	Engineering soils	
		Predominantly coarse	Predominantly fine
Fall	Rock fall	Debris fall	Earth fall
Topple	Rock topple	Debris topple	Earth topple
Slide	Rock slide	Debris slide	Earth slide
Spread	Rock spread	Debris spread	Earth spread
Flow	Rock flow	Debris flow	Earth flow

Source: National Research Council. 1996. "Landslides investigation and mitigation." Special Report 247. Transportation Research Board, National Research Council. Washington, DC.

for fish survival, and transported downstream by storm surges.

In lowland areas, where slopes are gentler, sediment collects in sand and gravel bars, and deposits on floodplains. Here, too, woody debris can play a role in trapping sediment. Erosion also takes place in lowland streams and rivers, principally as streambank erosion, which often causes significant losses to riparian agricultural land.

Sediment movement within the Bay is governed by tidal currents and freshwater inflow.

Most Pacific Northwest estuaries, including Tillamook Bay, are depositional environments (they accumulate sediment) (Komar 1997). Sediment which has accumulated in Tillamook Bay over the past 8,400 ± 400 years came from marine sources, the five major rivers and numerous smaller streams which flow into Tillamook Bay, and from bayshore erosion (Glenn 1978). In recent decades the upper (southern) end of the Bay (bayhead delta) has become very shallow, leading to speculation that the uplands have been producing more sediment than the Bay can accommodate and still retain its historic dimensions.

The Estuary

Tillamook Bay is a drowned river valley that became an estuary during Holocene time as sea level rose. Most of the Bay's Watershed is forested uplands, so most terrestrial sediment in the Bay is derived from those areas. Marine sediment presently enters through the Bay's one opening to the sea at its northwest corner.

Bayocean Spit, which separates Tillamook Bay from the ocean, is a transient feature. Over the last 8,400 years there have been several temporary openings to the sea. Most recently, the spit was breached between 1952 and 1956. Until approximately 2,000–3,000 years ago, an east-west ridge split the Bay into two parts, each with separate openings to the sea (Peterson and Darienzo 1989).

Sediment movement within the Bay is governed by tidal currents and freshwater inflow **(Figure 5-1)**. The most significant rearrangements of sediment take place during the rainy winter months. Sediment plays an important role in the Estuary's ecosystem, providing allochthonous food resources and material to form various benthic habitats. Estuarine species are adapted to survive, and in some cases rely upon, continuous sediment inputs. The continuous and sometimes rapid influx and movement of sediment also creates challenges to the Bay's human users. Navigation is problematic in much of the Bay during low tides, and oyster growing areas are disrupted by extreme sediment inputs, migrating shoals, and changing species distributions.

Allochthonous:

Organic material in an ecosystem's food chain not made by a photosynthesizing organism in the ecosystem. Leaves consumed by insects in a stream are allochthonous food. The opposite is *authochthonous*, organic material in an ecosystem's food chain created by photosynthesis within that ecosystem.

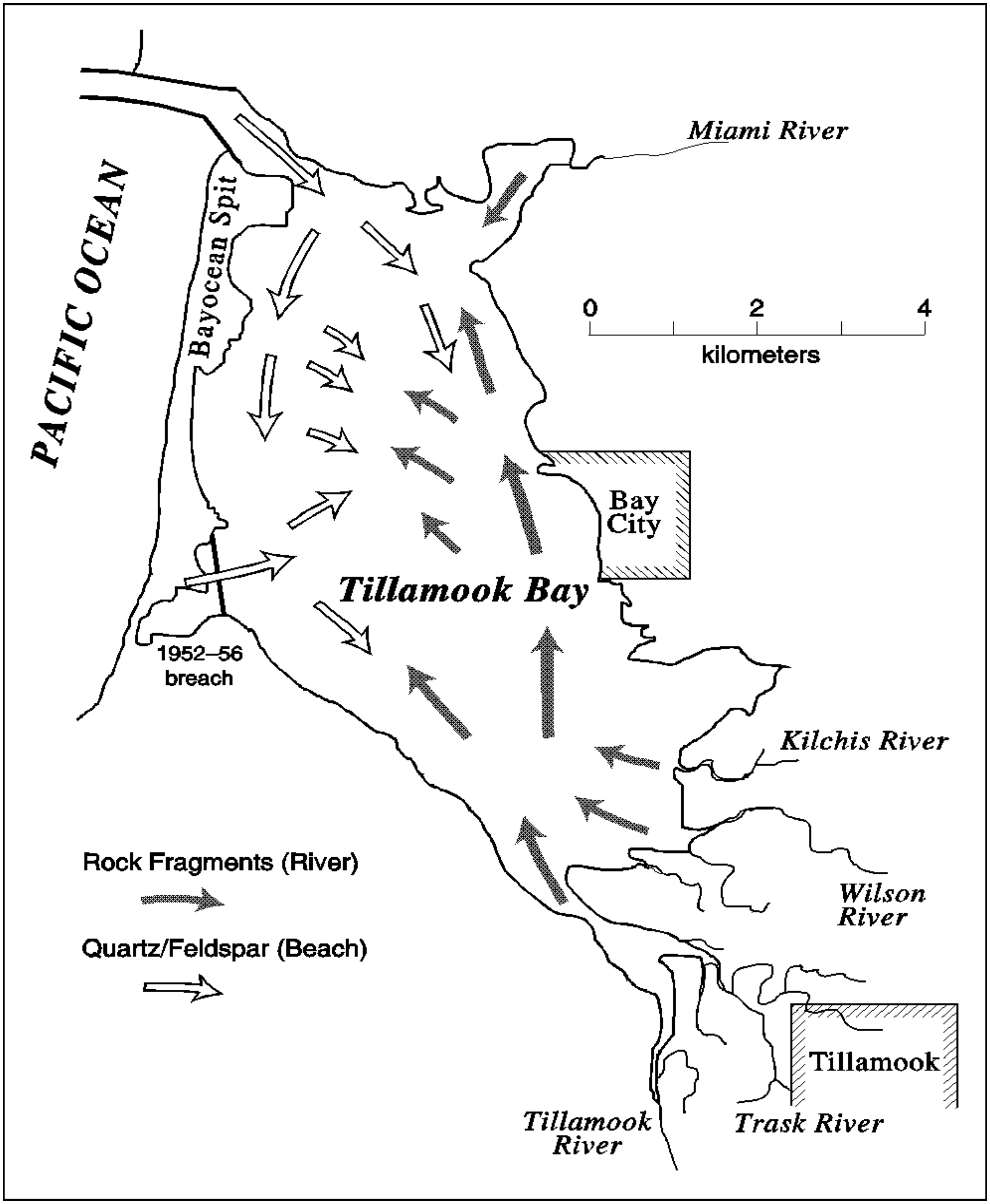


Figure 5-1. Inferred paths of sediment transport in Tillamook Bay of the sand and gravel derived from the figure rivers and from the ocean beach.

Source: McManus, J., P. Komar, G. Bostrom, D. Colbert, and J. Marra. 1998. "The Tillamook Bay National Estuary Project: Sedimentation study. Final report." Tillamook Bay National Estuary Project. Garibaldi, OR.

Bathymetry

A study of the changes in Tillamook Bay bathymetry between 1867 and 1995, based on bathymetric surveys in 1867, 1954, and 1995, showed that the Bay volume decreased from 40,589,762 yd^3 (31,051,168 m^3) in 1867 to 30,671,975 yd^3 (23,464,061 m^3) in 1954 (Bernert and Sullivan 1998). According to the 1995 bathymetric survey, volume had increased slightly to 32,454,912 yd^3 (24,828,008 m^3). Much of the increase in volume after 1954 can be attributed to dredging in maintained channels. U.S. Army Corps of Engineers records indicate that from 1929 to 1979, 1,600,000 yd^3 (1,224,000 m^3) of sediment were dredged from the ocean bar and entrance channel, with the spoils deposited offshore. Since 1979, 71,000 yd^3 (54,315 m$^{3)}$ have been dredged (Chesser 1995, as cited in Miller and Garono 1995).

Changes in available habitat types, represented roughly by amount of area at certain depths, can be noted between 1867 and 1995.

A change in the character of the Bay can also be seen. The numerous wide channels and deep holes of the 1867 Bay **(Figure 5-2)** have been gradually replaced by a few deep channels bounded by intertidal mud flats (**Figures 5-3 and 5-4**). The changes between 1867 and 1995 are mapped in **Figure 5-5**. The amount of available habitat types has changed with the total area of various depths. As shown in **Figure 5-6,** the percentage of bay bottom between +6.6 and +3.3 ft (+2 and +1 m) above mean lower low water (MLLW) has risen sharply (from 1.1% to 16%), largely at the expense of lower intertidal areas, which have fallen from 80% to 70%. Lands between -10 and -16.5 ft (-3 and -5 m) decreased from 16.1% of total bay bottom to 10.1%. The total area below -29.5 feet (9 m) MLLW (not shown in Figure 5-5) increased from 0.69% to 1.47% of total bay bottom.

Komar *et al.* (1997) looked at the bathymetric data for the three surveys and adjusted the change in bay volume based on an average sea level rise of 1.5mm/yr. They then divided the adjusted bay volume by the surface area of the Bay at mean low tide to estimate the rate of sediment accumulation (**Table 5-2**). The bay-wide average rate of accumulation is calculated at 26.8 in. (68 cm) per 100 yrs. from 1887 to 1954.

An organic-rich mud layer was found in the western Bay below the sand in one core sample. If further investigation determines that this mud layer was deposited from upland runoff, including run-off from the Tillamook Burn fires (1933, 1939, 1945, and 1951), then the rate of ocean influenced sedimentation in the western part of the Estuary is greater than 79 in. (200cm) per 100 years.

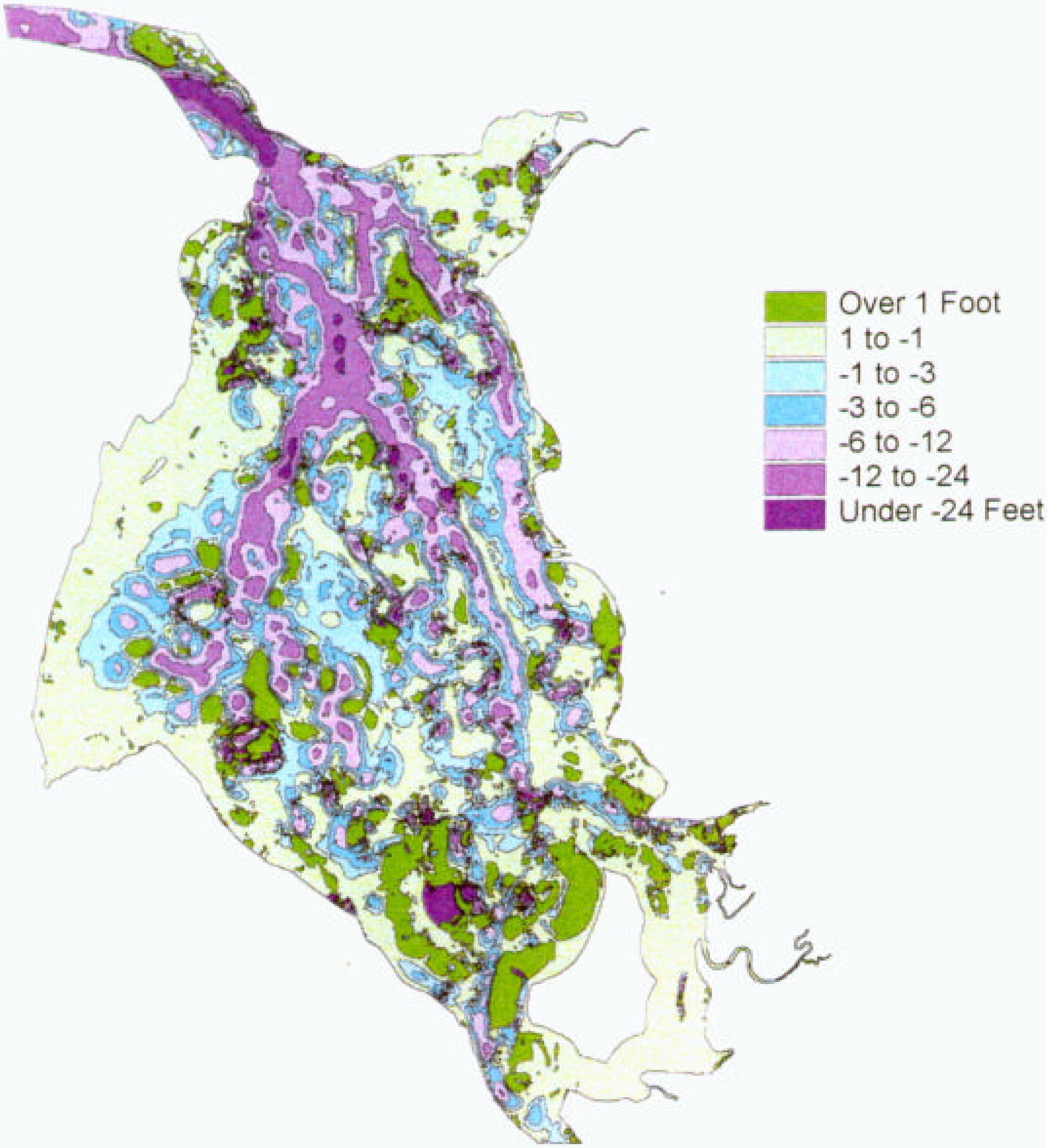


Figure 5-2. Bathymetric surface derived for Tillamook Bay from a survey in 1867. Note the large, deep area south of the inlet, and complexity of the Bay bottom.
Source: Bernert, J., and T. Sullivan. 1998. Bathymetric analysis of Tillamook Bay: Comparison among bathymetric databases collected in 1867, 1957, and 1995. E&S Environmental Chemistry, Corvallis, OR. Prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

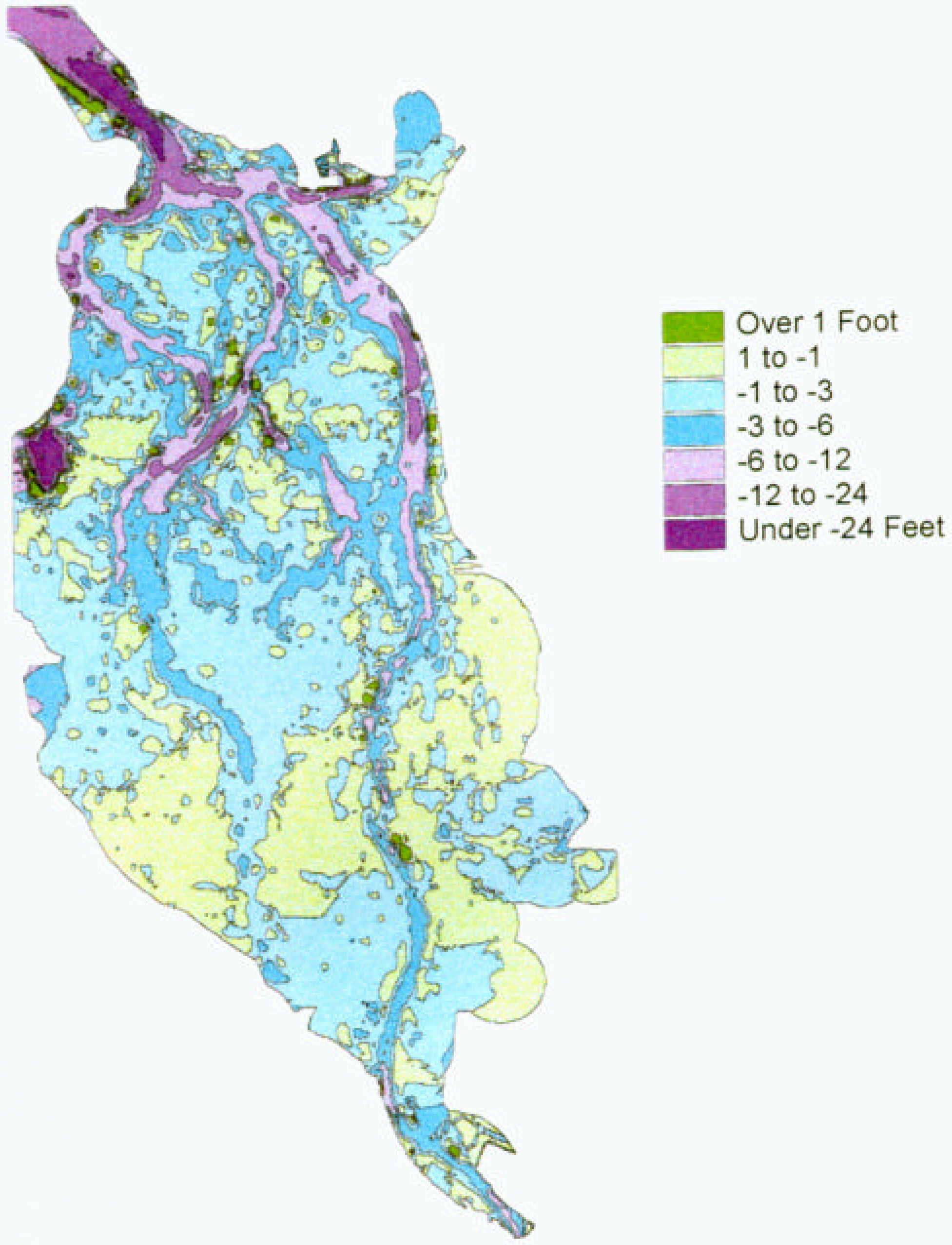


Figure 5-3. Bathymetric surface derived for 1957. Note the lack of complexity and deep areas in the south Bay since the Bayocean Spit breach.
Source: Bernert, J., and T. Sullivan. 1998. Bathymetric analysis of Tillamook Bay: Comparison among bathymetric databases collected in 1867, 1957, and 1995. E&S Environmental Chemistry, Corvallis, OR. Prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

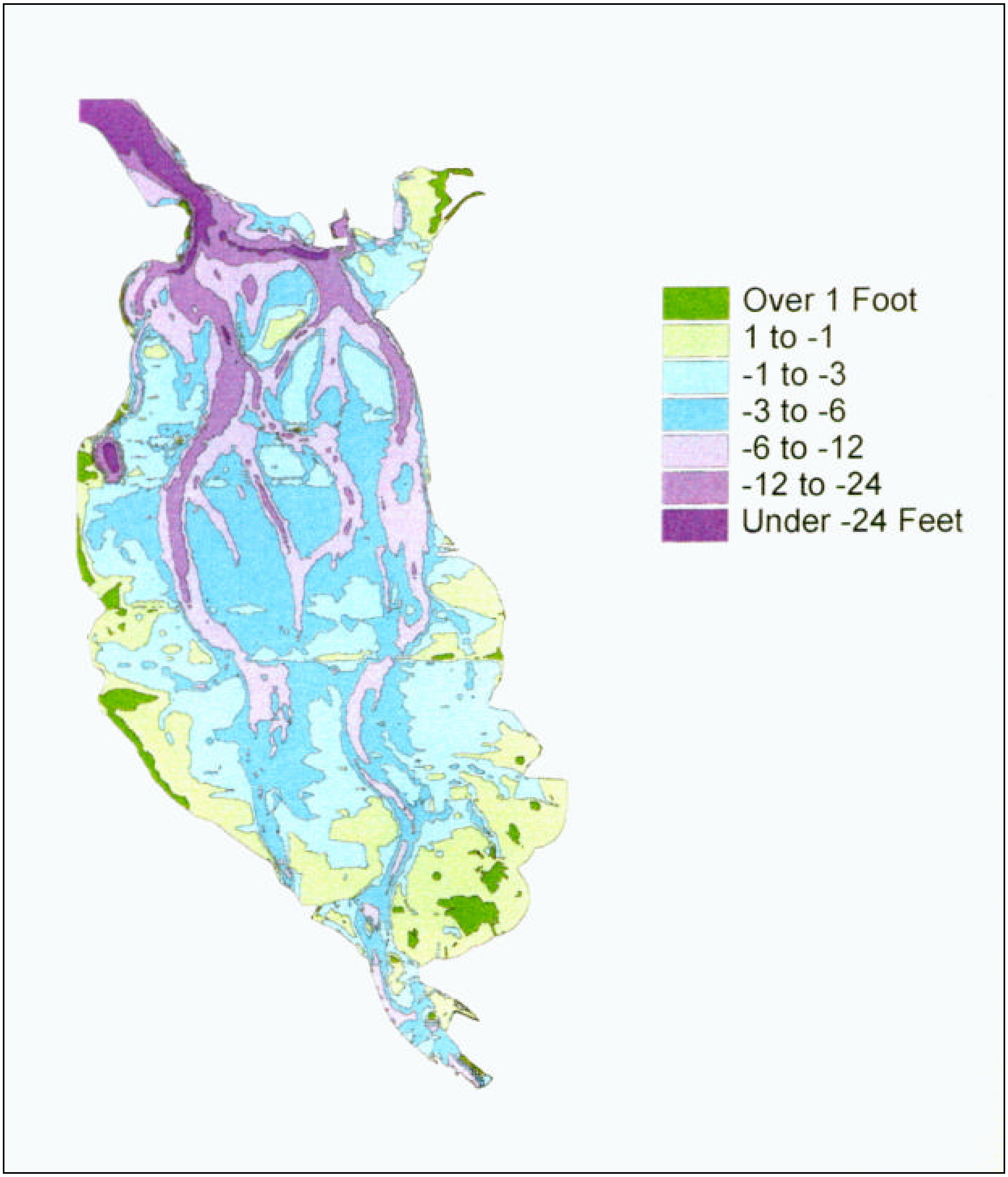


Figure 5-4. Bathymetric surface derived for Tillamook Bay from the 1995 survey. The single channel leading south and east from the Bay has become less well-defined, reflecting suspension of maintenance dredging between the 1957 and 1995 surveys.

Source: Bernert, J., and T. Sullivan. 1998. Bathymetric analysis of Tillamook Bay: Comparison among bathymetric databases collected in 1867, 1957, and 1995. E&S Environmental Chemistry, Corvallis, OR. Prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

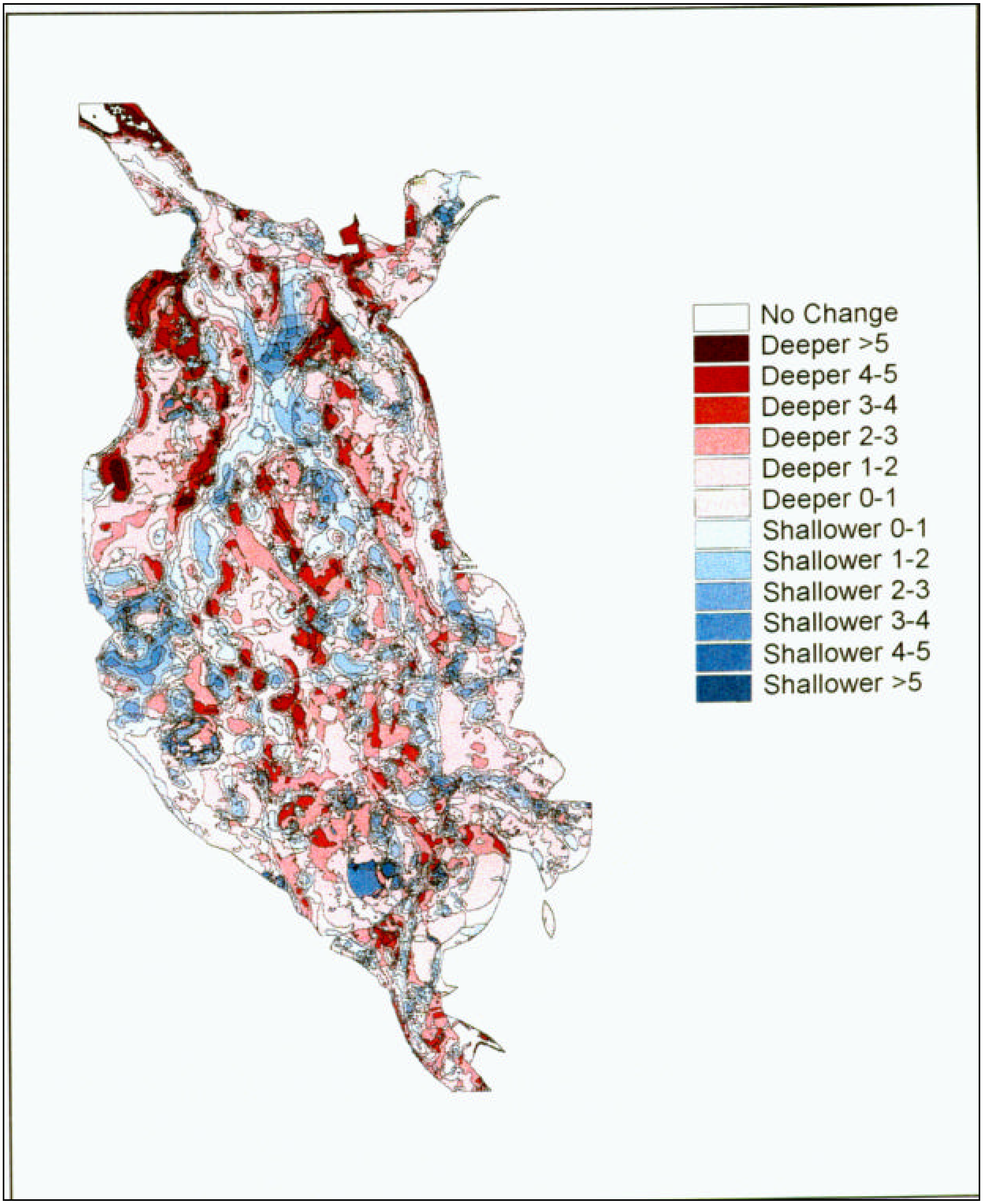


Figure 5-5. Inferred change in bathymetry from 1867 to 1995. No correction has been made for differences in benchmark elevation (datum shift) or sea level rise.
Source: Bernert, J., and T. Sullivan. 1998. Bathymetric analysis of Tillamook Bay: Comparison among bathymetric databases collected in 1867, 1957, and 1995. E&S Environmental Chemistry, Corvallis, OR. Prepared for the Tillamook Bay National Estuary Project, Garibaldi, OR.

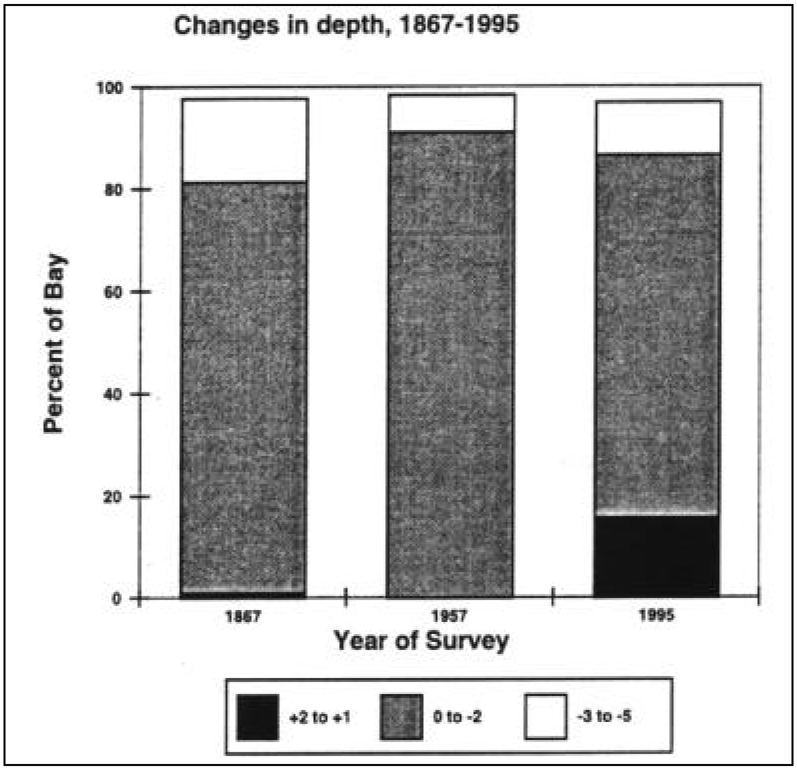


Figure 5-6. Changes in area of selected depths in Tillamook Bay between the 1867 and 1995 bathymetric surveys.
Sources: Based on data collected during 1867, 1957 and 1995 bathymetric surveys of Tillamook Bay, Tillamook Bay National Estuary Project, Garibaldi, OR.

Table 5-2. Modern sedimentation rates in Tillamook Bay

Location	Years	Rates (cm/100 yrs)
Average Bay (Bathymetry)	1867–1954	68
	1867–1995	48
	1954–1995	5
Western Bay	post-breach	>200*

*Based on assumption that mud layers in cores pre-date 1950s breach.
Source: McManus, J., P. Komar, G. Bostrom, D. Colbert, and J. Marra. 1998. The Tillamook Bay National Estuary Project: Sedimentation study. Final report. Tillamook Bay National Estuary Project, Garibaldi, OR.

Table 5-3. Historic sedimentation rates in Tillamook Bay

Location	Time (yrs < present)	Depth (meters)	Rate (cm/100 yrs)
Miami River delta			
Core 5-76	6,360–present	8.1	13
Core 3-76	7,850–present	18.5	24
Core 3-76	8,310–7,850	27.9	204
Core 5-76	>40,000–6,360	20.3	<4
South Bay			
Core 9-76	**3,300–present**	**6.6**	**20**
Core 9-76	**5,190–3,300**	**11.1**	**24**
Core 7-76	**6,970–present**	**20.3**	**29**
Core 9-96	**7,230–5,190**	**18.7**	**37**
Core 9-96	**7,450–7,230**	**23.3**	**209**
Core 9-96	**8,400–7,450**	**27.9**	**48**
North-Central Bay			
Core 13-76	**>40,000–present**	**6.1**	**<2**
Core 13-76	**>38,000–present**	**11.2**	**<3**
Core 13-76	**>40,000–present**	**14.8**	**<4**

*Based on assumption that mud layers in cores pre-date 1950s breach.
Source: McManus, J., P. Komar, G. Bostrom, D. Colbert, and J. Marra. 1998. The Tillamook Bay National Estuary Project: Sedimentation study. Final report. Tillamook Bay National Estuary Project, Garibaldi, OR.
Based on: Glenn, J.L. 1978. "Sediment sources and Holocene sedimentation history in Tillamook Bay, Oregon: Data and preliminary interpretations." Prepared by U.S. Geological Survey in cooperation with the Soil Conservation Service. Open file report 78-680.

Depositional History

The bathymetric data can be compared with the long-term rates of sediment filling based on coring work in the 1970s and 1996.

The bathymetric data can be compared with the long-term rates of sediment filling based on coring work in the 1970s and 1996 (Glenn 1978, McManus *et al.* 1998). The Holocene fill in the very deep parts of the modern river delta began to accumulate shortly before 8,000 yrs. before present (B.P.) (Glenn 1978). The Holocene core sample sites of Glenn (1978) are reorganized by area and shown in

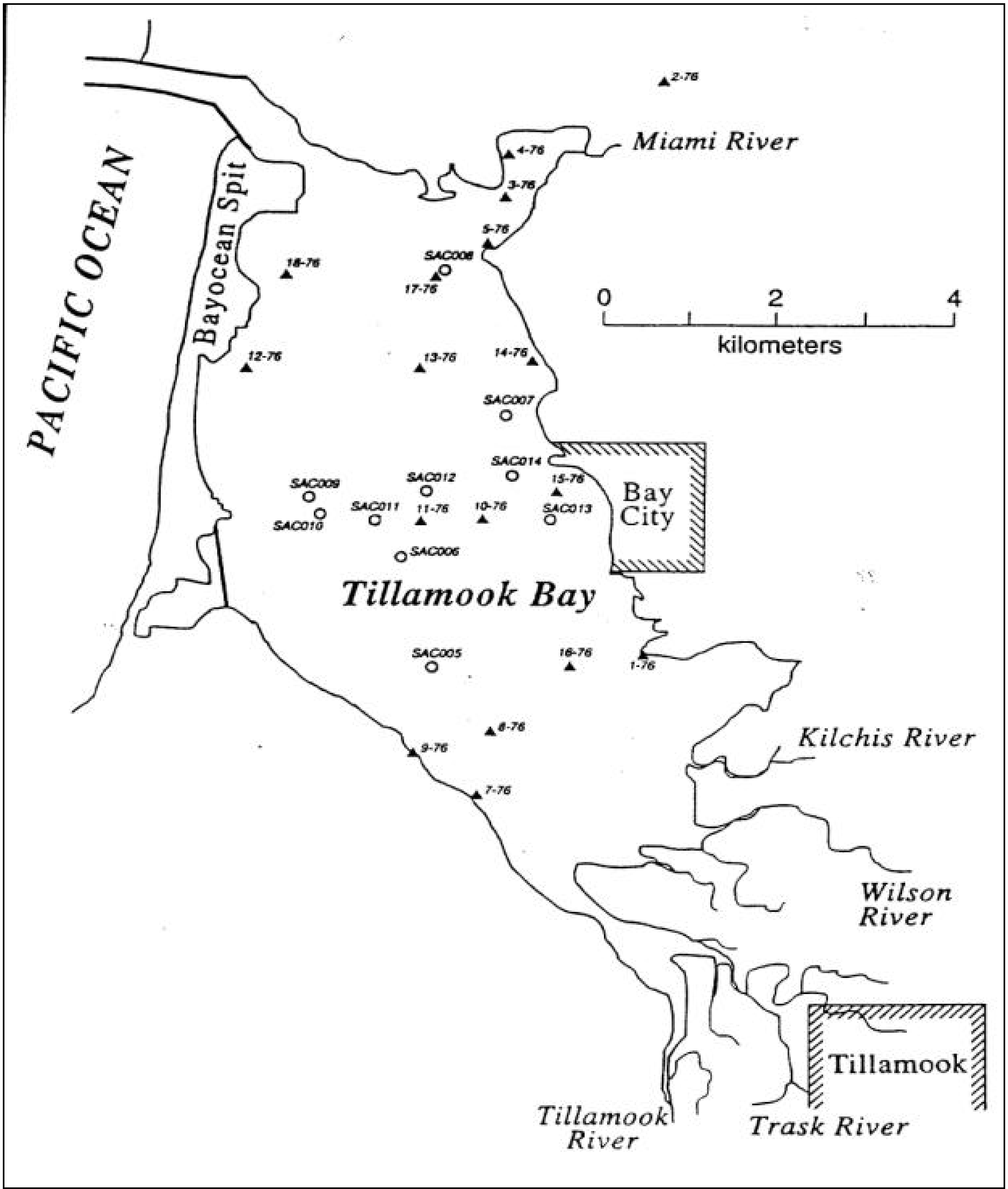


Figure 5-7. Coring sites for both McManus et al. 1998 (open circles) and Glenn 1978 (filled triangles).
Source: McManus, J., P. Komar, G. Bostrom, D. Colbert, and J. Marra. 1998. "Tillamook Bay National Estuary Project: Sedimentation study." Final report. Tillamook Bay National Estuary Project, Garibaldi, OR. Glenn, J.L. 1978. "Sediment sources and Holocene sedimentation history in Tillamook Bay, Oregon: Data and preliminary interpretations." Prepared by U.S. Geological Survey in cooperation with the Soil Conservation Service. Open file report 78-680.

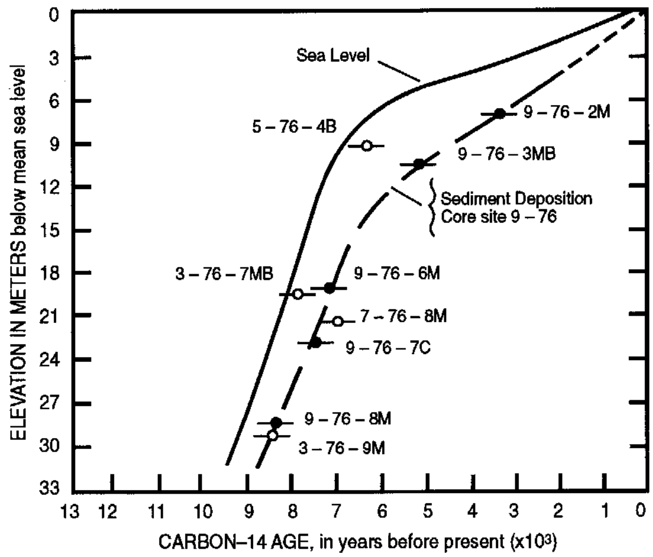


Figure 5-8. Data for the depths of organic material found in cores from Tillamook Bay, with the material dated by radiocarbon techniques. The results document the accumulation of sediments, which is compared with the "global" sea-level curve of Kraft (1971).

Source: Glen, J.L. 1978. "Sediment sources and Holocene sedimentation in Tillamook Bay, Oregon: Data and preliminary interpretations." Prepared by U.S. Geological Survey in cooperation with the Soil Conservation Service. Open file report 78-680.

Table 5-3 and Figure 5-7. In general, Glenn's work (1978) shows rapid deposition up to 6,000–7,000 yrs. B.P. (when sea level stopped rising as rapidly) and then a slower rate after that time. The early, rapid deposition (7,000–9,000 yrs. B.P.) likely reflects the geometry of the depositional embayment, its trapping efficiency, the rate of sediment supply, and the source of the sediment. McManus *et al.* (1998) summarized the variability in the sedimentation rates computed from Glenn's (1978) findings (Table 5-3). They indicate that the rates in the south Bay were once as high as 82 in. (209 cm) per 100 yrs., and decreased to approximately 8 in. (20 cm) per 100 yrs. The overall decrease in Bay sedimentation rate was shown by compiling all the data with carbon-14 ages (shown in Table 5-2) and presenting this as Figure 5-8. They concluded that the data shows an average sedimentation rate of 8–12 in. (20–30 cm) per 100 yrs. The Miami River delta and the south Bay are noted to have similar trends (McManus *et al.* 1998). In contrast, the predominantly marine sand in the north Bay apparently accumulated much more slowly (Table 5-3). However, they note that those rates are based on samples that were beyond the reach of radiocarbon dating.

Trap efficiency:
The quantity of sediment trapped and stored as a percentage of the sediment yield to a given location.

McManus *et al.* (1998) concluded that the historical (or pre-settlement) sedimentation rates for the Bay were approximately 4–8 in. (10–20 cm) per 100 years.

Subsidence:
Movement in which the surface of the earth is displaced vertically downward with little or no horizontal movement. Subsidence can occur slowly, as with the gradual removal of ground water from an aquifer, or rapidly, as in a major earthquake. The opposite phenomenon is *uplift*, where the surface moves upward.

Tsunami:
A sea wave produced by a rapid movement of submerged land, as in a submarine earthquake or volcanic eruption. Tsunamis can travel thousands of miles across oceans in a matter of hours and are potentially very destructive, even when generated far from a point of impact.

Two other factors have influenced pre-European settlement sediment deposition rates in Tillamook Bay. First, prior to 2,000–3,000 years ago, Tillamook Bay was split into two bays, north and south of an intervening bedrock ridge, with separate openings to the ocean (Peterson and Darienzo 1989). Second, both coastal subsidence and tsunamis can influence long-term sedimentation into the Bay. Coastal subsidence and uplift occur as a result of the collision of two tectonic plates off the Oregon Coast, and are considered precursors to a great subduction earthquake (Savage and Lisowski 1991). Evidence of several great earthquakes is preserved in marsh records in Tillamook Bay (Barnett 1997). Studies of marsh records throughout the Oregon and Washington coasts show evidence of marsh subsidence about 300 years ago (Atwater 1997, Madin 1992, Atwater *et al.* 1991) and earlier, thought to be associated with one or more great earthquakes. The regional average recurrence interval for the giant earthquakes is 450 yrs. ± 150 yrs., based on 11 events along the Oregon and Washington coasts (Geomatrix 1995). An indication of the potential effect is discussed in Doyle (1996), who estimated that 165 feet (50 m) of beach retreat (movement inland) would result from a possible coseismic subsidence of 30 inches (75 cm) at Siletz Bay.

The tsunamis associated with these earthquakes left lenses of beach sand far up the estuaries. In other words, large quantities of sand likely overtopped the spits and deposited in the bays and up through the estuaries, as found in a study of Siletz Spit (Wang and Priest 1995, Priest *et al.* 1996). McManus *et al.* (1998) also found evidence of tsunami deposits in core samples taken from Tillamook Bay. The depth of sedimentation associated with these events in most bays, such as Tillamook Bay, has yet to be determined. The cores analyzed by McManus *et al.* (1998) generally showed increases in the marine component of Bay sediment between 40 and 80 cm depth. Ongoing research in Oregon, on the Clatsop Plains; and in Washington, at the Long Beach Peninsula, Copalis Beach, and Grays Harbor; has located erosion scarps hundreds of feet inland associated with the tsunami of approximately 300 years ago, and for earlier events. Therefore, any spit that did exist along the mouth of Tillamook Bay was likely breached or overtopped by the tsunami approximately 300 yrs. B.P. as the land under and around the Bay subsided, with associated input of sand into the Bay from the tsunami. The subsidence has been estimated for Tillamook Bay at roughly 3.3 feet (1 m) (Peterson *et al.* 1997). Based on the regional marsh studies, the amount of subsidence and sand filling associated with the other giant earthquake events may have been somewhat less than that of the 300-yr. event for some events, and somewhat more in others, reflecting variations in the locations and magnitude of the giant earthquakes and local tectonic uplift.

The subsidence experienced during a subduction earthquake is recovered with relatively slow uplift within several decades after the event. Beyond that, elevation changes due to strain accumulation are not well understood. The written historic record of Tillamook Bay is only 150 years long, and does not include the immediate aftermath of the last great subduction earthquake, which probably occurred in January, 1700 (Satake 1995). Very recent data on local sea level changes in Oregon (see Figure 6-15 in the chapter on flooding) indicate that Tillamook is subsiding relative to sea level at a rate of approximately 0.04–0.08 inches (1–2 mm) per year (Vincent 1989). The slow rate of inundation and the short period of the data, plus the uncertainty of the data, suggest that any recent inundation in the Tillamook area is not significant when compared with other processes affecting bay depth and sediment accumulation.

Data indicate that Tillamook is subsiding relative to sea level at a rate of approximately 0.04–0.08 inches (1–2 mm) per year.

Sediment Composition

Most of what is known about the inorganic composition of Tillamook Bay sediment comes from both core and surface sample studies of the mineralogy from the beaches, bay shore, and lower rivers. These studies are useful in interpreting the source area for the sediments deposited in the Estuary over time. The primary studies have been those of Kulm *et al.* (1968), Glenn (1978), and the TBNEP study by McManus *et al.* (1998). One study analyzed grain roundness (Glenn 1978), and another, Avolio (1973), was primarily concerned with particle size distribution. The McManus *et al.* (1998) study used sediment chemistry in its evaluation, specifically carbon and nitrogen, as well as trace element chemistry.

The major non-opaque heavy mineral components in river bottom sediment samples are the pyroxene group of minerals and rock fragments (Kulm *et al.* 1968). The clinopyroxenes, augite plus diopside, comprise the bulk of the pyroxene group. The rock fragment crystals are primarily composed of feldspar and/or pyroxene (Glenn 1978). Glenn described most rock fragments as volcanic in origin, which is to be expected in a terrain dominated by volcanics. Glenn's results, as summarized in Bostrom and Komar (1997), are similar to Kulm *et al.* (1968), except Glenn found that Wilson River sediments had the greatest content of the mineral titanaugite (17%), with smaller amounts in the Kilchis (6%), and none in the other rivers' sediments. Also, in Glenn's work the percentage of rock fragments was highest in the Miami River (up to 34%) and had a general decrease in the rivers from north to south, reaching a low of 9–12% in the Trask River, and 15–16% in the Tillamook River. However, Bostrom and Komar (1997) concluded that river sediments from the five main rivers have not been sufficiently studied to trace the source of downstream sediments back to individual rivers.

Estuarine Sediment Interactions

Sedimentation in estuaries is a dynamic, natural, and beneficial process.

Sedimentation in estuaries is a dynamic, natural, and beneficial process. The strong currents which transport sediment continually rearrange an estuary's bathymetry. The dynamic nature of the Bay's bathymetry creates problems for navigation and other uses of the Bay. For the estuarine ecosystem, sedimentation is a source of organic matter for food. Large woody debris creates important habitat for insects and fish, and is itself an important source of food for marine organisms.

Impacts of Sediment on Bathymetry

An estuary may be self-maintaining from an ecological standpoint, but may not maintain conditions humans prefer.

Estuarine bathymetry is defined and altered by periods of strong flow. An estuary, given a variable influx of sediment and fresh water, will frequently relocate its principal bars and channels. Under these conditions, an estuary may be self-maintaining from an

Estuarine sediment deposition versus erosion

Tillamook Bay is a depositional environment that traps most fluvial sediment reaching the Bay.

The ratio of mean tidal prism to 6-hour mean fluvial discharge is approximately 47. This parameter, designated HR, has been related to sediment accumulation and scour for six estuaries in the Pacific Northwest, including Tillamook Bay, by Peterson *et al.* (1984). Two of the six estuaries, Tillamook Bay and Grays Harbor, have large values of HR: 47 and 86, respectively. Both of these estuaries were found to trap large quantities of fluvial sediment. The other four estuaries, Alsea, Siletz, Siuslaw, and Salmon, had HR values between 4 and 15. For these estuaries, river discharge is sufficient to offset tidal circulation and periodically flush fine-grained deposits from the estuary. This may explain how small estuaries like Salmon River persist for long periods in relatively stable condition.

A general trend in estuarine development is also indicated. As an estuarine embayment fills with river sediment, its HR value will gradually decrease, until an equilibrium between deposition and erosion within the bay is reached. That equilibrium point is indicated by an HR of 20 or lower. To reach an HR of 20, the volume of Tillamook Bay, as indicated by its tidal prism, and assuming a constant river input, would have to shrink to 43 percent of its current level.

ecological standpoint, but may not maintain conditions humans prefer. Areas like eelgrass beds and clam beds will relocate as the depths of different areas change. Substrate mobility is not compatible with oyster bed leases and other fixed human uses. Alternately, changes in climate or upland geography may result in a long-term change in freshwater inflow or sediment delivery rate, or even sea level. These changes are accompanied by steady changes in estuarine properties like bathymetry or channel morphology. All or part of certain habitats can be lost when changes like this occur. Bay circulation is also sensitive to changes in bathymetry. Changes in the way the tides propagate through the Bay may affect the distribution of salinity and marine-based nutrients, affecting shellfish or eelgrass bed quality.

Impacts of Sediment on Navigation

Prior to 1913, the Port of Tillamook maintained a shallow draft channel to the City of Tillamook for ocean-going ships.

The history of navigation on Tillamook Bay provides direct and anecdotal evidence that the Bay is filling with sediment, and also shows the difficulty in navigating a shallow, dynamic estuary. Prior to 1913, the Port of Tillamook maintained a shallow draft channel to the City of Tillamook for ocean-going ships (Figure 5-9). The 9-foot (2.7 m) deep channel from Bay City to Tillamook was abandoned in 1919, cutting the City of Tillamook off from the sea (The Research Group 1992). In 1925, the 16-foot (4.8 m) deep federally maintained channel south of Bay City was abandoned because the channel was refilling in three months, 12 times the normal rate. That same year, a federally maintained channel was authorized from the Bay entrance to Garibaldi. Maintenance of that channel required the removal of an average of 31,300 yd^3 (23,945 m^3) of material per year between 1929 and 1979. In 1979, a jetty was built along the south side of the entrance to complement the north-side jetty, which had been completed in 1917. The Garibaldi channel has been nearly self-maintaining since then (Coulton *et al.* 1996). Between 1979 and 1995, 71,000 yd^3 (54,315 m$^{3)}$ were dredged from the channel (Chesser 1995, as cited in Miller and Garono 1995).

Impacts of Sediment on Ecosystems

Estuaries are rich in life partly because of the food resources brought from the land.

Sediment in estuaries provides the raw materials for various substrate types. Sediment also contains organic material — leaves, herbaceous plants, and wood — which contributes to the base of the estuarine food web. Large woody debris — trees, branches, and root wads — also provides an important surface for plants and animals to live, and cover for fish and wildlife. Herring spawn on wood debris, branches and logs. The many diverse species which inhabit estuaries are adapted to the continuous sediment input. Estuaries are rich in life partly because of the food resources brought from the land.

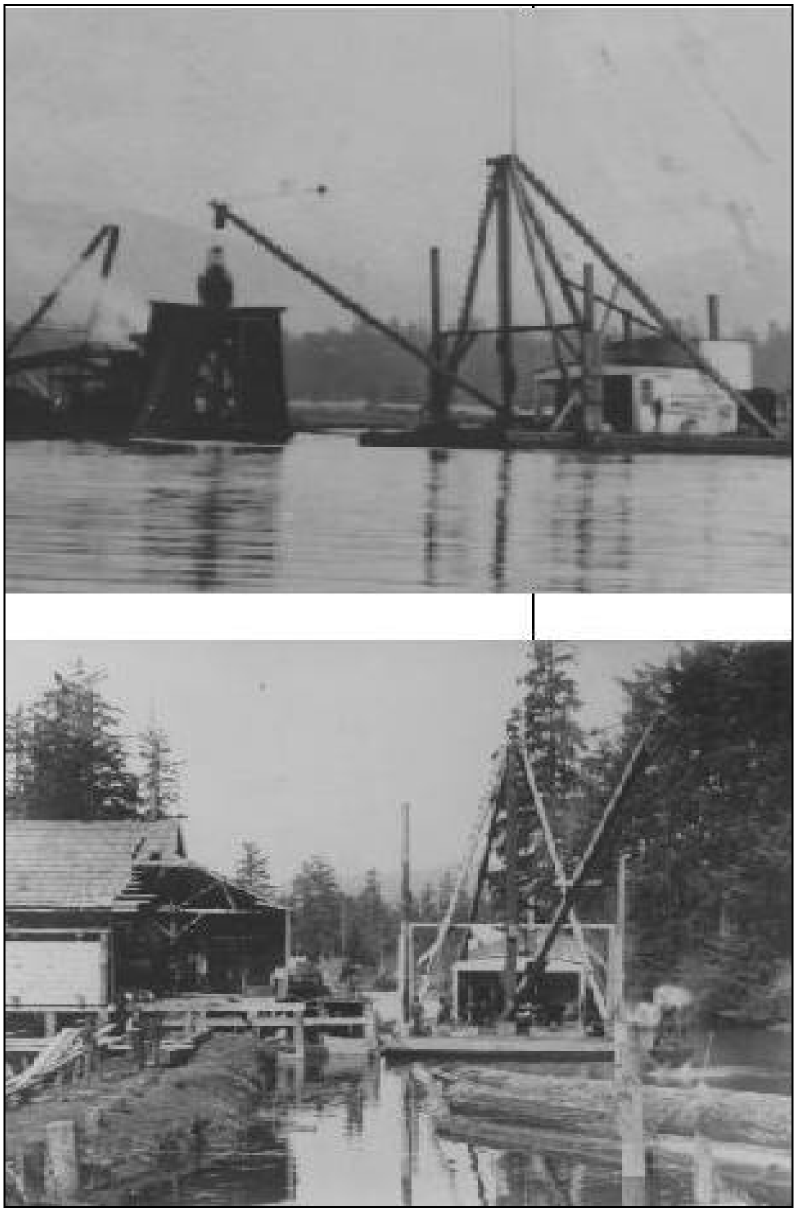


Figure 5-9. Historic photographs of dredging in Tillamook Bay and Hoquarten Slough.
Source: Tillamook Pioneer Museum collection.

Sediment also has negative impacts on estuaries. Suspended sediment inhibits biological productivity by smothering aquatic plants and blocking sunlight. A large amount of marine sediment entered Tillamook Bay through a breach of Bayocean Spit between 1952 and 1956. This sand, concentrated in the southwest corner of the Bay, has been implicated in the proliferation of burrowing shrimp and in a possible decline in eelgrass in the Bay in recent years.

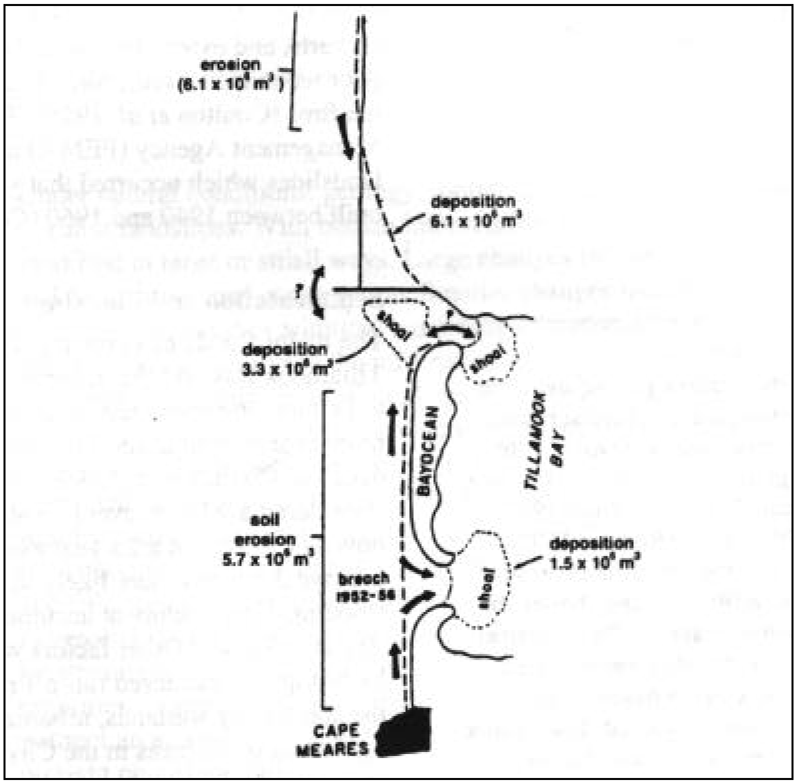


Figure 5-10. Approximate sediment budget for the 4-year breach of Bayocean Spit, showing 1.5 million cubic meters (1.96 million yd^3) of marine sediment entering the Bay.
Source: Komar, P., and T. Terich. 1976. "Changes due to jetties at Tillamook Bay, Oregon." American Society of Civil Engineers, Proceedings, 15th Coastal Engineering Conference. pp 1791-1811.

Significance of Historical Events

Intensive salvage logging operations following the Tillamook Burn forest fires worsened the erosion and sediment delivery to the Bay.

The exact causes of the apparent rapid filling of Tillamook Bay during this century are unknown. Two events are believed to be important: the extensive forest fires of the Tillamook Burn, and the breaching of Bayocean Spit in 1952. In the long history of Tillamook Bay, the brief period of the breach amounts to an intensive filling of the Bay which was essentially caused by human activities (Komar and Terich 1976). An estimated 1.96 million yd^3 (1.5 million m^3), of sediment entered the Bay during the breach (Figure 5-10) (Komar 1997). The forest fires of the Tillamook Burn may also have caused a relatively brief, intense pulse of sediment delivery to the Bay. Forest fires, even quite extensive ones, were no doubt a part of the Coast Range's history prior to European settlement (LaFrance and McDonald 1995, as cited in Miller and Garono 1995). However, the intensive salvage logging operations which followed, and especially the poor quality roads built through the burned areas (*i.e.*, undersized culverts, log culverts, and extensive sidecasting of materials are examples of the poor techniques used), worsened the sedimentation which followed the fires (Coulton *et al.* 1996). The Federal Emergency Management Agency (FEMA) acknowledged in 1990 that many landslides which occurred that year originated from salvage roads built between 1940 and 1960 (Coulton *et al.* 1996).

Sedimentation and Flooding

The major floods of February, 1996 have focused attention on Tillamook Bay and the accumulating sediment, which is perceived to be blocking rivers and channels. Flooding has generally become more pronounced in the Tillamook area over the last several decades. Coulton *et al.* (1996) reported that the 1964 flood, considered a 90-year event (probability 0.011) at the time, would now be considered a 25-year event (probability 0.04, or on the average 3.6 times more likely to occur). The exact effect on flooding of the sediment accumulating in and around Tillamook Bay is unknown. Other factors which influence the basin's hydrology — increased run-off rates, reduced retention of water by the soil and by wetlands, urbanization (*e.g.*, storm drains), the hardening of surfaces in the City of Tillamook, stream channelization and diking, and road beds which can act as flood-prolonging dikes — also affect Tillamook's flooding. Dredging the Bay or river channels to remove excess sediment, either to remove unnatural pulses like that from the breach of Bayocean Spit or to improve upland drainage, is being considered to help mitigate Tillamook's flood problems. However, any benefits are likely to be only temporary because of future sedimentation. Detailed studies of the hydrology of the Watershed should be completed before the community invests in dredging. For a more detailed discussion of flooding and sedimentation in the Tillamook Bay Watershed, see Chapter 6, Flooding.

Urbanization:
Urbanization, paving and other development of hard surfaces changes soil infiltration, with significant and lasting effects on peak flows. (Stockdale 1995, Urbonas and Roesner 1992). The hardened surfaces prevent soil infiltration and shorten the path to channels. Storm drains concentrate flow to localized outlets which might cause flooding. Increased flow volume and energy can also increase channel mobility as well as erosion and sediment transport (Botkin 1995).

Upland Sediment and Erosion

The Tillamook Bay Watershed is 89% forested upland (TBNEP Management Conference Agreement 1994). Forested areas account for approximately 85% of sediment produced in the Watershed (USDA 1978). Upland erosion occurs in two principal forms: landslides and surface erosion (Reckendorf 1995, as cited in Miller and Garono 1995). The principal source of sediment in the Tillamook Bay Watershed is mass wasting. Mass wasting is commonly referred to as landslide, but the term is somewhat inaccurate in that it does not cover the five basic failure modes: falls, topples, slides, spreads, and flows (NAS 1978). However, because of common usage (NAS 1978), the term landslide will be used in this discussion. As applied to the Tillamook area, the common types are rock slide, debris slide, and debris flow in steep terrain, and earth slide and earth flow on gentler slopes, as described in "Landslides: Investigation and Mitigation" (NRC

Mass wasting:
A general term for a variety of processes by which large masses of earth materials are moved by gravity, either slowly or quickly (AGI 1957).

Landslide:
A group of slope movements wherein shear failure occurs along a specific surface or combination of surfaces (NAS 1978).

1996).

Infiltration
Water seeping into and flowing through a soil.

Pore-pressure:
The unit of stress carried by the water in soil pores in a cross-section (Spangler 1960). Sharp gradients in pore pressure perpendicular to soil layers can cause different soil layers to partially separate, reducing the interface's resistance to shear stresses and leading to slope failure.

Slide-prone:
The conditions to produce slide-prone areas vary considerably. The typical conditions, as applied to the Tillamook Basin, where there has been extensive road building, tend to be steep slopes with (1) rock sequences likely to produce overhanging or over-steepened cliffs, such as massive lava flow over fractured flow or sedimentary rock; (2) a soil or rock sequence of permeable material over impermeable materials; (3) inclined (dipping) bedding planes in the direction of excavation; (4) fractured, faulted and jointed rock zones that act as water conduits; (5) cohesive, clayey soils that have become saturated; and (6) unconsolidated materials with relatively low shear strength (Bureau of Public Roads 1961).

Under natural conditions, geology, topography, and climate interact to cause landslides. With human intervention, the slope can be modified in large or small ways. Large changes include excavation and fills, as for road construction. Smaller changes include vegetation removal or addition, hardening of surfaces, and paving. All changes can influence the infiltration of water from rainfall or snowmelt. The rapid infiltration of rainfall, causing soil and rock saturation and a temporary rise in pore-water pressure, is generally believed to be the mechanism by which most shallow landslides are generated during storms (Figure 5-11) (Beschta 1978, NRC 1996). Road building creates cuts and fills. In a slide-prone landscape, the road cuts can undercut slopes and concentrate runoff along roads and fills, as well as increase infiltration and pore water pressure, increasing landslides. Other triggers could be undercutting of slopes by streams or the ocean, heavy rainfall, storm waves, volcanic eruptions, or earthquake shaking. In some cases landslides occur without an apparent cause because a combination of triggers brought on a slope failure (NRC 1996).

Landslides, which are extremely variable in size, velocity, and mechanics of movement, can be "shallow-rapid" or "deep-seated" (Washington Forest Practices Board 1995). Shallow-rapid landslides are typical on steep forested hillslopes (Mills 1997). A small debris slide (generally occurring on steep slopes with shallow soils) becomes a debris flow if the sliding soil, moving downslope, scours and entrains additional soil and vegetation in its path. In areas with steep slopes, debris flows are the dominant erosional mechanism (Mills 1997). Deep-seated landslides are more commonly slow-moving and are also highly variable in size, although a very large, rapidly moving deep-seated landslide occurred along the Wilson River in 1991 (Mills 1997).

Another source of sediment is surface erosion (Figure 5-11). Surface erosion is usually relatively unimportant in forested areas around Tillamook Bay because of the high rates of infiltration in the forest soils of the Coast Range. Severe fire can result in hydrophobic (water repellant) soils which can then become subject to surface erosion (Beschta 1978).

Compaction of the ground surface, or physical excavation (for example in road construction), can lead to surface erosion. This erosion becomes significant to stream systems if roads are built so that water drains directly into the channel, or into a gully with direct access to a stream. Roads which divert surface flow off the road and

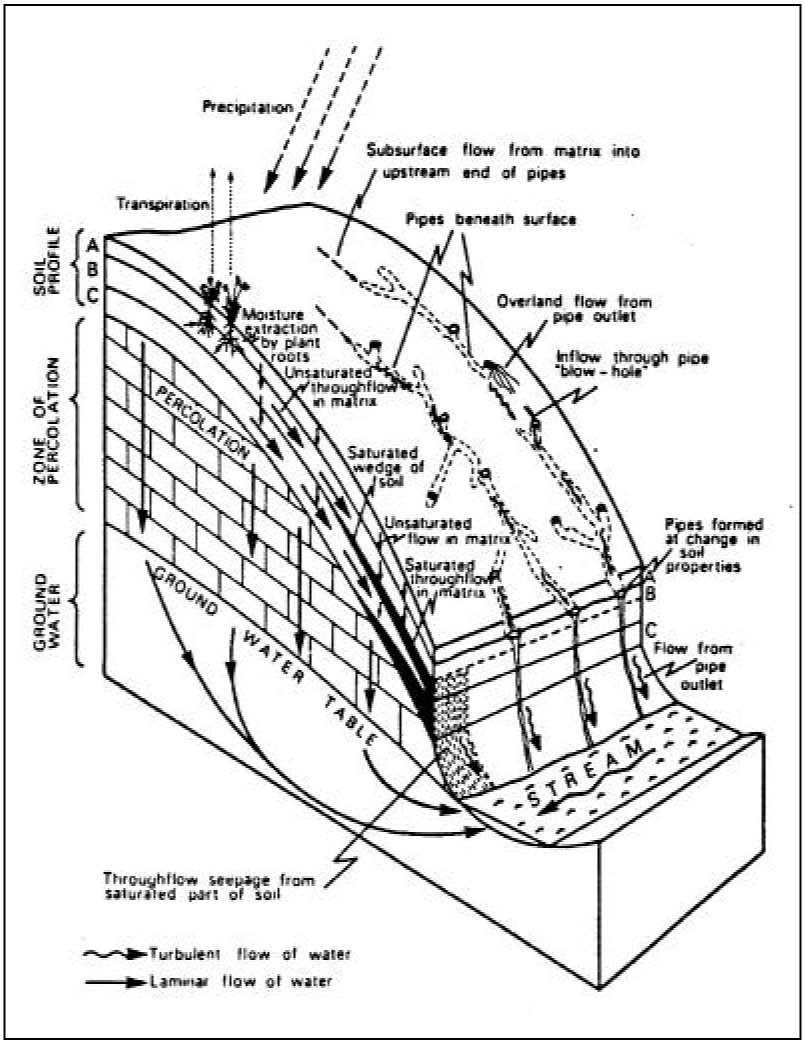


Figure 5-11. Schematic view of a forest substrate structure.

across the forest floor generally contribute little or no excess sediment to the fluvial system. Soil eroded by the surface flow should be trapped as the diverted water infiltrates into the forest floor, unless flows grow to the point where rills and gullies form on the surface, or insufficient distance is present between the road the stream. In general, sediment production from road beds is highly variable, and is greatest in the first few years after construction (Ketcheson and Meghahan 1996).

Table 5-4. Estimates for sediment yield in the Kilchis Watershed

Source type	Normal year	Major storm	Extreme storm
Road surface erosion	50–500 yd^3	50–1000 yd^3	100–5,000 yd^3
Road washouts	100 yd^3	2,500 yd^3	25,000 yd^3
Road landslides	2,000 yd^3	20,000 yd^3	200,000 yd^3
Abandoned road slides	0	5,000 yd^3	100,000 yd^3
Background landslides	100–1,000 yd^3	1,000–100,000 yd^3	100,000–500,000 yd^3

Source: after Mills, K. 1997. “Forest roads, drainage and sediment delivery in the Kilchis River Watershed.” Tillamook Bay National Estuary Project. Garibaldi, OR.

Estimates of Sediment Yield from the Forest Lands

There are few estimates of sediment yield from forest lands in the Tillamook area. Mills (1997) studied forest roads in the Kilchis River Watershed to determine the sediment delivery patterns in that area. A 1978 study by the U.S. Department of Agriculture, prepared for the Tillamook Bay Task Force, estimated sediment yield for the entire Watershed.

Kilchis River Watershed Study

Mills (1997) estimates sediment production values for the 47,000-acre (19,035 ha) Kilchis Watershed for five types of erosional processes for three climatological conditions (Table 5-4). Sediment production for a normal year is contrasted with production for a year with a major storm and production for a year with an extreme storm. The estimates in Table 5-4 do not include soil creep, or erosion of the channel bank, which may both be significant, even in normal years.

USDA Study

Upland erosion rates in Tillamook Bay’s Watershed have increased due to human activities, but the exact amount of increase is unclear. A report prepared for the Tillamook Bay Task Force (USDA 1978) estimated that total sedimentation rates in forest lands have increased substantially since 1875, with great increases after the major forest fires of the 20th century. The USDA (1978) report used the Universal Soil Loss Equation (USLE) to estimate sediment production for forested lands. Since this technique tends to overstate sheet and rill erosion on forest land — particularly where the soil has high infiltration rates typical of the volcanic soil areas in the

Pacific Northwest — the upland erosion results study are not presented here.

Sediment interacts with stream hydrology in complex ways to create the habitat characteristics of a stream.

Sediment Transport and Deposition in the Uplands

A great deal of sediment is transported through upland channels in debris torrents. Debris torrents tend to wash out a section of stream, opening the area to be restructured by the sediment and organic material delivered later. Channel morphology is a reflection both of large scale changes, like debris flows, and of less extreme high flow events. Sediment interacts with stream hydrology in complex ways to create the habitat characteristics of a stream.

Debris Torrents

Debris torrents are rapid movements of water-charged debris confined to steep headwater channels (Chesney 1982, Van Dine 1985). In general, a debris torrent is a debris flow confined to a channel (Chesney 1982). Debris torrents begin as landslides and debris flows, and can transport up to 100 times more material than the initiating slide when fully developed (Mills 1997). The material in a debris torrent may include soil, trees, and other organic matter. The most common triggering mechanism for debris torrents is extreme water discharge, either heavy rainfall or the temporary damming of a channel (Van Dine 1985). In one study, slides from hillslopes were found to be the dominant mechanism in 83% of 53 debris torrents (Swanson *et al.* 1976). Debris flows and torrents tend to deposit their material where channel gradient declines. They can also stop (deposit as a debris jam) at an acute tributary junction, plug up the channel, and cause the stream to severely erode the streambank to get around the plug. A debris torrent can cause long-term change in channel morphology which may benefit some species at the expense of others.

Colluvium:
A general term applied to incoherent deposits, usually at the foot of a slope or cliff and brought there by gravity. Tallus and cliff debris are included in such deposits (AGI 1957).

Debris torrents are likely the most important means of sediment transport in the upper watersheds in the Tillamook Bay Basin. Debris torrents involving colluvium may move with dangerous speed. Composition of up to 70% sediment and 30% water has been mentioned in the literature (Burns 1997). The composition of debris flows will reflect not only colluvial materials, which range from coarse grained debris to fine grained soils, but also abundant coarse organic material, including trees and other streamside materials.

Channel Morphology

The dynamics of hill slope erosion and sediment transport in forested uplands are illustrated in Figure 5-12. The profile extends from the hill slope to the channel network (regime). Regime systems are generally low-gradient, sand bed channels which are transport-limited. Near the top of the profile, systems are supply limited, such as where bedrock and cascades exist along the channel. Sediment supplies increase downstream, such as in colluvial slope positions, or in flattened lower stream reaches where regime or braided channels might be found. The figure also reflects the variation of large woody debris spatially over the watershed, and the two-dimensional, or planform, characteristics of the channel bottom that are important for aquatic habitat.

Planform:
A two-dimensional overhead view, as from an airplane.

Sediment transport:
Sediment in waterways is transported in four ways: (1) flotation load; (2) bed load; (3) suspended load; and (4) dissolved material. Flotation load consists of organic matter, mostly wood, which floats in and is washed down by the water.

Bed load material is sediment which is small enough to be entrained and pushed along by the force of the current near the bottom, but too large to be picked up by the flow. The size of the particles moved as bed load, which depends entirely on the strength of the current at the time, ranges from small pebbles to automobile-sized, or larger, boulders during catastrophic floods. The ratio of bed load to suspended load is typically 1:5 to 1:50 (Gordon *et al.* 1992). Bed load accounts for 10–30% of the total sediment yield in Pacific Northwest estuaries (Peterson *et al.* 1984). The proportion of bed load is higher during major floods and in clear headwater streams. Bed load tends to be left behind when the channel slope decreases or the channel is widened and the amount of energy in a flow regime is reduced. The gravel bars found in Tillamook Bay rivers are deposited as a result of this process.

Suspended load is smaller sediment particles carried by the current and buoyed along by the eddies and vertical currents in a flow. A stream or river’s suspended load carrying capacity is virtually unlimited, ranging from suspended load, to hyperconcentrated load, to mud flow. The small particles of suspended load typically settle out of the water as fine sediment and silt when the water enters flat terrain and slows. The preponderence of fine silts in the lower reaches of Tillamook Bay rivers and in the Bay itself is an example of this process.

Water makes an excellent solvent because of the asymmetric shape of its molecules. Minerals broken down into ions become part of the water itself, increasing the mineral content or “hardness” of the water. Dissolved load accounts for 38% by weight of all sediment transported by rivers worldwide (Gordon *et al.* 1992). However, dissolved load does not contribute to the accumulation of sediment in Tillamook Bay.

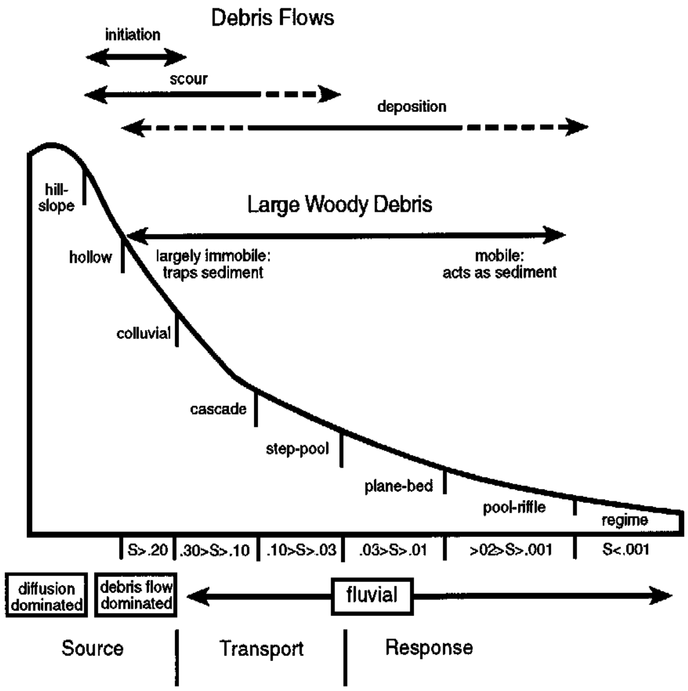


Figure 5-12. Illustration of idealized long profile from hilltops downslope through the channel network, showing general distribution of channel types and controls on channel processes. “S” is channel slope or gradient.

Source: Montgomery, D.J., and J.M. Buffington. 1993. “Channel classification, prediction of channel responses, and assessment of channel condition.” TFW-SH10-93-002.

In many situations, large organic debris (*e.g*., tree tops, trunks, and root wads) tends to stabilize channels. The wood structure slows the routing of fine organic matter and finer sediment particles. However, in gravel rich streams, where sediment supply has been increased by natural or human-induced changes, large organic debris has been found to increase braiding and meandering, which then increases bank cutting. The importance of woody debris to sediment transport is greatest in small streams and declines as channels grow and the stream’s hydraulic capabilities become dominant (Swanson *et al.* 1976).

Sediment and Aquatic Habitat

Debris flows, which deliver most sediment to fluvial systems, consist of rocks and boulders, soil, mineral components and particulate organic matter (POM), and the leaves and wood of trees, bushes, and herbaceous plants. Boulders and gravel-sized rocks settle in the streambed and become part of the channel structure or bed load. Tree trunks and branches will also become part of the channel structure, moving downstream during high flows. Smaller pieces of soil and POM become suspended in the water column. Leaves and needles remain attached to tree branches or float freely, contributing organic material to the food chain of the stream. All these inputs to the fluvial system have important and lasting impacts on the biota, such as fish, macroinvertebrates, and plants of the ecosystem.

Benthic macroinvertebrates:
Insects (invertebrates) which live on the stream bottom, or on submerged surfaces, such as woody debris or rocks.

Debris flows and debris torrents can have positive and negative effects on fish in streams. A debris flow from a forested hillside will contain soil sediment, organic material, and a substantial amount of large woody debris. This mixture causes significant changes in the affected stream reach (Chesney 1982). In the short term, a debris torrent can scour a channel or remove beneficial prey (benthic macroinvertebrates) and channel structures. Over the long-term, these events deliver woody debris, organic matter, and gravel that could result in the reestablishment of productive aquatic habitat and provide an important reset mechanism to the stream ecosystem. Recent literature reviews have identified habitat alterations as the disturbance class with the longest lasting effect on fish and macroinvertebrate communities (Richards 1992). Changes to the distribution of substrate types within a watershed can cause changes in the nutrient cycling, or spiraling, in the fluvial system, leading to changes in the availability of nutrients downstream (Richards 1992). Everest *et al.* (1987) report both increases and decreases in fish populations associated with landslide deposits.

Stream channelization and its effects on fish:
Of all land use impacts studied, channelization produced the most radical change to stream environments along the Luxapalila River in Mississippi. Fish populations in channelized sections of the river were found to have not recovered after 52 years. Habitat modification intended to mitigate the effects of channelization can be effective in shortening recovery times . The effectiveness varies, however, with fish species and with the time since modification (Niemi *et al*. 1990).
Of all fish families, salmonids have been found to be the least resilient in the face of anthropogenic disturbance (Detenbeck *et al.* 1992).

Salmonids depend on gravel beds for spawning and egg development. To be suitable for spawning, gravel deposits must provide: (1) interstitial voids within the gravel where the eggs can sit without being crushed; (2) water flow through the gravel sufficient to bring oxygen to the eggs and larvae; (3) bed stability between spawning and fry emergence; and (4) size and structure allowing the emergent fry to work their way out (Milner *et al.* 1981, as cited in ASCE 1992; Chapman 1988, as cited in Reeves 1992; ASCE 1992).

Reckendorf and Van Liew (1988, 1989) made a series of studies of sediment interaction with redds on the Tucannon Watershed in Washington. They created artificial redds, filled them primarily with sand in the early part of the winter runoff season, then added increasing amounts of fines during spring runoff. Dissolved oxygen levels in the redds decreased as the amount of sand and fines increased. In addition, the Fredle Index, a parameter that reflects the quality of streambed gravel for salmonid reproduction, was computed for freeze-core samples collected from the artificial redds and for the undisturbed substrate beneath the redds. Fredle Index values for the lower depth (10–25 cm.) portion of the sediment-intruded redds studied approached the values for the undisturbed gravel substrate (*i.e.*, complete packing with sediment to the background level of filling). The increase in sands and fines, and decrease in dissolved oxygen and Fredle Index values, all reflected decreased pore size and permeability of the artificial redds, and therefore a potential decrease in salmonid eggs' survival to fry emergence (Reckendorf and Van Liew 1988, 1989). Similarly, Reiser and White (1988) reported that salmonid egg survival was inversely related to the presence of material finer than small gravel (< 5 mm diameter). Shirazi and Seim (1979, as cited in ASCE 1992) found that egg survival was directly related to the ratio of bed sediment size to egg size.

Aquatic system productivity decreases with increased soil importation or decreased log availability to a stream.

Salmonids have evolved in watersheds with high erosion rates. It is not known at what point a human-caused increase (or decrease) in the erosion rate seriously impacts salmonids' productive capacity (Everest *et al.* 1987). In general, aquatic system productivity decreases with increased soil importation or decreased log availability to a stream (Edwards 1992). In a controlled study on a brown trout stream in Michigan, Alexander and Hansen (1986, as cited in ASCE 1992) added sand to a reach in order to study the effects on resident brown trout of increased sediment load relative to a control reach which received no added sediment. During the five-year study, the sedimented reach had a lower recruitment (hatch) rate than the control reach, resulting in a population decline in each successive age class each year of the study. After stopping the excess sediment input, the population recovered, with young trout becoming more numerous first. The results of this study support the findings of Lloyd (1987, as cited in Edwards 1992) that younger salmonids in Alaskan streams are more susceptible to increases in fine sediment than older individuals. Beschta (1978) speculates that populations quickly recover from a short (1–2 year) increase in suspended sediment, followed by a return to natural conditions, as demonstrated by the lack of decrease in the resident trout population in a small watershed in Oregon.

Salmonid species segregate by depth in stream pools (Reeves 1992). As pools become shallower due to sediment deposition, cutthroat trout (which prefer the deeper portions of pools) are shut out by juvenile coho salmon, which remain near the surface (Figure 5-13) (Reeves 1992). Schwartz (1991, as cited in Reeves 1992) examined several streams in the Oregon Coast Range where timber harvesting had occurred in the past. He found that cutthroat trout populations

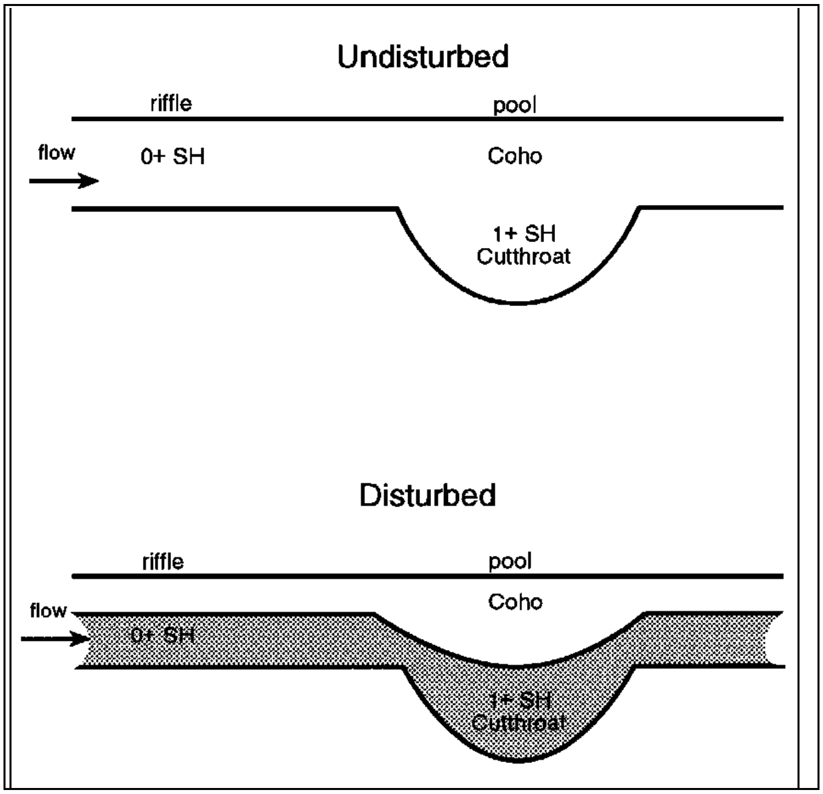


Figure 5-13. Generalized distribution of juvenile anadromous salmonids within pools that have not been altered (top) and that have been altered by sediment deposition (bottom).

Source: Reeves, G. 1992. "Sediment and aquatic organisms in the Pacific Northwest: the need for new perspectives." In: Proceedings, Technical Workshop on Sediments. Terrenne Institute. Feb. 3–7, 1992. 143 pp.

had not recovered in disturbed streams, even 25 years after logging had stopped.

The sediment which makes up the channel bottom is often the primary influence on benthic community diversity and abundance, and hence a major factor in overall stream productivity.

The sediment which makes up the channel bottom is often the primary influence on benthic community diversity and abundance, and hence a major factor in overall stream productivity. Sand and cohesive beds (*i.e.*, clays) create habitats which favor high density (high biomass) but low species diversity. Sand moves frequently in fluvial systems, and few species (mostly burrowing types) can accommodate this disturbance rate (Hynes 1970, as cited in ASCE 1992; Williams and Mundie 1978, as cited in ASCE 1992). The physical diversity and long-term stability of streams with boulders, cobbles, and coarse gravel beds result in a much greater diversity of species, but with lower overall density (Hynes 1970, as cited in ASCE 1992). The fraction of bed material smaller than 1 mm diameter is a good indicator of cold water stream habitat value, because density and diversity of benthic biomass tend to be inversely related to the fraction of fine material (Adams and Beschta 1980, as cited in ASCE 1992). Driftwood (large woody debris in fluvial systems) provides diverse habitats for microbes and macroinvertebrates (Maser and Sedell 1994). Some species burrow in and feed on the wood, others live on the surface and feed on the algae that grows on the wood.

Increased suspended sediment load can harm aquatic communities.

Little experimental evidence exists to verify the effects of suspended sediment on functional components of stream ecosystems or overall system productivity (Richards 1992). Some studies, namely Matter and Ney (1981, as cited in ASCE 1992), and May and Huston (1979, as cited in ASCE 1992), indicate that increased suspended sediment load can harm aquatic communities, at least in cold water streams. Possible mechanisms for this effect include suspended silt blocking sunlight from aquatic plants and clogging fish gills (Richards 1992). Alabaster and Lloyd (1982, as cited in Richards 1992) note that abrasion and blockage of gills due to suspended sediment can inhibit respiratory function and cause considerable mortality. Macroinvertebrate communities respond to increases in suspended sediment load, but the changes generally involve shifts in community structure rather than decreases in biomass (Gray and Ward 1982, as cited in ASCE 1992).

Forest Practices and Human Impacts

An important question in the discussion of erosion rates in upland areas is the natural rate of landslide occurrence versus that in historic times and the present day. Activities in the forested uplands — road building, clear cutting, and other timber harvest activities — have tended to increase the rate of landslides per unit area (Chesney 1982, Benoit 1978) and increase the storm runoff rate. The most predictable source of soil input to fluvial systems associated with logging comes from road building and skidding, especially if either is done without adequate design or construction techniques (Swank *et al.* 1989, as cited in Edwards 1992). More specifically, road failures are the most important contributor to increased sediment loads (LaFrance and McDonald 1995, as cited in Miller and Garono 1995). Timber harvesting may affect slope stability, resulting in increased landslide frequency, and may reduce the amount of woody debris in the slide material. Timber harvests, especially clearcuts, have been implicated in the decrease in soil stability when the harvested trees' root systems die and begin to decompose (Beschta 1978, Krogstad 1995).

The most predictable source of soil input to fluvial systems associated with logging comes from road building and skidding, especially if either is done without adequate design or construction techniques.

Sediment Production: Natural Variations and Human Impacts

The natural rate of landslide occurrence is generally not known, (Harr 1992) but has been established for site-specific studies over short time periods (NRC 1996). Natural rates of sediment production similarly are not known and difficult to establish. Studies which address the differences between pristine and managed watersheds are limited by the requirement that they focus on small watersheds which, while geographically close, may experience significantly different rainfall and wind patterns, and in any event are too small to represent a large watershed or the Coast Range generally (Grant and Wolff 1991, as cited in Ziemer and Lisle 1992). Such comparative studies are also limited to measuring differences in sediment yield due to harvest prescriptions or other management actions, including no activity. Further, the natural disturbance rate (*i.e.*, from fires, floods, etc.) before modern forest practices, or the activities of Native Americans, cannot be known (Harr 1992). Any absolute rate of sediment production for a hill slope or a watershed would apply only to that one area because of the substantial differences in topography, geology, soils, vegetation, climate, potential for landslides, large woody debris, and channel network differ substantially.

State regulations and laws

Sediment loading in the State's waters is regulated by the Department of Environmental Quality (DEQ). Oregon Revised Statutes (ORS) 468.015 states that it is policy "to protect, maintain, and improve the quality of the waters of the state (and) provide for the prevention, abatement, and control of new and existing water pollution." Oregon Administrative Rules (OAR) 340-41-006 include silt, turbidity, and color in a list of alterations or contaminants to waters which might create a public nuisance or render such waters harmful, detrimental or injurious to public health, safety, or welfare, or domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses or livestock, wildlife, fish, or other aquatic life, or the habitat thereof" (Plummer 1995).

The Oregon Forest Practices Act (FPA) contains rules to "protect, maintain and, where appropriate, improve the functions of streams, lakes, wetlands, and riparian management areas) (OAR 629-635-100(3)).

The goal for water quality is to ensure that, to the maximum extent practicable, non-point source discharges of pollutants (including excess sedimentation) resulting from forest operations do not impair the achievement and maintenance of the water quality standards" (OAR 629-635-100(7a)). The FPA's main water quality protection tool is the prescription of Riparian Management Areas (buffers) around water bodies within timber sales.

Timber Harvesting

Increased sedimentation in streams has been found to reduce pool depth, alter substrate composition, reduce interstitial spaces, and cause channel braiding.

Timber harvesting can alter the composition of landslides, debris flows, and debris torrents which provide sediment to stream systems. A debris flow from a forested hillside will contain soil sediment, organic material, and a substantial amount of large woody debris. Changing this mixture causes changes in the affected stream reach (Chesney 1982). The sediment and wood will be arranged by high flow events into pools and riffles, and waterfalls, and the wood structure will trap and store some of the organic and inorganic sediment. Increased sedimentation in streams has been found to reduce pool depth, alter substrate composition, reduce interstitial spaces, and cause channel braiding (McIntyre 1992). All of these changes have the potential to reduce stream ecosystem productivity for salmonids and other aquatic species. In the St. Regis River in Montana, the availability of pool habitats (pool/rifle ratio) was related to the degree of trout population recovery (Lund 1976, as cited in Niemi *et al.* 1990). Eventually, most of the flow's sediment and wood structure will be washed downstream, but this could take decades to accomplish. A landslide from a clearcut may not contain much wood. Therefore, the stream structure, pools, and riffles created by sediment and wood are not likely to form (Reeves 1992). Sediment will also not be trapped by the channel structure, but will move more rapidly down the system. (Everest *et al.* 1987). Little attention has been paid to these secondary effects of timber harvesting (Reeves 1992). In general, the quality of aquatic habitat in streams decreases with increased sediment and decreased woody debris (Edwards 1992).

Cederholm (1984) found that deepwater habitat, important to cutthroat trout (Reeves 1992), was lost when debris jams were removed from an Oregon stream. Some jams were removed in the 19th century to alleviate lowland flooding and aid navigation (Coulton *et al.* 1996). Wood debris was also removed from upland streams in the 1960s–1980s at the direction of fisheries management agencies, (*e.g.*, ODFW) believing that this would improve fish habitat.

Splash dams. Splash damming and log drives were both used in the Tillamook Basin around the turn of the century (Coulton *et al.* 1996). Most splash dams and associated log drives appear to have been along the Tillamook River and a tributary, Bewley Creek (**Figure 5-14**). Log drives without splash dams are documented along the Wilson, Trask, and lower Tillamook Rivers (**Figures 5-14 and 5-15**). Damage from log drives is not specifically described, but likely includes severe disruption of riparian vegetation, mechanical erosion of banks, and extensive changes to channel morphology. Splash dams would increase the extent of riparian, streambank, and streambed disruption beyond that of other log

Splash dam:
Commonly used during the late 19th and early 20th centuries, splash dams were wooden dams built in streams to create temporary log ponds. Dynamiting the dam when the pond was full released the water and logs down the stream corridor in a torrent.

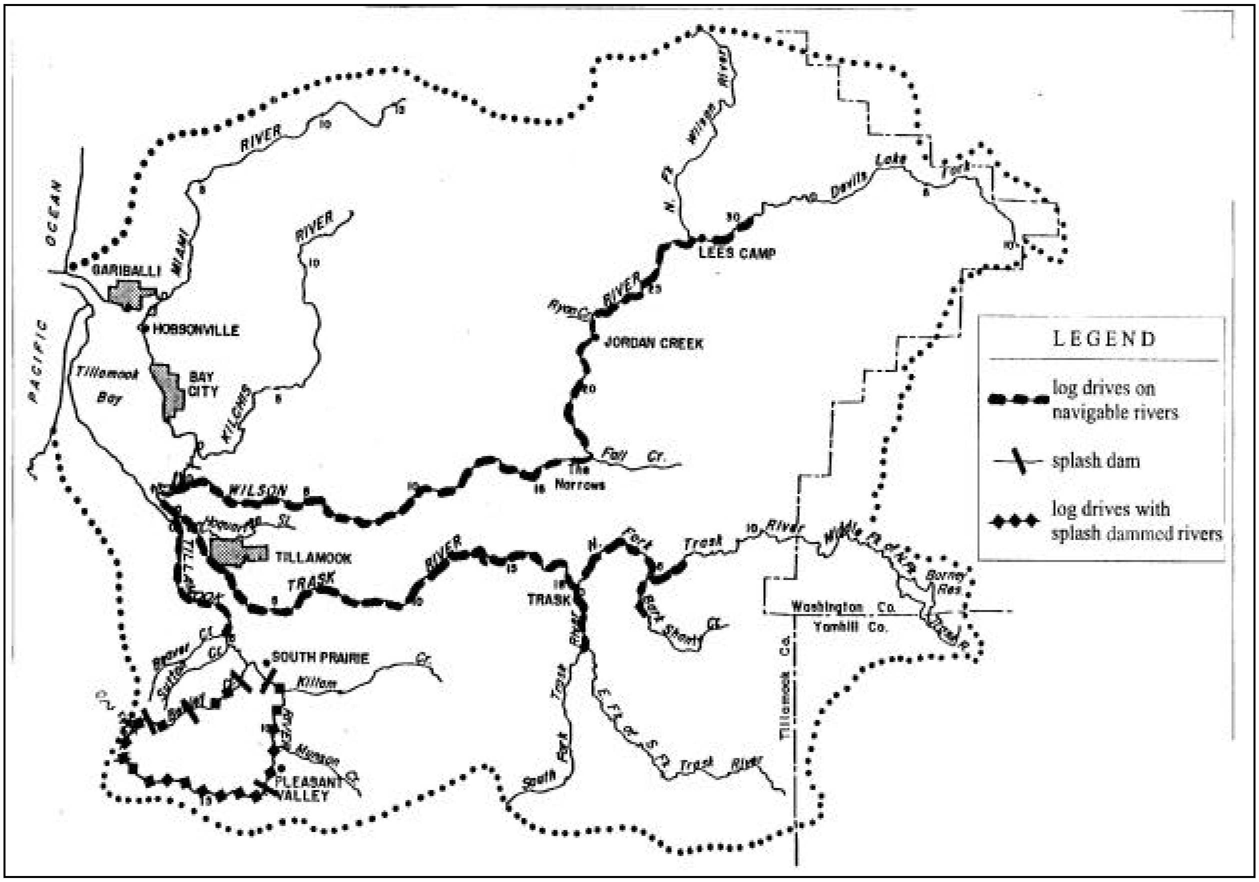


Figure 5-14. Splash dams and log drives on Tillamook Bay tributaries, circa 1880–1910.
Source: Oregon Historical Society.

drives. Log jams were constructed on the Wilson River as recently as 1964.

Increases in Sediment Production

Sediment production in the Watershed has been increased by the addition of roads and culverts. The recently completed survey of forest roads in the Kilchis River watershed documents this change. The forest fires known collectively as the Tillamook Burn are also suspected of contributing to an increased sediment load. Forest practices in general, both road building and harvesting, affect the rate and character of landslides, and therefor sediment production.

Figure 5-15. Historic photograph of a log drive on the Wilson River, circa 1990.
Source: Oregon Historical Society.

Roads and Culverts

Landslide frequency can be greatly accelerated by road building and management practices (Sidle *et al*. 1985). Roads are the primary source of increased sediment from forestry-related activities in the western United States (Mills 1997). According to Dave Michael, a Geotechnical Specialist with ODF, past road building and road maintenance failures, not timber harvest, make the most significant contribution to the mass wasting processes (*i.e.*, landslides) and sediment (especially gravel) production (LaFrance and McDonald 1995, as cited in Miller and Garono 1995). A storm damage inventory conducted after a major storm in 1990 in the Deschutes River area in Washington State found that roads constructed in the previous 15 years survived with minimal damage, while roads constructed earlier had high damage rates (Toth 1991). Much erosion from roads is due to major storms, and so is highly variable from year to year (Mills 1997). Beschta (1978) reported that most road failures in one watershed in Oregon did not occur until almost seven years after road construction. He noted three mechanisms which could explain this delayed response. Where side cast road fills had buried or incorporated organic material during

Much erosion from roads is due to major storms, and so is highly variable from year to year.

construction, decay of the organic material may have weakened the soil. Undercutting of the fill by concentrated flows from culverts could also cause road failures. Finally, a general lack of road maintenance after logging may have contributed to the failures. In one study in Idaho, researchers found average sediment production rates of 3.2–26.2 yd^3/ac/yr (6.0–49.5 m^3/ha/yr), and 1.0–79.5 yd3/ac/yr (1.9–149.9 m3/ha/yr) over the four years of the study (Mills 1997). Sediment delivery to streams depends on the percentage of the road drainage system which discharges directly to the channel; the proximity of non-stream discharges (*i.e.*, discharges across the hillside) to a channel; the volume of water involved and the potential for gully development (stream extension); and the volume of eroded material available (Mills 1997).

Landslides and washouts are clearly the dominant erosional process associated with roads in the Kilchis Basin.

Kilchis roads survey. Erosion and sediment delivery to streams in the Kilchis River Watershed has been examined by Mills (1997). The Kilchis Watershed contains 43,320 acres (17,545 ha) of forested lands (USDA 1978). Mills notes two principal concerns related to surface erosion from the road surface. First, Mills found that between 25% and 39% (by length) of roads in the Watershed deliver sediment directly to stream channels. This compares well with similar studies in comparable terrain elsewhere in the Northwest. The average distance from a stream crossing to the first cross-drainage structure was 436 feet (132.9 m). The average spacing between cross-drainage structures for the entire system was 381 feet (116.1m) (Mills 1997). The data suggest that forest roads built between 1920 and 1970, as most in the Kilchis basin were, were designed and maintained for efficient delivery of water (and sediment) to channels, as was the practice in previous decades. Current forest practice regulations require water to be quickly moved off road beds to facilitate infiltration of the water into the soil. A second concern is steep gradient roads which have cross-drainage structures spaced too far apart. Landslides and washouts are clearly the dominant erosional process associated with roads in the Kilchis Basin. This is particularly true in years with major storms (see **Table 5-4**). Overall, Mills inspected 106.7 miles (171.7 km) of active roads in the Kilchis basin. An estimated 100–200 miles (161–322 km) of abandoned roads were not surveyed.

The Tillamook Burn:
A series of forest fires which repeatedly burned much of the County's forest land. The greatest fire, in 1933, burned 239,695 acres, and killed nearly 12 billion board feet of timber.
Subsequent fires, in 1939, 1945 and 1951, brought the destruction to 354,936 acres burned and more than 13 billion board-feet of timber killed (Lucia 1984).
Repeated burns frustrated natural regeneration, and salvage logging and firebreak clearing caused tremendous sedimentation.
Although the area was replanted, poorly-built roads from that period continue to cause problems.

The Tillamook Burn

The Tillamook Burn fires of 1933, 1939, 1945, and 1951 (see side panel) affected sedimentation rates over a huge area for a few decades. Wood inputs and shading were drastically reduced and sedimentation increased by the fires and the damaging logging and fire control practices that ensued **(Figure 5-16).** However, this disturbance and its attendant increase in sediment production should not be perceived as out of the natural variations of sedimentation

Figure 5-16. Historic photograph of a destroyed riparian corridor on the Wilson River following the Tillamook Burn and related salvage operations.

Source: Oregon Historical Society.

rates through geologic time (LaFrance and McDonald 1995, as cited in Miller and Garono 1995). Active reforestation of the burned areas has reduced sediment production rates. There is reason to believe that reforestation has expedited the system's return to lower sediment production rates (LaFrance and McDonald 1995, as cited in Miller and Garono 1995).

Landslide Frequency and Size

Human activities on the land can increase the amount of sediment in water systems by up to a factor of 10 (Milliman and Syvitski 1992). Activities such as road building and timber harvesting increase the frequency of debris flows and hence sediment production (Chesney 1982). Swanson *et al*. (1976) found a 90% increase (factor of 1.9 increase) in landslide erosion rate for clearcuts in most land types, and a 300% increase (factor of 4 increase) in landslide erosion in landslide prone areas. Ketcheson and Froehlich (1978) found a 270% increase in erosion rate (factor of 3.7 increase) for areas with clearcuts but no roads, compared to areas with no management. Dent *et al*. (1998) studied landslides in areas impacted by a strong winter storm for stands of 0-9 years versus stands 100+ years old. They found increases up to 4.2 times in the landslide rate for the young stands, although one young stand experienced fewer landslides than the 100+ year old average, and two stands' increases were less than 2 times. Landslide frequency ranged from 11 to 37 slides per 1,000 acres for the heavily impacted sites.

Landslides were considered "human induced" if they occurred near roads, fire lines, or timber harvest or salvage activities.

Benoit (1978) used false color infrared photographs to identify human-induced and natural landslides in the Tillamook area. Of the 4,680 landslides identified, 4,440 (95%) were classified as human-induced. Landslides were considered "human induced" if they occurred near roads, fire lines, or timber harvest or salvage activities. The liberal criteria for human impacts may tend to overstate the anthropogenic role, however. Other studies which used only aerial photos have reported more landslides in managed areas than in unmanaged areas, but not on the scale of Benoit's (1978) findings. An increase of 580% (6.8 fold) is typical (Amaranthus *et al*. 1985). Aerial photo studies like Amaranthus *et al*.'s (1985) and Benoit's (1978) have been shown to be biased due to the inability to identify landslides under forest canopy (Pyles and Froehlich 1987, Mills 1997); aerial photo surveys under-estimate the number of landslides under forest canopy. The duration and magnitude of landslide increase due to forest practices is also not well researched. Further, studies conducted before current BMPs were introduced are of minimal value in representing the effects of current forest practices.

Studies conducted before current BMPs were introduced are of minimal value in representing the effects of current forest practices.

Timber Harvesting and Soil Stability

Vegetation, including trees, affects soil and slope stability mechanically and hydrologically. According to Dent *et al*. (1998), vegetation has two main hydrological effects:

- interception, storage of water on leaves and branches; and
- evapotranspiration, removal of water from the soil through plant growth and climate.

Vegetation has several mechanical effects on slope stability:

- roots reinforcement, roots which penetrate and cross potential slope failure planes, helping to bind the soils together, preventing landslides;
- buttressing and arching, trees acting as piles at the base of a landslide, containing the displaced soil and preventing the landslide from growing into a debris slide;
- surcharge loading, the weight contribution of the tree, logs, or other debris to the total load on the soil;
- root wedging, roots wedging apart and loosen soils, creating or weakening potential failure planes; and
- windthrow, trees knocked down by wind, dislodging the soil around their roots systems and creating impact loads on the soil.

Tree removal effects soil stability by:

- reducing interception and evapotranspiration;
- altering macropores;
- reducing soil infiltration rates;
- altering snowmelt patterns;
- reducing root reinforcement; and
- reducing buttressing and arching.

Timber Harvesting and Watershed Hydrology

Harris (1977) examined the hydrology in three small watersheds in Oregon's Coast Range over several years. Two watersheds were logged with differing clear-cut techniques, while the third was kept as a control. The sediment yield of the watershed which was entirely clearcut and burned, Needle Branch, increased an average of 181% over a 7-year period following logging. The Deer Creek watershed, which was clearcut only in patches, showed a statistically insignificant 25% increase in sediment yield in the seven years after logging.

Reporting on the same study as Harris (1977), Beschta (1978) notes that the patch-cut watershed (Deer Creek) showed increases in sediment production for three of eight years studied. The increases were due primarily to sedimentation from road failures. The discrete increases in sediment production highlight the importance of periodic influences like severe storms on sediment production. The analysis technique used by Harris (1977) tends to average out short-term increases. The clear-cut watershed also showed an increase in erosion, due primarily to surface erosion after a severe, intentional slash-burn. Roads in this watershed were built along ridges and on gentle slopes, so road-related mass failures did not occur. Sediment production from the clearcut Needle Branch returned to normal afte six years, suggesting that the maximum after-treatment erosion (where surface erosion is the dominant mechanism) occurs immediately after treatment. Maximum sediment production from other treatments, such as those used at Deer Creek, may not occur until several years after treatment.

USDA (1978) estimated that 60,613 tons of sediment enter Tillamook Bay annually. Of that total, 9,010 tons were determined to be derived from agricultural lands.

Lowlands

The Tillamook Bay Watershed is approximately 8% agricultural and urban lowlands (USDA 1978). USDA (1978) estimated that 60,613 tons (54,976 metric tons) of sediment enter Tillamook Bay annually. Of that total, 9,010 tons (8,172 metric), or 15%, were determined to be derived from agricultural lands. Sediment in lowland rivers and streams comes from fluvial transport from upland areas, and sheet and rill erosion and streambank erosion in the lowlands (USDA 1978). Upland sources and transport are discussed in a previous section of this chapter. Sediment moves through lowland streams and rivers continuously, though most transport takes place during high flow periods. As in upland streams, non-organic sediment plays an important role in stream channel morphology. Organic sediment, including wood, contributes to channel structure, and to the aquatic habitat and food resources of the fluvial ecosystem. Human uses of the lowlands have affected the rate and character of lowland sedimentation through changes in flooding frequency and size, and by the diking of floodplains and tidal wetlands. In addition, channel modification, removal of LWD, and streamside grazing have increased streambank erosion. These changes have in turn affected the quantity and quality of riparian and aquatic habitat in the lowlands.

Human uses of the lowlands have affected the rate and character of lowland sedimentation through changes in flooding frequency and size, and by the diking of floodplains and tidal wetlands.

Sources of Sediment

Erosion in agricultural lowlands typically takes two forms: streambank cutting, and sheet and rill erosion (Pedone 1995, as cited in Miller and Garono 1995). Streambank erosion is the more prevalent of the two types (USDA 1978). Significant streambank erosion typically takes place due to selective stratigraphic failure, soil saturation, and sloughing during high flow events (USDA 1978). Extreme streambank erosion tends to occur when fine textured soil has been deposited over gravel. The fines and sand are washed out of the gravel, causing sloughing and an overhanging streambank that drops into the river. This failure condition worsens with increased bank height, and decreased root depth (Reckendorf and Saele 1993). Serious erosion also occurs along steep, unvegetated banks and overhangs (**Figure 5-17**). Increased bank

Stratigraphic:
Vertical layers of sedimentary rock or earth of one kind formed by natural causes and usually made up of a series of layers lying between beds of other kinds.

Sediment delivery ratio

Sediment delivery ratio (SDR) is the sediment yield of the watershed at a point of interest divided by the gross erosion of the watershed above that point. Sediment delivery ratios can be defined collectively for all sediment, or for sediment of a particular type or from a particular source (Reckendorf 1991). SDR is a useful concept for quantifying the sediment transport characteristics of a channel at a point in time, and for how those characteristics change over time.

The SDR of a point depends on flow characteristics, and on the ability of a channel to store sediment upstream. Sediment storage can be divided into three categories, based on the length of time the sediment is held (reference). Sediment is stored temporarily in channel beds and in morphological forms like sand bars, accumulating during low flow depositional periods, and is moved on easily when flow increases. Sediment is often trapped for longer periods behind channel obstructions like boulders or logs. Once caught, this material might remain in the channel for years until an extreme flow can dislodge the obstruction or scour the deposit.

Very long term sediment storage occurs in channel floodplains. Depending on the recurrence interval of a flood of particular magnitude, sediment may lie in a floodplain for decades or centuries before it is moved again.

A channel’s SDR, like its flow regime, can change dramatically over time. Sediment produced at one time, say during a landslide, may take from months to years before it is finally delivered to a point or area of interest. Given this, a major storm, like the one which produced the floods of February, 1996 may wash years of accumulated sediment down into the low gradient stretches of river, or into the Bay itself, in the space of a few days.

Figure 5-17. Lack of riparian vegetation and trampling by livestock made this Trask River lowland site especially susceptible to erosion.
Source: Tillamook Bay National Estuary Project photo.

erosion is commonly associated with the removal of riparian vegetation. Cattle accessing streambanks can also increase erosion when their hooves break up the soil matrix and remove vegetation (USDA 1978). Streambank erosion is particularly problematic in the Tillamook area because the fine grained topsoil, originally deposited by lateral accretion in flood events, is easily transported directly to the Bay where some of the sediment can settle out of the water column. Stream bottom scour is also an occasional problem (USDA 1978). Sheet and rill erosion, which is most common along unvegetated road cuts and fills, but also occurs on construction sites and roadbeds, can contribute significant amounts of sediment in localized areas.

Sediment Movement and Deposition Patterns

Meandering:
To wind or turn in a course or passage.

Normally, as rivers reach lowlands, gradients decrease and sinuosity (*i.e.*, meandering) increases. The natural process operates in a dynamic equilibrium of slope and discharge versus sediment load (quantity) and size. Changes in channel slope, caused by straightening, diking, or removal of riparian vegetation, cause the stream to change channel load and size as the stream tries to establish a new dynamic equilibrium. The most visible changes in channel form typically involve displacement of sediment within the active channel, either through sediment deposition or erosion.

Streambank erosion and the associated stream bottom scouring cause shifting of the channel gravel deposits, resulting in changes in morphology (pools and riffles) and transport rates, depending on the volume and velocity of the stream flow. The constant shifting of sand bars in the lower reaches of rivers and in the Bay is related to this transport (USDA 1978).

The most visible changes in channel form typically involve displacement of sediment within the active channel, either through sediment deposition or erosion.

Rivers tend to form new channels during high flow periods, either by straightening meanders, abandoning loops which become oxbow lakes and wetlands, or forming new meanders. As part of this process, banks are eroded in some places and built up in others (Maser and Sedell 1994).

Because the upper (southern) Tillamook Bay is bordered by a wide floodplain and long, low gradient stretches along the major rivers, coarse sediment tends to form gravel bars in the low gradient portions of the rivers (Peterson *et al*. 1984). Sediment derived from upland sources and from the floodplain contributes to the progression of the river deltas (and hence the floodplain) into the upper Bay. As the deltas progress, subtidal lands become intertidal marsh and eventually high intertidal or supertidal meadow. The valley floodplain is built up over time from this process.

Organic matter from upland sources and the lowland riparian areas contributes to the allochthonous component of the base of the aquatic food web. Historically, woody debris from both sources created jams which contributed to the buildup and maintenance of the floodplain and provided cover and habitat for fish and other aquatic organisms (Coulton *et al.* 1996). The accumulation of sediment in river channels at key points like sharp meanders often signals, or contributes to, a river's channel structure changes during a subsequent high flow event.

Sediment discharge:

Sediment discharge is the amount of sediment moving past a point over a period of time, say during a storm event. In upper streams, peak sediment discharge precedes peak runoff. Further downstream, peak flow can precede peak sediment discharge as the lower reaches "wait" for sediment to arrive.

A high discharge of fine sediment occurs early in the event; this material is moved by the lower flows prior to the peak flows, which move the bed load. In general, sediment discharge depends on two factors: the amount of sediment transported to a channel from upland sources, and the ability of a channel to transport sediment. Therefore, a channel can be considered either capacity-limited (unable to move all the sediment available to it, and the SDR is low) or the channel is supply limited (the channel moves most of the sediment delivered to it and the SDR is high). The concept of "flow competence" is used to quantify a flow's sediment transport capability. It is defined as the largest-sized particle which can be carried, either as bed load or suspended load, by a flow regime. An increase in flow competence, by increasing discharge or velocity, would produce an increase in sediment discharge and SDR (Gordon *et al.* 1992).

Attempts to derive general equations for sediment transport have not succeeded (Gordon *et al.* 1992). The equations, whether based on physical principles or statistics, are all empirical to some degree, and hence not transferable between watersheds. To further complicate matters, bed load is often not included in the sediment load values reported in studies and in the literature (Milliman and Syvitski 1992).

Issues, Problems, and Human Impacts

Streambank erosion was identified as a critical issue in the lower reaches of Tillamook Bay's main tributary rivers twice in the 1970s (USDA 1978; SSWCC 1972, 1978). The conditions noted in both state reports, namely high bank erosion rates and resulting sediment deposition in the Bay, continue to the present day. Diking of the floodplain to support farming, principally the raising of dairy cattle, has reduced the connectivity between the floodplain and the rivers and eliminated important intertidal marsh and aquatic habitats. Gravel has been removed from low gradient portions of the rivers for many years. This practice is sustained in part by increased sediment production and transport from the uplands since European settlement.

Critical Streambank Erosion

A 1971–72 study conducted by the State Soil and Water Conservation Commission (SSWCC) identified six miles along the lower Trask, five miles along the lower Wilson, and three miles along the lower Kilchis Rivers as severe/moderate erosion areas (SSWCC 1972). The study was limited in time and funding, and therefore reflected only information readily available to Soil and Water Conservation District supervisors and local Soil Conservation Service staff. Severe erosion was noted in Tillamook County in the 1972 report (Figure 5-17). A later, more extensive study prepared for the Department of Environmental Quality (DEQ) by the SSWCC (1978) indicated severe bank erosion along the lowest portion of all five Tillamook Bay rivers (8 miles on the Miami, 7 miles on the Kilchis, 8 miles on the Wilson, 10 miles on the Trask, and 12 miles on the Tillamook). These two studies indicate that streambank erosion in the Tillamook Bay floodplain has been a problem for many years, and has probably contributed greatly to the accumulation of sediment.

Streambank erosion in the Tillamook Bay floodplain has been a problem for many years.

Widened Channels

Removal or destruction of riparian vegetation and large woody debris, channel straightening, diking, and debris flows from the upper Watershed (that move as sediment pulses through the fluvial system) have all contributed to increased streambank erosion. The end result is widening of rivers and the associated instream gravel bars. Over time, average width to depth ratios have gone from 15:1 (estimated from 1915 photos) to 30:1 at present (Reckendorf 1995, as cited in Miller and Garono 1995). Gravel bars which were buried by floodplain vertical accretion deposits are exposed when streambank erosion removes this overlay. Therefore, these gravel bars were not part of the active channel until recently, but were deposited long ago as river lateral accretion. These exposed gravels have commercial value, but are also of potential value to salmonids (primarily chum) which spawn in the lower rivers and Estuary area. The channel’s capacity to transport sediment is also reduced by the widening and shallowing, exacerbating the deposition and accumulation of sediment (Reckendorf 1995, as cited in Miller and Garono 1995).

Exposed gravels have commercial value, but are also of potential value to salmonids.

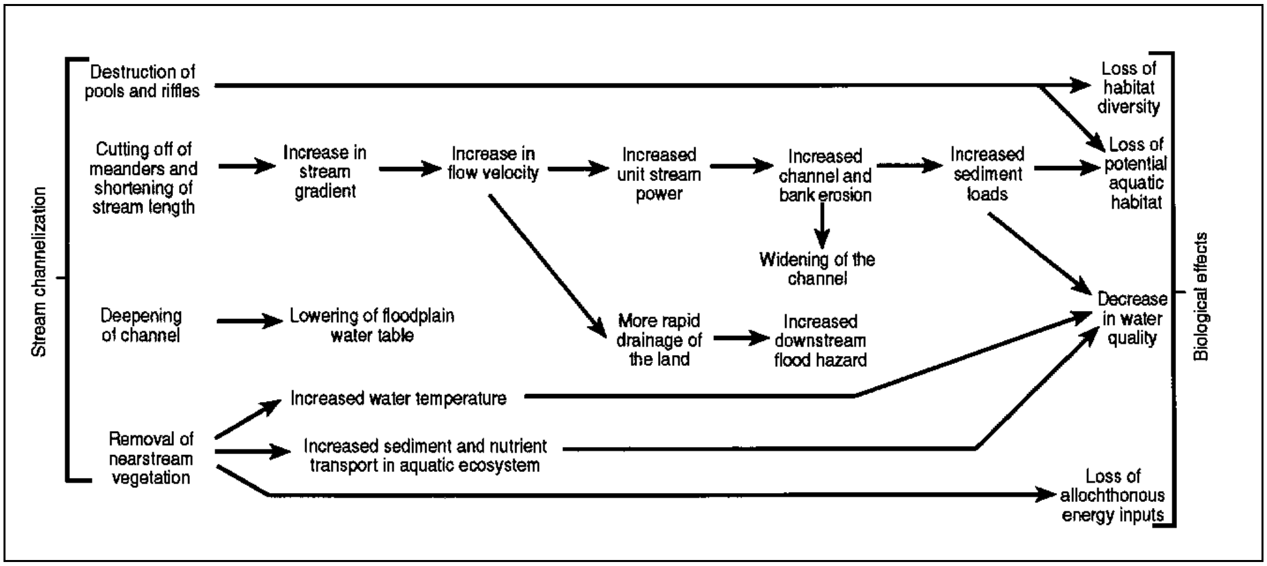


Figure 5-18. Stream channelization effects.
Source: Reiter, M. 1995. "Hydrology, sediment delivery, and stream channel morphology: The effects of gravel removal and channel modification on fluvial (river) system form and process." Impacts of Erosion and Sedimentation in Tillamook bay and Watershed. Summary of a TBNEP Scientific/Technical Advisory Committee forum. Tillamook Bay National Estuary Project, Garibaldi, OR.

Hydromodification

Hydromodification includes any work done to a natural system to modify the movement of water. Common forms include diking and draining wetlands or intertidal areas, tide gates, the straightening or channelization of rivers and streams, and the construction of flood impoundments (dams). Tide gates, a common element in hydromodification projects, are used in the Tillamook area (principally along the Tillamook River and the South Fork of the Trask) to prevent tidal waters from reaching former intertidal marsh or subtidal lands. Removal of log jams from Tillamook area rivers is another form of hydromodification. The effects of stream channelization are summarized in **Figure 5-18**.

Tide gate:
Tide gates, also called tide boxes or flap gates, are large valves installed on culverts through dikes or levees. The gates permit water to flow from the uplands to a main channel, but prevent water from flowing from the channel onto the land. Tide gates cut the connection between channels and intertidal and supertidal floodplains, both critical salmonid habitat. They also contribute to the accumulation of large amounts of sediment in their drainage ditches — sediment which is usually washed into the estuary instead of deposited on the floodplain.

Before hydromodification, Tillamook area lowlands (the areas around the Tillamook, Trask, Wilson, and Kilchis Rivers) were a floodplain crossed by unconstrained river channels. These meandering river channels deposited sediment on the inner banks of turns while eroding the outer banks. Under unmodified conditions, periods of high flow would have inundated the floodplain, causing the overall flow velocity to remain low and a portion of the suspended sediment to be deposited more or less evenly across the floodplain. Pockets and lowlands in the floodplain would retain a portion of the suspended sediment-laden waters after the floods subsided, contributing to the overall uniformity of elevation in the floodplain. Natural wood jams along the rivers probably increased the frequency and duration of these floods (Coulton *et al.* 1996, Maser and Sedell 1994). Coulton *et al.* (1996) summarized the hydromodification projects and activities, and their consequences, which have affected sediment production and transportation rates from agricultural lands. Clearing of floodplain forests and riparian thickets between the 1850s and 1920s made the banks more vulnerable to streambank erosion. Diking and draining wetlands between 1910 and 1930 and in the 1940s decreased flood and sediment storage capacity on the floodplain. Clearing logjams from the river mouths to improve navigation increased river flow and sediment transportation rates. Major floods in the 1960s and 1970s deposited sediment at the river mouths and in the Bay. Prior to hydromodification, rivers spread over the floodplain during periods of high runoff, depositing sediment evenly across the valley and slowing the flow, therefore reducing channel erosion. However, there has always been a natural background rate of streambank erosion.

An important landscape change which affects sediment transport to the Bay is the diking of floodplains and tidal wetlands, and the removal of woody debris from the channels.

An important landscape change which affects sediment transport to the Bay is the diking of floodplains and tidal wetlands, and the removal of woody debris from the channels. Until over-topped by floods, the dikes confine sediment to the channels, which carry it downstream. When high flows overtop the dikes, they trap sediment in irregular patterns on the floodplain. Property owners must then incorporate the sediment — which is low in organic matter — into the soil. Pastures take some time to recover their pre-flood production levels (USDA 1978). Under pre-settlement conditions, sediment would have been spread thinly over the floodplains and marshes with some deposited in the Bay. Since most sediment is now carried downstream, dikes and stream straightening have increased sediment transport through the system to the Bay.

Gravel Removal

Two types of gravel removal methods are used in the Tillamook Bay Watershed: dry pit mining, and bar skimming or scalping (Reiter 1995, as cited in Miller and Garono 1995). Dry pit mining extracts gravel from ephemeral stream beds. Bar skimming or scalping (the predominant method in Tillamook County) involves removal of the highest portions of gravel bars, those above the summer water level.

Ephemeral stream:
A stream that flows only briefly, and during a period of rainfall in the immediate locality.

The potential effects of in-stream gravel mining are summarized in **Figure 5-19.** Extraction of sediment from a stream channel can cause degradation in the channel both above and below the point of removal. Similarly, removal of a section of gravel may create a gap in the continuous transport of gravel down a channel, resulting in a mobile gap or shortfall in the bed gravel. However, cross sections taken over several years (1993–1997) at several stream locations in the Tillamook Basin generally show that sediment supply has been

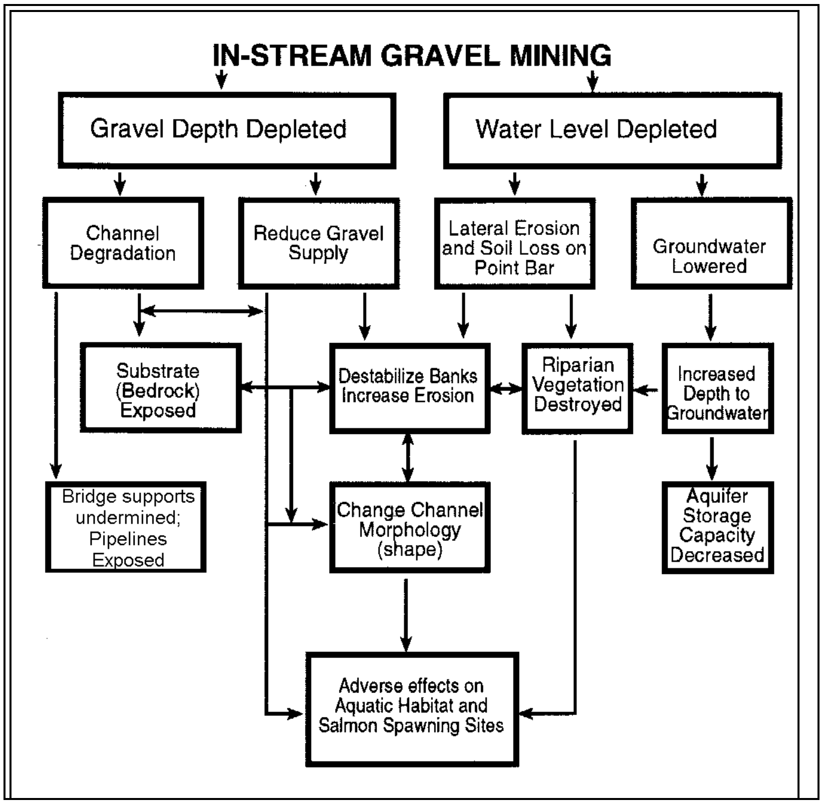


Figure 5-19. In-stream gravel mining.
Source: After Collins, B., and T. Dunne. 1989. "Gravel transport, gravel harvesting, and channel-bed degradation in rivers draining thesouthern Olympic Mountains, Washington." USA Environmental Geology Water Science. 13: 213-224.
As cited in: Reiter, M. 1995. "Hydrology, sediment delivery, and stream channel morphology: The effects of gravel removal and channel modification on fluvial (river) system form and process." Impacts of Erosion and Sedimentation in Tillamook bay and Watershed. Summary of a TBNEP Scientific/Technical Advisory Committee forum. Tillamook Bay National Estuary Project, Garibaldi, OR.

sufficient to replace scalped gravel. Preliminary analysis of the particle size distribution of the deposits in the surveyed years shows that coarser materials are deposited in high flood years such as 1996. Overview surveys in the Watershed show numerous debris flow source areas along upstream channels that will provide gravel to downstream areas for the near future.

Bar scalping may result in deeper, faster water, eroding adjacent streambanks more readily. On the other hand, the new deposition on the scalped areas may actually increase bar heights above pre-scalped elevations. Therefore, the increased bar elevation may decrease water depth, and therefore increase stabilization. In some locations, if gravel is removed, floodplain flood damage is temporarily reduced because of increased stream capacity. However, in the Tillamook Basin, the sediment load is sufficiently high that any gravel removed to increase flood capacity will likely be replaced the following runoff year. (Reckendorf, F. pers. com. 1997)

In general, the removal of gravel may impact salmon spawning areas (Reiter 1995, as cited in Miller and Garono 1995). Chum salmon fry entering shallow, scalped areas may also be stranded after water levels drop. A related issue is how large an area was available historically for chum spawning. Field examinations of the bars throughout the Kilchis River agricultural area show that a large portion of bar width is made up of gravel from the lateral accretion deposits that historically lay under the floodplain. As channel widening occurred in post European settlement time, as reconstructed from photographs, the finer textured vertical accretion deposits were eroded off through streambank erosion, and the underlying lateral accretion deposits became part of the modern gravel bars. In other words, a lot of the gravel bar scalping in the Kilchis Watershed is taking place on gravel bar areas that were not available for chum spawning in historic time. Detailed studies would be needed to show the extent of this situation throughout the Tillamook Basin.

Instream gravel mining in the Tillamook Bay Watershed stopped in October, 1997, because of concerns over salmonid habitat.

Instream gravel mining in the Tillamook Bay Watershed stopped in October, 1997, because of concerns over salmonid habitat. Still, forest practices which increase runoff and landslide intensity may cause these bars to grow larger or faster than normal. Adequate monitoring of salmon behavior around the bars during the next few years should reveal their value as spawning habitat.

Sediment and Aquatic Habitat

The discussion in the Upland section of Sediment and Aquatic Habitat applies equally well to the Lowlands. However, in the Lowlands, the portion of sand and fine sediment in the streambed increases, as does the turbidity of the water column. Both factors are detrimental to aquatic habitat (Castro and Reckendorf 1995).

Turbidity is measured by light attenuation and is directly related to the suspended sediment load in a water column. The reduced availability of light to primary producers in the ecosystem causes a general decrease in productivity along the food chain. Removal of riparian vegetation, increasing the total amount of light input to the stream, can reverse the shading effect, but the benefits will be counter-balanced by increased stream temperature and decreased inputs of wood and allochthonous organic material (Reeves 1992). Stream temperature can also increase due to sediment deposition.

Stream temperature can also increase due to sediment deposition.

Stream depth decreases with sediment accumulation, eliminating deep pools and moving water closer to the surface where it is warmed by the sun (Reeves 1992).

During the past decade, research into stream sediments' effects on aquatic habitat has focused almost entirely on the effects of fine sediment on salmonid habitat (Castro and Reckendorf 1995). However, some studies of macroinvertebrates have relevance to the effects of flow velocities and sediment. For example, Gore (1978) used macroinvertebrates as indicators of stream flow velocity ranges. Measurement of suspended sediment and of sediment intruded into spawning areas with the indicator macroinvertebrates, such as those used by Gore (1978), could better reflect sediment-deteriorated aquatic habitat than survival and emergence of salmonid embryos (Castro and Reckendorf 1995). Salmonids' survival is affected by many off-site environmental factors (blockages to fish passage, downstream pollution problems, and sport and commercial fishery) that do not affect local benthic macroinvertebrates. In addition, the local area benthic macroinvertebrates will reflect localized upstream pollution sources, as well as river gradient, stream geometry, and bed particle size (Castro and Reckendorf 1995). Invertebrate communities can be divided into guilds which are adapted to either depositional or erosional environments. However, either type can only deal with a limited rate of deposition or erosion, and both can become overwhelmed if conditions depart too far from normal. (Reeves 1992).

Summary

Sediment Sources

Sediment in Tillamook Bay is derived from two principal sources: the ocean, and the five rivers and numerous streams which flow into the Bay. Marine sediment — mostly sand — enters the Bay through the single inlet at its northwest corner. A large amount of marine sediment entered the Bay through a breach in Bayocean Spit between 1952 and 1956. Sediment from the rivers and streams consists of mineral and organic components of soil, rocks, and large organic debris, mainly wood. Most sediment is transported from the uplands during periods of high precipitation and flow.

The Estuary

The influx of sediment to estuaries is important to the estuarine ecosystem. Sediment contains organic material — leaves, herbaceous plants, and wood — which contributes to the base of the estuarine food web. Sediment also provides the raw materials for various substrate types. Estuarine species have adapted to survive, and in some cases rely upon, continuous sediment inputs and movement. Sediment can have negative impacts on estuaries. A rapid influx of non-organic sediment can cause radical changes in substrate type or depth, or increase turbidity to harmful levels. An overabundance of organic sediment or nutrients may lead to eutrophication and related problems. On the other hand, a deficit in key components of sediment, such as large wood, can result in a loss of both critical habitats and organic material important to the food chain.

Sediment movement within the Bay is dominated by tidal currents and freshwater flow. Large changes in channel and bar position occur during periods of high river flow. The main shipping channel between Garibaldi and the ocean, which was maintained by dredging prior to 1979, is now maintained in part by tidal scouring through the narrowed inlet.

Sediment influx reduced the volume of Tillamook Bay by 20% between 1867 and the 1950s, but Bay volume has been relatively stable since. The percentage of bay bottom between 3.3–6.6 ft (1–2 m) above MLLW rose sharply (from 1.1% to 16%). The increase came largely at the expense of lower intertidal areas (0–6.6 ft or 0–2 m below MLLW), which have fallen from 80% to 70% of total bay bottom, and lands 9.8–16.4 ft (3–5 m) below MLLW, which decreased from 16.1% to 10.1% of total bay bottom.

Tillamook Bay has seemed to fill rapidly with sediment during this century. The history of navigation on Tillamook Bay and the three bathymetric surveys provide direct and anecdotal evidence that the Bay is filling with sediment. The exact causes of the increase in sediment influx have not been determined. However, two events are believed to be important: the extensive forest fires of the Tillamook Burn, and the breaching of Bayocean Spit in 1952. The four-year breach of Bayocean Spit is estimated to have caused the addition of 1.96 million yd^3 (1.5 million m^3) of marine sediment, or 6.4% of the Bay's total volume. There is no reliable estimate of the excess sediment that may have entered the Bay as a result of the Tillamook Burn fires.

Research on deposition rates in Tillamook Bay reveals rapid deposition up to 6,000–7,000 years B.P. (when sea level rise slowed), followed by a slower rate after that time. The data shows an average sedimentation rate of 4–12 in.(10–30 cm) per 100 yrs.

Uplands

The Tillamook Bay Watershed is 89% forested upland, and forested areas contribute approximately 85% of the Watershed's sediment. The principal source of sediment from the forested uplands in the Tillamook Bay Watershed is mass wasting. Mass wasting is a general term for a variety of processes by which large masses of earth materials are moved by gravity, either slowly or quickly. Mass wasting events are episodic in nature and highly variable in size, making estimates of gross sediment yield for a particular area difficult.

There are few estimates of sediment yield from Tillamook area forest lands. A study of forest roads in the Kilchis River Watershed was conducted to determine sediment sources in that area. The study identified sediment production values due to roads and background landslides for three situations: a normal year, a year with a major storm, and a year with an extreme storm. A study by the U.S. Department of Agriculture, prepared for the Tillamook Bay Task Force, estimated sediment yield for the entire Watershed. However, this study used methods which are not applicable to the forest soils of the Pacific Northwest, so its conclusions are in doubt.

Woody debris and other organic material added to streams provide channel structure and allochthonous food sources, both of which benefit the aquatic ecosystem.

A great deal of sediment is transported in upland channels during debris torrents. More generally, channel morphology reflects both large-scale changes, like debris torrents, and less extreme high flow events. Channel structure at any one point in a stream is more a reflection of past high flows than of present conditions. Debris flows and debris torrents can positively and negatively affect fish in streams. Woody debris and other organic material added to streams provide channel structure and allochthonous food sources, both of which benefit the aquatic ecosystem. A large, scouring debris torrent may remove all stream structure down to bedrock, eliminating most of the former ecosystem. These events allow a stream reach to reset itself, and begin the evolution of a mature, complex stream system. Less dramatically, landslides which contain little wood or large rocks, or which contain a much fine sediment, can effectively reduce channel complexity, fill pools, or cut the interstitial flow of water in gravel beds.

Roads are clearly the principal cause of human-induced landslides in the forests. Landslide size and frequency in managed forests versus pristine forests is an important topic of ongoing research. Further, timber harvesting can alter the composition of landslides, debris flows, and debris torrents which provide sediment to stream systems. Timber harvesting and road building can also alter a watershed's hydrology, though the exact nature and importance of any of these potential impacts is still unclear.

Lowlands

The Tillamook Bay Watershed is approximately 8% agricultural and urban lowlands. An estimated 60,613 tons of sediment enter Tillamook Bay annually. Of that total, 9,010 tons, or 15%, derive from agricultural lands. Erosion in agricultural lowlands typically takes two forms: streambank cutting (the more prevalent), and sheet and rill erosion.

Streambank erosion was identified as a critical issue in the lower reaches of Tillamook Bay's main tributary rivers twice in the 1970s. The conditions noted in both state reports — namely high bank erosion rates and resulting sediment deposition in the Bay — continue to the present day.

The lowland channels around Tillamook Bay have been extensively altered through hydromodification: straightening streams; diking channels, wetlands, and floodplains; and armoring banks. Straightening increases a channel's ability to transport sediment, resulting in a greater rate of sediment delivery to the Bay. Cutting off wetlands and floodplains can exacerbate flooding in some areas, and result in less sediment deposition across the entire floodplain, and more in the Bay. Streambank armoring controls sediment in a localized area, but often results in increased erosion at some other point along the channel.

Conclusions and Recommendations

Most terrestrial sediment in the Tillamook Bay Watershed comes from steep, upland slopes, largely from mass-wasting events. Most human-induced sediment production is from landslides and washouts related to roads. Road improvement and decommissioning are the most effective measures to limit excess sediment production in the uplands.

Sediment transport through the fluvial network is not well quantified in the Tillamook Bay Watershed. The time required to move a quantity of sediment from the upper reaches of a stream to the rivers and the Bay is not known, nor is the exact effect on sediment transport of having more or less structure in the channels. The amount of sediment produced in any given year, or in an average year, is known only within a very broad range. The amount of time and effort required to measure sediment movement through a complex system is prohibitive, and the information would be of limited value to the long-term management of the Watershed. Projects which limit the excess production of sediment, for instance from roads, and which restore the sediment trapping ability of streams, for example through the replacement of large woody debris, would be more valuable to the Watershed than continued studies.

Alterations to the channels which cross the floodplains around Tillamook Bay have changed the hydrology and sediment transport patterns of the lower rivers and streams. Rivers and streams once meandered across floodplains in numerous, interconnecting channels. Agricultural development and flood control have resulted in the straightening and channelization of most of the waterways, and dikes have disconnected the channels from the floodplain. Straightened channels without active floodplains rapidly transport water and sediment to the Bay. The result is a more rapid accumulation of sediment in the channels and in the upper Bay near the river mouths. If left alone, the channels will create a new delta and floodplain system in what is now the Bay. The only options for correcting the unnatural sediment accumulation are to restore floodplain connectivity, or remove the sediment. Reconnecting the floodplains will result in more frequent flooding of those areas. Removal of the sediment entails dredging and disposal of the spoils. One option for dredge spoil disposal is to spread the material in a uniform layer across the former floodplain. This technique is an imitation of the natural function of floodplains, when sediment carried by a high flow is deposited on the flooded area.

The best option for restoring the Bay to its natural function is to slow the influx of sediment from the uplands.

Tillamook Bay is the final destination for most of the sediment produced in the Watershed. Reduced upland storage capacity and increased sediment transport through the lowlands have resulted in accelerated deposition in the Bay. Other factors, such as the breach of Bayocean Spit between 1952 and 1956, also caused the deposition of large amounts of sediment in the Bay. Sediment input to the Bay is natural, and the organisms which are native to the Bay are adapted to, and in some cases rely upon, an influx of sediment. Certain economic uses of the Bay, for instance navigation and oyster growing, are less compatible with constant sediment inputs, and the recent increase in sediment input has negatively affected them. The best option for restoring the Bay to its natural function is to slow the influx of sediment from the uplands. The other option is to dredge the Bay to remove excess sediment. Dredging is expensive and can significantly disrupt the estuarine environment. Any proposal to correct past environmental problems through dredging should be carefully considered.

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CHAPTER 6

FLOODING:
CAUSES, IMPACTS,
AND CHOICES

An anecdotal account of flooding in Tillamook County prior to settlement in the 1850s:

"Freshets of innumerable spring seasons had shoved and tumbled the fallen trunks [in the Wilson River valley]. Swirling red flood water had shouted and tugged at them and flung them into every elbow of the river channel; had piled new trunks upon them with each succeeding year and had plastered the whole conglomeration with red clay and dark loam torn from the higher levels of the hills.

Finally — and long before the first white settlers came — Nature had completed a series of formidable dams all along the stream. Under and around these obstacles the Wilson River found its way in the slack months of summer. Against them it raged and bunted in the high tide of winter. When the melting snows of the Coast Range poured down into the already swollen stream, the waters backed up into flood lakes that went eddying and swirling farther and farther across the level floor of the valley until they lapped the lower edges of the hills.

And each of these flood lakes, as they drained away, when the freshets ceased and the Wilson River returned to its channel, left toll of black loam upon the valley floor, deeper and richer each year until one can hardly compute their depth and the richness of the black fertility that had been storing up for ages before the settlers came.

I could see the irony of the river, which forbade the settlers the use of all this wealth that it had been hoarding up. It resisted savagely, drowning the cattle of those who made bold to try to take hold there and driving them back to hack out homesteads on the red shoulders of the hills about. So we settled up on the hills and there's where most of the folks stayed until this fellow came into the Wilson River and began tackling the driftwood dams with dynamite. I began imagining this public-spirited chap buying dynamite and devoting himself to the unselfish task of taming the river to its proper channel and releasing the black soil of the valley to the full use of man.

When the channel was cleared the Wilson River quit backing up over the level ground here each spring. So it was safe for the settlers to come down from the hills and take up homesteads on the bottom lands. As it was in the Wilson River valley, so it has been in similar forms in various other valleys of the many-rivered Tillamook."

—from D. Collins' 1933 book "The Cheddar Box"

Flooding today in Tillamook County:

"The February 1996 flood devastated Tillamook County, Oregon. With damages exceeding $50 million dollars, the County's 23,300 residents will be recovering from this disaster for the next several years."

—from the 1996 Flood Damage Assessment & Recovery Plan for Tillamook County, Oregon.

CHAPTER 6

FLOODING:

CAUSES, IMPACTS, AND CHOICES

Introduction

The February 1996 flood in Tillamook County rekindled public interest in the causes and solutions to flood problems in the region. The timing of the flood was opportune in that it occurred during the characterization phase of the Tillamook Bay National Estuary Project (TBNEP), a process that is identifying resource management issues and problems.

Management efforts will need to satisfy multiple objectives: to reduce flood-related hazards and damages, while minimizing the potential long-term environmental impacts and economic costs of flood control and floodplain management practices.

For all three of the original TBNEP resource management priority problems — water quality degradation, erosion and sedimentation, and fish and wildlife habitat loss — flooding is a unifying natural process, contributing to both the quality and impairment of these ecosystem issues. The Flood of 1996 focused attention on flooding. To resolve the flood problems in the Tillamook Bay area, and also solve the TBNEP original priority problems, management efforts will need to satisfy multiple objectives: to reduce flood-related hazards and damages, while minimizing the potential long-term environmental impacts and economic costs of flood control and floodplain management practices.

For purposes of this discussion, flood control is defined as the use of structural measures — dikes, levees, and dredging — intended to eliminate flooding, with maintenance and monitoring often assigned as lower priority concerns. Floodplain management includes more non-structural measures to reduce flood hazards — land use planning, restoration, and public education — with the understanding that not all flooding can be eliminated and that long-term management and monitoring is necessary and will result in the evolution of effective flood hazard reduction (Williams 1994).

Dikes:
Walls or mounds built around a low-lying area to prevent flooding.

Levees:
Artificial or a natural banks confining a stream to its channel or, if artificial, limiting the area of flooding (American Geological Institute 1976).

These primary management techniques, together with flood warning and flood fighting plans, constitute a comprehensive flood management program. Flood control is not a substitute for floodplain management. This is especially true in the Tillamook Bay area where many levees and dikes serve as flood control facilities while keeping high tides and salt water from inundating farmland. The objective of new flood management efforts in the Tillamook Bay area will therefore be to build upon the existing flood control practices by identifying present and pending flood problems and tailoring solutions that work within and add to an overall flood management framework.

Sediment from the flood of 1996 decreased the capacity of the rivers to convey flood flows, which may now cause flooding from less severe storm events.

Notable changes to the beds and banks of the valley rivers are a lingering reminder of the severe flooding. The flood of 1996 moved large quantities of sediment from upstream in the Watershed and rivers down into the tidally-influenced portions of the Bay's rivers. There is a general concern that the resulting decrease in the capacity of the rivers to convey flood flows may now cause flooding from less severe storm events (Cleary 1996b).

One consideration for reducing the potential flood hazard from the valley river reaches that have apparently "filled in" is to dredge, or excavate, the gravels and sands which the last flood deposited in these reaches. The term waterway modification encompasses management actions involving dredging for: navigation purposes; flood control and bank protection projects; and sea level rise considerations (ABAG 1992). Waterway modifications represent a possible partial solution to flood problems in the region, but may come with significant costs as well as economic benefits. Gravel harvesting can have a positive economic impact and proper management can minimize its environmental impacts. However, the economic costs of enough of this type of flood control work to actually reduce the next flood, and subsequent floods, may be extremely high. The environmental costs would also be high, as extensive and perhaps repeated interventions into the active river channels may lead to the unraveling of upstream and downstream ecologic functions and further impair water quality.

This chapter also characterizes the trends and status of the natural processes and human interventions that influence flooding in the Tillamook Bay area and explores flood-related issues associated with waterway modification. The resource management issues and actions necessary to effectively and appropriately address flood control and floodplain management, to protect and allow the communities in the Tillamook Bay region to continue to prosper, are also discussed.

Waterway modifications represent a possible partial solution to flood problems in the region, but may come with significant costs as well as economic benefits.

Flooding in the Tillamook Bay Area

Geomorphology:
The study of the forms, characteristics, and processes related to the landforms on earth.

Management of river systems should always be based on an understanding of the geomorphic evolution of the ecosystem (Kondolf and Sale 1985). The Tillamook Bay river systems have had, and continue to have, a rich history of natural geomorphic evolution and increasing human interventions. Historic summaries of past and recent flooding in this region are provided in Levesque (1980), Tillamook County (1996) and Coulton *et al.* (1996). Flood management strategies to resolve flood problems will need to be based on an understanding of the geomorphic evolution of the floodplains, human influences on flooding, and the present and future physical factors influencing flooding.

Geomorphic Evolution of the Floodplains

Flood management strategies to resolve flood problems will need to be based on an understanding of the geomorphic evolution of the floodplains, human influences on flooding, and the present and future physical factors influencing flooding.

Climate and weathering have long shaped the landscape and cause continual changes to the Bay ecosystem. An estuary is a dynamic landform. It evolves slowly through periods of aggradation, filling with sediments eroded from the landscape or transported along the coastline, while interrupted with periods of equilibrium, where a balance between the physical forces at work on the shoreline predominate **(Figure 6-1)**. The upland erosion of soil from rainfall, and transport of sediment and woody debris from runoff contributed to the evolution of valley floodplains and complex river patterns. The interaction of seasonal river flood and low flows with the tidal cycles, sea-level changes, and episodic seismic events added complexity and historic change to the river floodplain and Estuary margin, with the formation of freshwater and saltmarsh wetlands, distributary river channels, sloughs, and tidal channels (Coulton *et al*. 1996).

The hydraulic connection of the rivers to the floodplains sustained each of these parts of the valley landscape separately and together. Overbank flood flows and rainfall replenished floodplain soils and recharged alluvial aquifers. Seepage from riverbanks supplemented summer low flows and seasonally high water tables sustained floodplain wetlands (Coulton *et al*. 1996).

An estuary is a dynamic landform.

The Tillamook basin’s four distinct types of flood situations (Reckendorf 1997a) include: (1) estuarine tidal flooding of low-lying areas that flood throughout the year; (2) riverine bankfull floods (flooding to the tops of the natural streambanks) that have a chance of occurring about once a year; (3) first bottom floodplains floods that have a chance of occurring every 2–50 years; and (4) second bottom floodplain floods that occur less frequently with a 50 to 5,000-year return period. Most urban development is on the second bottom floodplains that have the least risk of flooding.

Human Influences on Flooding

The management of flooding, and of the sediment being transported to the Estuary, need to be considered in both a short- and long-term perspective.

The duration of significant human interventions into the Tillamook river valley floodplains and the watersheds, since the 1800s, has been brief in the context of the geomorphic evolution of the landscape. With this understanding, the management of flooding, and of the sediment being transported to the Estuary, need to be considered in both a short- and long-term perspective (Coulton *et al.* 1996).

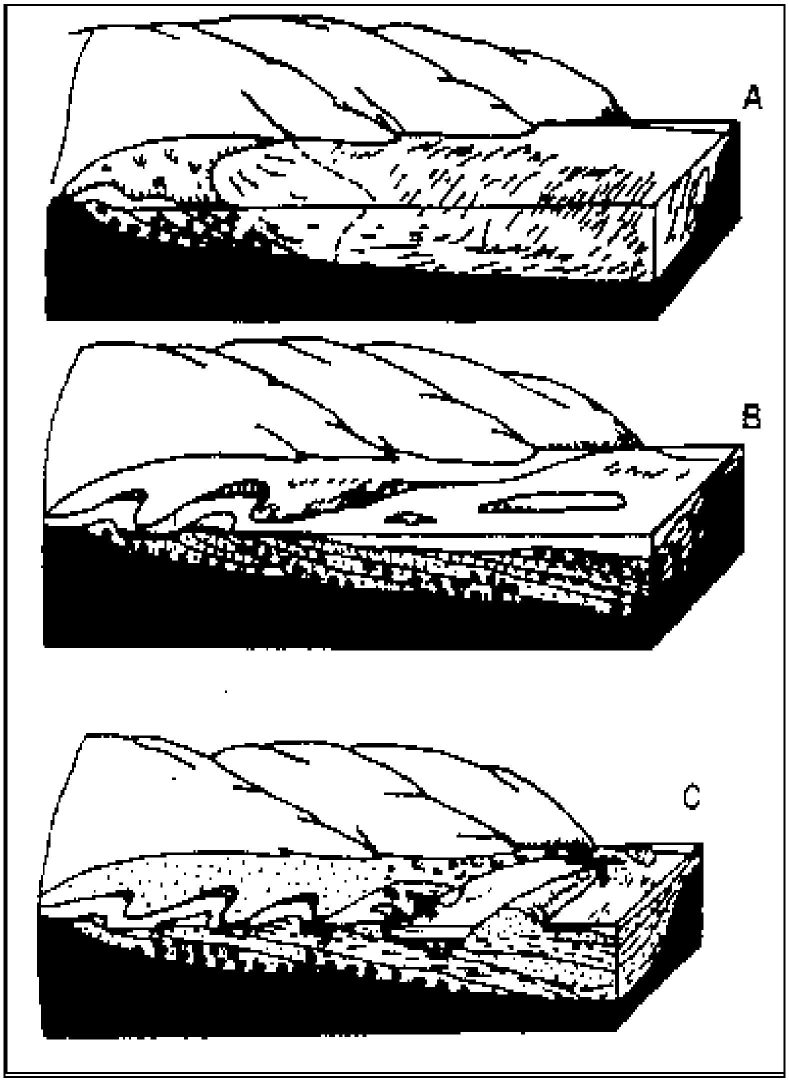


Figure 6-1. Schematic evolutionary sequence of an estuary associated with a large ratio of river load to sea level rise: (A) Flooding by the sea of the fluvial valley; (B) Progradation of the coastal plain; and (C) Developing of barriers by littoral transport.
Source: Perillo, G. 1995. Ed., Geomorphology and sedimentology of estuaries, Elsevier developments in sedimentology 53, New York.

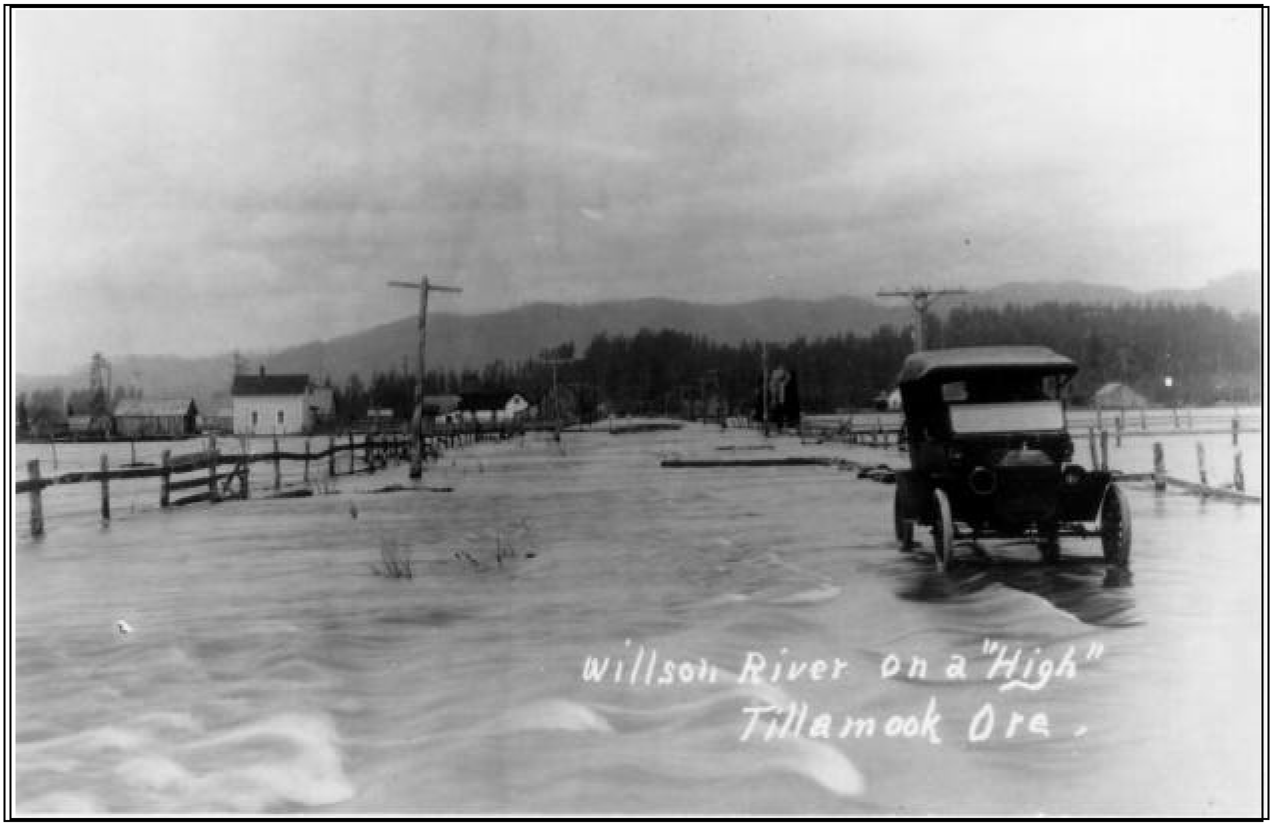


Figure 6-2. Historic photograph of flooding of the Wilson River.
Source: Oregon Historical Society.

As human populations increased in the Tillamook river valleys, the influence of man on the natural evolution of the floodplains increased. An early recognition of natural flood processes guided the early human settlers and generally kept people out of harm's way or at least minimized encroachment into floodplain areas. The valley landscape rapidly changed to accommodate more farm area, buildings and roads (**Figure 6-2**), as the population grew dramatically after the turn of the century, and marked the beginning of significant encroachments into these sensitive areas of the ecosystem (Coulton *et al*. 1996).

The Tillamook Burns of 1933, 1939, 1945, and 1951 — and especially the repeated and construction of salvage logging roads — disrupted the infiltration and water storage capacity of the upland areas.

As the human population encroached into floodplain areas, natural and human-induced catastrophic events continued to occur upstream in the river watersheds. The Tillamook Burns of 1933, 1939, 1945, and 1951 — and especially the repeated burns and construction of salvage logging roads **(Figure 6-3)** — disrupted the infiltration and water storage capacity of the upland areas. The loss of this natural flood attenuation mechanism, combined with the steep slopes and impermeable ground, increased the frequency and quantity of runoff and sediment delivery from heavy rainfall events. Landslides from natural slope failures or induced by road and culvert construction added pulses of sediment to the riverine systems and changed the

Figure 6-3. Historic photograph of the Wilson River riparian corridor, devastated by The Tillamook Burn and the salvage logging and firebreak cutting that followed.
Source: Oregon Historical Society.

valley river reaches' ability to convey flood water (Coulton *et al*. 1996).

Physical Factors that Influence Flooding

Many of the flood problems in the Tillamook Bay region result from human settlements developing on or near the low-lying river deltas and valleys along the margins of the Bay. River deltas reflect the balance between river system, climatic, tectonic, and shoreline dynamic forces (Ritter 1978). Flood elevations in these areas depend heavily on the changing relationships between these factors.

Tidal Effects

The most significant flooding in Tillamook Bay and the river valleys occurs when river flooding combines with tidal flooding.

The most significant flooding in Tillamook Bay and the river valleys occurs when river flooding combines with tidal flooding (Levesque 1980). The normal tidal range within the approximately 9,000-acre Bay is about a 7.5 foot elevation difference, reduced to about 5.2 feet at the southern end of the Bay, the farthest location from the channel entrance to the ocean. Extreme diurnal (twice a day) tide elevations have been recorded as high as 13.5 feet MLLW (mean lower low water) with the highest observed mean tidal elevation at the Garibaldi gauge of 14 feet MLLW (Levesque 1980).

Astronomical tides, or the predicted tides published in tide tables or charts, are exceeded during tidal flooding events due to storm surges. A storm surge is a rise in the local ocean water level caused by: (1) the landward progression of a low barometric pressure condition, which literally “lifts” the water surface above normal levels; (2) the effect of strong winds “piling up” water in shallow coastal estuaries, such as Tillamook Bay; or (3) a combination of the two effects. In the FEMA flood insurance study for Tillamook County, storm surges were evaluated for the time period October 15 to March 15, when extreme ocean conditions are typically more pronounced (FEMA 1978). During the February 1996 flooding, a high tide of 7.5 feet MLLW, approximately 2.0 feet above the predicted tide, contributed to the flood problems in Tillamook. In Tillamook Bay, navigation improvements at the Bay entrance and channel may affect the Bay’s tidal response (Levesque 1980), causing discrepancies between predicted and recorded tides at Garibaldi.

For estuarine and river reaches directly influenced by tidal flooding, waterway modifications will not effectively reduce flood hazards because the high tidal flood elevation ultimately controls these flood elevations.

For the low-lying areas along the edge of the Tillamook Bay, tidal flood elevations affect adjacent upstream flood elevations in the valley river reaches. **Figure 6-4** shows estimated tidal flood elevations for a range of return periods, including the 100-year return period, where Reach 2 corresponds to tidal flood conditions for the Miami River and Reach 1 involves the four other main Tillamook Bay rivers. These tidal flood elevations represent a combination of tidal flooding effects, derived by adding wave setup and runup heights to tidal stillwater elevations (FEMA 1978). The significance of tidal flooding is an extremely important concept to investigate and understand in the development of flood management strategies for the Tillamook Bay area. For estuarine and river reaches directly influenced by tidal flooding, waterway modifications will not effectively reduce flood hazards because the high tidal flood elevation ultimately controls these flood elevations.

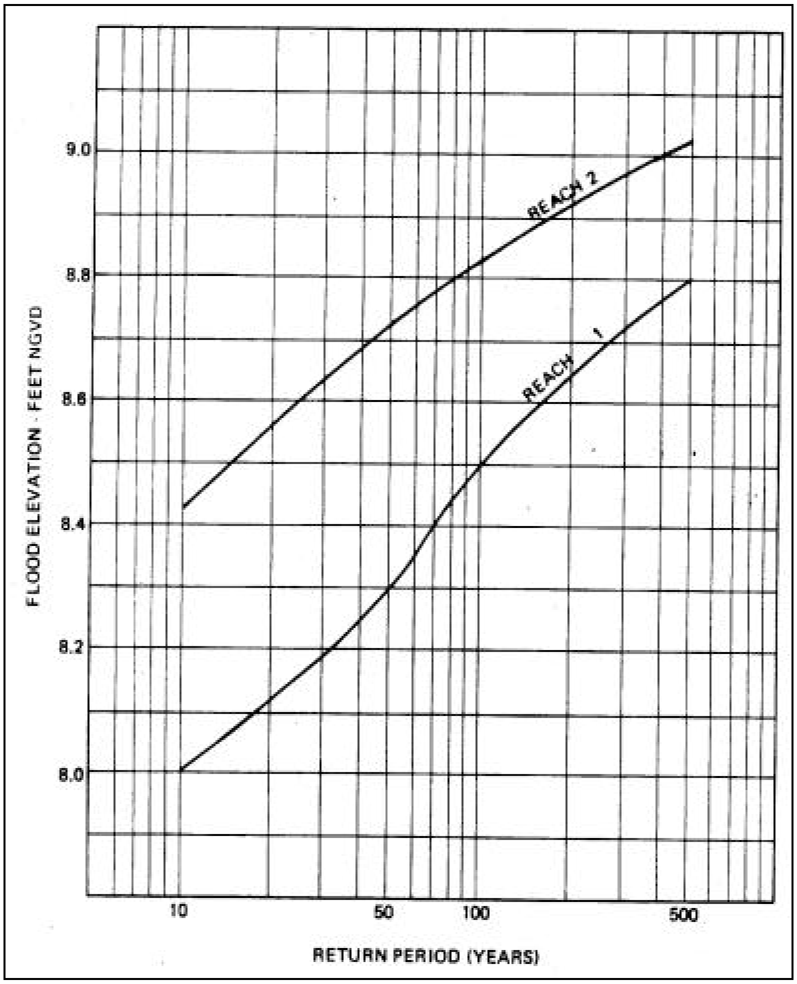


Figure 6-4. Tillamook Bay return period tidal flood elevations. Estimated tidal flood elevations — most extreme combination of astronomical tide, wave setup and wave runup — for Tillamook Bay. Reach 2 corresponds to the Miami River mouth and Reach 1 to the Trask, Tillamook, Kilchis, and Wilson River mouths.
Source: Federal Emergency Management Agency. 1978. Flood insurance study, Tillamook County, OR., prepared by CH2M-Hill.

Riverine Flooding and Floodplains

The TBNEP has been working to characterize the historic floodplain landscape in the Tillamook Bay area and the role of coarse woody debris in the ecological functions of the floodplain. Original field notes from the 1856–57 General Land Office (GLO) survey were used to reconstruct valley floodplain features (Patricia Benner in: Coulton *et al.* 1996). These forested wetlands were generally described in the survey notes as “river bottom lands” and further divided into lands within the upper reaches of the tidal rivers and lands beyond tidal influences **(Figure 6-5)**.

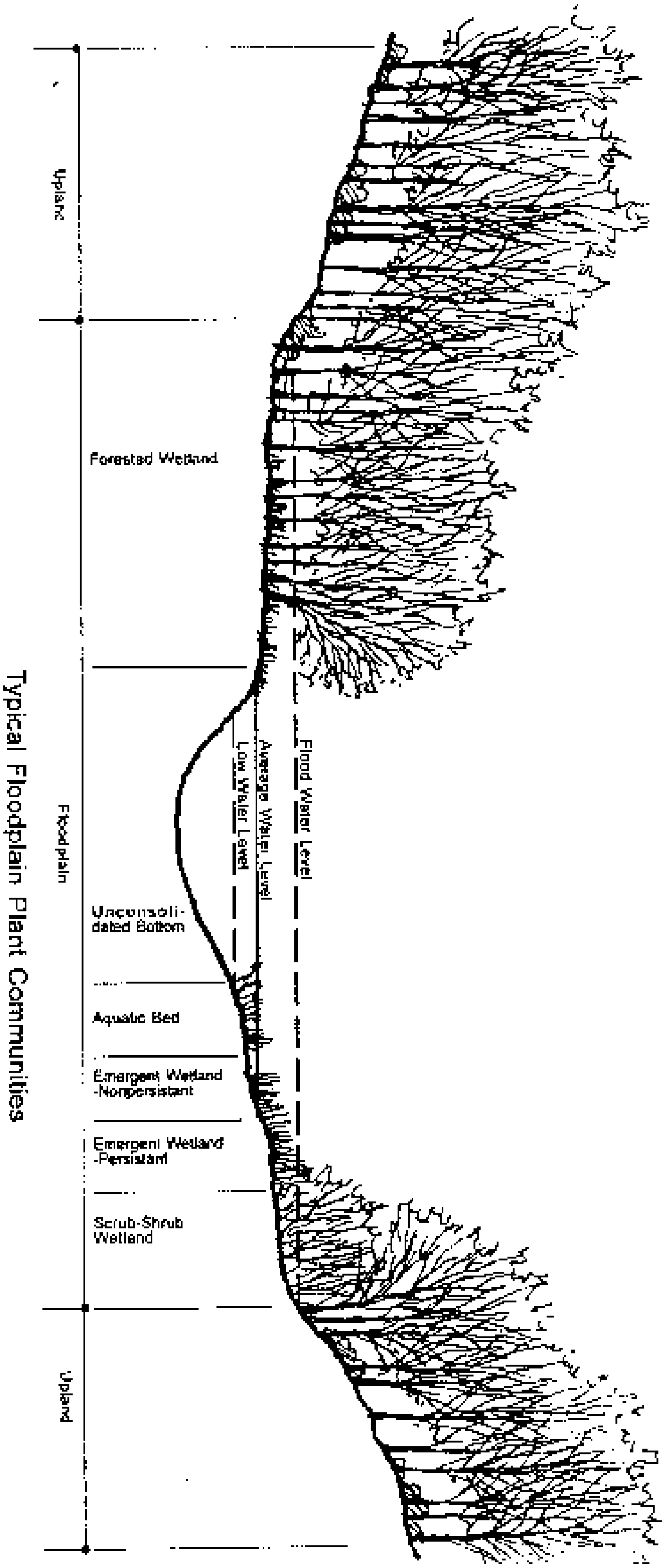


Figure 6-5. Typical floodplain plant communities.
Source: Federal Interagency Floodplain Management Task Force. 1995

The historic Tillamook Valley floodplains looked much different than those seen today (see the preface to this chapter). The river bottom forests, described in **Figure 6-6**, from the TBNEP Environmental History, consisted of a variety of trees, including black cottonwood, Sitka spruce, red alder, western hemlock, grand fir, big-leaf maple, and western red cedar. Spruce trees up to 80 inches in diameter and hemlock 60 inches in diameter were used as bearing trees by the early surveyors. Historically, forested floodplains provided woody debris to the lower river and Bay ecosystems, which added complexity to river patterns and nutrients to the rivers and helped to nurture and sustain fish populations. The forests slowed and regulated flooding across the valley floodplains, reduced erosion, and encouraged soil deposition (Patricia Benner in: Coulton *et al.* 1996).

Tillamook Bay communities and agricultural interests have developed and prospered to a large extent because of the natural evolution of river floodplains, which now sustain human activities.

Tillamook Bay communities and agricultural interests have developed and prospered to a large extent because of the natural evolution of river floodplains, which now sustain human activities. The natural process of flooding laid down wide expanses of fertile soils over time. An early account of the landscape summarizes this thought: “Dairying was a natural for Tillamook. The lush green pasture lands that the first settlers found seemed to be asking for cows to complete the pastoral picture.”

In order to protect the increasing value of farm property and structures, developing in floodplain areas, floodplain interventions increased and, by default, these interventions influenced sediment deposition. Dredging, woody debris removal, and levee and dike construction aimed to protect economic assets now located in floodplains from salt water intrusion and debris accumulation, as well as flooding. These attempts to control flooding have reduced the natural complexity of river channels and have separated the rivers from their floodplains. Ironically, the loss of natural floodplain functions due to diking has, in turn, impacted other resources with economic value, such as the fish and shellfish industries, which attracted commercial and residential development to the floodplain (Coulton *et al.* 1996). To some degree the diking has increased streambank erosion by increasing water depth and flow velocity between the dikes. In addition, the removal of large woody debris has made streambanks more vulnerable to this type of erosion process.

Attempts to control flooding have reduced the natural complexity of river channels and have separated the rivers from their floodplains.

River flooding tends to occur in December and January during periods of heavy rainfall or snowmelt, or a combination of both. River flooding combined with tidal flooding can extend the flood season from November to February. The lowland valleys are the most prone to flooding during these periods. Estimates of the floodplain acreage inundated during major floods and corresponding river watershed areas are provided in **Table 6-1**.

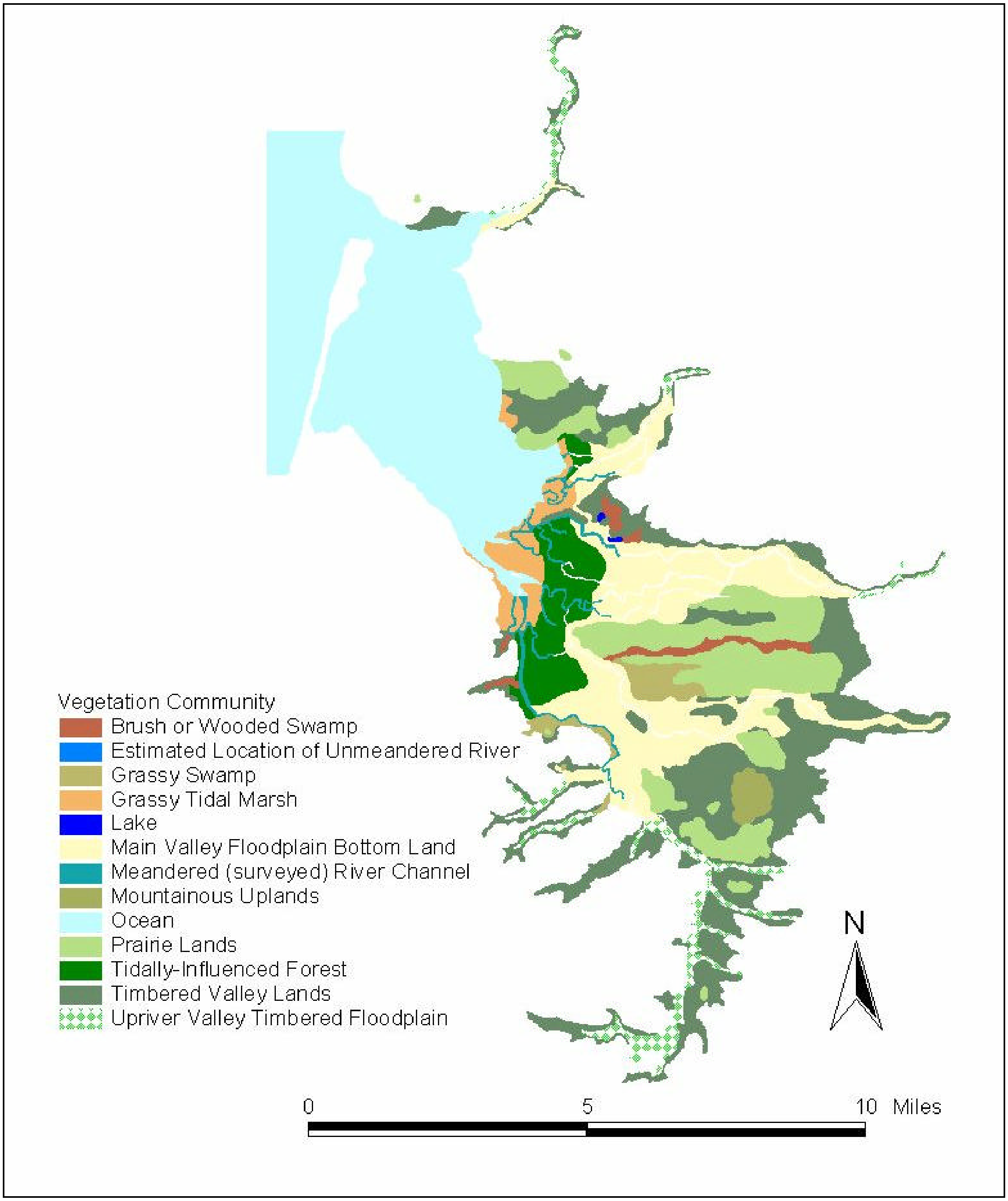


Figure 6-6. Characterization of the Tillamook Bay valley historic landscape, circa 1857.
Source: P. Benner in Coulton, K., P. Williams, P. Benner and M. Scott. 1996. Environmental history of the Tillamook Bay Estuary and Watershed, prepared for the Tillamook Bay National Estuary Project by Philip Willams and Associates, Portland, OR.

Table 6-1. Tillamook Bay river watershed and lowland floodplain areas

River	Watershed area (1)	Floodplain area (2)
Kilchis River	41,620 acres	660 acres
Miami River	23,390 acres	125 acres
Wilson River	123,557 acres	4,900 acres
Trask River	113,864 acres	3,600 acres
Tillamook River	36,395 acres	1,720 acres

Source: Tillamook Bay National Estuary Project Geographic Information System database. Garibaldi, OR.

The five Tillamook Bay river watersheds and mean annual runoff are shown in **Figure 6-7.** Return period peak flood flow estimates for the mouths of the five rivers are summarized in **Figure 6-8**. A comparison of unit discharges (flow per unit area) for recurrence interval flood discharges indicates the Tillamook Bay rivers have higher peak flood flows relative to watershed area than other coastal rivers **(Figure 6-9)**.

One primary natural function of a floodplain is to store and "slow down" flood waters during floods. By impeding peak flood flows, natural floodplains tend to lower flood elevations downstream and, correspondingly, reduce flood hazards...

One primary natural function of a floodplain is to store and "slow down" flood waters during floods. By impeding peak flood flows, natural floodplains tend to lower flood elevations downstream and, correspondingly, reduce flood hazards (**Figure 6-10**). As an example of this natural flood reduction benefit, an approximate 8-mile length of the floodplain along the Skykomish River in Washington State stores enough flood water to reduce flood flows by about 5% at downstream valley locations (Snohomish County Public Works 1996). In the Tillamook lowlands, considerable floodplain storage has been lost due to the construction of dikes and levees. Many of these flood control structures, built to protect pasture lands from salt water inundation during tidal flooding, have also blocked the natural ability of the river floodplains to spread out flood waters, slowing and storing flood water volumes flowing from the watersheds.

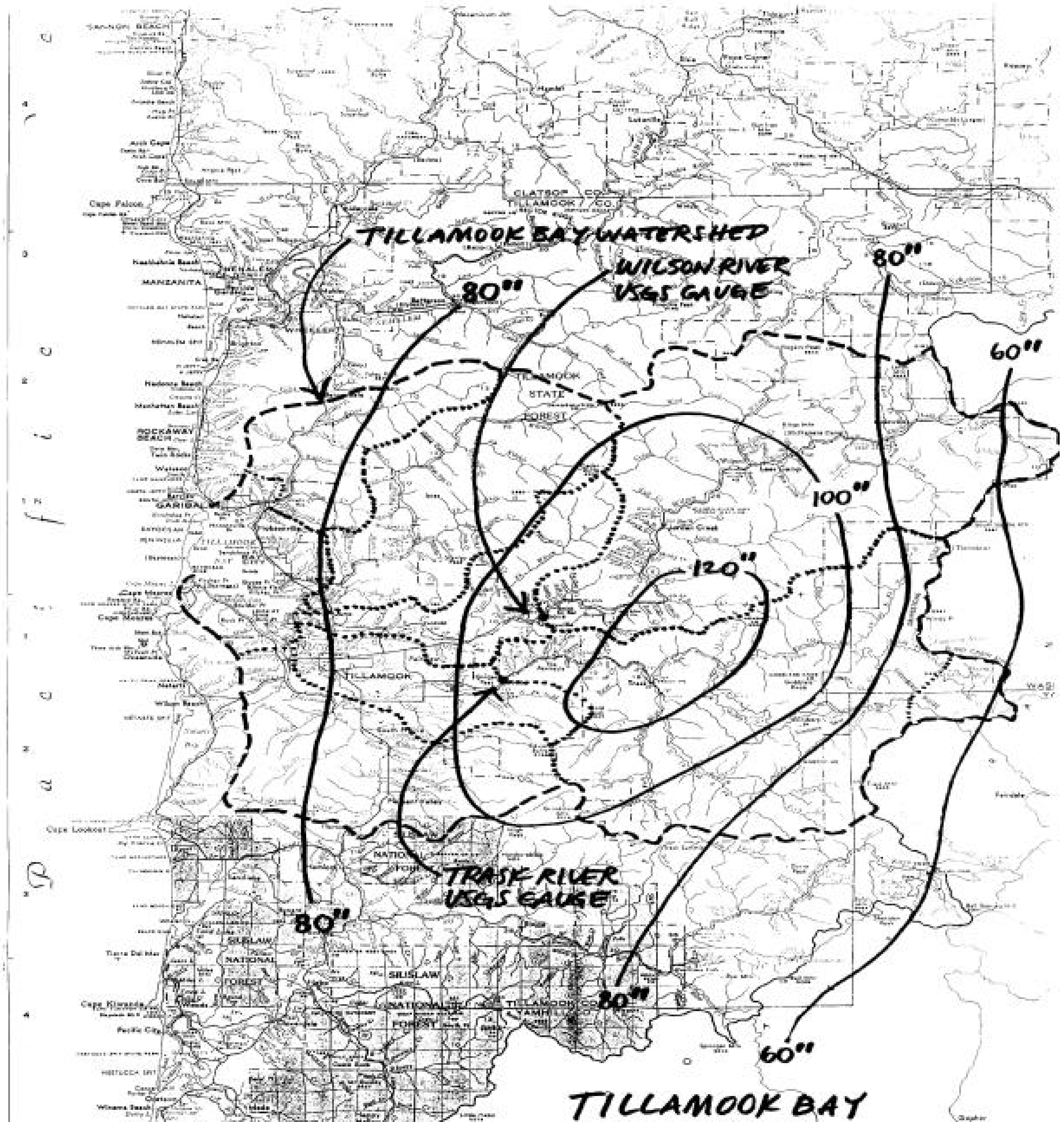


Figure 6-7. Tillamook Bay watersheds and mean annual runoff.
Sources: Mapping, Oregon Water Resources Department. 1972.
Mean annual runoff data, U.S. Department of Agriculture. 1971. Mean annual runoff in inches: Oregon Soil Conservation Service. Scale 1:2,200,000, M7-P-22101-N, July.

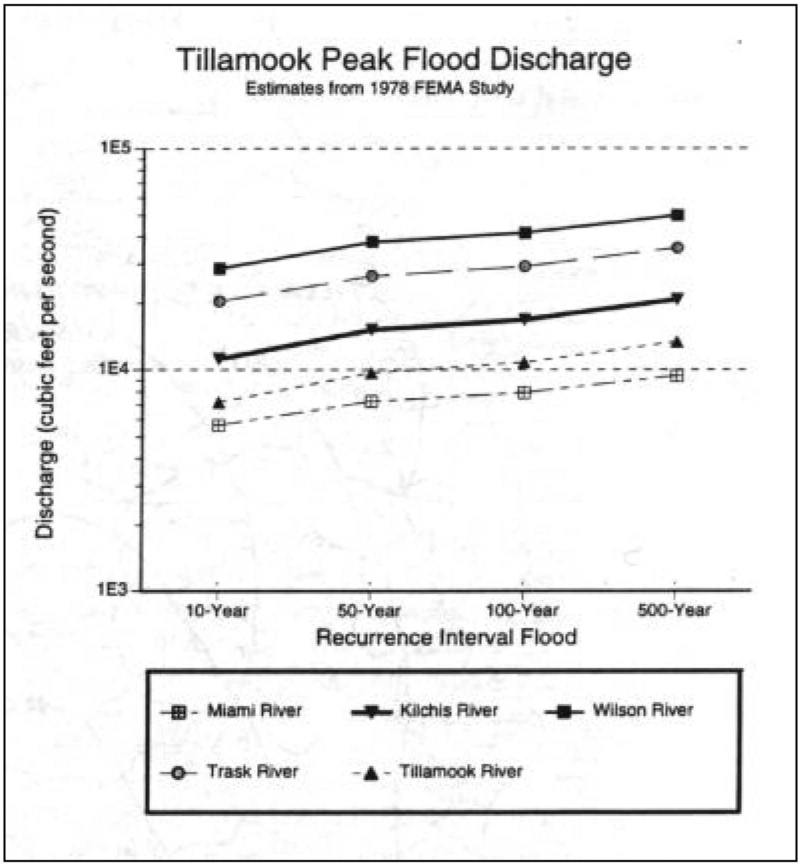


Figure 6-8. Peak flood discharge estimates at the mouths of the Tillamook Bay rivers.
Source: Federal Emergency Management Administration. 1978. Flood insurance study for Tillamook, OR.

Watershed Conditions

Within the Tillamook Bay Watershed, flooding and sediment transport have historically been dominant natural processes emanating from the small streams tributary to the larger rivers and floodplains — even before the well known series of “burns” began in the 1930's. Army Corps of Engineers (COE) reports from 1902 and 1907 state that “a considerable quantity of gravel, sand, and mud is annually deposited in the Bay and channels by the tributary streams” (Gilkey 1974). In the early 1970s, primary flood problems in the upper reaches of the Watershed were associated with streambank erosion and flash floods (Oregon Department of Geology and Mineral Industries 1973). The tributary streams in the area are characterized by short, steep slopes with variable soil and vegetation cover. Natural and human-induced watershed impacts can change sediment and flood flows to the main stem rivers, valley floodplains, and the Bay (Coulton *et al*. 1996).

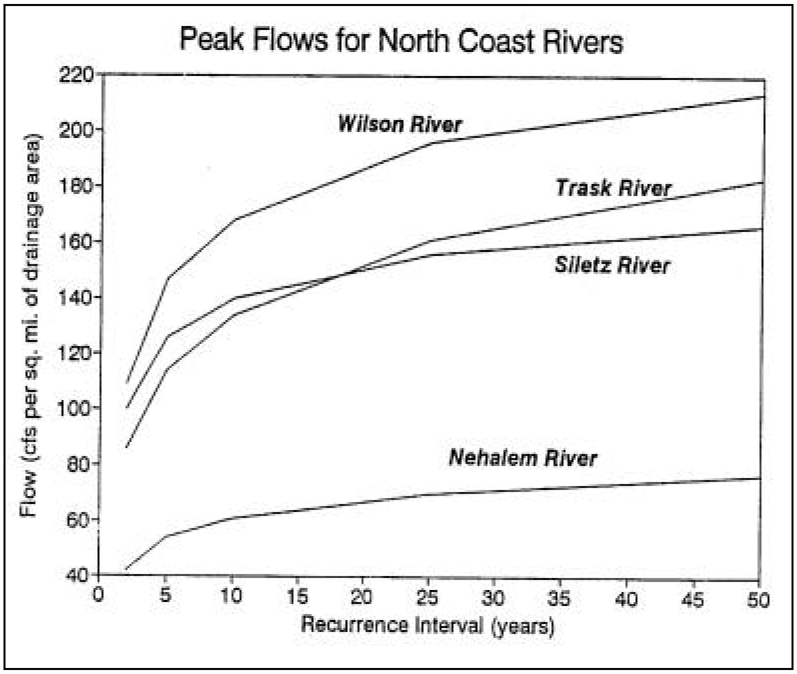


Figure 6-9. Unit flood discharge comparison for north coast rivers. Peak flow and recurrence interval analysis for north coast river basins shows the Wilson, Trask, and Siletz Rivers with greater peak flows than the Nehalem, relative to basin area.
Source: Tillamook System Coho Task Force. 1995. Tillamook Bay Coho stock status report, Oregon Department of Fish and Wildlife, Portland, OR.

The past Watershed burns have changed the hydrologic response of runoff — or the ability of the surface soils to retard runoff — from forested areas. Burned areas, and especially areas of repetitive burns, show a reduced ability to store moisture in surface soils. Accelerated runoff from burned areas can increase downstream soil erosion and sedimentation into rivers.

The documented sensitivity of valley flooding to upstream watershed conditions indicates the need for a strong, high priority management focus on restoring natural watershed functions. Future flood management efforts in the valley floodplains may be to no avail if watershed impacts, influencing the rate and volume of flood waters, are not adequately addressed. The TBNEP developed a watershed analysis framework, intended to identify key watershed processes and lead to effective management solutions to the priority problems and flood problems (Nehlsen and Dewberry 1995).

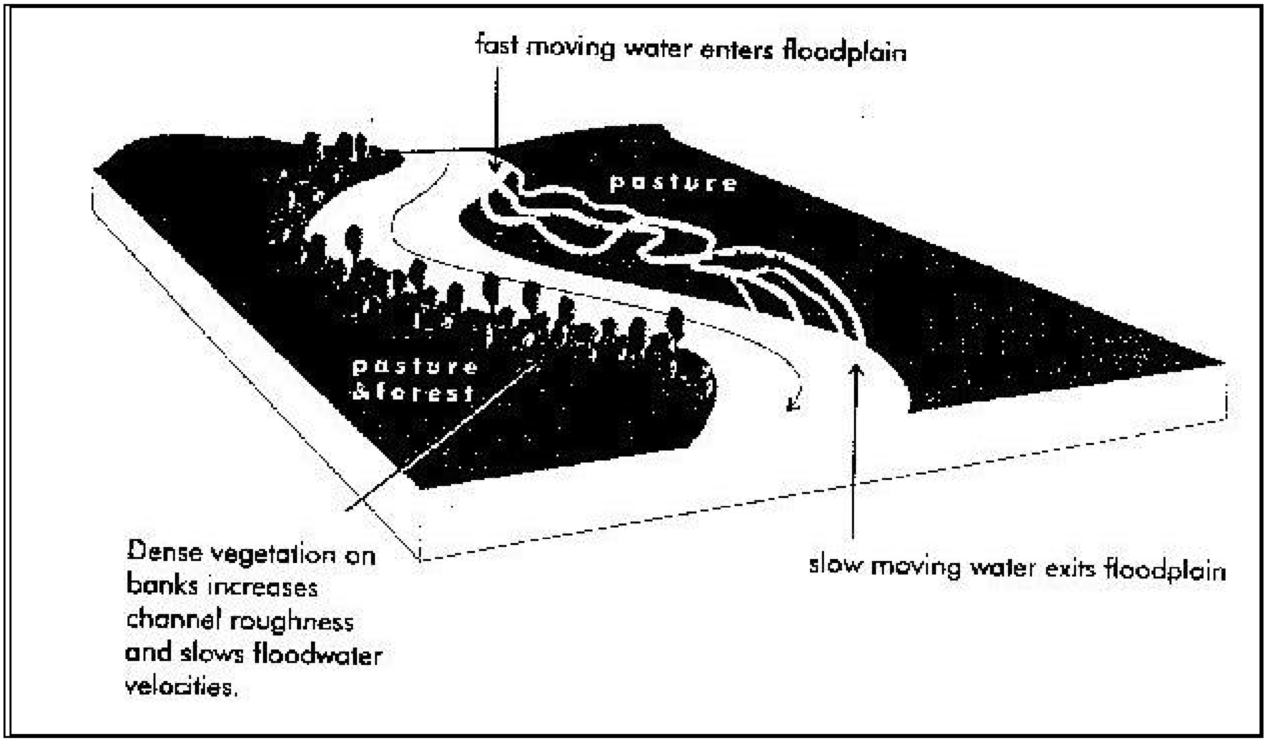


Figure 6-10. Floodplain flow attenuation.
Source: Coulton, K., P. Goodwin, C. Perala and G. Scott. 1996. An evaluation of flood management benefits through floodplain restoration on the Willamette River, Oregon, USA. Prepared in Portland, OR. for the River Network, Portland, OR.

The 1996 Flood

Until the February 1996 flood, observations of past flooding in the City of Tillamook indicated that flood elevations were remarkably similar for all of the past severe flood events because of the wide valley floodplain bordering Tillamook Bay (Tillamook County 1996). Tillamook residents' observations of recent and past flood levels indicate the February 1996 flood waters rose nearly 2 feet higher than floods since the late 1960s along the Highway 101 business corridor near Tillamook (Johnson 1997).

The estimated Wilson River peak of 35,000 cfs during the flood of February 8, 1996 is between a 50- and 100-year flood event.

The February flood destroyed the USGS stream gauge on the Wilson River near Tillamook. However, USGS field investigations of flood high water marks yielded an estimated peak flow of 35,000 cubic feet per second (unpublished data) at the Wilson River stream gauge during the peak of the flood event on February 8, 1996 (Miller pers. com. 1997). This estimated flow is between a 50- and 100-year flood event, according to FEMA flood statistics, and it is slightly less than the peak

Figure 6-11. Aerial photograph of flooding on February 10, 1996, at Tillamook, OR. after the floodwaters had begun to recede.
Source: Coulton, K. 1996. Philip Williams and Associates, Aerial reconnaissance of flooding for the Tillamook Bay National Estuary Project, Garibaldi, OR.

flow of record, a 100-year event of 36,000 cfs in January 1972 (Wellman *et al.* 1993). **Figure 6-11** is an aerial photograph of the 1996 flooding in Tillamook, taken as waters continued to recede on February 10.

Besides the peak flow and maximum elevations of flooding, the duration of flooding and the speed at which flood waters rose and fell had special significance in Tillamook County during the 1996 floods. Dairy herds on farms in low-lying floodplain areas were forced to stand in water for long periods of time, affecting bovine health and milk production (Tillamook County 1996). The swift rise and fall of river water levels collapsed waterlogged soils along steep riverbanks and led to the failure and erosion of many riverbanks during the flood event (Tillamook County 1996). These varied flood characteristics, experienced during the 1996 flooding, indicate flood management involves more than just reducing peak flood elevations.

The duration of flooding and the speed at which flood waters rose and fell had special significance in Tillamook County during the 1996 floods.

Impacts from the 1996 floods have challenged many accepted practices of floodplain management and flood control in Tillamook County. During the flooding, buildings that had been designed to the minimum FEMA standards (elevated to one foot above the regulatory 100-year floodplain elevation) received flood damages, most notably the new Safeway store, built in 1982, which had 20 inches of water in the store (Tillamook County 1996). This may have occurred because of the uncertainty inherent in the estimation of FEMA 100-year base flood elevations (BFEs) and the non-conservative requirement to elevate the first floor of buildings only one foot above the BFE (Reckendorf 1997b). Dikes and levees were also damaged due to the intensity and duration of flooding.

In the aftermath of the 1996 floods, Tillamook County produced a comprehensive Flood Hazard Mitigation Plan (Tillamook County 1996). This document provides a wealth of information on flooding and flood control in the County, but more importantly, it lays out a strategy for reducing the flood hazards that Tillamook County has experienced. The plan is guided by three goals: (1) reduction of flood-related hazards and damages, (2) reduction of environmental impacts of flood control, and (3) reduction of the long-term costs of flood control and floodplain management. Flood management policies and projects discussed in the plan are based, in part, on the understanding that flooding is a natural process and solutions to flood problems will be best determined by a comprehensive analysis of flood factors, not only within the floodplain but also within the watershed.

Impacts from the 1996 floods have challenged many accepted practices of floodplain management and flood control in Tillamook County.

Flood Management Concerns

Given the flood history of the Tillamook Bay area and observations from the 1996 flood, several flood management concerns have arisen. These concerns need to be addressed to resolve regional flood problems and TBNEP priority problems.

Flood Hazards

Two main types of flood hazards have been identified in Tillamook County: inundation and bank erosion (Tillamook County 1996). These processes occur in all river systems, whether natural or heavily developed, but are viewed as hazards because they affect human interests in the valley floodplains.

Inundation, defined in the Tillamook County Flood Hazard Mitigation Plan (FHMP) as flood water and debris flowing into an area, directly damages life and property, and the effects of this type of hazard can be observed and understood. Bank erosion is apparent where it occurs along a river, but its resolution as a flood management problem is less certain because it is also part of the natural process of a river channel

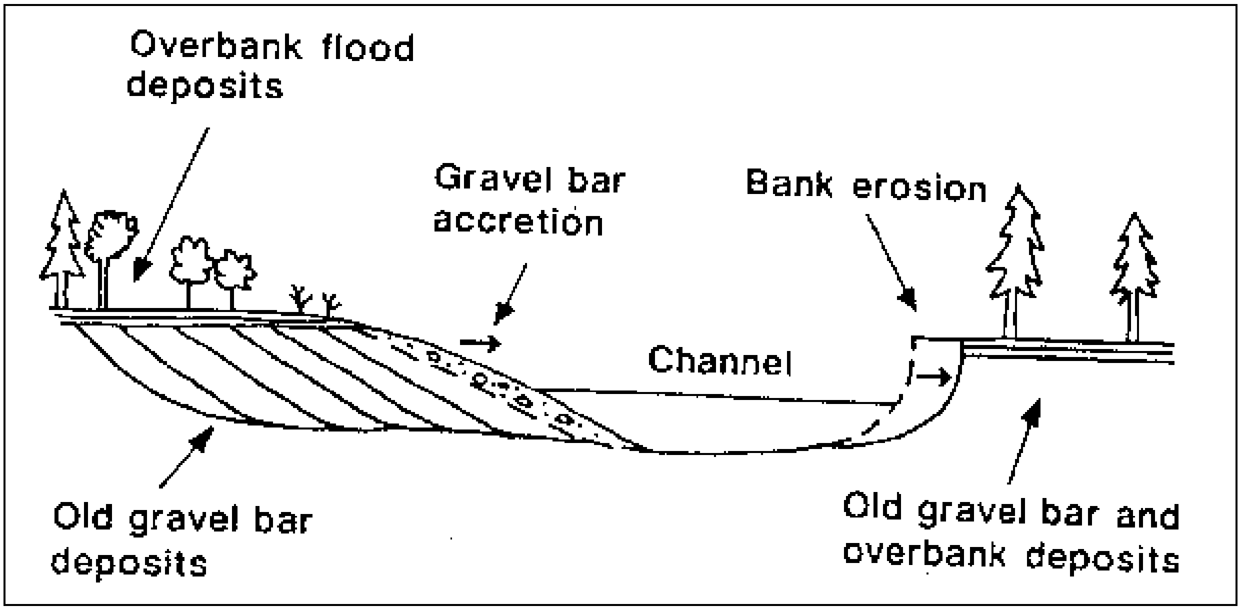


Figure 6-12. Schematic diagram of river bank erosion and deposition. Schematic diagram of lateral channel shifting at a river bend shows accretion of gravel bars and of fine sediments deposited by flood waters on the gravel, creating new floodplains on the inside of the bend while undermining occurs on the outer bank.
Source: Collins, B. and T. Dunne. 1990. Fluvial geomorphology and river gravel mining: A guide for planners, case studies included. California Department of Conservation, Division of Mines and Geology, 1416 9th St., Room 1341, Sacramento, CA. 95814.

forming and reforming in response to flow and sediment movement **(Figure 6-12)**.

Although severe flooding appears to cause severe bank erosion, more erosion tends to occur over the long term during the more frequent and less severe flood events. This is caused, in part, by the downstream movement of debris flows caused by severe precipitation and landslide events. In many circumstances, the streambanks are easier to erode than the coarser materials deposited in the rivers by debris flows (Reckendorf 1997c).

Although severe flooding appears to cause severe bank erosion, more erosion tends to occur over the long term during the more frequent and less severe flood events.

If a river has a developed meander pattern and a well-connected floodplain, the complexity of a natural river and floodplain system slows flood flows and spreads out the movement and volume of the flood waters (Leopold *et al*. 1992), reducing the potential for bank erosion as flood waters overtop the natural banks of the river channel. Many of the riverbanks in the Tillamook Bay valleys have been raised with dikes and levees. Although these structures have protected farmlands, they may be contributing to the bank erosion problem because the artificially higher banks concentrate flood waters and cause faster, more erosive flow conditions.

Accuracy of Floodplain Mapping

Effective flood management requires reliable tools and techniques. The 100-year floodplain map is a primary floodplain management tool. For the Tillamook Bay area, this mapping is available in the FEMA Flood Insurance Study for Tillamook County. These floodplain boundaries are established as minimum guidelines for development. The statistical information the maps portray is uncertain and this needs to be considered in land use planning applications.

The National Flood Insurance Program (NFIP) was established in 1968 and the study of flood hazards in Tillamook County was begun in 1975, one of the first such studies in Oregon. For these early FEMA studies, the 100-year floodplain boundary may be grossly in error because changes to upstream watersheds over the intervening 20 years may be increasing runoff to valley floodplains. If the rate and volume of runoff is increased from land use changes, a statistical 100-year flood flow value for today may be much greater than that same statistical value from 1975. Correspondingly, a current 100-year floodplain may be higher and larger than regulatory floodplain boundaries established in 1975 and currently used for planning purposes. The adequacy of FEMA studies within urban areas has also been questioned because of inadequate evaluation of floodplain fills and bridge hydraulics (Reckendorf 1997c, 1997d).

Floodplain maps are created using standardized techniques and existing data to help in the establishment of actuarial insurance rates. Unfortunately, potential “real world” flood problems experienced in Tillamook County, such as logs, debris, or sediment that can plug a culvert or bridge and increase flood levels above estimated regulatory 100-year floodplains **(Figure 6-13)**, are not typically accounted for during flood insurance studies and on regulatory floodplain mapping. In addition, ground elevations for the Tillamook County floodplain mapping are based on field surveys of river channels and aerial photography of overbank floodplains obtained in the mid-1970s. Ground conditions from river sediment deposition and floodplain development may have changed substantially since the time of the original surveys. Therefore, the current Tillamook County floodplain maps may not accurately represent present day flood hazards.

Figure 6-13. Historical photographs of log jams on the Trask River during the 1964 flood.
Source: Oregon Historical Society.

Flooding and Water Quality

Water quality has been identified as one of the main management concerns for Tillamook Bay. Pathogenic bacterial and viral contamination is the primary water quality problem affecting the agricultural and shellfish industries. As in many estuaries, other problems such as excess nutrient loading, hydrocarbons, heavy metals, and pesticides are of growing concern as land use in the Bay watersheds and valley floodplains intensifies. The transport, fate, and decay of these contaminants are highly complex. However, they all present a water quality problem because all are carried downstream in flowing water and many increase Bay water quality impacts during flood events.

Several procedures are in place for closing the Bay to shellfish harvesting in the event local spills or marine influences threaten Bay water quality. (See Chapter 4, Water Quality.) However, predictable conditions for Bay closure have traditionally been associated with heavy rain and flooding. Shellfish growing waters in Tillamook Bay are temporarily closed to harvesting when the Wilson River gauge rises to 7 feet or 2,500 cubic feet per second (TBNEP 1995). This flow is equaled or exceeded about 10% of the time, according to USGS streamflow statistics for the gauge (Moffat *et al*. 1990). The main Bay and lower Bay shellfish areas are re-opened five days after the Wilson River flow peaks.

Therefore, flooding directly impacts Bay water quality, as it tends to wash bacterial contaminants from accumulated manure and leaking septic systems off floodplain lands and toxic contaminants from urban areas. Flood levels may also impair the operation of sewage treatment facilities along the Bay margins. Flood management concerns therefore involve more than the quantity of flood waters, and solutions to flood problems will also need to address water quality problems.

The complex physical characteristics of the Tillamook Bay floodplains present a challenge for implementing effective flood management strategies.

Effectiveness of Flood Management Strategies

The complex physical characteristics of the Tillamook Bay floodplains and the desired TBNEP management goals present a challenge for implementing effective flood management strategies. Tidal effects, changing watershed conditions, and existing floodplain interventions make it difficult to assess the effectiveness of potential flood management strategies. Existing flood control features used to protect floodplain land uses have simplified natural streamflow processes in many places and reduced the complexity of instream habitats supporting fish and shellfish.

A comprehensive and strategic flood management approach, as opposed to a reactionary approach, will be more effective for resolving long-term and recurrent flood problems.

Managers hope to develop the right mix of flood control and floodplain management techniques to effectively resolve flood problems in the Tillamook Bay area. The FEMA studies done to establish floodplain areas in the County are more than 20 years old and this information may be inadequate for land use decision-making. Past flood management efforts have typically been reactions to past floods and little monitoring has been done to measure the effectiveness of these actions. The effectiveness of future flood management efforts will need to be assessed using modern techniques, involving modeling and monitoring. A comprehensive and strategic flood management approach, as opposed to a reactionary approach, will be more effective for resolving long-term and recurrent flood problems.

Existing Regulation and Management Structures

Federal Floodplain Regulation

National floodplain management was established with the Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973. According to FEMA (1990), to qualify for federally-subsidized flood insurance, communities must define their flood risks and adopt minimum floodplain management regulations to reduce those risks, as described in the National Flood Insurance Program (NFIP). Oregon was one of the first states and Tillamook County was the first Oregon county to undergo technical studies to delineate the 100-year floodplain as part of the NFIP in the early 1970s (Levesque, P. pers. com. 1997).

Incorporated and unincorporated communities in the Tillamook Bay area have been early participants in the NFIP and participation in the flood insurance program has increased dramatically. In 1980, more than 300 flood insurance policies were in effect in the County **(Table 6-2)** with a total insurance value of about $13 million (Levesque 1980). Today, nearly 1,100 policies are in effect with a total insurance value of about $122 million (Eberlein 1997).

The COE has played a historic role in flood control in the Tillamook Bay region because the COE designed and constructed most of the County’s river levees (Levesque, P. pers. com. 1997). Local jurisdictions are required to operate and maintain these flood control structures to COE standards in order to be eligible to receive COE funding for flood damage repairs (Ascher, T. pers. com. 1997).

Table 6-2. Comparison of Tillamook County Flood Insurance coverages between 1980 and 1997, and claims since 1978

City	No. of policies (in 1980)	Insurance coverage (1980$)	No. of policies (in 1997)	Insurance coverage (1997$)	Claims since 1978 (1997$)
Tillamook County	235	$9,393,700	766	$80,470,600	$1,416,161
City of Tillamook	15	$451,500	91	$10,623,100	$1,451,185
City of Bay City	6	$176,600	8	$722,100	$0
City of Garibaldi	0	$0	2	$693,000	$0
City of Manzanita	15	$572,500	47	$7,888,900	$1,954
City of Nehalem	11	$556,600	27	$3,184,300	$190,881
City of Rockaway	50	$1,960,100	155	$17,281,700	$48,777
City of Wheeler	3	$44,900	3	$685,300	$0
Totals	**335**	**$13,155,900**	**1,099**	**$121,549,000**	**$3,108,958**

Sources: Levesque, P. 1980. Principal flood problems in the Tillamook Bay drainage basin. Eberlein, M. 1997. Personal communication. FEMA Region 10, Bothell, WA.

State and Local Floodplain Regulation and Management

With completion of the requirements for NFIP acceptance, local governments within Tillamook County adopted the minimum requirements for floodplain management and Tillamook County was officially included in the program in 1978 (Levesque 1980). Local governments must enforce federal floodplain regulations and implement flood management activities to remain eligible for flood insurance under the NFIP.

Management of local flood control facilities, such as tide gates, dikes, and levees, is the responsibility of Tillamook County and the Stillwell Drainage District and Sunset Drainage District (Levesque, P. pers. com. 1997). No federal dollars are available for maintenance of these facilities and the local governments must budget labor and materials for the inspections and repairs necessary to ensure their continued integrity.

Two recent and significant changes affecting floodplain management and flood control in Tillamook County have been proposed. The recent County Flood Hazard Mitigation Plan includes a policy recommendation calling for the implementation of a new County development standard requiring finished floors to be 3 feet above the base flood elevation (BFE), the 100-year flood elevation, instead of the FEMA minimum requirement of one foot above the BFE (Ascher, T. pers. Com. 1997). Another recommended policy would require new levees to be constructed at least 40 feet back from riverbanks (Levesque, P. pers. com. 1997). Included in this policy is a provision to set back existing levees, if flood damages and repairs to levees become repetitive over time (Levesque, P. pers. com. 1997).

Federal Regulation of Waterway Modifications

Section 404 of the federal Clean Water Act initially regulated only “fill” activities in navigable waters of the United States and “removal” activities were also only regulated in navigable waters. Since August 1994, these regulations have been expanded to include “removal” activities that occur in a wider array of Section 404 waters. Section 404 waters now include streams, rivers, lakes, ponds, and wetlands: any area that is saturated below the surface for more than 14 consecutive days in the growing season (Oregon Insider 1994). Federal regulation of waterway modifications would therefore apply to work proposed to be done in river channels and in floodplain areas where Section 404 waters exist.

Federal regulations specific to waterway modifications have recently been refined. The Interagency Working Group on the Dredging Process was established in 1993 to develop a new national policy for dredging. The group recommended forming regional dredging teams to more effectively deal with dredging issues at the local level (U.S. Environmental Protection Agency 1996). In this time of reduced federal spending, more responsibility for the management and enforcement of federal regulations will probably be placed on local governments that benefit from the economic and environmental protection the regulations provide.

COE waterway modification assistance is not expected in Tillamook County, because the COE will not contract with Oregon counties. This is because an Oregon Constitutional provision, limiting the amount of debt counties may incur above their budgets to $5,000. conflicts with two COE policies. COE contracts require that counties fund all maintenance for COE projects, and for new projects, the counties are responsible for any construction costs exceeding the amount of federal dollars allocated for the project. The COE has refused to alter its position on these two provisions in Oregon and, therefore, Oregon counties are ineligible. These provisions do not apply to Oregon cities and other local governments (Levesque, P. pers. com. 1997).

State and Local Regulation and Management of Waterway Modifications

The State of Oregon owns the beds and banks of navigable waterways and therefore manages the use of these waterways.

The State of Oregon owns the beds and banks of navigable waterways and therefore manages the use of these waterways. In Tillamook County, the State owns waterways strictly because of tidality. Approximately 40 waterways in the County are state-owned, upstream to the respective heads of tide (Cleary 1996a).

A number of state and local agencies share the local management of riparian areas and wetlands.

A number of state and local agencies share the local management of riparian areas and wetlands. The Oregon Department of State Lands (ODSL) regulates river beds, banks and wetlands, the Oregon Department of Environmental Quality (DEQ) manages state waterway water quality issues, the Oregon Department of Forestry (ODF) manages riparian areas on State Forest lands, and counties manage riparian lands in unincorporated areas.

Since 1967, the ODSL has issued more than 4,000 permits for commercial gravel removal in the State with a total permitted volume of over 800 million cubic yards from Oregon rivers (OWRRI 1995). ODSL and COE may consider applications for gravel extraction for flood control on Tillamook Bay rivers for tidal reaches of the rivers including “no less than all areas west of Highway 101" (Cleary 1996b).

A 1992 Tillamook County Gravel Mediated Agreement was developed in response to state agency recommendations to protect fish habitat and spawning areas.

A 1992 Tillamook County Gravel Mediated Agreement was developed in response to state agency recommendations to protect fish habitat and spawning areas. Under the agreement, commercial instream (within the banks of a river) gravel removal above the heads of tide of the Kilchis, Miami, Wilson, Trask, and Tillamook Rivers was phased out by October 1, 1997. For the future, a Coordinated Resource Management Plan will control gravel removal from these rivers for non-commercial purposes and work to prevent unacceptable streambank erosion (Cleary 1996b).

The Tillamook County Soil and Water Conservation District (TCSWCD) is cooperating with the Natural Resource Conservation Service (NRCS) to survey gravel bar development and stream flows in the Kilchis River system to estimate gravel recruitment. This work is partially intended to provide scientific information to assist in the development of a sustainable process for gravel bar management as a part of the plan. Since 1993, nine gravel bars have been field surveyed and sediment samples of surface and substrate materials have been analyzed to better understand the seasonal movement of gravel in this river system (TCSWCD 1997). Rock barbs, or spur dikes, have been built at two locations along the river as demonstration projects to stabilize gravel bars and encourage the seasonal redeposition of gravel at predictable locations to help protect streambanks and establish fish habitat. One objective of the field work is to better understand how gravel bar growth may affect streambank erosion.

The TCSWCD and the NRCS are also working with the Oregon DEQ on a turbidity sampling project to develop relationships between streamflow and suspended sediment discharges from gravel removal areas.

Although the gravel planning process was begun in 1993, there has been limited progress in recent years and the status of the plan is uncertain. The state agencies, local governments, and local land owners are ultimately responsible for its development (Ascher, T. pers. com. 1997). It is anticipated that the ongoing work by the TCSWCD, the NRCS, and the TBNEP will provide the necessary resource management information to allow the plan to be finished (Ascher, T. pers. com. 1997).

Future Trends

Flooding Trends

A generalized history of tidal and river flooding in the Tillamook Bay area is shown in **Figure 6-14**. For this figure, “significant flooding” means events that had enough impact on local communities to warrant newspaper coverage. In this regard, the frequency of significant flooding seems to be increasing in the region. This trend may be attributed to the increasing human population and associated developments, some of which are occurring in flood hazard areas.

Rainfall and temperature data have been recorded at Tillamook and on the Oregon Coast since the late 1800s **(Figure 6-15)**. An analysis of these and other climate trends in the State by the Oregon State Climatologist indicates the Pacific Northwest may be entering a 20-year period of cooler, wetter weather (Taylor 1995). Increased precipitation in the coastal watersheds of Tillamook Bay may result in more frequent flooding. On a global level, climate change would probably change runoff patterns, with less and earlier runoff from snowmelt and more runoff from rainfall (Roos 1995). These potential trends in climate may dictate the need for flexible flood mitigation strategies that can accommodate changing local flood characteristics.

Climate change would probably change runoff patterns...dictating the need for flexible flood mitigation strategies that can accommodate changing local flood characteristics.

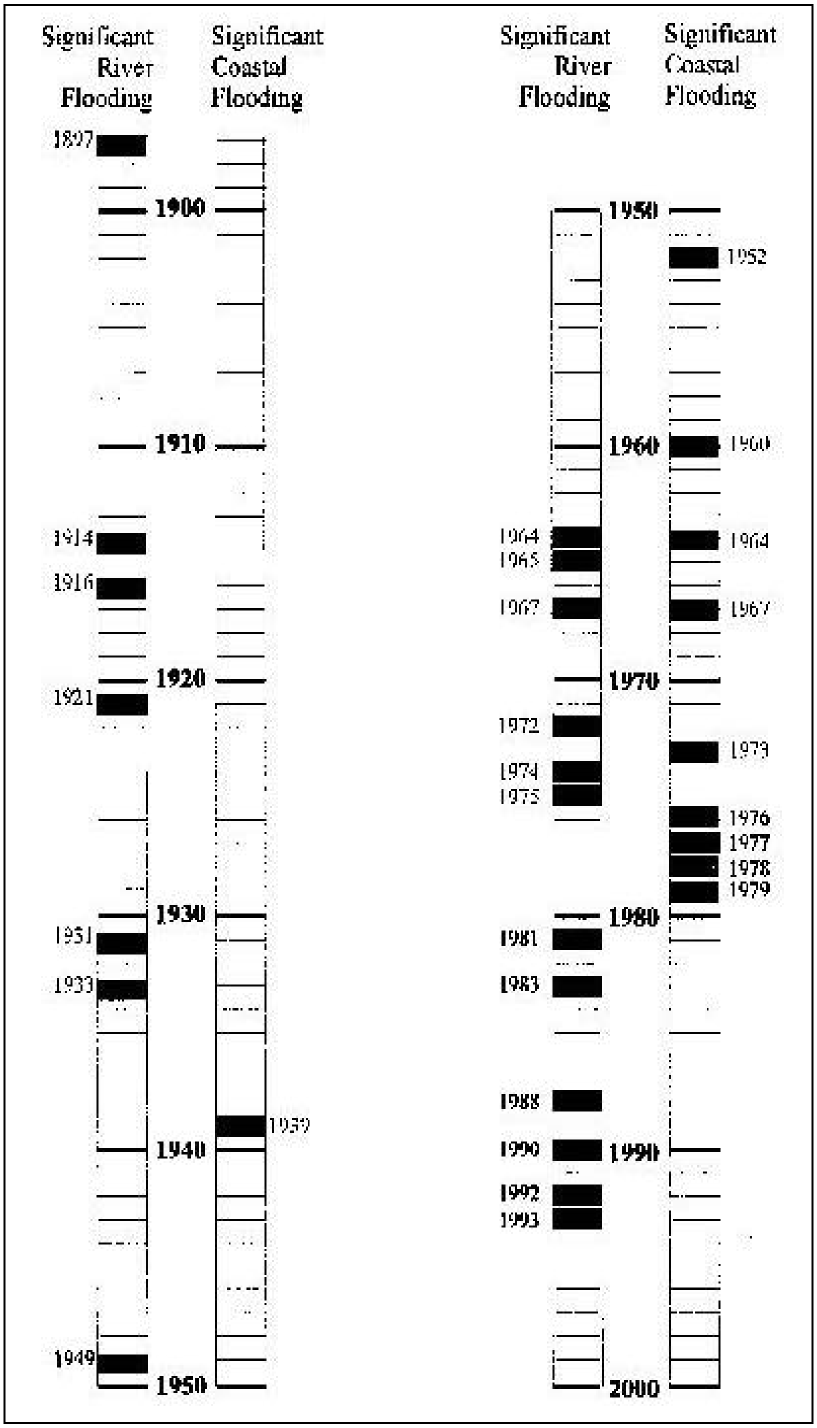
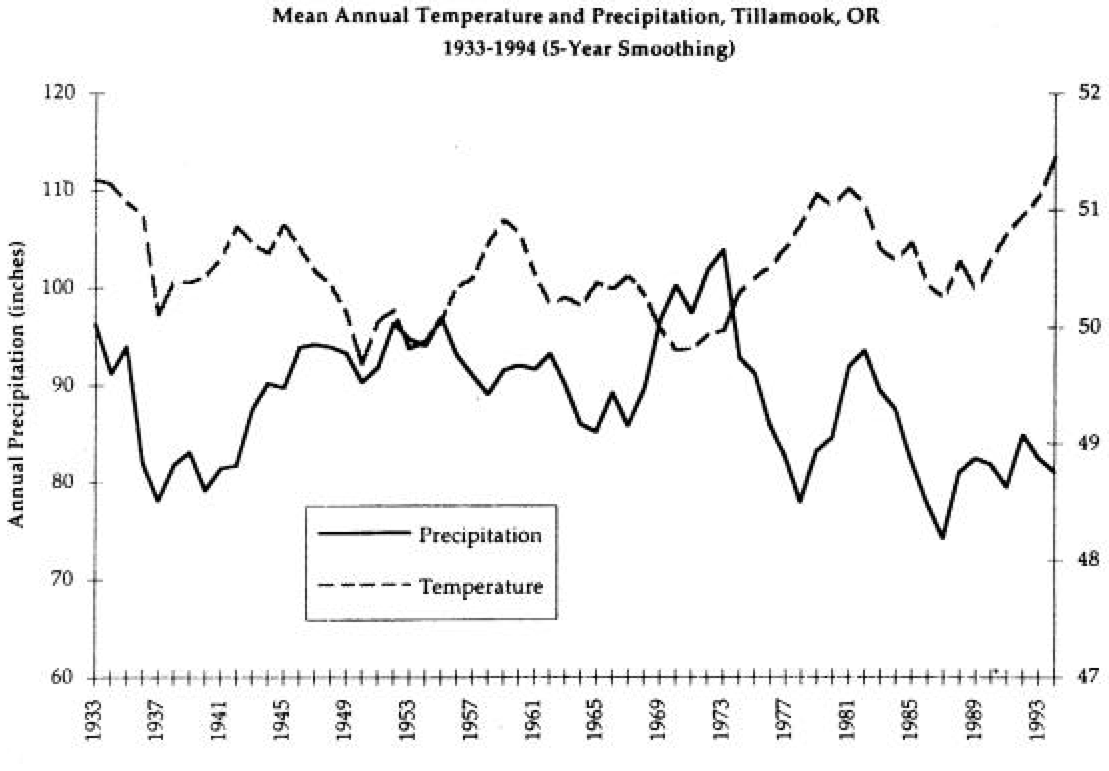


Figure 6-14. Generalized flood history for the Tillamook Bay area. *Source:* Coulton, K., P. Williams, P. Benner, and M. Scott. 1996. “An environmental history of the Tillamook Bay Estuary and Watershed,” prepared for the Tillamook Bay National Estuary Project by Philip Williams and Associates, Portland, OR.



Precipitation Estimated for Tillamook County, Oregon 1891 - 1920

Water Year	Annual Precipitation (inches)	Water Year	Annual Precipitation (inches)	Water Year	Annual Precipitation (inches)
1891	90.36	1901	113.98	1911	80.66
1892	77.44	1902	130.98	1912	107.46
1893	118.77	1903	111.97	1913	103.13
1894	97.60	1904	87.07	1914	77.18
1895	113.30	1905	89.49	1915	125.30
1896	95.98	1906	102.71	1916	79.27
1897	155.39	1907	80.64	1917	96.59
1898	119.93	1908	76.59	1918	107.92
1899	108.86	1909	85.13	1919	96.86
1900	119.34	1910	72.63	1920	130.75

Data obtained from the record at Newport, Oregon
From: Jones, 1924

Figure 6-15. Historic rainfall and air temperature trends for Tillamook, OR.
Sources: 1891-1920 data obtained from the record at Newport, OR., as cited in Jones, B. 1924. Report on potential waterpower in Trask, Nestucca, and Smith River basins in Oregon, U.S. Geological Survey, Washington D.C., January. 1933-1994 data from Taylor, G. 1995. Personal communication with Kevin Coulton. Sept. 12.

Sea Level Trends

Tillamook is being inundated by rising sea level at a rate of about 2 millimeters per year.

As another possible result of climate change, long-term flood mitigation strategies may need to consider rising sea levels. Local governments need to develop policies that address potential impacts from sea level rise on estuarine habitats and economic activities (ABAG 1992). In estuaries and coastal areas, sea level rise may necessitate the relocation or protection of low-lying facilities, such as wastewater treatment plants. New construction designs in coastal areas should consider local sea level trends (Roos 1995).

Relative sea level change for the Tillamook Bay area is documented as the net effect of the coastal land mass movement relative to the changing sea level. Compared with relative sea level changes elsewhere on the Oregon coast, Tillamook is one of the most significant locations, as it is being inundated by rising sea level at a rate of about 2 millimeters per year, as indicated by the rate scale at the bottom of **Figure 6-16**. This is the rate of land-level change relative to the changing global sea level (Komar 1992). Although this rate is relatively small, its effects will be most pronounced on flat tidal land areas, such as estuarine tide flats and marshes. A sea level rise may cause ecosystem changes as intertidal habitats become subtidal (ABAG 1992). If these changes occur in Tillamook Bay, the conversion of estuarine habitats may affect current flood and sediment transport processes.

Subsidence:
A term applied to the progressive depression of a land surface or a crustal elevation because of natural or artificial causes. Phenomena such as groundwater withdrawal, mining, or *karst* (a limestone region marked by sinks, abrupt ridges, protuberant rocks, caverns and underground streams) activity may cause subsidence.

Seismic Trends

Over the past decade, field investigations along the Oregon and Washington coast have uncovered geologic evidence of major periodic earthquakes associated with the Cascadia subduction zone. Observations of buried marshes — fossilized peat layers graded downward into intertidal muds — suggest coastal land areas, including Tillamook Bay, have experienced repeated cycles of slow uplift punctuated by rapid subsidence (Madin 1992).

Land subsidence may affect coastal flood problems by initiating tsunamis, accelerating coastal erosion, and changing the extent and location of flood land areas because of lowered ground elevations.

The last significant subsidence event along the Oregon coast was estimated to have been about 300 years ago and the intervals between these historic coastal quakes range from about 300 to 600 years (Madin 1992). Recent field research has estimated a paleosubsidence elevation change for the most recent great Cascadia earthquake (A.D. 1700) at about 1.0 meter (+/- 0.5 meter) for the Garibaldi area along Tillamook Bay (Peterson *et al.* 1997). Given these seismic trends, the possibility of land subduction in the Tillamook Bay area is another factor to consider in the development of a long-term flood management strategy.

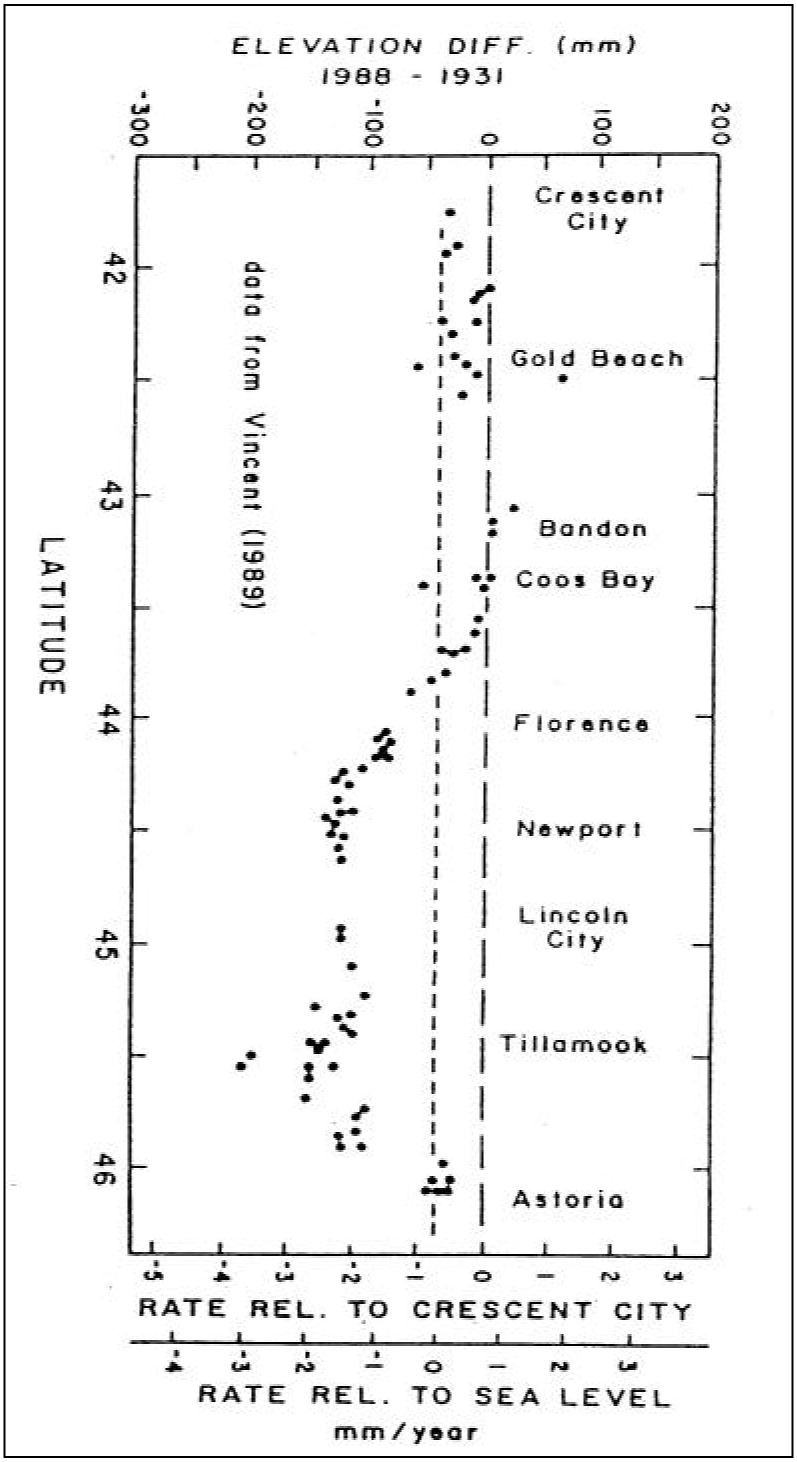


Figure 6-16. Historic rates of relative sea-level rise for the Oregon Coast. Elevation changes and their relationship to sea-level rise along the length of the Oregon Coast from Crescent City in California north to Astoria at the mouth of the Columbia River, based on repeated geodetic surveys along the coast.

Source: Vincent, P. 1989. Geodetic deformation of the Oregon Cascadia Margin: M.S. dissertation, University of Oregon, Eugene.

Land subsidence may affect coastal flood problems by initiating tsunamis, accelerating coastal erosion, and changing the extent and location of flood land areas because of lowered ground elevations.

Waterway Modification Trends

The COE was historically active in waterway modification projects in Tillamook Bay. From the mid-1890s to the mid-1970s, the COE performed maintenance dredging of the Bay and snag clearing in the Bay and lower river reaches for navigation purposes. Over time, changes in economic activity and improved ground transportation reduced the dependence of local commerce on navigation and, in turn, the need for dredging. As early as 1949, “the people of Tillamook had ceased to think of the Tillamook as a navigable river” (Orcutt 1951).

River dredging for flood control has been done in the past, *e.g.*, after the January 1972 flood, but it was limited to the mouths of the rivers. Investigations into the feasibility of dredging the rivers further upstream for flood control found that the initial cost of dredging would be equivalent to the cost of levees designed to provide the same level of protection, and maintenance dredging would be necessary because of the annual load of sediments deposited in the rivers and Bay (Levesque 1980).

In-channel extraction of sand and gravel is being scaled back in the County because of the assumed direct and cumulative impacts on the fisheries and shellfish resource industries which share the same ecosystem.

Aggregate Use Trends

Sand and gravel are two of the most important natural resources extracted from the earth, based on tonnage (Cooke and Doornkamp 1978). The sand and gravel industry in Oregon has prospered since the 1940s **(Figure 6-17)**. Throughout this time Tillamook County rivers have provided a significant amount of this natural resource for local development interests **(Figure 6-18)**. However, the in-channel extraction of sand and gravel has been scaled back in the County because of the assumed direct and cumulative impacts on the fisheries and shellfish resource industries which share the same ecosystem.

Forecasts of aggregate use in Tillamook County show a mild increase in consumption to the year 2050 **(Figure 6-19**). Total aggregate consumption for the County is estimated to be 28.9 million tons and virgin aggregate consumption will increase at a rate of 0.21% (Whelan 1995). Road construction will use up to 47% of the County’s aggregate, and logging and forest roads will represent about 15% of the total consumption (Whelan 1995).

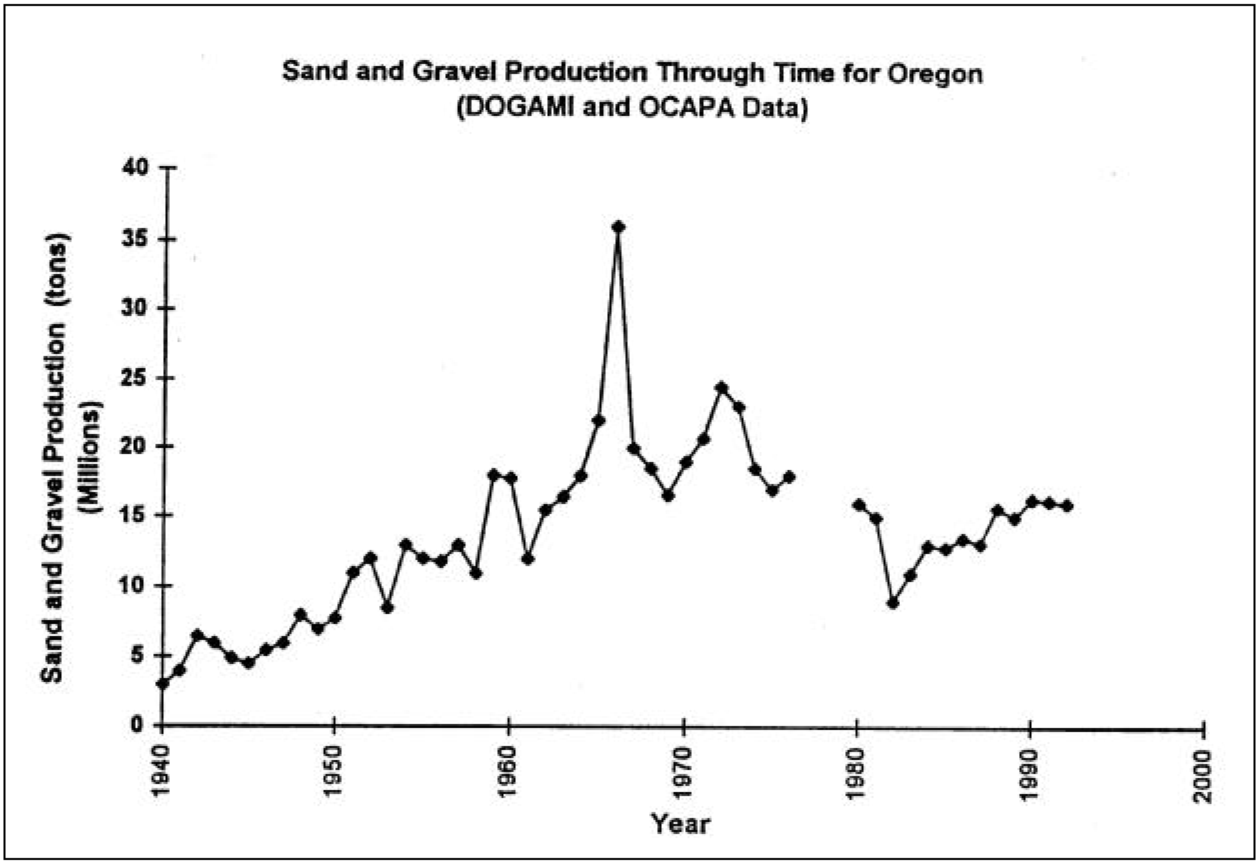


Figure 6-17. Annual sand and gravel production trends in Oregon.
Source: Oregon Water Resources Research Institute. 1995. Gravel disturbance impacts on salmon habitat and stream health, Vol. II: technical background report for the Oregon Division of State Lands, April.

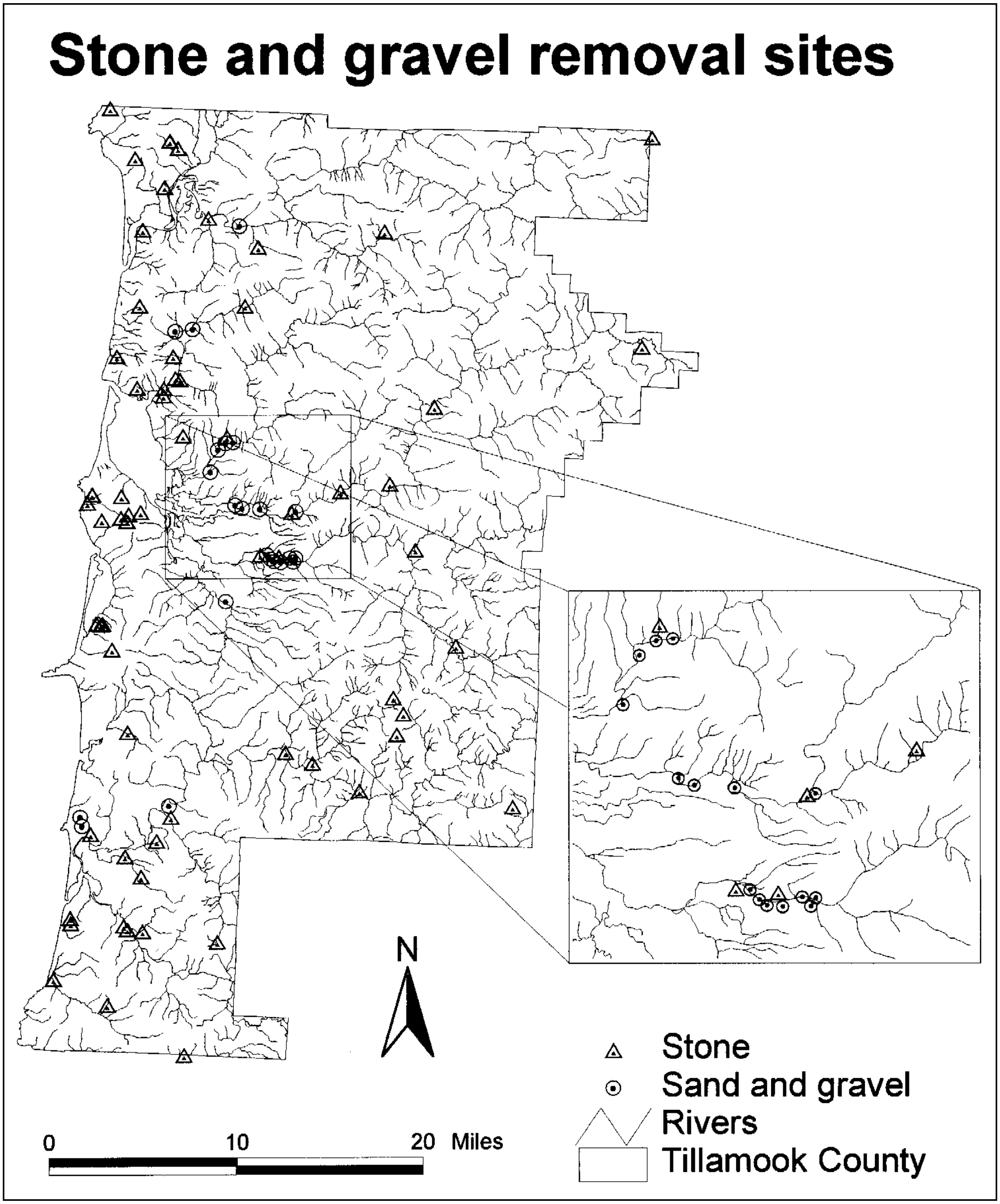


Figure 6-18. Locations of sand, gravel, and rock extraction sites in Tillamook County.
Source: Created by Ann Stark of Tillamook Bay National Estuary Project, using TBNEP Geographic Information System data and Feb. 25, 1997 personal communication from Geitgy, Oregon Department of Geology and Mineral Industries.

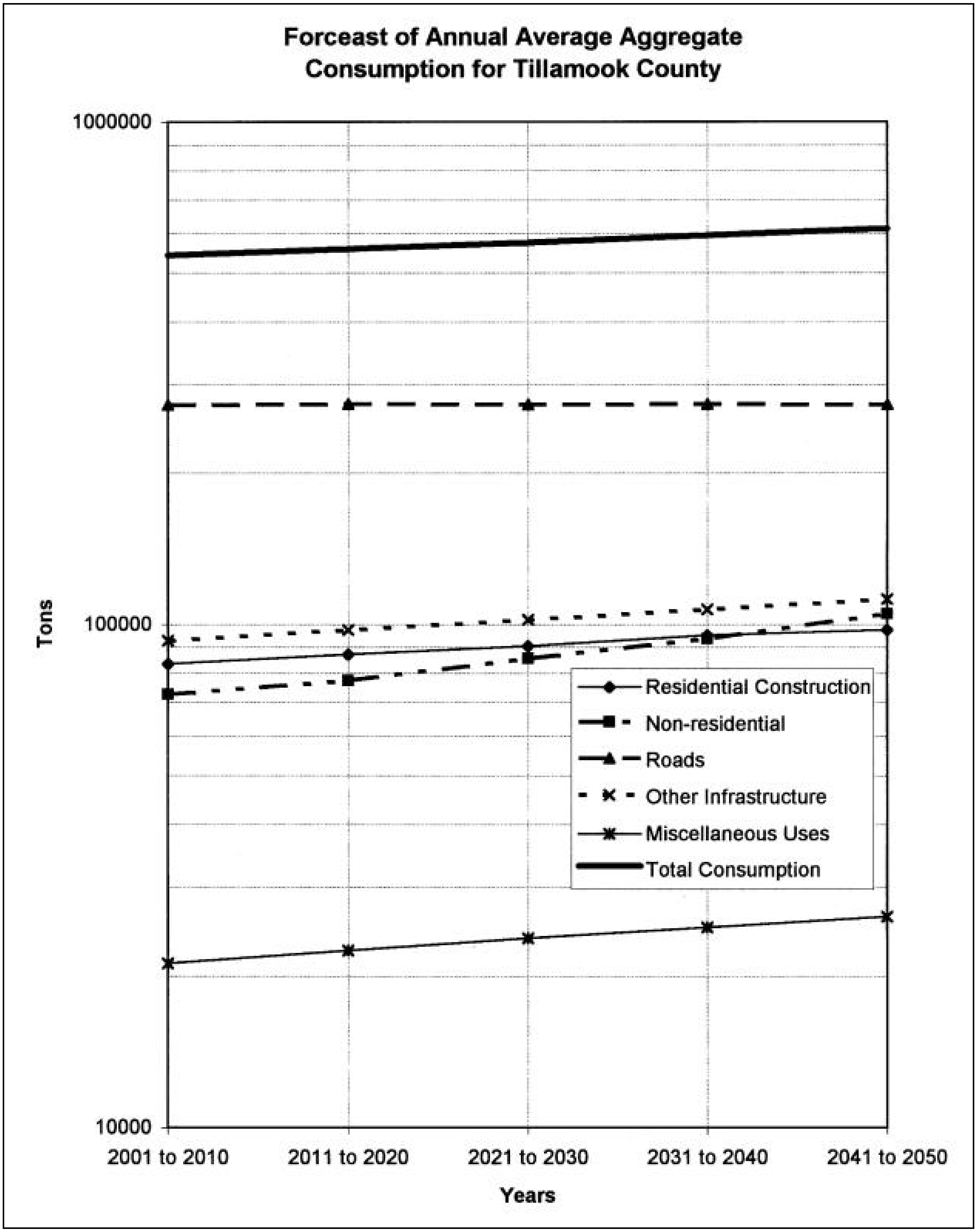


Figure 6-19. Aggregate consumption forecast for Tillamook County.
Source: Whelan, R. 1995. An economic analysis of construction aggregate markets and the results of a long-term forecasting model for Oregon. Oregon Department of Geology and Mineral Industries special paper 27.

In 1996, Tillamook County took the necessary steps through the Goal 5 process to protect a number of upland aggregate sources. This action was prompted by an element of the Coordinated Resource Management Plan (CRMP) that phased out commercial gravel extraction from the Tillamook Bay rivers by October 1, 1997 (Cleary 1996b). Six upland sources have been identified as capable of yielding enough aggregate to meet the County's future aggregate needs (Ascher, T. pers. com. 1997).

Management Alternatives for Flood Hazard Reduction

The Flood Hazard Mitigation Plan presents a comprehensive approach and a number of practical alternatives for reducing flood hazards in the County.

The recently published Flood Hazard Mitigation Plan (FHMP) for Tillamook County presents a comprehensive approach and a number of practical alternatives for reducing flood hazards in the County. The priorities and phasing for flood hazard reduction efforts described in the FHMP should generally begin with efforts that can be immediately started for low costs. A prioritized approach would involve: (1) implementing ordinances for policies adopted in the FHMP, (2) accomplishing mitigation projects for which grant funding is available, and (3) seeking funding for other flood hazard mitigation projects (Levesque, P. pers. com.1997).

A review of the flood history for the Tillamook Bay region, as well as other flood-prone areas in the United States, leads to the conclusion that the costly and extensive structural methods of flood control advocated throughout this century are simply not reducing flood damages. Lessons learned from major floods in the 1990s, especially in the Midwest United States, have changed minds in the floodplain management community. The concept of working with the river's own natural functions to manage floods is replacing the concept of intervening in these processes to try to control floods. Interest is growing in non-structural floodplain management methods, such as enforcing land use ordinances and restoring the floodplains.

Costly and extensive structural methods of flood control advocated throughout this century are simply not reducing flood damages.

Enforcement of Land Use Ordinances

Some of the most effective tools to reduce flood hazards have already been developed as land use planning ordinances. Many local governments have well-thought-out, rational plans for how to safely develop their communities. The problem comes down to the enforcement of these ordinances in the face of increasing land values and development pressures. Land use regulations always seem to be controversial, until flooding happens (Wright and Monday 1996).

FEMA adopted the 100-year flood years ago as the acceptable minimum standard to establish flood hazard zones from which actuarial flood insurance rates are set. Since the 100-year floodplain is a minimum standard, local governments can be more stringent than FEMA to protect their citizens' lives and property. The recent Tillamook County FHMP called for the adoption of a future conditions 100-year floodplain, *i.e.*, the 100-year floodplain anticipated assuming increased runoff from full buildout land use conditions as defined by current land use zoning information (Tillamook County 1996)**.** This effort may establish more conservative floodplain limits and could provide better flood hazard protection, compared to the current regulatory floodplain, which was established nearly 20 years ago and may be in error.

The FHMP also discusses the elevation, relocation or acquisition (condemnation) of flood-prone structures located in known floodplains. Reducing flood risk to insured properties is difficult once structures are built. Enforcing ordinances prohibiting new construction in floodplains could prevent future land use management headaches.

It may also be prudent to consider long-term flood hazard trends — such as sea level rise and land subsidence — in the development of land use ordinances. However, these conditions are difficult to quantify and factor into policy decisions.

Naturally meandering channels and adjacent wetlands typically have more frequent flooding, but lower flood peaks than human-altered streams.

Floodplain Restoration

Unaltered streams in natural lowland valley bottoms often meander through rich forested wetlands. These naturally meandering channels and adjacent wetlands typically have more frequent flooding, but lower flood peaks than human-altered streams and floodplains in similar geomorphic settings (Shields and Cooper 1994). Flood waves traveling through valley streams with natural riparian wetland floodplains have been observed to rise more gradually, to lower elevations, and to last longer than floods occurring on altered floodplains, which produced sharper, higher, and flashy flood conditions (Shields and Cooper 1994). This indicates natural riparian wetlands distribute flood flows and store water for slower release.

Historic mapping of the Tillamook Valley floodplains (See Figure 6-6) and anecdotal accounts of flooding prior to Euro-American settlement (see the Preface) indicate the historic floodplain landscape was much different than today. This information implies that the pastoral landscapes seen today in the river valleys were once heavily vegetated and complex forested lands which flooded often.

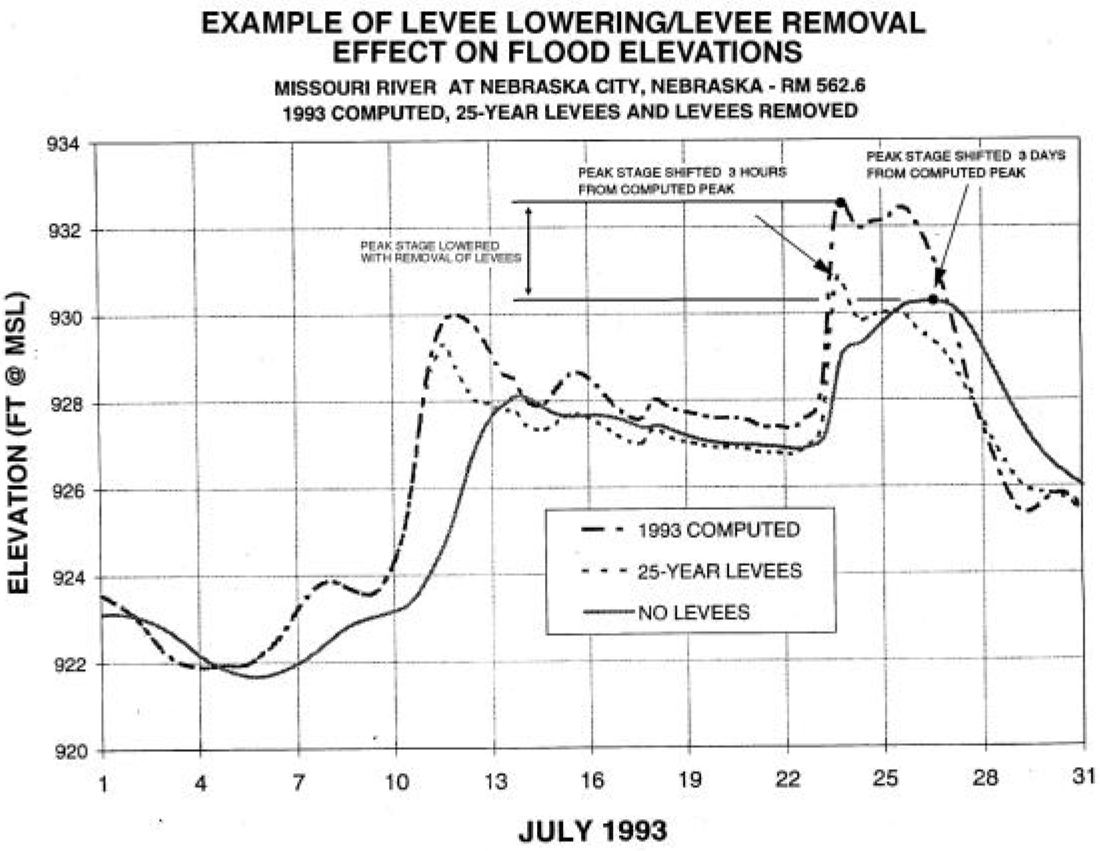


Figure 6-20. Example of the effects of lowering or removing levees on flood elevations.
Source: U.S. Army Corps of Engineers. 1995. Floodplain management assessment of the Upper Mississippi River and Lower Missouri Rivers and tributaries, June.

The reconnection of floodplain riparian areas and intertidal wetlands to the rivers in the Tillamook Bay valleys may help reduce erosion and flood hazards by reducing the height of flood waters currently constrained between levees and dikes. As an example, **Figure 6-20** compares flood elevations along the Missouri River, determined from model simulations by the COE, for three conditions: (1) the actual 1993 flood with existing levees (1993 computed), (2) levees lowered to provide protection only up to a 25-year flood (25-year levees); and, (3) levees removed (no levees) (U.S. COE 1995). The right side of the figure shows that reducing the height of, or removing, levees lowers flood elevations. A similar model study for Tillamook Bay would help to determine if the modification or removal of levees and dikes would reduce flood elevations.

Other national estuary projects have identified wetlands as one of an estuary's most valuable natural assets, providing habitat for fish and wildlife, flood control benefits, shoreline stabilization, open space, and water quality treatment (ABAG 1992). Vegetated tidal wetlands can reduce shoreline erosion by dampening the impact of waves, protecting the shore with plant roots, and acting as a trap for suspended estuarine sediments (ABAG 1992).

Floodplain restoration may benefit the local economy and ecosystem by reducing flood hazards while enhancing natural functions of the floodplains. Implementation of this type of floodplain management practice would support the objectives of the TBNEP Riparian Area and Wetlands Management Action Plan (TBNEP 1996). As with any proposed ecosystem restoration work, a thorough assessment of the economic impacts caused by removing land from agricultural production or residential zoning needs to be done. These economic tradeoffs need to be understood and accepted by local landowners.

Floodplain restoration may benefit the local economy and ecosystem by reducing flood hazards while enhancing natural functions of the floodplains.

The restoration and conservation of floodplain lands presents opportunities to reduce flood hazards while restoring the natural functioning of the river and floodplain. Conceptual measures for floodplain restoration that may be appropriate for Tillamook Bay rivers include: riparian corridor restoration (encouraging the growth of coarse woody vegetation in floodplains to slow the progress of a flood wave); floodplain terrace restoration (increasing the flow area of a degraded river channel while restoring the natural seasonal channel-floodplain interconnections) **(Figure 6-21)**; agricultural levee set-backs (increasing the distance of levees from riverbanks to provide wider floodplain channels while still protecting agricultural lands) **(Figure 6-22)**; and flood detention with bermed storage (lowering, shaping and strengthening levees into low-elevation berms that protect interior lands from frequent flood events, but overflow and detain portions of more severe flooding).

Measures for floodplain restoration that may be appropriate for Tillamook Bay rivers include: riparian corridor restoration, floodplain terrace restoration, agricultural levee set-backs, and flood detention with bermed storage.

Restoring floodplain vegetation can improve water quality by:

- decreasing water temperatures by shading and cooling water;
- reducing suspended sediment through filtration by plant material and reducing flood flow velocities and erosion; and
- removing soluble water pollutants through biological uptake by plant material.

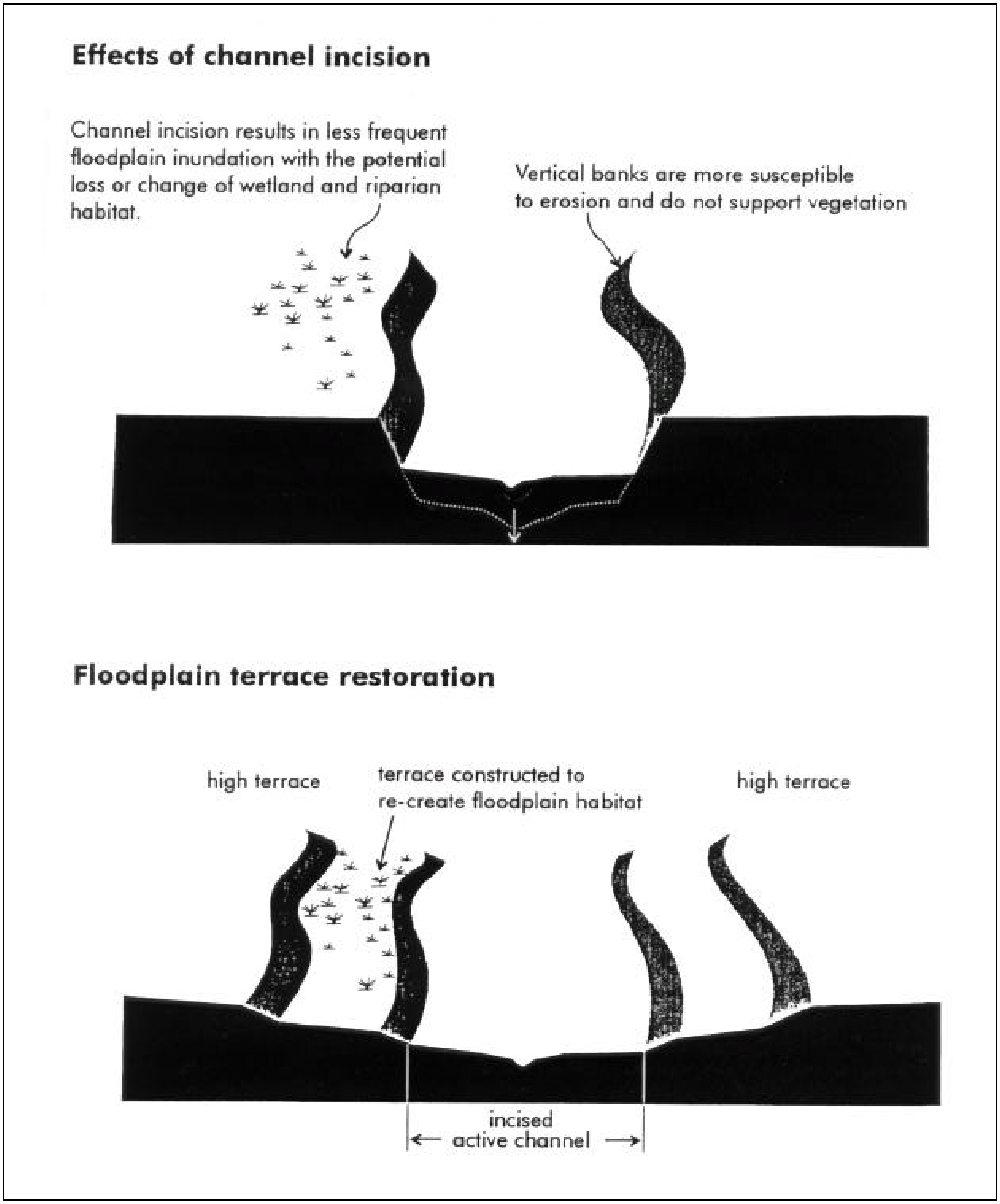


Figure 6-21. Floodplain terrace restoration.
Source: Coulton, K., P. Goodwin, C. Perala, and M. Scott 1996. Evaluation of flood management benefits through floodplain restoration on the Willamette River, Oregon, USA. Prepared at Portland, OR. for the River Network, Portland, OR.

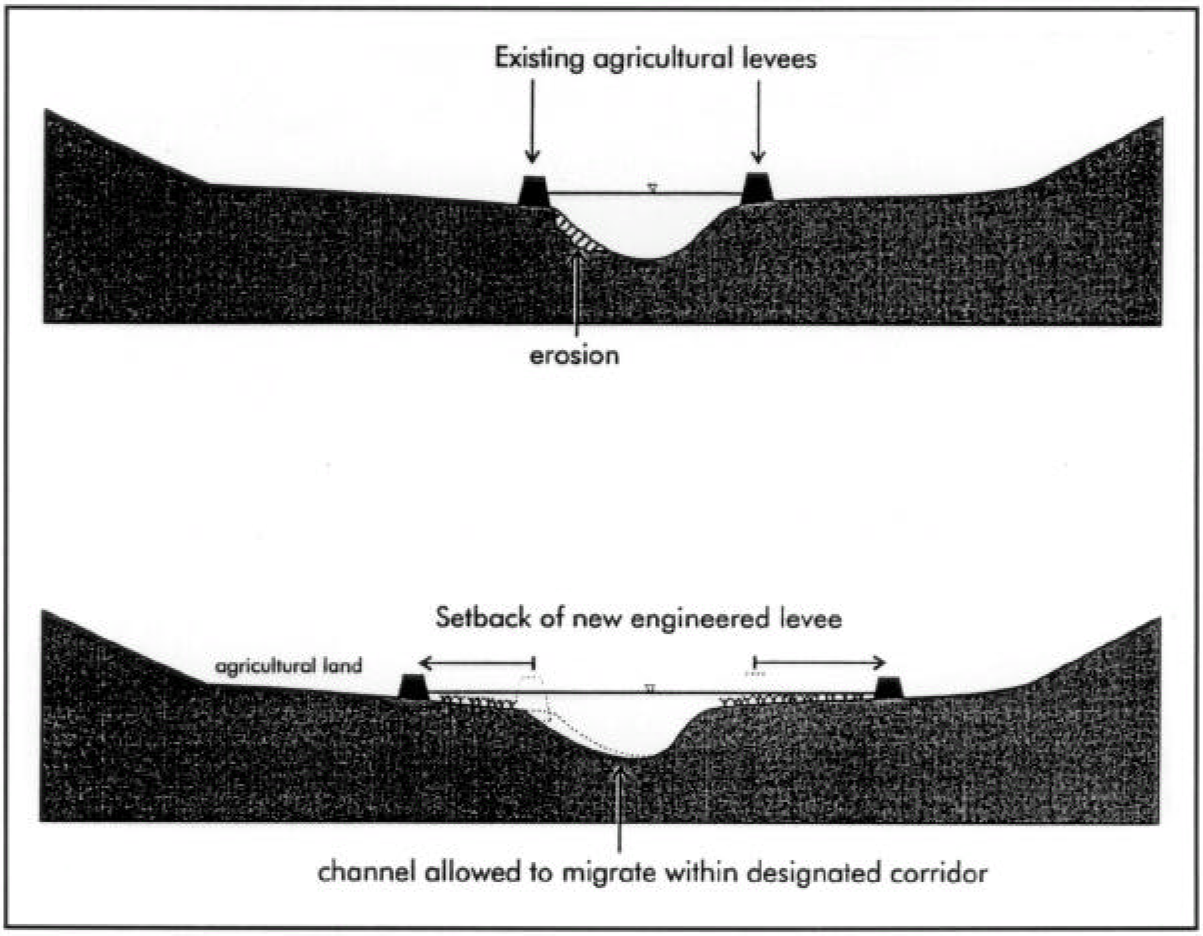


Figure 6-22. Agricultural levee setbacks.
Source: Coulton, K., P. Goodwin, C. Perala, and M. Scott. 1996. Evaluation of flood management benefits through floodplain restoration on the Willamette River, Oregon, USA. Prepared at Portland, OR. for the River Network, Portland, OR.

Restoring overbank floodplain flows can improve water quantities by:

- increasing floodplain groundwater infiltration from the river in the winter, subsequently increasing the seepage of cool groundwater back to the river to augment summer low flows;
- recharging surface aquifers for local water supplies; and
- reducing evaporation losses from stored water supplies in floodplain aquifers.

Establishing acceptable criteria for floodplain restoration is a necessary first step and recognizing the complexity of land ownership in most floodplain lands is vital to assessing the feasibility and success of a restoration project. A possible floodplain restoration approach for Tillamook valley floodplain may involve land assessment criteria to: (1) avoid prime farmland (develop restoration plans to co-exist with productive farmlands); (2) utilize existing floodplain lands (restore low elevation remnant river landscape features); and (3) utilize lands with hydric soils (land areas that support or previously supported wetlands) (Coulton *et al.* 1996). In addition to land ownership, the locations of existing roads and buildings and the economic costs and benefits of implementing these measures should be considered when planning these types of flood management measures. Other non-structural measures, such as flood hazard education, relocation and elevation projects, maintenance and monitoring, flood warning and emergency response are all necessary components of a comprehensive flood management approach and should be pursued in conjunction with ordinances and restoration measures.

Dredging for Flood Control

Historic Dredging for Flood Control

After the January 1972 flood, an estimated 184,000 cubic yards of sediment was removed from the mouths of the Wilson and Trask Rivers in an emergency dredging effort to restore river channel capacity for flood control purposes (Levesque 1980). Soon after the dredging was completed, a flood occurred on December 21, 1972. Observations indicated flood elevations were less in the immediate area of the dredging. However, the December flood was significantly smaller than the previous January flood (approximately 2.9 feet lower on the Wilson River stream gauge). Reviewing this method of flood control, COE determined that continued dredging would not be economically feasible because it would not prevent the effects of tidal flooding and annual dredging would be needed to remove the natural deposits of sediment.

COE determined that continued dredging would not be economically feasible because it would not prevent the effects of tidal flooding and annual dredging would be needed to remove the natural deposits of sediment.

It is important to learn from these past experiences when considering dredging as a means of flood control today. Based on the earlier dredging experience, dredging for flood control may be viable if: (1) dredging is done in upstream river reaches not strongly influenced by tidal flooding, (2) it is accepted that costly repetitive dredging may be needed to maintain a flood control benefit year after year, and (3) reduced flood elevations can be credibly demonstrated in subsequent floods.

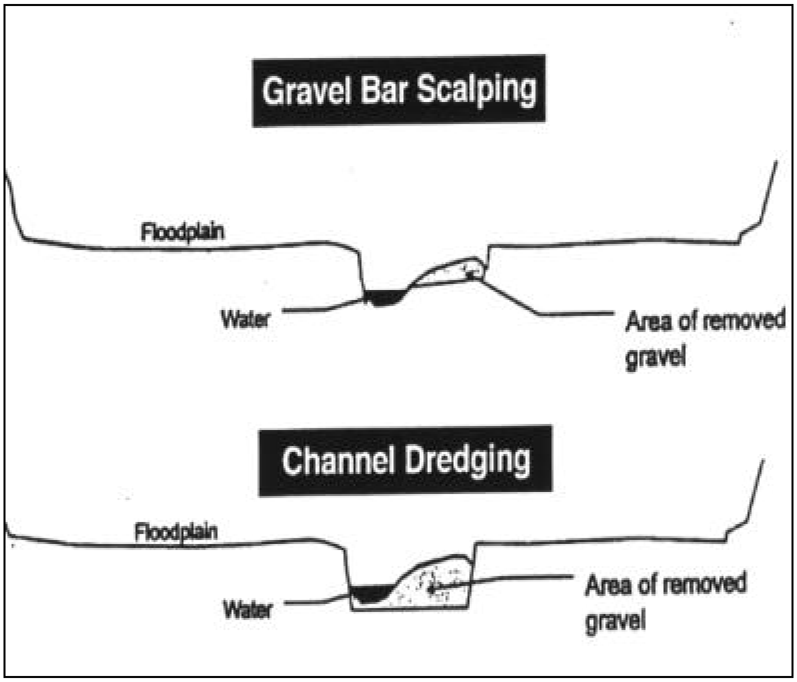


Figure 6-23. Instream gravel removal techniques.
Source: Snohomish County, WA. Public Works. 1996. Skykomish River floodplain management plan, public review draft, August.

Lessons Learned in Another Coastal County

Similar concerns along the Skykomish River in Washington State led to recommendations to allow gravel removal from specific areas of the river as a flood control method. Gravel removal for flood control, including bar scalping and dredging **(Figure 6-23)**, was subsequently investigated in the development of the Skykomish River Floodplain Management Plan (Snohomish County Public Works 1996).

Snohomish County officials determined dredging would be costly, significantly impact fisheries habitat, and potentially alter river processes. It was acknowledged that reducing flood hazard by dredging at one part of a river would likely increase flood hazards downstream. Bar scalping was deemed less detrimental to the river system and was permitted with specific recommendations. These recommendations included: (1) allowing bar scalping only to the extent that gravel removal does not exceed net deposition, (2) requiring monitoring of gravel accumulation and channel changes to better assess bar scalping impacts, and (3) identifying areas where bar scalping should not occur because of likely impacts. Gravel bar skimming typically extracts less sediment than other gravel removal methods. However, this type of removal practice may change the complex cross sections of natural stream channels to wide and flat sections.

Other Considerations

Instream gravel removal may reduce the potential for channel changes in rapidly aggrading reaches and help to maintain a desired channel conveyance capacity. Collins and Dunne (1990) indicate gravel extraction for flood control may be beneficial in aggrading reaches because lower river channel elevations tend to result in lower flood elevations, but they stress that this effort should be just one "part of a program for flood control." Based on the nature and extent of instream gravel removal, the subsequent physical effects of the removal may increase flood control benefits in rapidly aggrading rivers, but may also impact aquatic and riparian habitat by initiating significant changes in river morphology (Sandecki 1989).

Dredging and Tidal Flooding

Dredging the Bay or lower river reaches will not lower flood elevations established by tidal flood effects, and removing a foot of gravel from the Bay or a river bed may not lower flood elevations by one foot. Flood water elevations in the Bay are controlled by tidal flooding effects described earlier and elevations in the rivers' valley reaches are, in turn, controlled by Bay water elevations and the availability of overbank floodplain areas to store flood flows.

Dredging the Bay or lower river reaches will not lower flood elevations established by tidal flood effects.

Since flooding in the Bay occurs over a large area and flood elevations are controlled by the tides and regional weather conditions from the Pacific Ocean, tidal flood elevations in the Bay cannot be reduced by "dredging the Bay." As an example, consider a person standing in a large lake adjacent to where a stream flows into the lake and on the opposite side of the lake outlet. If the lake bottom were to be dredged near the person, he would experience the same water level because the lake water level is not controlled by the depth of the lake but by the conditions at the lake outlet.

In the lower reaches of the Tillamook Bay rivers, flood elevations at the river mouths and in the valleys are heavily influenced by tides and storm surge. These tidal flood effects establish a "base level" or level up to which river flood elevations are the same as flood elevations in the Bay. River flood elevations, higher than the base level for the flood event, are influenced by the cross-sectional area of flow and the hydraulic "roughness" of the flow area ground surface. River channels with wide floodplains and vegetation will typically respond less to a lowering of the river bed than narrow channelized rivers. In this respect, gravel removal for flood control may be more beneficial at constricted sections of rivers (that have been historically altered with levees or dikes) and upstream of coastal flooding effects.

Gravel Removal Impacts

Research into the effects of gravel removal on river morphology is still limited, but findings have indicated some river channels do have a certain amount of natural resiliency and may be capable of accommodating a degree of sediment removal. However, site-specific data should be obtained and physical responses should be carefully monitored.

Changes in a river channel gradient from instream excavation may change the transport and deposition rates of river sediments, and the location of subsequent deposits.

Changes in a river channel gradient from instream excavation may change the transport and deposition rates of river sediments, and the location of subsequent deposits (Collins and Dunne 1990). River sediments will tend to deposit in excavated reaches, resulting in excess stream energy downstream of the excavated area and erosion of the streambed. Artificially widened rivers may begin to act as sediment traps, requiring increasing gravel removal to maintain pre-excavation channel capacities (Brookes 1988).

These disruptions may result in downstream or upstream incision (down cutting) from the excavated area, as the river seeks dynamic equilibrium. Incision from gravel removal has been known to undermine river flood control works (Soil & Water 1985). Dredging permits issued by the COE on the Mississippi River do not allow dredging in the vicinity of revetments or dikes (Lagasse *et al*. 1980).

Instream sand and gravel removal may also coarsen the bed sediments in streams, significantly impacting anadromous fish.

Instream sand and gravel removal may also coarsen the bed sediments in streams, significantly impacting anadromous fish, because these fish require certain sizes of gravels for spawning (Allen 1969). Spawning fish have been observed to be capable of moving gravel up to a median size of approximately 10% of their body length (Kondolf and Wolman 1993). The removal of smaller gravels, of higher commercial value, may leave gravels too large for spawning fish to move. Other significant impacts to fisheries from instream dredging are the destruction of bottom-dwelling organisms and temporary water quality problems from turbidity (ABAG 1992).

Instream sediment removal may also cause river channel changes, threatening waterway crossing structures, such as bridges, pipelines or riverbank structures. The potential for damage to public transportation infrastructure is of such concern that some state transportation agencies are required to be informed of any instream gravel removal operation within one mile of a state highway bridge. Similarly, among the sand and gravel mining regulations developed for the C.O.E. (Boyle 1980), one condition stipulates instream excavations should be located far enough downstream that a grade of 1%, starting from the midpoint of the planned excavation depth, would intercept the existing channel bed at least 200 feet (60 m) downstream of a waterway structure.

Special issues need to be addressed for dredging in estuaries and tidal river reaches.

Special issues need to be addressed for dredging in estuaries and tidal river reaches. Waterway modifications in these areas may change local tidal currents or river flow patterns and, in turn, change sediment deposition, erosional processes (ABAG 1992), and vegetation communities. Damages from wave action may increase during storm events at high tides in deeper dredged waters, and the extent of the freshwater/saline water interface may shift in estuaries and river deltas, affecting agricultural or municipal water intakes, fisheries, and natural sedimentation processes.

Dredging Policies

Research by Collins and Dunne (1990) concluded that thorough policies have rarely been developed for identifying and managing the effects of instream gravel removal. Oregon and California do not independently monitor quantities extracted from rivers. Few states have limits to instream gravel removal as a function of hydrology or channel morphology, and most have no systematic monitoring program. Gravel removal permits issued by the COE on the Mississippi River since the 1940s have not restricted the volume of gravel extraction, only the locations of extraction (Lagasse *et al.* 1980).

Replenishment Rates

Ideally, the volume of gravel removed from a river, whether it is for non-commercial purposes such as flood control or for commercial purposes, should be sustainable; *i.e.* the removal rate should not exceed the replenishment rate. Exceeding natural replenishment conditions may throw the river system out of “balance” and lead to pronounced erosion, meandering and other effects. The relationship between sediment supply and transport varies depending on the geologic and hydrologic environment. Rivers with high rates of aggradation may be better suited to sediment extraction, while those in a state of dynamic equilibrium could suffer dramatic impacts (Collins and Dunne 1990).

Instream gravel removal case studies reviewed by Collins and Dunne (1990) indicate channel degradation can extend several miles upstream from the removal site, if the extracted gravel volume exceeds the natural supply. Therefore, it is important to establish river sediment removal rates compatible with the sustainable yield of the river. In many cases, a uniform annual replenishment rate is reasonably estimated and a uniform extraction rate is allowed year after year. However, actual annual river sediment yields vary considerably from year to year and may fall short of extraction rates and lead to instability in the river. To guard against this problem, state regulatory agencies in Washington have proposed limiting gravel extraction to half of the estimated replenishment rate (Bates 1987). By limiting gravel removal to conservative amounts less than the annual replenishment rate, disturbed portions of a river are more likely to remain as sediment transport reaches and significant geomorphic changes to the river and floodplain are less likely to occur.

One of the greatest management concerns and costs associated with navigation dredging projects in estuaries and rivers is disposal of the dredged materials.

Dredged Material Disposal

One of the greatest management concerns and costs associated with navigation dredging projects in estuaries and rivers is disposal of the dredged materials. Waterway excavations for flood control may also present a similar concerns if the excavated sediments are not acceptable for commercial sand and gravel uses. If floodplain management measures result in the removal of dikes or levees, disposal of these materials may also present a management concern. An existing dredged material disposal plan for Tillamook Bay-stipulates that certain shoreline areas be used for disposal. However, since volumes of material are relatively small, most materials are currently deposited in Bay navigation channels that have swift currents to disperse dredged sediments (Ascher, T. pers. com. 1997). This method is termed flow-lane disposal.

The role of the federal government in maintenance dredging assistance may be changing.

The traditional role of the federal government in maintenance dredging assistance for Tillamook Bay and other Oregon coastal estuaries may be changing due to budget cuts, government reorganization and judicial actions (69th Oregon Legislative Assembly 1997). If state and local interests will be required to bear more of the costs of dredging, innovative alternatives to the high cost of disposal may become attractive. Management considerations for dredged material disposal may include a combination of different placement options: in ocean, estuary, or the “beneficial reuse” of dredged material for habitat restoration in upland/wetland environments (U.S. EPA 1996).

Dredged Material for Estuarine Habitat Restoration

Insights from another national estuary project may be helpful for developing sediment management strategies in Tillamook Bay. Specific objectives of the San Francisco Estuary Project are to “determine the behavior and fate of sediments in the estuary and adopt policies to manage their modifications” and to “encourage the reuse of dredged material for projects such as wetland creation or maintenance, levee maintenance, landfill cover, and upland building material where environmentally acceptable” (U.S. EPA 1996).

The beneficial reuse of dredge materials for habitat restoration in tidal areas needs to be done with an understanding of the relationships between equilibrium tidal channel geometry and tidal prism volumes, and the natural geometry of estuarine features that will tend to evolve over time (Coats *et al*. 1995). For example, increasing the tidal prism of an estuary by removing levees and restoring tidal marshes will increase the volume of water exchanged over a tidal cycle and may increase the opening sizes of tidal inlets and channels.

Natural tidal marshes are sediment sinks.

Natural tidal marshes are sediment sinks. Dikes and levees constructed on tidal marsh lands have reduced the natural ability of estuary marshes to remove sediments by increasing the concentration of suspended riverine sediments transported directly into the Bay. Sediments deposited in non-vegetated sloughs and mud flats are likelier to be resuspended with wind wave action and transported into deeper navigable portions of an estuary than if they were deposited in vegetated tidal marshes. For estuaries experiencing a rising sea-level, restored tidal marshes can serve as long-term sediment sinks, keeping pace with the changing sea-level.

Many tidal marsh restoration areas are former marshes that have subsided from soil compaction caused by dewatering. Removing levees and restoring tidal flows to these subsided land areas can result in significant short-term sediment deposition opportunities. For example, observations of California tidal marsh restoration projects under these conditions have shown deposition rates of up to 1.0 foot per year (Williams, P. pers. com. 1997). With 100 acres of tidal marsh restored, this may correspond to a first year deposition volume of 100 acre-feet or approximately 200,000 cubic yards of sediment. This amount of sediment is naturally removed from the total amount of recirculated estuarine sediment and can help reduce river sediment deposition to maintain desired flood conveyance and reduce the need for maintenance dredging.

100 acres of tidal marsh restored may correspond to a first year deposition volume of approximately 200,000 cubic yards of sediment.

Subsided marsh lands can also be used for the direct deposit of dredged materials, bringing marsh elevations back up to former elevations and restoring the natural function of these areas in a shorter time period than natural sedimentation. Ongoing investigations by the TBNEP into Tillamook Bay circulation patterns, sediment transport processes, and historic marsh characteristics will help to identify the viable habitat restoration technique(s) for this particular ecosystem.

Flood Management Funding Opportunities

In this time of limited federal spending, funding opportunities for flood management are difficult to secure. Funding generally tends to be more available for communities that can show they are making efforts to resolve their own problems. The recent Tillamook County Flood Hazard Mitigation Plan (FHMP) represents this type of effort. Since the February 1996 flood, nearly $1 million in grants has been obtained to construct “cowpads” on high elevation areas, for high water refuges, and 26 homes have been elevated in the County (Ascher, T. pers. com. 1997). The County needs to further develop details of the FHMP to obtain more grant funding (Levesque, P. pers. com. 1997). Creative combinations of flood control and floodplain management measures may also leverage additional funding. Brief discussions of FEMA and COE funding opportunities for flood management are provided below.

Since the February 1996 flood, nearly $1 million in grants has been obtained to construct “cowpads” on high elevation areas, for high water refuges, and 26 homes have been elevated in the County.

FEMA Funding Opportunities

Since 1990, a FEMA program has actually rewarded communities for taking actions beyond the minimum standards of the NFIP to reduce flood hazards. The Community Rating System (CRS) acknowledges flood hazard reduction through better mapping and regulation efforts by reducing annual flood insurance premiums for community residents. From an economic viewpoint, the community cost of implementing actions to reduce flood hazards can be reduced by taking part in the CRS and lowering flood insurance policy holders' premiums. Communities can also obtain CRS credits by providing public education on flood hazards, instituting flood damage reduction measures (such as flood proofing or relocating homes and businesses out of the floodplain), and restoring natural floodplain functions.

Enactment of Title V of the National Flood Insurance Reform Act of 1994 creates significant opportunities for flood mitigation grant funding. The act authorizes FEMA to provide Flood Mitigation Assistance (FMA) to reduce or eliminate the long-term flood risk to insurable structures. The FMA pre-disaster grant program encourages funding applications that propose to acquire, relocate, demolish, or elevate insured structures (Federal Register 1997).

Even the COE has begun to turn a "shade of green" by acknowledging it may be more cost-effective to keep people out of the floodplain and let Nature run her course.

Similar efforts are encouraged through another provision of the 1994 Act, termed the Increased Cost of Compliance (ICC) coverage. The ICC coverage would provide $15,000 to property owners who purchase or renew flood insurance after June 1, 1997 and agree to pay an additional annual premium of $75. The funding would target insured structures that have been substantially or repetitively damaged (FEMA 1997).

COE Funding Opportunities

Monetary incentives for non-structural floodplain management have been proposed in the Water Resources Development Act of 1996 by providing a range of federal/non-federal cost-share for flood management projects from 75/25 to 50/50 (Mahan 1997). Even the COE has begun to turn a "shade of green" by acknowledging it may be more cost-effective to keep people out of the floodplain (Weisman 1997) and let Nature run her course.

The COE General Investigation authority can provide the vehicle for COE involvement in large and complex basin studies involving ecosystem restoration, floodplain management and/or watershed analysis. A project sponsor is needed to obtain Congressional endorsement of the project. Current cost sharing for ecosystem restoration projects is 50/50 (federal/non-federal) for the feasibility stage, 65/35 for the implementation stage and 100% non-federal for project operation, maintenance, repair, rehabilitation, and replacement. Specific avenues for funding waterway projects in the Tillamook Bay area may be available through Section 206, which authorizes the COE to construct projects that improve the quality of the aquatic environment, or Section 1135, which may be applicable to environmental restoration to improve floodplain conditions associated with the earlier construction of COE levees along the Tillamook valley rivers.

More traditional flood control may also be pursued under the Continuing Authorities Program without the need for Congressional approval. Section 205 projects involve the construction of flood proofing or flood damage reduction structures such as levees and possibly set-back levees in the Tillamook system. COE may also become involved in gravel-related restoration activities (Oregon Insider, 1994).

Recommendations

Floodplain Management

- Pursue the recommendations in the 1996 Tillamook County Flood Hazard Mitigation Plan (FHMP). The FHMP presents a sound combination of policy and technical recommendations to reduce flood hazards in the County.

- Prohibit new development in known flood hazard areas. It is more cost-effective to avoid creating flood hazards than to mitigate for them. As advocated in the Tillamook County FHMP, new development should be prohibited in known flood hazard areas and existing developments in these areas should be protected.

- Perform a feasibility study to identify opportunities for floodplain restoration. Evaluate findings from the TBNEP demonstration grant project assessing the feasibility of restoring estuarine wetlands by breaching dikes. Explore opportunities for floodplain restoration for flood hazard reduction in non-tidal portions of the river valleys.

- Educate the public about the historic function of the rivers and their floodplains. Most people are not aware of the “way things were” before settlement in the Tillamook Bay river valleys. If the public understood the reasons why the floodplains are so fertile and how floods used to shape the landscape, floodplain management measures, such as relocation and restoration, might become more acceptable.

Flood Control

- Reconsider repairing and replacing repeatedly damaged agricultural levees and dikes. The repeated costs of repairing some flood control structures may exceed the one-time cost of setting-back or removing that structure and changing the land use that the structure protected from flooding. Maintenance considerations could be expanded to include restoring aquatic habitat on the river-side of the dike as a part of dike maintenance, and evaluating alternatives to repairing dikes after future flood damages occur, such as removing, lowering, or setting back the structures, with regard for existing homes and roads.

- Consider a demonstration project involving gravel bar skimming for flood control. Research by others has identified gravel bar skimming as less damaging than channel dredging. This work would be more effective for controlling flood elevations if done upstream of potential tidal flooding effects and along constricted river reaches.

Floodplain Modeling

- Update statistical flood flow estimates for the Tillamook Bay rivers. Roos (1995) calls for reevaluating and updating flood hydrology every 20 to 30 years. Recurrence interval flood flow estimates from the 20-year-old FEMA flood insurance study for Tillamook County may be grossly in error. Data from the recently installed stream gauges on the Tillamook, Miami, Trask, and Kilchis Rivers can provide valuable information for this effort.

- Adopt and update the 1970s FEMA topographic work maps for floodplain modeling purposes. Irrespective of the model(s) selected to analyze flooding, detailed topographic data will be a basic need. Topographic mapping of the valley floodplains is available from these studies at a scale of one inch equals 1,000 feet, with 5-foot contour intervals and numerous spot elevations **(Figure 6-24)**. Significant floodplain land use changes since the date of the original mapping could readily be surveyed and incorporated into the mapping to develop current topographic information for developing floodplain management alternatives.

- Apply a modern computer model to analyze the complex flood processes in the Tillamook Bay rivers. In the intervening 20 years since the Tillamook Bay floodplains were first delineated in the Flood Insurance Study, there has been explosive growth in computer technology and sophistication of computer models to represent complex flood processes. A key consideration for flood modeling of Tillamook Bay rivers involves accounting for the unsteady flow characteristics of tidal and storm surge influences on flooding and the effects of floodplain storage on peak flows. These flood characteristics and their effects cannot adequately be analyzed using steady flow computer models, such as the COE HEC-2 model, which is limited to analyzing flooding for only one specific (steady) flow at a time.

- Select a computer model that can integrate flood flow simulation with a fate and transport analysis of the appropriate water quality parameters for Tillamook Bay. The Bay’s water quality priority problem is bacterial contamination. There have been questions about whether coliform bacteria are an appropriate indicator of water quality, and the relative contributions of human and natural bacterial sources are not well understood (Tillamook Bay National Estuary Project 1995). Water quality research needs should be closely coordinated with the selection of a floodplain model.

- Develop floodplain models with the initial intent of comparing the relative effects of flood management alternatives. Floodplain elevation estimation is highly uncertain because of: (1) the complexity of the streamflow process; (2) the lack of (and difficulty of obtaining) adequate physical data; and (3) the inherent limitations of existing equations and models which can only approximate flood processes. Modeling would be a valuable tool, used to quickly assess the relative effectiveness of flood management alternatives.

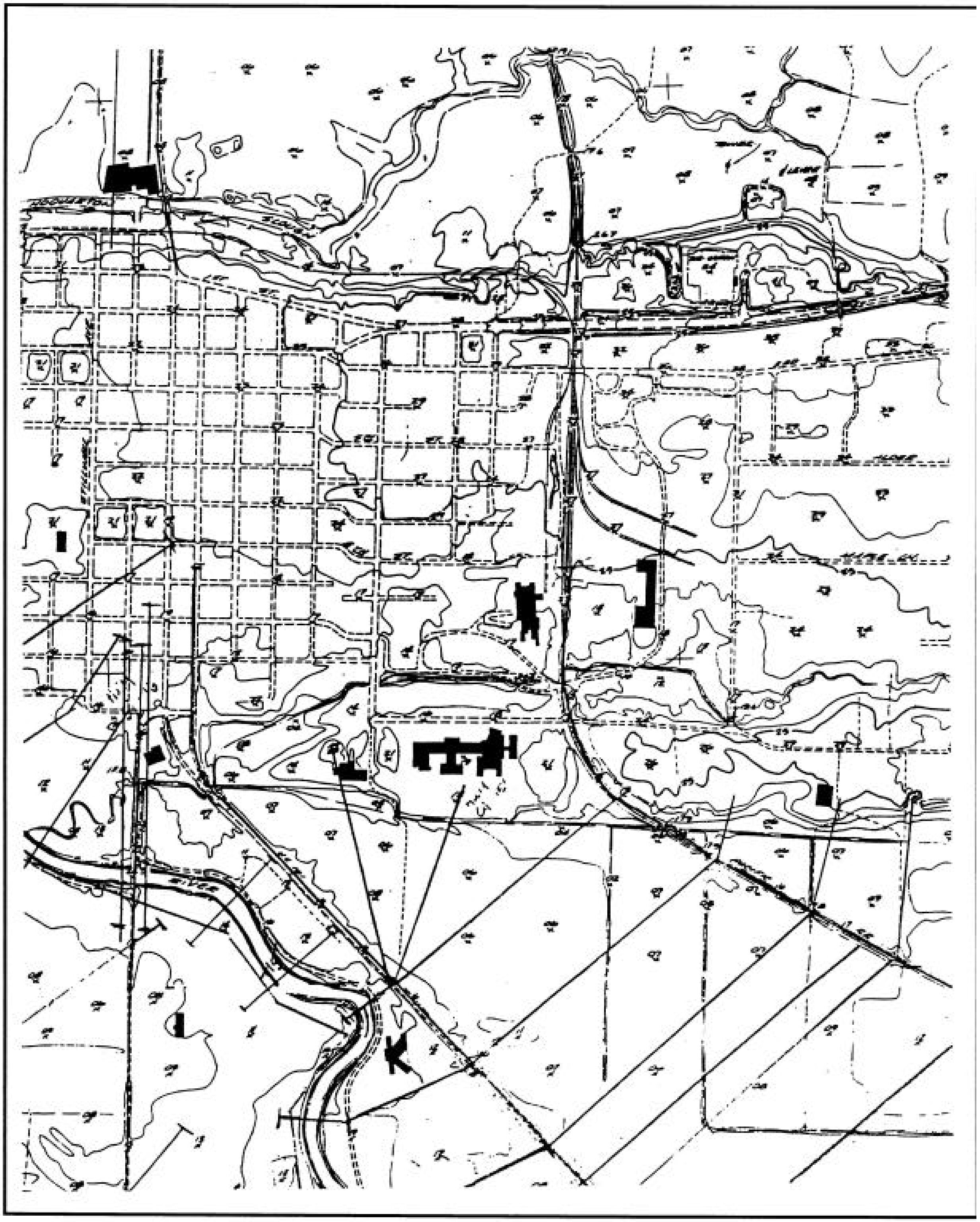


Figure 6-24. Example of FEMA topographic work maps for Tillamook County.

- Identify the floodplain model "end users" and involve them in project development from the start. Perhaps the most important consideration in the development and application of models as management tools is that the end user of the model have the interest and ability necessary to use the model over time.

Resource Monitoring

- Adopt a strategic resource monitoring program similar to other National Estuary Projects **(Figure 6-25)**. The San Francisco Estuary Project advocated the development of a "long-term, regional monitoring program and the support of additional basic research" (ABAG 1992). The program is intended to be implemented as part of the CCMP and will help with periodic assessments of the CCMP effectiveness.

- Expand the Baykeepers/Streamkeepers volunteer citizen monitoring program to include measurements helpful for flood management. Field measurements of high water marks after floods and photographs before, during, and after flooding can be extremely helpful for calibrating floodplain models. Interested county citizens could do this with proper training.

- Establish river channel monitoring sections at bridge locations, especially in the proximity of proposed waterway modifications. Existing bridges provide good access for repetitive channel measurements and can indicate river channel bed changes over time.

- Expand the gravel monitoring work by the TCSWCD and the NRCS to include other rivers in the Tillamook Bay area. Ongoing work by the TCSWCD and the NRCS on the Kilchis River includes the establishment of river cross-sections and repetitive measurements after floods to assess channel changes (Tillamook County SWCD 1997). If these efforts are expanded to other areas of flood concern, adequate topographic information will become available to define and refine flood conditions.

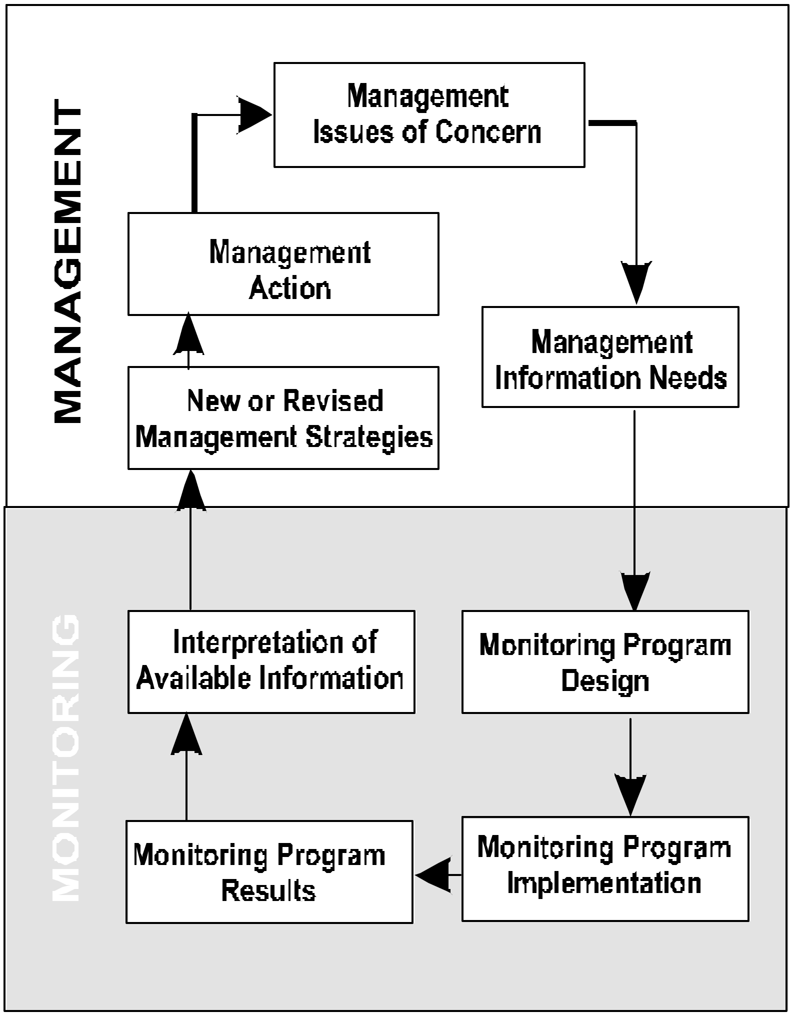


Figure 6-25. Monitoring and resource management relationships. *Source:* Adapted from Chesapeake Bay Water Quality Monitoring Program. 1989.

Sand and Gravel Management

- Require more comprehensive environmental impact monitoring of instream gravel removal. There has been no organized program to assess the environmental impacts associated with gravel removal in Oregon (OWRRI 1995). The available literature on instream gravel removal indicates that the volume of gravel is rarely adequately documented. This information would help with estimating river sediment replenishment rates and establishing sustainable sediment removal rates.

- Require more accurate boundary and volume measurements of instream gravel removal operations. The boundaries for instream gravel removal are typically referenced to a variable reference location, such as the channel centerline or a channel bank, which may change from year to year. It would be better to reference an absolute datum such as consistent elevation reference locations found on bridges, survey benchmarks, or other permanent locations. Little information exists on the volume of sediments removed from rivers. These data would provide significant input for estimating natural sediment replenishment rates for the purpose of establishing sustainable extraction rates.

- Promote aggregate recycling. An increasing trend in aggregate consumption is forecast for Tillamook County. Aggregate recycling is reducing the demand for virgin aggregate in Oregon. Approximately 4% of the State's aggregate was recycled in 1993 and forecasts indicate up to 6% of Tillamook County's total consumption may be recycled by 2050 (Whelan 1995). Perhaps gravel forest roads in the Tillamook Forest may be decommissioned in a manner conducive to recycling.

- Develop a comprehensive Tillamook Bay gravel management plan. A recent gravel management plan for a coastal river in California involved a comprehensive approach to evaluating management of this resource (Philip Williams & Associates *et al.* 1996). The resulting management plan provided long-term guidelines for protection of riverine resources with specific recommendations for accomplishing management goals. This work's primary management issues were to: (1) determine the volume of gravel that could be safely extracted without causing significant biological or geomorphic changes; (2) identify the optimum method and location for gravel extraction and the distribution of mining activities that would minimize impacts on riparian habitat; (3) identify monitoring activities that would identify gravel extraction impacts; and (4) identify non-stream sources of gravel and the associated market demand for these resources, as opposed to instream sources.

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Appendices

Appendix 3-A
Salmonid habitat requirements for Northern Oregon coastal streams

Appendix 3-B
Common and scientific names of fish recorded for Tillamook Bay, Oregon

Appendix 4-A
Summary of selected studies and management plans regarding Tillamook Bay and its watershed

Appendix 4-B
303(d) list. Detailed text describing the water bodies in the Tillamook Bay Watershed that are on the State’s list of Water Quality-Impaired Waters

Appendix 4-C
Maps of the waters listed, and the water bodies of concern for bacteria, temperature, flow modification, habitat modifications, sedimentation, nutrients, pH, and dissolved oxygen

APPENDIX 3-A

Salmonid habitat requirements for Northern Oregon coastal streams

Salmonid Habitat Requirements for Northern Oregon Coastal Streams

	Spawning (including upstream migration)									
	Migration	**Spawn timing**	**Location**	**Substrate size**	**Water depth**	**Water velocity**	**Dissolved oxygen**	**Spawning water temp**	**Percent fines tolerable**	**Notes**
Chinook Fall	Sept–Dec	Oct–Jan	Mainstem and large tributaries	Pea to orange (1.3–10.2 cm)	Extremely variable 0.05–7 m	0.1–1.5 m/s; max is 2.4 m/s	> 5 mg/l	5.6–13.9°C	Fines (<6.4 mm) less than 25% of substrate	Large body size limits movement over barriers
Chinook Spring	Apr–Jun	Sep–Oct	Upper mainstem streams	Pea to orange (1.3–10.2 cm)	Extremely variable 0.05–7 m	0.21–1.5 m/s; max is 2.4 m/s	> 5 mg/l	5.6–13.9°C	Fines (<6.4 mm) less than 25% of substrate	Require deep water for travel, pools for summer habitat
Coho	Sep–Jan	Oct–Jan	Small tributaries	Pea to apple (1.3–9.0 cm)	0.18–1 m	0.08–0.11 m/sec; max is 2.4 m/s	> 8 mg/l	4.4–14°C	Fines (<6.4 mm) less than 25% of substrate	Primary target for many sport fishermen
Chum	Nov–Dec	Nov–Dec	Lower mainstem and tributaries	Pea to orange (1.3–10.2 cm)	13-50 cm; ideal 21 cm	0.21–0.83 m/s; max is 2.4 m/s	> 5 mg/l; above 80% saturation is best	7.2–12.8°C	Fines (<6.4 mm) less than 25% of substrate	Strong swimmer but doesn't jump
Steelhead winter	Nov–May	Jan–May	Small tributaries with moderate gradient	Pea to apple (1.3–9.0 cm)	> 18 cm	< 2.4 m/s	> 5 mg/l	3.9–9.4°C	Fines (<6.4 mm) less than 25% of substrate	Late fish seem to prefer mainstem and large tributary

	Spawning (including upstream migration)									
	Migration	**Spawn timing**	**Location**	**Substrate size**	**Water depth**	**Water velocity**	**Dissolved oxygen**	**Spawning water temp**	**Percent fines tolerable**	**Notes**
Steelhead summer	May–Jul	Jan–Apr	Small tributaries with moderate gradient	Pea to apple (1.3–9.0 cm)	> 18 cm	< 2.4 m/s	> 5 mg/l	3.9–9.4°C	Fines (<6.4 mm) less than 25% of substrate	Athletic swimmer
Sea run cutthroat trout	Jun–Oct	Dec–Feb	Small headwater tributaries, 1st and 2nd order streams	Pea to golf ball (0.5–7.5 cm)	0.01–1 m; 10–15 cm best	0.11–0.90 m/s; max is 2.4 m/s	> 5 mg/l	6–17°C; best is 10°C	Fines (<6.4 mm) less than 25% of substrate	May spawn more than once

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Salmonid habitat requirements for northern Oregon coastal streams

	Incubation		**Rearing**						**Status**
	Incubation temp.	**Fry emerge**	**Fry habitat**	**Juvenile habitat**	**Preferred temp.**	**Freshwater residency period**	**Estuary residency period**	**Notes**	**1996 status**
Chinook fall	0.0–20°C; best 5–14.4°C	Mar–May	Stream; river edges	Deeper water in main river channel	7.3–14.6°C Growth stops at 20.3°C; lethal at 25.2°C	Days to 2 or 3 months Fall smolt	Extensive; 5–6 months April-Oct	Estuaries play a vital role in survival of young	Healthy and stable
Chinook spring	0.0–20°C; best 5–14.4°C	Feb–Mar	Stream; river edges	Deeper water in main river channel	7.3–14.6°C Growth stops at 20.3°C; lethal at 25.2°C	Days to 2 or 3 months Fall smolt	Extensive; 5–6 months April-Oct	Large body size limits movement over barriers	Depressed
Coho	4.4–13.3°C	Feb–June	Backwater pools and stream edges	Pools in summer; off channel alcoves, ponds, dam pools with complex cover in winter	11.8–14.6°C Growth stops at 20.3°C; lethal at 25.8°C	One year Spring smolt	Move through 2–9 days	Low pH (<5.01) can be lethal to alevins	State lists as “sensitive”
Chum	4.4–13.3°C	Late Mar–Apr	Move directly into estuary	High sediment levels (15.8–54.9 g/l) kills juveniles	6.7–14.6°C Growth stops at 20.3°C Lethal at 24.1°C	Hours to a few days, leave quickly Spring smolt	2–32 days	Use estuaries immediately for food and adjustment	Depressed
Steelhead winter	4.4–13.3°C	May–June	Stream edges	Pools, riffles and runs of tributary. Streams, complex habitat with LWD preferred	7.3–14.6°C. Growth stops at 20.3°C; lethal at 24.1°C	2–3 years Spring smolt	Move through in days	Good habitat = small and large wood complexity	Depressed

	Incubation		**Rearing**						**Status**
	Incubation temp.	**Fry emerge**	**Fry habitat**	**Juvenile habitat**	**Preferred temp.**	**Freshwater residency period**	**Estuary residency period**	**Notes**	**1996 status**
Steelhead summer	4.4–13.3°C	May–June	Stream edges	Pools, riffles and runs of tributary. Streams, complex habitat with LWD preferred	7.3–14.6°C. Growth stops at 20.3°C; lethal at 24.1°C	2–3 years Spring smolt	Move through in days	Summer steelhead require deep cool pools to live in before spawning	Hatchery fish — depressed
Sea run cutthroat trout	6.1–17.2°C	Mar–May	Stream edges and backwater pools, large wood important	Prefer pools but are often displaced by coho or steelhead; low velocity pools and side channels in winter	9.5–12.9°C. Growth stops at 20.3°C; lethal at 23.0°C	2–4 years Spring smolt	Used extensively as adults before upstream migration	Rearing in estuary is common	Depressed

Abbreviations used: C — Celsius (0°C = 32°F, 10°C = 50°F, 20°C = 68°F); centimeters (2.54 cm = 1 inch); LWD — large woody debris; m — meters (1 m = 3.3 ft); max — maximum; mg/l = milligrams per liter (2835 mg = 1 ounce, 1 liter = 1.06 quarts); mm — millimeter (25.4 mm = 1 inch); m/s —meters per second.

APPENDIX 3-B

Common and scientific names of fish recorded for Tillamook Bay, Oregon

Appendix 3-B. Common and Scientific Names of Fish Recorded for Tillamook Bay, OR.

Family and Common Name	Scientific Name
Petromyzonidae	
Pacific lamprey	*Lampetra tridentata*
Rajidae	
longnose skate	*Raja rhina*
Acipenseridae	
green sturgeon	*Acipenser medirostris*
Clupeidaae	
Pacific herring	*Cluea harengus*
American shad	*Alosa sapidissima*
Engraulidae	
northern anchovy	*Engraulis mordax*
Salmonidae	
chum salmon	*Oncorhynchus keta*
chinook salmon	*Oncorhynchus tshawytscha*
coho salmon	*Oncorhynchus kisutch*
pink salmon	*Oncorhynchus gorbuscha*
sockeye salmon	*Oncorhynchus nerka*
steelhead trout	*Oncorhynchus mykiss*
cutthroat trout	*Oncorhynchus clarkii*
Osmeridae	
surf smelt	*Hypomesus pretiosus*
longfin smelt	*Spirinchus thaleichthys*
Atherinidae	
jacksmelt	*Atherinopsis californiensis*
topsmelt	*Atherinops affinis*
Gadidae	
Pacific tomcod	*Microgadus proximus*
Gasterosteidae	
tubesnout	*Aulorhynchus flavidus*
threespine stickleback	*Gasterosteus aculeatus*
Syngnathidae	
bay pipefish	*Syngnathus griseolineatus*
Embioticidae	
shiner perch	*Cymatogaster aggregata*
pile perch	*Damalichthys vacca*
redtail surfperch	*Amphistichus rhodoterus*
walleye surfperch	*Hyperprosopon argenteum*
silver surfperch	*Hyperprosopon elligticum*
striped surfperch	*Embiotoca lateralis*
white seaperch	*Phanerondon furcatus*
Stichaeidae	
high cockscomb	*Anoplarchus purpurescens*
snake prickleback	*Lumpenus sagitta*
Pholididae	
penpoint gunnel	*Apodichthys flavidus*
saddleback gunnel	*Phlois ornata*

red gunnel	*Pholis schultzi*
rockweed gunnel	*Xerepes fucorum*
Anarhichadidae	
wolf-eel	*Anarrhichthys ocellatus*
Ammodytidae	
Pacific sandlance	*Ammodytes hexapterus*
Gobiidae	
arrow gobie	*Clevelandia ios*
Liparididae	
ringtail snailfish	*Liparis rutteri*
slipskin snailfish	*Liparis fucensis*
Scorpaenidae	
black rockfish	*Sebastes melanops*
blue rockfish	*Sebastes mystinus*
copper rockfish	*Sebastes caurinus*
Anoplopomatidae	
sablefish	*Anoplopoma fimbria*
Hexagraammidae	
lingcod	*Ophiodon elongatus*
kelp greenling	*Hexagrammos decagrammos*
rock greenlling	*Hexagrammos superciliosus*
Cottidae	
staghorn sculpin	*Leptocottus armatus*
buffalo sculpin	*Enophrys bison*
padded sculpin	*Artedius fenestralis*
prickly sculpin	*Cottus asper*
tidepool sculpin	*Oligocottus maculosus*
silver spotted sculpin	*Blepsias cirrhosus*
sharpnose sculpin	*Clinocottus acuticeps*
cabezon	*Scorpaenichthys marmoratus*
brown Irish lord	*Hemilepidotus spinosus*
red Irish lord	*Hemilepidotus hemilepidotus*
Agonidae	
pricklebreast poacher	*Stellerina xyosterna*
warty poacher	*Occella verrucosa*
Bothidae	
pacific sanddab	*Citharichthys sordidus*
Pleuronectidae	
English sole	*Paophrys vetulus*
sand sole	*Psettichthys melanostictus*
butter sole	*Isopsetta isolepis*
starry flounder	*Platichthys stellatus*

Source: Forsberg , B., J. Johnson and S. Klug. 1975. Identification, distribution and notes on food habits of fish and shellfish in Tillamook Bay, Oregon. Fish. Comm. of Oregon, contract rep. no. 14–16–0001–5456 RBS.
85 pp.

APPENDIX 4-A

Summary of Selected Studies and Management Plans Regarding Tillamook Bay and Its Watershed

Study Title: Tillamook Bay bacteria study background data review report
Citation: Jackson, J., Glendening, E., 1982, ODEQ
Years Data Collected: 1962–1978
Parameters: bacteria
Data Sources: ODEQ, FDA, Tillamook County, ODF&W, USDA
Report Summary:
The report summarized results from studies conducted in Tillamook Basin from 1962–1978. These studies were used to identify data gaps and help design the Tillamook bacteria study that was initiated in 1979. Jackson and Glendening concluded the following from the reports: (1)The Bay and sampled tributaries rapidly violate the bacteria water quality standard when it rains. (2) It appears that the Bay can violate the standards with less than a two inch rainfall. (3) It is not known for certain what the sources of the bacteria are. (4) Oyster meat may or may not violate bacteria standards when there is a water bacteria standards violation. (5) It is uncertain as to how long it takes for the Bay to comply with the standard after a storm subsides. (6) Clams are distributed throughout the Bay. A serious oversight exists when only oyster growing area water quality is considered. (7) Freshwater circulation in the Bay is not well known. Questions remain about bacteria laden freshwater reaching the oyster growing areas.

Study Title: Tillamook Bay Bacteria Study Fecal Source Summary Report
Citation: Jackson, J., Glendening, E., 1982, ODEQ
Years Data Collected: 1979–1980
Parameters: bacteria
Data Source: Oregon DEQ
Sites: Samples taken along all 5 tributaries to Tillamook Bay, samples in Tillamook Bay and selected creeks and sloughs
Report Summary:
Based on analysis of data collected by ODEQ from December 1979–October 1980, Jackson and Glendening concluded the following: Most of the bacteria loading of Tillamook Bay comes from the Tillamook, Trask, and Wilson river subbasins. The Miami subbasin, at times, will also contribute large amounts. Small streams in the near bay area may also carry fecal coliform bacteria, but because of their small flows will have a negligible loading impact on the Bay. Fecal bacteria conditions in the bay water are more degraded with heavier rains resulting from higher river flows. The majority of the fecal contamination occurs in the lower subbasins where the dairy farms and homes are located. The forest area is not a significant contributor of fecal coliform bacteria when compared to downstream fecal sources such as the urban areas and dairy farming. If significant fecal sources are located within the forest, they are isolated and their impact on water quality was not identified in this study. Elk herds were not found to be a significant source of contamination of Tillamook Bay, although they may have a localized impact not identified in the study. Recreation areas investigated were found not to significantly add to the fecal pollution in Tillamook Bay and its watersheds. Barnyards appear to contribute fecal material to nearby creeks with each storm event. Pastures appear to only contribute fecal material when the ground is saturated and runoff from the pasture occurs. No definite statement can be made about the fecal contribution from failing onsite systems. STPs are not significant fecal coliform contributors when the plants operate as designed.

Study Title: Tillamook Bay Drainage Basin Fecal Wastes Management Plan

Citation: Jackson, J., Glendening, E., June 1981, ODEQ.

Years Data Collected: 1979–1980

Parameters: bacteria

Data Source: Oregon DEQ

Sites: Samples taken along all 5 tributaries to Tillamook Bay, samples in Tillamook Bay and selected creeks and sloughs.

Report Summary:

Based on results from the 1979-1980 ODEQ bacteria study, Jackson and Glendening ranked manure management practices in order of increasing potential to pollute the streams in Tillamook Bay Drainage Basin:

1. Barnyard not adjacent to stream or ditch and good manure management in the field that keeps manure out of ditches and streams and no cattle access to a stream
2. Barnyard not adjacent to a ditch or stream but poor manure management in the field and/or cattle access to a stream
3. Barnyard adjacent to a stream or a ditch but good manure management in the field and no cattle access to a stream
4. Barnyard adjacent to a stream or ditch but poor manure management in the field that allows manure in ditches or streams, cattle have access to the stream

Study Title: Proposed Criteria for the temporary closure of Tillamook Bay to shellfish harvest

Citation: Jackson, J., Glendening, E., ODEQ, June 1981

Years Data Collected: 1979–1980

Parameters: bacteria

Data Source: Oregon Department of Environmental Quality

Sites: Samples taken along all 5 tributaries to Tillamook Bay, samples in Tillamook Bay and selected creeks and sloughs

Report Summary

Based on the results of the 1979-1980 sampling, the following conclusions were drawn:

1. During periods of high river outflows to the Bay in the winter, the Bay can greatly exceed the standards set for shellfish growing waters. Oyster meat during this same time period may or may not exceed the market standard. When oyster meat market standards are exceeded, it is not in proportion to the bacterial densities in the Bay because unfavorable salinities and temperatures may limit active pumping by the oysters.
2. During the late spring and summer, when river flows to the Bay are low, any abrupt increase of river inflows, causing base flows to at least quadruple in volume, can cause shellfish growing waters to exceed the standard. Oyster meats during these periods may become contaminated and exceed the market standard.
3. During dry periods in the summer when river inflows to the Bay are low, shellfish growing water standards are generally met.
4. No correlation exists between fecal coliform and real time parameters such as salinity and river flow. The exception is a reasonable correlation for salinity versus total and fecal coliform for the July samples. The relationship between salinity and coliform does not hold at other times of the year.

Study Title: Tillamook Bay Watershed Bacterial Trends Assessment

Citation: Wiltsey, M., Oregon DEQ, September 1990.

Years Data Collected: April 1979–May 1990

Parameters: fecal coliforms, salinity

Data Source: Oregon DEQ

Sites: Tillamook, Miami, Trask and Wilson Rivers, Bay sites from 3 critical shellfish growing areas

Report Summary:

No statistically significant trends in fecal coliform levels in the Bay or tributaries are reported at the 10% level. Two storm events were also evaluated, March 1980 and March 1985. A significant decrease was reported from March 1980 to March 1985. However, the Bay salinity was significantly higher in the latter time period. Difficulties in analyzing the Tillamook Bay and tributary data for trends include:

1. Data sets are not homogenous
2. Data are not normally distributed
3. Apparent trends in fecal coliform data can be caused by a trend in meteorological conditions such as rainfall or streamflow or other factors such as salinity.

Study Title: Seasonal Comparison of Fecal Coliform Concentrations in the Trask River and a Study of the Survival of E. coli in Tillamook Bay water, Final Report to the Tillamook NEP

Citation: Alexander D., Koretsky T., Department of Biology, University of Portland, December 1996

Years Data Collected: July 31, 1996 and October 19,1996

Parameters: fecal coliforms. E.coli, water temperature, salinity

Data Source: University of Portland

Sites: midstream water samples were collected at 5 sites on the Trask River and one site on Hoquarten Slough

Report Summary:

The concentration of fecal coliforms was higher at the Hoquarten Slough site than at any other sampling site. The concentration of dissolved oxygen in the Slough was very low (2.5 mg/L) at both sampling times. The lowest fecal coliform concentrations were detected at the three upstream sites. The fecal coliform concentrations did not correlate significantly with water temperature or salinity in the dry season samples, but did correlate strongly with the concentration of dissolved oxygen. Median fecal coliforms correlated significantly with water temperature and dissolved oxygen in the wet season. Laboratory studies showed that the concentration of viable E.coli in Tillamook Bay water varied significantly with temperature and with time. At 72 and 96 hours, the concentration of surviving E.coli differed significantly at all three temperatures (4,11 or 23° C). The flask incubated at 4° C maintained the highest concentration of viable cells, while the flasks incubated at 23° C had the lowest concentration. The concentration of E.coli remained lower in the Bay water and ocean water than in the river water at 72 hours and 96 hours, but no difference was detected between the Bay and ocean water.

Study Title: A Statistical Evaluation of the Water Quality Impacts of Best Management Practices Installed at Tillamook County Dairies, A Thesis Submitted to Oregon State University

Citation: Kramer-Dorsey, J., presented December 18, 1995.

Years Data Collected: 1965–1992

Parameters: fecal coliform

Data Source: Oregon DEQ (STORET)

Sites: 10-20 sampling sites along each of the 5 rivers draining to Tillamook Bay, 18 stations in the Bay and 6 stations near the Bay.

Report Summary:

A study of data was conducted to determine if the escape of fecal coliform organisms from dairies into the streams decreased by the installation of BMPs. The study had two phases. In the first phase data from 1985–1990 was analyzed for stations near two farms in the Tillamook Watershed. The Ln of the fecal coliform concentrations was not reduced in the individual upstream or the individual downstream models over the time period. Fecal coliform concentrations downstream were significantly higher than the fecal coliform concentrations upstream. No data existed to establish the upstream/downstream difference prior to the installation of BMPs. The second phase of the study was to estimate the changes in fecal coliform concentrations in the entire Tillamook watershed. The model depicts the response of fecal coliform concentrations by modifying the irregularities due to four major factors: antecedent precipitation, season, area and station. The precipitation effect was the most important key to the trend analysis. Prior to 1985 (pre-BMP) the Ln of the fecal coliform concentration was increasing with an increase in 120 hour antecedent precipitation. After 1985 (post -BMP) the Ln of the fecal coliform concentration decreased with an increase in the 120 hour antecedent precipitation.

Study Title: Tillamook Bay Watershed Bacterial Analysis Water Years 1979–1987
Citation: Arnold, G., Schwind, S., Schaedel, A., 1989
Years Data Collected: 1979-1987
Parameters: fecal coliform
Data Source: ODEQ
Sites: bay sites, all five tributaries
Report Summary:

The geometric mean of fecal coliform data from water years 79–81, 82–84 and 85–87 were compared. The fecal coliform levels in each of the tributaries decreased during the period of water years 82–84, when compared to the period of water years 79–81. Most fecal coliform values in the tributaries decreased during the period of water year 85–87, when compared to the period of water year 79–81. Increases in geometric mean fecal coliform concentrations were seen in Murphy Creek and Mills Creek. The Kilchis, Trask and Wilson all show fecal coliform reductions of between 25 and 70 percent, compared to the time period before the Rural Clean Water Program (RCWP) projects were started. Sampling upstream and downstream of selected RCWP sites indicated that the fecal coliform concentration downstream was much higher than the upstream concentration, presumably caused by fecal wastes entering the stream or river between the two sampling points. All the tributaries show strong seasonal variation in fecal levels. Levels in most streams and rivers are highest July –December, and lowest January–June. Bay fecal coliform data was compared to the FDA criteria for “restricted,” “conditionally approved,” and “approved.” The 6 sites within the oyster growing zone in the Bay, on the Bay’s west side, have shown consistent improvement in site classification. Each of the oyster growing area sites improved to the level of meeting “approved” or “conditionally approved” criteria. The 90th percentile values also showed considerable reductions.

APPENDIX 4-B

303(d) list

Detailed text describing the watershed bodies in the Tillamook Bay Watershed that are on the State’s list of Water Quality-Impaired Waters. This text is considered more accurate than the accompanying maps, and should be deferred to if there are discrepancies between the maps and the text.

Tillamook Basin 303d List

18-Dec-00

Waterbody Name	Boundaries	Parameter	Basis for Consideration for Listi	Supporting Data or Informatio
Bewley Creek	Mouth to RM 2	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82)	DEQ Data (2 Sites: 412212, 412228; RM 0.3, RM 1.0): 22% (5 of 23) and 13% (3 of 23) FWS values exceeded fecal coliform standard (400) with a maximum value of 2320 and 1200 respectively between 1986 - 1990.
Bewley Creek	Mouth to RM 2	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82)	DEQ Data (2 Sites: 412212 , 412228; RM 0.3, 1.0): 69% (9 of 13), 67% (8 of 12) Summer values exceeded fecal coliform standard (400) with a maximu value of 2400 and 2400 respectively between 1986 - 1989.
Dougherty Slough	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data - Ambient Mon (305(b), 1994); Jackson (1982)	DEQ Data (2 Sites: 412137 and 412138; RM 1.0 and 3.0): 32% (7 of 22) and 57% (12 of 21) FWS values exceeded fecal coliform standard (400) with maximum values of 8200 and 64000 respectively in WY 1980 (Tillamook Bay Bacteria Study, DEQ, 1982).
Dougherty Slough	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data - Ambient Mon (305(b), 1994); Jackson (1982)	DEQ Data (2 Sites: 412137 and 412138; RM 1 and 3): 33% (2 of 6) and 100% (6 of 6) Summer values exceeded fecal coliform standard (400) with a maximum value of 1600 and 5000 respectively in 1980 (Tillamook Bay Bacteria Study, DEQ, 1982).
Holden Creek	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Fall through Spring	Jackson (1982)	DEQ Data (3 Sites: 412196, 412195, 412194; RM 0.25, 1.0, 1.2): 92% (23 of 25), 96% (24 of 25), 96% (23 of 24) FWS values exceeded fecal coliform standard (400) with max values of 56000, 33000, 70000 respectively in WY 1980 (Till Bay Bact Study, DEQ, 82).

Waterbody Name	Boundaries	Parameter	Basis for Consideration for Listi	Supporting Data or Informatio
Holden Creek	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Summer	Jackson (1982)	DEQ Data (3 Sites: 412196, 412195, 412194; RM .25, 1.0, 1.2): 100% (6 of 6) Summer values exceeded fecal coliform standard (400) at all 3 sites with maximum values of 150000, 5400, 24000 respectively in 1980 (Tillamook Bay Bacteria Study, DEQ, 1982.)
Hoquarton Slough	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82)	DEQ Data (Site 412139; RM 2.0): 53% (18 of 34) FWS values exceeded fecal coliform standard (400) with a maximu value of 3100 between 1986 - 1991.
Hoquarton Slough	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82)	DEQ Data (Site 412139; RM 2.0): 52% (12 of 23) Summer values exceeded fecal coliform standard (400) with a maximum value of 2400 between 1986 - 1991.
Kilchis River	Mouth to Little South Fork Kilchis River	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 287: severe, data (DEQ, 1988)	DEQ Data (Site 412125; RM 0.1): 81% (17 of 21) Summer values exceeded fecal coliform standard (400) with a maximum value of 1700 between 1986 - 1994.
Killam Creek	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994)	DEQ Data (Site 412324; RM 0.1): 27% (8 of 30) FWS values exceeded fecal coliform standard (400) with a maximu value of 2320 between 1986 - 1990.
Killam Creek	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994)	DEQ Data (Site 412324; RM 0.1): 92% (12 of 13) Summer values exceeded fecal coliform standard (400) with a maximum value of 3140 between 1986 - 1989.
Miami River	Mouth to Stuart Creek	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 292: severe, data (DEQ, 1988)	DEQ Data (Site 412120; RM 0.9): 13% (4 of 30) FWS values exceeded fecal coliform standard (400) with a maximu value of 920 between WY 1986 - 1995
Miami River	Mouth to Stuart Creek	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 292: severe, data (DEQ, 1988)	DEQ Data (Site 412120; RM 0.9): 33% (8 of 24) Summer values exceeded fecal coliform standard (400) with a maximum value of 1600 between WY 1986 - 1995.

Waterbody Name	Boundaries	Parameter	Basis for Consideration for Listir	Supporting Data or Informatio
Mill Creek (Trask R Trib)	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Summer	Jackson (1982)	DEQ Data (2 Sites: 412216 and 412225; RM 0.5 and 2.5): 33% (2 of 6) and 100% (5 of 5) Summer values exceeded fecal coliform standard (400) with maximum values of 560 and 4300 respectively in 1980 (Tillamook Bay Bacteria Study, DEQ, 1982).
Mill Creek (Trask R Trib)	Mouth to Long Prarie Road	Water Contact Recreation (Fecal Coliform) - Fall through Spring	Jackson (1982)	DEQ Data (2 Sites: 412216 and 412225; RM .5 and 2.5): 78% (18 of 23) and 67% (10 of 15) FWS values exceeded fecal coliform standard (400) with a maximum value of 13000 and 100000 respectively in WY 1980 (Tillamook Bay Bacteria Study, DEQ, 1982).
Mills Creek	Mouth to US Forest Service boundary	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994)	DEQ Data (2 Sites: 412325, 412326; RM 0.1, 0.3): 30% (9 of 30) and 9% (3 of 32) FWS values exceeded fecal coliform standard (400) with maximum values of 1900 and 1400 respectively between 1986 - 1990.
Mills Creek	Mouth to US Forest Service boundary	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994)	DEQ Data (2 Sites: 412325, 412326; RM 0.1, 0.3): 85% (11 of 13) and 30% (4 of 13) Summer values exceeded fecal coliform standard (400) with maximum values of 2920 and 1340 respectively between 1986 - 1989.
Murphy Creek	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82)	DEQ Data (2 Sites: 412250, 412323; RM 0.1, 0.3): 71% (15 of 21) and 21% (7 of 33) FWS values exceeded fecal coliform standard (400) with maximum values of 2260 and 2060 respectively between 1986 - 1990.
Murphy Creek	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82)	DEQ Data (2 Sites: 412250, 412323; RM 0.1, 0.3): 85% (11 of 13) and 85% (11 of 13) Summer values exceeded fecal coliform standard (400) with maximum values of 2400 and 2400 respectively between 1986 - 1989.

Waterbody Name	Boundaries	Parameter	Basis for Consideration for Listi	Supporting Data or Informatio
Simmons Creek	Mouth to 0.5 mile above Hwy 101	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data; Jackson (1982)	DEQ Data (2 Sites: 412214, 412226; RM 0.2 (Hwy 101), 1.0 (0.5 miles above Hwy 101): 65% (17 of 26), 0% (0 of 17 FWS values exceeded fecal coliform standard (400) with max values of 17000, 200 respectively in 1980 (Till Bay Bact Study, DEQ, 82).
Simmons Creek	Mouth to 0.5 mile above Hwy 101	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data; Jackson (1982)	DEQ Data (2 Sites: 412214, 412226; RM 0.2 (Hwy 101), 1.0 (0.5 miles above Hwy 101): 100% (6 of 6), 0% (0 of 6) Summer values exceeded fecal colifor standard (400) with maximum values o 53000 and 150 respectively in 1980 (Til Bay Bact Study, DEQ, 82).
Tillamook Bay - Main	Marker No. 19 to South Bay	Fecal Coliform - Shellfish Growing Water - Annual	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 276: severe, data (DEQ, 1988)	DEQ Data (8 Sites: Mile 2.2 - 4.3): One site exceeded fecal coliform log mean criteria (14) with values ranging from 7 to 16 and all sites exceeded 90% criteria (43) with values ranging from 4 to 140 between WY 1992 - 1995.
Tillamook Bay - Upper	Southeast Bay to Dick Point	Fecal Coliform - Shellfish Growing Water - Annual	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 276: severe, data (DEQ, 1988)	DEQ Data (7 Sites: Mile 3.8 - 6.3): All sites exceeded fecal coliform log mean criteria (14) with values ranging from 2 to 65 and all sites exceeded 90% criteria (43) with values ranging from 220 to 920 between WY 1992 - 1995.
Tillamook River	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 277: severe, data (DEQ, 1988)	DEQ Data (Site 412151; RM 13.0): 36% (8 of 22) FWS values exceeded fecal coliform standard (400) with a maximum value of 1200 between 1986 - 1990.
Tillamook River	Mouth to Headwaters	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 277: severe, data (DEQ, 1988)	DEQ Data (Site 412151; RM 13.0): 80% (8 of 10) Summer values exceeded fecal coliform standard (400 with a maximum value of 1340 betwee 1986 - 1989.
Trask River	Mouth to Gold Creek	Temperature - Summer	DEQ Data (1995); NPS Assessment - segment 279: moderate, observation (DEQ, 1988)	DEQ Data (Site 412142; RM 4.2): 7 day average of 70.8 with 84 days above temperature standard (64) in 1995 and 8% (2 of 24) Summer values exceeded temperature standard with a maximum value 65.3 between WY 1986 - 1995.

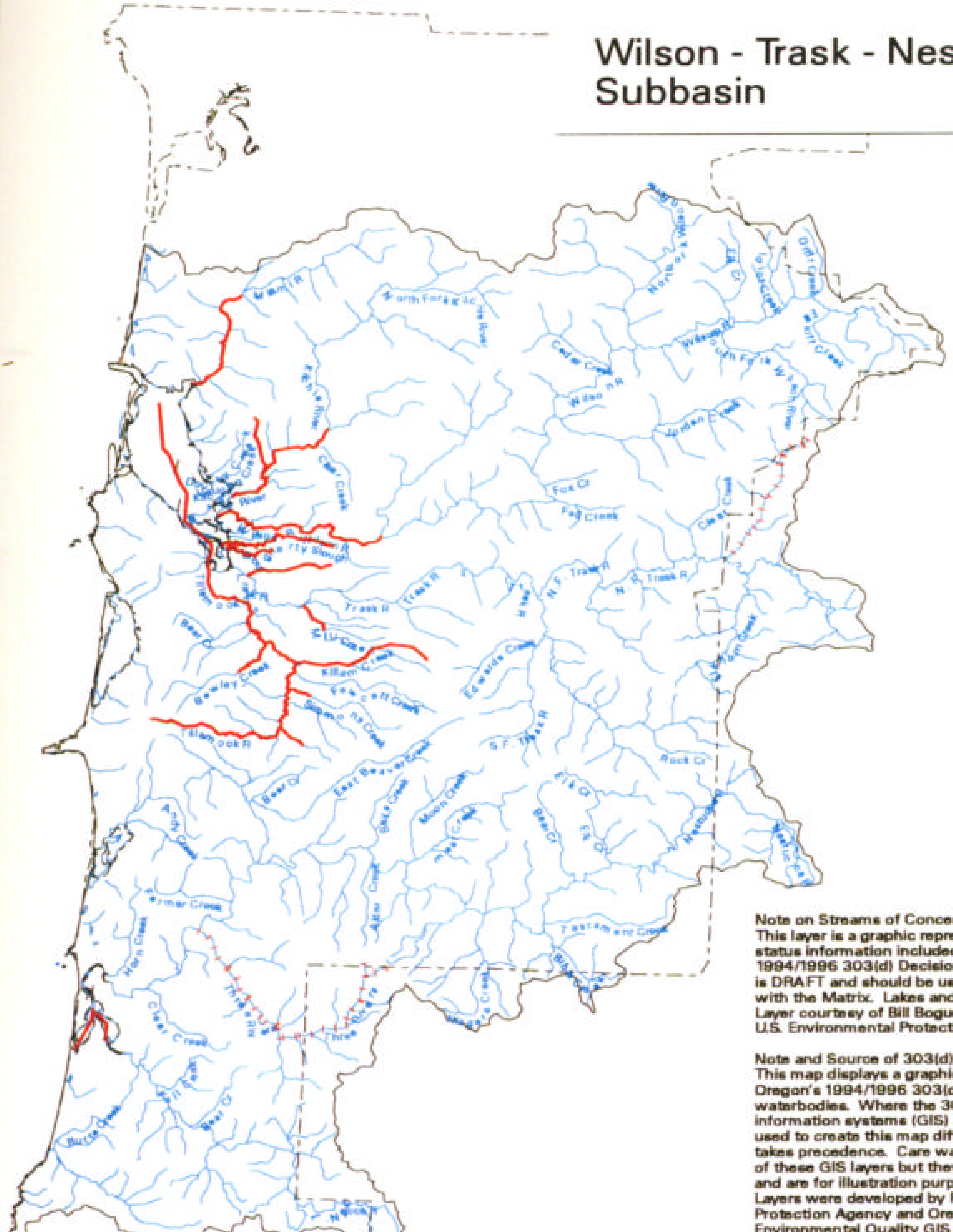
Waterbody Name	Boundaries	Parameter	Basis for Consideration for Listi	Supporting Data or Informatio
Wilson River	Mouth to Little North Fork Wilson River	Temperature - Summer	DEQ Data (1995); NPS Assessment - segment 281: moderate, observation (DEQ, 1988)	DEQ Data (2 Sites: 412131and 412130; RM 4 and 1.8): 7 day average of daily maximum of 69.5 and 65 days exceeded temperature standard (64) in 1995 and 13% (3 of 24) Summer value exceeded temperature standard with a maximum value of 66.2 between 1986 - 95.
Wilson River	Mouth to Little North Fork Wilson River	Water Contact Recreation (Fecal Coliform) - Fall through Spring	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 281: severe, data (DEQ, 1988)	DEQ Data (Site 412130; RM 1.8): 11% (5 of 44) FWS values exceeded fecal coliform (400) with a maximum value o 1100 between WY 1986 - 1995.
Wilson River	Mouth to Little North Fork Wilson River	Water Contact Recreation (Fecal Coliform) - Summer	DEQ Data, d1 in 305(b) Report (DEQ, 1994); Jackson (82); NPS Assessment - segment 281: severe, data (DEQ, 1988)	DEQ Data (Site 412130; RM 1.8): 29% (7 of 24) Summer values exceeded fecal coliform (400) with a maximum value of 1200 between 1986 - 1995.

APPENDIX 4-C

303-D Maps

Maps of the waters listed, and the waterbodies of concern for bacteria, temperature,
flow modification, habitat modifications, sedimentation, nutrients, pH,
and dissolved oxygen.

Wilson - Trask - Nestucca Subbasin



Note on Streams of Concern or Needing Data:
This layer is a graphic representation of stream status information included in Oregon's 1994/1996 303(d) Decision Matrix. This layer is DRAFT and should be used in conjunction with the Matrix. Lakes and reservoirs not shown. Layer courtesy of Bill Bogue, Region 10 U.S. Environmental Protection Agency.

Note and Source of 303(d) Layers:
This map displays a graphic representation of Oregon's 1994/1996 303(d) list of water quality limited waterbodies. Where the 303(d) list and the geographic information systems (GIS) layers of listed waterbodies used to create this map differ, the 303(d) list takes precedence. Care was taken in the preparation of these GIS layers but they are displayed "as is" and are for illustration purposes only.
Layers were developed by Region 10 U.S. Environmental Protection Agency and Oregon Department of Environmental Quality GIS staff from the U.S. Geological Survey 1:100,000 Pacific Northwest River Reach Files.

For a complete list of the streams and waterbodies, and to determine what water quality standard is violated, please refer to the actual 303(d) list.

For further information contact the Oregon Department of Environmental Quality at (503) 229-5279 (voice), (503) 229-6993 (TTY), or toll free within Oregon, 1-800-452-4011.

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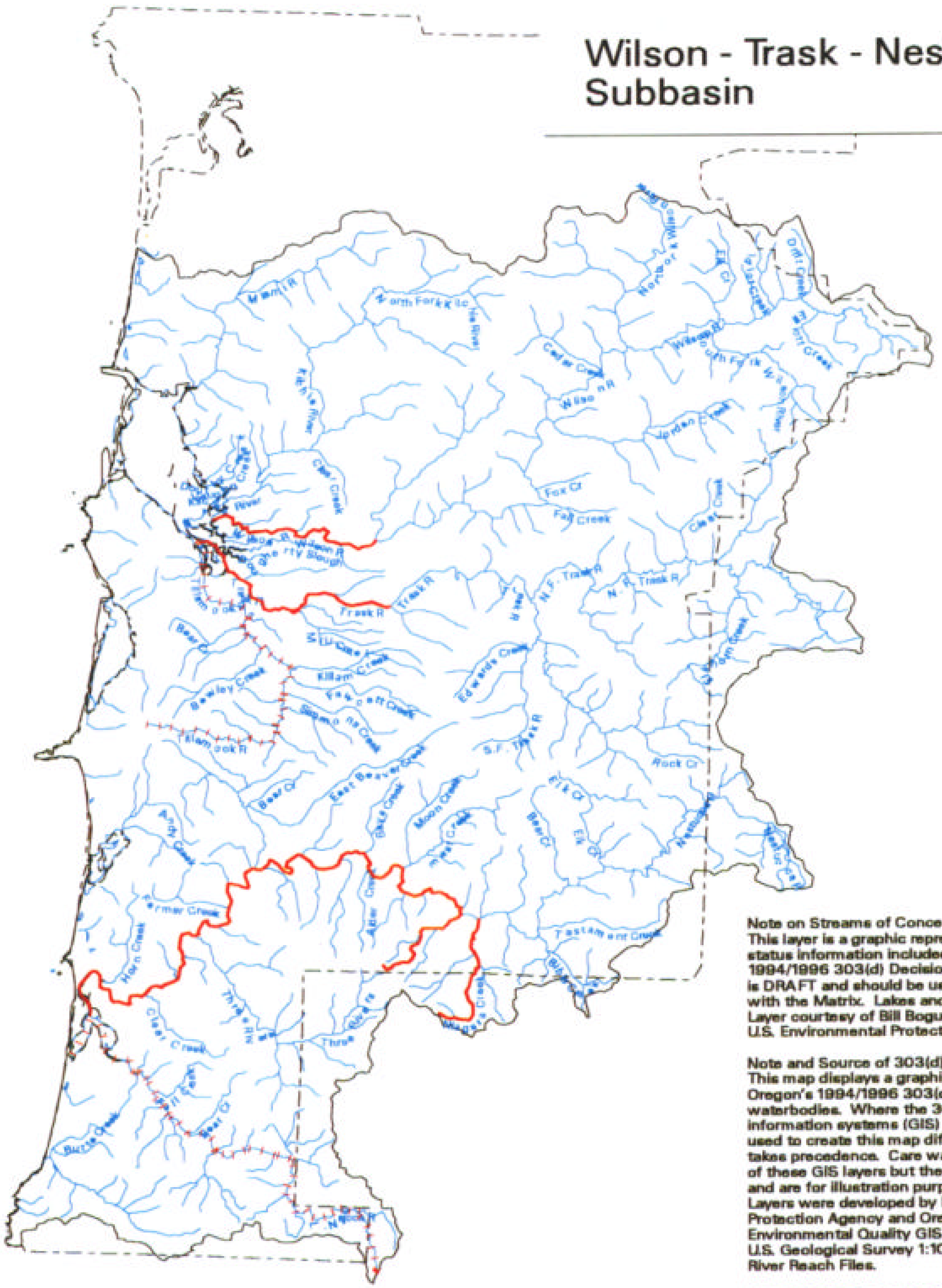
Bacteria

- 🟥 Waterbodies on Oregon's 1994/96 303(d) list of water quality limited waterbodies
- ⋯ Waterbodies of concern or those where more data is needed to establish water quality status

Wilson - Trask - Nestucca Subbasin



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Temperature

- 🟥 Waterbodies on Oregon's 1994/96 303(d) list of water quality limited waterbodies
- ▨ Waterbodies of concern or those where more data is needed to establish water quality status

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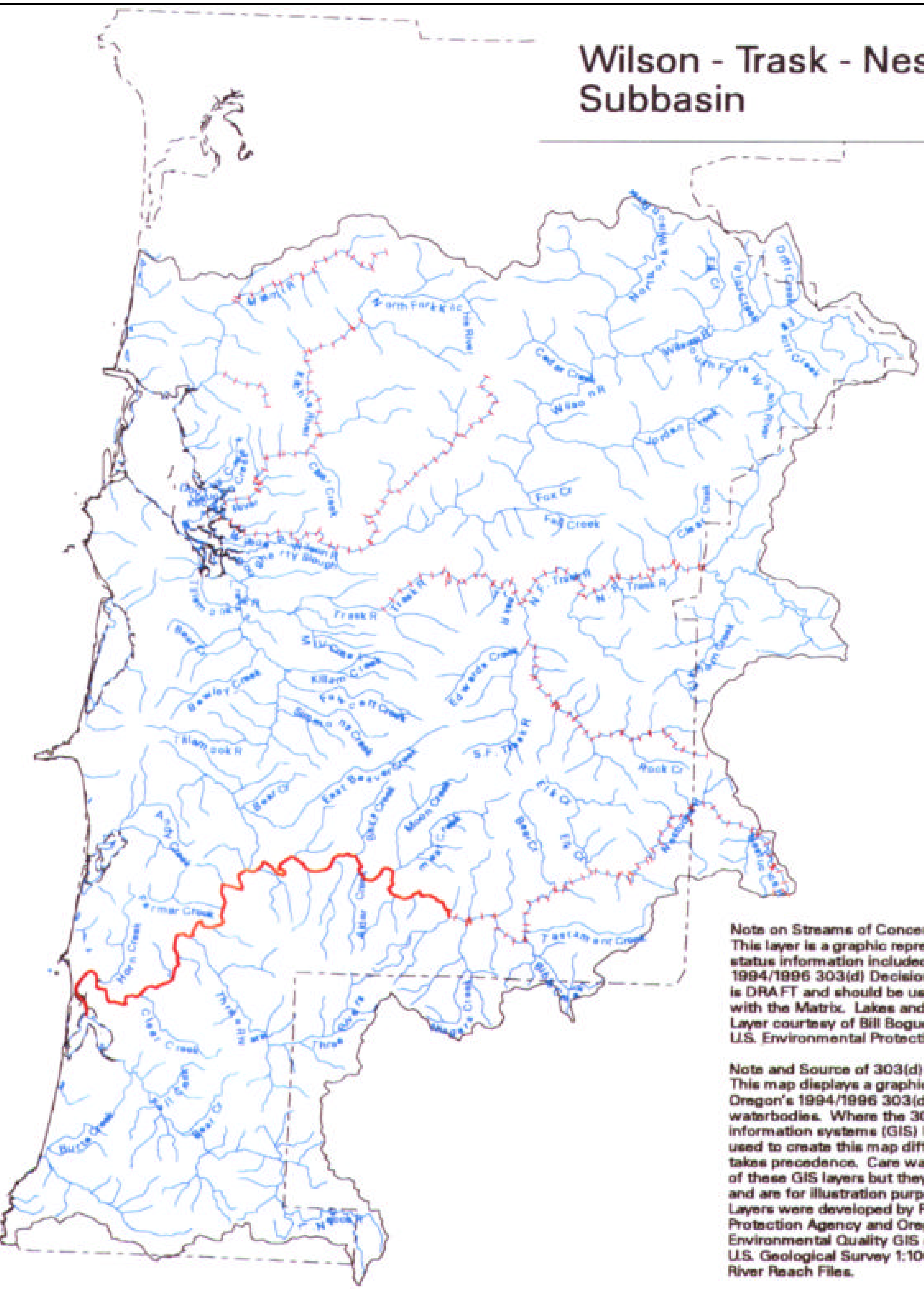
Wilson - Trask - Nestucca Subbasin



Flow Modification

- Waterbodies on Oregon's 1994/96 303(d) list of water quality limited waterbodies
- Waterbodies of concern or those where more data is needed to establish water quality status

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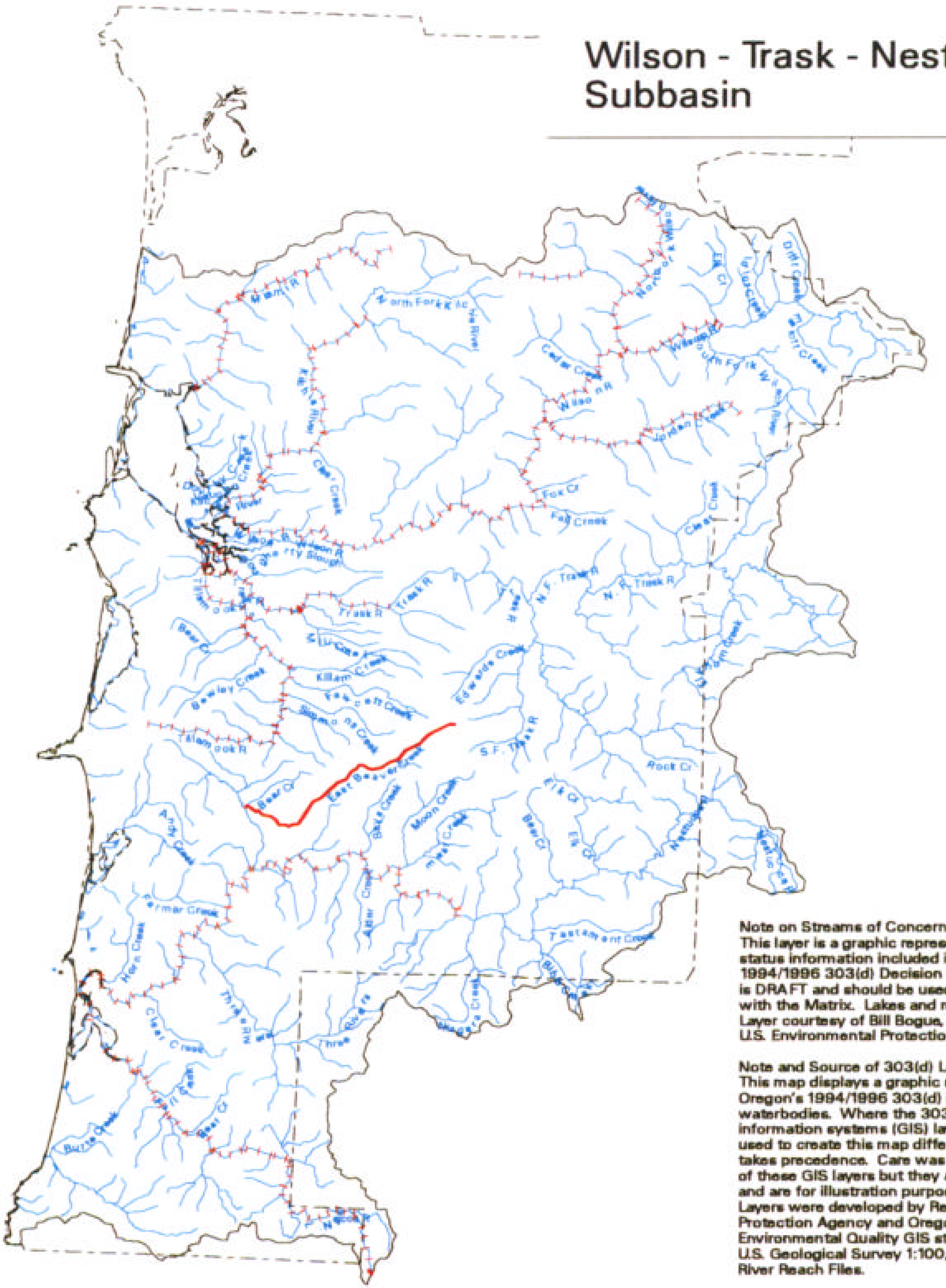
Wilson - Trask - Nestucca Subbasin



Habitat Modification

Waterbodies on Oregon's 1994/96 303(d) list of water quality limited waterbodies

Waterbodies of concern or those where more data is needed to establish water quality status

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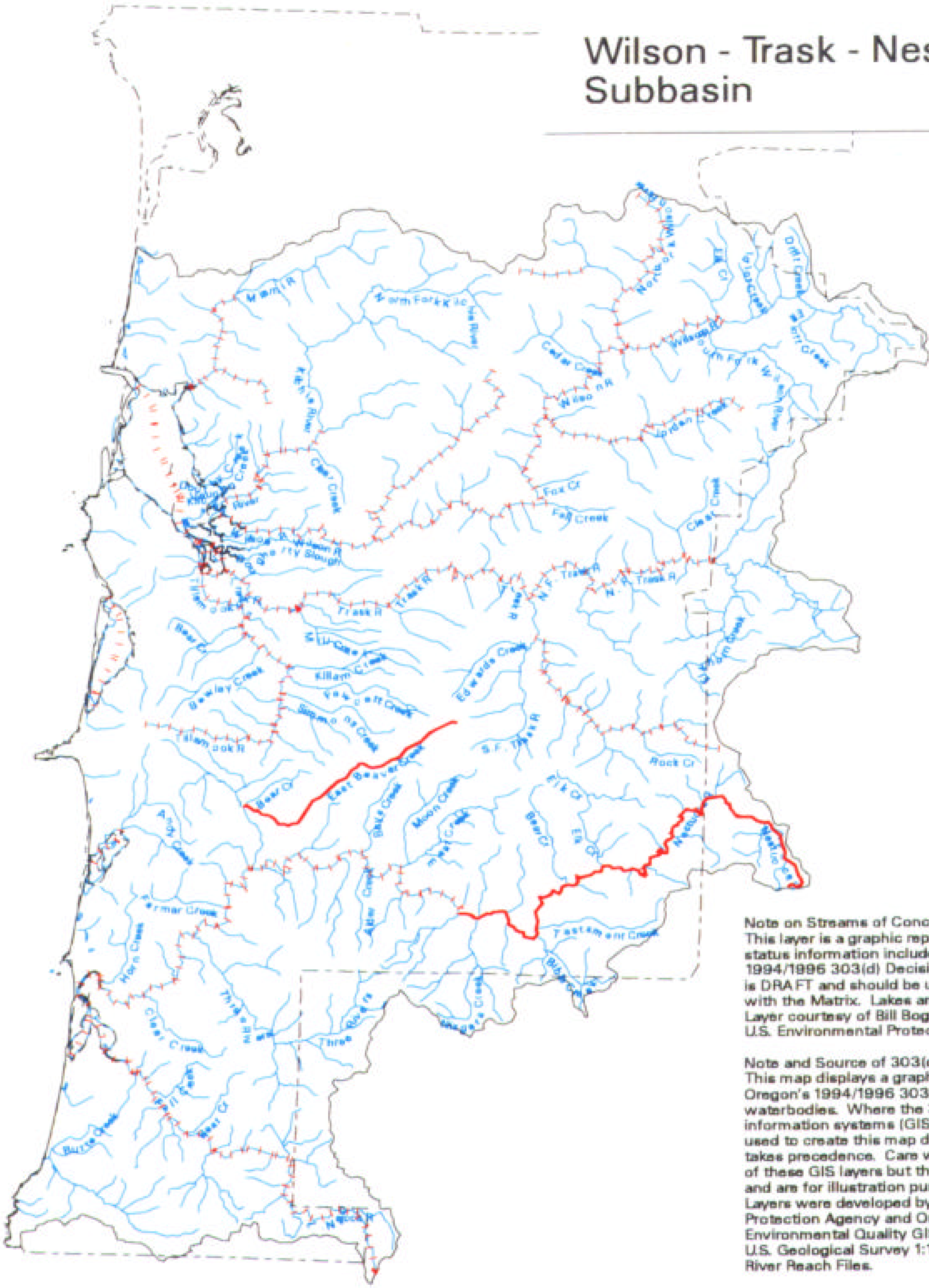
Wilson - Trask - Nestucca Subbasin



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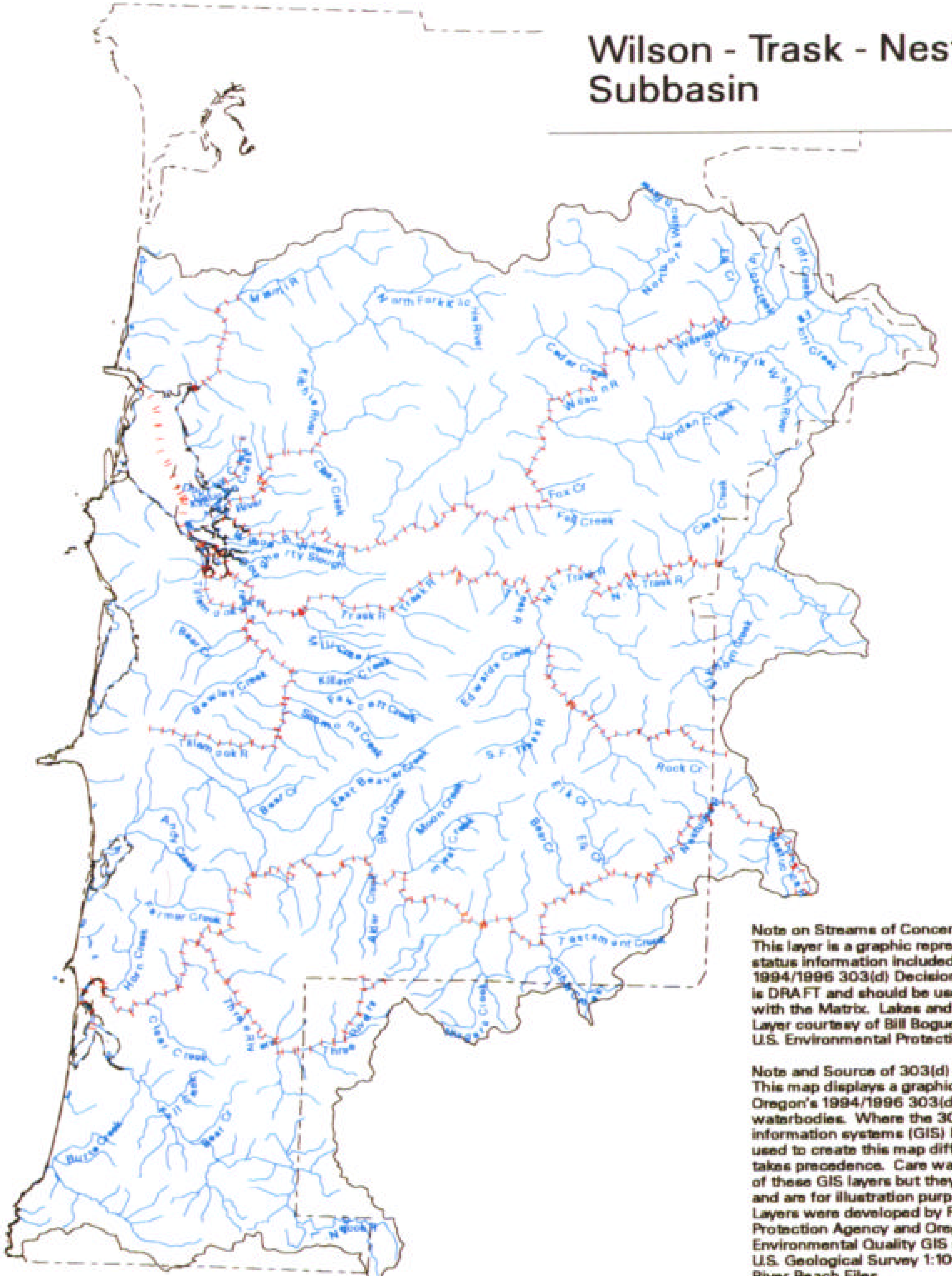
Sedimentation

- 🟥 Waterbodies on Oregon's 1994/96 303(d) list of water quality limited waterbodies
- ▨ Waterbodies of concern or those where more data is needed to establish water quality status

February 1997
Oregon Department of Environmental Quality GIS

Wilson - Trask - Nestucca Subbasin



Nutrients, pH, Dissolved Oxygen

- 🟥 Waterbodies on Oregon's 1994/96 303(d) list of water quality limited waterbodies
- ▨ Waterbodies of concern or those where more data is needed to establish water quality status

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