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STATE OF THE SOUND 1988 REPORT

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KATHERINE FLETCHER
Chair

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To the Governor, the Legislature, and other readers:

This is the second State of the Sound Report. Two years ago, we reported to you that it was time to move ahead with effective measures to address the signs of degradation in Puget Sound. We summarized what was known about the Sound, its resources, and the trends that threaten it. We underscored that our rapidly growing population will accelerate the problems of the Sound unless we are able to anticipate and prevent problems before they reach crisis proportions.

The past two years have dramatically changed the ways in which the state, along with local governments, the federal government, and the public are confronting and acting to solve the problems of Puget Sound. We now have a comprehensive management plan which is bringing together the considerable efforts and expertise of all of us in the Puget Sound region. From watershed action plans that will combat nonpoint pollution to a stepped-up regulatory program for control of toxicants in discharges; from wetland acquisition to student-run oil recycling--an impressive array of coordinated and innovative programs is now underway.

But the Sound itself will be slow to show the results of all this activity. We must recognize that we are in for a long-term effort if we are serious about cleaning up and protecting the Sound. And we must not get discouraged if one result of paying more attention to the Sound is to learn that its problems are more serious than we thought. Even as we attack the causes of pollution, we must also expect more shellfish closures, more reports of declining fish populations, and other sobering news.

Much remains to be done. We must fund the actions already identified in the Puget Sound Water Quality Management Plan. And we must put in place the long-term programs, commitments, and institutions that can address over time the problems we are dealing with. This report shows that we have reason for optimism. It also shows that despite this much progress, we must not be complacent. This second State of the Sound Report helps to provide both the perspective and knowledge we need to take the next steps to protect and preserve Puget Sound.

Sincerely,

Katherine Fletcher
Chair

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INTRODUCTION

The *State of the Sound Report* is prepared every two years by the Puget Sound Water Quality Authority (Authority) to provide a comprehensive, easily understandable summary of the current conditions of water quality and related resources in Puget Sound. This report discusses the status, overall health, and economic value of the Sound's resources. Wherever possible, current and foreseeable trends in water and sediment quality, habitat changes, and the health of biological resources are discussed. Unfortunately, in many cases long-term Soundwide monitoring and comprehensive research results do not exist. It is therefore difficult to draw conclusions about significant changes or trends that have occurred over time in key Puget Sound environmental indicators (such as water and sediment contaminant levels and the health of resident fish).

We are just beginning to develop the information that is needed to establish environmental trends. The proposed Soundwide ambient monitoring program, and the coordinated effort to establish and fund research priorities in Puget Sound, are critical to identifying both short- and long-term changes (both good and bad) that may occur in the Sound's water quality and biological resources in the future.

This chapter serves as the executive summary of the *State of the Sound Report*, and provides an overview of some of the most significant programs, studies, and activities that have taken place in the last few years. This information is discussed in more detail in the body of the report.

As stated in the Puget Sound Water Quality Act of 1985 (Chapter 90.70.055 RCW), another purpose of this report is to review significant public and private activities affecting the Sound, and assess whether these activities are consistent with the Puget Sound Water Quality Management Plan. The report should also recommend 1) actions that may be needed to improve current water quality programs, plans, and policies; and 2) any changes that may be necessary to protect and improve water quality in Puget Sound. Although this report describes many of the recent public and private activities that affect water quality and resources in the Sound, an assessment of their consistency with the Puget Sound plan has not been attempted here. However, such a review is underway. Agencies are now in the process of submitting status reports on their Puget Sound programs to the Authority. These reports will be used by the Authority to assess plan compliance and to support recommended changes in the 1989 Puget Sound plan (the draft plan is scheduled for release in June 1988). Recommendations for other actions that may be necessary to further protect and improve Puget Sound water quality will also be addressed in the 1989 plan.

In the 1986 *State of the Sound Report* we reported that two of the greatest challenges facing residents of Puget Sound were 1) the reduction of sources and potential cleanup of toxic chemicals that are severely contaminating parts of the Sound; and 2) the control of bacterial and viral contamination that has restricted use of the Sound's shellfish resources. Looking ahead, we also recognized that our expanding population in the Puget Sound area would put additional strain on the health of the Sound. While this characterization is still accurate today, the last two years have seen the beginning of extensive new efforts to address these and other problems. Many new and exciting programs have been initiated at all levels of government and in the private sector. In addition, progress has been made toward identifying and eliminating key sources of water pollution and causes of habitat degradation in the Sound.

Puget Sound is a valuable body of water that has begun to suffer from the effects of human activities. As a semi-closed system, it is extremely vulnerable, tending to retain contaminants instead of flushing them to the ocean. Signs of pollution are visible and, while some problems have gotten better (e.g., biochemical oxygen demanding wastes have decreased), other problems appear to be getting worse (e.g., liver tumors and reproductive failures in English sole). Although improved source controls appear to be resulting in decreased contaminant loading to the urban bays, these bays throughout the Sound continue to show evidence of contamination from point source discharges and stormwater. Additional shellfish beds were closed in 1987 because of bacterial pollution, and development continues to threaten wetlands and other habitat. Between 600,000 and 800,000 more people are expected to live in the Puget Sound area by the year 2000 (about a 20 to 25 percent increase), which will further threaten the Sound's water quality. A summary of certain biological problem indicators, including current status and possible outlooks for the future, is shown in Table 1-1. Planning activities and results of recent studies are summarized for several of the key issues facing Puget Sound in the rest of this chapter.

AGENCY COORDINATION

One of the major challenges in mobilizing and carrying out a comprehensive effort to protect Puget Sound is the fact that so many jurisdictions and levels of government must be involved. More than 450 public bodies have responsibility for some aspect of the Sound's water quality. In creating the Authority in 1985, the state legislature asked that the Authority bring together and coordinate the multiplicity of agencies and jurisdictions, as well as design the Puget Sound Water Quality Management Plan to be carried out by existing state and local entities. The participatory process of preparing the 1987 Puget Sound plan was created to help accomplish both of those goals. The plan itself sets up a partnership among agencies and between state and local governments to accomplish its 13 programs. It relies heavily on achieving effective implementation of existing governmental programs and focuses on the need to provide adequate funding for those programs. It also establishes new programs to address serious problems, such as nonpoint source pollution control, which is perhaps the most complex jurisdictional challenge yet faced in the Sound. The watershed approach in the Puget Sound plan is reflective of the heavy emphasis on local responsibility and multi-jurisdictional cooperation.

TABLE 1-1: BIOLOGICAL PROBLEM INDICATORS IN PUGET SOUND: POSSIBLE CAUSES, CURRENT STATUS, AND OUTLOOKS FOR THE FUTURE

Problem Indicator	Possible Causes	Current Status	Outlook
Histopathological abnormalities in bottomfish (e.g., liver lesions) and other organisms	Toxic chemicals in water, sediment, or food; dietary deficiencies; pathogens; natural environmental stress	Are most frequent in contaminated urban areas such as Eagle Harbor and the Duwamish Waterway. Frequencies of liver tumors in English sole reach 26 percent in Eagle Harbor, but are near zero percent in rural areas such as Carr Inlet. (1,2,3,19,28)	Condition may improve or worsen in response to changes in exposure to pollutants (or other environmental stresses). Toxicant concentrations in sediments appear to be decreasing with improved point source controls and pretreatment. (1,2)
Degradation of benthic communities	Toxic chemicals in water, sediment, or food; organic enrichment; habitat alteration; natural variation in recruitment or mortality	Not systematically studied, and benthic communities are subject to considerable natural variation. Abundances of benthic animals within normal ranges are found in most areas of the Sound. Increases in the abundance of pollution-tolerant worms may be found near some sewer and CSO outfalls, while depressed abundances of benthic animals are found in some small areas that are highly contaminated with toxic chemicals (e.g., near outfalls of the ASARCO smelter). (3,20,21)	Conditions may improve or worsen in response to changes in exposure to toxic pollutants, organic enrichment, habitat modification, or changes in natural factors affecting recruitment or mortality (e.g., El Nino). Conditions have improved since the 1950s when some urban bays were found to be abiotic. (2,3,4,5,6,28)
Chemically contaminated tissue	Toxic chemicals in water, sediment, and food	Concentrations of PCBs have declined in tissue, but low levels of PCB, PAH, and metals contamination are widespread. Concentrations of regulated contaminants in edible tissue very rarely exceed FDA action limits for seafood, but there are few detailed assessments of human health risks from consumption of seafood from Puget Sound. (2,3,7,8,9,22,28)	Tissue levels may change in response to changes in exposure to pollutants. The development of more sophisticated assessments of human health risks associated with eating Puget Sound seafood will provide a better understanding of the significance of any existing levels. Declines in tissue contamination could lead to removal of posted seafood consumption warnings from some urban locations in the Sound. Increases could lead to posting of more warnings, and even the closure of a commercial or recreational fishery.
Bacterial contamination of shellfish	Bacterial contamination of water by sewage or runoff from urban and agricultural areas	In 1986/87, five of 15 requests for commercial shellfish bed classification were denied because of bacterial contamination. Classification status changed at several other beds. (see Table 4-10)	Better control of point and nonpoint sources could decrease closures of shellfish harvest areas. Loss of control over sources could make the problem worse. (10,11)
Plankton blooms	Natural causes include stability of the water column during spring and summer which allows phytoplankton to remain near the surface, where high light levels promote growth. Substantial nutrient inputs may enhance blooms at the heads of sluggishly-circulating inlets.	Not systematically studied, but probably are at background levels in areas with adequate rates of water exchange. Anthropogenic nutrient inputs may be increasing bloom intensity by 30-50 percent in Budd Inlet, but other sites have not been studied in detail. (10,12,13)	Reduction of nutrient inputs may decrease bloom intensity in affected areas (e.g., Budd Inlet). (10,12,13)

Problem Indicator	Possible Causes	Current Status	Outlook
Paralytic shellfish poisoning (PSP)	PSP causes are not well understood, but changes in nutrient ratios or nitrogen availability may stimulate "red tides".	Beach closures caused by the presence of the PSP toxin in shellfish occur during the warmer months in most of Puget Sound. No closures have occurred south of Tacoma Narrows or in the southern half of Hood Canal. (23)	Difficult to predict, but the increases in beach closures experienced from 1978-1985 have leveled off. If nutrient or other anthropogenic inputs are affecting the development of red tides, this problem could increase or decrease, depending on changes in nutrient sources. Unknown additional factors may influence the frequency of red tides. (14,23)
Fish kills	Chemical spills, toxic chemicals in the water, low dissolved oxygen caused by decay of organic matter	Fish kills occur infrequently in the marine waters of the Sound. There were 14 pollution-caused freshwater fish kills reported to Ecology in 1986, while eight freshwater incidences were reported in 1985. (27)	Reductions in the frequency and severity of spills could reduce the problem. Reductions in the chemicals released in permitted discharges and nonpoint runoff, and decreases in nutrient inputs to sensitive areas also could improve the situation. However, natural occurrences of low dissolved oxygen will still occur infrequently in some areas. (15,16)
Declining fish stock	Overfishing, chemical contamination, loss of breeding habitat, natural variation in recruitment and mortality, loss and degradation of estuarine feeding and rearing habitat	Herring stocks are stable in the Central Sound, but are declining near Bellingham. Pacific cod are recovering from the deleterious effects of the El Nino of 1983. Hake and English sole are declining, possibly due to both anthropogenic and natural causes. Salmon are generally stable, probably because of catch limits and large-scale artificial propagation. (24,25)	Reduced pressures from overfishing and pollutant exposure could alleviate this problem, though natural fluctuations in fish stocks would still occur. (15,16)
Sporadic reproductive failures in harbor seals (e.g., premature births, pup mortality)	Not well understood, but disease and toxic chemicals such as PCBs in the food may be contributing to the problem	Populations appear to be increasing in southern Puget Sound and Hood Canal. The cause of these increases is unknown, but they could reflect continued legal protection of marine mammals rather than improvements in reproductive success. (26)	Continued declines in PCB releases may improve the situation, but additional unknown factors such as disease may be influencing harbor seal populations in the Sound. Pup mortality appears to be within natural limits of population variability. (17,18)

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Coordination between state and federal government is also critical to the successful protection of Puget Sound. The Puget Sound Estuary Program, which was formed in early 1986, is a joint federal-state program managed by the U.S. Environmental Protection Agency (EPA) Region 10, the Washington Department of Ecology (Ecology), and the Authority. Under the estuary program, EPA is responsible for technical studies, development of protocols, and analysis of biological and chemical relationships. The Authority is responsible for planning and Puget Sound plan oversight, public outreach and education, and development of research and monitoring programs. Ecology is the primary state agency with regulatory responsibility for the Sound's water quality. Ecology is implementing numerous programs of the plan, including those related to point source discharges, wetland protection, stormwater control, contaminated sediments, and reduction of nonpoint source pollution.

With the passage of the federal Water Quality Act of 1987, the estuary program initiated by EPA for Puget Sound and several other estuaries around the country was formally embodied in law. Puget Sound has now officially been designated as an "estuary of national significance" under that program. This designation will allow EPA Region 10 to continue its involvement in the overall effort and will continue coordination and integration of the federal and state efforts under the plan. The designation also ensures several more years of federal funding to identify and evaluate pollution-related problems in the Sound as well as to support planning and program development activities at the state and local levels. Perhaps the most difficult test of federal-state cooperation will be the extent to which federal activities and facilities will meet the requirements imposed at the state and local levels. Also important will be the integration of federal and state research and monitoring efforts.

An example of a recent federal/state cooperative effort is the Puget Sound Dredged Disposal Analysis (PSDDA) program which was jointly developed by the U.S. Army Corps of Engineers (Corps), EPA, Ecology, and the Washington Department of Natural Resources (DNR). This program is recommending new evaluation procedures and sites for the unconfined open water disposal of dredged material. Evaluation procedures are now being developed through PSDDA for analyzing the biological effects of contaminated dredged material.

There are new sources of funding for water quality efforts in Puget Sound. In 1986 the state legislature established the Centennial Clean Water Fund and financed it with an 8 cents per pack tax on tobacco products. The fund will provide $40 million per year in the first four years and $45 million per year in subsequent years for water quality efforts throughout the state. Projects and activities funded by this account include upgrading to secondary treatment sewage treatment plants that discharge to marine waters; activities to study and protect groundwater and freshwater resources (including lakes and rivers); and projects to address nonpoint source pollution effects. In addition to the cigarette tax, the state legislature earmarked $11 million in state general funds and capital funds for the 1987-89 biennium to carry out the Puget Sound plan. These funds are above and beyond previously existing water quality programs. The 1987 legislature during special session also approved higher permit fees for point source dischargers. Statewide, these permit fees will provide a maximum of $3.6 million per year to improve the statewide point source program, especially the control of toxicants in discharges and enhanced enforcement of permit limits.

Since the Puget Sound plan was adopted in December 1986, the Authority, Ecology, and other state and local agencies have been working to implement many of the plan's programs. In particular, the nonpoint source pollution program has made headway with Ecology funding of 12 "early action" watershed protection projects and 12 county watershed ranking processes. In addition, the Authority has issued regulations (Chapter 400-12 WAC) for local nonpoint planning. The Authority has been working with committees to establish programs in monitoring, research, and education and public involvement. These efforts are nearing completion. Other joint agency task forces are working on boaters' education, wetlands research, shellfish protection, environmental education, dredged material disposal, urban bay action plans, and other tasks related to Puget Sound and the plan.

Strong public support continues for Puget Sound cleanup efforts, and the Puget Sound plan is providing new direction and focus for water quality activities. The plan is based on the concept that it is far easier and less expensive to prevent degradation than to correct it. In addition, the Puget Sound Estuary Program has improved federal-state coordination and the effective use of resources. It is hoped that efforts to remedy the Sound's problems have been started in time to prevent serious deterioration. Effective planning and management based on strong citizen awareness and support, along with remedial actions in certain areas, are the only hope for protecting the Sound as the population continues to grow. One of our greatest challenges is to promote initiative and responsibility on the part of all players in the effort to protect Puget Sound. At the same time, coordination and communication must be maintained to ensure that efforts are not duplicated, that information is shared, and that priorities are set and addressed.

TOXIC CONTAMINATION

Toxic contaminants represent the most acute and greatest long-term threat to the habitats and biological resources of the Sound. Toxicants reach the marine waters of Puget Sound from many sources, but the principal known sources are municipal and industrial point source discharges, stormwater runoff, pesticides from nonpoint sources, and unpermitted discharges of wastewater. In addition, the dredging and disposal of contaminated sediments can disturb and redistribute these materials. The accumulation of toxicants in sediments and the resulting damage to natural populations is one of the most significant problems in Puget Sound.

Toxic contaminants bind to particles and are largely retained as sediments in the Puget Sound basin rather than being flushed out to open ocean waters. A variety of toxic compounds are found in a wide range of concentrations in the surface sediments of the basin. For example, concentrations of toxicants in surface sediment in the Sound's urban bays are elevated 100 times or more over the levels in the cleanest rural bays. Some degree of sediment contamination is detected almost everywhere in the Sound because there are both natural as well as anthropogenic (originating from humans) sources of certain contaminants such as iron and arsenic. However, the most adverse biological effects generally appear to be found in urban bays throughout the Sound.

High concentrations of toxic contaminants in bottom sediments have been associated with high prevalences of fish diseases and other adverse biological effects in the Sound's urban bays. Groundfish in contaminated areas of Puget Sound have been found to have numerous types of abnormalities such as fin erosion and liver lesions, including liver tumors. Liver tumors in English sole have been found at levels as high as 18 percent in certain urban bays, and pre-tumors have been found at levels as high as 36 percent. In the Sound's non-urban areas these figures are about one and four percent, respectively. Recent research has also documented incidences of reproductive failure in English sole from highly contaminated areas such as Eagle Harbor and the Duwamish waterway. The prevalence of liver tumors and reproductive failure in groundfish is correlated with exposure to high levels of toxic substances in bottom sediments, but no direct cause-and-effect relationships have been established.

Toxic contamination of sediment and biota may become more severe as population and commercial and industrial activities increase, particularly in areas that are now relatively undeveloped. While observed concentrations of many toxicants are increasing in the Sound, others (such as sediment levels of lead and mercury) appear to be decreasing. Because of the persistence of many toxic substances contamination is not easily reversed. Effects of toxicants are the most significant in urbanized areas around the Sound, particularly urban embayments with high levels of stormwater runoff, point sources, and riverine sources of contaminated water and suspended sediments. However, toxic contamination should be reduced in the future as the National Pollutant Discharge Elimination System (NPDES) permit system is improved. As cleaner sediments are deposited on the bottom, older sediments with higher concentrations of contaminants will slowly be buried and removed from the biologically active surface layer where many bottom-dwelling animals live.

Efforts by Ecology and local governments targeted at controlling toxic chemicals include better control of toxicants from point sources and pretreatment programs to limit the initial loading of these contaminants. In addition, targeted efforts conducted by EPA, Ecology, and others in urban bays include methodical programs of finding and responding to high levels of sediment contamination wherever they occur in the Sound. The sources, distribution, and biological effects of toxic contamination in Puget Sound are discussed in detail in Chapter 4 of this report.

POINT SOURCE POLLUTION

Sewage treatment plants and industrial facilities that discharge into rivers and the Sound are considered point source dischargers. They are regulated by state and federal discharge permits. Point source discharges (and stormwater and combined sewer overflows that are discussed below) occur throughout the Sound, but tend to be concentrated in urbanized areas such as Bellingham Bay, Budd Inlet, Commencement Bay, Eagle Harbor, Elliott Bay, Everett Harbor, and Sinclair Inlet. Due to a number of physical and chemical processes, the harmful effects of contaminated sediments from these concentrated point source discharges tend to be localized in these urbanized bays and inlets around the Sound (although the overall loading to the Sound is also of concern). Consequently, improvements in the control of point source discharges (particularly toxic contaminant reduction) will slowly improve the quality of water and surface sediments in these areas.

Since the 1960s substantial progress has been made toward limiting conventional pollutants including bacteria, sediments, and oxygen-demanding substances. For example, pulp mills have reduced oxygen-demanding discharges from two million pounds per day in 1969 to about 30,000 pounds per day in 1986. In addition, most sewage treatment plants in the Puget Sound area either have converted, or are working toward converting, from primary to secondary treatment. Many of these plants are scheduled to complete their treatment process conversion by the early 1990s, though the largest plant in the Sound (the West Point plant in Seattle) is not scheduled to achieve secondary treatment until the late 1990s. Conversion to secondary treatment will significantly reduce the discharge of many conventional and toxic pollutants to Puget Sound. The Municipality of Metropolitan Seattle (Metro) has estimated that upgrading to secondary treatment at its four primary treatment plants will reduce the total non-volatile toxicant (metals and extractable organics) loading to the Sound by 100 tons (91 metric tons) per year.

The discharge permit system for point source dischargers has not in the past effectively controlled the discharge of toxic pollutants into Puget Sound. Major weaknesses of the regulatory program identified prior to the adoption of the Puget Sound plan have been that discharge permits typically include effluent limits on only a few contaminants (usually conventional pollutants) with few limits placed on toxicants; there are few requirements for monitoring the environment that the pollutants are discharged to; and there is no systematic program for detecting unpermitted discharges, particularly outside of the urban bays. Largely as a result of the Puget Sound plan, Ecology is substantially strengthening its regulation of point source dischargers to deal with some of these problems. This effort is being aided by substantial funding increases from discharge permit fees and from state general funds.

Major Puget Sound plan elements that deal with point source discharges address the improved control of toxicants in permits, the adoption of sediment quality criteria, increased frequency of inspections (including unannounced inspections), inspection of unpermitted discharges, the requirement for more complete discharge monitoring and use of certified laboratories, and implementation of pretreatment requirements. Ecology is using the funding increases discussed above to support a significant portion of these improvements. This should begin to result in decreased contaminant loadings to urbanized bays and other areas. Unfortunately, it is still too early to see direct environmental benefits from these new programs.

One program that has been effective at identifying and eliminating point source toxic contamination in several urban bays around the Sound has been the Urban Bay Toxics Control Program. This program was developed in 1985 by EPA, Ecology, and other agencies and organizations, and much has already been accomplished by the action teams established by the program. For example, since 1985 Elliott Bay action teams have inspected 124 sites and facilities, assessed 28 penalties amounting to $44,200, and issued 36 notices of permit violations and 22 administrative orders for cleanup actions. A more complete description of this program and recent enforcement actions can be found in Appendix B of this report. Point source pollution in general is discussed in more detail on pages 90 to 100 of this report.

STORMWATER AND COMBINED SEWER OVERFLOWS

Stormwater, or surface water runoff, contains a complex mixture of suspended solids, nutrients, bacteria, viruses, and toxic materials such as lead, cadmium, mercury, organic pesticides, ammonia, and petroleum products. Stormwater samples in the Seattle area typically exceed EPA water quality criteria for cadmium, copper, lead, nickel, and zinc. Some storm drains in Seattle were found to be the major sources of lead and polychlorinated biphenyls (PCBs) found in the sediments of Elliott Bay. In more rural areas of the Sound stormwater runoff tends to contain fewer toxic chemicals and more fecal coliform bacteria. For example, stormwater discharging into Henderson Inlet in southern Puget Sound periodically violates state fecal coliform standards for water, and has been found to be one factor in the closure of commercial shellfish beds at the head of the inlet.

The Puget Sound plan requires that stormwater control programs be implemented in all cities and other urbanized areas of the Sound by the year 2000. Programs will emphasize source controls and best management practices (BMPs) rather than end-of-pipe treatment. Puget Sound cities and counties that are currently instituting stormwater management utilities or other means of dealing with stormwater problems include Anacortes, Auburn, Bellevue, Everson-Nooksack, Gig Harbor, Kent, Lacey, Mountlake Terrace, Olympia, Port Townsend, Poulsbo, Redmond, Renton, Steilacoom, Tacoma, Tumwater, and Winslow as well as portions of King, Snohomish, and Thurston Counties.

In addition to the urban stormwater programs aimed at existing urbanized areas, the Puget Sound plan requires all jurisdictions to control the quantity and quality of stormwater from new development. Jurisdictions must also ensure that existing stormwater control systems are adequately maintained and operated. Stormwater considerations will also be integrated with the plan's nonpoint program where stormwater is one of the pollution sources to be addressed in priority watersheds. To help implement stormwater elements of the plan, technical assistance, including manuals, guidelines, and model ordinances, will be provided by Ecology. Stormwater issues are discussed in more detail on pages 112 to 115 of this report.

Ten cities around the Sound have combined sewers where sanitary sewage, industrial wastewater, and stormwater are collected in a single sewer system. Discharges from these systems typically contain high concentrations of fecal coliform bacteria, nutrients, and suspended sediment (with associated high levels of metals and organic toxicants). During large storms some of this combined effluent is discharged directly to the Sound without treatment. For example, in an average year Metro discharges about two billion gallons of raw sewage, untreated stormwater, and industrial effluents from about 20 combined sewer overflows (CSOs) in the Seattle area.

Legislation enacted in 1985 requires Ecology to work with cities, sewer districts, and other jurisdictions to achieve the "greatest reasonable reduction" (an average of one untreated discharge per year) of CSOs at the earliest possible date. Three sewer jurisdictions with known CSOs (Everett, Metro, and the city of Seattle) have already submitted draft reduction plans and compliance schedules. The remaining jurisdictions have been required to monitor their CSOs through at least one rainy season and to develop reduction plans by the summer of 1988. Improvements in the quality of discharges from storm drains and CSOs will primarily affect water and sediment located in and adjacent to urbanized areas of the Sound. CSOs are discussed in more detail on pages 97 to 99 of this report.

NONPOINT SOURCE POLLUTION AND SHELLFISH

Nonpoint source pollution is typically defined as pollution that is discharged from diffuse, scattered sources rather than through pipes. Nonpoint pollution includes pathogens, sediments, and toxicants that are picked up by rainwater and carried into streams, rivers, and eventually the Sound, or that are discharged directly into the water from boats and other water-based sources. Because sources of nonpoint pollution are so numerous, varied, and difficult to detect, their cumulative effects on water quality and habitats of the Sound can be significant. The effects of nonpoint source pollution are experienced throughout Puget Sound. One of the more notable effects is the number of commercial shellfish growing areas that have been closed because of high levels of fecal coliform bacteria. This bacterial contamination appears to originate from failed on-site sewage disposal (septic) systems, domestic and wild animal wastes, and contaminated stormwater. In many areas bacterial contamination has increased with increasing rural development of residences and small (but numerous) noncommercial farms that use septic systems and maintain animals on their property. Nonpoint source contamination is likely to increase as population continues to increase in the Sound's more rural areas. Shellfish bed closures are discussed in more detail on pages 162 to 167 of this report.

Forest practices are another potential contributor to nonpoint source pollution. Sediment loading from timber harvesting and road construction can damage stream fish habitat, and poor forest practices can introduce pesticides and organic debris to streams. The Timber/Fish/Wildlife (T/F/W) agreement is a precedent-setting effort that was negotiated in 1986-87 by state resource agencies, timber industry representatives, Indian tribes, and environmental groups. The agreement provides for a more holistic approach to forest practices and includes, among other things, provisions for interdisciplinary teams to develop on-site harvest plans; protection of wetlands and riparian stream corridors; training and more emphasis on research and monitoring; and the provision for upland management areas for the use and protection of wildlife in harvested areas. If successfully implemented, this agreement will help protect valuable aquatic resources potentially affected by forest practices, and should result in improved water quality in streams and rivers influenced by forestry activities.

Agricultural practices can introduce a variety of nonpoint pollutants including sediment, fecal bacteria, nutrients, salts, organic chemicals, and pesticides. Programs have been developed by Ecology (e.g., the Dairy Waste Management Program), the U.S. Department of Agriculture Soil Conservation Service (SCS), and county conservation districts to manage and control agricultural nonpoint pollution. These programs generally rely on voluntary implementation of BMPs although enforcement of water quality standards may also be used. Voluntary implementation of BMPs is increasing throughout the Sound by both commercial and noncommercial farms, and improved water quality has been found in certain areas where the majority of land owners are implementing some form of BMP. However, the overall effectiveness of these programs has been limited in the past by inadequate funding and too little attention to noncommercial farms. These small farms represent a significant, largely uncontrolled source of agricultural nonpoint pollution in the Sound.

Failing on-site sewage disposal (septic) systems can discharge pathogens and household chemicals to groundwater, streams, and eventually to Puget Sound. Approximately one-third of the residents in the Puget Sound area are served by on-site systems and in some areas up to 12 percent of all on-site sewage disposal systems may be failing. In the 1987 and 1988 legislative sessions the Authority proposed a bill that would have required sellers of property to have the septic system inspected and to provide essential information on the system to the buyer when property is sold. This bill would have played a role in the effort to identify failing systems, educate residents about maintenance and use of sewage disposal systems, and reduce this source of nonpoint pollution to the Sound. Unfortunately, the bill was not passed but efforts to accomplish these goals continue.

Sewage discharge from boats is a potential problem during the boating season wherever large numbers of boats congregate. Boat fueling and maintenance activities can also be sources of pollution. A Boaters Task Force was created in 1987 to design an accelerated education program for boaters and to prepare legislation requiring sufficient pumpout facilities at existing and new moorage facilities.

The nonpoint source pollution program of the Puget Sound plan addresses these various nonpoint sources by using a three-pronged approach. First, a cooperative local watershed program has been established that will identify and rank watersheds in order of importance. Watershed action plans will be developed in each priority watershed to cover significant nonpoint pollution concerns in the watershed such as on-site septic systems, agricultural practices, and stormwater. Second, to supplement the watershed action plans, counties will prepare and/or coordinate countywide education programs to help citizens prevent nonpoint pollution. Local governments will also evaluate ways in which water quality considerations are incorporated into land use decisions, with particular attention to on-site sewage treatment. Third, the nonpoint program involves several state programs such as the Boaters Task Force and initiatives relating to on-site sewage treatment, and endorses the T/F/W agreement. The sources and effects of nonpoint pollution are discussed in more detail on pages 100 through 117 of this report.

LOSS OF WETLANDS

One major environmental consequence of Puget Sound's growth has been the destruction of wetlands for agriculture, ports, industries, and residential and commercial development. Of the approximately 22,500 acres (9,000 hectares) of coastal wetlands present in 1800, nearly 14,000 acres (5,600 hectares) have been diked, filled, and converted to other uses. Virtually all of the saltwater and estuarine wetlands have been lost in the Lummi, Duwamish, and Puyallup deltas. In stream corridors where pastures continue to be created there has been a 50 to 60 percent loss of wetlands, and in farming areas such as the Skagit Valley wetland losses are estimated to be as high as 90 to 95 percent. Commercial development in areas such as the Green/Duwamish river basin has eliminated over 95 percent of the original wetlands.

To protect some of the remaining estuarine and freshwater wetlands in the Sound, the Puget Sound plan's wetland program includes the development of state standards for wetland regulation augmented by a land acquisition program. The standards will be developed by Ecology and then implemented by local governments in their regulatory programs. The acquisition program conducted by the state will identify wetlands to be preserved in perpetuity. The 1987 state legislature appropriated $500,000 to fund the purchase of wetlands under the Puget Sound plan's wetlands program. In addition, The Nature Conservancy had raised over $1 million in private money for wetland acquisition as of January 1988, which will match the $4 million appropriated to DNR's Natural Heritage Program in the 1987-89 biennium. Loss of wetlands is described in more detail on pages 77 to 81 of this report.

PUBLIC EDUCATION

Extensive public involvement during the preparation of the 1987 Puget Sound plan (including public attitude surveys) revealed strong public sentiment and concern about the water quality of Puget Sound. Yet, as many people pointed out, a great need remains for education and more involvement of the public. Many people are not aware of how to translate their general concern about water quality into actions that will actually help. Many people are only vaguely aware of the specific causes of pollution.

Most difficult of all, many people support the protection of water quality in general--until they realize that their own activities or pocketbooks will be affected. While nearly everyone supports prevention rather than more costly cleanup after problems occur, many people affected by prevention proposals demand indisputable proof that there is a problem before they are willing to carry out pollution control activities. In addition, many people involved in activities which adversely affect the Sound are likely to suggest that other pollution sources are far more important than those they are responsible for. The Puget Sound plan is based on the need for a well-educated public. It is comprehensive and emphasizes the need for equity rather than singling out only certain parts of the problem. Recognizing that the protection and cleanup of Puget Sound is a long-term management challenge, education and public involvement become the essential ingredients for success.

It would be idealistic to think that there will be an end to fingerpointing and that all sectors of the community will gladly do whatever is needed to protect water quality. But progress is being made, and there is reason for optimism. Industrial and municipal point source dischargers have accepted the imposition of new permit fees to pay for a stepped-up regulatory program. Local governments have requested and accepted the lead role in designing and carrying out nonpoint pollution control programs. Many farmers have voluntarily put BMPs to work on their farms, to protect against water pollution and soil erosion.

Many diverse organizations are doing their part to involve and educate the public, often through effective use of peer-to-peer communication. With funding from the PIE-Fund, organizations ranging from Associated General Contractors to Puyallup

High School are carrying out model public involvement and education projects. In addition, over 100 people from diverse constituencies and organizations are helping to design a long-term education strategy for the Sound. Throughout the Puget Sound area there are numerous locally-based projects to rehabilitate streams, reintroduce fish into streams, clean up beaches, monitor water quality, recycle waste, collect hazardous substances, and educate the public.

PUGET SOUND IN PERSPECTIVE

It is important to attempt to assess our current knowledge of the status of Puget Sound's water quality and biological resources from both a historical perspective as well as in comparison to other similar estuarine systems. The historical perspective is important because it allows us to compare the present problems with those of the past and to look at the effectiveness of past measures that were aimed at cleaning up pollution in the Sound. Unfortunately, it is difficult to gain a historical perspective on a particular environmental problem (such as wetland losses or tissue levels of contaminants) because long-term data are often not available. In addition, comparison with other estuarine systems is very difficult because of the inevitable differences in the physical, biological, demographic, and economic features of the systems. Despite these difficulties, cautious interpretation of comparative information allows us to see how severe the problems in Puget Sound are relative to those of other estuaries. Also, by seeing how other regions have handled their problems, we may be able to make better decisions about how to handle our own problems or avoid problems before they arise.

In terms of a historical perspective on the problems in Puget Sound, it is significant to note that descriptive and qualitative observations of the bottom habitats in some areas of the urban bays (e.g., the Tacoma waterways and Everett Harbor) made in the 1950s indicated that many parts of these bays were completely devoid of life, or "abiotic". Bottom samples collected in the 1980s are rarely abiotic, although the bottom communities in certain urban embayments continue to show signs of stress (e.g., reduced numbers of species). However, the bottom-dwelling communities of the central basin of the Sound appear to be quite healthy and rich in species. A second indication of water quality improvement from a historical perspective is that we are beginning to see that maximum concentrations of certain chemicals (such as lead, mercury, silver, PCBs, PAHs, and DDT) are found in sediment layers that are below the surface sediment layer in central Puget Sound. This appears to indicate that more recently deposited sediments have lower concentrations of certain contaminants than did sediments that were deposited 20 or more years ago.

Despite the importance of the subject for scientists and managers, nothing more than a superficial scientific comparison of the natural and contaminated states of bays and estuaries nationally and internationally has ever been performed. Qualitative comparisons show that most estuarine systems are affected by the same major sources of contamination and resource depletion that result in water quality and habitat degradation, though to varying degrees. Puget Sound is unique because comparable biological communities are present in both the degraded areas and the relatively unaffected areas. Thus, the Sound provides a natural laboratory for the study of contaminants and their effects on natural populations.

A more quantitative comparison of the prevalence of toxic chemical contamination in the coastal environment of the United States is being conducted by the National Oceanic and Atmospheric Administration (NOAA). Sampling of sediments and tissues of bivalve molluscs and bottom-dwelling fish is performed at over 200 sites, 11 of which are located in the Sound. Because site characteristics (e.g., degree of tidal flushing and proximity to outfalls) and the species sampled vary, direct comparisons between areas are not possible. However, some interesting information is being developed by this program. Selected sites in Boston Harbor and Raritan Bay on the east coast and in San Diego Harbor in southern California generally had higher sediment contaminant concentrations than the few specific sites that are sampled in the Sound (Commencement Bay, Elliott Bay/Four Mile Rock, and Nisqually Reach). However, the Four Mile Rock site had the highest PAH concentrations of any site in the country.

Comparative studies of tissue concentrations of contaminants in fish from sites around the United States indicate that PCB concentrations in fish from the Hudson River, New York Harbor, San Diego Harbor, and much of Lake Michigan exceed those in fish collected from Commencement and Elliott Bays. However, PCB concentrations in fish tissue in Boston Harbor, western Long Island Sound, and San Francisco Bay are lower than those in Commencement and Elliott Bays. PCB levels in harbor seals from southern Puget Sound were among the highest in the world in the 1970s, although recent data suggest that these levels are declining.

WHAT REMAINS TO BE DONE?

One of the most important things to remember when considering the overall condition of Puget Sound and its resources is that the problems we see today did not occur overnight; they are the product of over 100 years of urban, industrial, and agricultural activity in the area. However, this does not mean that it will take another 100 years to clean up the Sound. Significant progress has been made in the last decade to recognize and begin to correct some of the problems. In addition, programs are now in place that are designed to help prevent the further degradation of water quality and biological resources in Puget Sound and, in the long run, improve the overall health of the ecosystem. However, there is still more that needs to be done.

There are a number of issues that were not adequately addressed in the 1987 Puget Sound Water Quality Management Plan. These issues need further analysis to determine to what extent they affect water quality and resources in the Sound and whether they are adequately addressed by existing laws and programs. Some of these issues are: transportation of hazardous substances; alternative means for treating human wastes; use and control of pesticides and other toxicants; human health risks associated with infectious wastes, toxicants, and the consumption of fish and shellfish; the regulation of federal facilities; atmospheric deposition of pollutants; the effects of plastics in the marine environment; the effects of nutrient enrichment in the Sound; and the effects of groundwater contamination on the Sound. These issues will be briefly discussed in the draft 1989 Puget Sound plan and, based on public comment, may be expanded and more thoroughly addressed in the final plan.

In addition to these issues, there are three general areas that need to be focused on and implemented if we are going to be able to protect the health and diversity of Puget Sound and its resources: research, monitoring, and education and public involvement. In the Puget Sound plan the Authority began efforts to create comprehensive programs in these three areas. Committees were established to set research priorities and deal with other research issues, to develop a Soundwide ambient monitoring program, and to develop a long-term strategy for education and public involvement.

The final report from the Committee on Research in Puget Sound was completed in March 1988, and received considerable discussion at the First Annual Meeting on Puget Sound Research that was held in Seattle on March 18 and 19, 1988. The committee concluded that there is no comprehensive and coordinated program for research on Puget Sound. It also recommended that a new institutional structure--the Puget Sound Research Foundation--be established to set Soundwide research priorities, generate research funding, translate and disseminate research results, and facilitate access to data so that management decisions in the future can be based on more factual, usable information. The committee suggested that the foundation would help generate the information that is necessary to understand the Sound's rich and complex ecosystem and to manage this system more effectively. The committee's recommendations will be considered by the Authority in preparing the 1989 Puget Sound Water Quality Management Plan that is scheduled to be released as a draft in June 1988.

The funding of a comprehensive, Soundwide monitoring program is also required to develop meaningful, long-term trends data for Puget Sound. This information is essential to detect improvements in the Sound that result from various management strategies and actions. It is also necessary to detect continued degradation that may be occurring that would require additional management and regulation. The final report on the proposed Puget Sound Ambient Monitoring Program was completed in April 1988 and includes a proposed sampling design, a data management approach, an institutional structure to manage the program, and a cost estimate for the proposed program. The Authority and Ecology have already identified funding for an initial phase of the program. This monitoring plan will be considered by the Authority in preparing the 1989 Puget Sound plan.

Education is also important for the Sound's future. To support the effort to increase awareness about water quality and Puget Sound, the Authority is distributing $1 million from the state Centennial Clean Water Fund for model projects in education and public involvement through the Public Involvement/Education Fund (PIE-Fund). The Authority also established a 12-member advisory panel, the Education and Public Involvement Advisory Group to develop a long-range strategy for education and public involvement related to Puget Sound. Six work teams composed of public and agency members considered a spectrum of issues relevant to education and public involvement. Eight background reports were produced which examine the role of formal education (kindergarten through twelfth grade and post-secondary), nonformal education, media, public involvement, action programs (e.g., Adopt-a-Stream), state agencies and interpretive centers, and user groups (e.g., business and industry) and their potential relation to the strategy. Specific elements of the education and public involvement strategy include increasing resources to local activities and programs; setting overall cleanup goals that the public and private sector can work toward; coordinating information resources; and making institutional improvements such as teacher training and coordinated state agency education and public involvement efforts. The draft strategy was completed in May 1988 and will be considered by the Authority in preparing the 1989 plan.

Chapter 2: The Puget Sound Basin

INTRODUCTION

This chapter describes the natural characteristics of the Puget Sound water quality planning area. This area encompasses the marine waters of Puget Sound south of Admiralty Inlet (including Hood Canal and Saratoga Passage), the marine waters north to the Canadian border (including portions of the Strait of Georgia), and that portion of the Strait of Juan de Fuca that is south of the international boundary with Canada. The planning area also includes the entire land area that drains into these water bodies. Although this chapter addresses the physical and biological features of the entire Puget Sound area, in many cases data are only available for Puget Sound south of Admiralty Inlet. The water quality planning area covers about 16,000 square miles (41,440 square kilometers), of which 80 percent is land and 20 percent is water (see Figure 2-1; Burns, 1985). There are about 2,354 miles (3,790 kilometers) of marine shoreline in the 12 counties that make up the Puget Sound planning area (Washington Department of Natural Resources, 1977).

PHYSICAL DESCRIPTION OF THE PUGET SOUND BASIN

Physical Geography

Puget Sound and the Strait of Georgia in British Columbia are inland arms of the Pacific Ocean. Their main connection to the Pacific is through the broad Strait of Juan de Fuca. Puget Sound south of Admiralty Inlet is especially complex and consists of a set of interconnecting basins with diverse and highly productive habitats and marine life.

The Strait of Juan de Fuca (see Figure 2-2 for place names) and the Strait of Georgia are large estuarine water bodies that are separated by a shallow ridge that breaks the water's surface as the San Juan Islands and forms sills in the passages between them. The shallow sill at Admiralty Inlet separates the rest of Puget Sound from these straits. The portion of the basin south of Admiralty Inlet contains approximately 38 cubic miles (158 cubic kilometers) of water (McLellan, 1954). The surface water temperature averages 55°F in summer and 45°F in winter and has an average salinity of 27 parts per thousand. Deep water in the Sound is around 43°F year around with a salinity of 30 parts per thousand (Burns, 1985).

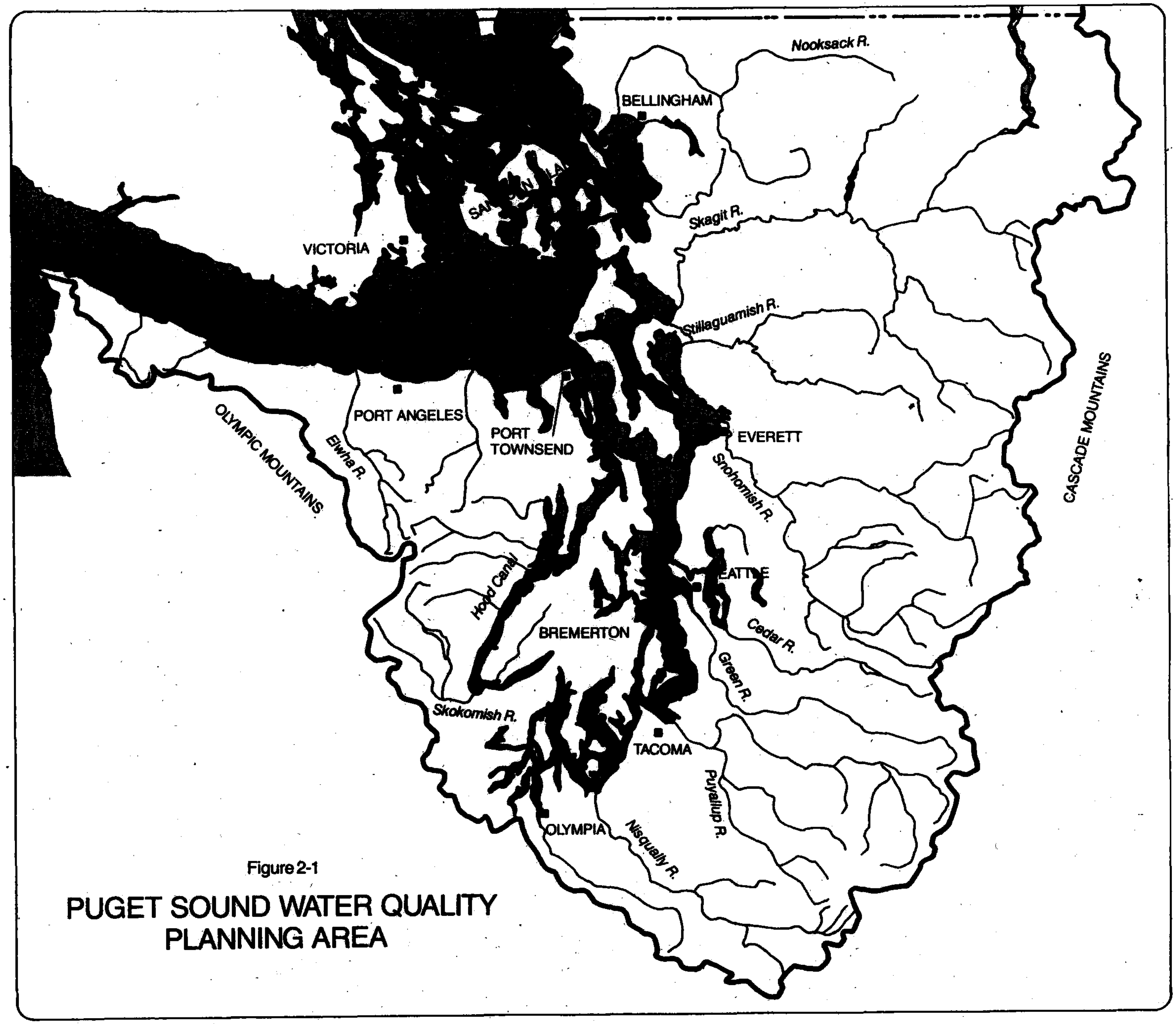


Figure 2-1

PUGET SOUND WATER QUALITY PLANNING AREA

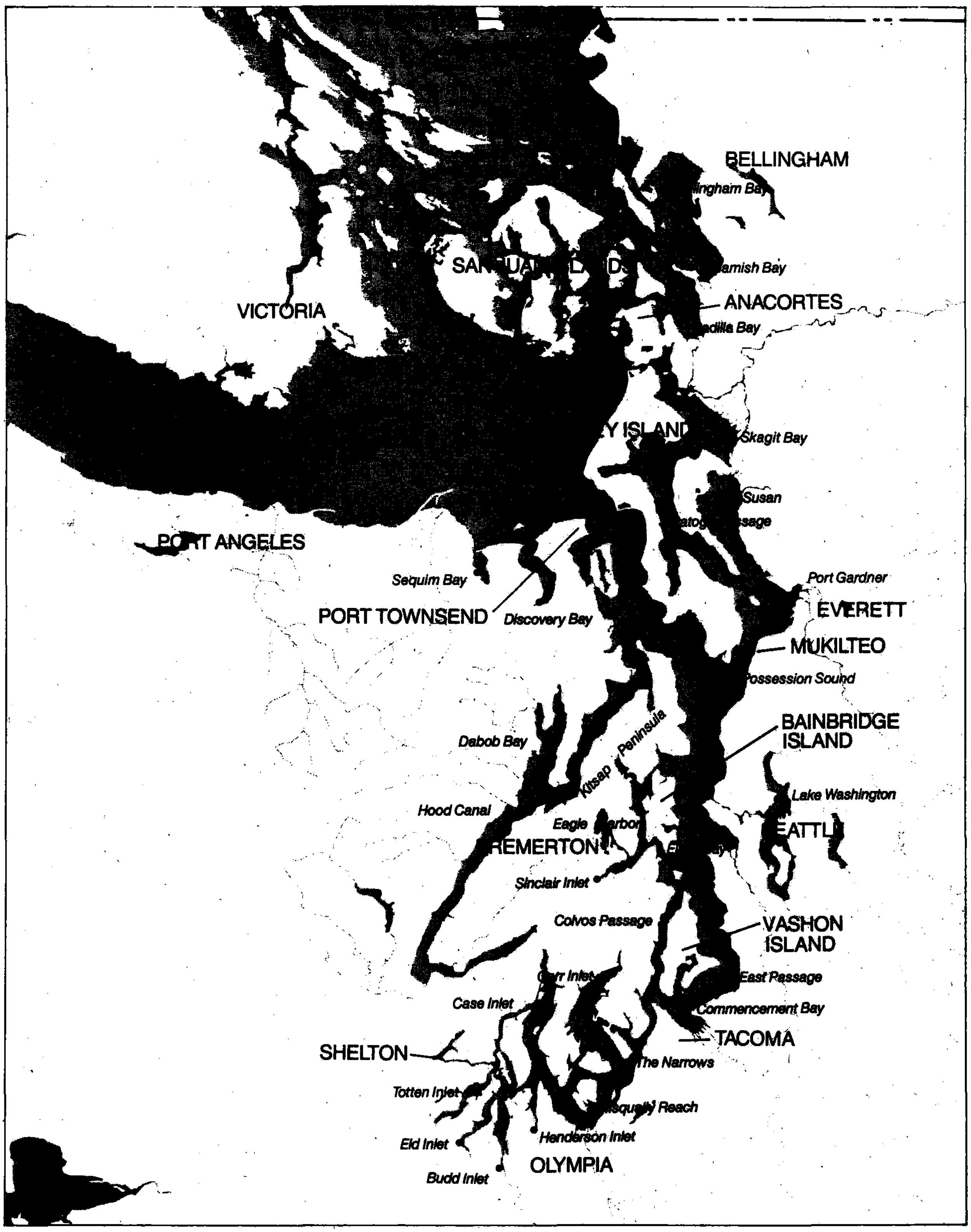


Figure 2-2

PUGET SOUND LOCATIONS

Puget Sound south of Admiralty Inlet is divided into four sub-basins by sills that average 150 feet (46 meters) in depth. The Main Sub-basin lies between the sills at Admiralty Inlet and the Tacoma Narrows and includes about 45 percent of the area and 60 percent of the volume of the four Puget Sound sub-basins (Burns, 1985). The deepest point in the Sound (920 feet or 281 meters) is located in this sub-basin just north of Seattle. The Whidbey Sub-basin lies between Whidbey Island and the eastern mainland and includes Saratoga Passage and Port Susan. Hood Canal is a long, narrow sub-basin with a major bay at Dabob Bay and a sharp eastward bend near its head at Lynch Cove. The Southern Sub-basin is the most complex of the basins because of its many inlets and islands and its convoluted shoreline. The southern inlets are the shallowest parts of the Sound and include large areas of tidal flats.

Land formations along the shores of the Sound consist primarily of bluffs and beaches left by the retreat of glaciers and subsequently modified by erosion and deposition by rivers. Some pre-glacial rock formations are exposed at sea level in the northern Puget Sound region starting at Fidalgo Island and extending through the San Juans (Figure 2-3). Virtually all of the rolling lowland areas of the islands and mainland of the Puget Sound area are formed of and underlain by glacial deposits of clay, sand, and gravel (Pacific Northwest River Basins Commission, 1970).

Soils in the planning area are generally poor due to their relative youth and their origin from glacial erosion. Mountain soils originate from the weathering of bedrock and contain little humus. Soils in the lowlands have developed a higher organic content from several thousand years of forest growth. Older and relatively richer soils are found in the southern lowland that was less affected by glaciation (Pacific Northwest River Basins Commission, 1970). Drainage can be hampered in some areas by subsurface clay deposits, producing marshy or boggy soils. Overall, the natural lowland soils of Puget Sound are not well suited to agriculture but often support forests. The highest quality soils are found in the flood plains of rivers, especially in diked wetlands of high organic content such as those of the Skagit delta. An areawide study of soil usability found that 72 percent of the land in the Puget Sound area had a high erosion potential, while 43 percent of the land had some degree of wetness that limited its usability (Pacific Northwest River Basins Commission, 1970).

FRESHWATER RESOURCES

Because Puget Sound is an estuary, its natural properties are affected by the inflow of fresh water. Fresh water enters the Sound from precipitation as rain or snow and as groundwater. However, by far the largest source of fresh water inflow to the Sound is surface water from rivers and streams.

Precipitation

Precipitation at measuring stations in the basin averages 16 to 96 inches (41 to 244 centimeters) per year, depending on location (Figure 2-4). The wettest places are the upper valley reaches of the western slopes of the Olympics and Cascades which strip the moisture from the ascending winds (estimates of up to 200 inches or 508 centimeters per year have been reported from the upper Nooksack Valley; National Weather Service). The driest area in the Sound is centered south of the San Juan Islands downwind of the Olympics. Approximately three-quarters of the year's precipitation falls between October and March (Figure 2-4) when the predominant winds are from the south. During this time soils around the Sound can become saturated with water, and their capacity to process wastes from septic tanks and manure applications may diminish. As a result, human and animal wastes may run off directly into ditches and streams and be introduced into the Sound. Heavy

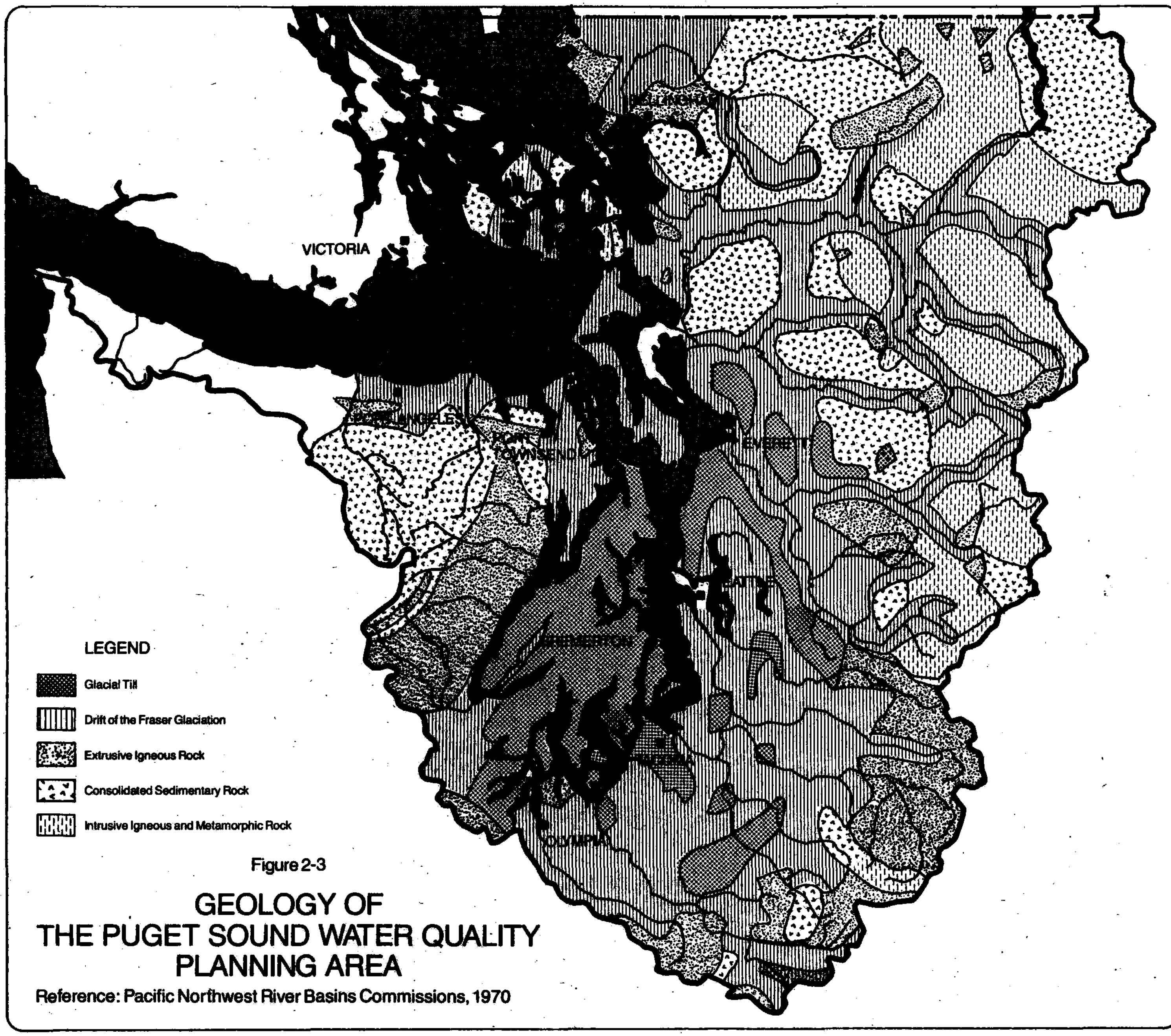


Figure 2-3

GEOLOGY OF
THE PUGET SOUND WATER QUALITY
PLANNING AREA

Reference: Pacific Northwest River Basins Commissions, 1970

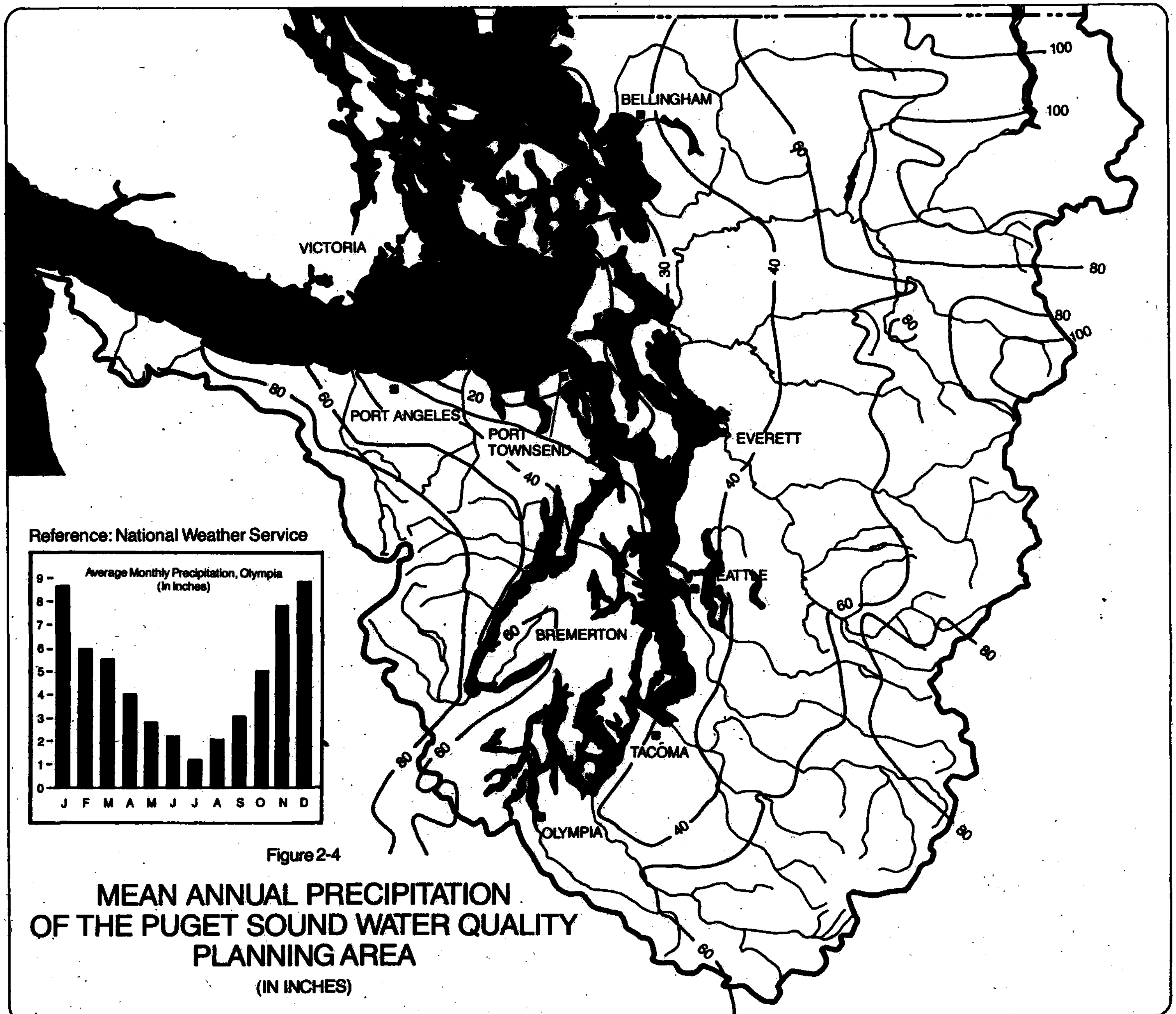


Figure 2-4

MEAN ANNUAL PRECIPITATION OF THE PUGET SOUND WATER QUALITY PLANNING AREA

(IN INCHES)

precipitation may also result in a combination of surface runoff and sewage being discharged untreated into the Sound from combined sewer overflows (CSOs). These problems are discussed in more detail in Chapter 4 of this report.

Groundwater

Groundwater is water in porous underground deposits, forming reservoirs known as aquifers (Figure 2-5). Most of the groundwater found in the Puget Sound area exists in sandy sediments deposited by streams and glaciers. Groundwater is used extensively in the Sound for drinking and for agricultural and industrial uses. Seven of the counties in the planning area (Clallam, Island, Jefferson, Kitsap, Mason, Snohomish, and Thurston) rely on groundwater for more than 75 percent of their drinking water supplies (Washington Department of Ecology, 1987a). Although water yield from an aquifer is a function of the rate and quantity of movement within the aquifer, the sustainable yield of water from an aquifer is controlled by the rate at which water soaks through overlying soils and rocks to recharge it. At present the extraction of groundwater for human uses has not exceeded the rate of recharge in most areas in the Sound, although excess groundwater extraction appears to have caused some saltwater intrusion in the San Juan Islands and elsewhere (Mullen, 1987, pers. comm.). However, it is essential that groundwater quantity and quality be protected. Contaminants from septic tank effluent, pesticides, landfill leachate, and other buried wastes, as well as saltwater, can potentially enter aquifers and make them unsafe for human or agricultural use.

Lakes

There are over 2,800 lakes and ponds covering a total of 175 square miles (453 square kilometers) in the Puget Sound area, ranging from small, cold alpine lakes to larger lakes in lowland valleys (Williams et al., 1975). There are also 24 major dam-created reservoirs in the basin with a total surface area of 70 square miles (181 square kilometers). Lakes in rapidly developing areas are particularly susceptible to degradation from nutrient enrichment and bacterial contamination caused by nonpoint source pollution.

Rivers

Rivers and streams in the Puget Sound area that are fed by rainfall, melting snow, and glaciers flow to marine waters from upland areas called drainage basins or watersheds. Washington Department of Ecology (Ecology) water resource managers have divided the Puget Sound water quality planning area into nine "Consolidated Watershed Basins" (Figure 2-6) based on major river systems: Nooksack, Skagit, Snohomish/Stillaguamish, Cedar/Green, Puyallup, Deschutes/Nisqually, West Sound, North Olympic, and San Juan. These watersheds vary in size from 112,500 to 1.95 million acres (45,000 to 780,000 hectares; Pacific Northwest River Basins Commission, 1970).

Over 10,000 rivers and streams stretching over 16,000 miles (25,760 kilometers) have been catalogued in the Puget Sound basin (Figure 2-7; Williams et al., 1975). There are more than 75 river systems draining into Puget Sound with estimated average annual discharges ranging from 20 to 18,000 cubic feet per second (0.6 to 510 cubic meters per second; Figure 2-8; U.S. Geological Survey, 1984). Eight major rivers account for more than 80 percent of the total amount of fresh water entering Puget Sound. The total average annual addition of fresh water to the marine waters of the Puget Sound basin is about 45,000 cubic feet per second (1,250 cubic meters per second). This adds up to approximately 27 million acre-feet or 9.5 cubic miles (39.6 cubic kilometers) per year (U.S. Geological Survey, 1984). Potential water quality impacts to rivers include fish and wildlife habitat degradation, and the introduction of nutrients, bacteria, and toxic chemicals, including insecticides and herbicides, that wash off the land from nonpoint sources or are deposited by point sources into streams and rivers.

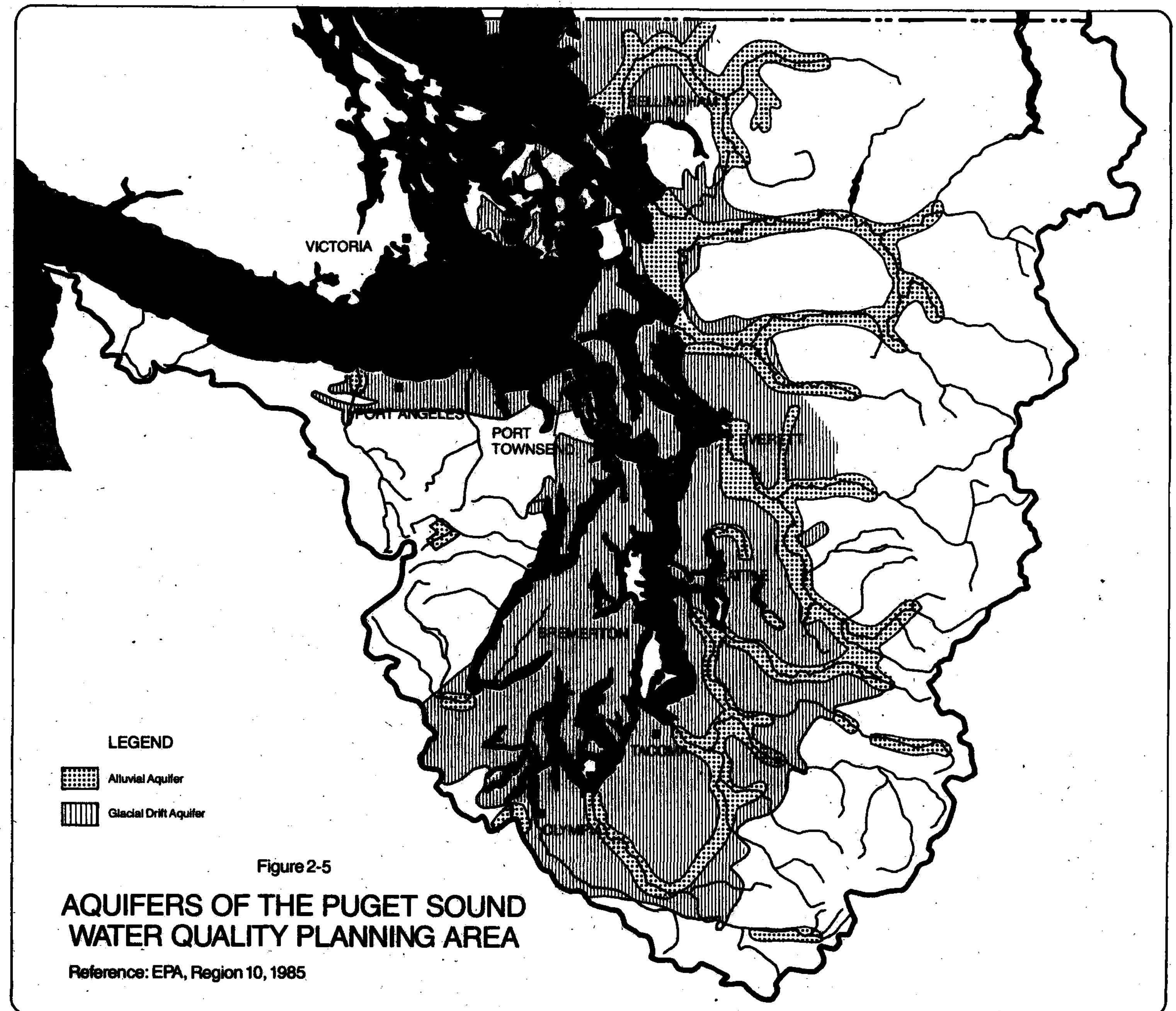


Figure 2-5

AQUIFERS OF THE PUGET SOUND WATER QUALITY PLANNING AREA

Reference: EPA, Region 10, 1985

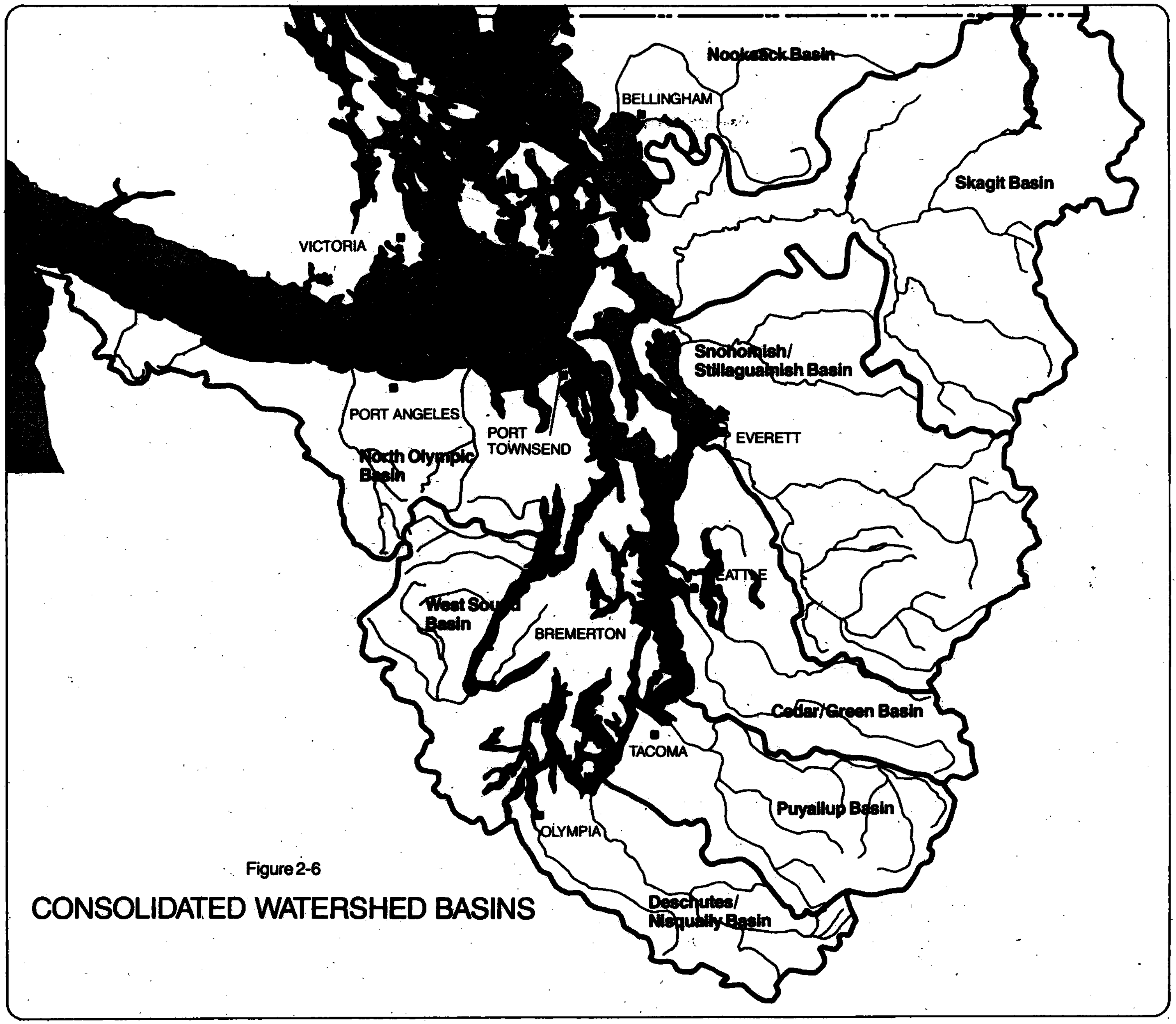
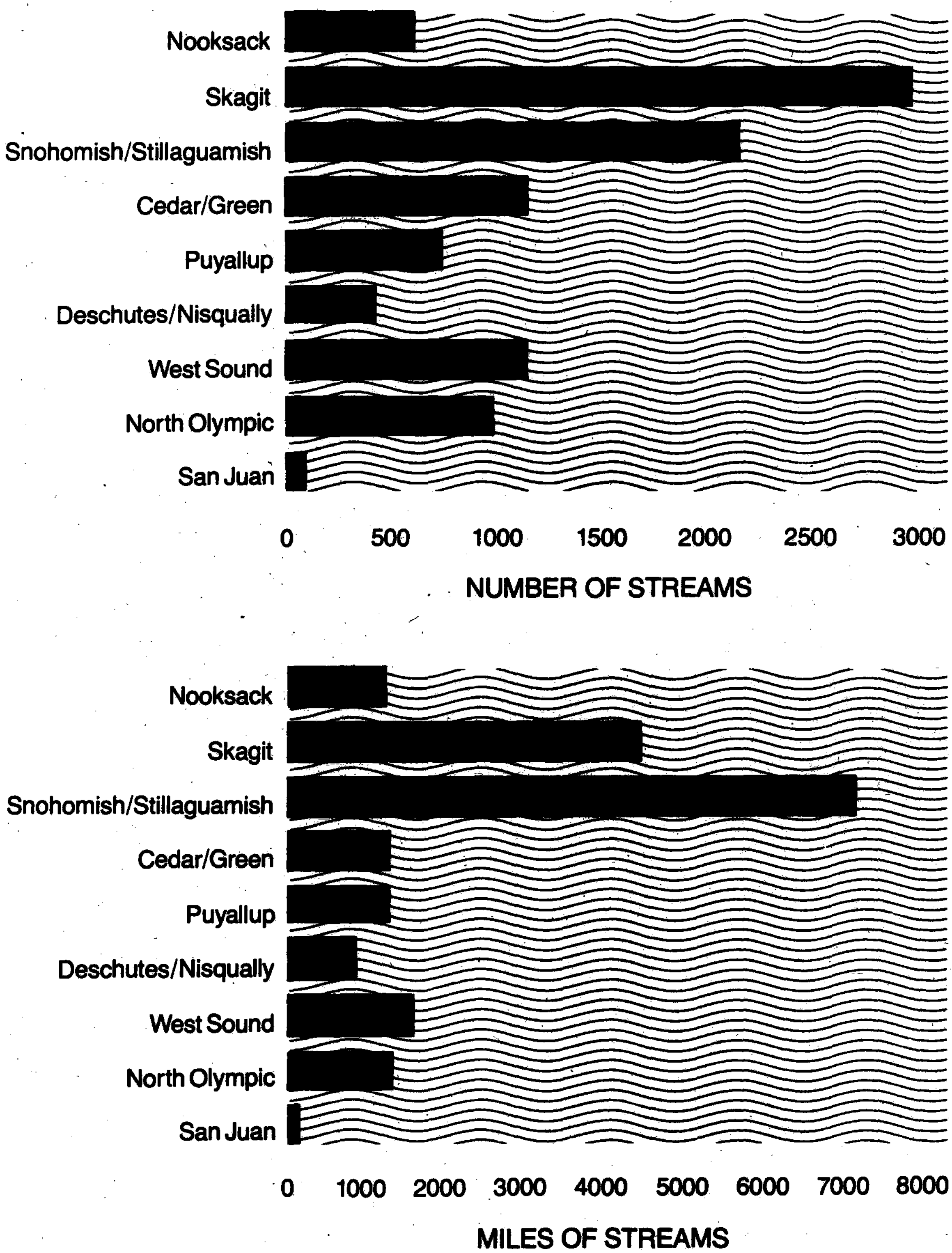


Figure 2-6

CONSOLIDATED WATERSHED BASINS



Reference: Williams et al., 1975

Figure 2-7

NUMBER AND MILES OF STREAMS IN THE PUGET SOUND WATER QUALITY PLANNING AREA (BY WATERSHED)

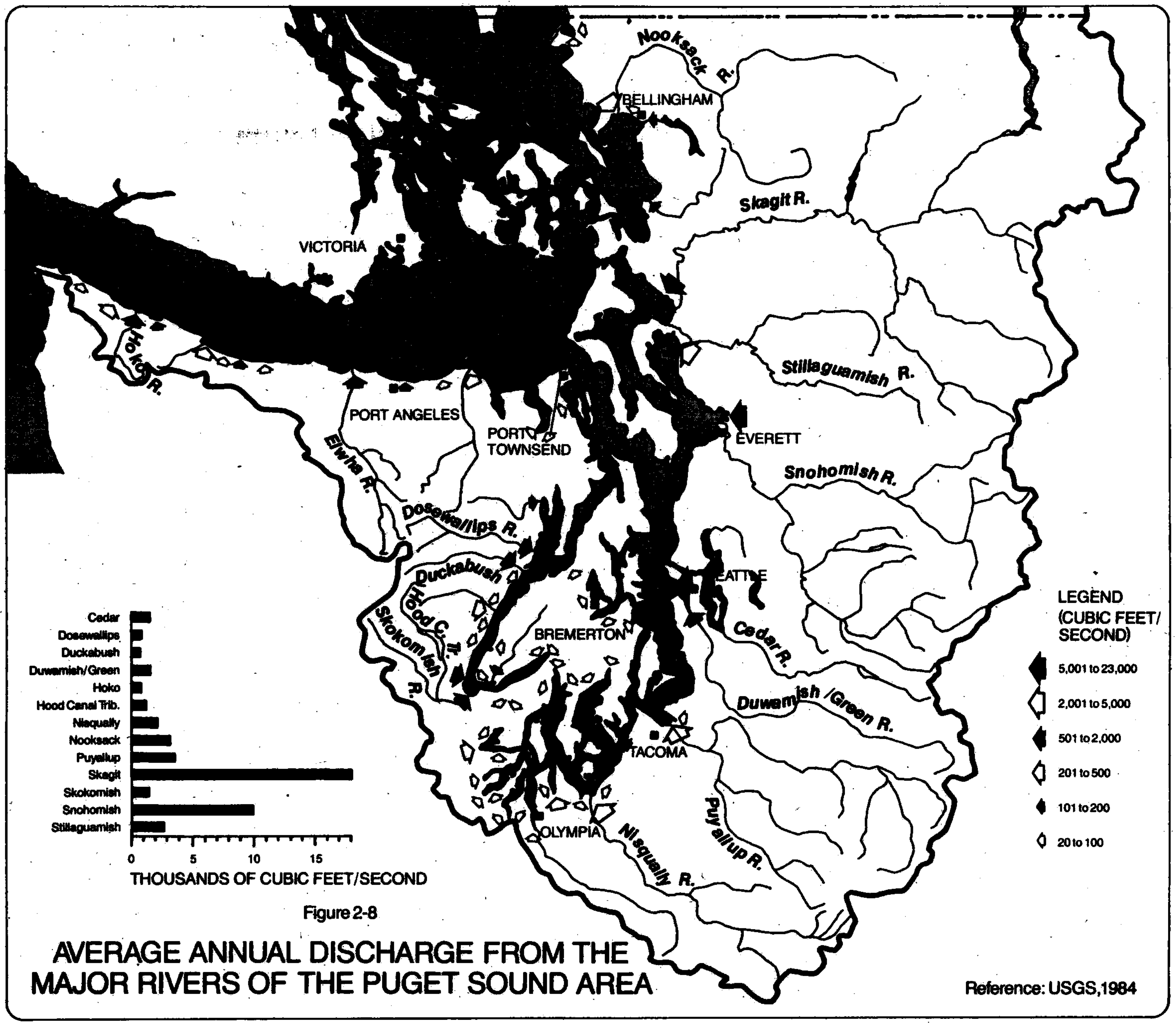


Figure 2-8

AVERAGE ANNUAL DISCHARGE FROM THE MAJOR RIVERS OF THE PUGET SOUND AREA

Freshwater flows to Puget Sound sub-basins

The freshwater flows reaching each of the four major sub-basins of Puget Sound differ because of the size and nature of the watersheds that drain into each basin. Sixty percent of the total fresh water entering the Sound flows into the Whidbey Sub-basin from the drainages of three of the largest rivers in the area (the Skagit, Stillaguamish, and Snohomish; Burns, 1985). These rivers collectively drain about 50 percent of the Sound. The Main Sub-basin receives 20 percent of the fresh water entering the Sound from the Puyallup, Green/Duwamish, Sammamish, and Cedar Rivers. No major rivers flow into the Hood Canal Sub-basin, but Hood Canal receives 10 percent of the fresh water entering the Sound through minor rivers (Skokomish, Dosewallips, Duckabush, Hamma Hamma, and an unnamed offshoot of the Skokomish River). The Southern Sub-basin receives less than 10 percent of the drainage into the Sound even though it has a large drainage area (Burns, 1985). It is fed mostly by small rivers and streams (the only major rivers are the Nisqually and the Deschutes).

ESTUARINE PROCESSES

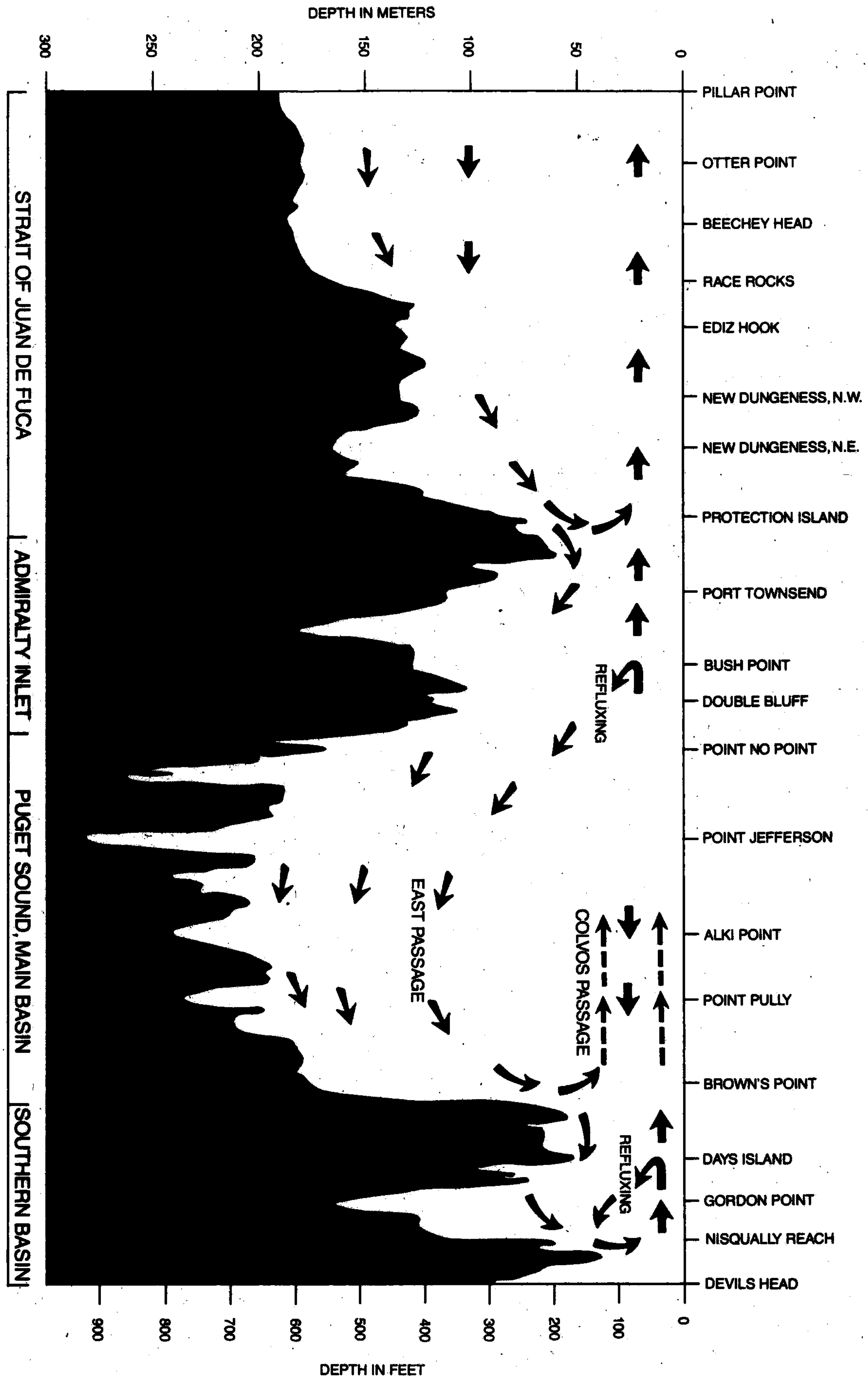
Flow patterns

Estuaries have a distinct pattern of water movement created by the action of the tides and the presence of fresh water. Since estuaries are extensions of the ocean, they are affected by the tides which pump large volumes of water back and forth, in and out of the Puget Sound basin. Fresh water entering the Sound from streams and rivers is lighter or less dense than saltwater and tends to float and flow over the top of seawater. As it does this, some of the saltwater is mixed up with the fresh water, creating a brackish (less salty) layer at the surface (about 30 to 190 feet or 10 to 60 meters deep in various parts of the Puget Sound region). This surface layer flows seaward under the force of gravity, eventually reaching the Pacific Ocean. To replace the seawater in the deep layer which was mixed into the surface layer, more seawater is drawn into the estuary from the ocean. This characteristic net estuarine circulation (seaward at the surface and landward below) exists throughout Puget Sound and the Straits of Georgia and Juan de Fuca.

The two-layered estuarine circulation pattern described above is complicated in Puget Sound by the presence of various islands and channels. For example, the blocking effect of Vashon Island disrupts the two-layered flow pattern in East Passage, where currents at all depths are generally to the south, and in Colvos Passage, where currents are generally to the north (Figure 2-9). The relatively shallow sills that divide the sub-basins of the Sound also disrupt the two-layered flow pattern. Implications of these complicated flows are that as much as one-half to two-thirds of the outflowing surface water from the Puget Sound Main Sub-basin may be diverted before going through Admiralty Inlet (Ebbesmeyer and Barnes, 1980). Researchers have estimated that as much as one-third to one-half of the outflowing water makes a submarine return trip through the depths of the Main Sub-basin instead of exiting to the Strait. More recent modeling efforts appear to indicate that about one-quarter of the outflowing water returns to the Main Sub-basin (Cokelet, 1987). The same type of complicated flow pattern can be inferred in the other sub-basins set off by sills (Ebbesmeyer and Barnes, 1980).

Exchange with the ocean

An important physical characteristic of an estuary is its ability to exchange water with the open ocean. Exchange helps cleanse the deep basins of the Sound and prevent them from becoming naturally stagnant from organic decay. Exchange also plays a critical role in governing the fate and effects of contaminants that enter Puget Sound. It has the potential to carry dissolved waste products out to sea.



Reference: Ebbesmeyer and Barnes, 1980

Figure 2-9

GENERALIZED VERTICAL CROSS-SECTION SHOWING NET CIRCULATION IN PUGET SOUND

However, in Puget Sound south of Admiralty Inlet, the diversion and remixing of surface water mentioned above limits the amount of exchange with the open ocean.

Puget Sound is not a pipe or open drain that will carry dissolved or suspended contaminants directly out to sea. The process is short-circuited by the recirculation of surface water and the settling out of sediments. For example, fresh water on the surface of the Main Sub-basin takes about a week to get from the mouth of the Duwamish River to the Admiralty Inlet sill. Then much of it spends an additional 10 days going back to its starting point. It must make the trip twice, on the average, before reaching the Strait of Juan de Fuca. Computer simulations of water movements have shown that after three months, only half of the number of theoretical water parcels released in East Passage escape to the open ocean (Figure 2-10; Ebbesmeyer, in Quinlan et al., 1985). Implications of this estuarine recirculation and resulting slow exchange with the ocean are that any contaminants carried in the surface water remain in the area for some time, and can be spread throughout the Sound before exiting to the Strait or settling out. In addition, any contaminants or items that wash up onto or adhere to shorelines (e.g., plastic garbage and oil) are likely to never leave the Sound.

Sediment in the Sound

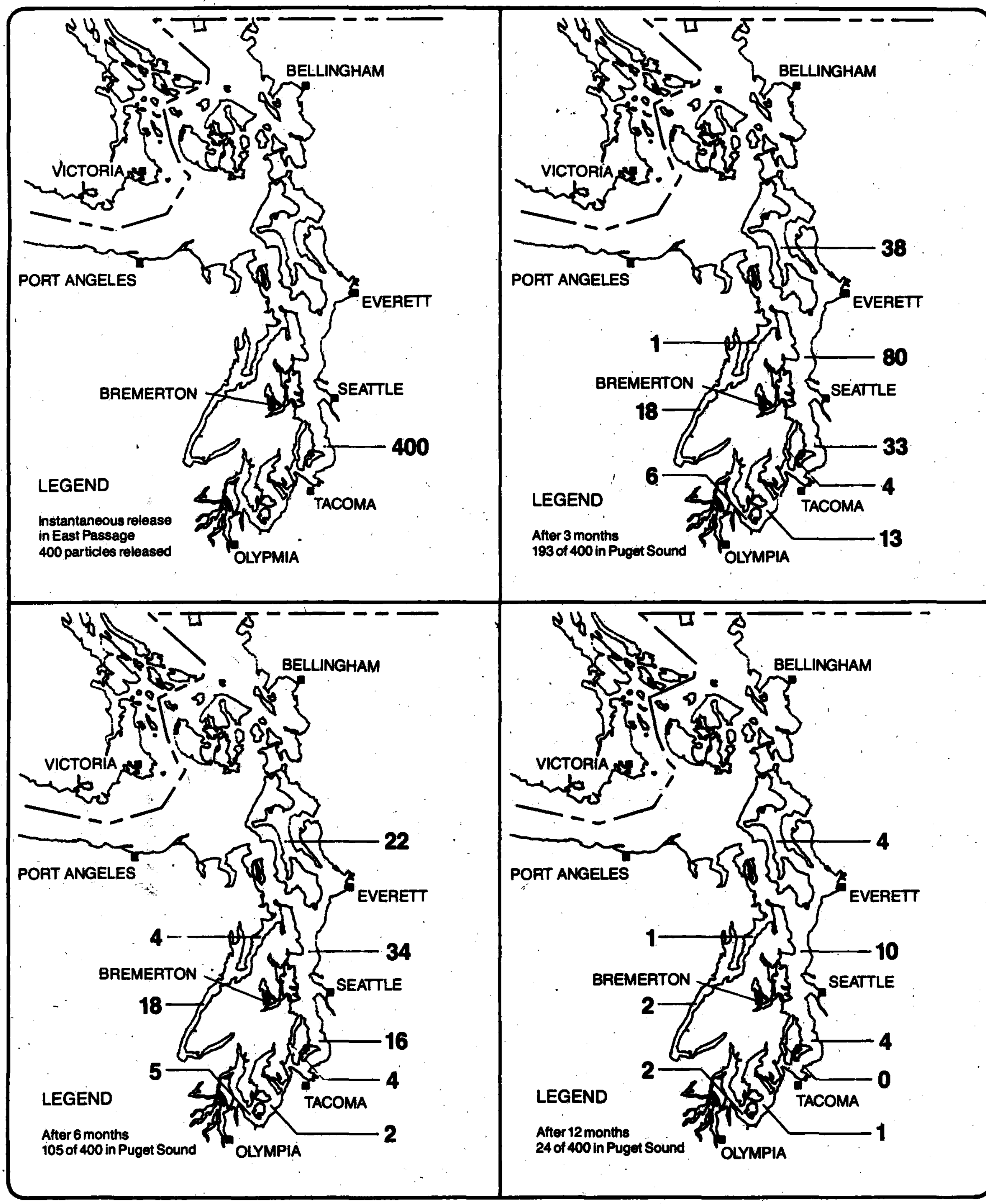
Estuarine circulation also controls the fate of the tons of sediment delivered to the Sound by river water and other sources. Particles initially suspended in the surface water settle into the deeper layer. Once they enter the deep layer, they are carried back inland. Since most fine particles can settle through the brackish surface water layer faster than they are carried out to sea, estuaries characteristically retain particles. Perhaps one to five percent of sediment particles initially present in the surface waters of the Main Sub-basin are carried out through Admiralty Inlet; the rest are trapped in the Sound (Quinlan et al., 1985). Since many contaminants bind to particles, the ability of the waters of the Puget Sound basin to carry those contaminants out of the basin to the ocean is very limited.

There have been a number of measurements of rates of sediment deposition and accumulation in Puget Sound, but natural variations over time and from place to place make generalizations about sediment accumulation difficult. Measurements of sediment deposition in the Main Sub-basin, made by dating a radioactive isotope of lead in core samples of bottom sediments, show that approximately 0.18 to 1.20 grams of sediment accumulate in a year on one square centimeter of the Sound's bottom (one-twentieth to two-fifths of an inch; Crecelius et al., 1984). Most of this sediment comes from rivers and shoreline erosion.

Sediments perform many important functions in the marine system. They form the habitat for bottom-dwelling (benthic) organisms and affect the fate of contaminants in the Sound. Organic detritus in nearshore and deep sediments supports a major branch of the food web of the Sound. However, sediment from land runoff can introduce chemicals, nutrients, and bacteria into groundwater, streams, and rivers (and eventually into the Sound) because these contaminants often are carried by sediment particles.

HABITATS OF THE PUGET SOUND AREA

The marine, freshwater, and terrestrial habitats of the Sound form a single, integrated ecosystem that supports a myriad of fish and wildlife species. Many of these species rely on a variety of habitats during different phases of their life cycles, further emphasizing the interrelated nature of Puget Sound habitats.



Reference: Quinlan et al., 1985

Figure 2-10

RESULTS OF COMPUTER SIMULATION OF DISPERSION OF THEORETICAL WATER PARCELS IN PUGET SOUND

Marine Habitats

About 2,354 miles (3,790 kilometers) of inland marine shores wrap around the Sound creating a wide diversity of habitats (Washington Department of Natural Resources, 1977). The factors that differentiate saltwater habitats include temperature, salinity, wave exposure, current speed, depth, availability of nutrients, and the texture, stability, and chemistry of the underlying rock or sediment. Typical habitats in the Sound include exposed rocky shores, sheltered bays, sand spits, and broad tidal flats. The boundaries between these habitats are blurred by the continual movement of water and life across them. Over 200 species of fish and 14 species of marine mammals live in Puget Sound (Washington Department of Fisheries, 1984). In addition, the Washington Department of Wildlife (WDW; formerly Department of Game) estimates that about 31 species of waterfowl and 57 species of shorebirds and other marine birds reside on a temporary or permanent basis around the Sound (Carleton, 1988, pers. comm). Many of these species rely on marine habitats, estuarine and freshwater wetlands, and non-wetland terrestrial habitats. For example, WDW estimates that up to 70 terrestrial wildlife species, and all of the anadromous fish species, rely on both the marine waters of the Sound and on freshwater habitats in the area.

Open water

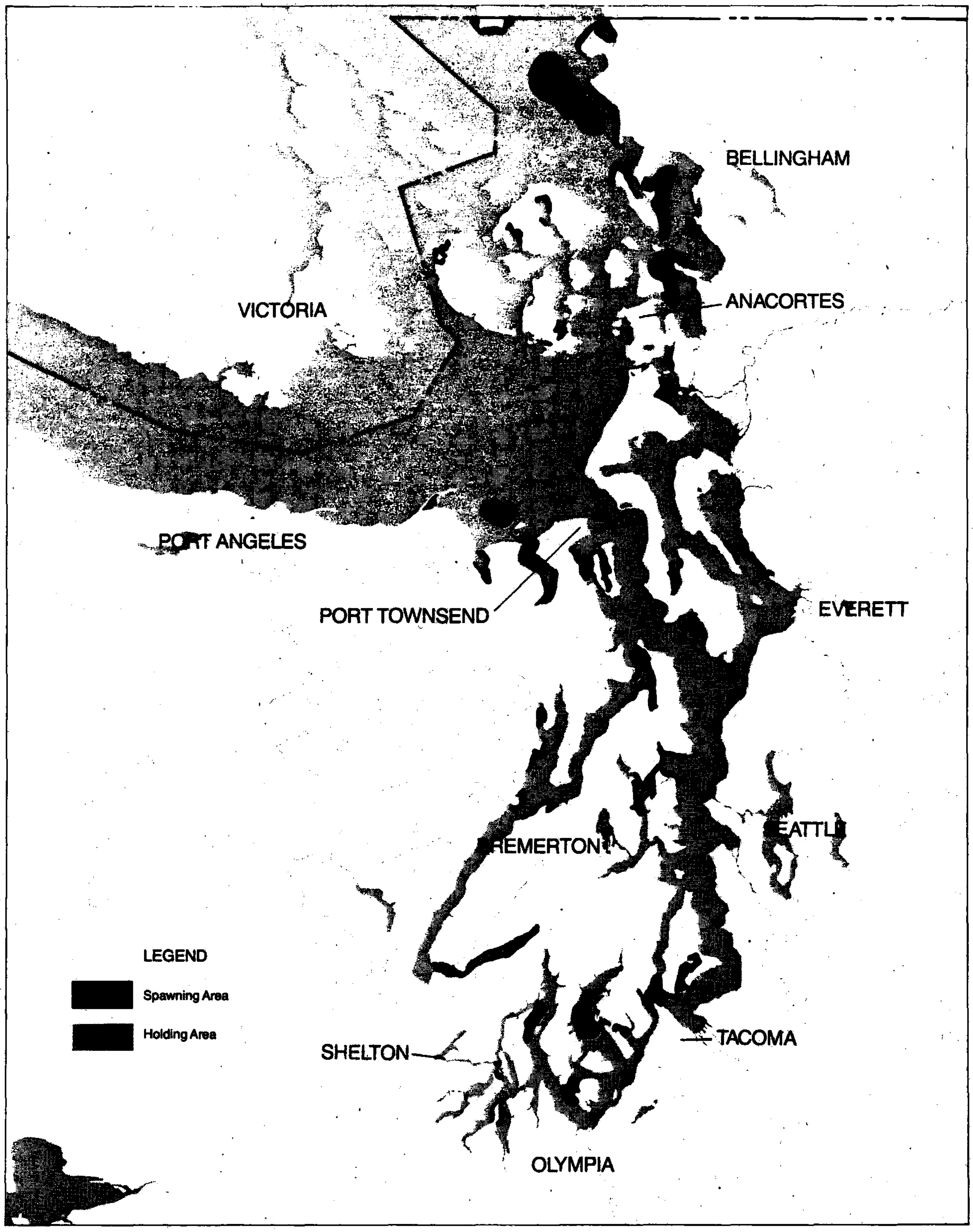
The open waters of the Puget Sound basin provide critical feeding habitat for a myriad of pelagic or open water organisms that swim or float freely in the Sound. Primary inhabitants of the open waters as depicted in the *Puget Sound Environmental Atlas* include free-floating phytoplankton (plants) and zooplankton (animals), and the pelagic fish such as the baitfish (herring, smelt, and sandlance; Figures 2-11 and 2-12), the salmonids (salmon and trout; Figure 2-13), and groundfish or bottomfish (hake, pollock, and cod; Figure 2-14). Larger species of the pelagic realm include marine mammals (harbor seals, sea lions, and orca whales; Figure 2-15), and birds such as loons, grebes, and auklets (Evans-Hamilton, Inc., 1987).

The Main Sub-basin of the Sound has one of the highest phytoplankton production rates of all deep-water estuaries in the world (Strickland, 1983). This production is a major contributor to the highly productive food web in the Sound. Much of the phytoplankton production occurs from April to August when conditions are optimal for growth. Phytoplankton blooms in turn influence the abundance of zooplankton which feed on these blooms. In fact, many of the smaller invertebrates of the Sound release their eggs during phytoplankton blooms when a food source for the hatching larvae is assured (Strickland, 1983). During these times surface waters may be filled with the planktonic larvae of crabs, clams, shrimp, snails, sea urchins, starfish, worms, and other creatures, and with the eggs and larvae of some bottom fish (notably sole). These zooplankton in turn provide an abundant food supply for juvenile and adult fish, birds, and marine mammals.

Benthic habitats

Benthic or bottom habitats support a diverse assemblage of organisms that vary depending upon the texture or particle size of the bottom material (e.g., mud, sand, gravel, or rock), as well as the degree to which they are exposed to the rising and falling tides. The softest and finest-grained bottom habitats in Puget Sound can be extremely productive. Although intertidal mudflats may not be beautiful shorelines, they are vital habitats for many highly prized species of shellfish (Figure 2-16), fish, and birds. The biological production of the entire Sound depends heavily on these habitats.

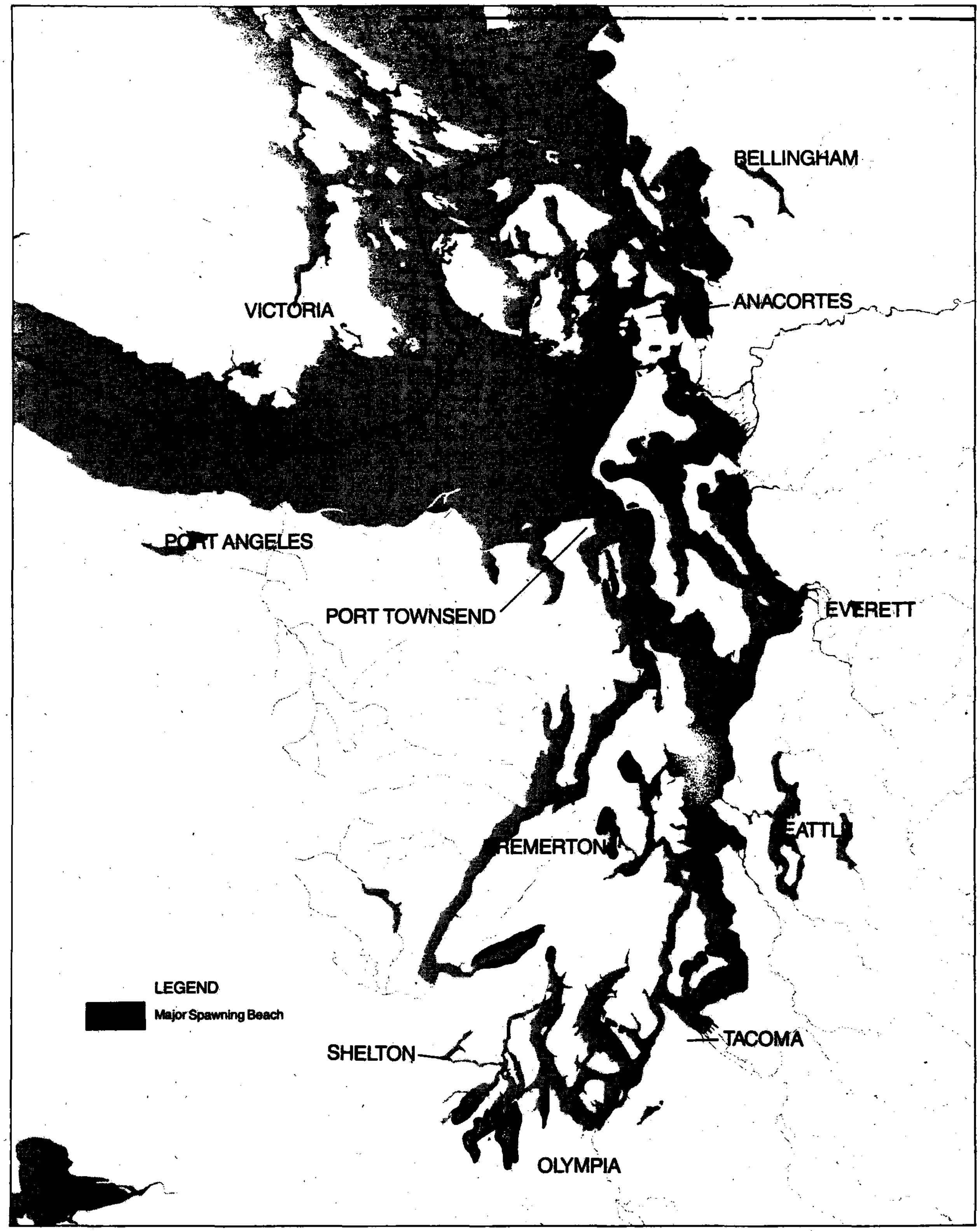
Characteristic soft-bottom species include worms, tunicates (sea squirts), starfish, sea cucumbers, clams, crabs (Figure 2-17), and some popular sport fish including flounder, halibut, and sole. Many of these animals feed either by filtering out microscopic plankton and bacteria from the surrounding water (filter feeders), or by in-



Reference: WDF, 1984; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-11

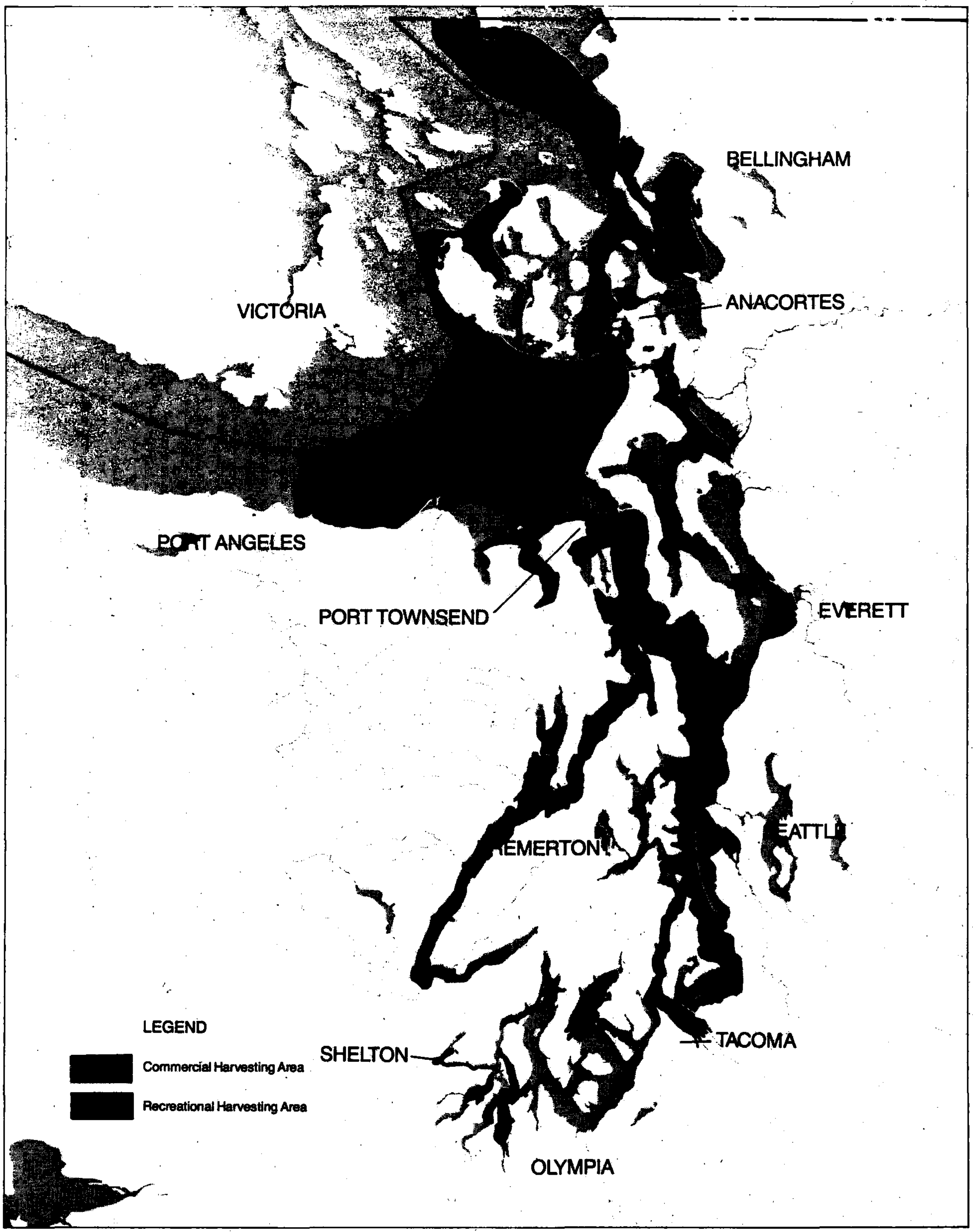
LOCATIONS OF MAJOR PACIFIC HERRING
(CLUPEA HARENGUS PALLASI)
SPAWNING AND HOLDING AREAS



Reference: WDF, 1984; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-12

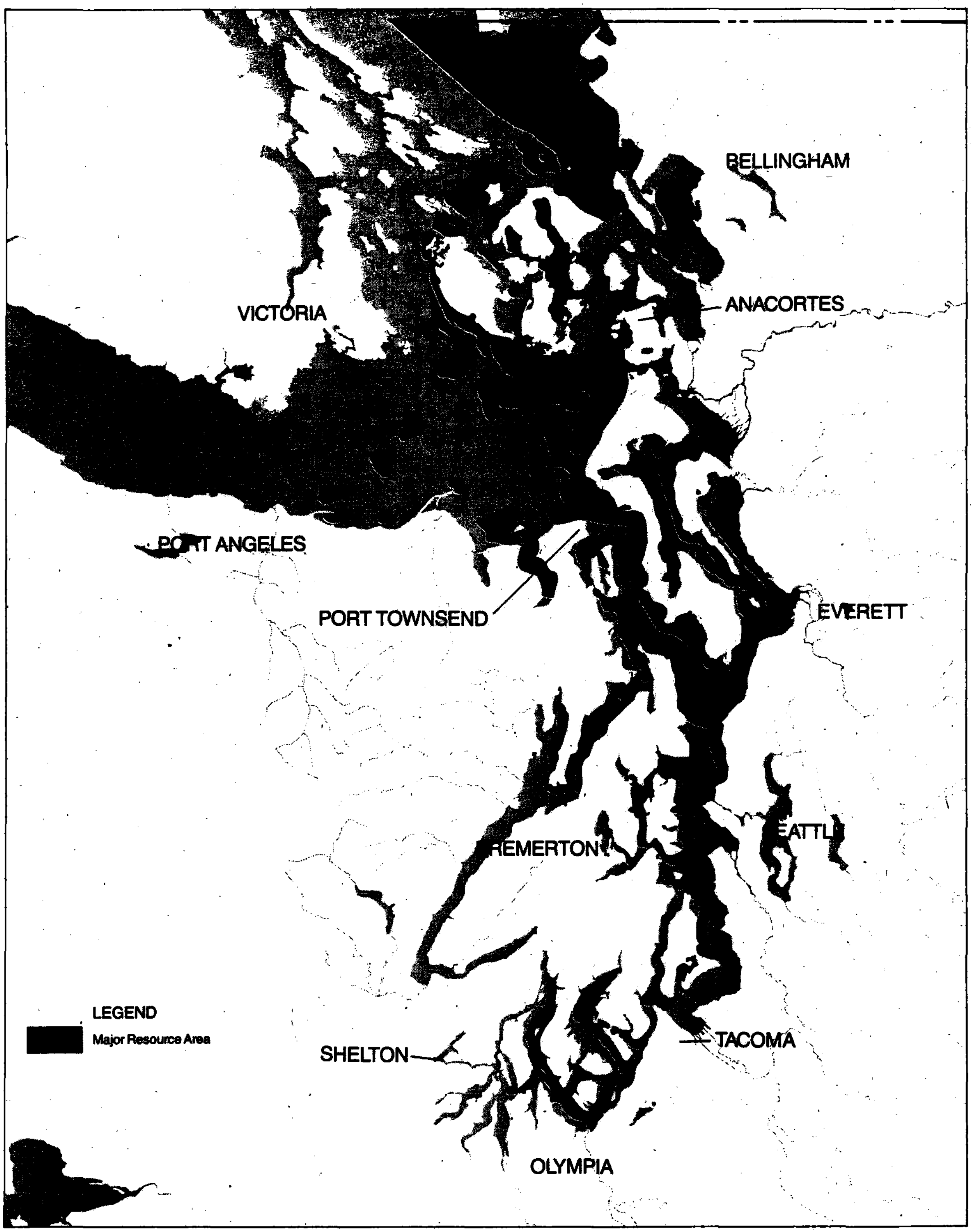
LOCATIONS OF MAJOR SURF SMELT
(HYPOMESUS PRETIOSUS PRETIOSUS)
SPAWNING BEACHES



Reference: WDF, 1984; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-13

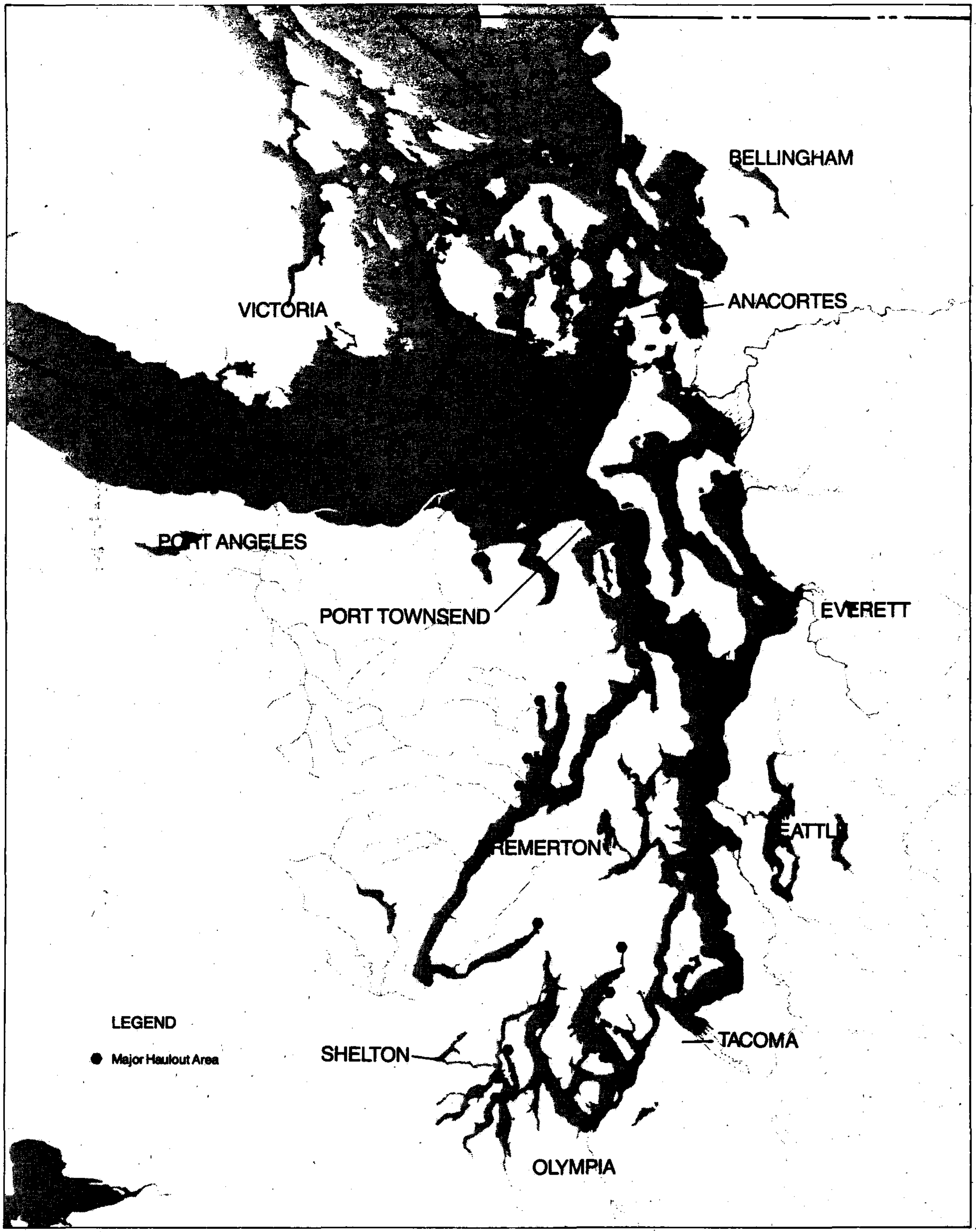
LOCATIONS OF MAJOR
COMMERCIAL AND RECREATIONAL
SALMON HARVESTING AREAS



Reference: WDF, 1984; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-14

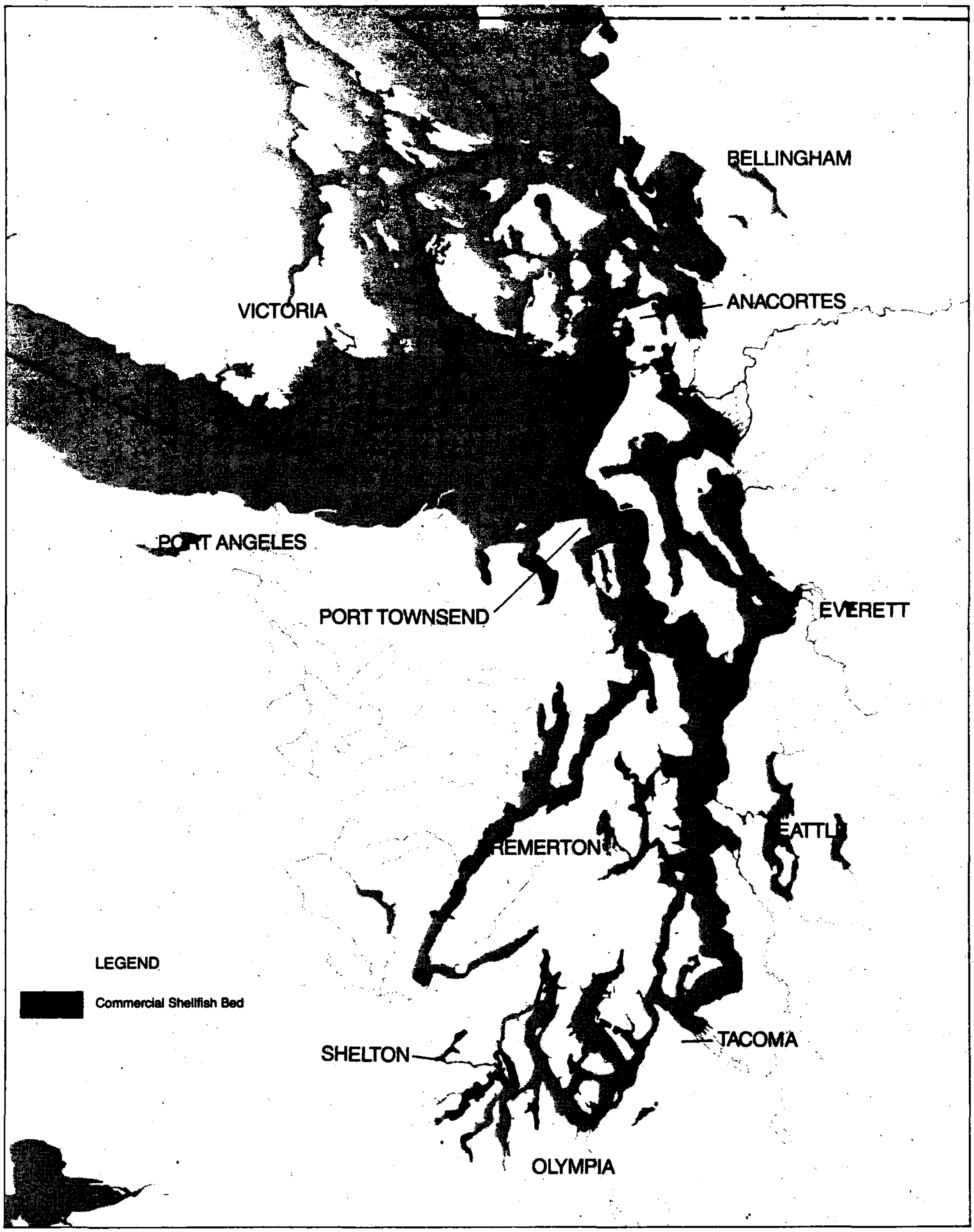
LOCATIONS OF MAJOR GROUNDFISH RESOURCE AREAS



Reference: Ecology, 1979

Figure 2-15

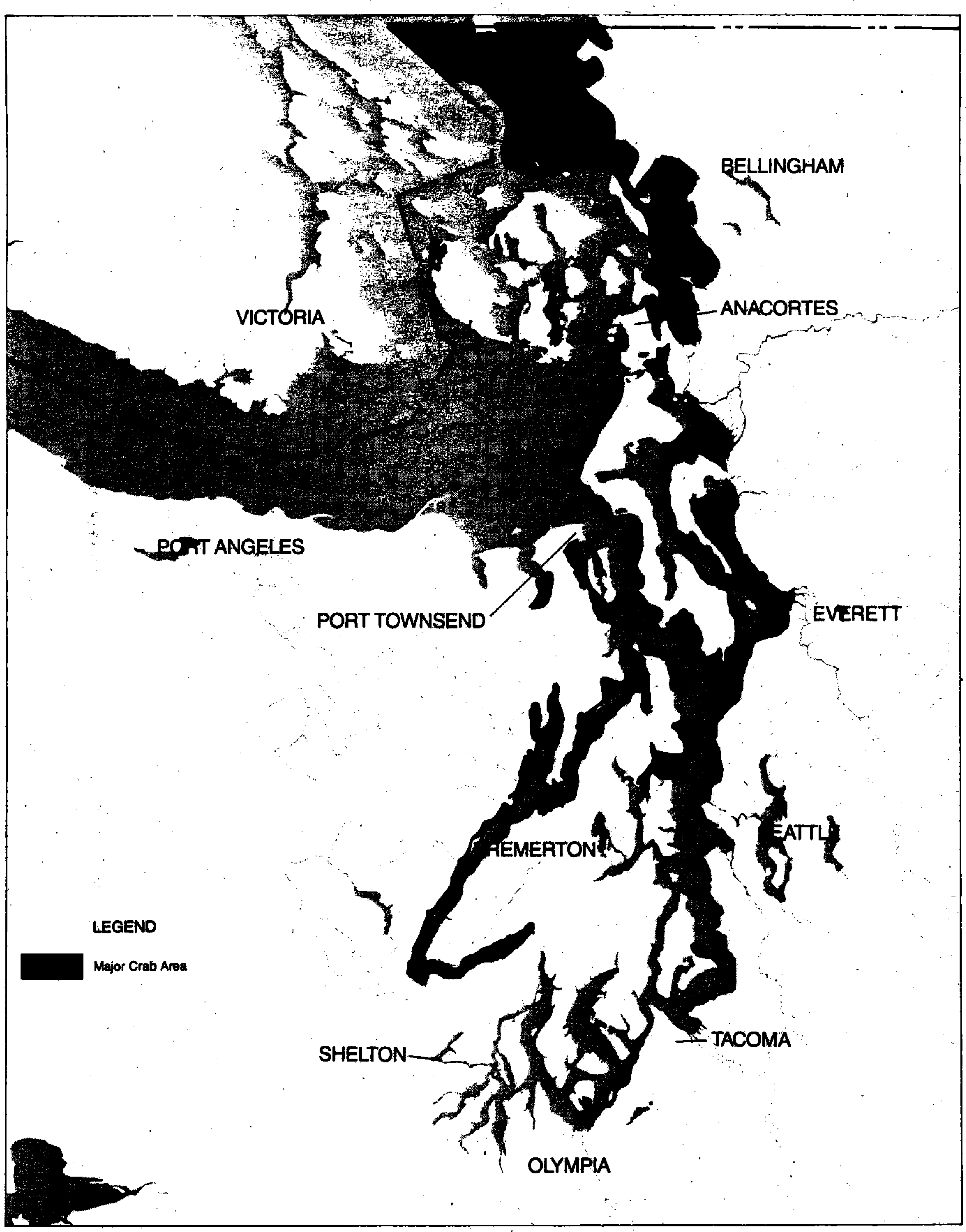
LOCATIONS OF SEAL AND SEA LION HAULOUTS IN PUGET SOUND



Reference: Saunders, 1984; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-16

LOCATIONS OF COMMERCIALLY HARVESTED INTERTIDAL CLAM AND OYSTER BEDS



Reference: WDF, 1984; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-17

LOCATIONS OF MAJOR DUNGENESS CRAB *(CANCER MAGISTER)* POPULATIONS

gesting organic material (detritus) that has accumulated in and on the bottom material (deposit feeders). In turn, many of these filter and deposit feeders are eaten by groundfish such as halibut. Because of these feeding modes and their close contact with bottom sediments, bottom-dwelling animals tend to concentrate harmful substances that are present in the water, such as fecal coliform bacteria, or that have accumulated on the bottom, such as toxicants adhering to sediment particles.

Habitats characterized by coarse sediment, from pure sand to mixtures of sand, gravel, and cobbles, make up most of the beaches of the Puget Sound basin. These sediments are also found subtidally in areas of faster water movement such as the western shore of Whidbey Island. The dominant animals in coarse sediment habitats are clams that dig in the sand or hide between rocks (intertidal and subtidal cockles; manila, littleneck, and butter clams; and subtidal geoducks; Figure 2-18). Their principal food is phytoplankton and detritus from the overlying water. Also found in this habitat are burrowing harpacticoid copepods (resembling little shrimp) which are an important food source for juvenile salmonids (Feller, 1977).

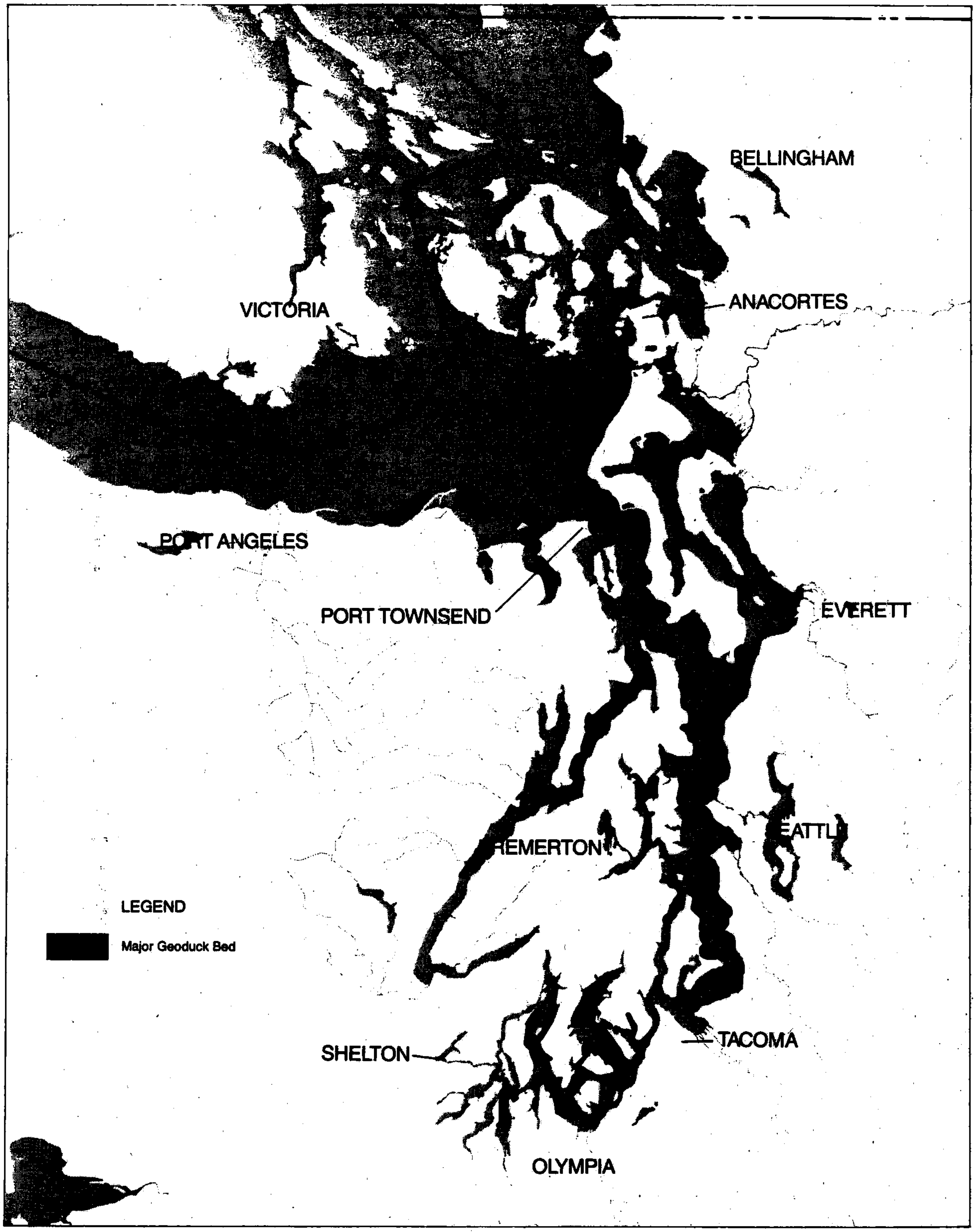
Rocky intertidal and subtidal habitats support plants and animals uniquely adapted for gripping the rock or for taking refuge from the strong wave action and currents that are usually present. Seaweeds such as the leafy green sea lettuce, brown rockweeds, red nori, and giant brown kelp attach to the bottom by a holdfast that secures them against the strong waves and currents. Intertidal and subtidal seaweed beds provide valuable habitat for the wide range of invertebrates and fish that live along rocky shores (Figure 2-19). Rocky shore invertebrates include sea anemones, snails, limpets, barnacles, mussels, starfish, crabs, and shrimp (Kozloff, 1983). Fish species present include sculpins, gunnels, rockfish, sea perch, greenlings, and ling cod (a valuable sport and commercial fish).

Eelgrass beds

Shallow subtidal soft-bottom communities are often characterized by the presence of eelgrass, a dominant plant species that provides critical, highly productive marine habitat in Puget Sound (Figure 2-20). In deeper water, eelgrass provides food, substrate, and shelter for a great diversity of organisms. It is estimated that Puget Sound eelgrass beds support 191 invertebrate species, 76 fish species, and 86 bird species (Phillips, 1984). Most animals do not consume eelgrass directly, but eat either its decayed detritus or the microalgae, seaweeds, organic coatings, bacteria, and microfauna that colonize its surfaces. The herbivores and omnivores that feed directly off eelgrass surfaces include flatworms, snails, and small crustaceans. These, in turn, support a menagerie of carnivores such as nudibranch sea slugs, jellyfish, certain crabs, and starfish. Eelgrass beds perform an important role in supporting the larval and juvenile stages of many types of commercial and sport fish. Just after they enter saltwater, juvenile salmon feed extensively on small worms and crustaceans living in these habitats. Surf smelt spawn on beaches composed of pea-sized gravel, and herring deposit their eggs predominantly on eelgrass blades (Figure 2-11; Washington Department of Fisheries, 1984).

Estuarine wetland habitat

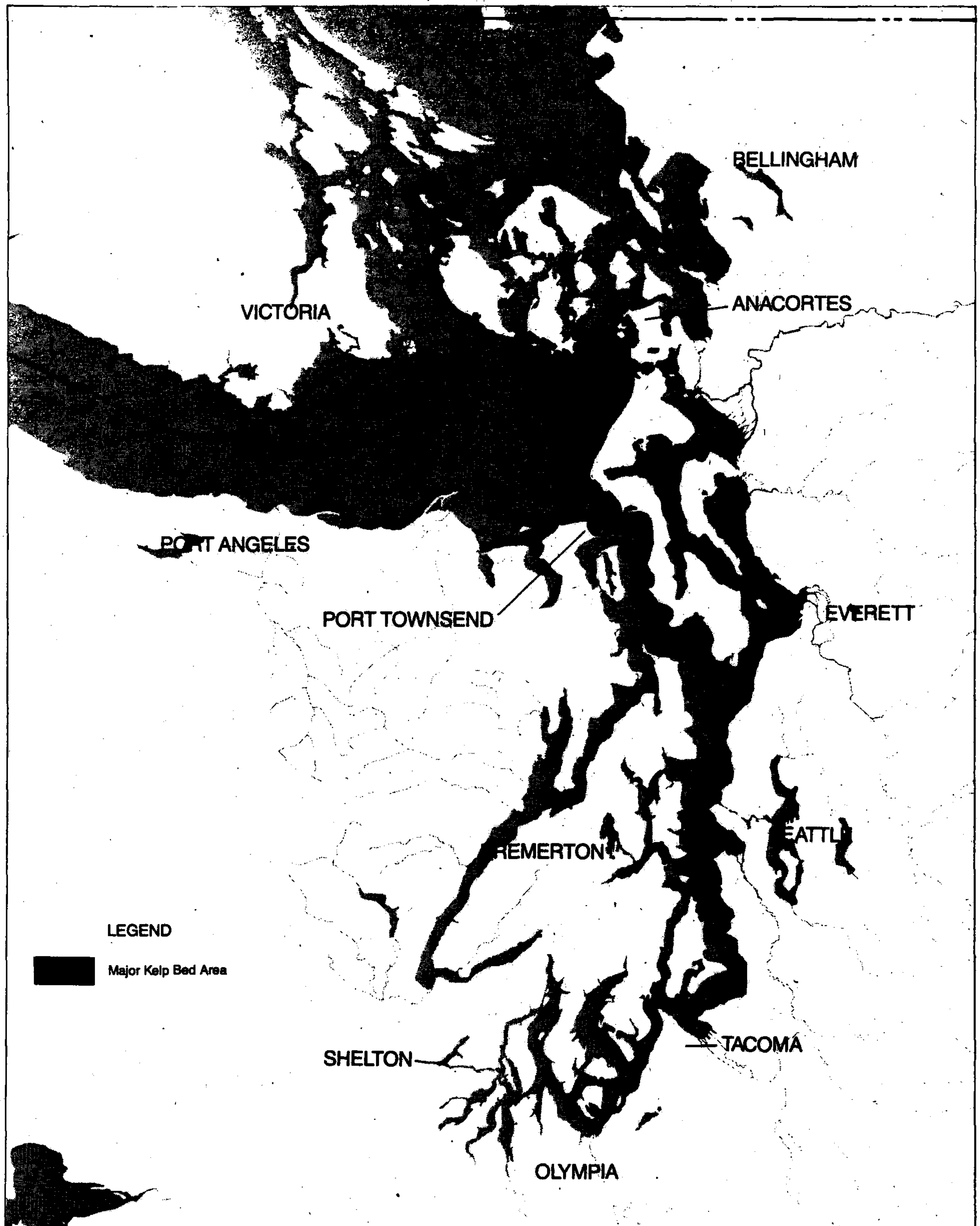
Estuarine wetlands include vegetated salt marshes, intertidal eelgrass beds, and unvegetated mudflats that are strongly influenced by ocean waters. Estuarine wetlands extend upstream and landward to the point where ocean-derived salinity is less than 0.5 parts per thousand (Cowardin et al., 1979). Vegetated salt marshes are characterized by salt-tolerant grasses. They provide critical habitats for crabs, shrimp, marine fish, shorebirds and waterfowl, and upland animals (Thom, 1987). Unvegetated wetlands are an important habitat for fish, shellfish, shorebirds, waterfowl, and coastal marine or aquatic mammals. In particular, muddy shallows support resident and migratory populations of shorebirds and waterfowl (e.g., herons, geese, ducks, loons, grebes, plovers, sandpipers, gulls, and terns) that congregate in



Reference: Saunders, 1984; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-18

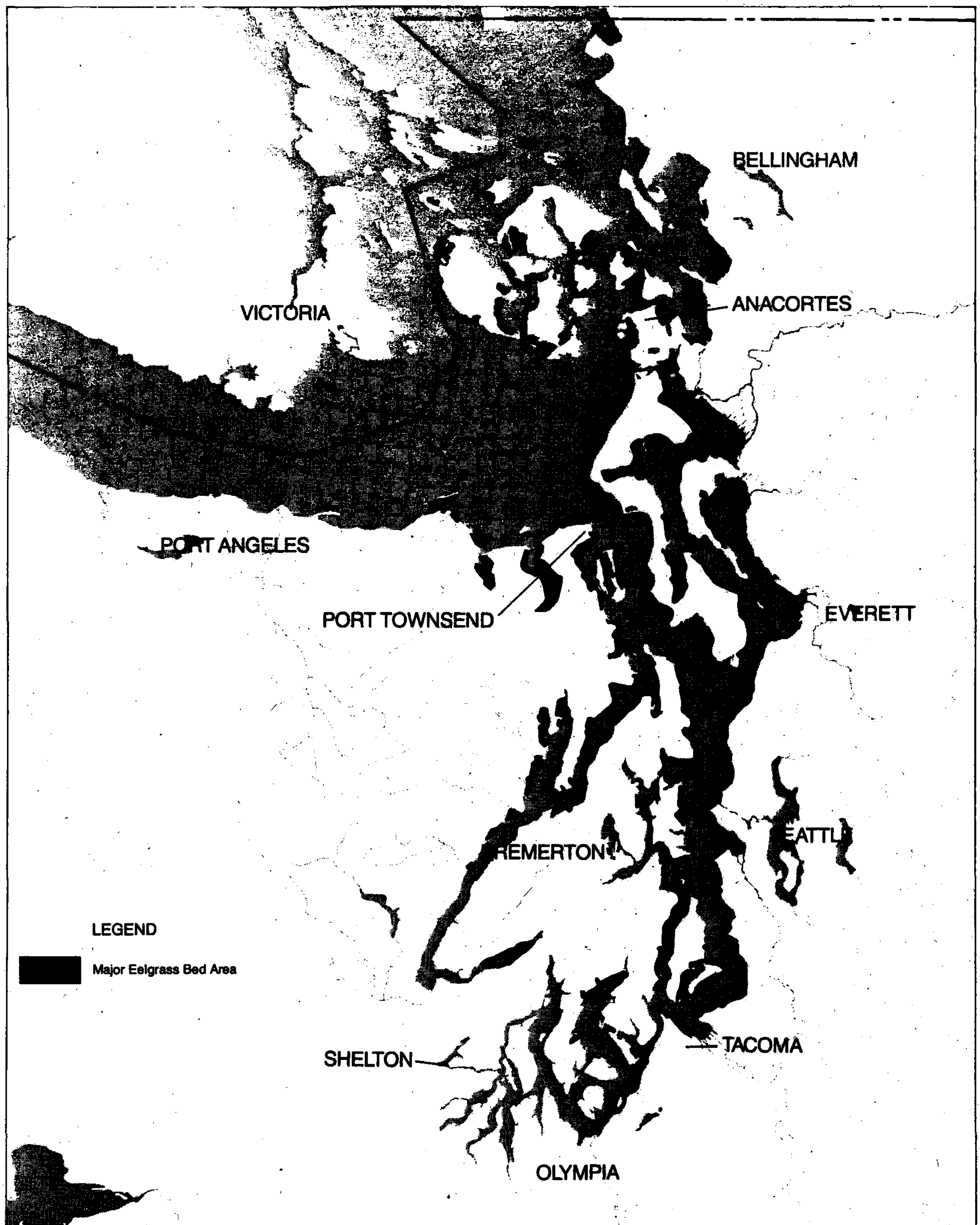
LOCATIONS OF GEODUCK
(PANOPEA GENEROSA) BEDS



Reference: Ecology, 1979; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-19

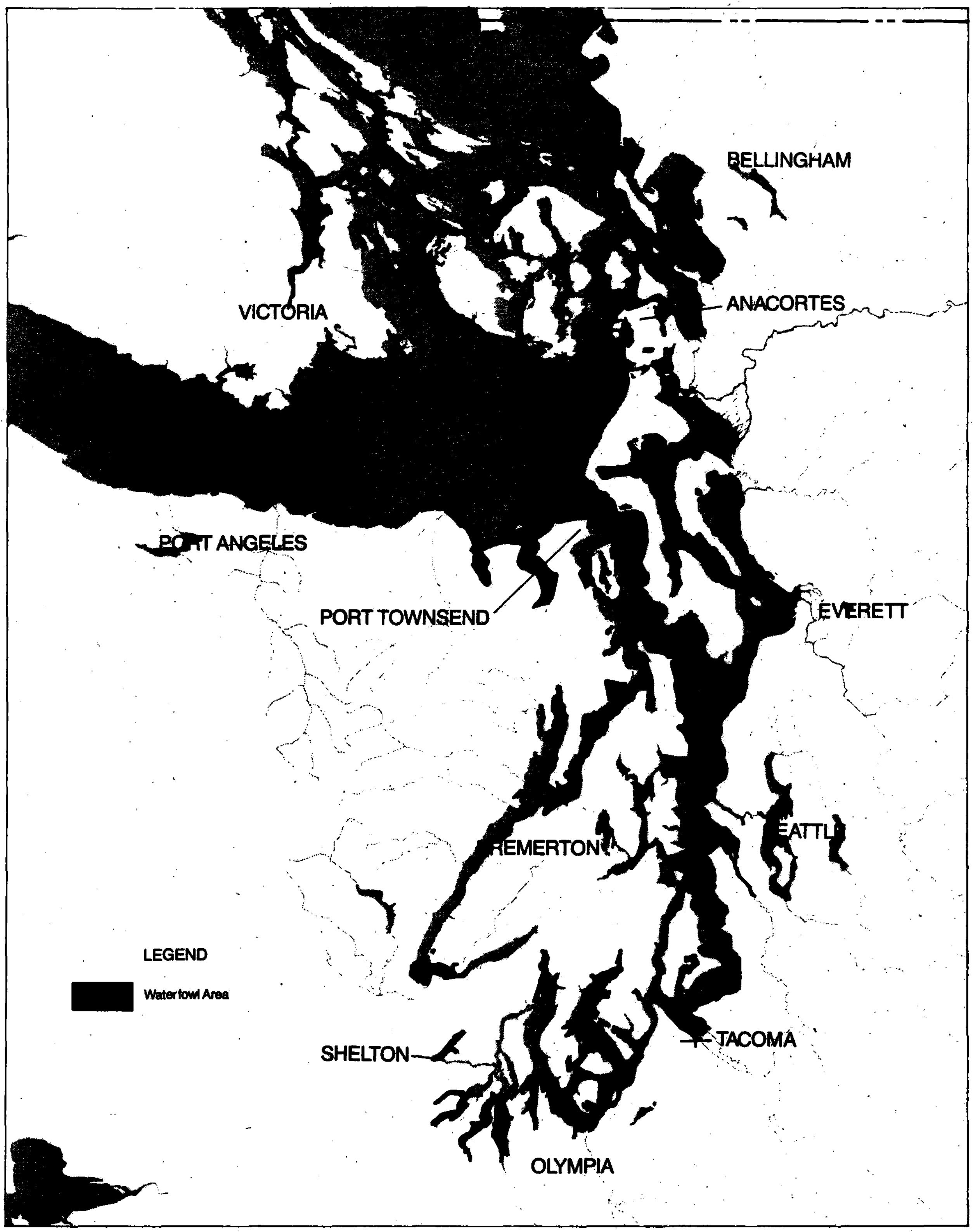
LOCATIONS OF MAJOR KELP BEDS



Reference: Ecology, 1979; Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 2-20

LOCATIONS OF EELGRASS BEDS



Reference: Ecology, 1979

Figure 2-21

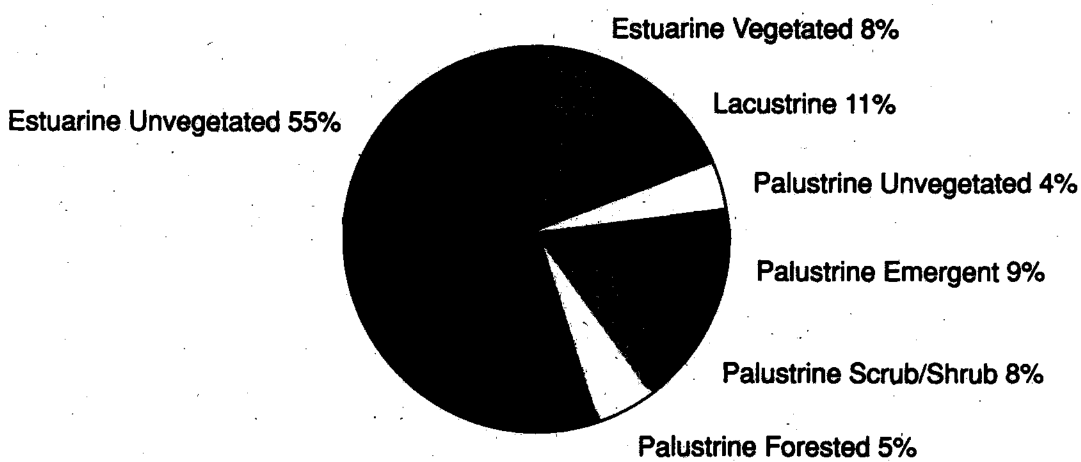
MAJOR WATERFOWL HABITATS
IN PUGET SOUND

the vicinity of these highly productive areas to feed on aquatic vegetation, small worms, crustaceans, and fish (Figure 2-21).

Estuarine wetlands comprise 63 percent of the total wetland area studied in the coastal areas of Puget Sound (Boule' et al., 1983). Much of these are unvegetated beaches or mudflats (Figure 2-22). Of the approximately 13,000 acres (5,200 hectares) of inventoried salt marshes, 61 percent are located in the Skagit and Snohomish estuaries. Wetland and eelgrass habitats including the Nisqually and Skagit Flats, Padilla Bay, and Dungeness Spit are bird feeding areas of importance to the entire Pacific coast (Evans-Hamilton, Inc., 1987). Unfortunately, these productive habitats are sensitive to water quality degradation and physical disruption. In particular, development of shorelines in urban embayments has resulted in a substantial loss of eelgrass beds. The WDW estimates that the state has lost 33 percent of its historic eelgrass beds (Washington Department of Game, 1987).

Freshwater and Terrestrial Habitats

Representative freshwater and terrestrial habitat types that occur in the Puget Sound basin are illustrated in Figure 2-23. Freshwater habitats include lakes, rivers, and freshwater wetlands (swamps, marshes, bogs, wet meadows, etc.), while terrestrial habitats include alpine highlands, evergreen and deciduous forests and clear-cut areas, riparian (stream) corridors, and agricultural lands. Major human activities such as timber harvesting, agriculture, and urban land development that occur in terrestrial habitats can produce changes in hydrology and water quality

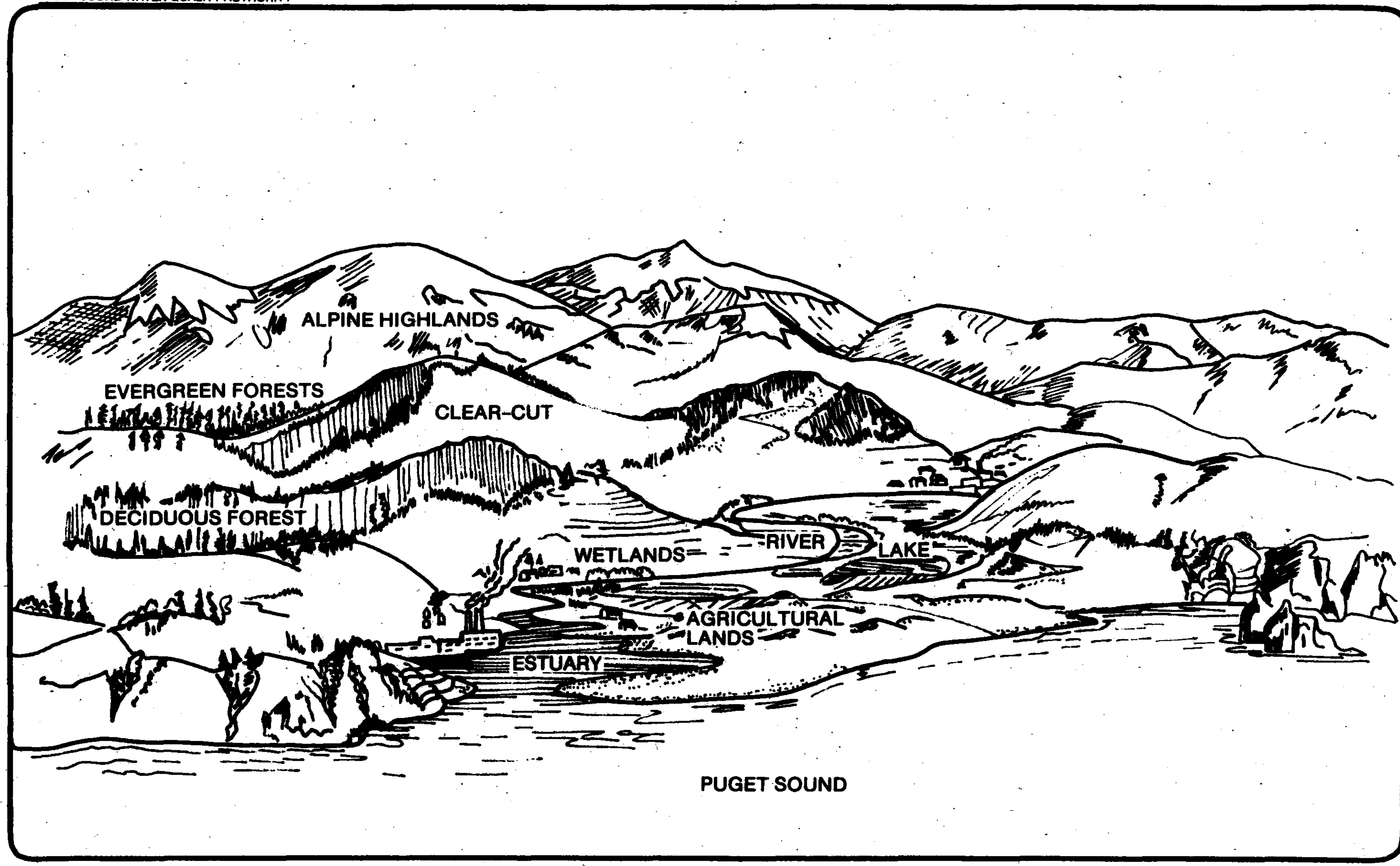


Data represent only coastal areas in the 12 Puget Sound counties that were studied using 1970s aerial photography.

Reference: Boulé et al., 1983

Figure 2-22

RELATIVE ACREAGE OF DIFFERENT WETLAND TYPES IN THE SHORELINE AREAS OF PUGET SOUND COUNTIES



Reference: Modified from Proctor et al., 1980

Figure 2-23

REPRESENTATIVE TERRESTRIAL HABITATS IN THE PUGET SOUND WATER QUALITY PLANNING AREA

which affect aquatic habitats. Aquatic habitats can also be affected directly by activities such as dredging and/or filling wetlands, damming and channelizing rivers, diking, dredged material disposal, spills of petroleum and other products, and shipping and boating. Since the wetlands, lakes, streams, and rivers of the Puget Sound area ultimately drain to the Sound, any effects from water quality on these aquatic habitats have the potential to result in similar, or cumulative and more significant, effects on Puget Sound itself.

Freshwater wetland habitats

Freshwater wetlands are habitats transitional between terrestrial and aquatic systems where the influence of surface or groundwater has resulted in predominately water-saturated soils and/or the development of plant and animal communities uniquely adapted to aquatic and/or intermittently wet conditions (Cowardin et al., 1979; PSWQA, 1986a). Lacustrine wetlands are the shallow waters and associated shoreline vegetation of lakes. They make up 10 percent of the wetland area studied around Puget Sound (Figure 2-22) and are generally over 20 acres (8 hectares) in size (Boule' et al., 1983). Palustrine wetlands are persistent wet areas located adjacent to streams or created by springs, seeps, or surface runoff. They are the most diverse and scattered group of wetlands in the Puget Sound area and represent 27 percent of all studied wetlands (Boule' et al., 1983). They are also the least adequately inventoried of all wetland groups (PSWQA, 1986a; Sheldon, 1987, pers. comm.), primarily due to their relatively small size (most are less than 10 acres or 4 hectares).

The natural values of freshwater wetlands are well documented and include both biological and physical functions and processes as depicted in Figure 2-24 (U.S. Congress, 1984; PSWQA, 1986a). Biological attributes of wetlands include high rates of plant production and extremely valuable fish and wildlife habitat. WDW lists over 175 wildlife species that use wetlands for primary feeding habitat and over 140 species that use them for primary breeding habitat (PSWQA, 1986a). Fish and wildlife use of the various wetland types is shown in Table 2-1. Lacustrine and palustrine wetlands in the Puget Sound area provide critical habitat for various species of freshwater and anadromous fish, reptiles and amphibians, waterfowl, marsh birds (e.g., coots and rails), wading birds (e.g., herons and egrets), shorebirds, and aquatic mammals (e.g., otters and beavers).

The physical and economic values of wetlands include groundwater recharge and discharge, flood control, shoreline anchoring and erosion control, and water quality improvement (Figure 2-24; PSWQA, 1986a). Discharge of groundwater may be important to augment low flows in streams that originate in wetlands. Wetlands that are most important for flood control are those associated with river flood plains in the Puget Sound basin. Wetlands can reduce flood peaks and the frequency of flooding in downstream areas by temporarily storing stormwater, thereby moderating the intensity of flood flows (U.S. Congress, 1984; Wald and Schaefer, 1986). This function may eliminate the need for costly engineered flood control measures such as dredging, diking, and creation of localized detention facilities.

Wetlands are valuable for erosion control because they slow runoff flows, absorb and dissipate wave energy, stabilize the shore, and increase the deposition of suspended sediment. Water quality benefits attributable to wetlands include trapping of suspended sediments, removal of toxic substances often attached to fine sediments, removal of nutrients, and the removal of pathogens (PSWQA, 1986a; Horner, 1986). Research by King, Pierce, Snohomish, and Thurston Counties is currently examining the potential use of wetlands for stormwater management and nonpoint source pollution control, as well as the impacts on wetlands from being used for water quality control (Stockdale, 1986; Stockdale and Horner, 1987).

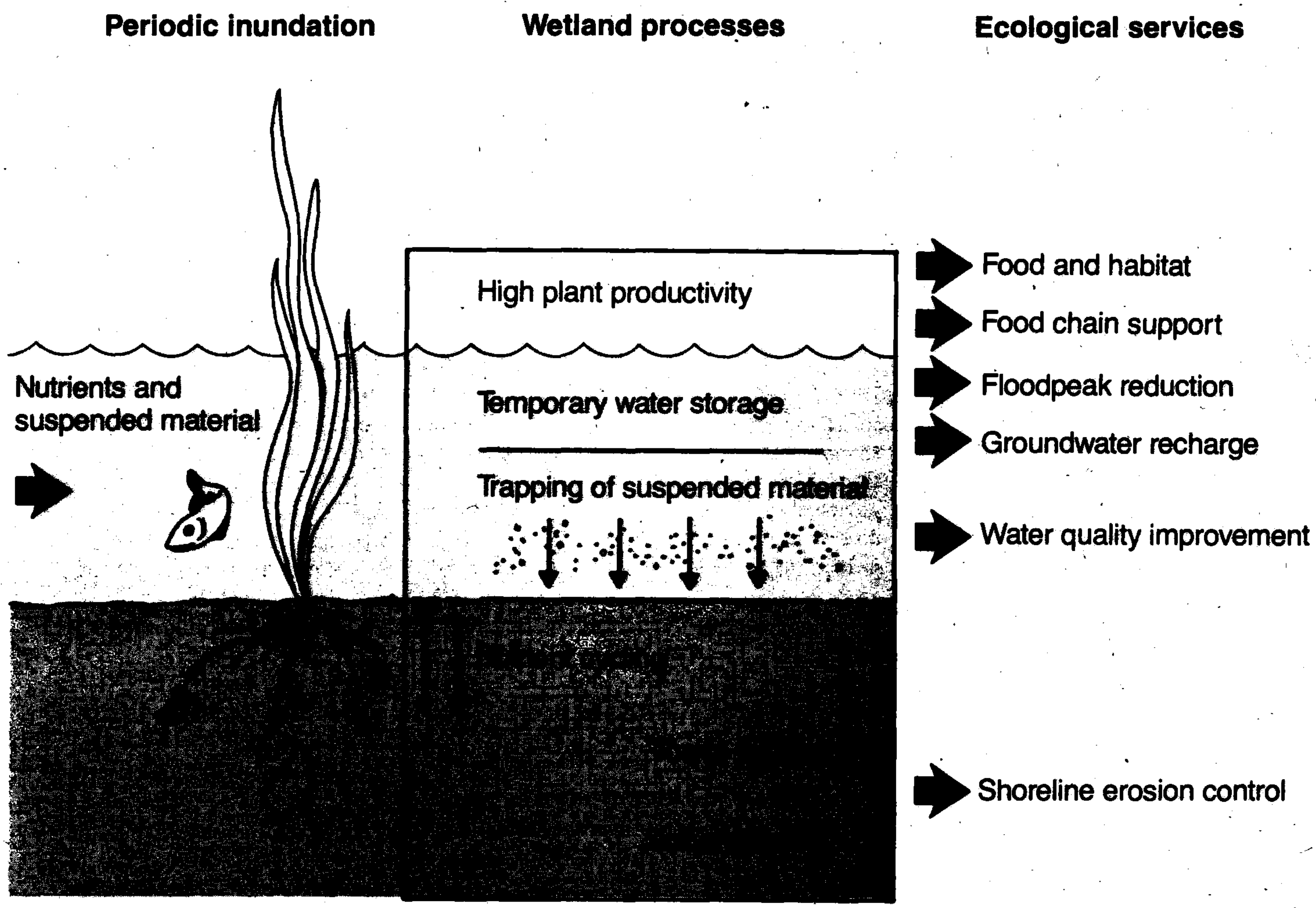


Figure 2-24

RELATIONSHIP BETWEEN WETLAND PROCESSES AND VALUES

References: PSWQA, 1986a; U.S. Congress, 1984

TABLE 2-1: FISH AND WILDLIFE USES OF DIFFERENT WETLAND TYPES

Sp - Spring
S - Summer
F - Fall
W - Winter

◆ - Areas are used but are not high priority sites
● - Areas receive heavy use, are important during one phase of life cycle
■ - Areas are critical to the survival of one or more species in the group

Fish and Wildlife	Unvegetated Estuarine				Saltmarshes				Lacustrine				Open Water Palustrine				Nonwoody Palustrine				Woody Palustrine			
	Sp	S	F	W	Sp	S	F	W	Sp	S	F	W	Sp	S	F	W	Sp	S	F	W	Sp	S	F	W
Shellfish																								
Nonmobile (oysters, clams)	■	■	■	■	◆	◆	◆																	
Mobile (crabs, shrimp)	■	■	■	■	■	■	◆																	
Fish																								
Salmonids (salmon, trout) Migratory	■	■	■	◆	●	●	●	●	●	●	●	●	●	◆	◆	●	●			●	◆			◆
Resident									●	●	●	●	◆	◆	◆	◆	◆	◆	◆	◆				
Marine fish (flatfish, spiny)	■	■	■	■	■	■	◆	◆																
Freshwater (bass, bluegill)									■	■	■	■	●	●	●	●	◆	◆	◆	◆				
Reptiles and Amphibians						◆	◆		■	■	●	●	■	■	●	●	◆	◆	◆	◆	■	◆	◆	◆
Birds																								
Water birds (loons, grebes)				◆					●	●	●	●	●	●	●	◆	●	●	●					
Waterfowl (ducks, geese, swans)	◆	◆	◆	◆	●	●	●	●	●	●	●	●	■	■	■	■	■	■	■	■	■			
Raptors (hawks, eagles, owls)					◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	●	●	◆	◆	●	●	◆	◆	◆	◆
Marsh birds (herons, egrets)	●	●	●	●	●	●	●	●	●	●	◆	◆	■	■	■	■	■	■	■	■	■	■	◆	◆
Wading birds (cranes, rails)									●	●	◆	◆	◆	◆	◆	◆	■	■	■	■	■	●	◆	◆
Shorebirds (plovers, sandpipers)	■	●	■	■		●	●		◆	◆	◆	◆	◆	◆	◆	◆	■	■	◆	◆				
Gulls and terns	●	●	●	●	●	●	●	●	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆				
Marine birds (auklets, murres)	◆		◆	◆																				
Passerine (jays, warblers, wrens)		◆				●			●	●	●	●		●	●				●	●	●	●	●	●
Upland game (pheasants, grouse)																		●	●			●	●	
Mammals																								
Marine (seals, sea lions)	◆	◆	◆	◆																				
Predators (raccoon, coyote)	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Freshwater aquatic (otter, beaver)									■	■	■	●	■	■	■	■	■	■	■	■				
Deer family (deer, elk)	◆	◆	◆	◆					◆	◆	◆	◆					◆	◆	◆	◆	◆	◆	◆	◆
Bear	◆	◆	◆	◆	●	◆	◆	●	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆

Wetlands, and the fish, wildlife, and plants that are dependent on wetlands, provide significant economic and recreational benefits. These include: 1) contribution to a nationwide commercial marine harvest valued at over $10 billion annually; 2) support for a major portion of the nation's annual multi-million dollar fur and hide harvest; 3) fishing, hunting, birdwatching, nature observation, and other wetland-related recreation and educational activities that generate billions of dollars annually; and 4) open space values such as the provision of greenbelts and viewsheds (Sec. 2, Emergency Wetlands Resources Act of 1986).

Terrestrial riparian habitats

Of the numerous species that utilize wetlands, many are also dependent on non-wetland habitats during portions of their life cycles (e.g., eagles, herons, some ducks and shorebirds, beavers, otters, and raccoons). Buffer zones adjacent to wetlands are important as escape habitats, and help protect or minimize impacts to the adjoining wetland areas. The riparian corridors adjacent to many freshwater streams are excellent examples of a non-wetland terrestrial habitat that is critical to the health and survival of numerous species. For example, streamside vegetation shades the water and keeps it at the cool temperature that is necessary to support numerous species of commercial and recreational fish. In addition, these corridors provide many of the same physical values and water quality benefits as wetlands (such as erosion control).

SUMMARY AND CONCLUSIONS

The physical and biological environments described in this chapter illustrate the richness and complexity of the habitats available to the plants and animals that inhabit the Puget Sound basin. Prior to alteration by intensive human development in the last century, Puget Sound was unquestionably one of the environmental wonders of the world. In many ways it still is. However, pressures related to resource development and human population growth have taken their toll on the natural habitats and species of the Sound. Critical physical resources such as surface and groundwater are being seriously affected both in terms of quality as well as available quantity. Certain open water marine habitats with reduced circulation are being degraded by nutrients from point and nonpoint sources, and bottom habitats in certain areas such as urban bays and the sheltered embayments in southern Puget Sound are being affected by toxic chemicals and bacterial contamination. In addition, critically important habitats such as marine kelp and eelgrass beds, and estuarine and freshwater wetlands, are being degraded or destroyed by development pressures. The extent and characterization of human development and its implications are the subject of the following chapter.

Chapter 3: Human Development of the Puget Sound Area

INTRODUCTION

Knowledge of human habitation, economic development, and human uses of the Puget Sound area is fundamental to understanding the present and likely future water quality of the Sound. Human activities tend to alter or damage the natural environment. Whether these actions are intentional or not, the larger the population the more potential there is for detrimental environmental changes. Population in the Puget Sound planning area is currently estimated at nearly three million people. In the future, as the regional population and economy change, as lifestyles change, and as we learn about and respond to the environmental consequences of human activities, the amount and type of damage created by human activities may be reduced. On the other hand, population growth will greatly increase the challenges of environmental protection.

Certain industries are considered most important in determining patterns of economic, population, and land use development. Regions typically have an economic base, or a set of industries that are basic to the regional economy. The basic sector of the Puget Sound economy began as natural resource industries (timber, mining, fishing, agriculture, and associated processing and manufacturing activities) and transportation, especially shipping. This pattern evolved over the decades to include heavy manufacturing. Today service industries are becoming increasingly important, while resource and manufacturing industries are decreasing in importance.

This chapter reviews population and economic growth in the Puget Sound area and the status of key water-dependent activities. Historical trends in water and land development and associated activities by humans around the Sound are not elaborated upon here, but a discussion of these can be found in the first *State of the Sound Report* (PSWQA, 1986b).

DEVELOPMENT IN THE PUGET SOUND AREA

The history of the development of Puget Sound and lands surrounding it by humans is briefly summarized in the following Puget Sound Timeline (Table 3-1). Useful periods for dividing the course of history include the habitation by Native Americans following the Ice Age, settlement in the area by non-Indians from 1845 to 1880, the "Big Boom" period from 1880 to 1940, transition to the modern

TABLE 3-1: PUGET SOUND TIMELINE

BEFORE 1845: THE NATIVE AMERICAN PERIOD	
By 8000 BC	Native Americans reside in the basin.
1700	Native American civilization well established in the basin.
1792	Captain Vancouver explores and names Puget Sound.
1833	Fort Nisqually established as first trading post on Puget Sound.
1845-1880: NON-INDIAN SETTLEMENT	
1845	First permanent non-Indian settlement at Tumwater.
1851	California Gold Rush construction boom reaches Puget Sound
1853	Washington Territory established.
	First steam sawmill built in Seattle by Henry Yesler.
1854-55	Puget Sound Indian treaties.
1880-1940: THE BIG BOOM	
1883	Transcontinental railroad connects Tacoma with East Coast.
1889	Washington statehood.
1891	Puget Sound Naval Shipyard established at Bremerton.
1897	Klondike Gold Rush begins.
1899	Mt. Rainier National Park established.
1910s	Large losses of wetlands for agriculture and industrial development.
1910	Tacoma approves municipal dock facilities.
1911	Port of Seattle established.
1913	Commercial harvest of salmon on Puget Sound peaks.
1914	World War I begins.
1916	First Boeing airplanes built.
1917	Lake Washington Ship Canal opens.
1920s	Adverse effects of pulp industry on Puget Sound.
1930s	Communities around Lake Washington begin sewage treatment.
1937	U.S. and Canada treaty for joint management of Fraser River sockeye salmon.
1940-1970: TRANSITION TO THE MODERN ECONOMY	
1940	Original Tacoma Narrows Bridge collapses.
1941	US enters World War II.
1945	State establishes Water Pollution Control Commission.
1948	First Federal Water Pollution Control Act passed.
1950s	Bridges built: Hood Canal, Agate Pass, and Tacoma Narrows.
	First oil refinery on Puget Sound.
1958	Metro formed to construct and operate regional sewage treatment system.
1966	Metro's West Point treatment plant begins operation.
1968	Formation of the Washington Environmental Council.
1970-1987: RECENT TIMES	
1971	Passage of the Shoreline Management Act.
	Passage of the State Environmental Policy Act.
1972	Passage of the federal Clean Water Act
1974	Boldt Decision in federal court affirming Indian treaty fishing rights.
1978	Hood Canal Bridge destroyed in windstorm.
1981	Trident submarine facilities completed at Bangor.
1982	Northern Tier Pipeline project dies.
1985	Puget Sound Salmon Management Plan adopted.
	The U.S./Canada salmon treaty of 1937 renegotiated.
1986	Puget Sound Water Quality Management Plan adopted.
1987	Passage of the federal Water Quality Act of 1987.
	Everett Navy Home Port approved and subsequently appealed.
	Timber/Fish/Wildlife agreement negotiated.

economy that occurred from 1940 to 1970, and the period from 1970 to the present. This chapter will primarily deal with the last two periods, and will consider the future of the region to the year 2000.

Pre-1970: Transition to the Modern Economy

The relative importance of resource-oriented industries to the regional economy declined after World War II. In general, the economic base of the Puget Sound region became much more diversified as shown in Figure 3-1. Oil refineries were built on Puget Sound starting in the 1950s. A Kaiser aluminum plant was established in Tacoma, and in 1966 the Intalco Aluminum Company began production at Cherry Point north of Bellingham. Ship-building (which had mushroomed during the war) continued to be a major industry in Puget Sound. This era also saw the growth of the tourist industry, especially during and after the 1962 Seattle World's Fair. Employment sectors which decreased in importance between 1950 and 1966 included the forest products industries, agriculture, and wholesale and retail trade (Figure 3-1).

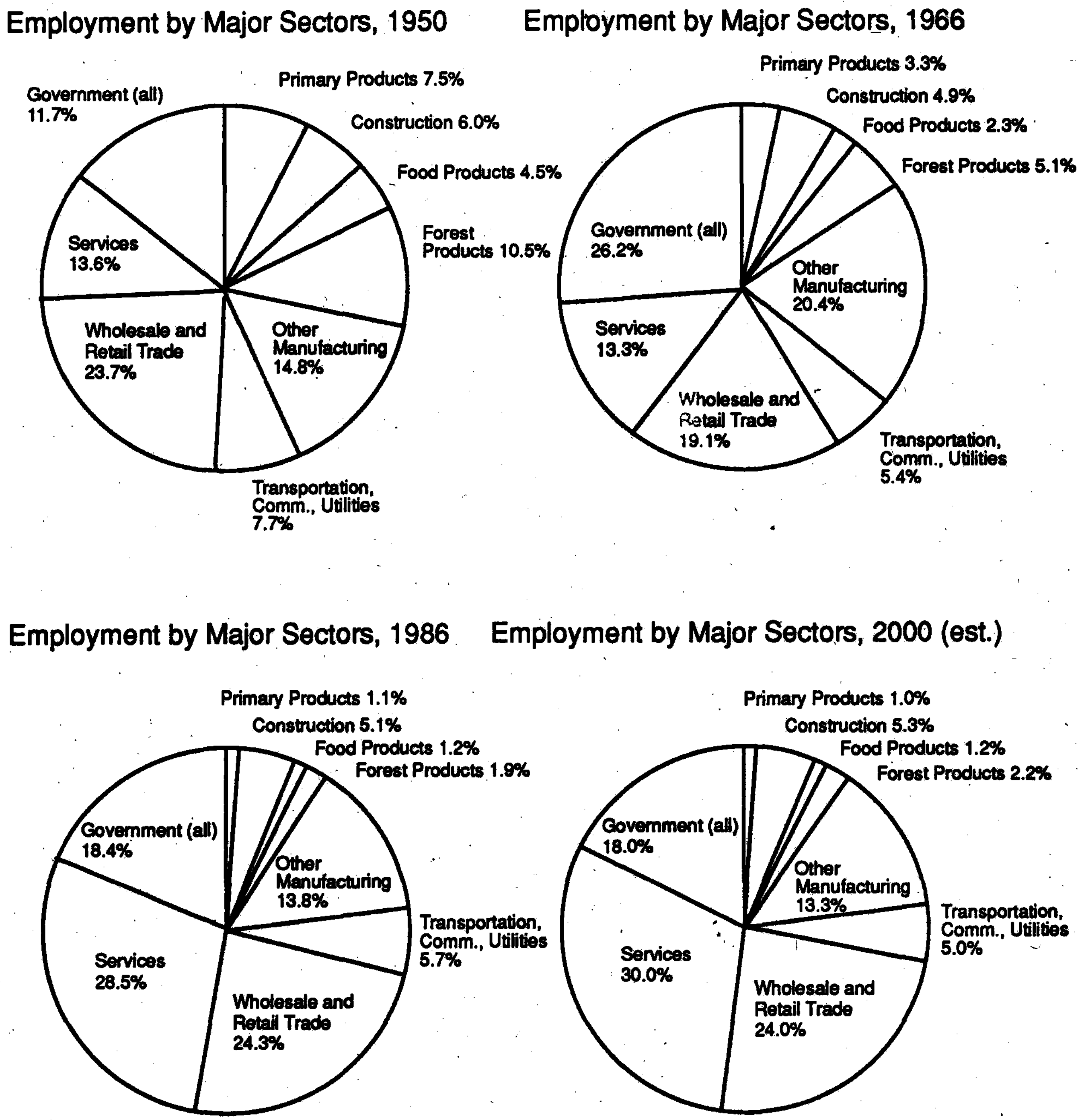
In addition to major changes in the relative importance of various sectors, the overall size of the regional economy expanded rapidly as shown in Table 3-2. Total employment grew by nearly 80 percent between 1950 and 1966, with particularly strong growth in manufacturing of aerospace and other transportation equipment and in government services.

TABLE 3-2: EMPLOYMENT BY MAJOR SECTORS, PUGET SOUND REGION (NUMBER OF JOBS)

Sector	1950	1966	1986	2000 (Est.)
Primary products	31,495	24,660	14,330	18,400
Construction	24,952	37,599	64,340	97,500
Food products	18,737	17,044	15,000	22,000
Forest products	43,785	38,494	24,060	40,500
Other manufacturing	62,124	152,984	176,600	244,800
Transportation, comm., utilities	32,398	40,947	72,710	92,000
Wholesale and retail trade	98,923	144,012	308,990	441,800
Services	57,140	100,502	362,300	552,200
Government (all)	49,415	196,439	234,180	331,300
TOTAL	418,969	752,681	1,272,510	1,840,500

(Reference: Washington Department of Employment Security, 1987)

Post-war land development was radically different from earlier settlement patterns. With the construction of freeways and an extensive road and bridge system throughout the region, the distance that people could commute to work increased greatly. As people commuted to urban jobs from suburban or rural areas where they lived on larger lots, the average population density in King County decreased from 8.2 persons per acre before 1960 to only 4.4 persons per acre for development after 1960 (PSWQA, 1986b). In addition, urban annexation and zoning changes encouraged the expansion of non-agricultural commercial and industrial uses into the



Reference: Washington Department of Employment Security, 1987

Figure 3-1

BASIC EMPLOYMENT BY MAJOR CATEGORY, 1950, 1966, 1986, and 2000 (estimated)

more rural areas during this time period. These pressures from urban development led to significant declines in the acreage of productive agricultural land in the Puget Sound region (Figure 3-2), particularly in the Green, Sammamish, Puyallup, and Snohomish river valleys.

In the mid-1960s the Pacific Northwest River Basins Commission (PNRBC) directed a comprehensive study of water and related land resources in the Puget Sound area (PNRBC, 1970). This report, titled the *Puget Sound and Adjacent Waters Study*, still provides the best available basinwide data on land use. Figure 3-3 (taken from that study) shows broad classes of land use in the Puget Sound region in the mid-1960s. At that time, most of the land was in forest use and urban settlement occupied only a very small fraction (about five percent) of the land area. Cropland accounted for about one-third of the acreage used for agriculture in 1966. The study estimated that about 25 percent of the land within the built-up areas was used for housing, about 10 percent for commercial and industrial purposes, and about 30 percent for streets, highways, parks, schools, and other public uses. The balance was vacant land or airports, intercity roadways, and railroads (PNRBC, 1970).

1970 to 1987: The Post-industrial Age and the Service Economy

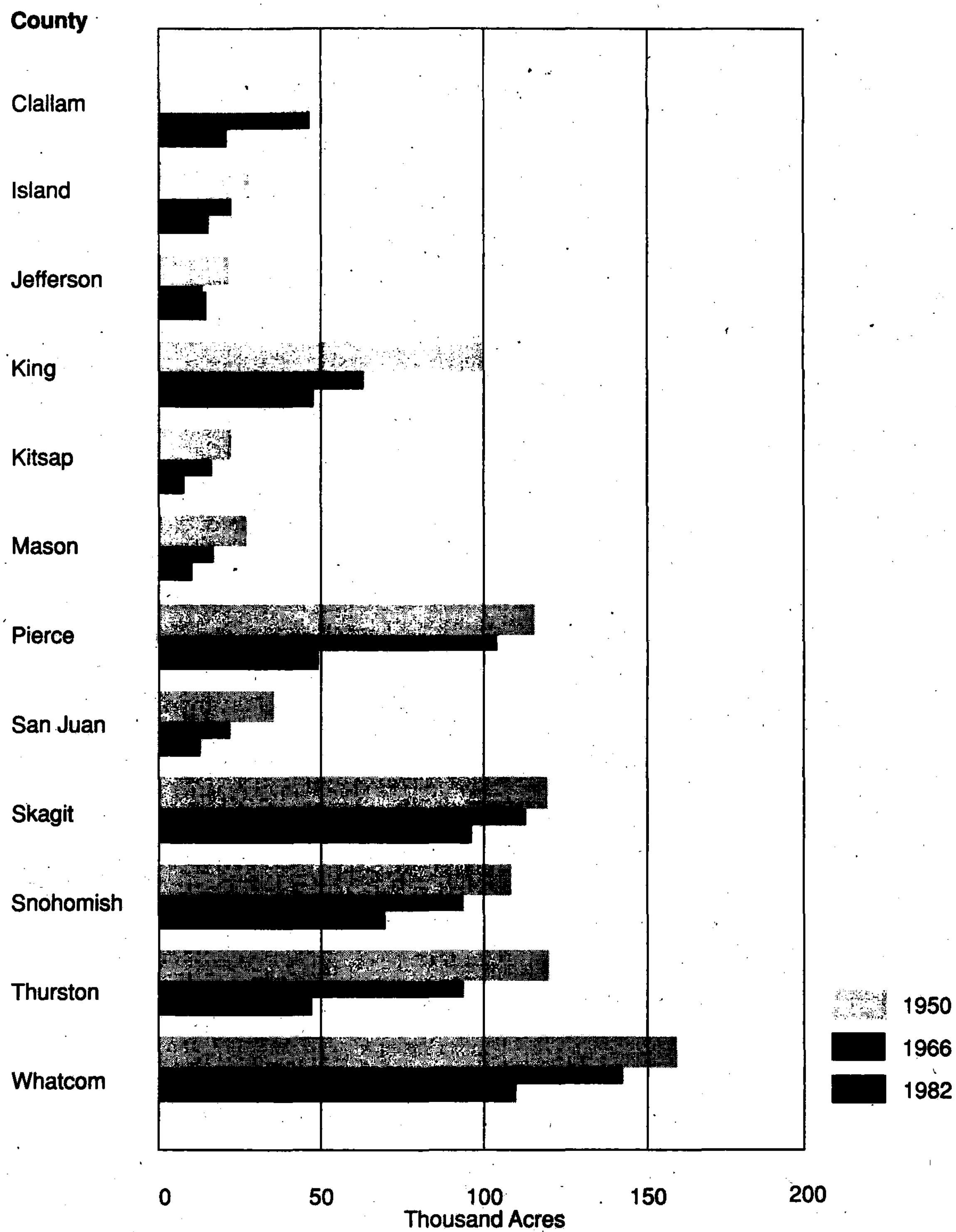
Contrary to early predictions of an era of industrial growth, the 1970s began badly for the regional economy. The Boeing work force dropped dramatically between 1969 and 1971 due to adverse business conditions. Simultaneously, the forest products industry entered a slump due to high domestic interest rates which slowed the construction industry. In contrast to the post-World War II years when the growth of manufacturing led the expansion of the Puget Sound regional economic base, the period since 1970 has seen more diversified growth in the economic base with a decline in the manufacturing and government sectors (Figure 3-1). Service industries and wholesale and retail trade are now the dominant employment sectors in the Puget Sound region.

The relative importance of resource-based industries is much greater in the more rural counties of the Puget Sound area than in the more urbanized central Puget Sound counties (Snohomish, King, Kitsap, and Pierce) as shown in Table 3-3. For

TABLE 3-3: EMPLOYMENT BY MAJOR SECTORS, RURAL COUNTIES VERSUS CENTRAL PUGET SOUND, 1986 (Number of Jobs)

Sector	Rural Counties		Central Puget Sound	
	Number	Percent	Number	Percent
Primary products	7,370	4.6	6,960	0.6
Construction & mining	7,840	4.9	56,500	5.1
Food products	2,500	1.6	12,500	1.1
Forest & paper products	7,360	4.6	16,700	1.5
Other manufacturing	10,880	6.7	165,720	14.9
Transportation, communications, utilities	6,030	3.8	66,680	6.0
Wholesale & retail trade	36,930	23.0	272,060	24.5
Services	35,440	22.0	326,860	29.4
Government (all)	46,370	28.8	187,810	16.9
TOTAL	160,720	100.0	1,111,790	100.0

(Reference: Washington Department of Employment Security, 1987)



Reference: U.S. Census of Agriculture, 1950, 1966, and 1982

Figure 3-2

AGRICULTURAL LAND USE IN PUGET SOUND COUNTIES, 1950, 1966, AND 1982

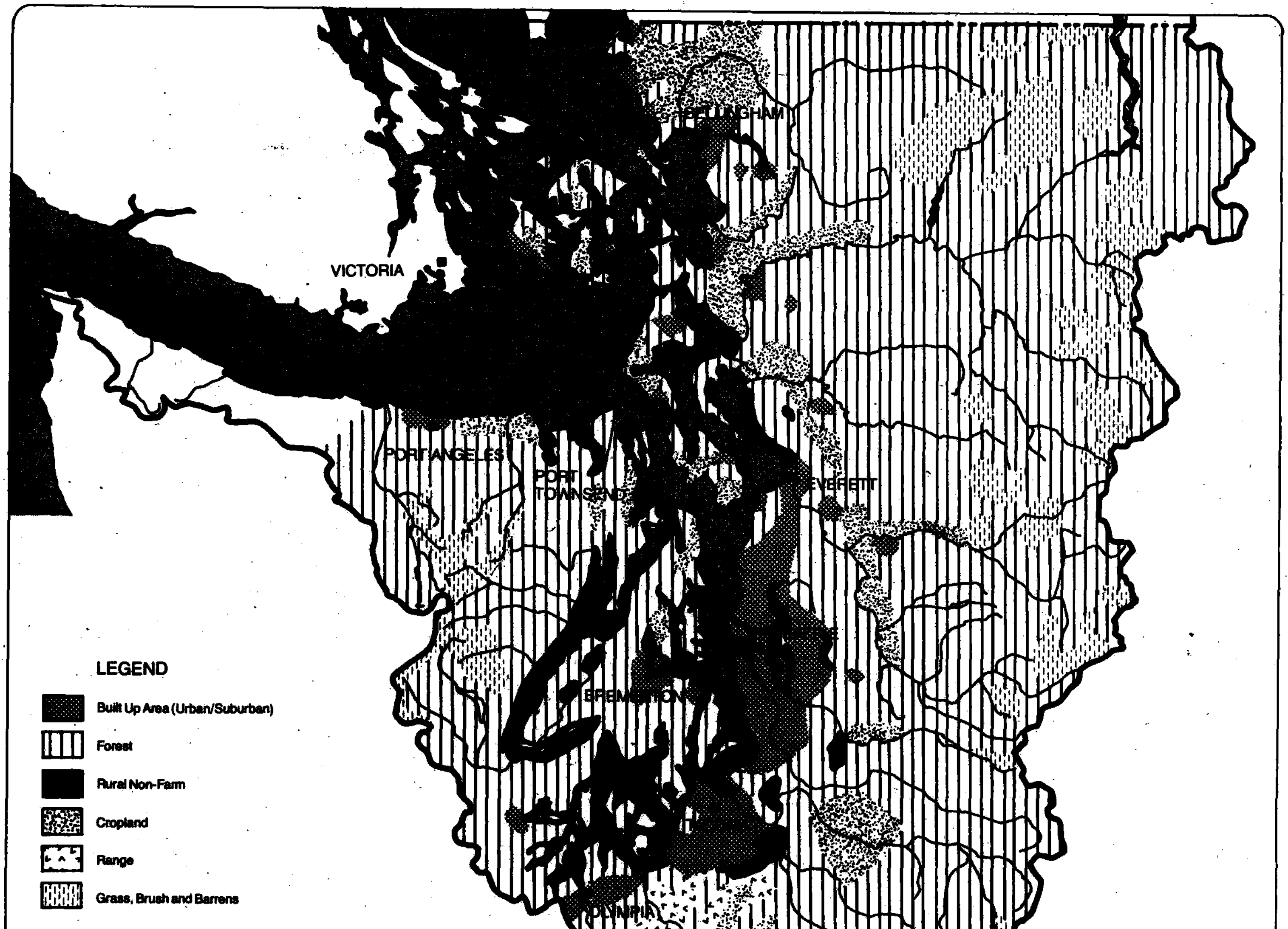
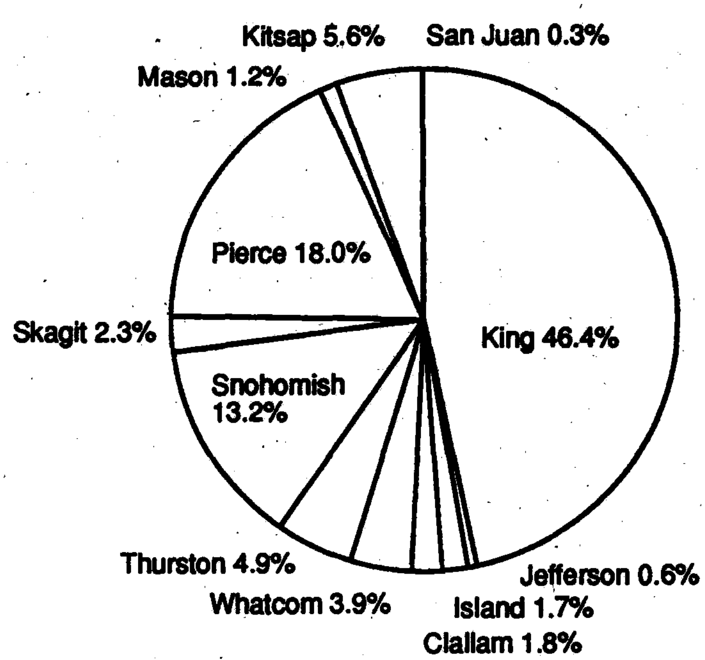


Figure 3-3

LAND USE IN THE MID 1960s, PUGET SOUND WATER QUALITY PLANNING AREA

Reference: Pacific Northwest River Basins Commission, 1970 example, the primary products (agriculture) sector made up 4.6 percent of the total employment in rural counties but only 0.6 percent of the employment in the urban counties of the Sound in 1986 (Washington Department of Employment Security, 1987). Conversely, manufacturing and services employment represented a greater percentage of total employment (14.9 and 29.4 percent, respectively) in the central Puget Sound counties than they did in the other more rural counties of the area (6.7 and 22.0 percent, respectively; Table 3-3).

The population of the Puget Sound region is currently estimated at nearly three million, with King County accounting for 46.4 percent of the 1987 estimated population (Figure 3-4). Pierce County has retained 18 to 19 percent of the region's population since 1910, while Snohomish County has increased its share of the region's population from 7.9 to 13.2 percent in the last three decades. Most of Washington's population growth since 1980 has occurred in the state's largest counties, five of which border on Puget Sound. King, Kitsap, Pierce, Snohomish, Thurston, and Whatcom counties increased by about 276,000 people between 1980



Reference: Washington Office of Financial Management, 1987

Figure 3-4

PERCENT OF 1987 PUGET SOUND POPULATION, BY COUNTY and 1987, which accounts for 79 percent of the entire state's population growth in that time period (Washington Office of Financial Management, 1987).

The rate of population growth, rather than sheer numbers of people, is often a good indicator of potential environmental and institutional stresses and problems in an area. This is because land use planning activities, the provision of basic services, and local enforcement of laws and regulations may not be able to keep up with the demands of an increasing population in rapidly growing areas. Puget Sound counties represented nine of the ten fastest growing counties in the state for the period between 1980 and 1987 (Washington Office of Financial Management, 1987). Much of this growth took place in "amenity" and unincorporated areas where population is not necessarily associated with basic employment. Island County had the highest rate of growth in the state (18 percent), while San Juan, Thurston, Snohomish, and Mason Counties also had very high rates of growth (Figure 3-5). Although Island and San Juan Counties are experiencing rapid growth (largely due to vacation and retirement uses), their 1987 population estimates are quite small relative to the rest of the Puget Sound area (52,100 and 9,200 persons, or 1.7 and 0.3 percent of the region's population, respectively; Figure 3-4).

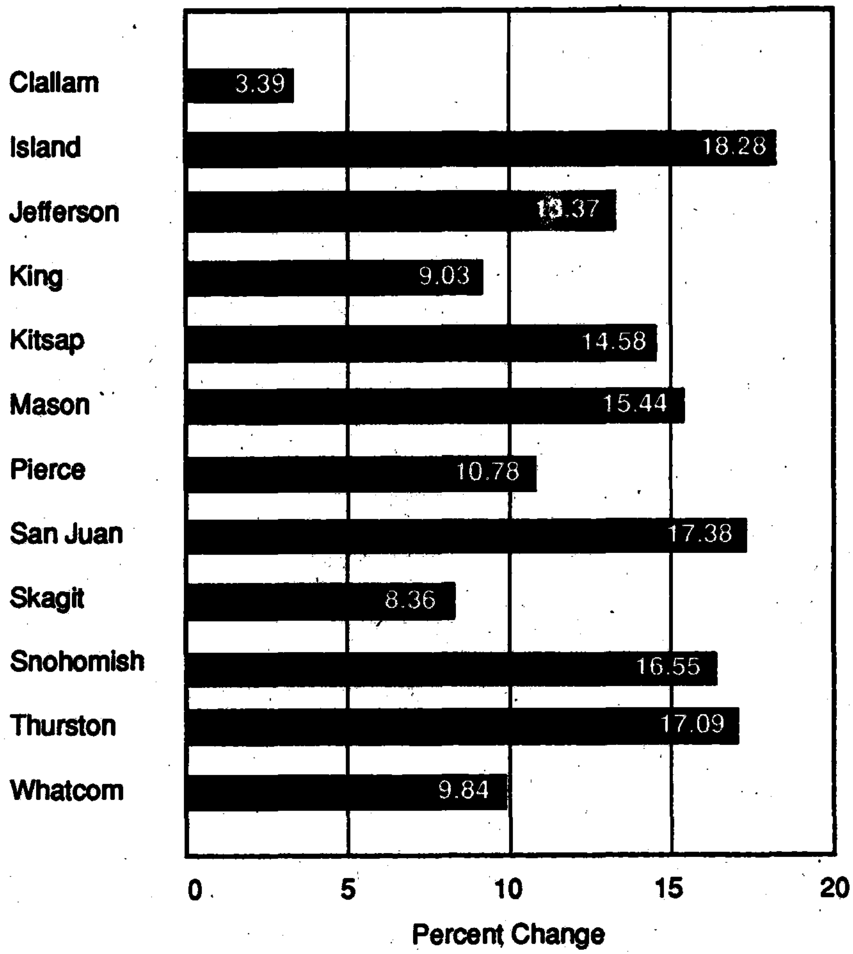
No comprehensive study of land use in the Puget Sound region has been made since the *Puget Sound and Adjacent Waters Study* of the 1960s. However, using data on housing, employment, and population characteristics in the central Puget Sound region, estimates of land use can be made for the early 1980s (Table 3-4). Comparing these estimates to those for 1967, it appears that intensively used urban land plus rural non-farm settlement has increased by 232,200 acres (a 42 percent increase from 547,200 to 779,400 acres). Conversely, the combined acreage of forest, pastureland, and cropland appears to have decreased by about 385,700 acres (a five percent change) between 1967 and 1984.

TABLE 3-4: ESTIMATED ACRES OF LAND USE IN THE PUGET SOUND WATER QUALITY PLANNING AREA BY CATEGORY IN 1967, 1984, AND THE YEAR 2000 (Thousands of Acres)

	1967	1984	2000
Intense urban	308.4	509.4	824.0
Pastureland	467.6	248.8	248.8
Cropland	230.4	245.8	245.8
Streets and highways	120.0	273.5	273.5
Rural, non-farm*	238.8	270.0	466.9
Forest	7,191.6	7,009.3	6,497.8
TOTAL	8,556.8	8,556.8	8,556.8

*Rural, non-farm uses include river wash tidelands, mines, and rural non-farm residences.

(Reference: PSWQA, 1986b)



Reference: Washington Office of Financial Management, 1986

Figure 3-5

PERCENT POPULATION GROWTH IN PUGET SOUND COUNTIES FROM 1980 TO 1987

The Future: Looking to the Year 2000 and Beyond

Economic forecasts from the federal Bureau of Economic Analysis for the most urbanized counties, modified to represent the economy of the Puget Sound area as a whole, can be used to estimate total employment and the composition of employment in the year 2000 (Figure 3-1 and Table 3-2). As was the case in 1986, services are anticipated to be the largest source of jobs, followed by wholesale and retail trade and government. Other anticipated trends are a strong aerospace business for the Boeing Company, expansion of international trade through Puget Sound ports, continued development of high-technology industry, and new economic activity resulting from research activity at the region's colleges and universities.

Population estimates for 1987 and forecasts for 1990 and 2000 made by the Washington Office of Financial Management (OFM) are presented by county in Figure 3-6. The population of the Puget Sound region is expected to grow from the current estimated 2,985,800 to 3.1 million by 1990, and to approximately 3.6 million by the year 2000 (OFM, 1986). This population forecast for the year 2000 is slightly less than the estimate that was reported in the first *State of the Sound Report* (3.7 to 3.9 million people; PSWQA, 1986b). Employment is expected to expand from the current 1.27 million to 1.84 million in the year 2000 (Table 3-2). These estimates suggest that the Puget Sound area will account for about 66 to 68 percent of the state's total population through the year 2000; the Sound contains about 23 percent of the total area in the state.

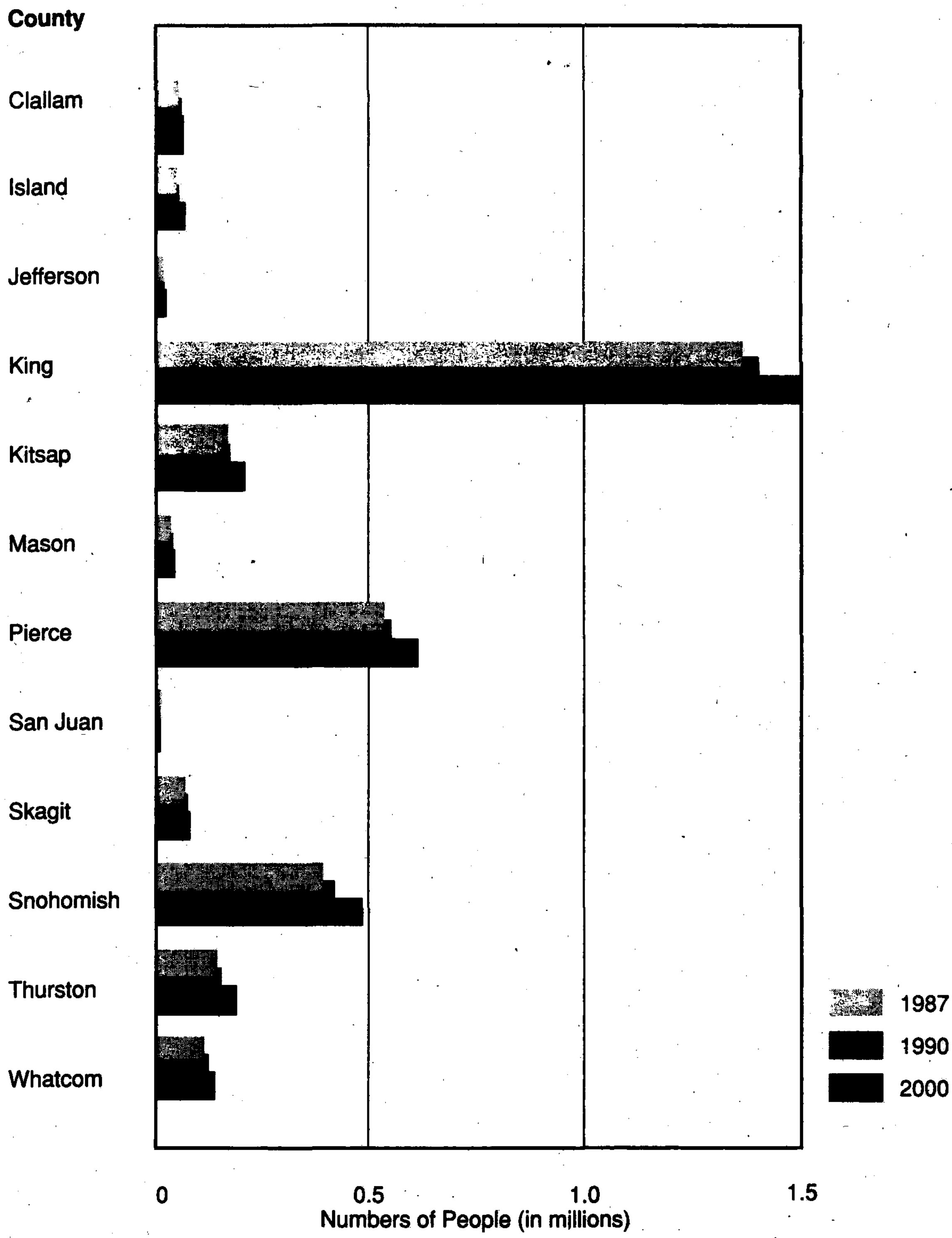
The Puget Sound Council of Governments (PSCOG) has provided estimates of population and economic growth into the year 2020 for the four counties in its jurisdiction (King, Kitsap, Pierce, and Snohomish). Population estimates indicate that about 1.5 million more people may move to the central Puget Sound region between 1987 and 2020, with Snohomish County projected to have the most rapid growth rate (PSCOG, 1988). Total employment in the four counties is projected to almost double (from 1.3 million in 1987 to 2.3 million in 2020) with most new employment opportunities being in retail trade and services.

Land use forecasts for the year 2000 suggest that almost 1.3 million acres or 15 percent of the land in the Puget Sound area will be in intense urban or rural non-farm use by the year 2000 (Table 3-4). Most of this intensively used land is projected to be in the central Puget Sound region. These forecasts are based on the assumption that the acreages of highways, railroads, and waterways are fixed and that acreage of agricultural land will remain roughly constant (recent declines in pastureland may be offset by public policies designed to preserve agricultural lands; PSWQA, 1986b).

These forecasts have tremendous significance for planning and regional water quality. Between 1987 and the year 2000, a projected population increase of 20 percent in the Puget Sound region will be accompanied by a 62 percent increase in lands developed for intense urban activities and a 73 percent increase in lands developed for rural non-farm use. No increase is projected in agricultural land use, but about a seven percent decrease in forest land use is projected (Table 3-4). Employment and economic activity are projected to shift increasingly to services, government, trade, and construction. Thus, residential, commercial, office, and retail land uses will grow. Heavy industrial activities such as pulp and paper and smelting are not projected to increase significantly, and may decrease depending on national and international economic conditions.

MODERN WATER DEPENDENT ACTIVITIES

The value of the waters and habitats of the Puget Sound basin can be represented by the uses made of them. These uses are called "water-dependent activities." Key water-dependent activities include ports and shipping, maritime recreation such as boat launching and fishing, wet moorage (although dry moorage has recently



Reference:Washington Office of Financial Management, 1986

Figure 3-6

POPULATION ESTIMATES FOR PUGET SOUND COUNTIES, 1987, 1990, and 2000

proliferated), fishing and aquaculture, shipbuilding, and aesthetic appreciation of the Sound. The economic importance of several key water-dependent activities is discussed in this section.

Marine Shipping

Marine transportation on Puget Sound has played a key role in the commerce of the region since the area was first populated by Native Americans. However, the importance of the various types of marine shipping as well as the importance of various commodity groups has changed over time. Table 3-5 shows how the relative influence of foreign, coastal (between U.S. coastal ports), internal (between Puget Sound harbors), and local (between locales in any one harbor's jurisdiction) shipping has changed over time.

Total tonnage shipped increased from 29.73 million to 53.58 million tons (26.97 million to 48.61 million metric tons) between 1953 and 1985 (U.S. Army Corps of Engineers, 1985). Much of this growth resulted from the dramatic increase in foreign trade in the past 17 years (from 12.12 million to 25.69 million tons or 10.99 million to 23.31 million metric tons), with a resulting decrease in the dominance of internal shipping between Puget Sound harbors. Although the export of logs and wood chips still contributed the largest fraction of foreign tonnage (6.52 million tons or 5.91 million metric tons) in 1985, the growth of container cargo traffic from the major urban ports has been substantial.

Table 3-6 shows categories of major commodity groups shipped from or to each of the Puget Sound harbors in 1985. Logs and rafted logs made up a large proportion of the total commodities shipped at Everett, Olympia, Port Angeles, and Tacoma Harbors, while lumber products were primarily shipped at Port Gamble and Port Townsend Harbors (U.S. Army Corps of Engineers, 1985). Crude oil and various petroleum products (including fuels, oils and greases, and solvents) made up large proportions of the commodities shipped at Anacortes, Bellingham, Seattle, and Tacoma Harbors. All other commodities not listed separately in Table 3-6 are listed as "other products" in the table. This large and diverse category of commodities (including food products, chemicals, apparel, cement, and manufactured products, among others) represented a significant portion of the shipping activity at Bellingham, Seattle, and Tacoma Harbors.

TABLE 3-5: TONNAGE OF MARITIME SHIPPING IN PUGET SOUND FOR 1953, 1968, 1983, AND 1985 (Short Tons* in Millions)

	Total	Foreign		Coastal		Internal		
Year	Tonnage	Imports	Exports	Recp.	Ship.	Recp.	Ship.	Local
1953	29.73	1.75	1.42	6.47	1.32	9.50	5.48	3.79
1968	46.64	5.50	6.62	5.29	3.66	14.28	6.32	4.97
1983	51.22	10.73	15.30	5.96	4.90	7.06	4.20	3.07
1985	53.57	10.33	15.36	9.73	4.50	6.36	4.74	2.55

*Short ton = 2,000 pounds

(Reference: U.S. Army Corps of Engineers, 1985)

Estimates of the tonnage and value of foreign import and export commodities shipped at Puget Sound ports and harbors are compiled by the Port of Seattle using a different data base than that used by the U.S. Army Corps of Engineers (Corps). Total tonnage of foreign shipments to or from Puget Sound ports totaled 29.78 million tons (27.02 million metric tons) in 1986 (Port of Seattle, 1987). The estimated value of these shipments totaled $38.37 billion, with import trade accounting for 83 percent of this value. A recent forecast suggests that foreign cargo movements could double to nearly 60 million tons (54 million metric tons) by the year 2000 (Hannus, 1987, pers. comm.).

Although no Soundwide analyses have been completed for the impact of port activity on the economy, the Port of Seattle estimates that harbor operations lead directly to 24,000 jobs and, through multiplier effects, to a total of 37,000 jobs in King County and 54,000 jobs statewide (Doolittle, 1987, pers. comm.). The regionwide impact of port activity is probably about three times that measured by the Port of Seattle, or about 150,000 jobs statewide.

Capture Fishery

The harvest of fish and shellfish has been one of the most important human uses of the Puget Sound basin for as long as there have been people in the area. Each

TABLE 3-6: TONNAGE BY COMMODITY GROUP, PUGET SOUND PORTS, 1985 (Short Tons*)

Port	Grains[1]	Sand & Gravel[2]	Logs[3]	Lumber Products[4]	Crude Oil[5]	Dist. Fuel[6]	Other Petroleum[7]	Other Products	Total
Anacortes Harbor	0	29,982	265,934	2,440	6,682,090	1,608,630	1,237,952	381,281	10,208,309
Bellingham Bay & Harbor	0	44,606	36,997	126,184	209,794	143,445		765,852	1,326,878
Everett Harbor		963	3,395,409	179,731	2,060	8,445	47,705	493,955	4,128,268
Hammersley Inlet	0	0	352,894	146,769	0	0	0	1,795	501,458
Olympia Harbor	4,887	800	567,227	139	0	758	13,938	17,834	605,583
Port Angeles Harbor	30	42,561	2,153,304	278,305	0	75,283	259,875	117,449	2,926,807
Port Gamble Harbor	0	6,200	273,129	325,405	0	0	0	58,578	663,312
Port Townsend Harbor	0	6,698	0	284,789	0	5,886	18,284	183,212	498,869
Seattle Harbor	812,282	2,643,579	271,007	479,348	39,603	1,799,458	1,235,811	8,948,925	16,230,013
Swinomish Channel	0	1,000	683,981	0	0	0	0	11,025	696,006
Tacoma Harbor	3,322,576	602,249	3,025,075	978,532	1,731,144	743,090	873,987	4,517,879	15,794,532
TOTAL	4,139,775	3,378,638	11,024,957	2,801,642	8,664,691	4,384,995	3,687,552	15,497,785	53,580,035

1. Grains: 0103** (Corn), 0106 (Sorghum grains), 0107 (Wheat), & 0111 (Soybeans)
2. Sand & Gravel: 1442 (Sand, gravel, crushed rock)
3. Logs: 2411 (Logs), 2412 (Rafted logs)
4. Lumber Products: 2414 (Timber, posts, poles, piling), 2416 (Wood chips, staves, moldings), 2421 (Lumber)
5. Crude Oil: 1311 (Crude petroleum)
6. Dist. Fuel: 2911 (Gasoline), 2912 (Jet fuel), & 2914 (Distillate fuel oil)
7. Other Petroleum: 2915 (Residual fuel oil), 2916 (Lubricating oils & greases), 2917 (Naptha, petroleum solvents), 2918 (Asphalt, tar & pitches)

*Short ton = 2,000 pounds
**Commodity group numbers as defined by the U.S. Army Corps of Engineers

(Reference: U.S. Army Corps of Engineers, 1985)

species has a certain natural abundance, but even without the effects of human activities, populations will fluctuate greatly from year to year as a result of climate, ecological competition and predation, and natural events (such as the eruption of Mount St. Helens in 1980 and the El Nino event in 1982-83). The tools developed to capture these marine resources are efficient enough that it is possible to overharvest virtually every species present. In addition, destruction of habitats for spawning and larval rearing in rivers and lakes, and the loss or alteration of nearshore estuarine wetlands, intertidal areas, and shallow subtidal areas has had a profound effect on salmon, surf smelt, and herring production in some areas. Loss of freshwater habitat for salmon due to such things as logging, construction of dams, and urbanization has also adversely affected natural production. In addition, fishery losses have historically resulted from the degradation of saltwater by dredging and filling, toxic contamination, and the depletion of dissolved oxygen. It is difficult to separate the effects of natural fluctuation, overfishing, and pollution for species that are extensively harvested. The following sections discuss the harvest trends of the major resources and summarize their economic importance.

Knowledge of trends in the availability of major commercial and recreational fish species in Puget Sound is limited by several constraints. Historical data are available only for fish catch and not for absolute abundance. Trends in catch reflect not simply changes in abundance but also in the harvesting effort expended. The extent to which a particular resource is harvested depends on weather, changes in technology, fluctuations in market conditions, and management decisions. Natural phenomena such as changes in migration patterns can also affect catch and give the false appearance of a change in fish abundance. The Washington Department of Fisheries (WDF) collects data on both commercial and recreational (sport) fishing in Puget Sound, but their sport catch data are less comprehensive than the commercial catch data. Over the last year, WDF has started updating the sport catch data and is seeing different geographic trends than appeared from the earlier data. However, the updated information is still less comprehensive than their commercial data.

The Puget Sound fishing industry is an important part of the local economy as well as a significant contributor to the state's fishing industry. Fishing provides benefits to both Indian and non-Indian communities, and will continue to increase in importance with proper management of habitat and fishery resources in Puget Sound. Changes in public taste over the last few years have increased the price of fish relative to other protein sources. The total value of all commercial and recreational fish and shellfish in Puget Sound was estimated at $168 million in 1986 (Table 3-7). Salmon harvests represent the bulk of the value of the Puget Sound catch. Herring and other baitfish, groundfish (cod, hake, pollock, rockfish, surf perch, dogfish, sole, and flounder), and shellfish (clams, oysters, scallops, mussels, abalones, crabs, shrimp, octopus, squid, sea cucumbers, and sea urchins) account for the rest. Much of the commercial shellfish catch is generated by aquaculture facilities which are discussed in the following section. Recreational or sport catches of fish and shellfish are discussed following the aquaculture section. As the population and personal incomes continue to increase in the Puget Sound area, so will the demand for both commercial and recreational fishing.

Salmon

Reliable data on the capture fishery of salmon in Puget Sound date only from the early part of the 20th century. With the rapid increase in the non-Indian population and the development of large scale commercial fish canning techniques, the harvest of salmon increased dramatically in the late 1800s and early 1900s. Between 1913 and 1920 the primarily non-Indian fleet harvested four to eight times the current average annual catch. This may represent the overfishing that drove Puget Sound salmon stocks into decline (Ward et al., 1974; Ward and Hoines, 1982). Figure 3-7

TABLE 3-7: ESTIMATED VALUE OF PUGET SOUND FISHERIES, 1986

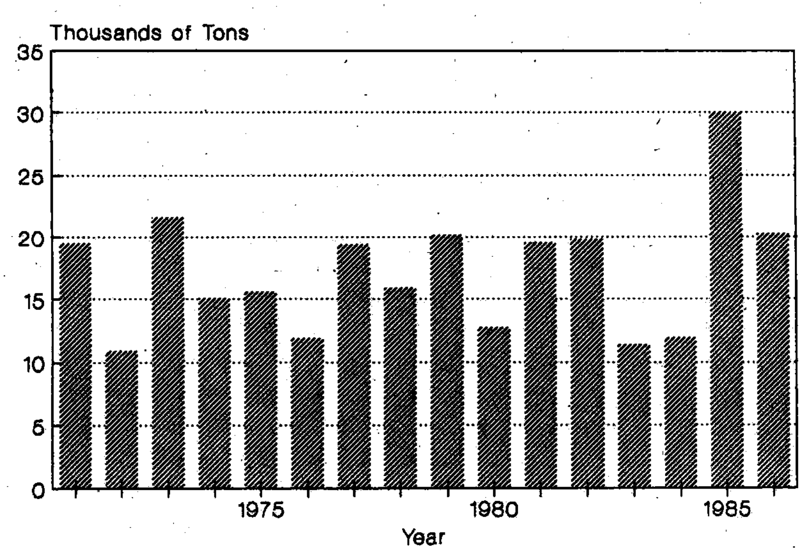
	Landings by Indian & Non-Indian Commercial (tons)	Commercial Catch Value ($1,000,000)	Retail Value ($1,000,000)	Five Year Avg. Commercial Catch Value ($1,000,000)	Sport Catch Value ($1,000,000)
Salmon	20,226	44.45	131.84	34.37	74.56
Other anadromous[1]	1,421	6.49	19.47	-----	-----
Baitfish	672	0.53	1.58	0.56	-----
Groundfish	13,132	2.13	6.39	1.84	4.21
Shellfish[2]	8,426	14.43	43.29	11.14	23.26
TOTAL	43,877	68.03	202.57	47.92	102.04

1. Includes aquaculture salmon and steelhead trout production as well as landings of wild salmon eggs and sturgeon.
2. Includes both capture fisheries and aquaculture production.

(References: Hoines, 1988, pers. comm.; Ward, 1988, pers. comm.; PSWQA, 1988c; WDF, 1988; Hoines and Ward, 1987; Palsson, 1987; U.S. Bureau of Labor Statistics, 1986; Ward and Hoines, 1982; Brown and Mathews, 1969)

shows the commercial salmon catch from 1971 to 1986. Natural salmon production is far below what it was before extensive development of the Puget Sound area. Overfishing played a role in this decline, but destruction of spawning and rearing

Figure 3-7: COMMERCIAL LANDINGS OF SALMON IN PUGET SOUND



Reference: WDF, 1988

habitat by logging, dam and lock construction, and development of salt and freshwater shorelines is believed to have had the most serious impacts. However, catches of salmon species from the Sound are now relatively stable.

Stabilization of salmon populations has been accomplished in part by stringent management measures that are implemented using a process now referred to as "sharing the burden of conservation." These measures include careful limitation of catch for each species and frequent partial closures of fisheries. Salmon populations are managed to ensure that adequate numbers of adult fish "escape" or return to spawn (reproduce) in freshwater. Harvest numbers are typically set by escapement goals for each stream system. However, there is some concern that the current "sharing the burden" management process may allow a fishery to remain open even if escapement goals are not being met. Managers occasionally allow fisheries to be harvested to "floor levels" which allow for some escapement but which tend to slow the rebuilding of the fishery. In addition, the management of salmon resources is complicated by the imprecise estimates of the total recreational harvest of salmon. The present harvest is dependent on a large and sophisticated hatchery system. Without artificial propagation present catch levels could not be sustained.

Chinook and especially coho salmon fisheries in the Sound have been heavily supplemented by hatchery production, in which the tribes are playing an active role. Commercial and sport catches of these species have been increasing for roughly the last two decades. However, some are concerned that continued hatchery production is occurring at the expense of the remaining wild stocks. Hatchery fish are released into open water at a size and in such numbers that they displace or even eat the natural fish. In addition, there is concern that the special breeding used to refine hatchery stocks may reduce the genetic diversity of the salmon species, leaving them susceptible to epidemic disease or other catastrophe. Perhaps the greatest problem generated by mixed stocks of hatchery and wild salmon relates to harvest levels. Because hatchery fish have such high survival rates in incubation, they can be harvested at much higher levels than wild fish. Therefore, if unlimited harvest is permitted on mixed stocks the wild stocks may be overharvested. To prevent this from occurring, resource managers set mixed stock harvest limits based on the "weakest" or wild stock. In addition, many major river systems are managed to protect the wild fish (Mills, 1988, pers. comm.).

Legal and socioeconomic factors have affected management and allocation of the Puget Sound salmon fishery in recent years. The Boldt decision in federal court in 1974 recognized the reserved right for salmon in existing Indian treaties, and allocated half of all harvestable western Washington salmon and steelhead resources that pass through usual and accustomed fishing areas to Puget Sound and coastal treaty tribes. Because of the allocation of the salmon harvest between Indian and non-Indian fleets, the management structure for salmon has changed rapidly. In 1985 the Puget Sound Salmon Management Plan was adopted. This is a comprehensive management plan for Puget Sound salmon that integrates Indian and non-Indian management activities. Also in 1985, the United States and Canada entered into a historic, long-negotiated agreement that covers harvest and management of international salmon resources that commingle in the offshore waters of Canada, Alaska, Oregon, and Washington. This agreement established the Pacific Salmon Commission that currently negotiates escapement goals for the U.S. and Canadian waters. Puget Sound tribal governments are actively involved in the commission. These developments have already resulted in more effective management of the salmon resource. A Columbia River salmon management plan has also been developed by the U.S. Departments of Commerce and Interior, the Oregon Department of Fish and Wildlife, the Washington Departments of Fisheries and Wildlife, and several inland tribes in Oregon and Washington. This plan will affect the Puget

Sound fishery but the plan was developed without the involvement of Puget Sound and Washington coastal treaty tribes.

Salmon represent the most important commercial capture fishery in Puget Sound. The value of the 1986 commercial capture salmon catch at the boat was $44.45 million (compared to $26.7 million in 1984; Table 3-7; WDF, 1988). The commercial catch is valued by the price per pound paid at the boat before the fish is processed. Salmon retail value shown in Table 3-7 reflects the value of the fish to the consumer, and includes wages and other expenditures involved in processing the fish.

Baitfish

Herring is an important fish species in terms of abundance and catch in Puget Sound. The commercial herring catch has four components: a sac-roe fishery (in which eggs or roe are collected from whole fish), a small kelp-roe fishery (in which eggs attached to kelp are collected together), a general purpose fishery, and a bait fishery. Herring catches in Puget Sound were quite low until 1957 when the general purpose fishery was begun. The fishery was conducted during fall and winter in the eastern Strait of Juan de Fuca and San Juan Islands area (especially in Bellingham Bay), catching both fish originating from the Strait of Georgia and a newly discovered stock from central and southern Puget Sound and Hood Canal. The catch was used for production of fish meal and oil, as food for zoo animals, and as bait for king crab in Alaska. After careful monitoring and several attempts at management measures to stem a serious decline, the general purpose fishery was closed in 1983. A decrease in the average size of the fish caught indicated that overfishing was occurring.

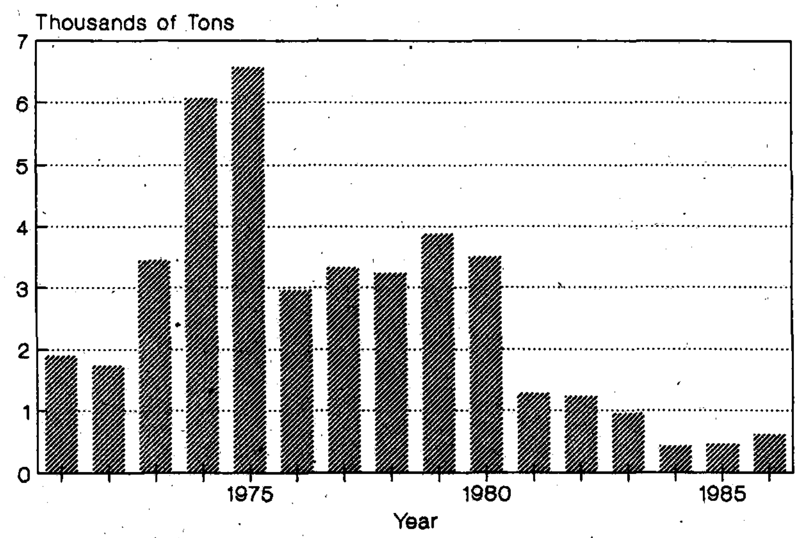
Catches of the sac-roe fishery during spring in the southeastern Strait of Georgia (which average 2,000 to 4,000 tons per year or 1,815 to 3,630 metric tons per year) and the year-round bait fishery in the central and southern Sound (600 tons per year or 545 metric tons per year) were stable until 1980. In 1980 the sac-roe fishery was closed by the Canadian government due to low populations of surviving young. In 1986 the sac-roe fishery was still closed but the commercial bait fishery in Puget Sound provided $483,000 in revenue at the boat. The sac-roe fishery was opened in the Sound in 1987 but production data are not yet available (Ward, 1988, pers. comm.). Total commercial landings of herring from 1971 to 1986 are shown in Figure 3-8. While the total number of herring that spawn in central Puget Sound and Hood Canal appears to be relatively stable, the population that spawns in the northern Sound in May and June has been in a period of decline (Day, 1987; Bargmann, 1988b).

Smelt also provide a small commercial catch of 133,000 pounds (60,300 kilograms) in Puget Sound (WDF, 1988). Total commercial catch value for Puget Sound baitfish was $530,000 in 1986 (Table 3-7).

Groundfish

Groundfish are fish that live on or near the bottom. This group includes the hake, pollock, and cod; the rockfish; greenling and lingcod; surf perch; the flatfish (flounder, sole, and halibut); and the spiny dogfish. Cod, English sole, and starry flounder historically have dominated the groundfish catch from Puget Sound. English sole dominates the commercial catch from the central Sound and Hood Canal, and cod and pollock dominate the catch in the outer waters of the Strait of Juan de Fuca. Total groundfish catch has increased steadily in the last 20 years to over 14,000 tons (12,700 metric tons) annually (WDF, 1988). Over the last decade hake, pollock, and dogfish have increased as a fraction of the total weight of catch, but this may reflect changing fishing habits as much as changing abundance. Landings and catch rates of pile perch have declined in Puget Sound over the last few

Figure 3-8: COMMERCIAL LANDINGS OF HERRING IN PUGET SOUND

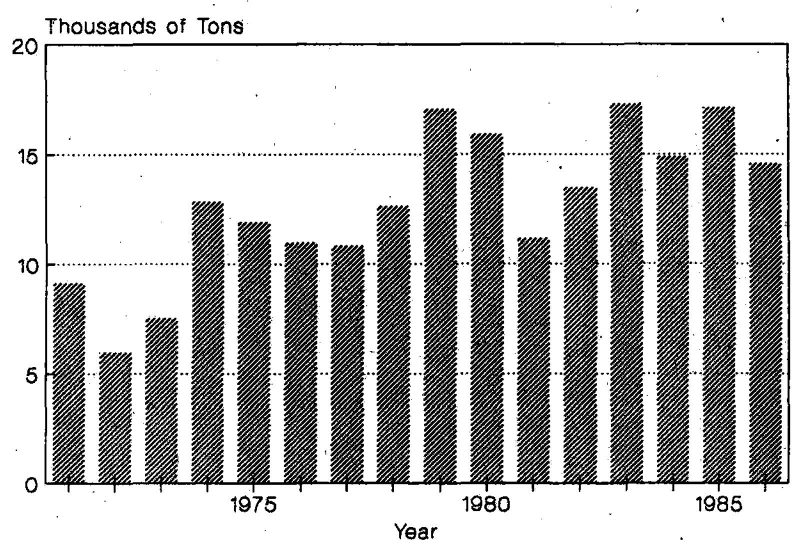


Reference: WDF, 1988

years, and Pacific cod appear to be declining in abundance in central Puget Sound (Bargmann, 1988b).

The commercial catch of groundfish has followed a fluctuating upward trend since the 1920s (catch since 1971 is shown in Figure 3-9). English sole is the dominant species in this group. Much of the recent increase in catch of English sole is attributed to increased fishing effort. However, catch per unit of effort (an indirect measure of population status) is declining in most areas of the Sound (Bargmann, 1988b). This decline is greatest in central Sound, a possible indication that overfish-

Figure 3-9: COMMERCIAL LANDINGS OF GROUNDFISH IN PUGET SOUND



Reference: WDF, 1988

ing or some other detrimental factor such as contamination may be occurring in this area (Quinnel, 1984). The total commercial groundfish harvest was valued at $2.13 million in 1986 (Table 3-7). This represents a decline from a value of $3.6 million in 1984 (PSWQA, 1986b).

Shellfish and other species

Shellfish captured in commercial fisheries in Puget Sound include geoducks, scallops, octopus, squid, crabs, and shrimp. Sea cucumbers and sea urchins are also captured commercially in the Sound. Total commercial landings of all shellfish in Puget Sound were estimated to be 8,426 tons (7,644 metric tons) of processed meat weight in 1986 (Table 3-7; WDF, 1988); about half of this total was represented by aquaculture production (see following section and Table 3-8).

Harvest of extensive subtidal beds of geoducks is regulated by WDF. Production is limited to a maximum harvest of 2,500 tons (2,265 metric tons) a year on subtidal tracts put up for bid by the Washington Department of Natural Resources (DNR) but only 1,400 tons (1,270 metric tons) were harvested in 1986 (WDF, 1988). Scallops, blue mussels, octopus, and squid are also harvested. Puget Sound crab (Figure 3-10) and shrimp are important commercially as a capture fishery. Most shrimp come from southern Hood Canal where there is a stable population. The harvest of nontraditional marine resources such as squid, sea cucumbers, sea urchins, and marine algae is increasing in Puget Sound (Figure 3-11). This represents a change in American eating habits as well as increasing exportation to foreign markets (sea urchins are shipped to Japan). These catches are likely to increase over time.

Aquaculture

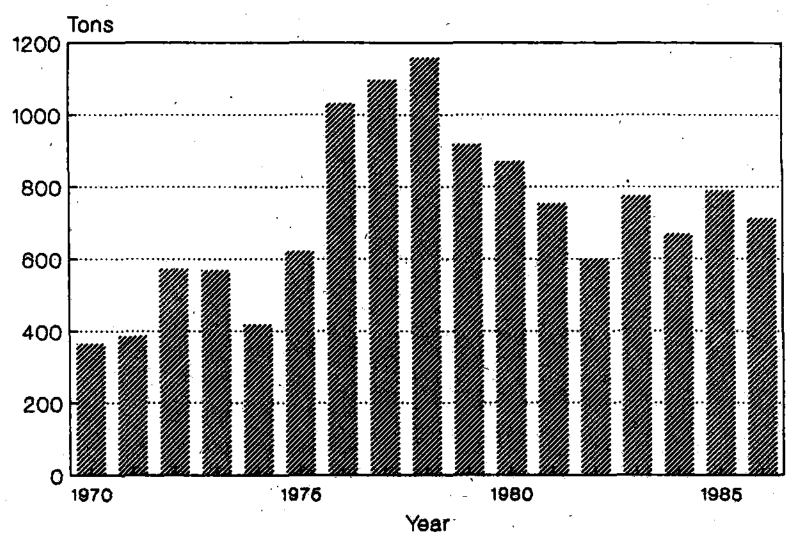
Aquaculture in the state of Washington involves the controlled cultivation and harvest of aquatic animals and plants such as shellfish, finfish, and edible "sea vegetables" (marine algae). This industry utilizes a number of different production methods to produce a wide variety of species. Methods include tideland cultivation,

TABLE 3-8: PUGET SOUND AQUACULTURE PRODUCTION, 1986

Species	Processed Weight (tons)	Reported Value ($1,000)
Oysters, Pacific	1,730.37	4,395.14
Oysters, Olympia & edulis	6.43	219.40
Oyster, seed	--	156.95
Clams, manila	1,791.04	3,367.16
Clams, other	692.36	873.64
Mussels	148.66	349.41
Chinook salmon, eggs	0.66	32.76
Chum salmon, eggs	0.18	7.35
Coho salmon, adults & eggs	1,211.72	3,960.61
Atlantic salmon, adults & juveniles	14.73	348.30
Steelhead, trout, adults, juveniles & eggs	186.92	2,118.36
TOTAL	5,783.07	15,829.08

(Reference: WDF, 1987)

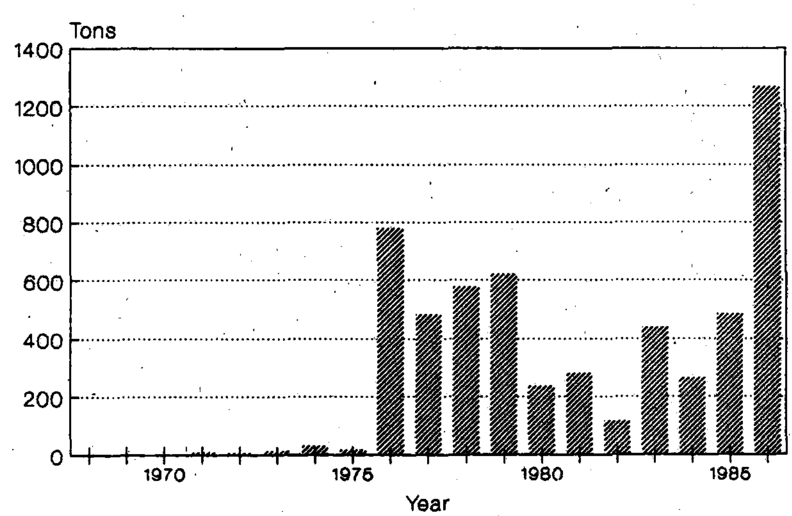
Figure 3-10: COMMERCIAL LANDINGS OF CRABS IN PUGET SOUND



Reference: WDF, 1988

off-bottom culture (for oysters) open water suspension, net pen rearing, and pond or tank culture. In 1986 state aquaculture production in processed weight totalled 8,412.2 tons (7,630 metric tons) with an estimated reported value of $22.7 million (WDF, 1987). Table 3-8 shows the total 1986 aquaculture production in Puget Sound which had a reported value of $15.8 million (WDF, 1987). Pacific oyster production accounted for about 30 percent of this value, while coho salmon and manila clams were also important. Other species with the economic potential to be-

Figure 3-11: COMMERCIAL LANDINGS OF SEA CUCUMBER, SEA URCHIN, & SQUID IN PUGET SOUND



Reference: WDF, 1988

come viable aquaculture industries include nori (an edible seaweed), geoduck, and sturgeon.

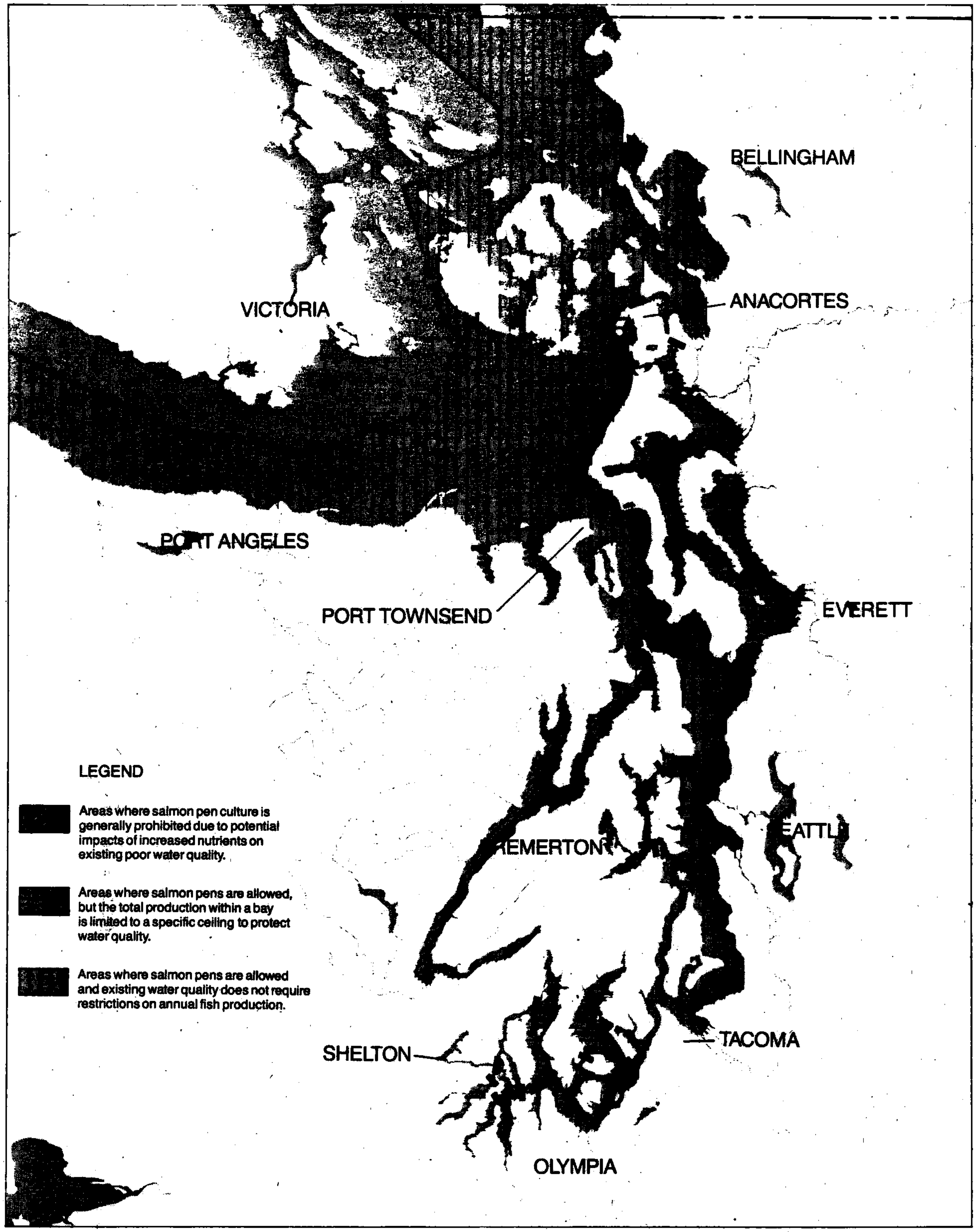
Although the aquaculture industry represents only a small proportion of all the income-generating industries in the Puget Sound area, it is an important industry in several of the more rural counties surrounding the Sound. For example, shellfish growers in Mason County are the third largest employer. They harvested $7 million worth of clams and oysters in 1985 (Wolf et al., 1987). The industry provides an opportunity for sustainable long-term growth in these counties, several of which are currently economically distressed. However, there is substantial public controversy over some aspects of the industry, particularly over the floating culture of salmon, shellfish, and nori.

There are 12 salmon net-pen facilities operating in Puget Sound in 1988, located in Clallam, Kitsap, Mason, Jefferson, and Skagit Counties. Two more facilities are in the construction phase and 12 more are actively seeking permits to begin development in Clallam, Island, Jefferson, and Mason Counties (Pitts, 1988, pers. comm.). Opposition to the siting of these aquaculture facilities has focused on potential conflicts with boating, fishing, and aesthetic values (such as residential views). Other concerns are related to the potential effects on water quality and bottom organisms. There have been some additional questions about the introduction of disease and competition with natural fishery stocks. There is little evidence that wild fish stocks have been adversely affected by diseases introduced from aquaculture operations, and WDF has strict guidelines for disease control. Four counties (Island, Jefferson, San Juan, and Skagit) have instituted temporary moratoria on facility siting until these and other concerns can be resolved.

A recent study of the environmental (physical, chemical, and biological) effects of salmon net-pens found that the only potentially adverse effect which has a high probability of occurring is the accumulation of organic-rich sediments beneath the pens. Sediment accumulation can consequently reduce the oxygen available for bottom-dwelling organisms as well as change the bottom community to species that are more tolerant of organic enrichment (e.g., polychaete worms; Weston, 1986a). All other quantifiable potential effects associated with salmon net-pens (e.g., effects on water circulation, water quality, phytoplankton productivity, and the introduction of exotic species) are less probable and highly dependent upon site-specific conditions or the species cultured (Weston, 1986a). The study did not attempt to quantify the use conflicts or aesthetic effects potentially associated with net-pen aquaculture in Puget Sound.

The Washington Department of Ecology (Ecology), in conjunction with the Washington Department of Agriculture (WSDA), WDF, and DNR, has released interim guidelines for the siting of salmon net-pen facilities in Puget Sound (Weston, 1986b). The guidelines require minimum amounts of current, depth, and horizontal separation from significant bottom habitats, and restrict salmon production in 19 Puget Sound sub-basins to eliminate potential nutrient enrichment problems. Adverse physical, chemical, and biological effects may be minimized or eliminated if these and other siting guidelines (e.g., EDAW, Inc. and CH_2M Hill, Inc., 1986) are followed (Inveen, 1987). Areas where aquaculture is limited because of water quality concerns are shown in Figure 3-12.

Another issue which involves all forms of aquaculture is the question of whether counties or the state should have the primary regulatory responsibility for the siting and development of aquaculture facilities. For example, Jefferson and San Juan Counties are developing shoreline master program amendments in 1988 that specifically address aquaculture (Pitts, 1988, pers. comm).



Reference: Weston, 1986b

Figure 3-12

AREAS WHERE AQUACULTURE IS LIMITED BECAUSE OF WATER QUALITY CONCERNS

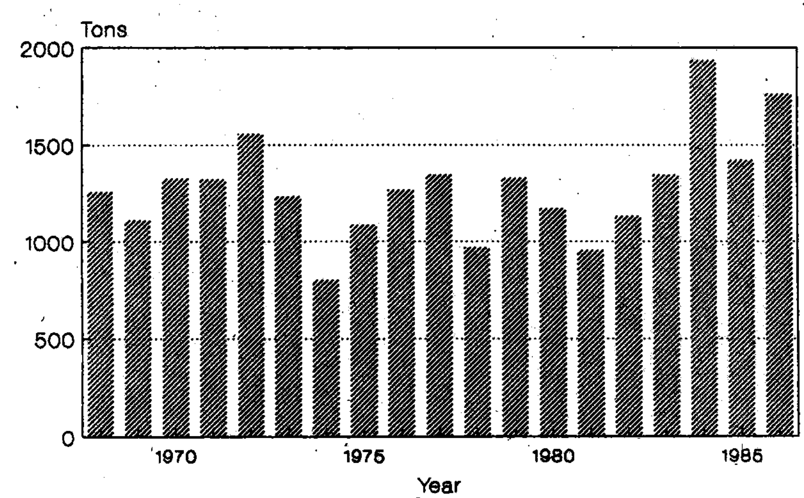
WDF is currently preparing a programmatic environmental impact statement (EIS) for salmon net-pen culture to improve the level of knowledge, evaluate impacts, and develop mitigation measures which might reduce potential conflicts associated with the siting of net-pen facilities. The draft EIS is scheduled to be released in December 1988. Opposition to nori culture operations (such as those proposed near Guemes Island and in Burrows Bay, Skagit County) has focused primarily on potential hazards to recreational boating and commercial fishing, interference with recreational and commercial crabbing, and interference with views. In October 1987 DNR released a programmatic EIS for nori culture which addresses these concerns and provides guidance for the siting of nori and other sea vegetable operations (DNR, 1987b).

Shellfish

Shellfish species cultivated in aquaculture operations include the bivalve oysters (Pacific, Olympia, and edulis), clams (manila, native littleneck, softshell, horse, and butter), and mussels. Natural population abundances of bivalves may be influenced by human activities because their immobility makes them relatively easy to cultivate. For example, commercial oyster growers typically "seed" stocks by adding human-cultivated young oysters to the population. Thus, most of their harvest is not of natural stock. Commercial Pacific oyster planting and harvesting have been fairly stable over time, probably due to the transplanting of seed oysters in commercial beds. Increasing yields in the period from 1980 to 1986 (Figure 3-13) may have resulted from the better setting of young oysters. Aquaculture production of Pacific oysters in Puget Sound generated 1,730 tons (1,570 metric tons) of processed meat with a reported value of $4.4 million dollars in 1986 (Table 3-8). Recent research in genetics may increase the marketability of oysters during summer months. Oysters collected in the summer are normally not as palatable because the natural spawning activity that occurs at this time tends to soften their flesh. However, scientists have produced "sexless" oysters that do not spawn, and therefore have firm flesh throughout the year.

The necessity of clean water to maintain existing natural populations and for future growth of the oyster aquaculture industry cannot be overstated. Certain historically

Figure 3-13: COMMERCIAL LANDINGS * OF PACIFIC OYSTERS IN PUGET SOUND

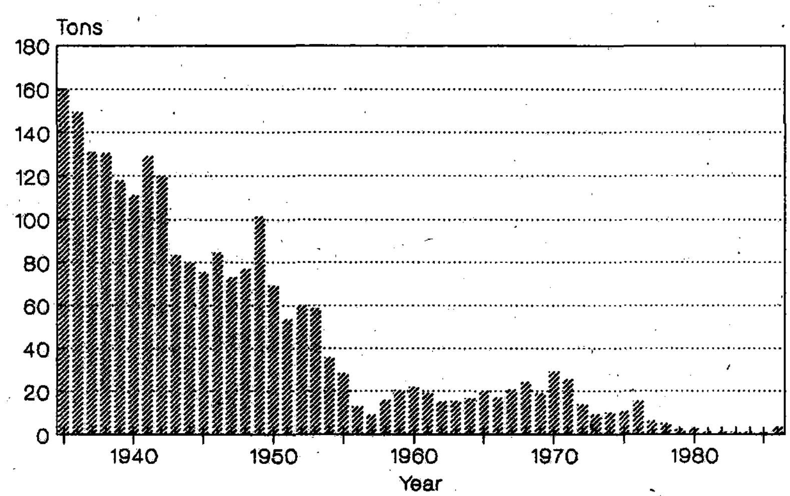


* Values include capture fishery as well as aquaculture production.
Reference: WDF, 1988

productive areas in Puget Sound have been taken out of production due to fecal coliform bacteria in the water and other forms of pollution. This increasingly serious problem is discussed in more detail in Chapter 4 of this report.

Commercial production of native (Olympia) oysters has decreased from 1935 to the 1980s (Figure 3-14). Pollution in south Puget Sound from pulp mill wastes is thought to have played a major role in the decline. Further impacts from overharvest and predation (from flatworms and oyster drills which were introduced with Pacific oyster seed from Japan) nearly caused the oyster to become extinct. However, the oyster's recent comeback has been assisted by improved water quality (e.g., decreased biochemical oxygen demand (BOD)), improved management of the aquaculture industry, improved hatchery technology, increased research, good sets of hatchery-raised young oysters in 1985, and a favorable market that encouraged increased development of aquaculture operations in the south Sound. In 1986 7,457 pounds (3,380 kilograms) of Olympia oysters (with a reported value of $167,364) were harvested by aquaculture operations in Puget Sound (WDF, 1987).

Figure 3-14: COMMERCIAL LANDINGS *
OF OLYMPIA OYSTERS IN PUGET SOUND



* Values include capture fishery as well as aquaculture production.
Reference: WDF, 1988

Aquaculture clam fisheries primarily consist of manila and native littleneck clams. In the 1930s and 1940s hardshell production was exclusively native littlenecks. Manilas were accidentally introduced into the state's water along with oyster seed from Japan in the mid-1930s. Conditions in Puget Sound are similar enough to those in the manila clam's native Japan that they began populating intertidal beaches in the south Sound in the 1950s. Manila clams are now by far the most important commercial hardshell clam in the steamer clam market. An estimated shell weight of 1,791 tons (1,624 metric tons) of manila clams (with a reported value of $3.4 million) were produced by Puget Sound aquaculture facilities in 1986 (Table 3-8).

Finfish

The aquaculture production of finfish in Puget Sound involves the cultivation of chinook, chum, coho, and Atlantic salmon and steelhead trout. In 1986 finfish aquaculture production in the Sound totalled 1,414 tons (1,282 metric tons) with a reported value of $6.5 million (Table 3-8). Much of this production was of market size coho salmon, although Atlantic salmon production is increasing in the Sound. Aquaculture operations produce not only market-size adult fish but also juvenile fish and eggs.

Sea vegetables

The aquaculture production of sea vegetables such as the marine algae nori is increasing in Puget Sound. Nori is most commonly used in making sushi, a popular Japanese food. At least 15 species of nori are native to the marine waters of the state. Two private sector nori farms are currently operating in Puget Sound (one near Vashon Island and the other near Johns Island in San Juan County). Other sea vegetable facilities are proposed near Guemes Island and Burrows Bay.

Recreation and Aesthetic Enjoyment

The marine waters of the Puget Sound basin represent an invaluable aesthetic and recreational resource for residents and tourists alike. People have a strong desire to live near the water, and the value of this resource is reflected in the high property values of shoreline residences. The recreational use of the marine waters is also dramatic. A study completed by the Washington Interagency Committee for Outdoor Recreation (IAC) found that one-third of all outdoor recreational activities by Washington residents involved fresh- or saltwater (IAC, 1985).

Other surveys have shown that of all activities cited by in-state vacationers in 1986, sightseeing was the most popular (cited by 85.4 percent of all respondents), followed by visiting scenic areas (81.4 percent), going to a beach (58.7 percent), swimming (56.8 percent), and boating (31.4 percent). The most popular in-state vacation destination area was the western Puget Sound/Olympic Peninsula region which was visited by 27.9 percent of all 1986 vacationers (Blazey, 1987).

Recent estimates by the Washington Department of Trade and Economic Development (WDTED) indicate that resident and non-resident travelers spent $3.51 billion and created 74,620 jobs statewide in 1986 (WDTED, 1987). Seventy-eight percent of these expenditures ($2.75 billion) were made in counties bordering Puget Sound (Table 3-9). In addition, travel-generated employment accounted for 54,825 jobs in the Puget Sound region, which represented 73 percent of all travel-generated employment in the state in 1986.

Recreational boating

Saltwater recreation is clearly very important to the economy of the region. For example, a study of the recreational marine boating industry in Washington estimated that in 1986 direct and indirect boating sales generated $895 million and $2.4 billion, respectively, and provided jobs for 17,300 people statewide (Northwest Marine Trade Association, 1987; Morse and Stokes, 1987). The recreational boating industry in the Puget Sound area contributed at least 80 percent of this total (White, 1987, pers. comm.).

Recreational fishing

The popularity of recreational or sport fishing has increased over the last 15 years. Demand for water-based recreation depends on income and population. As these increase the demand for recreation in Puget Sound will increase. The value of salmon fishing to overall recreation in Puget Sound is large compared to the rest of the fishery. With over a million people fishing each year, it can be valued at from $25 million to $106 million depending on the measure of value used. The higher the species density, the more valuable the recreational experience becomes. Careful management of the fisheries will ensure that their value is retained and improved over time. The value of the 1986 sport salmon fishery was estimated at $74.56 million (Brown and Matthews, 1969; U.S. Bureau of Labor Statistics, 1986; Hoines and

TABLE 3-9: TOURIST EXPENDITURES AND TRAVEL-GENERATED EMPLOYMENT ESTIMATES BY COUNTY, 1986

County	Expenditures ($1,000,000)	Employment (Number of Jobs)
Clallam	40.0	960
Island	13.0	370
Jefferson	12.8	325
King	1,700.0	38,600
Kitsap	33.0	1,000
Mason	13.5	375
Pierce	680.0	6,550
San Juan	32.0	720
Skagit	35.0	700
Snohomish	85.0	2,200
Thurston	55.0	1,575
Whatcom	55.0	1,450
TOTAL	$2,754.3	54,825
OTHER COUNTIES	755.0	19,795
STATE TOTAL	$3,509.3	74,620

(Reference: Washington Department of Trade and Economic Development, 1987)

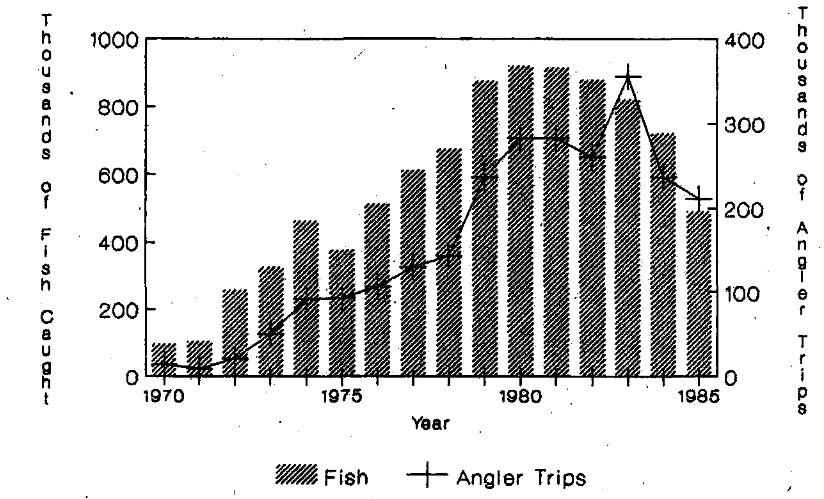
Ward, 1987; PSWQA, 1988c). Sport and commercial catches are valued differently, the sport catch being valued by the estimated amount people are willing to pay for a fishing day. This was estimated at $74.16 per fishing day for salmon and groundfish (Brown and Mathews, 1969; U.S. Bureau of Labor Statistics, 1986; Hoines and Ward, 1987; PSWQA, 1988c).

Recreational groundfish catches were estimated at 500,000 fish in 1986. This harvest was valued at $4.21 million (Table 3-7), up dramatically from a 1984 value of $1.5 million. As shown in Figure 3-15, groundfishing has grown in popularity over the last 15 years, and the total catch and number of angler trips have been fairly well correlated. In 1986 over 211,000 angler trips were spent in pursuit of groundfish in the Sound (Palsson, 1987). This does not count the number of people fishing for salmon who may have switched to groundfishing when their limit was reached. Recreational halibut fishing is also showing a marked increase in Puget Sound (Figure 3-16). Recreational fishing for rockfish has increased by nearly an order of magnitude between the mid-1970s and mid-1980s, but the catch rate (number caught per trip) declined during that time (Bargmann, 1988b). A small but popular part of the recreational groundfish catch, the sport fishery for lingcod, was closed on the inner Sound in 1978 and restricted in outer waters due to declining catches. Populations apparently rebounded sharply in the 1980s as a result of these restrictions (Bargmann, 1988b), and the fishery was reopened in 1983. Studies are currently underway to determine appropriate management measures to prevent future closures. Baitfish such as juvenile herring and smelt are also taken in a recreational fishery in the Sound.

Recreational shellfishing

Many shellfish species that are captured or cultivated commercially are also collected by recreational harvesters. Natural populations of oysters, clams, squid,

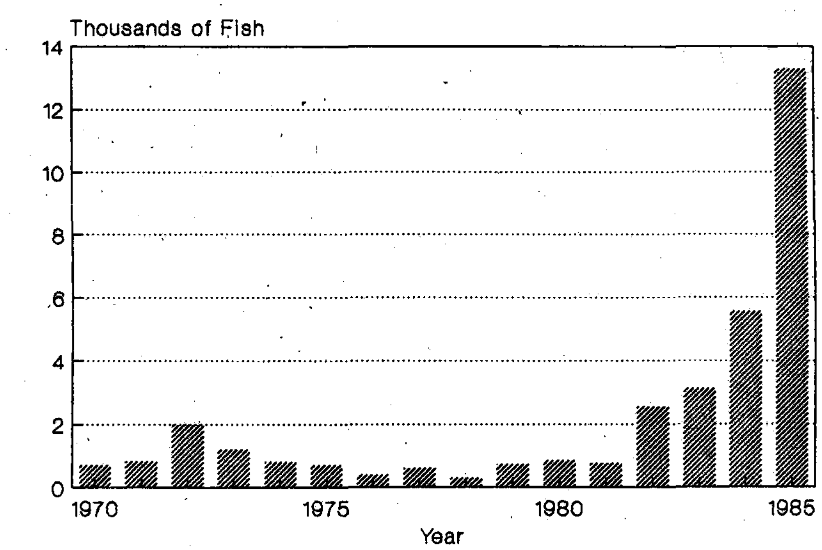
Figure 3-15: RECREATIONAL LANDINGS OF GROUNDFISH IN PUGET SOUND COMPARED TO ANGLER TRIPS



Reference: Palsson, 1987

crabs, and shrimp are some of the more popular target species around the Sound. Although they are not technically shellfish resources, sea urchins, sea cucumbers, and marine algal species such as nori are also collected in Puget Sound for human consumption. The number of recreation days spent on the Sound collecting oysters and hardshell clams has increased over 60 percent in the last 10 years (Hoines and Ward, 1987). In 1986 the recreational harvest of shellfish in Puget Sound was valued at $23.3 million (Table 3-7). The recreational clam harvest, estimated at about 1,662 tons (1,507 metric tons) shell weight in 1986, was over half the size of the total aquaculture harvest in Puget Sound (Hoines and Ward, 1987). In addition,

Figure 3-16: RECREATIONAL LANDINGS OF HALIBUT IN PUGET SOUND



Reference: Palsson, 1987

recreational shellfishers now take about 50 percent of all shrimp harvested in Puget Sound and about 30 percent of all crab (Ward, 1988, pers. comm.).

As with finfish, there is often no straightforward relationship between population abundances of shellfish species and their harvests. Populations of intertidal clams and oysters are much easier to assess than those of fish, since the animals are immobile and easily accessible. This immobility, and the fact that bivalves feed by filtering large amounts of water and particles, make natural populations highly sensitive to the impacts of contamination and other sources of environmental degradation. The state currently manages only a small percentage of tidelands for shellfish because many tidelands are privately (about 80 percent) or federally owned. However, this may change based on a recent court case (Orion Corporation v. State) that suggests that there is a difference between private ownership of tidelands and the ownership of the resources on the tidelands.

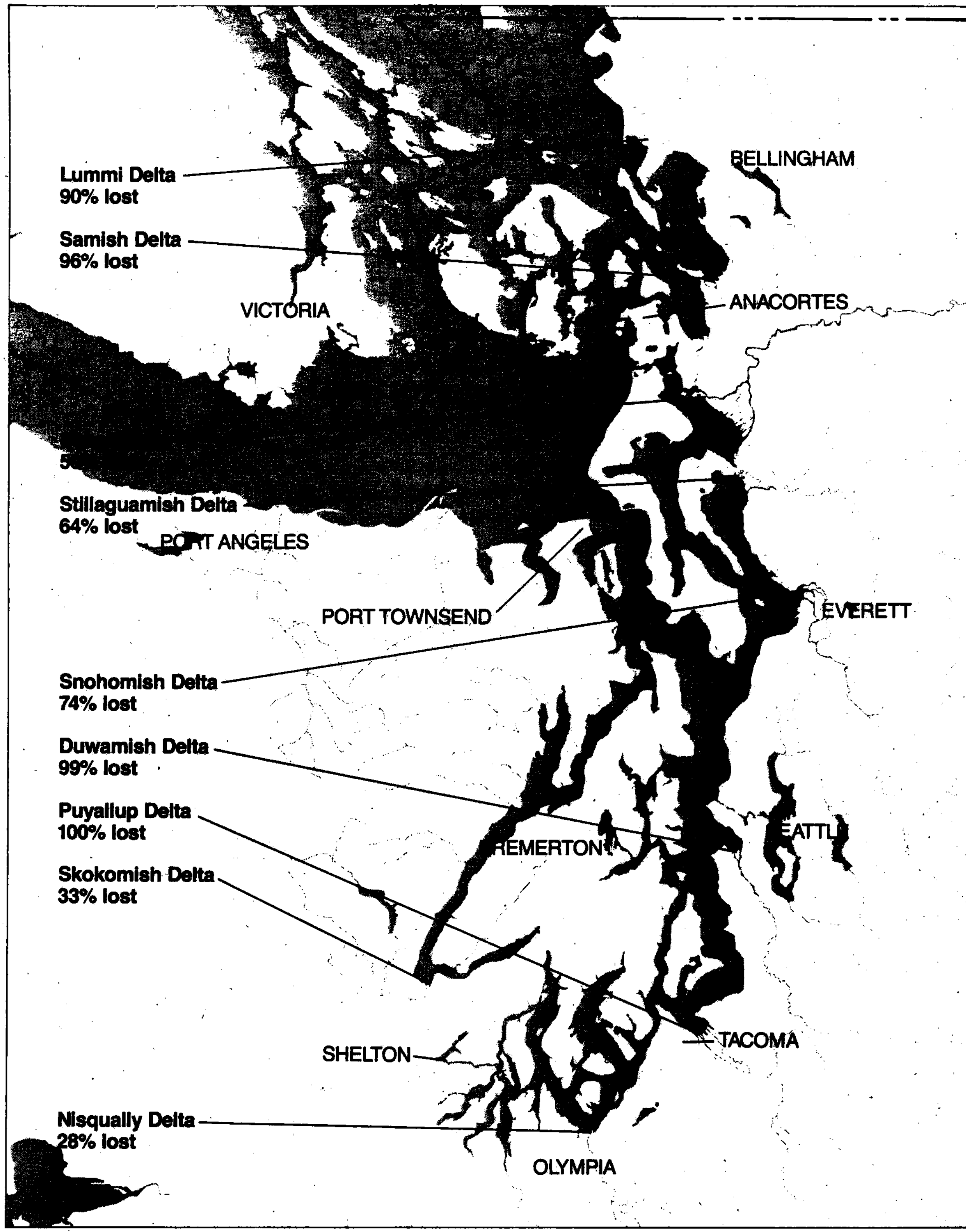
LOSS OF WETLANDS

One major environmental consequence of human activities in the Puget Sound basin has been the widespread destruction and alteration of wetlands. In the past 10 years major wetland losses in river valleys have occurred when areas have been filled or drained to create office and high-technology industrial areas, warehouses, residential development, and farmland. In addition, freshwater wetlands of western Washington have been extensively degraded or eliminated by residential development. Development activities (including multiple-unit residential construction) affect freshwater wetlands from sediment loading, contaminated runoff, altered hydrology, and loss of undisturbed buffers. Direct loss through filling is also a continuing problem. Saltwater and estuarine wetlands have also been severely affected and in many major estuaries totally eliminated by dredging, filling, and bulkheading for ports and related industrial development.

In order to make accurate estimates of wetland loss trends, it is essential to have accurate inventories of existing wetland coverage that can then be compared to historical data. Unfortunately, historical wetland data are often quite difficult to interpret from historic maps and aerial photographs, and may not be available for many areas. Bortleson et al. (1980) compared current and historical wetland areas at 11 major river deltas on the Puget Sound region and found that nearly 60 percent of the coastal wetlands present in 1800 have been converted to other land uses (Figure 3-17). However, very few other studies have evaluated long-term trends in wetland losses in the Puget Sound region.

A study to determine the present extent of wetlands within coastal areas of Washington was released in 1983 (Boule' et al., 1983). The study used existing mapped information to determine the surface area of coastal zone wetlands in 15 Washington counties that have marine waters. Another fairly comprehensive wetland inventory was completed by Kunze (1984) as part of the Washington's Natural Heritage Program (this study is discussed in more detail in Appendix B). National Wetland Inventory (NWI) maps have been completed for the Puget Sound area using more recent aerial photography. These maps improve and update the previous (1983) wetland study.

An important limitation of existing inventories, as well as of studies that look at trends in wetland conversions, is that they are often incomplete. The extent of protection afforded by existing laws and regulations is also often incomplete. Depending on their size and location, wetlands may be regulated by one or several of the following authorities: the Corps under Section 10 of the Rivers and Harbors Act and, with the U.S. Environmental Protection Agency (EPA), Section 404 of the Clean Water Act; the state of Washington under the Shoreline Management Act



Reference: Bortleson et al., 1980

Figure 3-17

LOSSES OF WETLANDS FROM MAJOR RIVER DELTAS IN THE PUGET SOUND REGION

(SMA) and/or the Hydraulic Project Code; and by local government ordinances (PSWQA, 1986a). The problem is that many wetlands are not covered under any of these jurisdictions and none of the jurisdictions protect the wetland in its entirety. For example, in 1983 76 percent of the palustrine vegetated wetlands (freshwater marshes) studied in King County were not protected by either the SMA or the Section 404 permitting process (Boule' et al., 1983). The Corps recently revised its policy and now requires a permit for the placement of dredged or fill material in isolated wetlands greater than one acre (0.4 hectare) in size. This expansion of Corps jurisdiction may help protect some of these isolated wetland systems, although protection of isolated wetlands will ultimately best be accomplished by local policies and regulations because of uncertainties with the federal program.

To better understand impacts to wetlands that fall outside the Corps or SMA jurisdictions, Ecology recently completed an analysis of the State Environmental Policy Act (SEPA) permitting process to determine how effective SEPA was at identifying and therefore minimizing potential impacts to otherwise unprotected wetlands (Hull and MacIvor, 1987). They concluded that there is insufficient regulation of isolated wetlands; that the SEPA environmental checklists are inadequate to identify wetland areas and impacts; and that there is a general lack of knowledge about wetland management at the local level. Because of these problems, it is conservatively estimated that about 530 acres (212 hectares) of unprotected freshwater wetlands are being degraded or destroyed statewide each year (Hull and MacIvor, 1987).

Under the wetland protection elements of the Puget Sound Water Quality Management Plan (W-4 and W-5; PSWQA, 1987), Ecology will develop standards designed to minimize wetland degradation and loss. The standards are scheduled for release by November 1, 1988. At that time local governments will be required to assess their wetland protection efforts against the Ecology standards, and identify and take actions which meet the minimum requirements.

In recent years regulatory agencies have recognized the importance of avoiding or at least minimizing wetland losses as well as the degradation of important wetland values. The Section 404 permitting process is designed to evaluate the public and private need for a proposed wetland fill project, the water-dependent nature of the proposed project, and whether practicable alternative (upland) sites are available. If a project meets these requirements, resulting wetland losses must be mitigated (avoided altogether or made less severe) or compensated for in some way. Wetland mitigation may take place either on-site (e.g., by redesigning to reduce impacts) or off-site (e.g., by attempting to restore, enhance, or re-create wetland habitat and values). However, U.S. Fish and Wildlife Service national mitigation policies as well as the regional mitigation policy of EPA Region 10 express a clear preference for on-site and in-kind mitigation.

Many recent projects have utilized a combination of various strategies to mitigate for unavoidable wetland loss (Good, 1987). For example, a total of 19 estuarine habitat mitigation projects that used one or more mitigation techniques (e.g., substrate modification, shoreline creation, eelgrass transplantation, and/or marsh complex formation) were either planned or implemented in six Puget Sound counties (Clallam, King, Pierce, Skagit, Snohomish, and Whatcom) in 1986. However, the success of these techniques for resource mitigation is largely unknown (Cooper, 1987).

Some mitigation projects have been successful in supporting targeted or desired plant and animal species. A 9.6-acre (3.8-hectare) wetland system was constructed in the Puyallup River estuary in 1985-86 as mitigation for the filling of a vegetated wetland area. Old fill was excavated to create an intertidal area, and appropriate wetland species were planted. The wetland now provides rearing habitat for juvenile salmonids, and at least 34 species of shorebirds and waterfowl use the site (Thom et al., 1987). A more complete description of this project is found in Appendix B. A 0.8-acre (0.3-hectare) gravel and sand mound was constructed at Terminal 25 in the East Waterway in Seattle in 1984 to mitigate for the loss of a sand-gravel intertidal beach. It now supports algae and a rich population of the bottom-dwelling animals which are important food items for juvenile salmonids (Columbia Science, 1985). In addition, WDF scientists have shown that artificial reefs can provide key habitat components for rocky habitat fish species, and thus can mitigate for the human degradation of rocky habitats in Puget Sound (Hueckel et al., 1987).

The increasing regulatory emphasis on wetland protection is slowing the net loss of wetland habitats and values. However, questions still remain about the effectiveness of mitigation projects, particularly with respect to replacement of habitat functions and values. EPA Region 10 recently assessed the effectiveness of wetland mitigation projects that were negotiated as a result of Section 404 permit requirements by examining 35 wetland creation/restoration projects in Washington. Extensive review of project files as well as site visits revealed that although wetland mitigation requirements have increased dramatically since 1982, most mitigation projects have generally not been successful at replacing the functions and values of the original wetlands that were eliminated (EPA, 1987a, b). This lack of success was attributed to two main factors: 1) resource agencies have not been successful at negotiating mitigation plans that fully compensate for loss of wetland values, nor have they required monitoring to determine whether a mitigation project is actually working; and 2) the science of wetland creation and restoration is not fully understood, so projects are often approved without knowing whether a particular technique will adequately provide the desired functions and values (EPA, 1987b). Thus, wetland mitigation projects are affected by both regulatory as well as scientific constraints.

An example of this problem is illustrated by a wetland mitigation project that has been constructed on North Creek in Bothell (King County). To mitigate for the filling of the creek bed and the surrounding wetlands, the developer rerouted the creek (which had been previously channelized), planted its banks with trees and other vegetation, and attempted to create new wetlands. The stream relocation component of this project is generally considered an improvement and a success. However, even after detailed planning and engineering, the re-created wetland system is not functioning as a wetland because it is too dry. The natural complexity of wetlands, the many different functions they perform, and the many different species they support make it very difficult to create wetlands that perform as many or even the same functions as the natural wetlands. Unfortunately, the science of wetland creation and restoration is far behind the regulatory use of these techniques (EPA, 1987a), and more research is needed before the techniques are effective at replacing lost wetland functions and values. Thus, construction within wetlands, even with mitigation, almost always results in net losses of the resource. Because of these continued losses, project alternatives should be sought which minimize or eliminate alterations of wetlands.

Another important technique for preventing the loss of valuable wetlands is protective acquisition. Both government and private/nonprofit wetland acquisition programs are active in the Puget Sound area. The Washington Natural Heritage Program in DNR was established in 1981 as an amendment to the Natural Area Preserves Act (Chapter 79.70 RCW). The program identifies and preserves outstanding natural areas and maintains a statewide inventory of natural communities, species, and features. A recent study by DNR (Kunze, 1984) evaluated the most significant coastal wetlands in the Puget Sound region for possible inclusion in the program. The Natural Heritage Program currently manages 22 natural area preserves statewide (DNR, 1987a).

The federal Emergency Wetlands Resources Act of 1986 provides new emphasis and funding for wetland preservation through federal Land and Water Conservation Fund monies. As directed by this act, IAC prepared a Wetlands Priority Plan in 1987 as an amendment to the Statewide Comprehensive Outdoor Recreation Plan (SCORP). The plan addresses the status of wetlands, protection strategies, and a criteria system that selects priority wetlands (IAC, 1987). This criteria system is to be coordinated with wetland program elements W-1 and W-2 of the Puget Sound plan.

The Nature Conservancy (a private conservation organization) acquires and manages land containing significant habitats across the country. Wetland protection is an important part of the Conservancy program. In 1987 the state legislature (Senate Bill 5911) voted to match each dollar privately raised by The Nature Conservancy with three dollars in public funds (from the real property excise tax) over the next two years. In response, the Conservancy's fund-raising goal was raised from $1 million over three years to $1.3 million over a two-year period. As of January 1988 private contributions to this wetland campaign had totalled over $1 million (The Nature Conservancy, 1988). Six native wetlands of statewide significance have already been protected by the Conservancy's wetland campaign, including an 89-acre (36-hectare) area bordering the Snoqualmie River that will become the Snoqualmie Bog Natural Area Preserve. This group is actively negotiating the purchase of more than 20 additional wetland sites throughout the state.

In response to the wetland acquisition elements of the Puget Sound plan (W-1, W-2, and W-3), particularly the requirement to take early action to acquire important wetlands already identified, $500,000 of the state Aquatic Lands Account for the 1989-91 biennium was appropriated for acquisition of Puget Sound wetlands. DNR recently allocated some of this money to Snohomish County to help buy Otter Island and other important remaining wetlands in the Snohomish River delta. Other public and private wetlands are being protected through acquisition of land, development rights, easements, and other acquisition tools.

SUMMARY AND CONCLUSIONS

The trends in population growth and economic development discussed in this chapter are critical to understanding how development activities by humans affect the water quality and biological resources of the Puget Sound area. With a current population of nearly three million people, a tremendous potential exists for the continuation and possible increase of detrimental impacts to the natural environment. One of the most important trends to examine is the rate of population growth and where most of the growth is occurring. The fastest growing areas in the state are currently the more rural counties surrounding Puget Sound--Island, San Juan, Thurston, Snohomish, and Mason Counties. Although these counties contribute relatively small proportions to the region's total population, their growth is significant because it often occurs in areas that are currently important for rural, agricultural, groundwater recharge, or open space purposes. By the year 2000, intense urban and rural non-farm land uses are projected to increase 62 and 73 percent, respectively, and in combination will constitute 15 percent of the total land use in the region (approximately double what they were in 1984). These trends are expected to continue beyond the year 2000.

The economy of the region has shifted and will continue to shift increasingly toward services, government, trade, and construction with resulting increases in commercial, office, retail, and residential land uses. Heavy industrial activities such as pulp and paper and smelting are not projected to grow significantly. However, the region continues to support a wide range of water-dependent activities, many of which are directly dependent on the good environmental quality still found in many portions of the Sound (e.g., the fisheries, aquaculture, and marine recreation industries).

One consequence of the human development trends discussed in this chapter has been the significant loss of estuarine and freshwater wetlands in the Puget Sound area. It is estimated that nearly 60 percent of the coastal wetlands in the area have been eliminated, and unprotected freshwater wetland losses continue at an estimated rate of over 500 acres (200 hectares) a year. Many development projects which affect wetlands are now required to provide mitigation and sometimes compensation, but this does not eliminate the continued loss of wetlands. Protective acquisition is an important tool to protect specific wetlands from damage. Land use regulations can effectively address human actions that affect wetland areas. Regulations provide a broader base of protection than is otherwise available through acquisition. Additional effects which result from human activities, particularly the introduction of contaminants into the Sound, are discussed in detail in the following chapter.

Chapter 4: Contamination of the Puget Sound Basin

INTRODUCTION

Puget Sound is an integrated ecosystem in which the cumulative effects of human activities can affect biological resources throughout the area. The subject of this chapter is the contamination of the water, sediments, and organisms of Puget Sound: its nature, causes, history, distribution, and consequences for the health of living resources and the health of humans using those resources.

A contaminant is a substance that is not naturally present in the environment, or is present in unnatural concentrations which can adversely affect the environment. Contamination is usually expressed in terms of concentration or the quantity of contaminant in a given amount of air, water, sediment, or animal tissue. For example, the amount of contaminant in a sample of water, sediment, or tissue can be expressed as a fraction of the sample's total weight (or volume). Because of the range of concentrations that exist and are measurable with modern equipment, and because of the ability of some substances to cause biological harm when present in tiny amounts, the magnitude of such fractions ranges from percentages (parts per hundred) to parts per million (ppm) and parts per billion (ppb). For example, seawater from Puget Sound commonly has 30 pounds of salt in each 1,000 pounds of pure water (30 parts per thousand; ppt). In a bathtubful of seawater (about 60 gallons) there would be about 15 pounds of salt. If, instead of 15 pounds of salt, one teaspoon of salt is placed in the same amount of water, the resulting concentration would be about 30 parts per million. A concentration of 30 parts per billion would result from adding less than a single grain of salt. One part per billion is equivalent to five people out of the total population of the earth.

Although concentrations of parts per billion may seem insignificant, certain compounds can be harmful to organisms at these concentrations (e.g., polychlorinated biphenyls (PCBs)). For example, humans show symptoms of mercury poisoning at levels of 20 parts per billion in their blood. If there is one part per million of oil in the water, half of the exposed Dungeness crab larvae will be killed.

CLASSES OF CONTAMINANTS

Society produces, uses, and disposes of such a tremendous variety of materials (many of which come into contact with Puget Sound) that it is impossible to discuss each in detail. However, contaminants affecting the Sound can be grouped into categories based on common properties.

Organic Chemicals

These are some of the most frequently discussed contaminants in the Sound but some of the least understood. Organic chemicals are, in general, those that contain carbon. Within this definition is an almost infinite variety of natural and synthetic (manufactured) compounds. Naturally occurring organic matter is generally not toxic, but it may cause water quality degradation if present in large amounts. For example, the decay of organic matter (including the natural remains of organisms, human sewage, and pulp mill waste) can cause a problem when it occurs on such a large scale that the bacteria consume most or all of the dissolved oxygen from the water and other organisms die of asphyxiation. In technical terms, the amount of oxygen in a water body used up by bacteria as they decompose organic matter is called the biochemical oxygen demand (BOD). Fish kills caused by oxygen depletion (e.g., BOD in excess of five to 50 milligrams per liter) were fairly common in parts of Puget Sound before cleanup measures were applied to discharges from sewage treatment plants and pulp mills in the 1960s. However, fish kills now occur infrequently in the marine waters of the Sound (Washington Department of Ecology, 1987e).

Synthetic organic chemicals include a wide variety of plastics, synthetic rubbers, pesticides, herbicides, and other substances. Many synthetic organic chemicals are known for their resistance to decomposition or breakdown (which is called persistence) and their toxicity to living organisms. Some of the most persistent and toxic of the synthetic organic chemicals contain the elements chlorine and bromine, members of a group of elements called halogens. Compounds combining halogens in organic chemicals are called halogenated hydrocarbons. For example, many insecticides (e.g., DDT) and herbicides are halogenated hydrocarbons. The PCBs are a family of toxic halogenated hydrocarbons produced as coolants and insulators for electrical components. Polycyclic aromatic hydrocarbons (PAHs) are another family of highly toxic compounds that originate mostly from the burning of natural organic compounds such as wood, coal, and oil, but are also found in unburned oil products. New synthetic compounds continue to be created and introduced into society and, ultimately, into wastewater discharges. The effects of many of these compounds (and their component parts) on the water quality and organisms of Puget Sound are largely unknown.

Inorganic Chemicals

All other chemical compounds (anything not containing carbon) are called inorganic. The inorganic chemicals that are most relevant to contamination in Puget Sound include metals such as copper, lead, zinc, chromium, cadmium, arsenic, and mercury. Low concentrations of metals are present naturally in seawater, washed there by erosion of rocks and soils on land. Also among the inorganic chemicals are some simple compounds that act as nutrients for marine plants. The primary inorganic nutrients are compounds of nitrogen (nitrates and ammonia) and phosphorus (phosphates), two of the main constituents of fertilizers. Other examples of inorganic contaminants include acids used in pulp and paper processing and alkali found in home and industrial cleaning compounds (e.g., drain cleaner).

It is difficult to determine when to categorize some inorganic chemicals as contaminants. Virtually all of them occur naturally in seawater, and several (especially the nutrients) are essential for life. However, most inorganic chemicals can be harmful when present in large enough quantities or at the wrong place or time. Copper, for example, is essential to life in very minute quantities but is toxic at higher concentrations. Also, excess nutrients can increase the natural growth of phytoplankton which rob the water of life-giving oxygen when they die and decay (causing fish kills and putrid odors). Since these substances are damaging in excess amounts, additions to the system by human activities may result in degraded water quality or harmful effects to biological resources.

Biological Contaminants

Disease-causing bacteria and viruses (pathogens) are introduced into Puget Sound by treated municipal sewage discharges, septic systems, discharges from boats, and runoff from farms, forests, and cities. These biological contaminants can cause diseases such as typhoid, cholera, salmonella, and hepatitis in humans. To protect people from potentially dangerous levels of microorganisms in the Sound, health officials have the authority to close contaminated beaches to swimming and shellfish gathering. Shellfish are good indicators of microbial contamination for the same reason that such contamination makes them unsafe to eat; they take up and concentrate microorganisms in large quantities through filter feeding. Out of perhaps thousands of species of microbes that may be introduced into the Sound by human activities, only certain species (e.g., fecal coliform bacteria) are monitored in shellfish because of costs and limitations of laboratory culture and detection techniques.

Fecal coliform bacteria originate in the intestinal tract of warm-blooded animals, including humans. They are indicators of fecal material from warm-blooded animals and, although they are not pathogenic (disease-causing) themselves, they indicate that pathogens may be present. Fecal coliform bacteria (usually measured as colonies of organisms per 100 milliliters of water) are introduced in stormwater and combined sewer overflow (CSO) discharges, by failed on-site sewage disposal systems, and by wild and domestic animals. These bacteria typically exhibit high levels of variability in the natural environment. Fecal coliform counts vary depending on a number of physical factors including water temperature, turbidity, and tidal influences. In addition, although this group of bacteria originate in warm-blooded animals, they are able to survive in the fresh and marine waters and sediments of Puget Sound. The cold temperatures of Puget Sound waters and sediments tend to enhance the potential for fecal coliform survival and possibly regrowth after the organisms are deposited in the open environment (Vasconcelos, 1988, pers. comm.). This potential for regrowth in sediments and water further complicates the process of trying to detect and eliminate original sources of these biological contaminants.

Another class of biological contaminant is the phytoplankton species *Gonyaulax catenella*. This organism produces a powerful toxin that causes paralytic shellfish poisoning (PSP) in humans who consume shellfish contaminated with *Gonyaulax*. "Blooms" of *Gonyaulax* are sometimes incorrectly called "red tides," although frequently such blooms are not visible. The occurrence and implications of biological contaminants is discussed in more detail at the end of this chapter.

Sediments and Other Particles

Particles in the water and sediments are important potential contaminants. Particles enter the Sound naturally from shorelines and rivers; they are also generated in Puget Sound by the growth of plants and animals. They contain both inorganic chemicals eroded from rock and organic chemicals extracted from soil and derived from organisms. Human activities add to the natural influx of particles. For example, road building and clearcutting of forests can increase the erosion rate from shorelines and river banks; dredging stirs up clean and dirty particles from the bottom of the Sound and redistributes them; and contaminant-laden particles are added to the Sound in sewage effluent and from urban stormwater systems. High levels of sediments can cloud the water (limiting light to plants) and smother animals or damage their gills and other sensitive tissues. Furthermore, suspended particles tend to take up certain contaminants from the water and concentrate them on the particle surfaces. Smaller particles are particularly efficient at this process. Thus, sediments in the Sound can not only be harmful, but can also act as a pathway for the transport of contaminants. Estuarine circulation in the Puget Sound basin retains most particles and the contaminants bound to them, thus preventing their transport to the ocean.

PHYSICAL, CHEMICAL, AND BIOLOGICAL PROCESSES

The transport and fate of contaminants in Puget Sound are affected by a number of complicated and interacting processes as shown in Figure 4-1 and discussed below. Contaminants that enter the Sound can be roughly grouped into those that enter in the dissolved state and those that enter bound to particles. Contaminants can undergo complex and varied physical and biological transformations that are largely dependent on their chemical properties (such as their water solubility) before they eventually end up in their final resting place. Some are immediately concentrated in the surface layer; some remain in solution and are dispersed and diluted in the Sound; some immediately settle out into the sediments; and some are transported far out in the Sound before settling out.

Transport and Transformation

Certain contaminants that enter Puget Sound are transported to depositional areas (called sinks) where they accumulate, while others are flushed out of the Puget Sound basin. The chemical and physical properties of contaminants strongly influence how they are transported and where they eventually end up (their fate). The environmental behavior of contaminants is complex because contaminants (particularly metals) can occur in numerous forms with different chemical properties. Important environmental processes that govern the fate of different contaminants in the Sound are: the physical and chemical interactions of contaminants with seawater and the particles it contains; transportation of contaminants by moving water and particles; chemical transformations of contaminants in seawater, sediments, and organisms; and the physical "packaging" of contaminants in the fecal pellets of pelagic organisms which can accelerate their deposition to the bottom of the Sound. Figure 4-1 illustrates some of the more important and better understood pathways and sinks for contaminants in Puget Sound.

Solubility

One of the most important factors affecting the fate of a contaminant entering the Sound is how easily it dissolves in seawater. The more soluble a contaminant, the longer it remains within the waters of the Sound where its fate is determined mainly by currents. As it enters the Sound, water containing dissolved contaminants is rapidly diluted by mixing and dispersed throughout the Sound. After being transported part way out of the Sound and then back again, dissolved contaminants may eventually travel into oceanic waters. Some of the more soluble contaminants are the nutrients in sewage effluent and phenolic organic compounds in wastes from pulp and paper mills. Dissolved contaminants can enter the Sound through rivers, surface runoff, municipal or industrial discharges, atmospheric deposition, or the ocean.

Particle Binding and Transport

Some dissolved contaminants can chemically bind or adhere to particles by a process known as sorption. Sorption tends to occur more on fine-grained sediments (silts or muds) than on coarse, sandy sediments mostly because smaller particles have proportionally greater surface areas than larger sediment particles. Fine organic particles suspended in water have a high sorption capacity, especially for dissolved organic contaminants. In addition, dissolved metals can combine with other dissolved inorganic substances to form insoluble particles that settle out of the

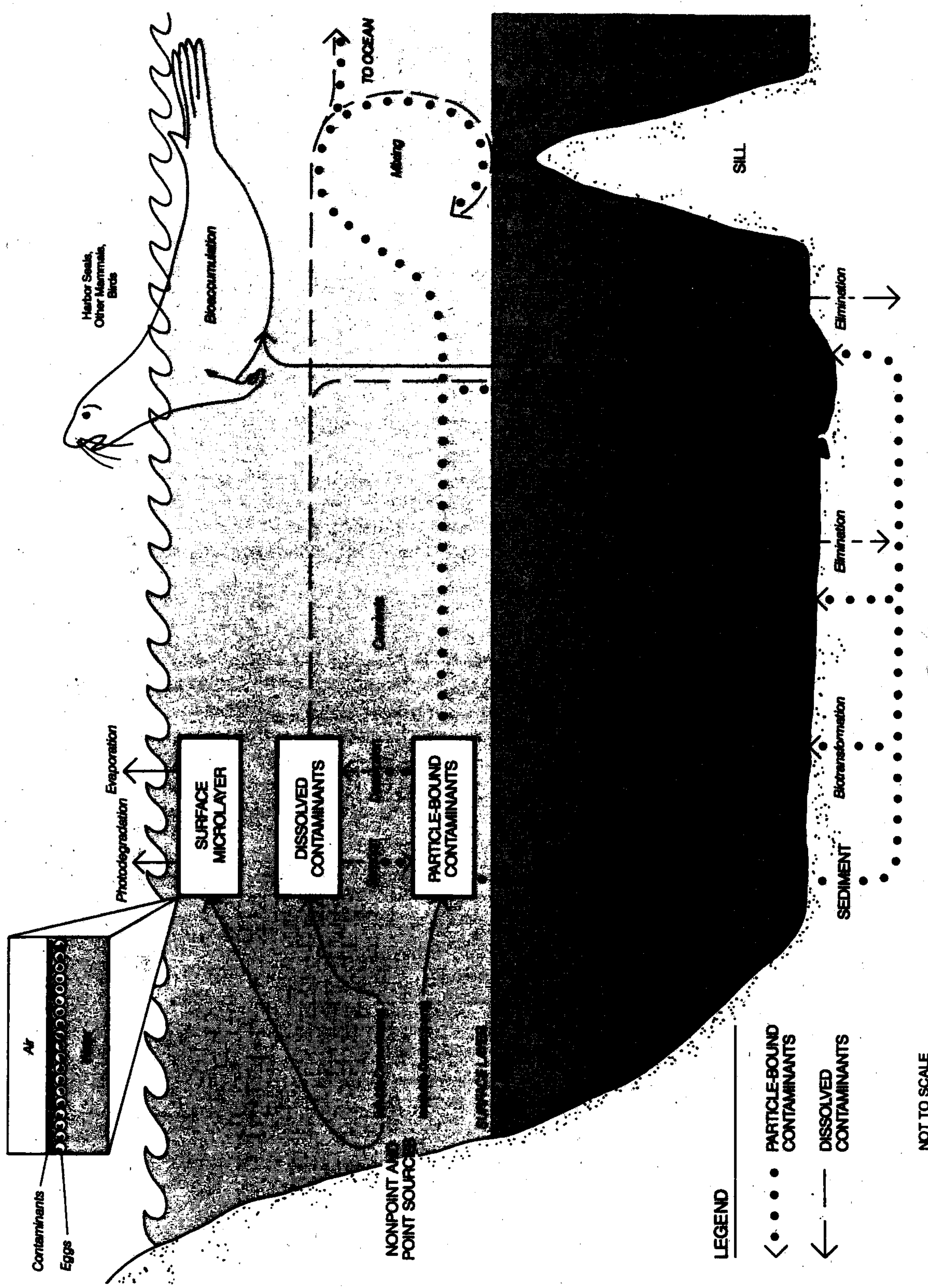


Figure 4-1

GENERALIZED TRANSPORT AND FATES OF CONTAMINANTS IN PUGET SOUND water. Many of the contaminants that enter the Sound are poorly soluble and have a much greater affinity for particles (especially organic particles) than for water. Relatively insoluble contaminants such as PCBs and PAHs are predominantly associated with fine-grained particles that have a high content of organic matter. Bacteria in Puget Sound also adhere to organic particles as a source of nutrition.

The fates of contaminants bound to particles are very different from those of dissolved contaminants (Figure 4-1). Particles suspended in Puget Sound water are constantly settling under the force of gravity. Where they settle depends on their size and density and on the strength and direction of currents, but they are rarely transported as far as those that are dissolved. Because contaminated particles do not spread as far from sources as contaminated water does, the habitat degradation caused by particles is more localized but usually more intense. Contaminants in sediments can be up to a thousand times more concentrated than those dissolved in the water. The result is the formation of "hot spots" (or areas of high contamination) of toxic sediments near sources of contamination. The urbanized bays of Puget Sound are especially prone to becoming "hot spots" for a number of reasons. Industrial sources tend to be congregated in urban bays; contaminant-laden rivers discharge into several urban embayments in the Sound; and several physical processes effectively trap particles and their associated contaminants within these bays. For example, when fine organically enriched particles in river water contact seawater, they tend to adhere to one another and settle more rapidly (a process known as flocculation).

Resuspension and Dissolution

Bottom sediments can be a source as well as a burial place of contaminants. For example, sediments and associated contaminants can be stirred up (resuspended) into overlying water by strong currents driven by wind, ship traffic (in shallow waterways), dredging operations, or even by organisms actively burrowing and feeding in the sediments (a process called bioturbation; Figure 4-1). During resuspension, particle-bound contaminants can be transferred back into the dissolved state or redissolved. Redissolution tends to affect metals more than PCBs or PAHs because of their respective chemical properties.

Spills

In contrast to the steady long-term flow of low levels of contaminants from various sources around the Sound, large amounts have been spilled in small areas by occasional accidents or historic dumping practices. Oil spills provide a good example of how physical processes affect the fates of contaminants. Oil is a complex mixture of many organic compounds. A small fraction of the compounds in crude oil will dissolve in water. The other compounds float on the water's surface, evaporate into the atmosphere (the lighter fractions), or clump into tar balls that sink to the bottom (the heavier fractions). Portions of all the fractions adhere to particles which eventually sink to the bottom. Spills of raw sewage follow a similar pattern: some "floatables" such as oil and grease rise to the surface, other components such as nutrients dissolve in the water, and the remaining insoluble fractions (including particles) eventually sink to the bottom.

Bioaccumulation

The uptake and retention by animals of chemical contaminants obtained from food, water, or sediments is called bioaccumulation. The compounds most readily bioaccumulated from water are those with the lowest water solubilities such as complex PCBs and DDT. Since these compounds are highly soluble in fats and oils, they are readily stored in the fatty tissues of organisms including the liver and muscles. Contaminants can be bioaccumulated from both sediment and water. Bottom-dwelling organisms (such as worms and clams) that feed on sediments are particularly susceptible to this kind of uptake. In addition, new evidence suggests that groundfish can directly take up contaminants from the sediments through their skin (Stein et al., 1987). In this way, bottom sediments, usually considered a sink for contaminants, can also be a source of contaminants to animals. Bioaccumulation also occurs when contaminated organisms are eaten by another organism. This is a particularly critical process for animals that are higher on the food web such as fish and seals.

Biotransformation

The chemical alteration of a contaminant by an organism, called biotransformation, can sometimes make a contaminant more toxic. The complete breakdown of an organic compound to simple chemical compounds (e.g., water and carbon dioxide) is called biodegradation. Metals are chemical elements and cannot be broken down, but many (e.g., mercury, lead, and arsenic) can be biotransformed into more complex compounds.

Estuarine organisms have widely varying abilities to chemically transform contaminants. Bacteria, which are widely distributed in the water column and in sediments, are generally effective at transforming and degrading contaminants. They can degrade some of the simpler PAHs and PCBs but are largely ineffective at transforming or degrading the more complex forms. Bacteria cannot degrade metals, but they can transform some metals by bonding them to small organic molecules. The resulting organometallic (organic and metallic) compounds can be far more toxic and easy to bioaccumulate than the metals in elemental form (especially in the case of mercury).

Higher organisms also have some ability to chemically transform contaminants, and this chemical transformation can increase or decrease the toxicity of the contaminant. For example, the digestive systems of fish can biotransform contaminants such as PAHs and produce highly toxic metabolites or breakdown products that are even more toxic than the original compound. Clams and oysters have less of this ability and thus have a greater tendency to bioaccumulate. Fish, clams, and other marine organisms have a very limited ability to transform or degrade PCBs. Thus, PCBs, which are readily taken up, tend to accumulate in these animals over time. Organisms have several ways of releasing contaminants and their transformed byproducts back into the environment (Figure 4-1). Bottom-dwelling organisms that feed on sediments (e.g., polychaete worms) release non-bioaccumulated contaminants as fecal material.

Biotransformed compounds released into the environment are seldom measured in environmental studies because they are numerous and difficult to detect in the laboratory. In addition, because biological and geochemical processes can transform compounds in the sediments, it is very difficult to trace contaminants back to their original sources. It is also difficult to predict the toxicity of compounds just based on source effluent bioassays because the toxic characteristics of compounds may increase (or decrease) in the natural environment due to transformation.

SOURCES AND LOADINGS OF CONTAMINANTS

The sources of contaminants reaching Puget Sound are varied. Each contaminant can reach the Sound by several different routes, and each type of source can carry many different contaminants. The total amount of a contaminant that reaches the Sound is called the "loading" of the contaminant. Loading is calculated by multiplying the concentration of the contaminant by the volume released. For example, if a river carries a contaminant at a concentration of one part per billion and that river flows at a rate of one cubic kilometer per year (about the flow of the Skagit River), the loading from that river is about one ton (907 kilograms) of contaminant per year. The main sources and loadings of contaminants in Puget Sound are discussed below.

Point Sources

A point source is one that discharges contaminants to the water at a single point of conveyance such as a pipe, trough, or slough, even if that pipe carries an accumulation of waste products from a broad area and from many different original sources. That is, the waste pipe from a single factory is a point source, and so is the effluent pipe from a sewage treatment plant that collects the waste from many square miles of homes, factories, businesses, roads, and parks. Combined sewer overflows and storm drain pipes are now treated as point sources by the regulations, although contamination in stormwater is normally caused by nonpoint sources such as oil from streets and parking lots, spilled products washed from industrial yards, or airborne contaminants that settle out.

The institutional and regulatory framework for controlling point source discharges is quite complicated, as discussed in the *Industrial and Municipal Discharges Issue Paper* (PSWQA, 1986c) prepared by the Puget Sound Water Quality Authority (Authority). These discharges are permitted under the federal National Pollutant Discharge Elimination System (NPDES) which is administered by the Washington Department of Ecology. NPDES permits generally specify maximum amounts of certain contaminants (e.g., fecal coliform bacteria, suspended solids, BOD, some metals, and occasionally some organic toxicants) that can be discharged, and permit holders are required to monitor concentrations of at least some of these contaminants in their discharges. NPDES permits for municipal treatment plants and industrial discharges are categorized into "major" and "minor" discharges. Major dischargers are generally those that discharge flows greater than one million gallons per day (MGD) and that are designated as major by agreement between the state Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA; Springer, 1988, pers. comm.). Table 4-1 lists all major municipal and industrial point sources that discharge directly into Puget Sound. There are more than 700 active municipal and industrial NPDES permits in the Puget Sound basin, and of these, approximately 70 percent are for industrial facilities (PSWQA, 1986c). The majority of these permitted industrial facilities are categorized as minor discharges by EPA based on an assessment of the volume and toxicity of their wastewater. Major industrial discharges are those that receive 80 or more points on a rating system devised by the EPA to categorize industrial discharges. Industries may be listed as major dischargers based on their past history of permit compliance or if the discharge has the potential for significant effects on environmental water quality (Kawabata, 1988, pers. comm.).

Major weaknesses of the regulatory program for point source discharges include: discharge permits have typically included effluent limits for only a few contaminants (usually conventional pollutants) with few limits placed on toxicants; there have been limited requirements for monitoring receiving water or conducting bioassays; there has been no system to verify the accuracy of lab analyses of monitoring samples; inspections have been relatively infrequent; and there is no systematic program for detecting unpermitted (illegal) discharges, particularly outside of the urban bays. Many of these problems have been caused by chronic underfunding and understaffing of the program in Ecology.

In the last two years, a number of events have occurred that promise improvements in these areas. In early 1987 the U.S. Congress passed the Water Quality Act of 1987 which makes general improvements throughout the point source program. Among the changes are restrictions on weakening permit conditions (backsliding), stricter civil and criminal penalties for violations (including felony-level penalties

TABLE 4-1: MUNICIPALITIES AND INDUSTRIES WITH MAJOR[1] DISCHARGES IN THE PUGET SOUND AREA

Source	Facility Type[2]	Discharge to	Design Flow (MGD)[3]	BOD lbs/D	TSS lbs/D
Anacortes, city of	Sewer system, M/P	Guemes Channel	1.0	2,000	2,000
ARCO Cherry Point	Petro. refin., I	Strait of Georgia	2.60	--	--
Bellingham, city of	Sewer system, M/P	Bellingham Bay	10.4	--	--
Boise Cascade, Steilacoom	Paper mill, I	Chambers Creek & P.S.	4.30	--	--
Bremerton, city of	Sewer system, M/S	Sinclair Inlet	<1	18,100	22,600
Central Kitsap County Plant	Sewer system, M/S	Port Orchard Bay	4.80	10,700	13,400
Chambers Cr. STP	Conv act sludge, M/S	Puget Sound	12.00	24,240	30,300
Des Moines Sewer District	Sewer system, M/P	P.S.-East Passage	4.32	4,938	10,000
Edmonds, city of	Sewer system, M/P	Puget Sound	7.00	0	0
Enumclaw, city of	Sewer system, M/S	White River	1.75	1,800	1,800
Everett, city of	Sewer system, M/S	Snohomish River	10.60	12,000	0
Georgia-Pacific Corp.	Paperboard mill, I	Bellingham Bay	--	--	--
Intalco Aluminum	Alum. smelter, I	Strait of Georgia	0.03	--	--
ITT Rayonier, Port Angeles	Pulp mill, I/S	Pt. Angeles Hbr. & St. of Juan De Fuca	--	--	--
James River Corp.	Paper mill, I	St. of Juan de Fuca	6.80	--	--
Kaiser Aluminum	Aluminum, I	Hylebos Waterway	1.53	--	--
Lakota Water and Sewer District	Sewer system, M/P	P.S.-Dumas Bay	4.70	6,121	4,831
Lynnwood, city of	Sewer system, M/P	Browns Bay	4.50	0	0
Marine Power & Equipment	Shipyard, I	Duwamish River	--	--	--
Marine Power & Equipment	Shipyard, I	Lake Union	--	--	--
Metro, Alki	Sewer system, M/P	P.S.-Central basin	7.10	3,516	3,200
Metro, Carkeek Pk.	Sewer system, M/P	P.S.-Central basin	3.37	2,937	2,888
Metro, Renton	Act. sludge, M/S	P.S.-Central basin	61.00	117,000	121,000
Metro, Richmond B.	Sewer system, M/P	P.S.-Central basin	1.57	1,709	2,048
Metro, West Point	Sewer system, M/P	P.S.-Central basin	141.00	151,540	268,912
Miller Creek STP	Sewer system, M/P	P.S.-Central basin	3.44	4,159	3,837
Mobil Oil Corp.	Petroleum, I	Strait of Georgia	1.38	--	--
Mount Vernon, City of	Sewer system, M/S	Skagit River	1.98	--	--
Occidental Chem. Corp.	Chemical, inorg., I	Hylebos Waterway	<1	--	--

TABLE 4-1: (CON'T.)

Source	Facility Type	Discharge to	Design Flow (MGD)	BOD lbs/D	TSS lbs/D
Olympia, city of	Act. sludge, M/S	Budd Inlet	16.30	30,300	--
Pennwalt Corporation	Chemical, I	Hylebos Waterway	12.90	--	--
Port Angeles, city of	Sewer system, M/P	St. of Juan de Fuca	4.84	--	--
Port Townsend Paper Co.	Pulp mill, I/S	Port Townsend bay	17.40	--	--
Puyallup, city of	Sewer system, M/S	Puyallup River	10.72	9,267	9,267
Redondo Water and Sewer District	Trickling filter, M/S	P.S.-Poverty Bay	2.80	2,861	2,983
Salmon Bay Steel Co.	Steel mill, I	Lake Washington	--	--	--
Salmon Creek STP	Sewer system, M/P	P.S.-Central basin	3.98	4,446	4,465
Scott Paper Co.	Pulp mill, I/S	Everett Harbor	--	--	--
Shell Oil Co.	Petroleum, I	Fidalgo Bay	2.23	--	--
Shelton, city of	Sewer system, M/S	Oakland Bay	3.30	2,187	3,609
Sonoco Products Co.	Paperboard mill, I	White River	0.40	--	--
Sound Refining Co.	Petroleum, I	Hylebos Waterway	0.07	--	--
Sumner, city of	Conv.act sludge, M/S	White River	2.62	5,800	5,200
Tacoma, city of, Central, #1	Sewer system, M/P	Puyallup River	28.50	29,750	24,750
Tacoma, city of, West, #2	Sewer system, M/P	P.S.-Tacoma Narrows	2.00	1,970	1,235
Tacoma, city of, North, #3	Sewer system, M/P	Commencement Bay	10.00	2,420	1,250
Tacoma Kraft	Pulp mill, I/S	Inner Comm. Bay	32.17	--	--
Texaco Inc.	Petroleum, I	Fidalgo Bay	2.57	--	--
U.S. Oil and Refining Co.	Petroleum, I	Blair Waterway	0.20	--	--
Weyerhaeuser, White River	Wood products, I	Boise Creek	--	--	--
Weyerhaeuser, Everett	Pulp mill, I/S	Snohomish River	19.40	--	--

1. Major municipal dischargers are generally defined as those that receive flow greater than 1 MGD and that are designated as major by agreement between EPA and Ecology; major industrial dischargers are generally those that receive 80 points or more on an EPA rating scale of industries. Military facilities are not included on this table.

2. M = municipal permit; I = industrial permit; P = primary treatment; S = secondary treatment

3. MGD = million gallons per day

(Reference: Ecology, 1987b)

for knowing violations), and stricter requirements for toxics controls. The act phases out the availability of federal grants for wastewater treatment plant construction but replaces grants with a revolving loan fund. The act also generally delays the national stormwater program.

The Washington legislature recently enacted several laws designed to improve the regulation of point sources. An important law was enacted in 1986 (see Chapters 70.146, 82.24, and 82.32 Revised Code of Washington; RCW) that establishes a special tax (8 cents per pack) on tobacco products to fund water quality improvement activities statewide. The account generated by this tax, called the Centennial Clean Water Fund, provides $40 million per year in the first two biennia and $45 million per year in the subsequent biennia for water quality purposes statewide. This account provides significant aid to local governments and utilities for new and upgraded pollution control facilities. At the request of the Authority a laboratory certification bill was passed in 1987 (RCW 43.21A.230-43.21A.235). It authorizes an Ecology program to certify labs used by permit holders to develop effluent monitoring data. Another bill passed in 1987 increases the ability of Ecology to charge fees for discharge permits (RCW 90.48.600-90.48.640) which will allow increased staff and funding for Ecology's point source program.

Under the Puget Sound Water Quality Management Plan, Ecology has initiated a number of actions to strengthen the point source program. These include adoption of specific numerical water quality standards for 22 toxic substances; developing a procedures manual for permit writers; increasing both routine and intensive inspections of dischargers; and providing additional staff to the pretreatment program. Improved monitoring requirements and additional staff to write permits will be added in the coming year.

Municipal treatment plants

Outfalls from municipal sewage treatment plants are significant point sources of contaminants to Puget Sound. Several levels of treatment are available for municipal wastewater. Primary treatment is a physical process of settling and skimming that removes about half of the conventional pollutants (bacteria, nutrients, BOD, and total suspended solids (TSS)) and half of the metals from wastewater (Galvin et al., 1984). Secondary treatment involves biological treatment of wastewater. Secondary treatment removes about 85 to 95 percent of conventional pollutants, three-quarters of the metals, and a variable percentage of other toxic pollutants from the wastewater (Figure 4-2). It is important to note that although treatment processes remove metals from the wastewater to varying degrees, these metals are generally transferred to the resulting treatment byproduct (sewage sludge).

There are approximately 110 municipal treatment plants in the Puget Sound basin and, of these, 25 (including Metro's West Point plant, which is the largest) are still using primary treatment (PSWQA, 1986c; Ecology, 1987b). Thirteen of these plants are expected to achieve secondary treatment by the end of 1989 (including Des Moines, Hartstene, Lakota, Langley, Manchester, Mukilteo, Penn Cove, Port Townsend, Richmond Beach (Metro), Southwest Suburban Sewer District (two plants), Steilacoom, and Tacoma (Central)). The remaining 12 plants (including those at Anacortes (two), Bellingham, Edmonds, Lynnwood, Metro (two), Port Angeles, Skagit County, and Tacoma (two)) are expected to achieve secondary treatment by the early 1990s, with the exception of the West Point plant that is expected to complete its conversion to secondary by the late 1990s. Metro has estimated that upgrading to secondary treatment at its four primary treatment plants will reduce the TSS loading to the Sound by 16,000 to 18,500 tons (14,500 to 16,800 metric tons) per year, and that the total non-volatile toxicant loading (metals and extractable organics) from these plants will decline by 100 tons (91 metric tons) per year

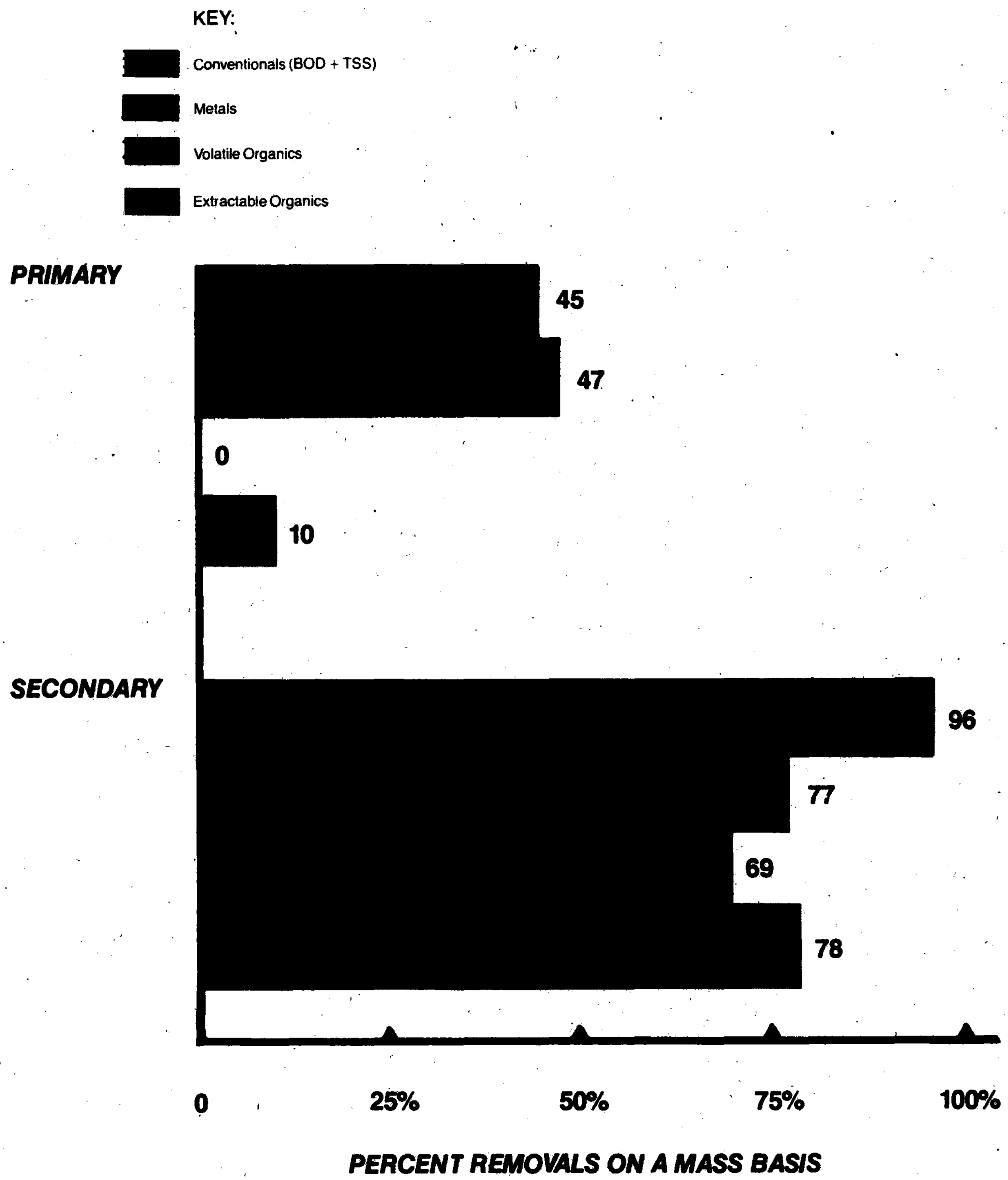


Figure 4-2

TREATMENT PROCESS PERCENT REMOVALS

Reference: Galvin et al., 1984

(Metro, 1985; Romberg, 1988, pers. comm.). Similarly, additional amounts of toxicants will be removed by secondary treatment upgrades at other municipal treatment plants in the Puget Sound basin.

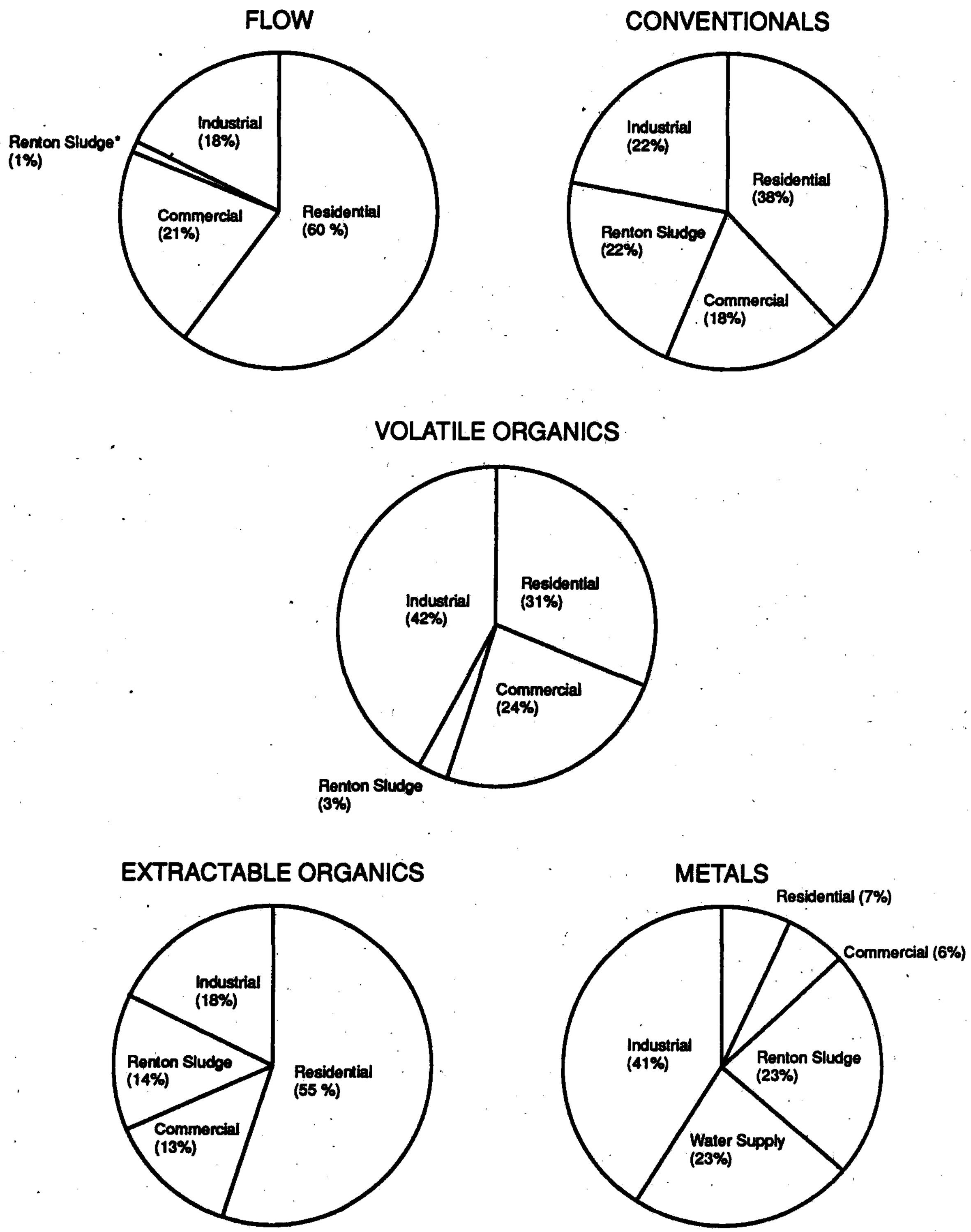
A major consequence of converting the remaining primary treatment plants to secondary treatment will be a dramatic increase in the production of municipal sewage sludge (the semi-solid matter that settles out in the treatment process). Because secondary treatment produces about twice as much sludge as does primary treatment, conversion to secondary treatment will approximately double sludge production in the Puget Sound basin in the next few years (Hope, 1986). Metro alone expects to produce 122,600 tons (111,200 metric tons) of sludge per year by 1991 (Metro, 1987).

Depending on its chemical and physical properties, sludge can be viewed either as a valuable resource or as an environmental hazard of considerable proportion. Sludge contains high levels of primary nutrients (e.g., nitrogen), but may also contain significant quantities of contaminants such as pathogens (e.g., bacteria and viruses), metals (e.g., cadmium, lead, arsenic, and mercury), and toxic organic compounds (e.g., PCBs and pesticides). Because of the potential for sludge to contain substantial concentrations of toxic contaminants, the federal Water Quality Act of 1987 has strengthened provisions for sludge management. Recycling sludge as a useful product (e.g., through land application practices) is preferred over disposing of it as a waste product (by landfilling or incineration), but beneficial reuse of sludge requires that it be relatively contaminant-free. Vigorous pretreatment programs to keep contaminants out of the wastewater and therefore out of the resulting sludge, as well as periodic monitoring of sludge quality, are required before this resource can be used to its full benefit (PSWQA, 1986c).

Contaminant loadings from municipal treatment plants vary dramatically depending on the various types of land uses serviced by any one system. Metro has developed a model to get a better idea of the relative contributions of various contaminant groups from the various land use categories (e.g., residential, commercial, and industrial). Modeling results shown on Figure 4-3 indicated that residential flows contributed 60 percent of the total flow to Metro's West Point plant, as well as significant proportions of conventional pollutants (38 percent) and extractable organics such as PAHs and plasticizers (55 percent). Commercial facilities contributed 21 percent of the flow but moderate to low percentages of the major contaminant groups. Industrial facilities represented only 18 percent of the total flow to the plant, but contributed a major proportion of the metals (41 percent) and volatile organics such as chloroform and benzene (42 percent; Galvin et al., 1984). Since this modeling effort was completed there have been several changes that could modify the results shown in Figure 4-3. Sludge from the Renton sewage treatment plant is no longer sent to West Point, and industrial pretreatment practices are now more widespread. As a result, the relative contributions from residential and commercial sources may be greater than shown.

Industrial dischargers

The second major class of point source dischargers is the industrial waste dischargers. Industries discharge their wastewater either to municipal sewage treatment plants or to their own outfalls which must be permitted under the NPDES system. Industries account for approximately one-third of the fresh water used in the Puget Sound area (U.S. Geological Survey, 1985) and are significant contributors of certain contaminants to the Sound. Over the years there have been significant improvements in the level of treatment and resulting water quality of effluents discharged by industrial point sources. For example, secondary wastewater treatment facilities constructed at major pulp mills throughout the Sound have dramatically reduced BOD loadings and resulted in improved water quality in such



*Sludge from the Renton sewage treatment plant is no longer sent to West Point.

Reference: Galvin et al., 1984

Figure 4-3

ESTIMATED SOURCES OF WASTEWATER TO WEST POINT TREATMENT PLANT, 1982

(Percent Contribution by Mass)

places as Bellingham Bay and Steilacoom. Improved water quality has also contributed to the return of oyster populations in the south Sound. However, there are still large quantities of conventional and toxic contaminants discharged into Puget Sound every day by permitted industrial dischargers, and unpermitted (illegal) dischargers are believed to contribute additional quantities of contaminants.

One way to reduce the quantity of contaminants discharged by industrial dischargers is through pretreatment. Industrial pretreatment is defined as the biological, chemical, or physical treatment of wastewater before it is discharged into the municipal sewer system. Pretreatment is useful not only in removing toxic substances in the wastewater, but also in controlling conventional pollutants that can interfere with the proper operation of a wastewater treatment plant. The pretreatment program aims to reduce the discharge of pollutants that may pass through the sewage treatment plant to contaminate the water, sludge, or air. Pretreatment also reduces the exposure of treatment plant workers or equipment to damaging substances, and the direct contamination of surface or groundwater through CSOs or leaks in the collection system (PSWQA, 1986g). Treatment of industrial wastewater at its source (particularly wastewater containing hazardous pollutants) has been found to be much more efficient than treatment of these wastes at municipal plants. This is because wastes are segregated and present in relatively concentrated forms at their source, and industrial plant operators can apply a specific treatment that will target the chemicals present in the effluent. Officially delegated industrial pretreatment programs are currently operated by Anacortes, Everett, Lynnwood, Metro (Seattle), and Tacoma.

The concept of controlling the discharge of industrial pollutants at their source has been expanded and refined by the Urban Bay Toxics Control Program that was jointly developed by EPA, Ecology, and other agencies and organizations (see Appendix B for a more complete description of this program). Source control activities (including door-to-door inspection of facilities) by action teams for Commencement Bay, Elliott Bay, and Everett Harbor have helped identify unpermitted direct discharges. For example, between October 1985 and September 1987 Commencement Bay action teams have conducted 134 site inspections, assessed seven penalties amounting to $94,000, and issued two notices of permit violation and six administrative orders for cleanup actions (Ecology, 1987d).

Combined sewer overflows

Combined sewers transport sanitary sewage from homes, businesses, and industries as well as stormwater runoff from homes, streets, parking lots, and land. Pipes in a combined system carry both sanitary sewage (dry weather flow) and stormwater (wet weather flow). When it rains the volume of water and sewage in the pipes may exceed their capacity and the overflow can be discharged (untreated) directly into lakes, streams, and the marine waters of the Sound. These overflow locations or CSOs are a significant source of contaminants. Some CSOs overflow almost every time it rains (e.g., Metro's Denny Way CSO on Elliott Bay in Seattle), while others rarely overflow (e.g., the city of Seattle's Florida Street CSO). CSOs can have significant negative effects on the water, sediments, plants, and animals around the discharge pipe. CSO discharges typically contain high levels of bacteria and contaminants, and often flow directly onto the shoreline where they are not readily dispersed or diluted. There are nearly 200 known CSOs belonging to 10 different municipalities in the Puget Sound area (Table 4-2). Little is known about the volume or frequency of discharges from most systems, or the impact of these CSOs on water and sediment quality (PSWQA, 1986d).

One CSO that has been fairly well studied is the Denny Way CSO, the largest on Puget Sound. Surveys show that elevated levels of oil and grease, BOD, heavy metals, and organic toxicants are found in sediments in the vicinity of the CSO (Romberg et al., 1987). Other studies have shown that CSO contaminants are also carried out into Elliott Bay in the surface water layer (Curl et al., 1987). In addition, species diversity (the number of different kinds of organisms) of intertidal and subtidal benthic plants and animals is reduced in the vicinity of the pipe indicating a stressed environment (Armstrong et al., 1980). Bioassays have shown that the sediments off the CSO are quite toxic (Long, 1985). Toxic sediment "hot spots" have been identified off other CSOs in Elliott Bay, so it is quite probable that some CSOs that have not been studied are having a significant effect on water and sediment quality in the Sound.

TABLE 4-2: MUNICIPALITIES IN THE PUGET SOUND AREA WHICH HAVE COMBINED SEWER OVERFLOWS (CSOs)

System	Volume (MGY)[1]	Discharge Frequency	Number of Outfalls	Discharge to
Anacortes	ND[2]	Multiple	9	Guemes Channel & Fidalgo Bay
Bellingham	ND	2/yr	2	Bellingham Bay
Bremerton	3.3*	690 hrs/yr	21	Sinclair Inlet
Everett	260*	ND	16	Port Gardner & Snohomish R.
Metro	2,400	Up to 51 events/yr	25	Elliott Bay, Duwamish R., Lake Union, & the Ship Canal
Mt. Vernon	ND	ND	2	Skagit R.
Olympia	0	1/10 yr storm event	3	Budd Inlet
Port Angeles	ND	Multiple	7	Port Angeles Harbor
Seattle	204*	ND	82	Elliott Bay, Central P.S., Lane Union, & the Ship Canal
Snohomish	ND	ND	3	Snohomish R.

1. MGY = Million gallons per year
2. ND = No Data

*Unverified estimates

(Reference: Ecology, 1987c; PSWQA, 1986d)

Until recently, federal and state programs virtually ignored CSOs, although some jurisdictions (e.g., Metro) have been working since the 1970s to eliminate these discharges. State legislation enacted in 1985 (RCW 90.48.480) requires Ecology to work with cities, sewer districts, and other sewer entities to achieve the "greatest reasonable reduction" (an average of one untreated discharge per year) of CSOs at the earliest possible date. Although reduction plans and compliance schedules were due by January 1988, only three of the 10 sewer jurisdictions with known CSOs in the Sound had submitted reduction plans on schedule (Everett, Metro, and Seattle). Due to delays in adopting implementation rules, Ecology will not take enforcement action against the other seven cities for missing the January 1988 deadline (Ecology, 1987c). Ecology is, however, requiring that these municipalities monitor their CSOs through at least one rainy season and develop a CSO reduction plan by the summer of 1988.

Point source summary

The National Oceanic and Atmospheric Administration (NOAA) has initiated a program to estimate pollutant discharges from different sources in the coastal zone throughout the United States. This program, called the National Coastal Pollutant Discharge Inventory (NCPDI), has developed screening level assessments of the relative contributions of point and nonpoint pollutant discharges in the Puget Sound area (Arnold et al., 1987). Discharge estimates for all point sources were based on 1985 flow and pollutant monitoring data from NPDES permits. If actual data on pollutant concentrations were incomplete or not available, estimates of "typical" pollutant concentrations for the particular type of facility were used. For example, flow, BOD, and TSS are commonly monitored as part of the NPDES permitting process, and Soundwide loading estimates for these pollutants were quite accurate. However, almost no other pollutants are routinely monitored and therefore were estimated using "typical" concentrations for each facility type (which made these estimates less accurate). Although simplifying assumptions, modeling, and the use of "typical" concentrations introduce error and overlook atypical contributions from point source discharges, the NCPDI appears to represent the current state of the art for areawide pollutant load estimating. However, these estimates are less reliable for assessing the loadings to a particular sub-area of Puget Sound. In addition, the inventory should not be used to evaluate the loadings from a particular urban area or facility unless actual monitoring data were used for the estimates (Arnold et al., 1987).

A summary of NCPDI-estimated discharges from municipal sewage treatment plants (also known as publicly owned treatment works, or POTWs) and industrial point sources in the Puget Sound study area is presented in Table 4-3. Municipal and industrial sources accounted for approximately five and 10 percent, respectively, of the total flow discharged from all sources in the Puget Sound study area. Despite this comparatively low total flow, sewage treatment plants contributed an estimated 40 percent of the total BOD, 90 percent of the total phosphorous (TP), 65 percent of the total cadmium (Cd) and petroleum hydrocarbons, and 80 percent of the total chlorinated hydrocarbon pesticides discharged into the Sound by all sources estimated in the inventory. These estimates correspond fairly well to other previous attempts to develop mass balance estimates of metals loading in Puget Sound (Romberg, 1988, pers. comm.). Relative to all other sources, industrial point sources were estimated to contribute about 40 percent of the total arsenic (As; Arnold et al., 1987). This finding probably reflects the fact that the ASARCO smelter (a major source of arsenic) was still operating in early 1985 (the year these estimates were based on).

Point source discharges are present in all areas of Puget Sound (Figure 4-4) but tend to be clustered around the industrialized urban areas including Tacoma (eight major discharges into Commencement Bay) and Seattle (a total of 10 major discharges into central Puget Sound). The contaminant loading estimates provided in Table 4-3 do not indicate the degree to which these major discharges are congregated, nor the degree to which pollutant effects from these discharges are localized, in certain parts of the Sound. As an example, in Commencement Bay eight major dischargers (16 percent of the total number in Puget Sound) account for 23 percent of the flow discharged from all major point sources in the Sound. However, these discharges contribute 20 percent of the TSS and 25 percent of the BOD from all major point sources in the Sound. The Seattle area has 20 percent of the total number of major point dischargers in Puget Sound, but they contribute 47 percent of the total flow, 64 percent of the TSS, and 52 percent of the BOD from all major point discharges in the Sound (Ecology, 1987b).

Nonpoint Sources

Nonpoint source pollution is pollution that enters the water from dispersed and uncontrolled sources rather than through pipes. On land, nonpoint pollution is usually carried by surface water runoff. Nonpoint pollution also originates from a variety of water-based facilities and activities including marinas, recreational boating, boat

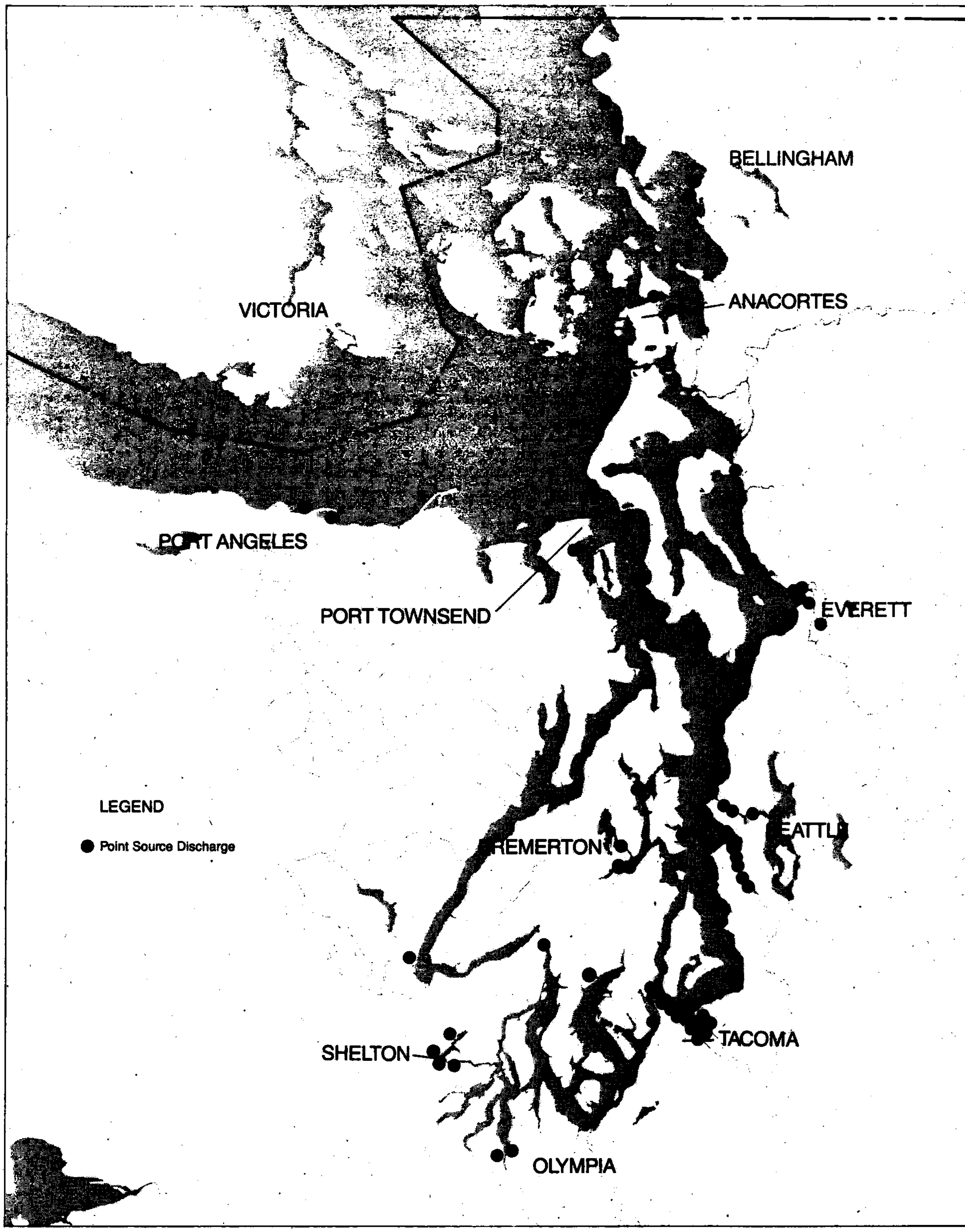
TABLE 4-3: TOTAL POLLUTANT DISCHARGE INTO THE PUGET SOUND STUDY AREA BY SOURCE CATEGORY, BASE YEAR 1985

	SOURCES							
Pollutants	Annual Discharge All Sources	POTW[1]	Industrial	Urban Runoff	Cropland Runoff	Forestland Runoff	Rangeland Runoff	Upstream Sources
Flow (BG)[2]	2,245	111	218	152	54	1,175	131	404
Conventional								
BOD (tons)	74,722	31,688	16,186	8,632	934	13,949	803	2,530
TSS (tons)	1,578,651	21,549	25,933	118,130	123,249	1,210,120	68,070	11,600
Nutrients								
TN (tons)	17,919	6,355	1,103	1,819	927	6,987	402	326
TP (tons)	5,633	5,114	82	286	37	68	3	43
Heavy Metals								
As (tons)	45	15	19	4	0	5	0	2
Cd (tons)	14	9	2	1	0	0	0	2
Cr (tons)	208	27	19	8	11	120	6	17
Cu (tons)	140	30	9	28	7	47	1	18
Fe (tons)	45,332	888	21	2,270	3,690	36,280	2,043	140
Pb (tons)	197	19	23	123	1	22	0	9
Hg (lbs)	1,531	456	234	160	25	299	20	337
Zn (tons)	443	91	77	130	14	93	4	34
Petroleum Hydro-Carbons (tons)	14,921	9,984	201	4,736	0*	0*	0*	0*
Chlorinated Hydrocarbon Pesticides (tons)	787	637	19	64	68	0*	0*	0*
Pathogens								
FCB[3] (cells)($x10^{12}$)	120,000	280.0	8.99	120,000	0*	0*	0*	170.0

1. POTW = public owned treatment work
2. BG = billion gallons
3. FCB = fecal coliform bacteria

*Relatively small contributions are rounded to 0.

(Reference: Arnold et al., 1987)



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 4-4

LOCATIONS OF POINT SOURCE DISCHARGES IN PUGET SOUND THAT ARE PERMITTED TO DISCHARGE OVER 100 MILLION GALLONS OF EFFLUENT PER YEAR (100 MGY)

repair, commercial fishing and shipping, and log storage. Pollution from these sources is usually associated with spills of petroleum products, illegal dumping of sewage and solid waste products, and the uncontained runoff from ship repair and log storage yards.

Land-based activities that can generate nonpoint pollution include a wide range of activities associated with forestry, agricultural, rural residential, and urban land uses. Pollution and habitat alteration from these sources is generally associated with soil erosion, pesticide and herbicide application, animal wastes, failed on-site sewage disposal (septic) systems, landfill leachate, development/construction, urban runoff, and household wastes. Nonpoint pollution from land-based sources usually takes an indirect route to the Sound. Contaminants may be contained in soil or groundwater, or they may be carried through the air before reaching the Sound as atmospheric deposition. Most often, though, contaminants are washed into the numerous conduits for surface water flow (e.g., swales, ditches, culverts, storm drains, streams, and rivers) where they are transported to the Sound. Generalized sources, processes, and effects of nonpoint source pollution are summarized in Figure 4-5, and source categories are discussed in the following sections.

Probably the most difficult and insidious characteristic of nonpoint source pollution is its inherent elusiveness and invisibility. It is often difficult to isolate, identify, and control this form of pollution because sources are often dispersed and obscure; there are often numerous sources which affect any one area; and the sources are usually some distance away from where the contamination might be detected or where there might be some effect on the quality or biological resources of the water body. In addition, although individual sources of nonpoint pollution are generally quite small compared to point sources, their cumulative effect on the Sound may be as significant because of the large number of uncontrolled sources.

Source control measures, such as the implementation of best management practices (BMPs), and targeted watershed management are known to be effective means of reducing or eliminating nonpoint source pollution (Novotony and Chesters, 1981; National Water Quality Evaluation Project, 1982; Maas et al., 1985; Hopkins and Clausen, 1985; U.S. Soil Conservation Service, 1987a; Maas et al., 1987). BMPs specifically designed for nonpoint pollution control vary depending on the source and type of contaminants present. For example, suggested BMPs for controlling bacterial contamination from farm animal wastes include fencing along streams to control animal access to the water and collecting manure in storage facilities to prevent it from being washed into streams (Joy, 1986; Wallace, 1987).

The Authority's *Nonpoint Source Pollution Issue Paper* (PSWQA, 1986e) summarized the existing institutional and regulatory framework for controlling this source of pollution to the Sound. Based on earlier work accomplished by local, state, and federal agencies in Washington (as well as throughout the nation), the Authority formulated a locally-based approach to address nonpoint source pollution as part of the Puget Sound Water Quality Management Plan. As a first step in implementing the nonpoint pollution elements of the Puget Sound plan, Ecology requested nominations from counties, interest groups, and tribes for watersheds that should be the highest priority for controlling or preventing nonpoint pollution sources. A total of 33 nominations were received and ranked by Ecology (with Authority staff assistance), and the top six watersheds (located in King, Snohomish, and Whatcom Counties) were selected for funding (see Appendix A for more complete descriptions of these by county). Additionally, ongoing shellfish protection projects in six watersheds in Clallam, Jefferson, Kitsap, Mason, Pierce, and Thurston Counties were also incorporated into the overall program; these 12 watersheds constitute the "early action watersheds" under the nonpoint source control

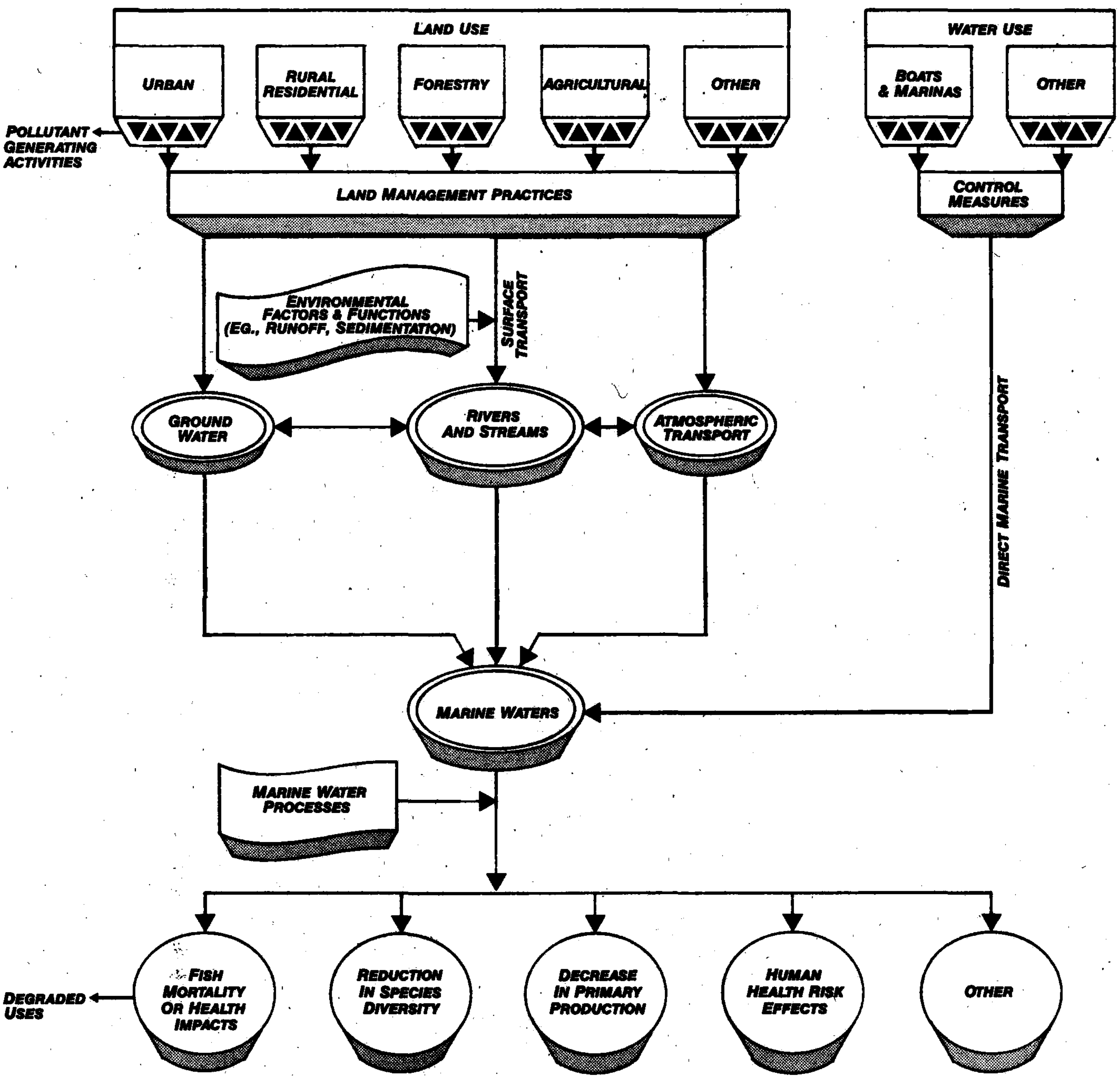


Figure 4-5

NONPOINT POLLUTION: SOURCES, PROCESSES, AND EFFECTS

program, and action plans are currently underway. The countywide selection of other priority watersheds is discussed below.

The Puget Sound plan calls for comprehensive nonpoint source pollution control to be accomplished by local governments at the watershed level, with certain state programs supporting these local efforts. In the countywide watershed ranking processes, priority watersheds will be identified for the preparation and implementation of action plans. Watershed action plans will focus on the sources most significant in each watershed. Agricultural practices, on-site sewage disposal systems, stormwater and erosion, forest practices, and boats and marinas are the major sources to be reviewed. Action plans will specify measures to prevent nonpoint source pollution, enhance water quality, and protect beneficial uses in each watershed. Criteria and procedures for ranking watersheds, and for developing and implementing local watershed action plans, are included in a state regulation promulgated by the Authority entitled Local Planning and Management of Nonpoint Source Pollution, Chapter 400-12 of the Washington Administrative Code (WAC).

Preparation and implementation of watershed action plans will be conducted by watershed management committees composed of representatives of counties, cities, affected parties, tribes, conservation and other special purpose districts, and affected state and federal government agencies. Action plans will be implemented by local and other appropriate entities with oversight by Ecology. The nonpoint program in the plan calls for countywide education programs and evaluations of how local government decisions affect water quality. These latter elements recognize the need for pollution prevention efforts throughout the Sound, not just in priority watersheds. All 12 Puget Sound counties have established watershed ranking committees, and are scheduled to submit final ranked lists to Ecology by January 1, 1989. Ecology will then help fund, using the Centennial Clean Water Fund, the development of action plans for the top priority watershed(s) in each county. These action plans will be consistent with Ecology's Section 319 Management Program that is discussed below.

The federal Water Quality Act of 1987 established in Section 319 a nationwide program for nonpoint pollution control. Each state is required to submit an assessment report and management program to EPA by August 1988. Ecology's assessment report will describe the nature, extent, and effects of all nonpoint source pollution on all water bodies in the state. The report will also address BMPs and the effectiveness of federal, state, and local programs for nonpoint source control. The management program will describe the various programs to be used in the next four years to implement BMPs for the various pollution categories, and will also set priorities for pollution controls on a watershed and statewide basis. The report will include information on the adequacy of existing laws for implementing programs, identify new laws if needed, and describe program funding sources. Ecology's assessment report and management program will incorporate the nonpoint program of the Puget Sound plan.

Forest practices

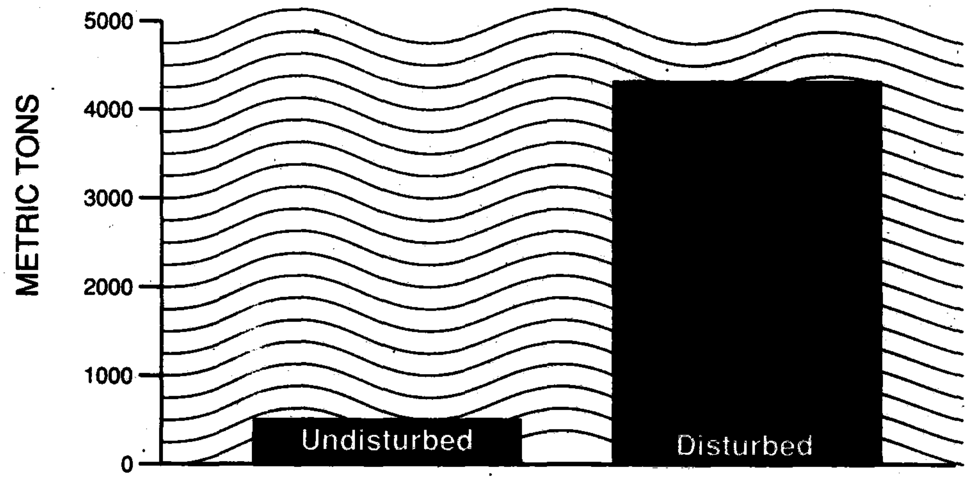
Over 80 percent of the Puget Sound land area is composed of highly productive forested land, and nearly 75 percent of the surface water runoff to Puget Sound originates in forested watersheds. About 50 percent of these forested lands are actively managed for commercial harvest, and each year about 50,000 acres (20,000 hectares) of timber are harvested in the Puget Sound area (PSWQA, 1986e). Virtually every watershed within the Sound is affected to some degree by forest practices which have the potential to significantly influence water quality and habitats. Typical forest practices that have been linked to nonpoint contamination, water quality problems, and habitat degradation include: road construction, maintenance, and abandonment; site preparation; clearcut and partial cut practices; removal of streamside vegetation; salvage logging; herbicide and pesticide spraying; and management of logging slash and debris. Specific BMPs (if implemented correctly) have been found to reduce nonpoint pollution effects associated with these practices (Lynch et al., 1985).

Water quality problems most often identified with forest practices include mass wasting (landslides), sedimentation, elevated stream temperature, and pesticides and organic debris (although properly placed large organic debris such as trees is now recognized as a valuable component of fisheries habitat). Of these, sediment effects resulting from forestry activities are the most difficult to pinpoint because erosion and sedimentation processes also occur naturally in undisturbed watersheds. Numerous studies have documented forestry-related sediment effects on freshwater systems including those prepared by the U.S. Forest Service (USFS), the Washington Department of Wildlife (WDW; formerly known as the Department of Game), Ecology, and others (Madej, 1982; Peak Northwest, Inc./Lummi Tribal Fisheries Dept., 1986; Bilby, 1985; Duncan et al., 1987). Results of a study on the Big Beef watershed in Kitsap County found that erosion from disturbed portions of the watershed (which is about 20 percent deforested) accounted for 88 percent of the total stream sediment loading, while natural processes in undisturbed portions accounted for the remainder (Figure 4-6; Madej, 1982). A major contributor of sediments in the disturbed watershed area was erosion of unpaved roads.

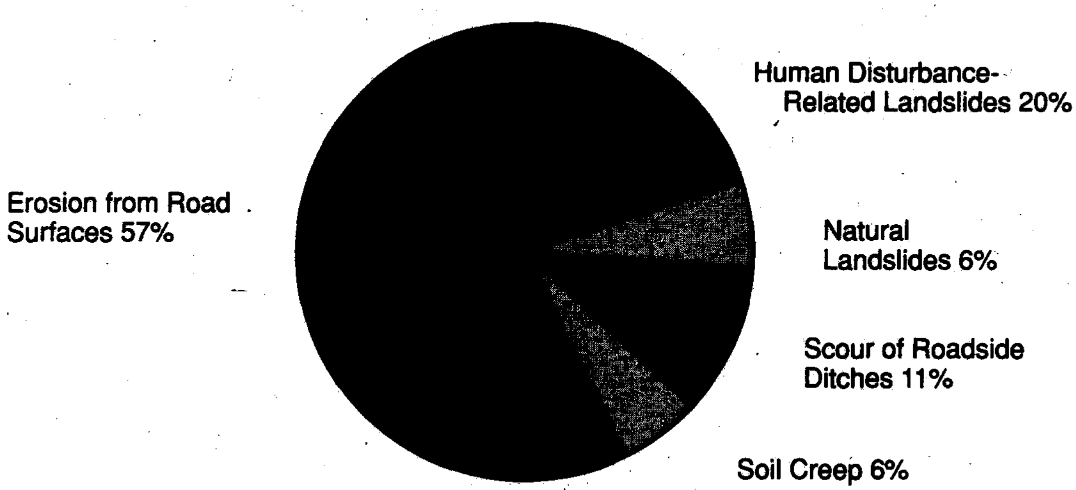
Ecology and other agencies have identified stream segments in the Nooksack, Puyallup, and Stillaguamish Water Resource Inventory Areas where surface water quality is degraded due to forest practices. In addition, although no comprehensive surveys have been done, there is anecdotal evidence of forestry impacts on streams in Jefferson, Snohomish, Skagit, and King Counties. Siltation caused by forest practices may also be affecting shellfish areas in Skookum and Totten Inlets (PSWQA, 1986e). There are few data, however, on downstream and marine water quality degradation related directly to forest practices. According to the Washington Department of Natural Resources (DNR), no studies have looked at the effects of forest practice-related sedimentation, water volume increases, or pesticide application on larger streams or estuarine areas remote from the forest practices. Studies are also lacking on the downstream effects of sediment from different nonpoint sources within a watershed (PSWQA, 1986e). Clearly more research is needed on these topics, and researchers need to coordinate their efforts to involve all concerned parties.

The Timber/Fish/Wildlife (T/F/W) Agreement recently developed by state resource agencies, environmental groups, timber industry representatives, and treaty Indian tribes represents an important step toward gaining better land use management as well as additional information on the effects of forest practices. This agreement resulted in modification of various provisions of the Forest Practices Act (Chapter 76.09 RCW) in 1987 (see Title 222 WAC). It includes, among other things: the establishment of interdisciplinary teams of scientists and resource professionals (including 30 additional professionals from Indian tribes) to work on avoiding adverse impacts associated with forest practices; a program of applied research and monitoring to assess the effectiveness of current practices; a case-by-case management approach to address site-specific environmental needs; increased protection of riparian streamside zones; the provision for upland management areas or undisturbed areas for wildlife use and protection in harvested areas; a process to address tribal concerns for fisheries and archaeological/cultural resource protection; and recommendations for enhanced enforcement by Ecology and DNR (Northwest Renewable Resources Center, 1987).

The Puget Sound plan endorses T/F/W, and Chapter 400-12 WAC requires that watershed action plans be consistent and coordinated with the T/F/W agreement. With improved regulations, use of site-specific inspections, and cooperative



ANNUAL STREAM SEDIMENT LOADING ESTIMATES FOR DISTURBED AND UNDISTURBED AREAS OF BIG BEEF CREEK WATERSHED



Reference: Madej, 1982

Figure 4-6

PERCENT OF SEDIMENT LOADING TO BIG BEEF CREEK FROM VARIOUS EROSIONAL SOURCES monitoring, the T/F/W process should result in improved water quality and widespread aquatic resource protection once it is fully implemented. Several "success stories" that have already resulted from the T/F/W process are described in Appendix A of this report.

Agricultural practices

Agricultural nonpoint discharges result from a variety of activities associated with both crop and animal production. As is the case with most nonpoint sources, pollution from agricultural activities is highly variable and depends on both environmental factors (e.g., precipitation, runoff, and sedimentation) and land treatment practices (e.g., row cropping and manure management). Crop production can introduce pollutants by disturbing the soil and increasing runoff, by removing vegetative cover, and by increasing nutrients and other chemicals through the application of fertilizers, insecticides, and herbicides. Animal production activities can cause increased stream pollution by employing inadequate waste management systems in animal confinement areas; by increasing runoff and erosion due to overgrazing pasture lands; by improperly applying manure to fields; and by allowing animals unlimited access to streams where they can trample vegetation and damage streambanks. Pollutants most often associated with agricultural practices include sediments, fecal bacteria, nutrients, salts, organic chemicals, and pesticides (PSWQA, 1986e).

Proper agricultural waste management is a major challenge. The following helps describe the magnitude of the challenge. There are approximately 1,000 commercial dairies in western Washington and an unknown number of small/noncommercial farms. These commercial dairies alone have about 176,000 cows, and the small, unaccounted-for farms have an untold number of additional cows, horses, goats, pigs, fowl, and other animals. In addition, other agricultural practices such as cattle ranching generate unknown quantities of animal wastes that find their way to the Sound. If the animal waste management systems of farms are not adequate, and the farms are located near surface water bodies, water quality problems may result. Although many commercial and small noncommercial farmers do an excellent job of protecting water quality, others do not.

Nonpoint pollution from agricultural activities can be controlled and significantly reduced through the use of BMPs (Maas et al., 1987; National Water Quality Evaluation Project, 1982). BMPs for crop production activities include conservation tillage, terracing, contour farming, the planting of cover crops, nutrient and pesticide management systems, and improved irrigation and drainage systems. Animal production BMPs can be grouped under the categories of stream corridor management, pasture management, waste management, and runoff control. Some of the more common practices include fencing of streams, revegetating unstable stream banks, planting winter cover crops, constructing roofs over animal confinement areas, confining and storing liquid and solid animal wastes, properly applying manure wastes to fields, and installing drainage systems to separate clean runoff and surface water from contaminated wastewater (McKamey and Wallace, 1987; Wallace, 1987; PSWQA, 1986e).

Although BMPs are widely recognized as the best means of controlling agricultural nonpoint pollution, the effectiveness of many BMPs has not been well documented on a watershed-sized scale (Baker and Johnson, 1983). A long-term study of agricultural BMP application and resulting water quality changes is currently being conducted in the LaPlatte River Watershed in Vermont (Meals, 1985). This study has utilized extensive land use and surface water quality monitoring networks to determine the effects of agricultural BMP implementation in the watershed. Preliminary results have shown that sediment and nutrient loads appear to be decreasing, although the natural variability in climate, streamflow, and water quality data, as well as the incremental nature of the BMP implementation, has made it difficult to detect significant water quality changes that are directly attributable to BMPs and land use changes.

Another detailed study of BMP effectiveness on a watershed basis is being done by the Oregon Department of Environmental Quality in the Tillamook Bay area (Jackson, 1987). This ongoing study is part of a national effort called the Rural Clean Water Program, and has received substantial federal funding to conduct an overall evaluation of nonpoint source pollution and its effects on Tillamook Bay. Extensive water quality monitoring by this study determined that most of the bacteria found in the bay originated from dairy animal and human fecal sources in the river subbasins. With the cooperation of the local dairy industry, a detailed fecal wastes management plan was implemented which includes improved animal waste storage and disposal systems. Although the cleanup effort is only about half complete and there are still periodic shellfish bed closures, Tillamook Bay and its tributaries are already exhibiting a 16 to 78 percent reduction in fecal coliform concentrations, and the shellfish industry in the bay has improved (Jackson, 1987).

A concerted effort is being conducted in Washington by the U.S. Department of Agriculture Soil Conservation Service (SCS), Ecology, and local conservation districts to encourage the implementation of agricultural BMPs. Tables 4-4 and 4-5 summarize the number and type of these practices being implemented in the 12

TABLE 4-4: AGRICULTURAL BEST MANAGEMENT PRACTICES (BMPs) IMPLEMENTED IN THE PUGET SOUND BASIN IN 1986 AND 1987*

BMPs Installed	Fiscal Year 1986	Fiscal Year 1987
Number of landowners contacted	2,000	1,925
Landowners using some type of BMP	481	412
Length of stream fencing	72,000 feet	58,966 feet
Length of fish habitat protected	24,991 feet	3,467 feet
Length of streambank protection installed	N/A	3,400 feet
Number applying waste management systems	N/A	16
Number of waste storage ponds	95	33
Number of waste storage structures	27	14
Number of roof runoff systems	44	28
Safely handled wet manure	N/A	251,327 tons
Area where waste properly utilized	10,000 acres	3,974 acres
Area where cover crop planted	N/A	299 acres
Area planned for conservation practice implementation	N/A	14,573 acres
Area benefitted by application of BMPs	N/A	8,200 acres

*Numbers represent projects accomplished in each year.

N/A = Information not available

(Reference: U.S. Soil Conservation Service, 1986, 1987b)

counties of the Puget Sound area. Large dairy producers in particular have generally been willing to implement BMPs, and cooperation is growing as more farmers see the economic as well as environmental benefits of these practices. Implementation of BMPs among the noncommercial or small farms in the Sound (which usually have a small number of animals) is much less extensive. The cumulative effects of poor animal keeping practices from these small operations continues to be an important threat to water quality in the Sound (Wallace, 1987).

On-site sewage disposal systems

A primary source of nonpoint pollution originating in suburban and rural residential areas is failure of on-site sewage disposal (septic) systems. Health officials normally decide a system has failed when the sewage effluent collects on the ground surface or when toilets and drains no longer pass the wastewater (Carlile, 1985). However, a system can affect the groundwater long before it is obvious to the homeowner or an inspector that it has failed. Systems fail for a number of reasons, in many cases because they were not designed to last more than 20 or 30 years or

TABLE 4-5: AGRICULTURAL BMP IMPLEMENTATION SURVEY RESPONSE, BY PUGET SOUND COUNTY

	CLALLAM*	ISLAND	JEFFERSON*	KING*	KITSAP**	MASON**	PIERCE*	SAN JUAN	SKAGIT*	SNOHOMISH*	THURSTON	WHATCOM*
Percent of farms implementing BMPs	15	NR[1]	80	44	10	10	ND[2]	NR	53	73	10	70
Number of large animals with direct access to streams	2,500		1,000	ND	ND	400	ND		ND	ND	700	2,500
Total stream fencing (miles)	0		12.0	6.6	1.7	0.25	ND		ND	ND	1.5	8.0
Number of waste storage ponds, lagoons, and structures	14		5	135	ND	1	5		49	50	0	92
Number of roof runoff systems	1		1	76	4	4	1		6	ND	ND	38
Proper application of manure												
Total acreage	1,000		500	ND	ND	ND	ND		ND	ND	ND	5,300
No. of farms	ND		ND	30	ND	3	13		50	50	0	ND
Stream rehabilitation												
No. of projects	ND		ND	ND	ND	ND	2		ND	175	0	ND
No. of feet	500		10,000	35,000	ND	ND	ND		ND	ND	ND	ND
Stream replanting												
No. of projects	0		ND	ND	10	ND	2		ND	ND	2	ND
No. of feet	ND		2,600	ND	ND	ND	ND		ND	ND	ND	ND

1. NR = No response to this survey
2. ND = No data available for this question

*Data from these counties pertain to commercial farms only.
**Data from these counties pertain to commercial and noncommercial farms.

(Reference: PSWQA, 1988d)

they were designed for more seasonal (vacation) use rather than year-round use. Other reasons for failure include installation in unsuitable soil; installation in areas with high seasonal water tables; improper design or construction techniques; installation on an undersized lot; and lack of maintenance and improper use which often relates to a lack of knowledge on the part of residents (PSWQA, 1986e). For example, some people do not know that they are served by an on-site system; some do not know the location of their facilities, some do not know that regular maintenance is necessary; and some do not know that certain household products can damage the system's effectiveness.

In 1985 the Washington Department of Social and Health Services (DSHS) estimated that there were approximately 383,000 on-site sewage disposal systems in the Puget Sound area and that about 11,000 new systems are built each year (PSWQA, 1986e). This means that approximately 405,000 systems were in operation in 1987. DSHS estimates that the basinwide failure rate for on-site systems is approximately 3.5 to 5.0 percent (Plews, 1986, pers. comm.), which suggests that between 14,000 to 20,250 systems may have failed in 1987. However, local sanitarians in some parts of the Sound estimate much higher failure rates in certain areas. For example, a recent Authority survey of local health departments found that in some areas up to 12 percent of all on-site systems are failing (PSWQA, 1988b). Despite these estimates of failure, only 1,775 repair permits were issued in 1986 (DSHS, 1987). The potential increase of this source of contamination has serious implications for land use and water quality planning, particularly in the rural shoreline areas of the rapidly growing counties such as Island, San Juan, Thurston, and Mason Counties. Most of the new subdivisions in these areas are using on-site sewage disposal systems, and many have soils (such as clay or hardpan) that are not well suited for sewage disposal systems.

Failed on-site sewage disposal systems represent a significant health hazard because domestic wastewater contains household hazardous substances, bacteria, viruses, and other microorganisms that can be potentially harmful to people. Among other things, typhoid fever, gastrointestinal infections, and infectious hepatitis have been linked in some cases to failing sewage disposal systems around the Sound (PSWQA, 1986e). In addition, increased levels of fecal coliform bacteria (which is used as an indicator of pathogen presence) in certain embayments has caused DSHS to close some commercial and recreational shellfish beds around the Sound (see section at the end of this chapter that discusses potential human health risks).

It is not clear to what extent commercial shellfish closures can be directly linked to failing on-site sewage disposal systems, but in several areas studied by Ecology (e.g., Burley Lagoon/Minter Bay and Henderson and Eld Inlets) sewage disposal systems were implicated as one of the causes of the closures (Determan et al., 1985). Many areas in western Washington are poorly drained and not well suited for on-site disposal systems. Ecology estimates that soils with substantial limitations for wastewater disposal cover 50 percent of the Minter watershed and about 75 percent of the Burley/Purdy watershed (Determan et al., 1985).

Recreational boating and marinas

Nonpoint pollution effects from recreational boating and marinas have received considerable attention nationwide and locally. These effects are, however, quite controversial because, like other sources of nonpoint pollution, researchers are often unable to demonstrate clear cause-and-effect relationships between specific pollution sources and resulting water quality degradation or effects on biological resources. The type of pollution most commonly associated with recreational boating is bacterial contamination from illegal discharges of raw or partially treated human wastes. Other pollutants associated with boating include detergents, petroleum hydrocarbons (oil and grease), some metals (in anti-fouling paints), and plastics and other garbage.

Pollutants associated with marinas typically include petroleum hydrocarbons, heavy metals, oxygen-demanding wastes, organic chemicals, paint chips and solvents (contributed by small boatyards at marinas), bacteria and other pathogens, and plastics and other garbage (Cardwell, 1982). Of particular concern at some marinas is the discharge of untreated sewage from "liveaboards" (boats that are not houseboats, but that are used as residences) where the owners do not use a holding tank or upland disposal facilities. The most significant water quality problems at marinas appear to be reductions in the dissolved oxygen concentration and increases in the temperature of the underlying water (Parametrix, Inc., 1981). These effects result in large part from the generally poorly flushed quality of marinas (they are designed to be quiet areas little influenced by waves and currents). Development of marinas may also destroy or degrade salt marshes and eelgrass beds.

Perhaps the most critical issue with respect to boating sources of nonpoint pollution is the potential influence of recreational boating activities on bacterial levels in the surrounding water and shellfish beds. Although the practice is illegal, many owners of boats equipped with marine toilets and/or holding tanks discharge sewage, galley waste, and other material directly into the water wherever the boat happens to be (Seabloom and Plews, 1987). In addition, some owners of small boats not equipped with built-in marine toilets dump human waste and garbage directly overboard. Although the discharge from one boat probably has little or no effect (particularly in open water), if many pleasure boats happen to congregate in a small bay or inlet for a weekend, their accumulated waste discharges may contribute to bacterial (and possibly viral) contamination in the immediate area and render nearby shellfish unsafe for human consumption.

Direct effects of boat bacterial wastes are particularly difficult to quantify because coliform bacteria counts vary with temperature, turbidity, tides, day of the week, season of the year, boat densities, and the number of persons aboard each boat. In addition, it is difficult to separate boat contributions from other point and nonpoint sources of bacteria such as sewage treatment plant outfalls, failed on-site sewage disposal systems, and streams that might be carrying animal wastes. One study conducted in Port Ludlow was able to rule out other nonpoint sources and found that boating activities during a holiday weekend significantly increased water and shellfish bacterial levels. Illegal discharges of sewage from as few as 10 percent of the boats were found to account for the elevated levels of bacteria in the area. Bacterial levels in the water and shellfish significantly declined after most of the boaters left (Patmont et al., 1985). A study of boat anchorage areas in the northern Strait of Georgia and the Sunshine Coast area of British Columbia also was able to eliminate onshore sewage as a potential source of pollution. This study found that increased fecal coliform bacteria counts in water and shellfish tissue were attributable solely to overboard sewage discharges from boats (Kay, 1982). However, other studies of nonpoint pollution contributions from boating activities (e.g., in Eagle Harbor and Sequim Bay) have been far less conclusive (PSWQA, 1986e; Seabloom and Plews, 1987).

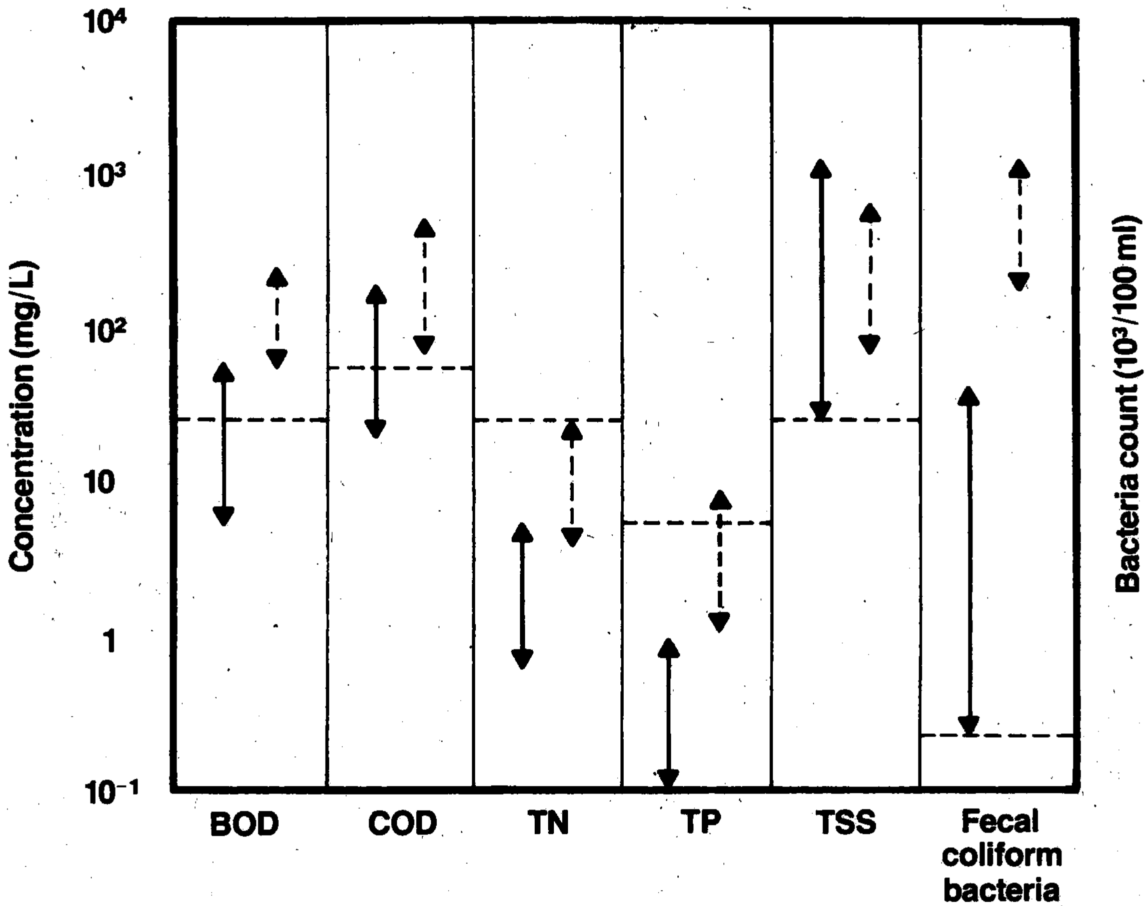
Health authorities have taken a cautious position with respect to the potential health hazards and water quality effects associated with recreational boating and marinas. The discharge of raw or partially treated sewage does occur in small harbors and bays; to what extent this occurs and the long-term implications of such illegal discharges are not known. However, state and local health agencies are increasingly recommending the closure of recreational shellfish beds in certain areas. Beds at Jarell Cove and Squaxin Island located in Mason County and Penrose Point State Park located in Pierce County have been closed because of heavy boating use and the potential for human health risk (see the section in this chapter that discusses potential human health risks). In addition, DSHS (in accordance with the National Shellfish Sanitation Program) has initiated the closure or restriction of commercial shellfish activities at a number of areas located within one-half mile of marinas because of the potential for high bacterial counts. DSHS will not approve any new commercial shellfish ventures in areas located within one-half mile of a marina (DSHS, 1988; Walker, 1987, pers. comm.; Mitchell, 1987, pers. comm.). These problems may only get worse as the number of boaters increase and more marinas are developed.

A Boaters Task Force was created in 1987 as called for in the Puget Sound plan's nonpoint program (element MB-3). The task force is made up of members from the State Parks and Recreation Commission's existing Boating Safety Advisory Committee (which includes boaters and local governments) plus representatives from the Authority, DSHS, Ecology, DNR, the Washington Department of Fisheries (WDF), the Washington Interagency Committee for Outdoor Recreation (IAC), tribes, shellfish growers, marina owners, the marine sanitation industry, owners of small commercial vessels, and environmental groups. This task force is working on a boater educational program that will be implemented by the State Parks and Recreation Commission. The task force is also developing a legislative proposal that would provide for the installation of pumpout facilities at marinas near environmentally sensitive or polluted areas and in other areas used heavily by boaters. Under plan element MB-4, the State Parks and Recreation Commission will install pumpout stations at selected state parks beginning in the summer of 1988, with priority given to parks located in poorly flushed bays with shellfish resources. The first pumpout station installed under this program will be located at Mystery Bay State Park near Port Townsend.

Stormwater runoff

Stormwater includes contaminated runoff from industrial, commercial, and residential areas as well as erosion from construction activities. Surface runoff is one of the major mechanisms by which toxic pollutants from nonpoint sources are transported to surface water bodies and eventually the Sound (Harper-Owes, 1983). In urban and suburban areas particularly, precipitation falling on roofs and other impervious surfaces (e.g., parking lots and streets) picks up sediments and surface chemicals as it makes its way toward collection systems (gutters, street drains, and roadside ditches). These stormwater collection systems then usually discharge directly into natural stream networks where fish and other biological resources may be affected. In addition to carrying excess amounts of sediments and other pollutants, stormwater runoff can create flooding and streambed scouring problems because more impervious surfaces result in higher volumes and rates of runoff.

Characteristic pollutants found in stormwater include sediments or suspended solids, nutrients (fertilizers), pathogens (bacteria and viruses), and toxic materials such as arsenic, cadmium, chromium, copper, lead, mercury, organic pesticides, and petroleum products (Galvin, 1987). Concentrations of conventional pollutants (e.g., BOD, TSS, total nitrogen, total phosphorous, and bacteria) found in stormwater are usually comparable to or greater than those in effluent from secondary sewage treatment plants and CSOs (Figure 4-7). In addition, volumes of stormwater runoff in some areas may be comparable to point source discharges, depending on the level of development in the area. Stormwater metals concentrations can be significantly higher than those found in sewage. In a Metro study of stormwater runoff, six metals (arsenic, cadmium, chromium, copper, lead, and zinc) were found in 100 percent of the stormwater samples (Galvin and Moore, 1982). While these and other chemicals are usually present in small amounts, under certain conditions they can build up in sediments near storm drain outfalls.



LEGEND

Stormwater, range of concentrations

Secondary effluent treatment, typical concentrations

Combined sewer overflows, range of concentrations

Reference: Modified from Galvin, 1987; Hvitved-Jacobsen, 1986

Figure 4-7

CONCENTRATIONS OF CONVENTIONAL PARAMETERS IN STORMWATER AS COMPARED TO THOSE IN SECONDARY-TREATED MUNICIPAL EFFLUENT AND COMBINED SEWER OVERFLOWS

Dust and sediment particles (and their associated toxic pollutants) that are washed into stormwater systems can quickly pass through the collection system and be discharged into surface waters, or they can accumulate in collection system pipes and be discharged intermittently during periods of high stormwater flow. Storm drain sediments that have collected over time at stormwater outfalls or discharge points have been identified as a major source of toxicants in the Duwamish River (Lampe, 1987). One storm drain outfall represented a major source of lead to the Duwamish; investigators traced the source back to a former smelter that crushed batteries to recover lead. Another storm drain (the Florida Street drainage system in Seattle) contained high levels of creosote, pentachlorophenol, copper, arsenic, and PCBs which (except for the PCBs) were traced back to a wood treatment facility. Thirty cubic yards (23 cubic meters) of contaminated sediments removed by the city of Seattle from this system contained 145 pounds (66 kilograms) of contaminants. Sediments removed by Seattle City Light and the Boeing Company from storm drains near the King County Airport contained very high levels of PCBs (about one pound (400 grams) of PCBs in 70 cubic yards (53 cubic meters) of sediment; Lampe, 1987).

Recognizing the significant effects associated with stormwater runoff, the difficulties associated with engineered solutions, and the fact that the problems will worsen unless properly managed, a wide variety of strategies have been devised to manage this source of pollution. Three basic approaches are usually taken to improve stormwater quality: 1) remove pollutants before they enter the stormwater or major water body (e.g., through pretreatment practices and BMPs); 2) reduce the rate and volume of stormwater runoff by minimizing the area of impervious surfaces (e.g., by designing more greenbelts, open spaces, and permeable surfaces); and, 3) retain stormwater in sedimentation ponds to reduce the rate of runoff and to allow sediment particles (and attached pollutants) to settle out. Other methods for controlling the quality of stormwater runoff (discussed in more detail in the Authority's *Nonpoint Source Pollution Issue Paper*, PSWQA, 1986e) include oil-water separators, grassy swales, street sweeping, and infiltration devices. Construction erosion controls include straw bale filters, runoff control, sediment traps, vegetation buffers, and grass seeding. The effectiveness of these measures is quite variable (e.g., street sweeping was found to be largely ineffective in Bellevue; Pitt and Bissonnette, 1984; Prych and Ebbert, 1986). Effectiveness is largely dependent on the particular physical and chemical stormwater qualities in any one area, and the site-specific application of any particular technique.

Runoff is naturally controlled in undisturbed areas because it soaks into the ground or flows into wetland areas and streams. Runoff caused by construction of impervious surfaces can be managed by sending the runoff into a grassy swale area or into natural or constructed wetlands. Although these methods typically improve the quality of stormwater runoff, the effects that stormwater runoff might have on wetlands and groundwater resources are not well known. The design and management of wetlands for water quality improvement are also not well understood or widely tested.

King County, in cooperation with other counties, agencies, and organizations, is currently undertaking a research program to address these issues. A literature review was completed in 1986 to assess the state of knowledge regarding the use of wetlands for stormwater runoff management and nonpoint pollution control (Stockdale, 1986). In addition, a detailed survey of 71 King County wetlands was performed during the spring and summer of 1987. The objectives of the survey are to compare wetlands that have and have not received urban stormwater runoff for ecological changes and the extent of problems created in wetlands by urban runoff. Research results, although not yet available, will be used to determine whether wetlands can be incorporated into runoff management programs.

The institutional and regulatory system that manages stormwater runoff is discussed in the Authority's *Nonpoint Source Pollution Issue Paper* (PSWQA, 1986e). In urban areas where stormwater is collected in piped systems and discharged to lakes, river, or marine waters, NPDES permits will be required for stormwater discharges. The federal Water Quality Act of 1987 clarifies the application of the point source NPDES program to stormwater runoff. This act also establishes new federal deadlines for permits to be issued for stormwater outfalls. Permits are required by 1991 for industrial stormwater outfalls and municipal stormwater systems serving 250,000 people or more (Seattle). For municipal systems serving 100,000 to 250,000 people (Tacoma), permits are required by 1993. In addition, Ecology has the authority to require smaller cities to have permits (e.g., Bellevue).

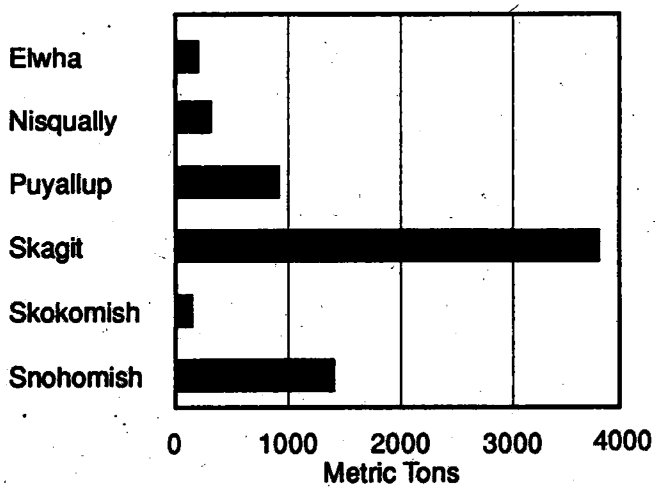
The Puget Sound plan addresses stormwater runoff in several ways. Runoff from industrial sites is to be included in the discharge permit for the industry. In addition, under plan elements SW-3 and SW-4, Ecology is required to develop technical manuals and program guidelines (including model ordinances) to be used by cities and counties to develop and implement stormwater programs over the next several years. In designing the program, Ecology will make use of the considerable body of literature that exists on urban stormwater control. They will also work closely with Puget Sound cities and counties, including those with existing stormwater management utilities (such as Anacortes, Auburn, Bellevue, Everson-Nooksack, Gig Harbor, Kent, Lacey, Mountlake Terrace, Olympia, Port Townsend, Poulsbo, Redmond, Renton, Steilacoom, Tacoma, Tumwater, and Winslow as well as portions of King, Snohomish, and Thurston Counties). In addition, stormwater and erosion control are to be considered by county watershed management committees as they prepare their action plans under the nonpoint program. Any prescribed control measures must be consistent with the Puget Sound plan. The Washington Department of Transportation will also develop a program to control highway runoff.

Nonpoint source summary

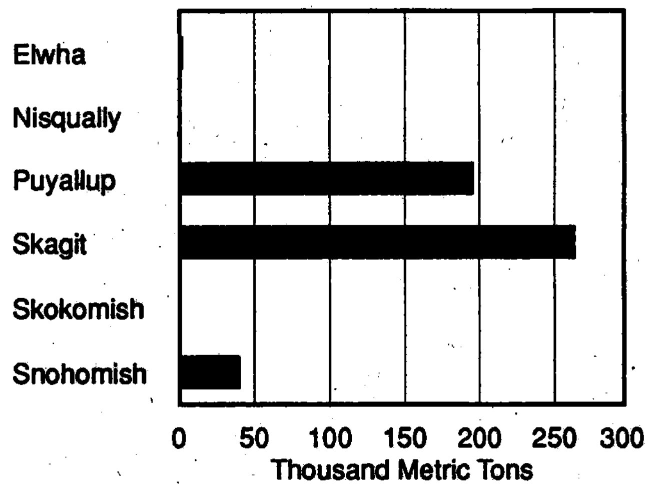
Information on water flow and water quality is available for a limited number of rivers and streams in the Puget Sound basin (U.S. Geological Survey, 1987). These data were used to develop rough estimates of the amount of certain contaminants (inorganic phosphorus and nitrogen, suspended solids, and fecal coliforms) that these streams and rivers carry into Puget Sound each year (Figure 4-8). Much of this contamination originates from nonpoint sources, although point sources are also present on some rivers. For example, according to the data, the largest contributor of inorganic nitrogen to the Sound is the Skagit River which transports nearly 4,150 tons (3,770 metric tons) annually. This system also contributes about 290 tons (260 metric tons) of phosphorous and 290,000 tons (263,500 metric tons) of suspended solids on an annual basis (Figure 4-8). There are too few data on toxic contaminants in rivers to allow quantitative estimates.

Loadings from nonpoint sources and storm drain systems can be estimated based on the relationship between land uses and the characteristic contaminant loadings associated with those land uses. For example, a study of the effects of land use on water quality in the Newaukum Creek Basin found that urban areas contributed the highest levels of lead and zinc while concentrations of suspended solids, nutrients, and bacteria were highest in agricultural runoff (Prych and Brenner, 1983).

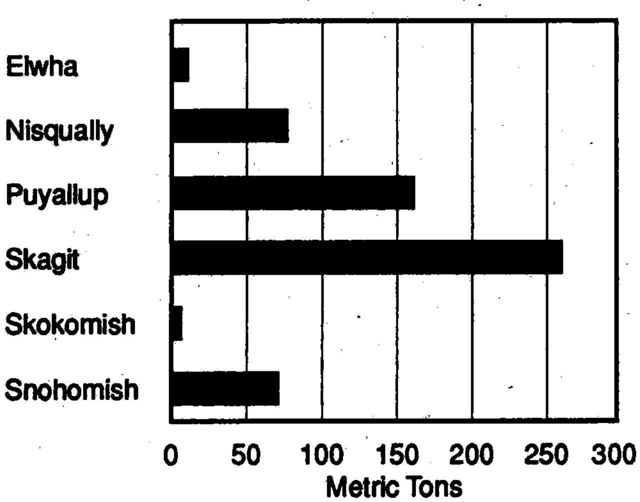
NCPDI estimates of nonpoint source pollutant discharges in the Puget Sound study area for the base year 1982 are summarized in Table 4-3 (Arnold et al., 1987). As discussed above in the Point Source Summary, this inventory has certain limitations which restrict its usability. It is very difficult to develop estimates of pollutant loading from nonpoint sources because actual monitoring data are quite limited and pollutant discharges tend to vary seasonally and yearly because of changes in precipitation, land use, and economic activity (among other factors). NCPDI urban



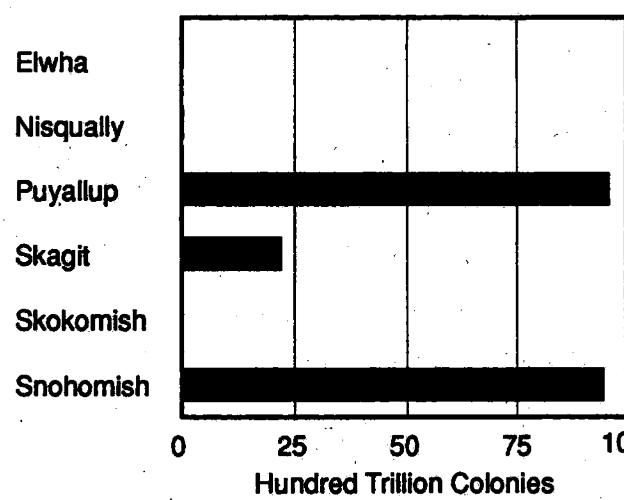
ANNUAL LOADING OF NITROGEN
Water Year 1985 (metric tons per year)



ANNUAL LOADING OF SUSPENDED SOLIDS
Water Year 1985 (metric tons per year)



ANNUAL LOADING OF PHOSPHORUS
Water Year 1985 (metric tons per year)



ANNUAL LOADING OF FECAL COLIFORM
Water Year 1985 (metric tons per year)

Reference: USGS, 1987

Figure 4-8

ANNUAL CONTAMINANT LOADING TO PUGET SOUND RIVERS, 1985

runoff pollutant loading estimates were based on values developed by EPA's National Urban Runoff Program, while volumes of runoff and sediment loads were calculated using a watershed basin simulation model developed by the U.S. Department of Agriculture. Nonurban forest and agricultural runoff pollutant estimates were based on 1982 precipitation records, as well as information on land use, soil type, erodibility, topography, crop management practices, and other factors that could influence runoff and erosion. Because 1982 was considered a "wet year", nonpoint source pollution values are probably overestimated because they reflect the high runoff and erosion potential associated with above-average rainfall. Despite these limitations, the NCPDI estimates provide a good overview of nonpoint source pollution contributions on a Soundwide basis. However, these estimates should not be used to assess pollutant loading on a more local scale.

NCPDI estimated that forestland runoff contributed 50 percent (the most from any source) of the total flow from all point and nonpoint sources in the Sound, largely because of the extensive area of forested land in the Sound. Because of this large flow, forested areas contributed about 75 percent of the total sediment (TSS), 40 percent of the total nitrogen (TN), 60 percent of the total chromium (Cr), and 80 percent of the total iron (Fe) discharged to the Sound. The relatively high contribution of TSS does not necessarily imply that forestland sites are highly erosive. This estimated contribution is more a function of the large amount of forested land present in the Puget Sound area. In addition, nutrients and metals contributed from forested areas represent elements that are naturally present in eroded soils. These elements are not as reactive or biologically available as metals from urban point and nonpoint sources (Arnold et al., 1987).

Urban stormwater runoff was estimated to contribute about seven percent of the total flow from all point and nonpoint sources but about 60 percent of the total lead (Pb), 30 percent of the total zinc (Zn; the most from any one source), and much of the total fecal coliform bacteria in the Puget Sound study area (Arnold et al., 1987). Contributions of pathogens from nonurban sources are known to exist, but because these sources are very difficult to estimate accurately, they were assumed to have a negligible contribution in the NCPDI estimates. In addition, because pathogen estimates were derived from a Soundwide database, they do not adequately address localized nonpoint contributions and effects (such as the influence of failed on-site sewage disposal systems and other nonpoint source pollution on bacterial levels in commercial shellfish beds in southern Puget Sound).

Atmospheric Deposition

Many of the particles and air pollutants from transportation, industrial, and other sources settle out on impervious surfaces and are washed into streams as stormwater runoff (as discussed above). Air pollutants may also be deposited directly into fresh water bodies and the Sound, but very little research has been done on atmospheric deposition. It is unclear what proportion this contamination source contributes to the total loading of contaminants in the Sound or what water quality problems might result from this source.

Sources of atmospheric pollutants include industrial smokestacks and other industrial emissions (e.g., dry cleaners), motor vehicle exhausts, aerial spraying of pesticides, evaporation from waste water treatment plants, landfill gases, incinerator emissions, wood stoves, and slash burning. A wide variety of pollutants from these sources is transported and sometimes transformed in the air, and may eventually be deposited in the surface waters of the basin. Recent studies in the Great Lakes region have indicated that toxic substances (e.g., metals, insecticides, and PCBs) are entering the lakes via atmospheric deposition and accumulating in fish. In another study of the Southern California Bight, atmospheric sources of metal accounted for about 45 percent of the total lead input (Hodge et al., 1978).

There are currently no direct measurements of atmospheric deposition of contaminants to the Sound. The Puget Sound Air Pollution Control Agency (PSAPCA) conducts an annual survey of toxic industrial emissions that are permitted (under the federal Clean Air Act) in the four counties within its jurisdiction (King, Kitsap, Pierce, and Snohomish Counties). In 1986 industries in these four counties reported emissions of 81 toxic air contaminants (PSAPCA, 1987). Of the 81 chemicals reported in 1986, 21 are Puget Sound "pollutants of concern", including chloroform (97 tons; 88 metric tons; reported in 1986), lead (249 tons; 226 metric tons; reported), and phenol (2,054 tons; 1,863 metric tons; reported). Because ambient concentrations of most of these toxic air contaminants are not measured in the Puget Sound area, it is not known whether the deposition of these and other airborne contaminants in the fresh and marine waters of the Sound may be a concern.

Metro's *Toxicant Pretreatment Planning Study* conducted in the early 1980s found that about 25 percent of the total lead input to the Sound is coming from atmospheric sources (Romberg et al., 1984). A more recent effort to quantify the various sources of lead (and other metals) to Puget Sound indicates that atmospheric sources contribute 25 tons (23 metric tons) of lead to the central basin of the Sound each year (about 20 percent of the total sources; Paulson et al., 1988). "Fugitive" or escaping dust from a Harbor Island (Seattle) lead smelter that washed into storm drains was found to be a major source of lead to the Duwamish River (Lampe, 1987). Clearly, more research needs to be done to determine whether airborne contaminants represent a significant contribution to the Sound and what water quality effects (e.g., effects in the sea-surface microlayer) may be resulting from the atmospheric deposition of contaminants. PSAPCA and EPA are currently conducting studies to quantify ambient concentrations of toxic air pollutants which will help determine to what extent atmospheric deposition may contribute to water quality problems in the Sound.

Solid and Household Hazardous Waste Disposal

The average American generates about five pounds (2.3 kilograms) of solid waste a day. In the past the most common means of disposing of this massive amount of garbage were sanitary landfills. However, landfills are becoming a less attractive disposal option because of the large area they require, the odor and other aesthetic problems associated with the facilities, and the increasingly recognized problem of containing the toxic leachate and gases generated by many landfills. Because of more stringent federal and state regulations, only about half of the nation's 9,200 landfills still have valid operating permits.

Many communities are looking to various means of recycling and garbage incineration to deal with their solid waste disposal problems. For example, King County is currently exploring the option of constructing a large solid waste incinerator as well as instituting a waste reduction recycling program. The incineration project has met with intense opposition in certain cases because of concerns about toxic emissions and other problems associated with increased truck traffic. Incinerator technology exists that can significantly limit emissions of toxic gases (e.g., hydrogen chloride and sulfur dioxide) and toxic metals, but the resulting fly ash and bottom ash (about 10 percent of the original waste material) must still be disposed of properly. Although aggressive recycling programs will help reduce the volume of solid waste that must be ultimately disposed of in landfills or by incineration, communities in the Puget Sound area are faced with some very difficult decisions regarding options for future solid waste disposal.

Household hazardous wastes come from a variety of toxic products used in the home including paints, paint thinners, lawn and garden insecticides and herbicides, fertilizers, cleansers, degreasers, medicines, cosmetics, dyes, and automotive products such as antifreeze, battery acid, and oil (see Figure 4-3 for the estimated residential contribution of metals and organic compounds). These products have become a serious source of uncontrolled toxic waste because of the lack of both education on their safe use and disposal and a good means for their disposal. They are commonly emptied down drains or flushed down toilets where they can potentially damage on-site systems or pass through treatment plants not designed to handle certain hazardous substances. Hazardous wastes are also dumped in storm drains, ditches, or backyards where they can contribute to nonpoint pollution by entering streams, rivers, and groundwater. Several counties and a few cities have collection sites for some household chemicals, and some counties and cities hold collection days when citizens may bring in household wastes for appropriate disposal (e.g., King and Thurston Counties, the city of Bellevue, and the Hood Canal Coordinating Council). However, as successful as these events are, most citizens around the Sound are often left with the dumpster, ditch, storm drain, or backyard incinerator as the only convenient disposal mechanisms available to them.

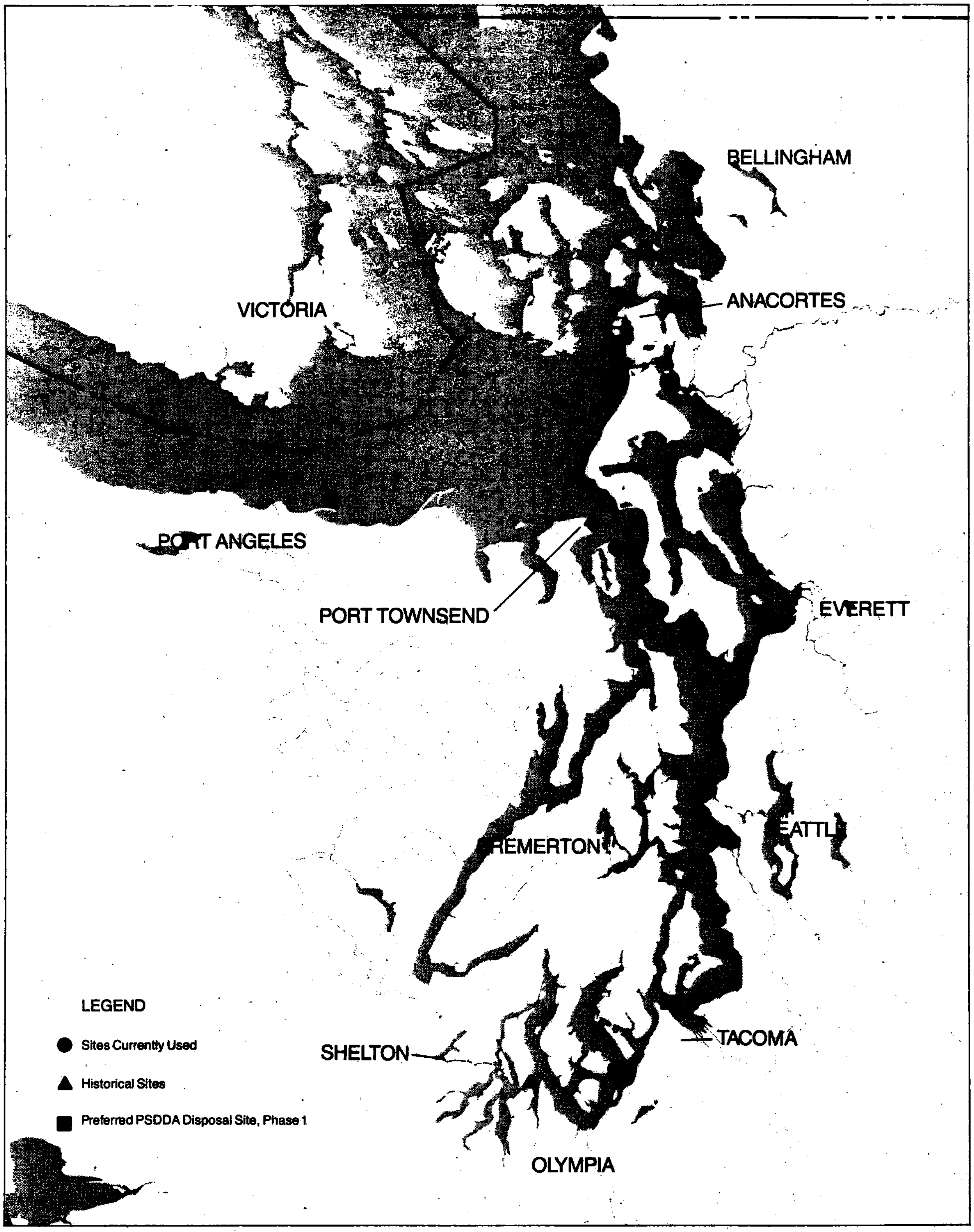
An additional growing concern in Puget Sound involves the disposal of infectious wastes (e.g., blood and blood products, contaminated medical supplies, lab cultures, used first-aid supplies, disposal diapers, and other wastes) from hospitals, laboratories, and homes. Much of this material is currently disposed of in the general solid waste garbage system. This practice puts garbage collectors, landfill workers, and the general public at risk. There are no federal laws that deal directly with the treatment, collection, and disposal of these wastes. However, the 1988 state legislature passed Senate Bill 6264 directing Ecology and DSHS to assess the public health risks associated with infectious wastes, review current and preferred waste management practices, and recommend regulatory programs to minimize public health risks associated with infectious wastes.

Dredged Material Disposal

Dredging is carried out in river mouths and harbors by the U.S. Army Corps of Engineers (Corps) and port districts to deepen channels for new harbor facilities and to maintain old ones that fill in with sediment. Dredging and the open water dumping of dredged material can temporarily block sunlight to aquatic plants, foul the gills of animals, and bury bottom-dwelling organisms. In addition, the open water dumping of material dredged from contaminated sites such as urban bays can spread contamination to relatively uncontaminated areas. Sites for disposal of dredged material in Puget Sound are shown in Figure 4-9.

In 1985 a cooperative study was initiated among the Corps, EPA, Ecology, and DNR to examine and redesign a program for the unconfined, open-water disposal of dredged material in the Sound. This study, known as the Puget Sound Dredged Disposal Analysis (PSDDA), has attempted to identify acceptable open-water disposal sites, define consistent evaluation procedures to determine which sediments may go to these sites, and formulate effective site management plans that will minimize environmental impacts (Tilley et al., 1987). Under the Puget Sound plan, Ecology will develop rules for how to dispose of dredged material that is too contaminated for unconfined open water disposal.

The PSDDA process has taken a unique approach toward judging the acceptability of material for open water disposal: the sediment evaluation is based on known or suspected contaminant effects on organisms. For example, if screening level values for sediment chemistry (developed through the PSDDA process) are exceeded,



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, 1987)

Figure 4-9

DREDGED MATERIAL DISPOSAL SITES IN PUGET SOUND

bioassay tests would be required to determine if the material to be dredged is acceptable for open water unconfined disposal.

The PSDDA study is being carried out in two phases, with the first covering central Puget Sound and the second covering the south and north portions of the basin. Phase I is nearing completion. Draft reports and an EIS have been distributed for comments.

Phase 1 of PSDDA has proposed disposal sites at Everett, Seattle, and Tacoma (Figure 4-9). The sites were selected by overlaying maps of sensitive resources (e.g., crabs and fish) and other factors (major shipping lanes, commercial and recreational fishing areas, etc.) and picking sites that appeared to be less sensitive to harm than most areas. Field studies were then carried out to collect detailed information on currents, sediment movements, and existing biological resources at each area. These data were used to refine and choose the final proposed disposal sites. Site management will include monitoring of sites to determine whether the program is successful. In 1987 the state legislature approved increased dredged material disposal site fees to cover the costs of implementing the PSDDA program (Chapter 79.90 RCW).

In 1987 permits were issued to the U.S. Navy to dispose of dredged material associated with the construction of a major new Navy base in Port Gardner Bay at Everett. This material is too contaminated to be permitted at any unconfined open water disposal site. Sediments unacceptable for regular in-water disposal will be dumped in deep water and then capped with a layer of cleaner sediments. Various studies and models indicate that the material can be capped and that the cap should prevent the contaminants from affecting marine resources in the area, although capping has never been attempted at that depth so the models cannot be verified. The permits require extensive monitoring.

Several groups and agencies have expressed concern that the project will harm the environment. These groups have proposed project alternatives that could minimize harm to important aquatic resources in the area. Seven environmental and citizen groups and the Tulalip Tribes have appealed the issuance of the permits to the state Shorelines Hearings Board and the Pollution Control Hearings Board. The permits could be modified depending on the findings of a joint hearing by the two boards. The groups were successful in obtaining a court injunction that stops any further work on the project until a decision is reached on the appeals. The permit will not be issued until it is reviewed and approved by the Shorelines Hearings Board.

Oil and Chemical Spills

Oil and chemical spills are intermittent but highly significant sources of contaminants to the Sound because of their potential for both short- and long-term biological and water quality effects. When an oil spill occurs, much of the material (depending on the type of oil) remains at the surface where it can be encountered by many species of marine birds and mammals. Surface oil can also affect the floating eggs and larvae of marine fish, and if a spill reaches the shoreline it can cause significant biological and aesthetic damage (PSWQA, 1986f). Heavier oil that may settle to the bottom can affect important species of clams, crabs, and fish. Oil and chemical spills can occur as chronic small-volume spills (e.g., in harbors and marinas), or they can occur as major events such as the large spill of crude oil in Port Angeles Harbor in December 1985 and two spills near Anacortes in early 1988: the sinking of and spill from an oil barge and the spill of contaminated water from an oil tanker. A significant amount of oil and grease is also contributed to the Sound's water bodies from storm drain systems. The long-term consequences and cumulative effects of spills and chronic discharges in the Sound are largely unknown.

The U.S. Coast Guard (USCG) is the lead agency responsible for oil spill response in the Sound, with state and local agencies performing a secondary role (e.g., San Juan County has an active oil spill response committee). In 1984 there were 460 spills reported to the USCG in Puget Sound. In 1986 this number dropped to 229 spills, with 76 percent of those reported being 20 gallons (76 liters) or less (USCG, 1987). Figure 4-10 shows that the major sources of spills in the Sound are fishing vessels, with unknown sources also representing a significant fraction. Spill response and spill cleanup activities are monitored by the USCG and Ecology, with technical assistance provided by NOAA, WDF, and WDW personnel (PSWQA, 1986f). However, the individual or industry responsible for a spill is usually expected to fund the necessary cleanup action. The petroleum industry founded the Clean Sound Cooperative to ensure that specialized vessels, equipment, and crews would be available at any time to clean up oil spills in Puget Sound. The cooperative receives annual fees from members and owns cleanup equipment which is operated by a contractor. Members of the cooperative can call for a rapid cleanup response in any spill situation. A similar organization exists in British Columbia, Canada.

Summary of All Sources

Figure 4-11 schematically depicts some of the major point and nonpoint sources of contamination which are briefly discussed in the following listing (numbered sources correspond to those in the figure). It is evident that no one source discharges only one contaminant. Instead, pollution from the various sources is usually made up of complex mixtures of contaminants.

1. Atmospheric sources include gaseous and particulate lead and hydrocarbon exhausts from automobiles; gases and particles from factory and power plant chimneys; and PAHs and other combustion products from wood stoves and vehicles. These enter the water directly or are carried by runoff.

2. Forestry and logging contribute contaminants from soils that are eroded off roads and clearcuts, herbicides, and insecticides, and also cause fisheries habitat degradation.

3. Runoff from commercial and domestic agriculture carries fertilizers, pesticides, particles eroded from soil and shorelines, and nutrients and pathogens from animal waste.

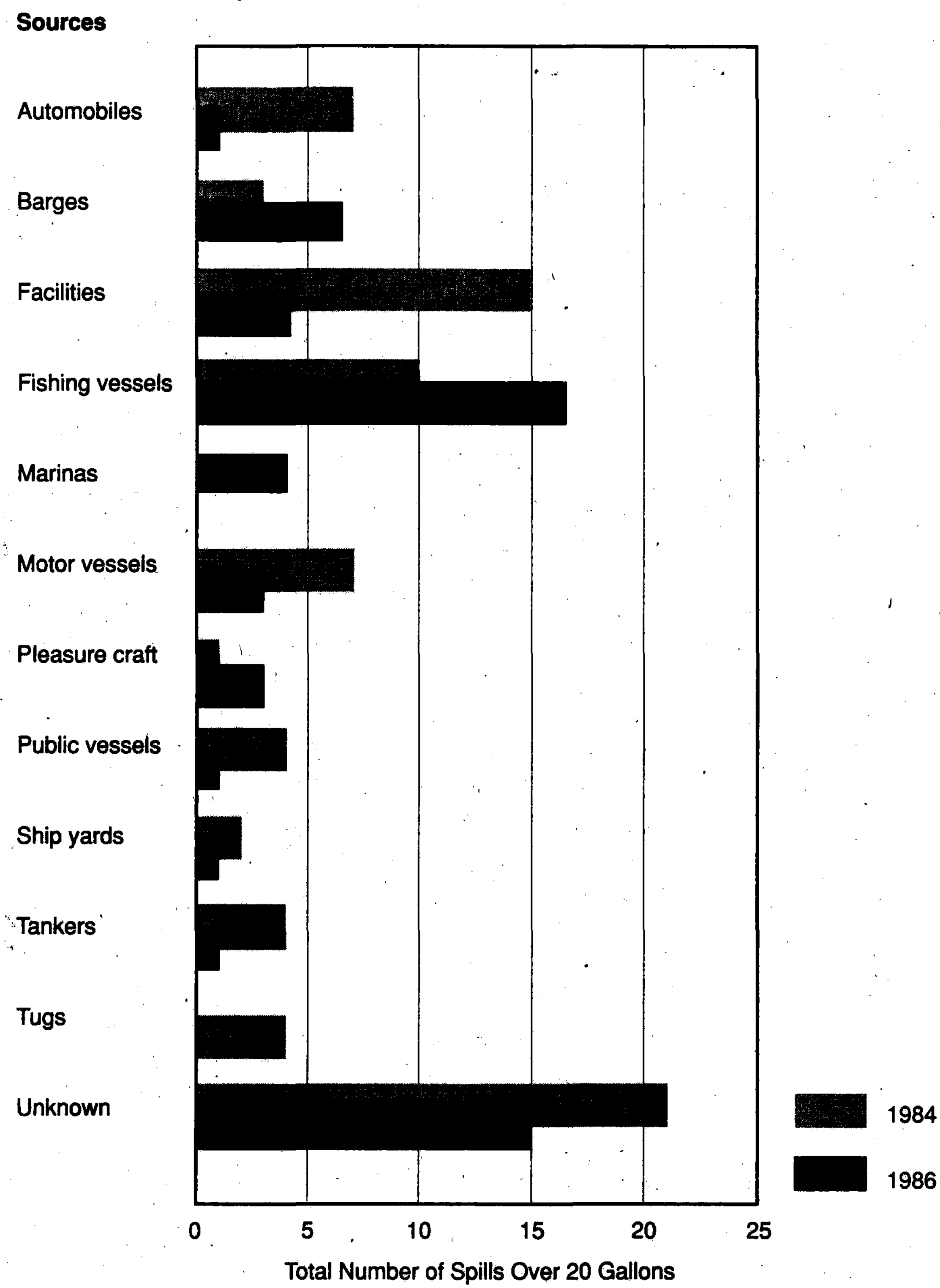
4. Runoff from suburban and rural residential areas carries wastes from lawns and gardens, pets, cars, on-site sewage disposal systems, and household paints and chemicals.

5. Landfills can contaminate surface water and groundwater with virtually every material used and disposed of in society.

6. Highways are significant sources of hydrocarbons, metals, and contaminated particles that wash off into roadside ditches and storm drains.

7. Rivers, though usually not the source of contaminants, carry them into the Sound. The contaminants enter the rivers as direct discharges or as runoff.

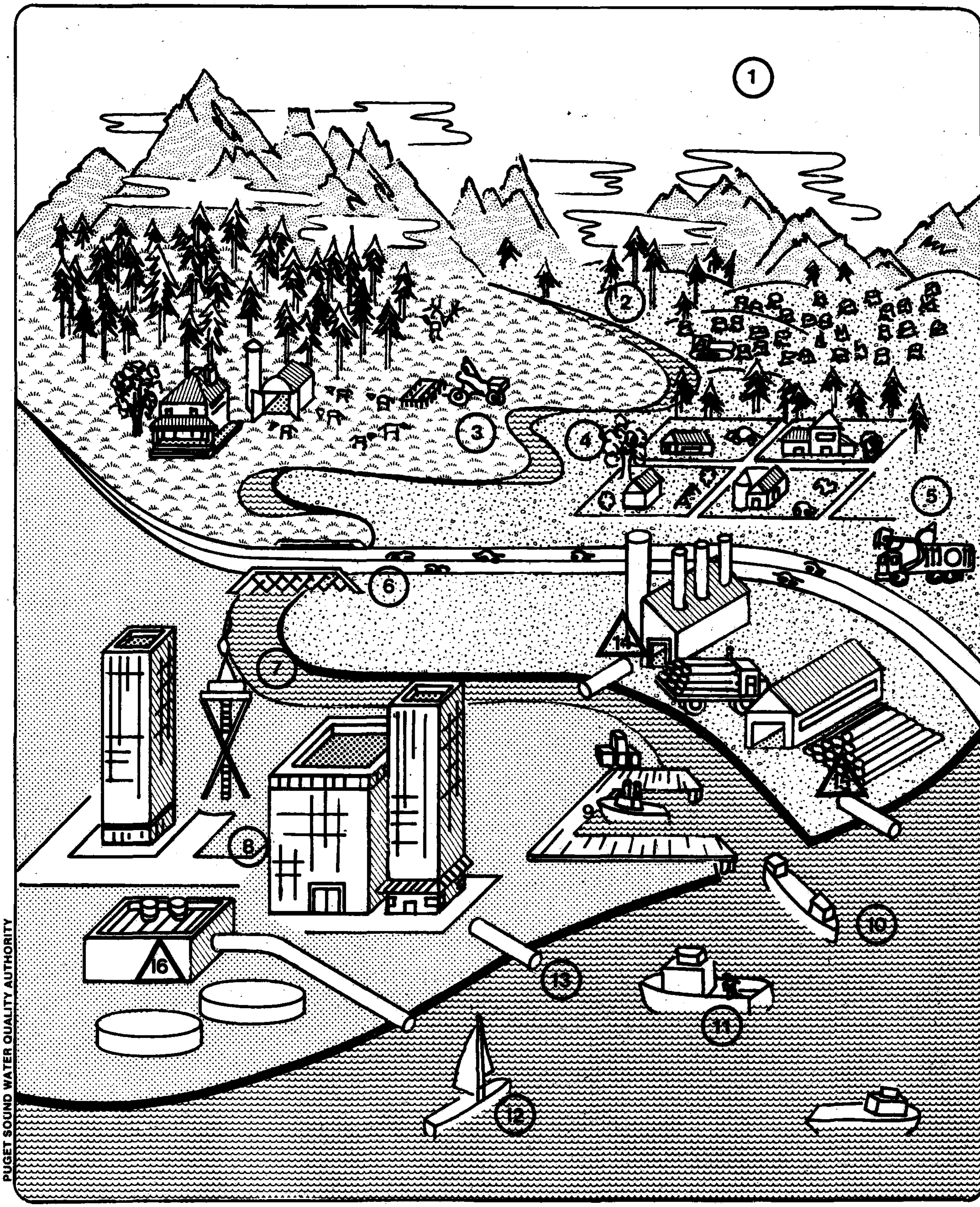
8. Surface runoff from urbanized areas contains a mixture of contaminants (including pathogens, toxic metals and organics, nutrients, and sediments) from streets and motor vehicles, commercial and industrial activities, and human and animal inhabitants.



Reference: USCG, 1987

Figure 4-10

OIL AND CHEMICAL SPILLS IN THE MARINE WATERS OF PUGET SOUND, 1984 AND 1986



PUGET SOUND WATER QUALITY AUTHORITY

Figure 4-11

SOURCES OF CONTAMINANTS ENTERING PUGET SOUND

(Numbered Sources Discussed In Text)

9. Shipbuilding, drydocks, and other marine industries contribute metals, organic chemicals, and other ship-related debris that can enter the Sound directly or through the storm drain system.

10. Shipping can be a source of spills or discharges of cargo, fuel, bottom paints, sewage, and refuse, and of metal contamination directly to the Sound.

11. Dredging and dredged material disposal redistributes contaminated particles in the Sound.

12. Recreational boating contributes petroleum products, bottom paints, sewage, and refuse spillage directly to the Sound.

13. CSOs combine surface stormwater runoff from urban and suburban areas with sewage and industrial wastewater and discharge some of it directly to the Sound without treatment.

14. Industries discharge a wide range of contaminants to rivers and the Sound including toxic metals and complex organic and inorganic compounds depending on the particular industry.

15. Waterfront forest products industries, such as pulp and paper mills and log-shipping yards, discharge wastewater to the Sound.

16. Municipal sewage treatment plants discharge large volumes of treated wastewater that contains a complex mixture of contaminants including pathogens, nutrients, oils and greases, toxic organic chemicals and metals, and sediments.

The sources and associated impacts of selected contaminant groups are shown in Table 4-6. Toxic contaminants not listed in this table are discussed in the following section on the distributions and trends of contamination.

DISTRIBUTION AND TRENDS OF CONTAMINATION

Contamination of the water, sea-surface microlayer, sediments, and organisms will be discussed in this section. Since the last *State of the Sound Report* various environmental studies conducted by governmental agencies, academic institutions, and private companies have increased our level of understanding of what the major sources of pollutants are and where contaminants appear to be concentrated. Several of these studies are discussed in more detail in Appendix B of this report. Most studies have focused on sediments because the major chemicals of concern in Puget Sound tend to be most highly concentrated in the sediments. For example, the so-called Eight Bay Study conducted by Battelle Pacific Northwest Marine Laboratory for EPA showed that while stations in the urban embayments had higher levels of sediment contamination and fish/shellfish disease than did more rural embayments, these rural embayments (e.g., Case Inlet and Samish Bay) also showed some indication of degraded sediment quality (Battelle, 1986). A recent EPA study has further investigated the degree of toxic contamination in less-developed areas of Puget Sound (Tetra Tech, Inc., 1988b). Ongoing studies of the contamination of the sea-surface microlayer in Puget Sound indicate that eggs and larvae of marine organisms that come in contact with the microlayer may be affected by the toxicants that tend to concentrate there (Hardy et al., 1988a, 1988b, 1986). Other studies are investigating the strong correlation between diseases in fish and contaminated sediments in the Sound. For example, liver tumors were found most frequently in fish from Eagle Harbor which is heavily contaminated with PAHs (Malins et al., in press).

One way to judge the severity of contamination in a given location is to compare the concentration of a particular contaminant in a site thought to be contaminated to

TABLE 4-6: SOURCES AND ASSOCIATED IMPACTS OF SELECTED POLLUTANTS

Pollutant	Possible Sources	Water Quality & Associated Impacts
Sediment	Forestry Landslides Streambanks Agriculture Mining Construction Roads Urban runoff	*Decreases light transmission through water which decreases primary productivity and obscures sources of food, habitat, hiding places, and nesting sites. *Directly effects respiration and digestion. *Decreases survival rates of fish eggs and therefore size of population; affects species composition. *Increases temperature of surface water layer and decreases oxygen supply for supporting aquatic life. *Decreases value for recreational and commercial activities (e.g., aesthetic values, sport and commercial fishing, boating and swimming activities, and navigation. *Increases drinking water costs. *Carries organic chemicals including pesticides.
Nutrients (nitrogen and phosphorous)	Forestry Animal operations Fertilized fields Septic systems Urban runoff Industry POTWs[1]	*Algal blooms and decay of organic materials create turbid conditions. *Blooms of toxic algae affect health of swimmers and aesthetic qualities of waterbodies. *Favors survival of less desirable fish species over commercially/recreationally more desirable/sensitive species. *Interferes with boating and fish activities. *Reduces quality of public water supplies. *Reduces dissolved oxygen levels which can suffocate fish species. *Reduces waterfront property values. *Nitrates can cause infant health problems.
Pathogens (bacteria and viruses)	Wildlife Animal operations Manure on fields Septic systems Boating Urban runoff POTWs	*Introduces disease-bearing organisms to surface waters. *Reduces recreational usage. *Increases treatment costs for drinking water. *Creates human health hazards.
Pesticides (including insecticides and herbicides)	Forestry Agriculture Residential uses Golf courses Landfills Urban runoff	*Some hinder photosynthesis in aquatic plants. *Sublethal effects lower organism's resistance and increase susceptibility to other environmental stresses. *Can affect reproduction, respiration, growth, and development in aquatic species and reduce food supply and destroy habitat for aquatic species. *By definition these chemicals are poisons: if released to aquatic environment before degradation, can kill non-target fish and other aquatic species. *Some pesticides/herbicides can bioaccumulate in tissues of fish and other species. *Some pesticides/herbicides are carcinogenic and mutagenic and/or teratogenic. *Reduces commercial/sport fishing and other recreational values. *Creates human health hazard from human consumption of contaminated fish/water.

1. POTWs = publicly owned treatment works

(References: PSWQA, 1986e; Maas et al., 1987)

the concentration of that same contaminant in a "reference" site that has low or undetectable levels of contaminants. The reference site generally is far from known sources of contaminants, and resembles the study site in terms of environmental characteristics, such as depth and sediment type. The severity of contamination at a study site is quantified by calculating the elevation above reference (EAR), which simply is the ratio between the contaminant concentrations at the study site and the reference site. This approach has frequently been used in evaluating sediment contamination, but it also may be used for other components of the environment. EAR is a benchmark of contamination, based on relative concentrations. However, EAR does not necessarily indicate harm because the elevation over reference at which harm might occur is not known.

Another way to judge contamination at a site is to look for biological effects in the field or in the lab. In the field, the numbers and types of bottom-dwelling animals can be measured and compared to data from reference areas which are assumed to be clean. If the animal population at the site being tested is much different from reference areas and if other factors (e.g., physical disturbance, grain size, depth, etc.) can be ruled out, then the difference may be attributed to contamination. However, because of the large natural variability in the populations of bottom-dwelling organisms, a population in the contaminated area must be severely harmed for the damage to be reliably detected. For example, in many cases more than 40 percent of the species (and/or 30 percent of the individuals) have to be eliminated in a bottom-dwelling community before the change will be statistically measurable (PSWQA, 1988a). Collecting more samples in the field increases the statistical reliability of the assessment, but also significantly increases the cost of the study.

Organisms can be collected in the field and studied for various signs of disease or stress. For example, English sole in urban bays of Puget Sound are found to have increased frequencies of liver tumors when compared to English sole from cleaner areas. Thus disease in fish is an indication of the level of contamination of an area. However, a disease response in a fish may be caused by exposure at a location removed from where the fish was actually collected because fish tend to swim over wide ranges. Also, exposure may occur when the fish was in a larval or juvenile form with the disease developing only after the fish matures. This makes it difficult to use diseases in fish to identify contaminated areas without actual water or sediment samples.

Sediments can be taken into the lab where selected organisms can be exposed to the material (or chemical extracts of the material), and their responses noted through various bioassay tests. These tests can be more sensitive than contaminant measurements of sediments taken in the field because most causes of variability can be controlled in the lab. The results of bioassay tests must be carefully evaluated because the various organisms and conditions used in the bioassay may not be the same as those that occur in the field. For sediment contamination, the present trend in Puget Sound is to apply a combination or "triad" of methods consisting of sediment chemistry, bottom-dwelling organism population estimates, and bioassays to compare degrees of contamination at various locations (Long and Chapman, 1986).

The EAR approach to judging the significance of chemical concentrations is being replaced by comparing the chemical concentrations in the sediments being tested to apparent effects threshold (AET) sediment quality values. In the AET method a very large number of sediment samples are analyzed using sediment triad data as discussed above. The resulting database is used to identify the concentration for each chemical at or above which sediments have always failed a biological test. That concentration is the apparent threshold above which effects always occur (hence the name, apparent effects threshold). Although applying an AET-derived sediment quality value to measured chemical concentrations does not constitute a proof of harm, it is much better evidence that harm is occurring in the environment than simple elevation above reference (Johns et al., 1987).

EPA, the Corps, Ecology, and DNR are funding the development of sediment quality values for Puget Sound through the PSDDA process discussed earlier. The development of AET sediment quality values is an ongoing, evolving process that currently has several scientific weaknesses (e.g., the AET data base does not address chronic lethal and sublethal effects in higher organisms such as liver tumors and impaired reproduction in groundfish; Varanasi, 1988, pers. comm.). However, AET sediment quality values are worthwhile as pragmatic management tools and represent an improved methodology for assessing sediment quality and the effects of sediment contamination. AET sediment quality values are currently being used by Ecology to develop criteria for classifying sediments in Puget Sound that have adverse effects. These criteria will be used to limit discharges through the stormwater and NPDES programs and to identify sites with sediment contamination (see Puget Sound plan element P-2).

Water Column Contamination

Nutrients and biochemical oxygen demand

In the open waters and many large embayments of Puget Sound the growth of phytoplankton is controlled by light and the stability of the water column rather than by nutrient levels (Winter et al., 1975; Anderson et al., 1984; Tetra Tech, Inc., 1988a). Therefore, added nutrients generally do not affect phytoplankton growth or water quality in the Sound except in specific locations such as the heads of shallow, sluggishly circulating inlets and embayments, and possibly in some nearshore (shoreline) areas (Thom et al., 1988). Fish kills can occur in these areas because low flushing rates allow algal blooms to proliferate and then die in place as nutrients are depleted, and the oxygen lost in near-bottom waters (when the algae decompose) is not replenished as fast as it is consumed. Examples of areas prone to this problem include Budd Inlet, Dyes Inlet, and Liberty Bay in Kitsap County and Lynch Cove in Mason County.

The discharges of oxygen-demanding wastes from pulp mills and untreated sewage that caused fish kills in the past have largely been controlled (Tetra Tech, Inc., 1988a; Dexter et al., 1985). However, nutrient enrichment from anthropogenic (human-generated) sources can further decrease dissolved oxygen concentrations in areas naturally prone to this problem. Recent studies by Ecology indicate that nutrient inputs from the LOTT (Lacey, Olympia, Tumwater, Thurston County) wastewater treatment plant may be increasing the intensity of algal blooms in Budd Inlet by 30 to 50 percent (URS, Inc., 1986; see Appendix B for a more complete description of this study). To address this problem, Ecology has stipulated in an NPDES permit that the plant remove at least 90 percent of the nutrient load from April through October.

Toxic contaminants

Toxic contaminants in the water column of Puget Sound have been studied less thoroughly than have the toxic contaminants in the sediments. The available information is summarized in Table 4-7. In some cases (e.g., arsenic and iron) natural sources contribute more total mass of contaminants than human sources (Dexter et al., 1981; Galvin et al., 1984). However, toxic contaminants from point sources (including CSOs) can result in acute effects because contaminants are often more concentrated in the vicinity of the discharge pipe and may be more bioavailable than those originating from natural sources.

TABLE 4-7: DISTRIBUTION OF CERTAIN CONTAMINANTS IN PUGET SOUND

	Water	Microlayer	Sediments	Tissue
PAHs	Detected at very low concentrations (<0.5 ppb) in Central Puget Sound. PAHs in water are associated mostly with particulates suspended in water. (1,2,3,4,5)	Can be enriched over 2,000x above concentrations in underlying water. Concentrations in urban areas can be over 1,000x higher than concentrations in rural areas. (3,6,7)	Elevated in urban bays. In Commencement Bay, EAR* ranged from 1x to 570x, with a median EAR of 36x. The highest EARs were found in Eagle Harbor, where values for creosote PAHs were as high as 5,600x. (1,5,8,9,10,11)	Are metabolized and do not accumulate in muscle tissue. Highest metabolite concentrations are found in the liver and bile of bottom fishes from contaminated urban bays, including Eagle Harbor, Mukilteo, the Duwamish River, and Commencement Bay. PAHs have been linked to liver cancers in bottom fish from these areas. (11,12,13,14,15)
PCBs	Undetected or detected at very low concentrations (0.001-0.01 ppb) in Puget Sound. PCBs in water are associated mostly with zooplankton and particulates suspended in the water. (4,6,11)	Not widely studied. PCBs have been found in about half the samples taken in Elliott and Commencement Bays, with concentrations ranging from 0x to 129x the U.S. EPA water quality criteria. (3,7)	Elevated in urban bays; EAR>100x in some sites in Elliott and Commencement Bays. The EAR for PCBs exceeded 1,000x in sediments from an industrial site on the Hylebos Waterway. (8,9,16,17)	Found in nearly all organisms in nearly all areas. Highest levels are found in fatty tissues of marine mammals with long lifespans (e.g., harbor seals). In fish, PCBs concentrate in liver. Concentrations in muscle tissue of fish caught recreationally average approximately 100 ppb. (15,18,19,20,21)
Copper	Detected at very low concentrations (0.1-0.01 ppb) in waters of Central Puget Sound. Copper is found in both dissolved and particulate phases. Concentrations near the surface are elevated near urban areas. (4,22,23,24)	Concentrations elevated from 10x to 20x above concentrations in the underlying water. Copper exists primarily in the particulate phase in the microlayer. Concentrations were up to 300x higher in Elliott Bay than in Sequim Bay. (6,7,25)	Concentrations elevated above reference in Commencement and Elliott Bays, Sinclair Inlet, and Everett Harbor. Highest concentrations were found along the Ruston Shoreline (EAR up to 2,220x), near the old ASARCO smelter. (8,9,11,24,26)	A natural component of the blood of crabs, snails, and some other invertebrates. Concentrations tend to be higher in these organisms than in fishes. Concentrations in the muscle tissue of fish from along the Ruston Shoreline were significantly higher than the concentrations in the muscle tissue of fish from Carr Inlet, but were well under any legal limit. (8,11,18,19)
Lead	Generally detected at low concentrations (<1 ppb) in the water of Central Puget Sound, although high concentrations have been found in Elliott Bay. (6,22,25)	Concentrations elevated from 25x (Sequim Bay) to 55x (Port Angeles Harbor) above the concentrations in the underlying water. Greatest enrichment occurs in particulate fraction. Concentrations in Commencement Bay were elevated from 1x to 150x above those in Sequim Bay. (6,7,25)	Elevated concentrations found in Commencement and Elliott Bays and in Sinclair Inlet. In Commencement Bay, median EAR=7.3x, but EARs up to 680x were found along the Ruston Shoreline. (4,8,9,16,18,24)	Can accumulate in certain tissues of invertebrates, fish, birds, and mammals. Lead has been found in crab muscle tissue and seal liver and kidney tissue, but generally does not accumulate at high levels in fish muscle tissue. (4,11,13,18,19,20)
Zinc	Detected at low concentrations (1-10 ppb) in non-urban waters of Central Puget Sound, but higher concentrations were found in the Duwamish River. (4,6,22,25)	Concentrations were enriched from 14x (Sequim Bay) to 66x (Port Angeles Harbor) compared to the underlying water. Concentrations in Elliott Bay were 1-40x higher than those in Sequim Bay. Greatest enrichment occurs in the particulate fraction. (6,7,25)	Concentrations above reference values found in Commencement Bay, Everett Harbor, Sinclair Inlet, and in several sites near Seattle. Greatest EAR (up to 220x) were found along the Ruston Shoreline. (4,8,9,16,18)	Generally the metal with the highest tissue concentrations. Zinc can accumulate in the tissues of bivalve molluscs, crabs, fish livers, and birds. Concentrations in edible tissues tend to be higher in molluscs (squid, clams) than in fish, but concentrations are only slightly elevated in organisms from urban areas. (8,18,19,20)

	Water	Microlayer	Sediments	Tissue
Mercury	Detected at very low concentrations (<0.01 ppb) in the waters of Central Puget Sound, although not widely studied. (4,18)	Not widely studied, but concentrations in Elliott Bay were 1-72x higher than those in Sequim Bay. (7)	Concentrations elevated above those in rural reference areas found in surface sediments of Elliott and Commencement Bays and Sinclair Inlet. High subsurface concentrations were found in Bellingham Bay. The greatest EAR (up to 1,200x) were found along the Ruston Shoreline, although historical contamination in Bellingham Bay was of similar magnitude. (4,8,9,11,18,24)	Slightly elevated concentrations in muscle tissue from crabs and finfish from Commencement Bay, Elliott Bay, and Sinclair Inlet. In the mid 1970s tissue concentrations in dogfish from Elliott and Commencement Bays were above Food and Drug Administration (FDA) limits, but recent data are not available. (8,13,18)
Arsenic	Detected at low concentrations (1-10 ppb) in Central Puget Sound, although concentrations in sediment pore water can be 10-60x higher than those in the water column. Concentrations tend to be relatively high in marine waters throughout the Pacific Northwest. (4,18,27)	No data available.	Elevated in some sites in Elliott and Commencement Bays and in Sinclair Inlet. The greatest EAR (up to 3,600x) were found along the Ruston Shoreline, near the ASARCO smelter. (4,8,9,11,18,27)	Concentrations in fish and invertebrates from areas containing contaminated sediments similar to those from reference areas. The naturally high arsenic concentrations in the water of Puget Sound is a major source of arsenic to organisms. (8,13,18,19)

*EAR = Elevation above reference, an indicator of toxicity.

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17. Stinson et al., 1987
18. Dexter et al., 1981
19. Matta et al., 1987
20. Calambokidis et al., 1984
21. Landolt et al., 1987
22. Paulson and Feely, 1985
23. Feely et al., 1986
24. Tetra Tech, Inc., 1985b
25. Hardy et al., 1985
26. Peterson and Carpenter, 1986

Contaminants in the water column can occur in both dissolved and particulate forms, which may have different levels of toxicity and different environmental fates. Chemicals that are highly soluble (e.g., compounds such as salts and volatile organics) are found primarily in the dissolved state (Paulson and Feely, 1985; Feely et al., 1986). Concentrations of soluble contaminants tend to decline rapidly with distance from their sources because of dilution. Most of these contaminants are ultimately transported out of Puget Sound.

Toxic contaminants in the water column are found mainly in the particulate phase (Dexter et al., 1981; Paulson and Feely, 1985; Feely et al., 1986; Bates et al., 1987). These contaminants include metals and organic compounds such as PCBs, PAHs, and chlorinated pesticides such as DDT. Also, many substances initially in solution are "scavenged" by particles in the water, which means that they leave the dissolved state to become associated with existing particles (Feely et al., 1986). Particulate contamination from natural sources (e.g., metals in eroded soil) tends to vary seasonally depending on erosion and river flow (Crecelius et al., 1975).

Particles and their associated contaminants eventually sink and become incorporated into the sediments. The location where particulate contaminants from the water column reach the sediments depends on the amount of transport provided by currents, the density and buoyancy of the particles, and the depth of the water column through which the particles must sink. Uptake of particles by planktonic organisms can also accelerate their movement to the bottom (as the particles become "packaged" in feces of zooplankton and higher-level organisms). Contaminants introduced into Puget Sound as particulates in the water column tend to settle and produce high sediment concentrations close to the point of release, particularly in shallow areas with slow currents. This is because when fine, organically rich particles in rivers and stormwater contact seawater, they tend to adhere to one another and settle out more rapidly (a process known as flocculation). Typical estuarine flow patterns that occur at the point of salt- and freshwater mixing tend to prevent these settling particles from being transported far from their source.

Measured concentrations of dissolved and particulate toxicants in the water column of Puget Sound tend to be highest near point sources and in urban areas. For example, the concentration of dissolved copper in Elliott Bay waters in 1981 declined from 1.6 ppb to 0.6 ppb over the distance from 0.6 miles (1 kilometer) to 1.8 miles (3 kilometers) from the mouth of the Duwamish River (Paulson and Feely, 1985). Also, the amount of PAHs contained in the particulate phase of the near-surface water column declined by 80 percent over the distance from Seattle to Admiralty Inlet (Bates et al., 1987). Further information on trends in toxicants in the water column is available for PAHs, PCBs, copper, lead, zinc, mercury, and arsenic in Table 4-8.

Sea-surface Microlayer Contamination

The sea-surface microlayer, located at the interface between the water and the air, is only about 0.002 inches (50 micrometers) thick. It contains high concentrations of floating organic material, composed of a complex mixture of natural and (sometimes) synthetic substances. This organic film has a patchy distribution on the sea surface, and is often visible as a "slick" (Evans-Hamilton, Inc., 1986). The sea surface is a highly productive habitat, supporting an abundance of bacteria, microalgae, and planktonic animals that feed on these sources of food. Moreover, the surface-dwelling eggs and larvae of numerous species of invertebrates and fish may be sufficiently buoyant during certain life stages to be exposed to the sea-surface microlayer. In Puget Sound, the eggs of English sole and sand sole develop on the sea surface, suspended under but possibly in contact with the microlayer (Figure 4-1; Hardy et al., 1986; Hardy and Antrim, 1988).

TABLE 4-8: SOURCES, EFFECTS, AND TRENDS IN SELECTED TOXIC CONTAMINANTS IN PUGET SOUND

	Sources	Effects	Trends
PAHs	Natural and anthropogenic sources include petroleum (e.g., crude oil, crankcase oil, and creosote), atmospheric inputs of particulates produced from combustion (e.g., automobile exhaust and forest fires), and runoff from coal mines. PAHs are also present in municipal effluents, urban runoff, and some industrial effluents. (1,2,3,4,5)	PAHs are highly correlated with liver tumors in bottom fish and may be associated with altered benthic communities and sediment toxicity. The most severe effects observed to date are in Eagle Harbor; other urban areas also have higher rates of liver tumors in bottom fish than do rural areas. (1,6,7,8,9)	Concentrations of combustion-related PAHs have generally decreased with the decline in the use of coal since the 1950s, but concentrations are highly dependent on proximity to sources. Inputs probably will not vary considerably in the near future, although population increases could cause increased inputs. (4,10)
PCBs	PCBs are used as a coolant for electrical components such as transformers and capacitors, although production has been banned since the early 1970s. PCBs can enter the Sound through runoff, spills, illegal dumping, and movements (e.g., in groundwater) from hazardous waste sites.	PCBs can be associated with altered benthic communities, sediment toxicity, and reproductive failure in marine mammals and birds. PCBs may be carcinogenic to humans. The compounds can accumulate in the food chain. Concentrations in marine mammals and birds in southern Puget Sound are high enough to potentially affect reproduction, although cause-and-effect relationships have not been investigated. The impact on human health from consuming fish tissue from Puget Sound that contains PCBs is currently under study. (5,11,12,13,14)	Concentrations in most areas have decreased over time, probably due to a ban on manufacture. In the absence of releases from spills, dumping, or landfills, this decrease should continue. (2,4,15)
Copper	Natural sources, including oceanic water, rivers, and shoreline erosion, contribute about 10x more copper to Puget Sound than do anthropogenic sources. Anthropogenic sources include municipal waste, industrial wastes, and contaminated sediments. (2,3)	Copper is an essential nutrient (especially for crustaceans) at low concentrations, but can be acutely toxic at high concentrations. High concentrations of copper in sediments along the Ruston Shoreline are associated with altered benthic communities. Copper contamination of the sea surface microlayer in urban areas probably is high enough to affect the hatching of floating fish eggs and the growth of phytoplankton. (11,16,17)	Industrial inputs have decreased because the ASARCO smelter has closed. Other trends will be influenced by changes in emissions from industrial and municipal sources, cleanup of contaminated sediments, and population growth. (2,3,4)
Lead	Natural sources, including oceanic water, rivers, and shoreline erosion contribute about 7x more lead to Puget Sound than do anthropogenic sources. Anthropogenic sources include atmospheric inputs from automobile exhaust, urban runoff, industrial effluent, smelter slag, and contaminated sediments near Harbor Island and the Ruston shoreline. (2,3,18)	Lead can be acutely toxic at high concentrations. The metal is associated with altered benthic communities and sediment toxicity along the Ruston shoreline. (2,3,18)	Anthropogenic inputs have decreased because of the reduction of lead content in gasoline and the closure of the ASARCO smelter. Further reductions in the amount of lead in gasoline may continue this trend. (3,4)
Zinc	Natural sources, including oceanic water, rivers, and shoreline erosion, contribute about 10-20x more zinc to Puget Sound than do anthropogenic sources. Anthropogenic sources include municipal and industrial effluents, smelter slag, and atmospheric inputs. (2,3)	Zinc is an essential trace nutrient, but can be acutely toxic at high concentrations. Zinc is associated with altered benthic communities and sediment toxicity along the Ruston Shoreline. Concentrations in urban microlayers do not appear to be toxic. (11,16)	Anthropogenic inputs have decreased because of the closure of the ASARCO smelter and the replacement of steel/zinc pipes in municipal water systems. Future trends will be mediated by reductions in effluent concentrations and increases in population. (2,3,4)

	Sources	Effects	Trends
Mercury	Historically, anthropogenic and natural sources may have been similar in magnitude. Natural sources include inputs from the atmosphere and groundwater. Anthropogenic sources include industrial and municipal wastes.	Organic forms are acutely toxic to marine organisms in high concentrations and are readily bioaccumulated. Mercury is associated with altered benthic community structure and sediment toxicity in City Waterway and along the Ruston shoreline. Limited data indicate that concentrations in dogfish tissue typically exceeded allowable levels for foods marketed in the United States during the 1970s. (3,5,11)	Concentrations in mussel tissue and in sediments in Bellingham Bay have declined since the early 1970s. Inputs from the ASARCO smelter have ceased. (3,19)
Arsenic	Natural sources, including oceanic water, rivers, and shoreline erosion contribute over 10x more arsenic to Puget Sound than do anthropogenic sources. Natural concentrations are about 6x higher in the rivers in the northern Sound than in the southern Sound. The principle anthropogenic source was the ASARCO smelter; other sources include urban runoff and some industrial effluents. (2,3,20,21)	Arsenic is acutely toxic to most marine organisms. This element is associated with altered benthic communities and sediment toxicity along the Ruston Shoreline and in Hylebos Waterway. (11)	The major anthropogenic source (ASARCO) has ceased operations, so concentrations in the sediments and biota along the Ruston Shoreline and the surrounding region should decline. Other sources should remain fairly constant, unless controls of runoff from areas using slag for fill are implemented.

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Concentrations of contaminants in the microlayer can be orders of magnitude greater than the concentrations of the same contaminants in the underlying water (Evans-Hamilton, Inc., 1986). Sources of contamination to the sea-surface microlayer may include the atmosphere (e.g., dust, smoke, or rain), urban runoff, and the water column (e.g., floatable oil and grease from industrial outfalls and organic matter from wastewater treatment plants). A large portion of the contaminants in the microlayer eventually become associated with suspended particles and sink to the bottom. However, contaminants with low solubility in water and contaminants associated with floating particles can become concentrated at the sea surface (Hardy et al., 1988a).

Substances that have been found to concentrate in the microlayer in Puget Sound include PAHs, PCBs, pesticides, bacteria, and metals (Hardy et al., 1986). Additional information on these microlayer substances of Puget Sound is given in Table 4-7. Concentrations of microlayer contaminants tend to be higher near their sources (i.e., urban areas). Several laboratory bioassays have demonstrated that microlayer samples from Elliott Bay, Commencement Bay, and Port Angeles Harbor are often toxic. For example, in a laboratory bioassay, the hatching success of sand sole eggs exposed to a sample of the microlayer from Port Angeles Harbor was reduced as much as 42 percent compared to the hatching success of sand sole eggs exposed to a sample of the microlayer from Sequim Bay (a rural "control area;" Hardy et al., 1988a). Toxicity and the resulting reduced hatching success was believed to be due to a mixture of chemicals rather than to one particular contaminant (Hardy et al., 1988b). However, results of these laboratory bioassays cannot yet be extrapolated to determine what effects the microlayer may be having on naturally occurring surface-dwelling eggs and larvae. There is little evidence that naturally spawned pelagic fish eggs actually come in contact with the sea-surface microlayer (Varanasi, 1988, pers. comm.). More research is needed to verify the results of the laboratory studies, to determine whether actual exposure to the microlayer is occurring in the field, and to determine whether microlayer exposure may be affecting adult populations of Puget Sound fish and invertebrates.

The relative importance of contamination of the sea-surface microlayer compared to contamination of the sediments and the water column is also unknown for Puget Sound. For instance, very little is known about the extent of sea-surface contamination throughout the Sound; how winds may be able to move patches of the contaminated microlayer from place to place; or the persistence of the microlayer, which relates to how long organisms may be exposed to the contaminants. However, microlayer contamination seems to be an emerging concern around the world (Hardy, 1988).

Contamination of the microlayer by tributyl tin (TBT; a powerful toxicant commonly used in antifouling paints) may be a concern in Puget Sound, particularly near marinas. Contamination of the microlayer by relatively high levels of TBT has been discovered near recreational boat marinas in England (Cleary and Stebbing, 1987). This compound has been implicated in causing reproductive and developmental problems in numerous species in harbors and near marinas in Europe and in the Chesapeake Bay (Gibbs and Bryan, 1986; Hall et al., 1987), and it has a substantial potential for bioaccumulation (Ward et al., 1981). Because of the large number of marinas in Puget Sound, microlayer contamination in marinas may warrant particular attention in the future. TBT has been detected in water from marinas in Bremerton and near Indian Island (Grovhaug et al., 1986).

In 1987 the Washington state legislature banned the sale or use of any TBT-based marine paint except for limited use of TBT paint that releases low amounts of the compound consistently over its lifetime (Chapter 70.54 RCW). The slow-release paints can only be used on aluminum hulls or (in spray cans of sixteen ounces or less) for outboard or lower drive units. A number of other states have banned some uses of TBT, and Congress is working on similar national actions. However, the federal legislation will not regulate use of TBT-based paint on large commercial or military vessels.

Groundwater Contamination

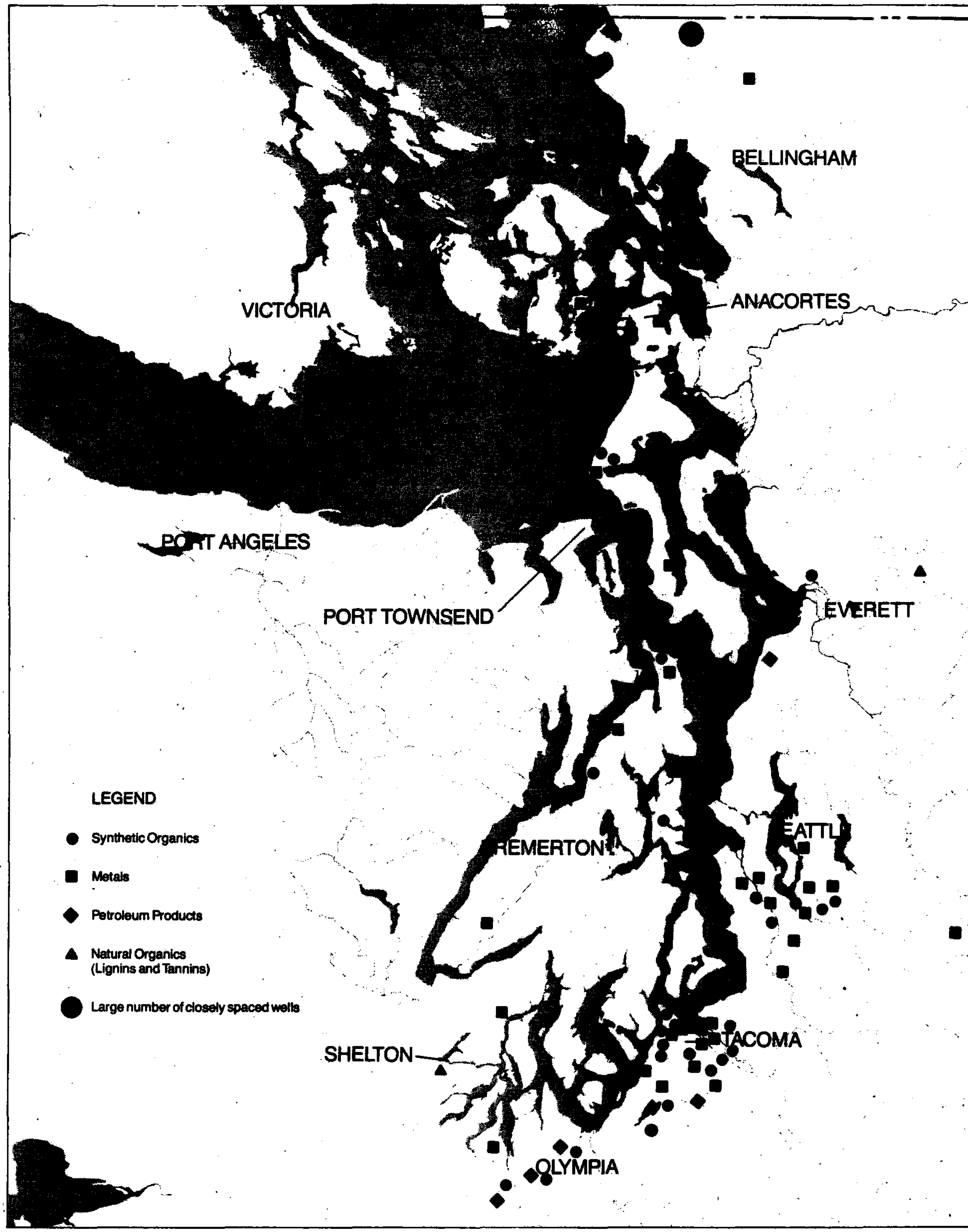
Some groundwater aquifers in the Puget Sound Basin are experiencing water quality degradation in localized areas. Not only does the groundwater become unsafe and unusable, but the contaminants in it may eventually reach Puget Sound by way of springs, seeps, and streams. Trends in groundwater contamination reflect local sources and the movements of the groundwater (Goldstein, 1987, pers. comm.; Ecology, 1986). Some groundwater contamination by synthetic organic chemicals, metals, and petroleum products has been detected by Ecology in all of the counties in the Puget Sound area (Figure 4-12). This problem is most severe in the industrialized portions of Pierce and King Counties. Farm chemicals, including fertilizers and pesticides, have been detected at high levels in the groundwater in localized areas of Thurston, Skagit, and Whatcom Counties.

Groundwater contamination can affect the quality of drinking water. Each of the counties in the Puget Sound area (except for King County) obtains over 50 percent of its drinking water from groundwater. Sites where groundwater contamination from sewage, fertilizer, saltwater intrusion, and other sources results in violations of state drinking water standards are shown in Figure 4-13 (Ecology, 1986, 1987a). Sewage can reach groundwater from faulty on-site sewage disposal systems as well as piped sewer systems. Fertilizers and pesticides can reach groundwater in agricultural and suburban areas. In addition, groundwater contaminated by industrial activities can seep into the Sound (e.g., along the industrialized waterways of Commencement Bay).

Saltwater intrusion occurs when fresh water is removed from an aquifer near the ocean faster than it is replenished by rainfall. There are indications that saltwater intrusion is occurring in the San Juan Islands, on Whidbey Island, and in other sites along the shoreline of Puget Sound, but little is currently known about the extent of this problem. Where saltwater intrusion has been detected in the area, groundwater chloride concentrations have rarely increased more than 10 milligrams per liter (mg/l) or 0.01 parts per thousand (ppt; Skinner, 1988, pers. comm.).

Comprehensive programs to protect and restore groundwater have been initiated in response to recent legislation. The federal Safe Drinking Water Act of 1986 requires each state to develop and implement a wellhead protection program. These programs provide protection plans for the wellhead areas of public drinking water systems, including control of potential sources of contamination. The same act sets up a demonstration program to identify principal or sole source aquifers, and to develop and implement comprehensive plans to prevent contamination of these aquifers. The federal Water Quality Act of 1987 includes a requirement that EPA study conditions in certain aquifers, including existing and potential point and nonpoint sources of pollution and actions necessary to control those sources. The Whidbey Island sole source aquifer is one of those to be studied, and EPA is currently evaluating sole source aquifers in Pierce and Snohomish Counties (Mullen, 1987, pers. comm.).

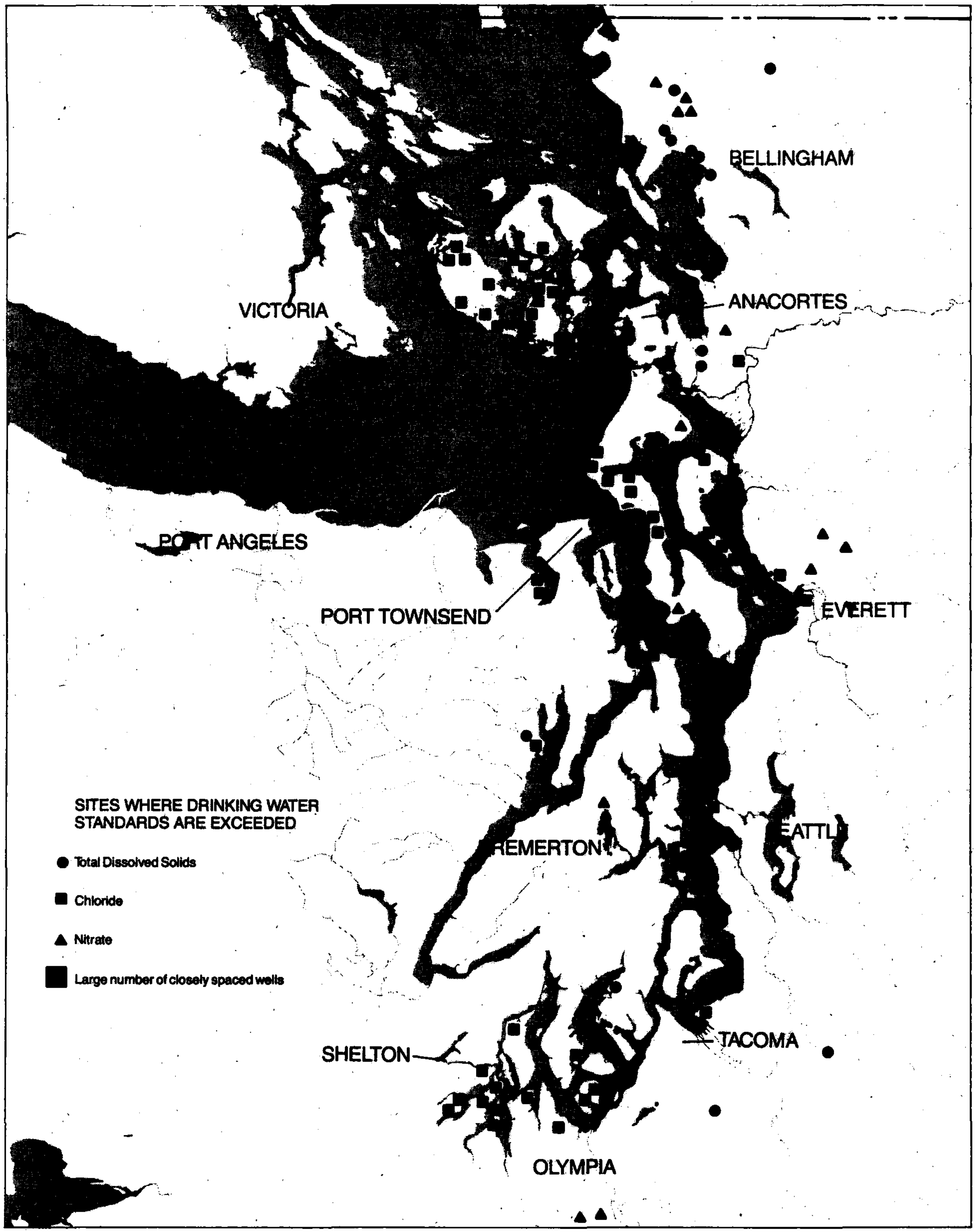
In response to growing concern about groundwater resources in the state, legislation was passed in 1985 that sets up a comprehensive process for more effective groundwater management. In late 1985 Ecology adopted Chapter 173-100 WAC (entitled Ground Water Management Areas and Programs) that defines procedures for identifying and designating groundwater management areas. This regulation



Reference: Ecology, 1987a

Figure 4-12

KNOWN GROUNDWATER CONTAMINATION SITES IN PUGET SOUND



Reference: Ecology, 1987a

Figure 4-13

SITES WHERE DRINKING WATER STANDARDS ARE EXCEEDED IN PUGET SOUND

also establishes procedures for developing groundwater management programs to protect groundwater quality, assure groundwater quantity, and efficiently manage water resources so that future needs can be met. Local agencies and water users are in the process of submitting requests to Ecology for the designation of groundwater management areas throughout the Sound. Once designated, groundwater management programs will be developed for each area by a lead agency working in conjunction with a groundwater advisory committee composed of agency, tribal, and citizen group representatives and local water users. As of January 1988 nine groundwater management areas had been designated in the Puget Sound area. Protection of groundwater resources is also being coordinated with local watershed planning efforts to control nonpoint sources of pollution (see the earlier discussion of nonpoint sources).

Contamination Of Sediments

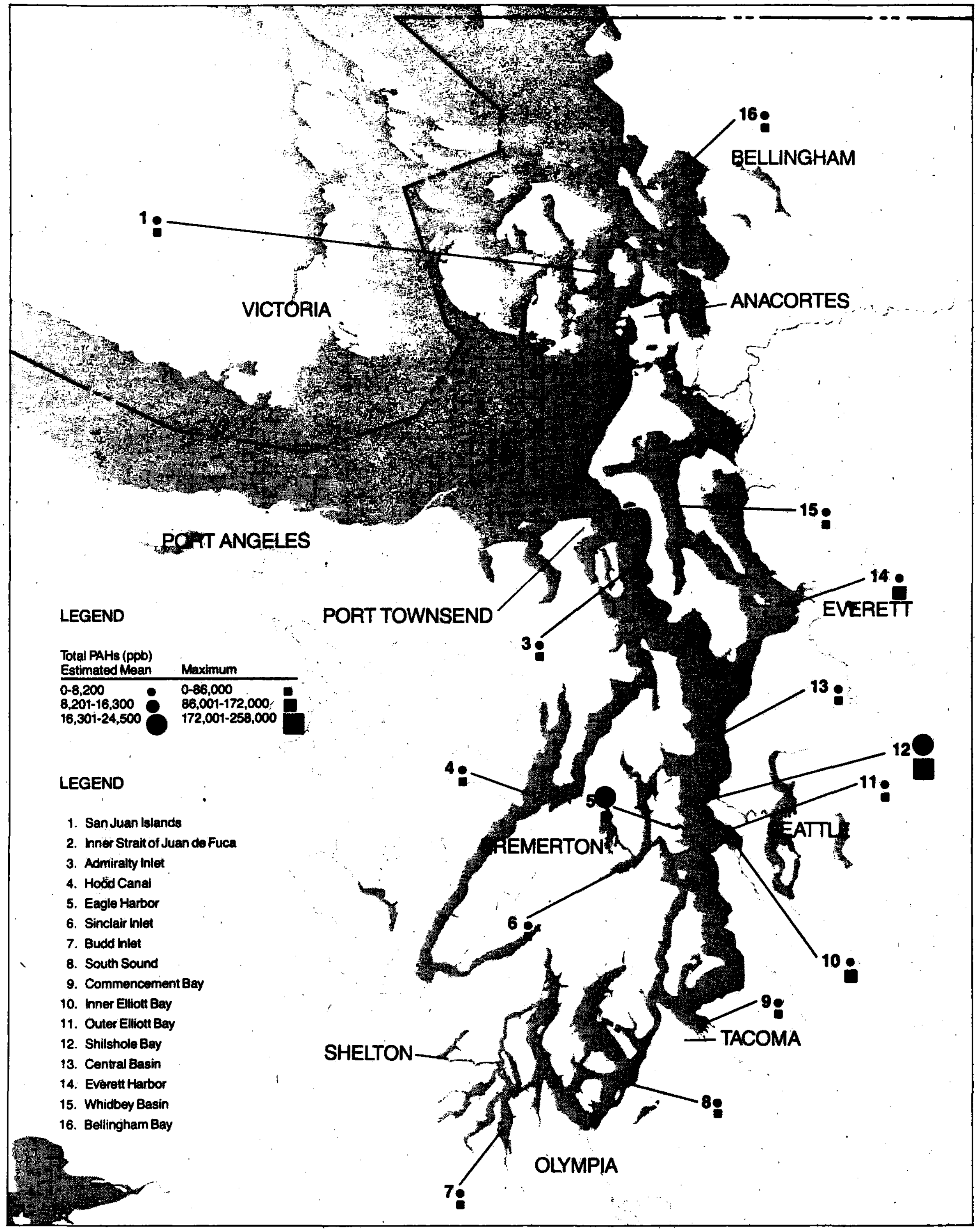
Current conditions

Severe chemical contamination of the sediments appears to be patchy in distribution and is generally found close to the contaminant sources. Most studies have been conducted in urban areas near suspected sources, and few samples have actually been collected in the parts of Puget Sound not located near urban areas.

Thousands of chemicals are known or suspected to exist in the environment, and over 900 synthetic organic chemicals have been tentatively identified in Puget Sound sediments (Dexter et al., 1981; Battelle, 1986; Malins et al., 1987). However, reliable surveys have been conducted for only about 150 toxic chemicals. These chemicals were chosen because they have one or more of the following characteristics: 1) inclusion on the EPA "priority pollutant" list consisting of 126 contaminants; 2) a demonstrated or suspected effect on human health or marine life; 3) one or more present or past sources to the Sound that are large enough to be of concern; 4) a potential for persisting in a toxic form in the environment; or 5) a potential for entering the food chain.

Also, the chemicals selected for study were dictated, to some extent, by the ability of scientists to detect them. No matter how sophisticated a laboratory's analytical capabilities may be, there will always be chemical contaminants in the environment that are impossible to test for (because of limitations in detection technology). Another problem associated with contaminant studies is the accuracy and quality control of laboratory sample analysis techniques. The laboratory certification bill proposed in the Puget Sound plan (see plan element L-1) and adopted by the 1987 state legislature (Chapter 43.21A RCW), will help improve the timeliness and quality of sample results and help standardize procedures used for sample analysis. In addition, there are now established protocols for environmental sampling and analysis (including quality assurance/quality control (QA/QC) procedures) that will help standardize individual studies, improve data quality, and make the comparison of data from different studies more meaningful (Tetra Tech, Inc., 1986c)

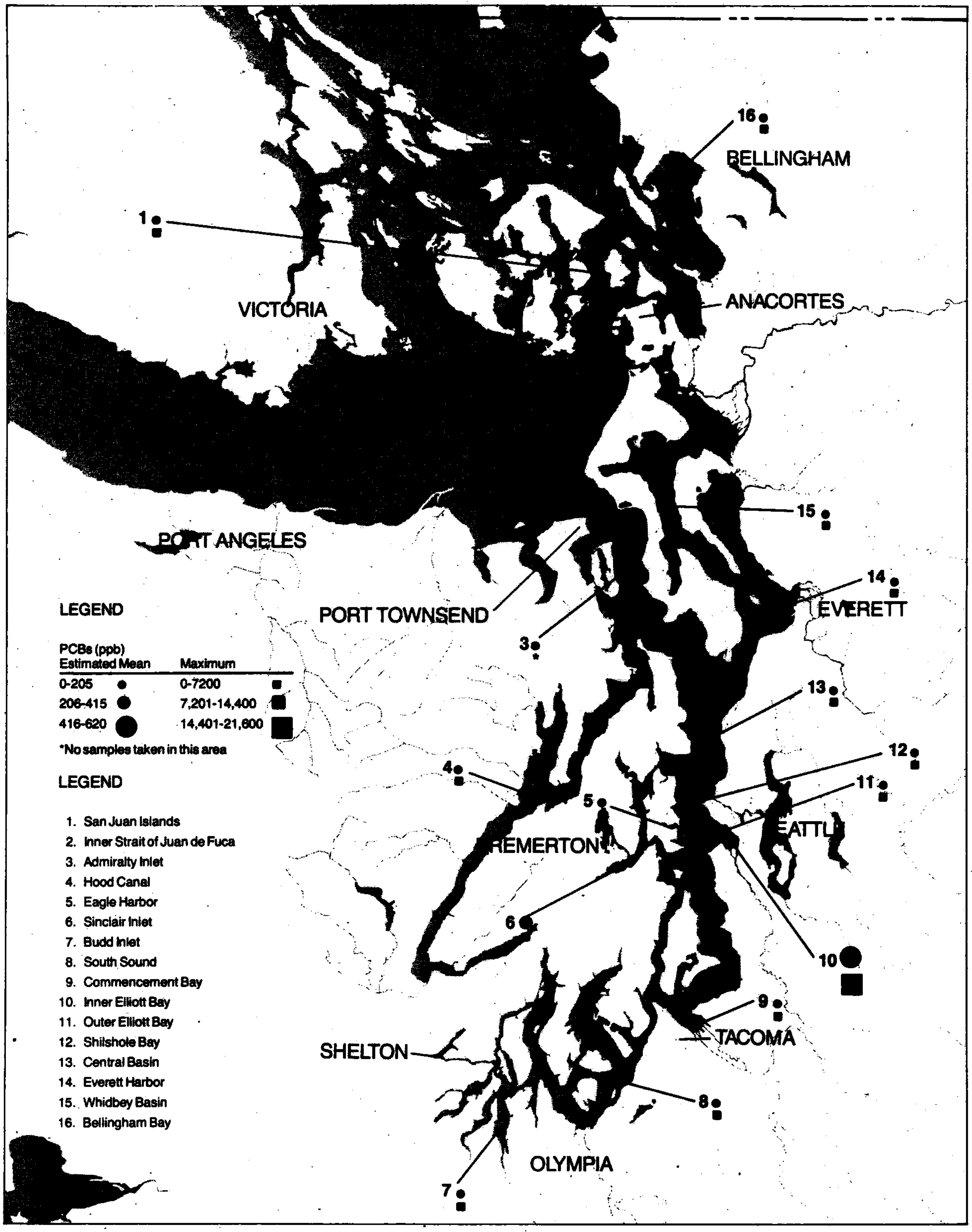
The distribution of PAHs, PCBs, copper, lead, zinc, mercury, and arsenic in the sediments of Puget Sound is summarized in Figures 4-14 through 4-20 and in Tables 4-7 and 4-8. Data shown on the figures were derived from the *Puget Sound Environmental Atlas* (Evans-Hamilton, 1987), the most comprehensive synthesis of data collected between 1980 and 1986. As explained in the atlas, not all areas were sampled equally. For example, most sampling programs have focused on areas that are known to be contaminated, so the information presented probably represents a "worst case scenario" for each location. The contaminants shown in the figures and



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Figure 4-14

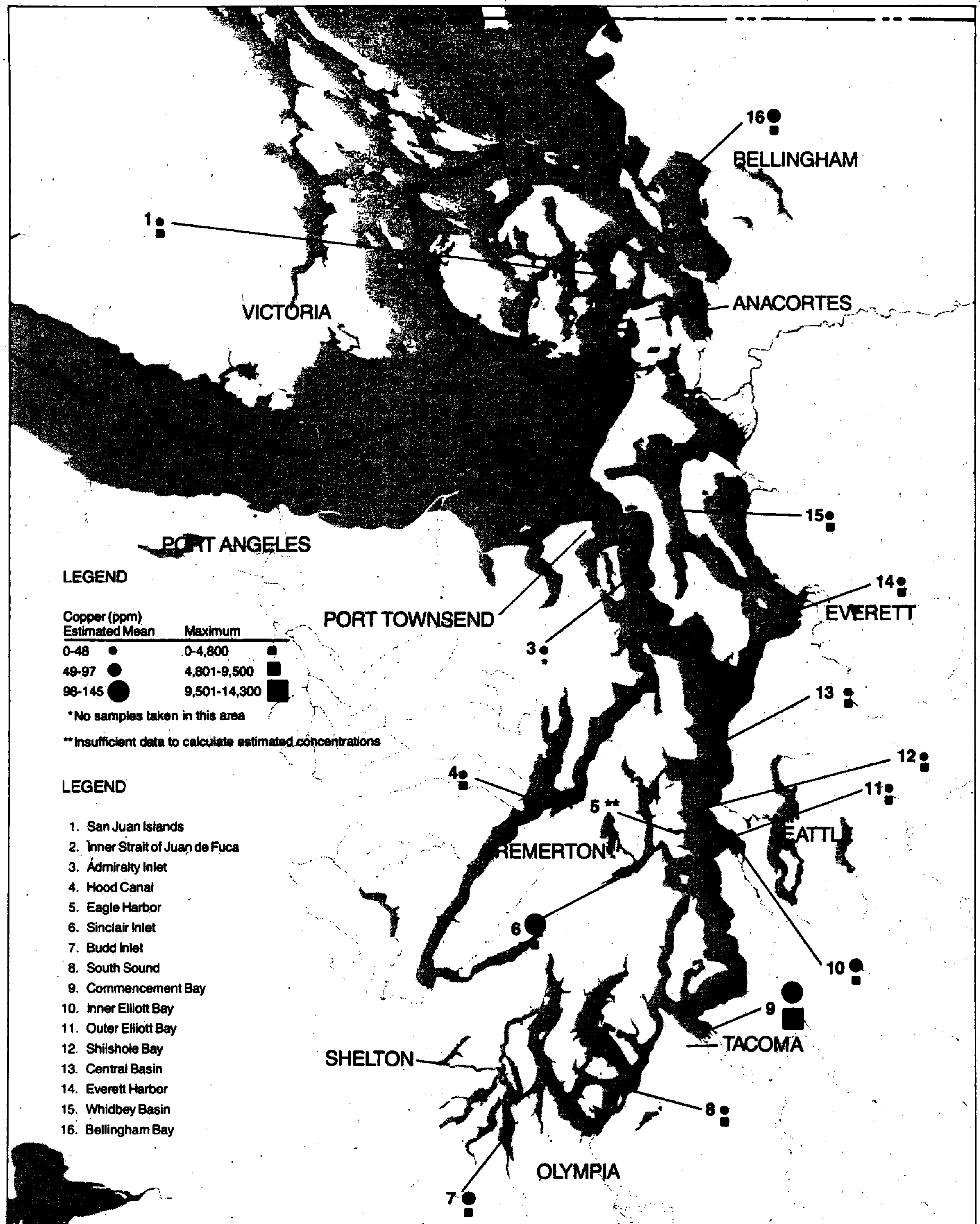
DISTRIBUTION OF PAHs IN PUGET SOUND SEDIMENTS



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Figure 4-15

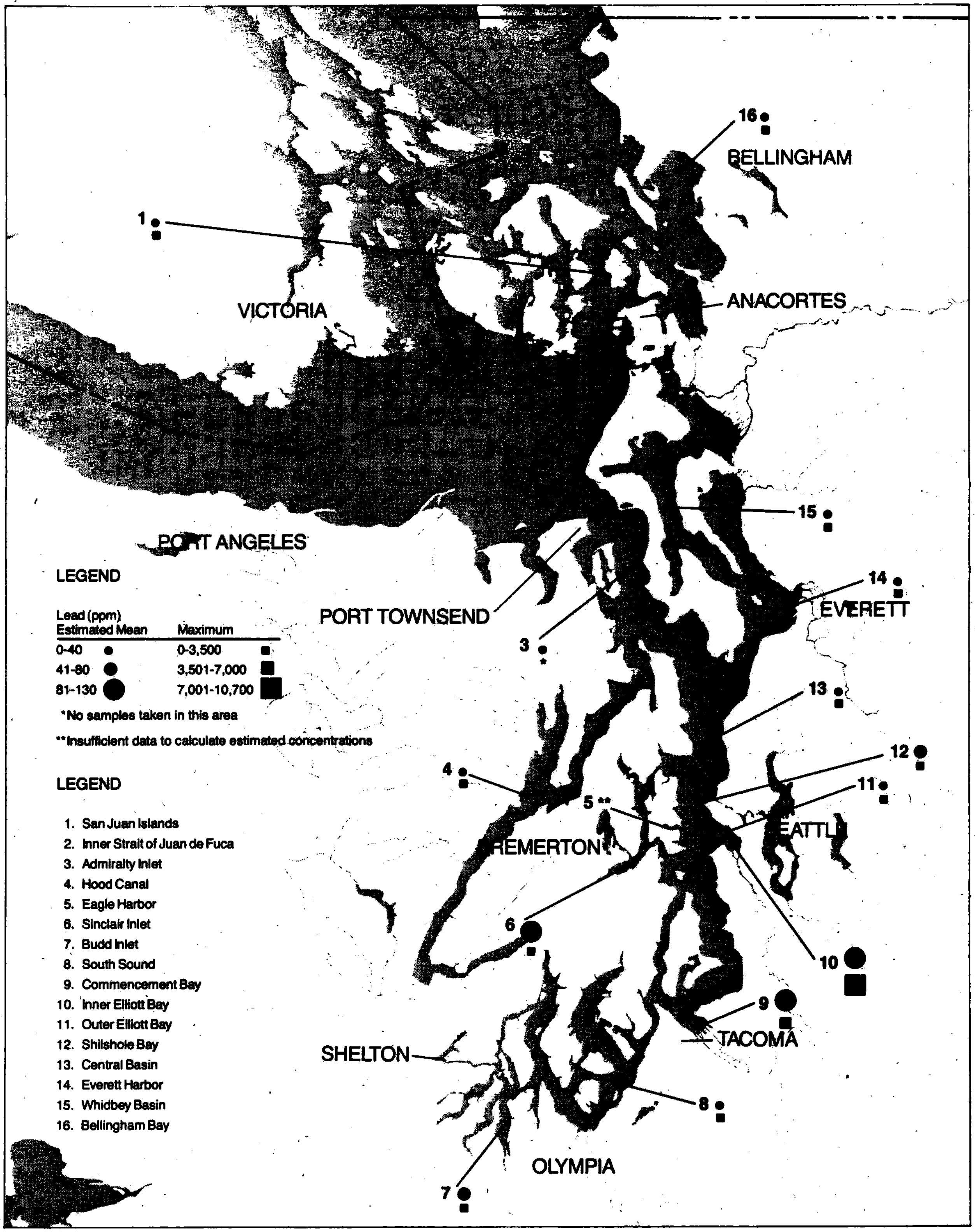
DISTRIBUTION OF PCBs IN PUGET SOUND SEDIMENTS



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Figure 4-16

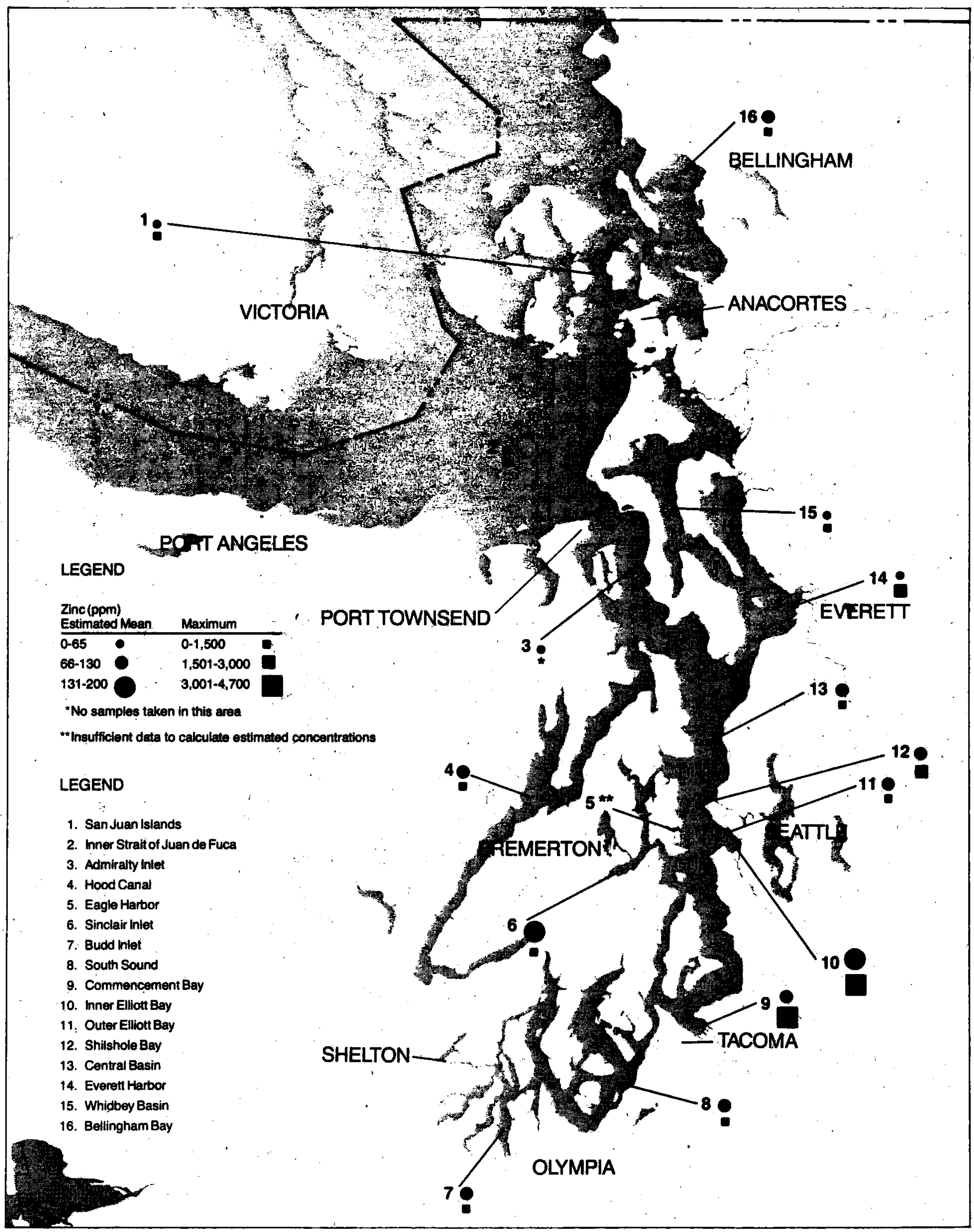
DISTRIBUTION OF COPPER IN PUGET SOUND SEDIMENTS



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Figure 4-17

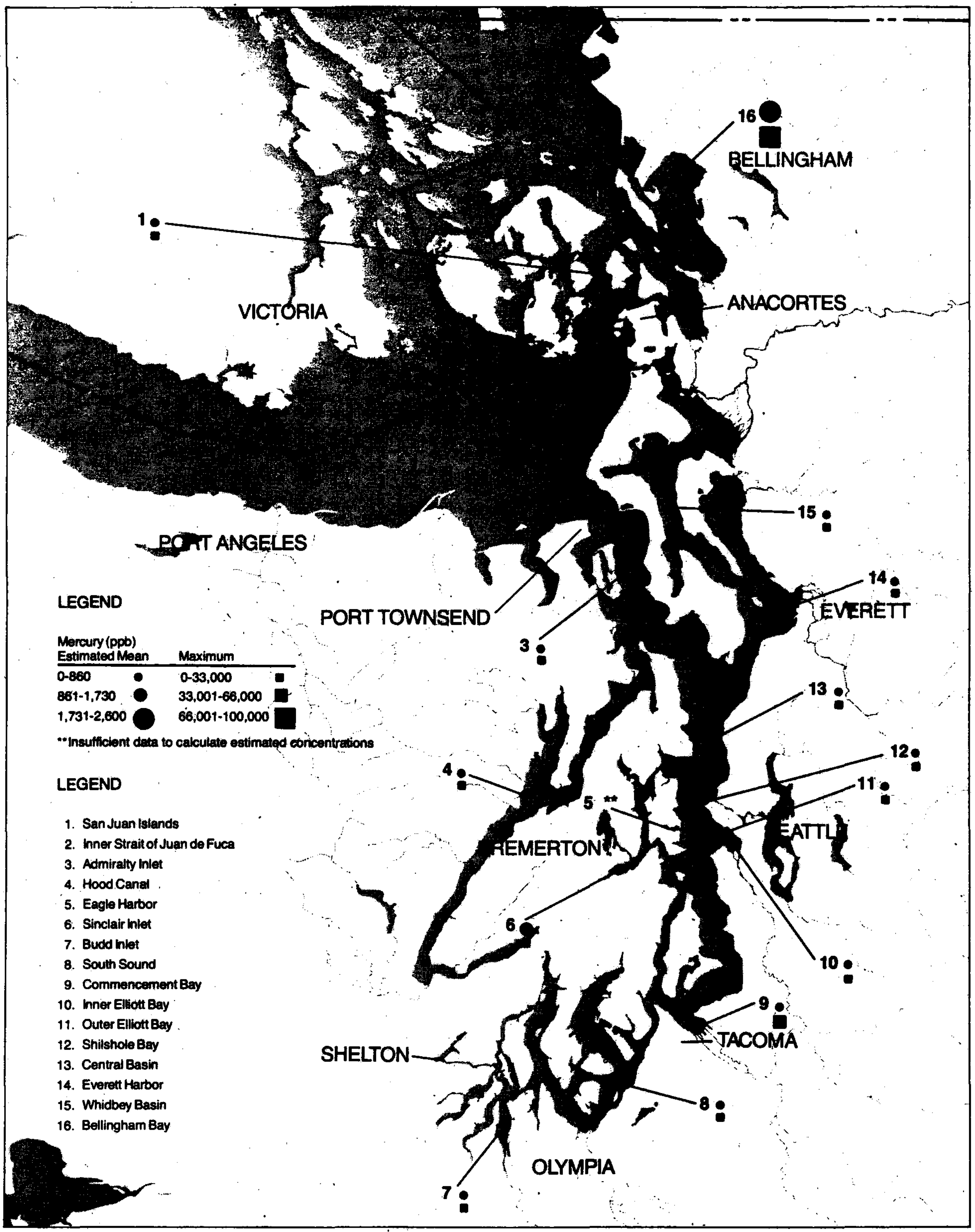
DISTRIBUTION OF LEAD IN PUGET SOUND SEDIMENTS



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Figure 4-18

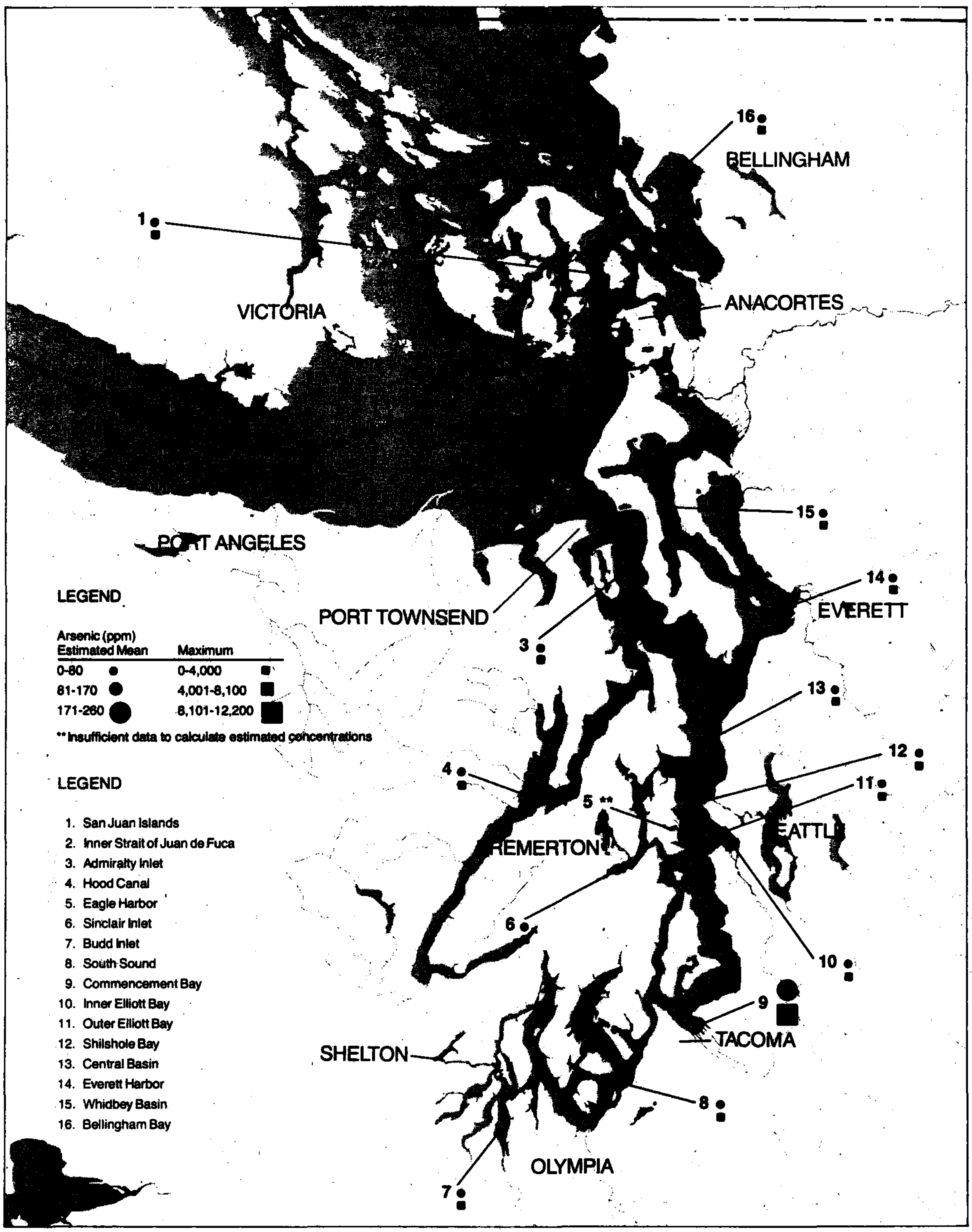
DISTRIBUTION OF ZINC IN PUGET SOUND SEDIMENTS



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Figure 4-19

DISTRIBUTION OF MERCURY IN PUGET SOUND SEDIMENTS



Reference: Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Figure 4-20

DISTRIBUTION OF ARSENIC IN PUGET SOUND SEDIMENTS

tables were selected because they are known to cause environmental degradation in Puget Sound and because they have been relatively well-studied. However, other sediment contaminants also may be damaging the environment in the Sound. The data discussed below constitute the best available information, but sediment contamination has not been completely characterized in any given area.

The heavily industrialized areas of Seattle (e.g., the West Waterway of the Duwamish River) and Tacoma (e.g., the Ruston Shoreline and Hylebos Waterway) are the most contaminated areas yet studied in the Puget Sound basin (Romberg et al., 1984; Tetra Tech, Inc., 1985a, b; Yake, 1985; Stinson et al., 1987). The sediments in these areas contain a complex mixture of toxic substances. Eagle Harbor on Bainbridge Island is highly contaminated in certain areas with PAHs likely derived from creosote used to treat wood at a nearby factory. Everett Harbor and Sinclair Inlet also have received sufficient study to identify them as areas of high sediment contamination (Crecelius et al., 1984; Tetra Tech, Inc., 1985c; Battelle, 1986). Some areas that were of concern in the past are now less contaminated. For example, mercury contamination observed in the sediments of Bellingham Bay during the late 1960s has lessened since its source (a plant that produced bleach and caustic) has been controlled (Webber, 1974).

Several sites are being investigated as abandoned hazardous waste disposal sites under federal and state "superfund" programs. Commencement Bay was the first such area identified. The research undertaken there has formed the technical basis for much of the contaminated sediments work now underway in Puget Sound. In Eagle Harbor severe sediment contamination is currently being investigated under Superfund programs, as is Harbor Island in Elliott Bay. These investigations identify the distribution and level of contaminants, try to identify the parties responsible for the contamination, work to stop or reduce the ongoing chemical discharges, and may ultimately require responsible parties to clean up the contamination. Cleanup is also accomplished using public superfund monies.

Remedial action projects for contaminated sediments are also underway or being planned in urban embayments. Simpson Tacoma Kraft Company has begun a project to cap contaminated sediments at its plant on Commencement Bay in Tacoma. Capping and/or removal of contaminated sediments at the Denny Way CSO in Elliott Bay has also been discussed. The Superfund investigations mentioned above will eventually recommend whether remedial actions should be undertaken in their study areas. In addition, the EPA/Ecology urban bay studies in Commencement Bay, Elliott Bay, Everett Harbor, and Budd Inlet (discussed in more detail in Appendix B), and a comparable effort by the city of Seattle in Lake Union, are identifying and controlling sources of contamination to sediments. After sources are controlled remedial actions can be considered.

Areas that have intermediate to low levels of sediment contamination (e.g., central Puget Sound between Seattle and Tacoma) are predominantly affected by the transport of contaminants by water currents from areas with high contaminant loads (Romberg et al., 1984; Paulson and Feely, 1985; Feely et al., 1986; Curl et al., 1987). Areas with very low levels of sediment contamination are generally far from major development (e.g., Carr Inlet and Sequim Bay; Tetra Tech, Inc., 1985a; Stubin, 1986). However, transport by air and water has introduced some anthropogenic contaminants even in these areas. It is likely that no area of Puget Sound is completely free from some contamination by toxic chemicals.

Contamination of sediments in Puget Sound by TBT may be an emerging issue of concern because of the chemical's tendency to bind to particles and its high potential for bioaccumulation. Little data are available on the extent and degree of TBT sediment contamination in Puget Sound. TBT and other related compounds (butyltins) have been detected in sediments in the Duwamish West Waterway, along the Seattle waterfront, and in Everett Harbor, but were not found in sediments from Port Gardner or President Point (Krone et al., 1988). At present, scientists at NOAA and the National Marine Fisheries Service (NMFS) are developing improved analytical techniques to measure TBT in sediments; techniques already exist for TBT measurement in tissue and in water. The Corps began a screening survey of six marinas in the Puget Sound area in late 1987 to determine if TBT could be detected in the sediments (Smith, 1987, pers. comm.). It appears that data on TBT concentrations in the sediments of Puget Sound may become available in the near future.

Trends in sediment contamination

Accurate measurements of the concentrations of many toxic chemicals in the environment have been made only in the last several years and are very costly. Because of this, there are not enough years of sediment contaminant data to accurately assess trends in surface sediment concentrations over time. Scientists must therefore rely on methods that evaluate the history of sediment chemistry changes as recorded in the deeper sediment layers. Sediments continually accumulate on the bottom of Puget Sound with newer deposits burying older sediments. The approximate date that sediments were deposited often can be estimated by using radioisotope dating methods. The history of contamination can then be evaluated by measuring the contaminant concentrations in successive sediment layers. However, this is often very difficult because contaminants may change chemically after they have been deposited, and the sediments may be altered physically by currents or animals (bioturbation), thus disrupting the successive layers.

Detailed historical sediment data exist only for some contaminants in Puget Sound (Crecelius and Bloom, 1988; Bloom and Crecelius, 1987; Barrick and Prahl, 1987). Historical trends in contamination of sediments in central Puget Sound by PCBs, PAHs, and lead are shown in Figure 4-21 and are summarized in Table 4-8. Trends in the central Sound result from the combined effects of all the pollution in the region, while trends in enclosed embayments reflect the history of specific local sources. Trends in the central basin of Puget Sound show that concentrations of several metals (e.g., lead, mercury, and possibly arsenic and silver) have leveled off or decreased (Bloom and Crecelius, 1987). Specific trends in urban embayments may differ, but presumably sediments will begin to show improvements as a result of aggressive source controls now being implemented. One goal of the Soundwide ambient monitoring program is to better determine trends in areas that have not been well studied.

PCBs were not detected in sediments deposited before about 1930 (Figure 4-21; Crecelius and Bloom, 1988). The manufacture of PCBs began during the 1930s, and their use increased until the early 1970s, when their manufacture was banned. The concentrations of PCBs in sediments were highest in the layers deposited in the 1960s. By 1980 the sediment concentrations in central Puget Sound were lower.

PAHs have natural sources (e.g., forest fires), but a significant increase in their concentration was observed in the sediments of central Puget Sound dating from the turn of the century up until the 1950s. This increase corresponds to the period of rapid growth in the use of fossil fuels (Figure 4-21). PAH concentrations in central Sound sediments are currently less than half of the peak concentrations from the 1950s, but still are about 15 times higher than the baseline levels from the 1880s (Crecelius and Bloom, 1988). The decrease in concentrations of PAHs observed since the late 1950s may have been due to improvements in industrial practices and the conversion from coal to cleaner-burning oil and gas for home heating.

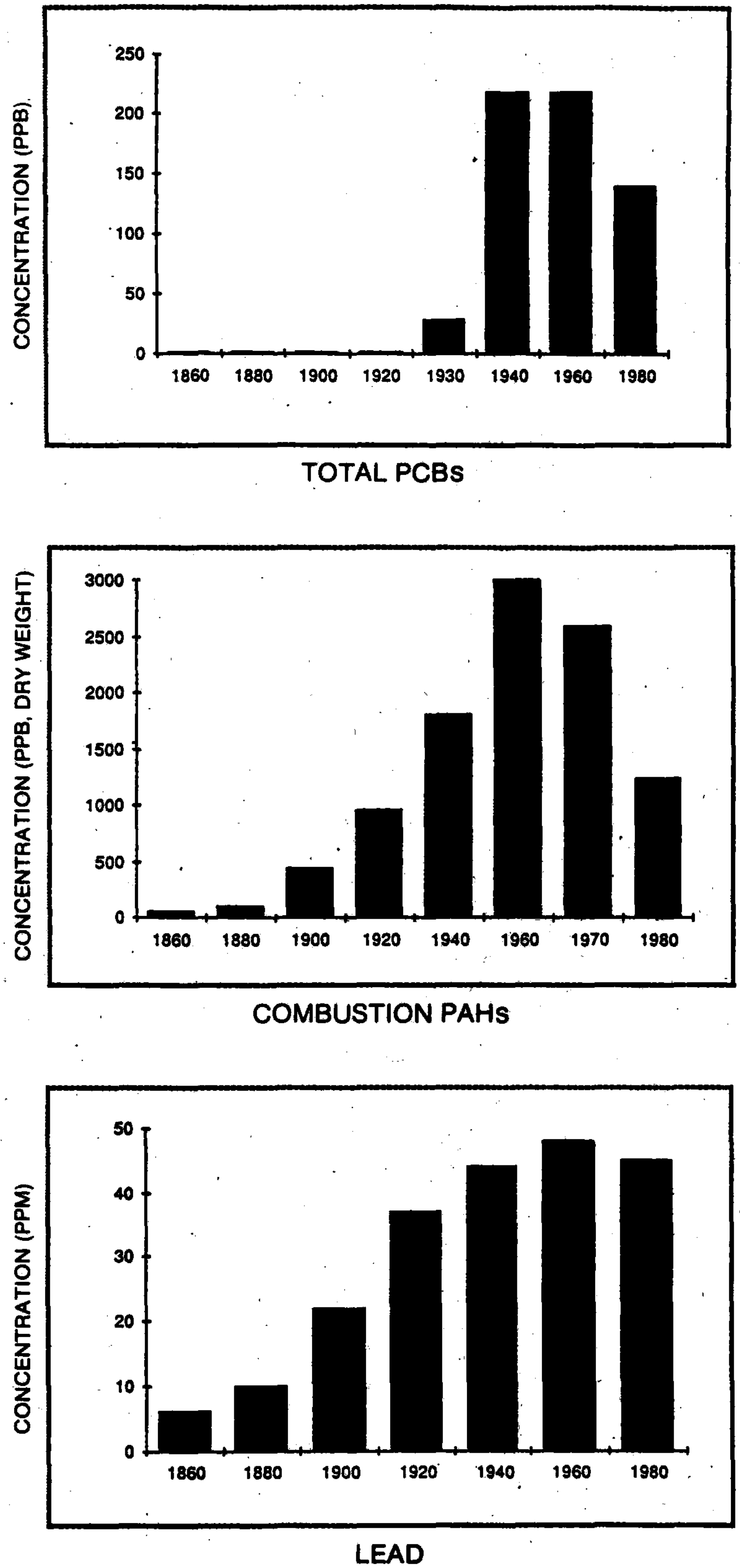


Figure 4-21

HISTORY OF SEDIMENT CONTAMINATION BY PCBs, PAHs AND LEAD IN CENTRAL PUGET SOUND FROM 1860 TO 1980

References: Crecelius and Bloom, 1988; Barrick and Prahl, 1987; Galvin et al., 1984

Lead and other metals have both natural sources (e.g., erosion of soils) as well as anthropogenic sources that contributed to the measurable concentrations observed in the sediments deposited in the 1880s (Figure 4-21; Romberg et al., 1984; Bloom and Crecelius, 1987; Barrick and Prahl, 1987). Sediment lead, mercury, and silver concentrations increased over the last century, but have since leveled off or decreased slightly. This recent decline in lead suggests that one important historical source of lead contamination was automobile exhaust. The amount of lead emitted by automobiles has declined substantially since 1974 when EPA instituted the requirement that new automobiles use lead-free gasoline (Dexter et al., 1985). In addition, the closing of the ASARCO lead-copper smelter in 1985 also probably contributed to decreases in lead concentrations observed in the surface sediments.

Cause-and-Effect Relationships?

One of the most important and difficult tasks confronted by environmental scientists is determining the direct cause or causes of a biological condition observed in the environment. Cause-and-effect relationships are difficult to prove because, in addition to chemical contamination, organisms are continually exposed to a wide range of other environmental stresses, both natural and anthropogenic. These stresses may include changes in water temperature and salinity, variations in food quality and availability, predation, competition, disease, and overharvesting of commercial species.

The information presented in the following sections on contamination of organisms and the human health effects of eating contaminated seafood from Puget Sound suggest that toxic contamination of sediments (discussed in the previous section) is having deleterious effects on the biota of Puget Sound. However, the direct cause-and-effect relationships for these phenomena are not easily established. The greatest impacts on the environment and the biota are found in urbanized areas such as Elliott Bay and Commencement Bay. However, no area of Puget Sound is completely free of pollution.

A summary of biological conditions in Puget Sound, possible causes of those conditions, and an assessment of how the conditions might be affected by pollution is discussed by Long (1988b) and presented in Table 4-9. Some biological conditions are natural phenomena (e.g., low dissolved oxygen in the heads of rural inlets), while others are wholly attributable to anthropogenic influences (e.g., contamination by PCBs). Moreover, the causes of some biological conditions are not yet understood (e.g., the spread of paralytic shellfish poisoning). Nonetheless, it is clear that for those areas of the Sound with serious degradation (such as toxicants in urban bays and bacteria in southern Puget Sound), the reduction of pollutants will likely result in improved water and sediment quality and healthier populations of organisms in the long run.

Contamination of Organisms

Since the last *State of the Sound Report* (PSWQA, 1986b), several new studies have contributed to the general understanding of contaminant effects on organisms as well as the potential for health risks to human consumers of Puget Sound fish and shellfish. For example, we now know that significant correlations exist between the prevalence of liver tumors in groundfish and sediment concentrations of aromatic hydrocarbons such as PAHs (Malins et al., 1984). In Puget Sound liver tumors were found most frequently in fish from Eagle Harbor; the harbor has high levels of PAHs. In addition, English sole from Eagle Harbor and the Duwamish waterway show a higher prevalence of reproductive failure than fish from Port Susan or Sinclair Inlet (Johnson et al., 1988). A recent study discussed in more detail in Appendix B has estimated the amount of contaminants that recreational anglers might ingest by eating fish from the urban embayments of the Sound (Landolt et al., 1987).

TABLE 4-9: BIOLOGICAL PROBLEM INDICATORS IN PUGET SOUND: POSSIBLE CAUSES, CURRENT STATUS, AND OUTLOOKS FOR THE FUTURE

Problem Indicator	Possible Causes	Current Status	Outlook
Histopathological abnormalities in bottomfish (e.g., liver lesions) and other organisms	Toxic chemicals in water, sediment, or food; dietary deficiencies; pathogens; natural environmental stress	Are most frequent in contaminated urban areas such as Eagle Harbor and the Duwamish Waterway. Frequencies of liver tumors in English sole reach 26 percent in Eagle Harbor, but are near zero percent in rural areas such as Carr Inlet. (1,2,3,19,28)	Condition may improve or worsen in response to changes in exposure to pollutants (or other environmental stresses). Toxicant concentrations in sediments appear to be decreasing with improved point source controls and pretreatment. (1,2)
Degradation of benthic communities	Toxic chemicals in water, sediment, or food; organic enrichment; habitat alteration; natural variation in recruitment or mortality	Not systematically studied, and benthic communities are subject to considerable natural variation. Abundances of benthic animals within normal ranges are found in most areas of the Sound. Increases in the abundance of pollution-tolerant worms may be found near some sewer and CSO outfalls, while depressed abundances of benthic animals are found in some small areas that are highly contaminated with toxic chemicals (e.g., near outfalls of the ASARCO smelter). (3,20,21)	Conditions may improve or worsen in response to changes in exposure to toxic pollutants, organic enrichment, habitat modification, or changes in natural factors affecting recruitment or mortality (e.g., El Nino). Conditions have improved since the 1950s when some urban bays were found to be abiotic. (2,3,4,5,6,28)
Chemically contaminated tissue	Toxic chemicals in water, sediment, and food	Concentrations of PCBs have declined in tissue, but low levels of PCB, PAH, and metals contamination are widespread. Concentrations of regulated contaminants in edible tissue very rarely exceed FDA action limits for seafood, but there are few detailed assessments of human health risks from consumption of seafood from Puget Sound. (2,3,7,8,9,22,28)	Tissue levels may change in response to changes in exposure to pollutants. The development of more sophisticated assessments of human health risks associated with eating Puget Sound seafood will provide a better understanding of the significance of any existing levels. Declines in tissue contamination could lead to removal of posted seafood consumption warnings from some urban locations in the Sound. Increases could lead to posting of more warnings, and even the closure of a commercial or recreational fishery.
Bacterial contamination of shellfish	Bacterial contamination of water by sewage or runoff from urban and agricultural areas	In 1986/87, five of 15 requests for commercial shellfish bed classification were denied because of bacterial contamination. Classification status changed at several other beds. (see Table 4-10)	Better control of point and nonpoint sources could decrease closures of shellfish harvest areas. Loss of control over sources could make the problem worse. (10,11)
Plankton blooms	Natural causes include stability of the water column during spring and summer which allows phytoplankton to remain near the surface, where high light levels promote growth. Substantial nutrient inputs may enhance blooms at the heads of sluggishly-circulating inlets.	Not systematically studied, but probably are at background levels in areas with adequate rates of water exchange. Anthropogenic nutrient inputs may be increasing bloom intensity by 30-50 percent in Budd Inlet, but other sites have not been studied in detail. (10,12,13)	Reduction of nutrient inputs may decrease bloom intensity in affected areas (e.g., Budd Inlet). (10,12,13)

Problem Indicator	Possible Causes	Current Status	Outlook
Paralytic shellfish poisoning (PSP)	PSP causes are not well understood, but changes in nutrient ratios or nitrogen availability may stimulate "red tides".	Beach closures caused by the presence of the PSP toxin in shellfish occur during the warmer months in most of Puget Sound. No closures have occurred south of Tacoma Narrows or in the southern half of Hood Canal. (23)	Difficult to predict, but the increases in beach closures experienced from 1978-1985 have leveled off. If nutrient or other anthropogenic inputs are affecting the development of red tides, this problem could increase or decrease, depending on changes in nutrient sources. Unknown additional factors may influence the frequency of red tides. (14,23)
Fish kills	Chemical spills, toxic chemicals in the water, low dissolved oxygen caused by decay of organic matter	Fish kills occur infrequently in the marine waters of the Sound. There were 14 pollution-caused freshwater fish kills reported to Ecology in 1986, while eight freshwater incidences were reported in 1985. (27)	Reductions in the frequency and severity of spills could reduce the problem. Reductions in the chemicals released in permitted discharges and nonpoint runoff, and decreases in nutrient inputs to sensitive areas also could improve the situation. However, natural occurrences of low dissolved oxygen will still occur infrequently in some areas. (15,16)
Declining fish stock	Overfishing, chemical contamination, loss of breeding habitat, natural variation in recruitment and mortality, loss and degradation of estuarine feeding and rearing habitat	Herring stocks are stable in the Central Sound, but are declining near Bellingham. Pacific cod are recovering from the deleterious effects of the El Nino of 1983. Hake and English sole are declining, possibly due to both anthropogenic and natural causes. Salmon are generally stable, probably because of catch limits and large-scale artificial propagation. (24,25)	Reduced pressures from overfishing and pollutant exposure could alleviate this problem, though natural fluctuations in fish stocks would still occur. (15,16)
Sporadic reproductive failures in harbor seals (e.g., premature births, pup mortality)	Not well understood, but disease and toxic chemicals such as PCBs in the food may be contributing to the problem	Populations appear to be increasing in southern Puget Sound and Hood Canal. The cause of these increases is unknown, but they could reflect continued legal protection of marine mammals rather than improvements in reproductive success. (26)	Continued declines in PCB releases may improve the situation, but additional unknown factors such as disease may be influencing harbor seal populations in the Sound. Pup mortality appears to be within natural limits of population variability. (17,18)

REFERENCES CITED:

1. Malins et al., 1987
2. NOAA, 1987
3. Tetra Tech, Inc., 1985a
4. Tetra Tech, Inc., 1985b
5. Tetra Tech, Inc., 1985c
6. Battelle, 1986
7. Versar, Inc. 1985
8. Landolt et al., 1987
9. Gahler et al., 1982
10. URS, Inc., 1986
11. Matches et al., 1984
12. Tetra Tech, Inc., 1988a
13. Anderson et al., 1984
14. Robinson and Brown, 1983
15. FWPCA, 1967
16. Dexter et al., 1985
17. Calambokidis et al., 1984
18. Calambokidis et al., 1985
19. Tetra Tech, Inc., 1986b
20. Galvin et al., 1984
21. Nichols, 1985
22. EPA, 1988
23. Lilja, 1988, pers. comm.
24. Bargmann, 1988a, pers. comm.
25. Sekulich, 1988, pers. comm.
26. Calambokidis, 1988, pers. comm.
27. Ecology, 1987e
28. Long, 1988b

Metals were found in low levels (except for arsenic) in recreationally caught fish. PCBs were present in all specimens of recreationally caught fish in the urban bays, though usually in low concentrations. These reports are discussed in more detail in the following sections.

In spite of progress made in controlling the release of toxic chemicals, disturbed bottom communities and areas of high mortality in amphipod bioassays still exist in the immediate vicinity of some point source discharges and stormwater outfalls in Puget Sound. Degradation also exists in areas where the habitat is altered or destroyed by dredging and filling and in a few areas seriously contaminated by historic sources. Fish mortality ("fish kills") was common in the 1960s but today occurs only rarely in the marine waters of the Puget Sound basin. It is possible that contaminants introduced in one part of the Sound may show up in or affect organisms found in other parts of the Sound. This is because contaminants can be transported in currents and contaminated organisms can move from one location to another. Organisms may also accumulate contaminants like PCBs over time by low-level but continuous (chronic) uptake from the water, sediments, or food organisms.

The accumulation of residues of organic contaminants (e.g., PCBs, PAHs, and DDT) and metals in the body tissues of the organisms of Puget Sound is a concern (Malins et al., 1982). Organics accumulate to higher concentrations in organisms than do metals. However, organics concentrate more in internal organs than in muscle tissue of organisms. The greatest bioaccumulation of toxic substances is observed mainly in organisms found in the industrialized urban areas of Puget Sound (Evans-Hamilton, Inc., 1987). The human health implications of this bioaccumulation are discussed at the end of this chapter.

Levels of contamination in organisms

The most important organic contaminants (in terms of potential effects on biota) observed in Puget Sound organisms include certain halogenated hydrocarbons (e.g., PCBs, DDT and its breakdown products) and PAHs. Some of these chemicals readily bioaccumulate, are known animal carcinogens (cancer-causing), and have been found at levels that are believed to harm organisms in the Sound. The geographic patterns of bioaccumulation are illustrated for PCBs and PAHs in Figures 4-22 and 4-23. These figures represent averages of data from several studies conducted since 1980. However, there have been no comprehensive studies that have consistently looked at tissue accumulation in the same organisms from the same stations over time. Available data shown on the figures probably represent the highest levels present in each area because sampling was generally concentrated in sites with the worst known or suspected contamination.

PCBs are found in various tissues of all the species that have been examined in Puget Sound. Generally, PCB concentrations tend to be lower in muscle tissue than in liver tissue (Malins et al., 1982). Concentrations of PCBs are higher in invertebrates and in fish that live on or near the bottom in the contaminated urban areas of Puget Sound than they are in these animals in the relatively clean non-urban areas (Figure 4-22). The 1974 PCB spill in the Duwamish Waterway is a likely source of the contamination in Elliott Bay. In addition, historic uses of PCBs presumably were higher in the urban areas than in the non-urban areas.

High concentrations of PCBs in the tissues of marine birds were observed in some locations near Elliott and Commencement Bays (Riley et al., 1983; Calambokidis et al., 1985). In some cases, these concentrations were unusually high compared to those in marine birds from other regions of the world. However, only a limited number of herons, pigeon guillemots, and gulls have been analyzed at selected areas. Studies of Puget Sound glaucous-winged gulls have shown that eggshell thinning is most prevalent in birds found in the urban-industrial areas of the Sound, and

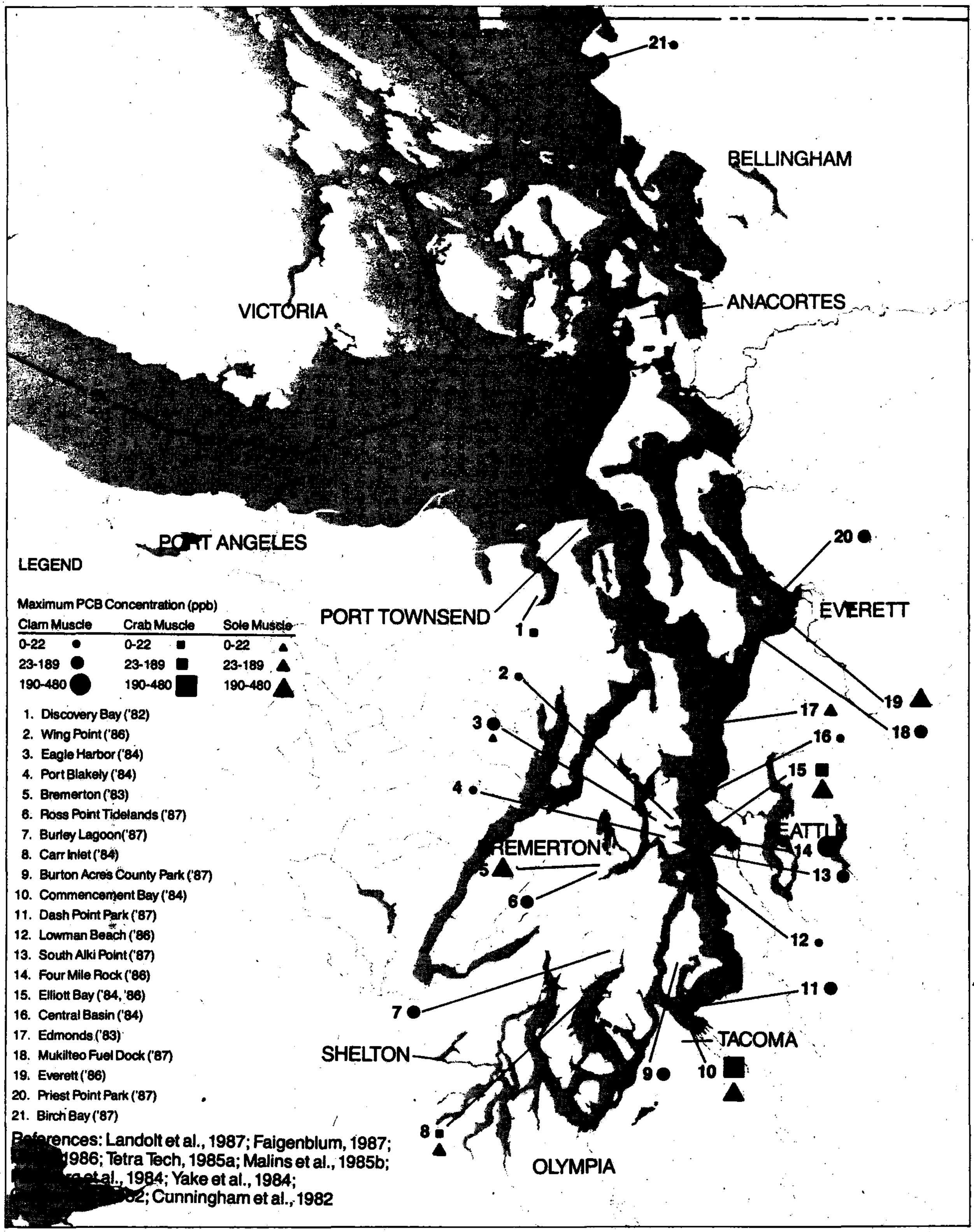


Figure 4-22

MAXIMUM CONCENTRATIONS OF PCBs IN BIOTA FROM PUGET SOUND LOCATIONS

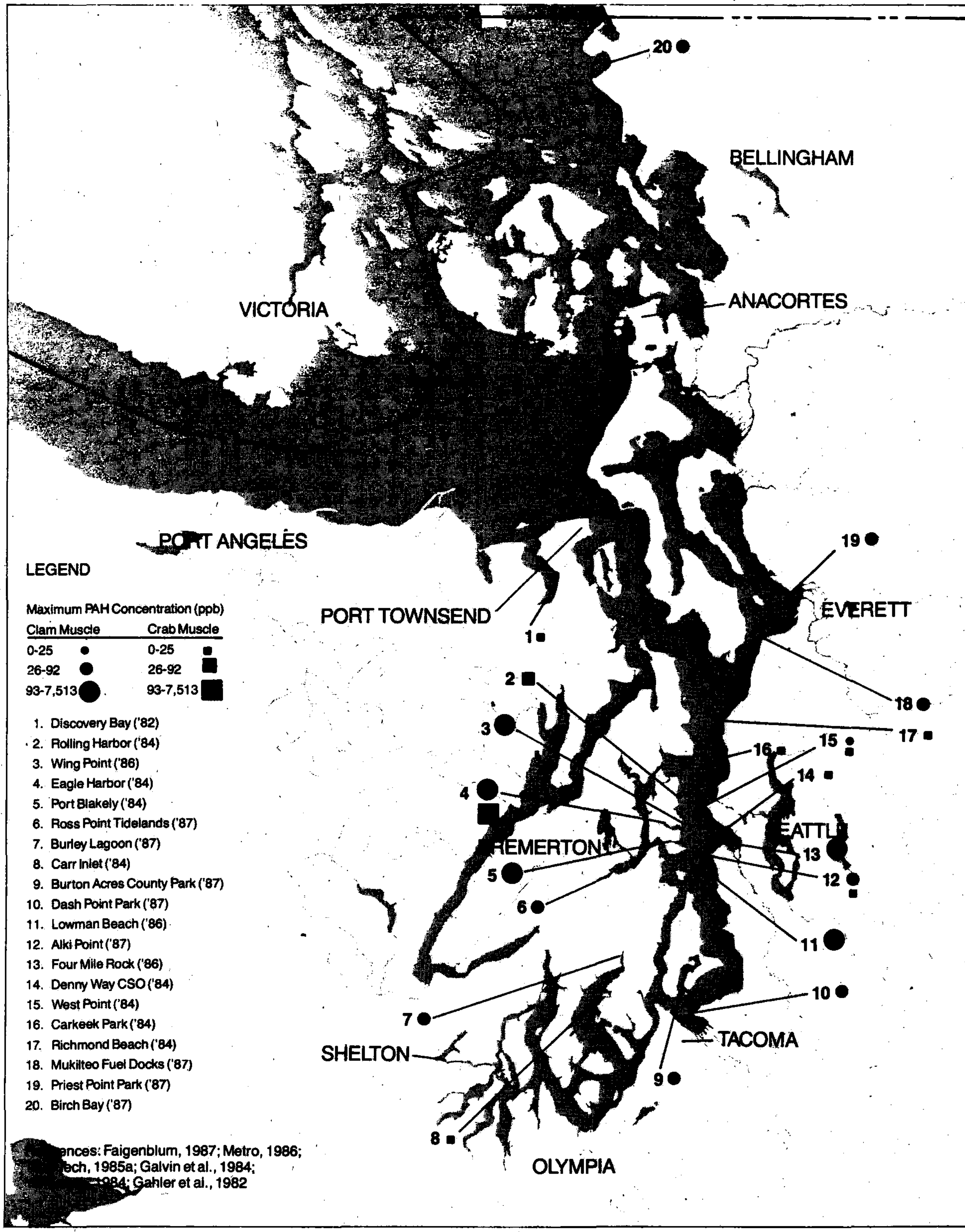


Figure 4-23

MAXIMUM CONCENTRATIONS OF PAHs IN BIOTA FROM PUGET SOUND LOCATIONS birds nesting in these areas may be experiencing some reproductive failure (Speich et al., 1988). Widespread sampling of other populations of marine birds in Puget Sound has not occurred so their overall condition is not known. Some marine birds do not feed exclusively in Puget Sound and may be accumulating chemicals from food eaten elsewhere. Further studies may be needed to determine whether a serious problem exists with contamination of marine birds.

PCBs appear to be the most highly concentrated contaminant of all those measured in the marine mammals of Puget Sound (Calambokidis et al., 1984, 1985). The concentrations of PCBs found in harbor seals in southern Puget Sound in the 1970s were among the highest reported in the world, although levels now appear to be dropping. In studies conducted from 1977 through 1985, PCB concentrations in the blubber of harbor seal pups from the southern Sound averaged about 175 ppm (wet weight) in 1972, 85 ppm between 1975 and 1977, and 25 ppm in 1984-85 (Calambokidis et al., 1988). Blubber concentrations in seals from other areas of the Sound also appear to have dropped since the 1970s. It is not known why PCB blubber concentrations were so high in southern Puget Sound seals. It is suspected that seals were accumulating the compound through the food chain from several possible sources in the southern Sound such as a site on McNeil Island. PCBs probably had an impact on Puget Sound harbor seal populations in the 1970s (reproductive problems were reported in southern Sound populations in the early 1970s). However, PCBs do not appear to be currently affecting harbor seals in the Sound because populations are increasing in most areas (Calambokidis et al., 1988).

DDT and its breakdown products are still found in organisms throughout Puget Sound, but concentrations generally appear to be low and declining (Matta et al., 1987). The use of DDT was banned in the United States in 1972, but these substances are quite stable chemically. Therefore, current sources of DDT contamination still may come from sites affected by past applications (e.g., resuspension of existing contaminated sediments and runoff from farms).

The potential for bioaccumulation of PAHs appears to differ among types of organisms. Sedentary, filter-feeding molluscs (e.g., clams and mussels) appear to lack an effective mechanism for metabolizing PAHs, so these organisms tend to accumulate this contaminant group at substantial levels (Yake et al., 1984). Shellfish in the Commencement Bay waterways, Elliott Bay and Duwamish waterways, Eagle Harbor, and the area around the Mukilteo fuel depot show high levels of PAHs (Figure 4-23). PAHs do not accumulate in fish muscle tissues because fish metabolize or change these substances in the liver (Krahn et al., 1986). However, elevated levels of harmful PAH metabolites (metabolic breakdown products) have been found in the bile of English sole.

In general, the concentrations of metals in organisms throughout Puget Sound are not as variable as those of organic contaminants like PCBs and PAHs. Marine fish usually do not accumulate substantial amounts of most metals in tissue, even in areas with metal-laden sediments such as the Ruston Shoreline (Tetra Tech 1985a; Landolt et al., 1987). The limited data available for salmon indicate that no edible muscle tissue samples exceeded U.S. Food and Drug Administration (FDA) levels for the accumulation of metals (Romberg et al., 1984). Arsenic is ubiquitous in the environment and is found in relatively high concentrations in fish through the northeast Pacific. Fish in Puget Sound actually have lower levels of tissue arsenic than many species in the open ocean (Long, 1988a, pers. comm.). Arsenic concentrations in Puget Sound fish tend to be highest in Commencement Bay, Elliott Bay, and Sinclair Inlet, but much of the arsenic is probably of natural origin and does not appear to effect the health of fish (Malins et al., 1982).

Elevated concentrations of certain metals such as mercury, lead, and copper were found in the tissues of bivalves, crustaceans, and birds from industrialized areas of the Sound (e.g., the Duwamish River, Commencement Bay, and Bellingham Bay; Dexter et al., 1981). For example, mussels near a bleach and caustic plant in Bellingham Bay had elevated tissue concentrations of mercury; the plant released substantial amounts of mercury during the late 1960s (City of Bellingham, 1985). In the mid-1970s dogfish sharks were found to have elevated mercury concentrations (average concentrations approximately 1.0 ppm) in both urban and rural areas in Puget Sound, with the highest concentrations observed in Elliott and Commencement Bays (Hall et al., 1977). However, dogfish appear to concentrate mercury in their tissues, and these levels are not necessarily elevated above natural background levels. Marine fish in most of the Sound do not have tissue levels of mercury that are elevated above natural levels (Crecelius, 1988, pers. comm.). Concentrations of metals in the liver and kidneys of harbor seals from southern Puget Sound were not high except for mercury in some individuals (Calambokidis et al., 1984)

Effects of contamination on organisms

Environmental stresses may act singly or in combination to affect organisms in a myriad of ways. For example, chemical contaminants often combine to make complex chemical mixtures. This makes it difficult to single out the effects of a particular contaminant and also raises the possibility that some unknown combination of chemicals could be interacting to cause a biological problem. Since only a small number (about 150) of the total known chemicals (more than 6,000) are measured with any frequency in the environment, the real cause of a particular biological effect (for example, reproductive failures in urban bay groundfish) may be overlooked. In addition, sublethal contaminant effects detected in organisms (e.g., groundfish liver tumors) may or may not be affecting the health of individuals or entire populations of organisms.

Amphipod bioassays and sediment toxicity

Sediment toxicity bioassays are used to determine whether sediments are toxic to the organisms that might live on or within the sediments. Only a few types of hardy species can occupy sediments that contain high concentrations of toxic chemicals, which probably explains why the bottom-dwelling community might be less diverse (or less healthy) in a contaminated area. Much of the bioassay data on the toxic effects of sediments in Puget Sound have been generated using a bioassay test with the amphipod crustacean, *Rhepoxynius abronius*. Amphipods are small, shrimp-like animals (sometimes called sand fleas) that live near the sediment surface in many parts of the Sound. They are important prey for many types of fish and many are sensitive to contamination. The amphipod bioassay measures mortality in a test population of *Rhepoxynius abronius* following a 10-day exposure to field-collected sediment in the laboratory.

The results of amphipod bioassays conducted on sediments from over 300 locations throughout Puget Sound are presented in Figure 4-24 (Long, 1985, 1988b). These data are biased towards the worst case because studies were usually conducted in suspected areas of contamination. In general, very high maximum amphipod mortalities (greater than 50 percent) have been found at sites with high concentrations of toxic chemicals in the surface sediments (Bellingham Bay, Commencement Bay, Eagle Harbor, Elliott Bay, and Everett Harbor; Tetra Tech, Inc., 1985a,b,c, 1986b).

In addition to the amphipod bioassay, a variety of other tests have been conducted on Puget Sound water and sediments. They include bioassays based on the mortality and/or abnormality of developing oyster larvae, genetic abnormalities induced in fish cell cultures, respiration changes in oligochaetes (small marine worms), and changes in bacterial luminescence. These different bioassay methods have been used to evaluate dredged material disposal effects, and are being used to develop

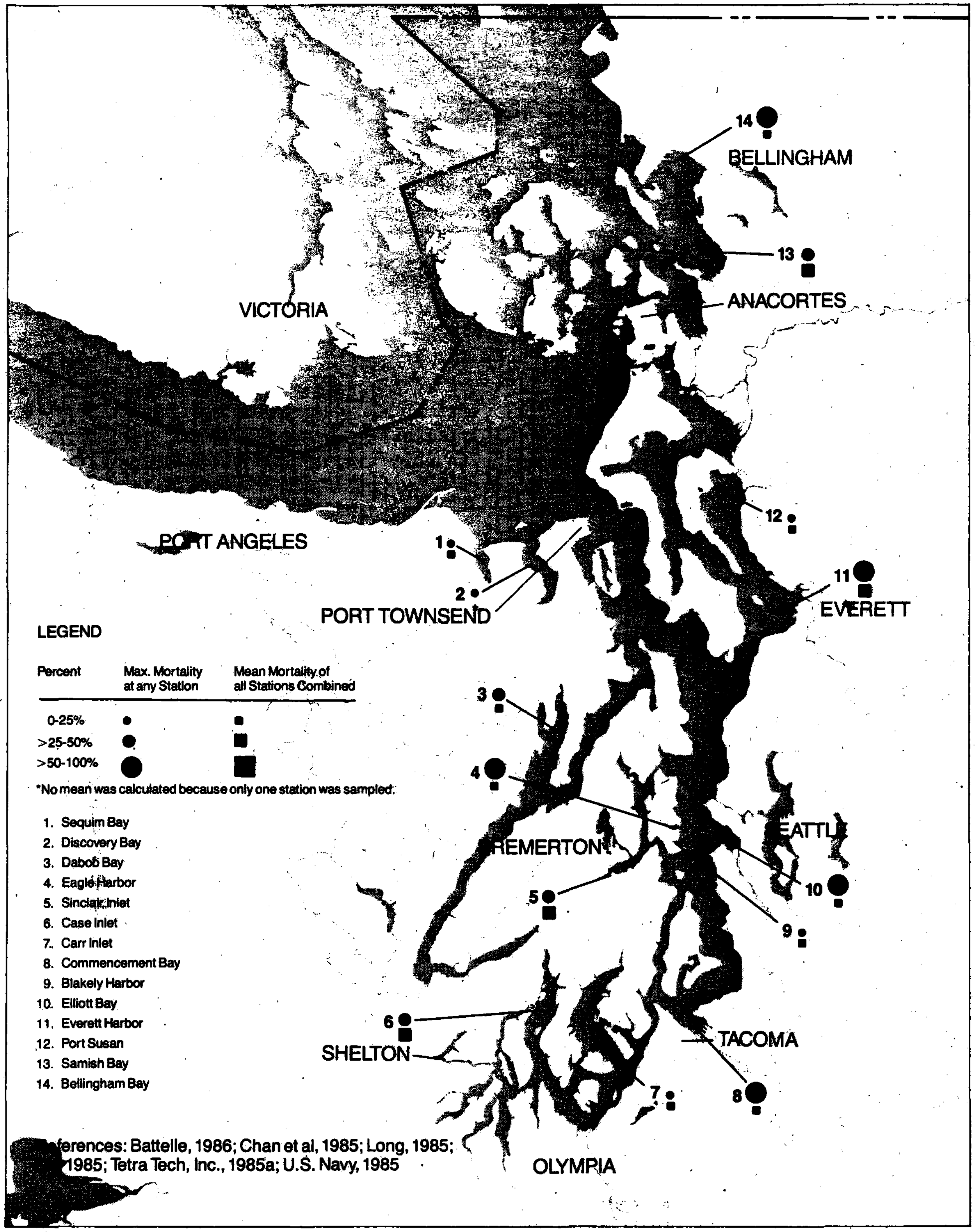


Figure 4-24

AMPHIPOD MORTALITY FROM SEDIMENT BIOASSAYS IN PUGET SOUND

AET levels for sediment contaminants. In general, these additional bioassays have shown trends similar to those shown by the amphipod mortality bioassay (Williams et al., 1986). However, the lack of total correspondence indicates that various bioassays each have a distinct response to contamination.

Liver abnormalities in English sole

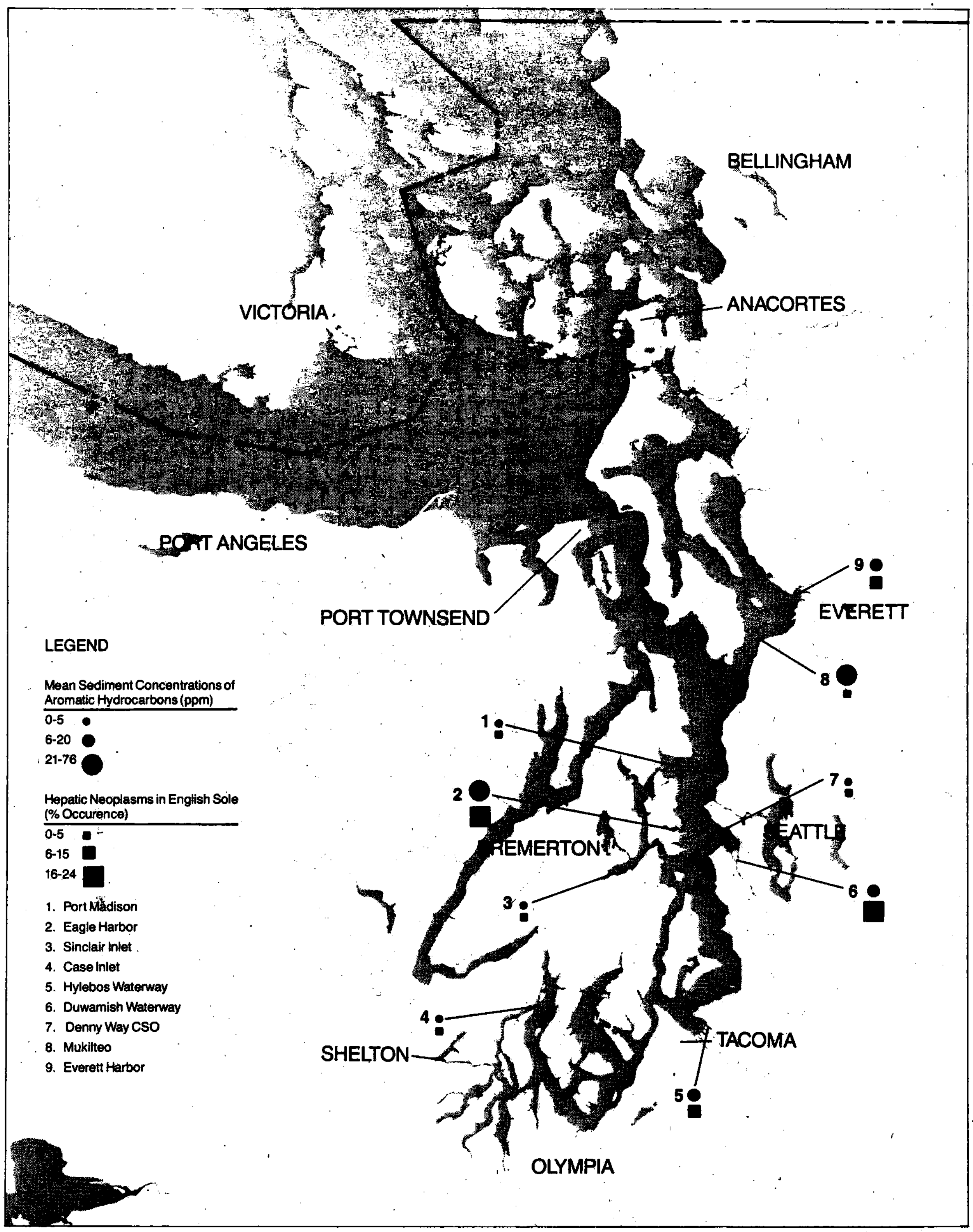
A variety of liver abnormalities (tumors and pre-tumors) have been found in English sole and other groundfish species throughout the Puget Sound basin. Lower rates of these liver abnormalities also have been found in rock sole and the Pacific staghorn sculpin from the Sound. Liver abnormalities are comparatively rare in the other species examined thus far in Puget Sound (Malins et al., 1987).

Numerous field studies have found a strong statistical association between liver abnormalities in English sole and chemical contamination of the sediments (e.g., Malins et al., 1984; Tetra Tech, 1985a). Concentrations of sediment PAHs and the percent occurrence of liver tumors in English sole in nine areas around Puget Sound are shown in Figure 4-25. Statistical analyses have shown a significant correlation between these two variables, with a higher proportion of fish with liver tumors found in highly contaminated areas. Prevalence of liver tumors was also correlated with concentrations of metals. However, a number of factors may contribute to the development of the observed abnormalities including nutritional imbalance, genetic disorders, viral infections, and age of the fish. There also is a possibility that some chemical not actually measured in the chemical analyses of the sediments could have caused the tumors.

Because of the above uncertainties in the cause-and-effect relationships between sediment contamination and liver tumors, laboratory studies were initiated by NMFS to determine the cause of the tumors. The results have been summarized recently by Schiewe et al. (1988). A spectrum of liver lesions similar to those observed in field surveys (including pre-tumors) were produced in English sole exposed to extracts of urban sediments. The types of lesions detected in these fish were not detected in control English sole exposed to an extract of non-urban sediments. Overall, the findings of these studies represent an important step forward in establishing a cause-and-effect relationship between liver tumors in English sole and exposure to chemical contaminants associated with sediments.

Other studies have produced some new discoveries related to the problem of liver tumors in English sole. The route of exposure to PAHs appears to be at least partly in the food. The food organisms consumed by English sole in areas with sediments contaminated by PAHs may contain much higher concentrations of PAHs than do the sediments (Malins et al., 1987). In addition, a recent study by NMFS indicates that sole may take up contaminants directly from the sediments through their skin (Stein et al., 1987). A possible means by which PAHs such as benzo(a)pyrene could influence the development of liver tumors is by binding to DNA (the genetic material) in the cells of the liver (Varanasi et al., 1986).

Research is continuing in these and other areas to gain a better understanding of how contamination may be affecting the organisms that live in Puget Sound. For example, researchers have found that English sole from Eagle Harbor and the Duwamish waterway show a higher prevalence of reproductive failure (inhibited ovarian maturation) than sole from Port Susan and Sinclair Inlet (Johnson et al., 1988). Although no direct cause-and-effect relationship has been established, this sublethal effect may partly explain the decreasing abundances of English sole that have been observed in central Puget Sound over the last few years (Quinnell, 1984; Bargmann, 1988).



Reference: Malins et al., 1987

Figure 4-25

CONCENTRATION OF SEDIMENT AROMATIC HYDROCARBONS AND PERCENTAGE OCCURENCE OF LIVER ABNORMALITIES IN ENGLISH SOLE FROM SELECTED PUGET SOUND LOCATIONS

POTENTIAL HUMAN HEALTH RISKS

Risks Due to Chemical Contamination

Human health problems caused by direct contact with chemically contaminated water and sediments have not been documented in Puget Sound, even in industrialized bays. Heavy consumption of contaminated seafood for a period of years, however, could pose a human health risk. It is possible to assess the relative health risks of eating seafood from different locations in the Sound. In general, health risks associated with a given chemical are proportional to intake of the chemical (an assumption accepted by most researchers). Thus, fish with high concentrations of a given chemical pose greater human health risks when eaten than do those with low concentrations. Seafood taken from urban areas tend to have higher levels of contaminants than seafood taken from rural areas (Figures 4-22 and 4-23). Therefore, risks can be reduced by avoiding the intake of seafood from known areas of contamination (such as Commencement Bay and Eagle Harbor).

FDA has established "action levels" for mercury and 13 organic compounds in fishery products for interstate commerce (FDA, 1982). Broadly speaking, these FDA levels identify a chemical level which should not be exceeded or eaten by the consumer. The action levels apply to an average national consumer who eats seafood from a wide variety of places (and with a wide variety of chemical levels). Action levels exist for very few chemicals. Because these guidelines reflect the potential health concerns of a "typical" nationwide consumer, they may not be completely protective of a consumer who eats fish from a specific area such as an urban bay. However, they are the only guidelines for seafood consumption risks currently available in the U.S.

There have been several studies in the past few years on chemical contaminant levels in Puget Sound seafood (Hall et al., 1977; Romberg et al., 1984; Versar, 1985; City of Bellingham, 1985; Tetra Tech, Inc., 1986b; Landolt et al, 1987; Faigenblum, 1987). FDA guidelines for most toxicants have very rarely been exceeded in Puget Sound fish, shellfish, and edible seaweeds (PCBs and mercury levels occasionally exceed accepted standards in groundfish at some urban sites such as Bellingham Bay). Since 1980 a very small fraction of edible tissue samples from marine organisms of Puget Sound has exceeded the PCB guideline of 2 parts per million.

In 1986 the Puget Sound Estuary Program commissioned a report (and approach) on health risk assessment for use in the Sound (Tetra Tech, Inc., 1986e). This approach provides a basic guideline for all health risk assessments so that these studies can be done in a consistent manner in the future. Risk assessment is a sophisticated method for the quantitative evaluation of possible health effects associated with the consumption of contaminated seafood. Since state-of-the-art methods of analytical chemistry can now measure tissue contaminants in minute concentrations, public agencies in Puget Sound need to be able to determine if consumption of small amounts of toxic chemicals poses a health risk.

The basic approach of risk assessment is to estimate the exposure and effects of contaminants based on the various consumption rates of seafood (and hence of the chemicals in seafood). Based on the potency of each chemical (which is established by laboratory tests), consumption rates can be used to calculate the probability and extent of adverse health effects (such as cancer). Very small amounts (less than FDA action levels) of toxic chemicals may be harmful if consumed frequently over one's lifetime. EPA Region 10 in Seattle is currently conducting a risk assessment for several types of Puget Sound seafood. Risk assessment is a relatively new method of evaluating health impacts, and its scientific basis is still evolving. Although risk assessment has not yet been widely applied in the Sound, its use will probably increase in the future. This method should put the potential health risk (or lack of risk) from eating Puget Sound seafood into perspective for the consumer. However, scientists, policymakers, and the public must work together to define the acceptable level of risk.

Despite the concern over heavy consumption of groundfish (such as cod and English sole) and shellfish from contaminated areas of Puget Sound, little is known about contamination of resident blackmouth salmon and whether consumption of this species represents a risk to the typical recreational fisherperson in Puget Sound. In limited analyses of salmon muscle and liver tissue by EPA, Metro, and NOAA, PCB concentrations in salmon were generally lower than those in bottom fish. Ongoing studies by EPA and DSHS involving chemical analyses of clams, salmon, cod, English sole, and edible seaweeds will provide additional information to quantitatively assess the health risks associated with ingestion of chemically contaminated seafood from the Sound (Faigenblum, 1987).

NOAA has conducted a two-year study of the degree to which consumers of fish caught recreationally from the urban embayments in Puget Sound may be exposed to contaminants (Landolt et al., 1987). The study found that tissue from recreationally caught fish generally contained low levels of metals (with the exception of arsenic) and organic compounds. Arsenic levels varied greatly among species and geographic locations, but were highest in squid and walleye pollock (particularly those collected from Commencement Bay). Although generally present in low concentrations, PCBs were found in all of the recreationally caught fish from the urban bays. Cooking the fish was found to reduce tissue levels of PCBs and other organic contaminants by 50 to 90 percent, but cooking had little or no effect on arsenic concentrations (Landolt et al., 1987). This study did not attempt to assess the risk associated with eating fish from urban bays, but did provide estimates of contaminant doses being consumed by urban anglers.

The above studies suggest that there is at least some potential for harmful effects on human health from toxic chemicals in Puget Sound seafood. It is also important to note that most of the studies of tissue contamination in Puget Sound have focused on the biota in highly contaminated urban areas (such as Elliott and Commencement Bays), which is not where most recreational fish are caught. Therefore, most of the available information presents the "worst-case" conditions.

To date, the King, Kitsap, Pierce, Snohomish, and Thurston County Health Departments have issued health advisories on seafood from specific areas in Puget Sound (Sagerser, 1988, pers. comm.). The advisories state that most of the seafood from these counties is safe to eat but that fishing and shellfish harvesting from industrial areas should be avoided. Also, authorities recommend that the skin and internal organs of groundfish from such areas should not be eaten. Since 1985 more specific advisories have recommended that people avoid eating fish and shellfish (including crabs) from Eagle Harbor, the waterways of Commencement Bay, and Budd Inlet near the Cascade Pole Company.

Brief comparisons of the tissue contamination in the urban and rural areas of the Sound and comparisons with other urban areas of the U.S. can provide a perspective on the significance of the chemical contamination of Puget Sound seafood. Direct comparisons with other parts of the nation are difficult because site characteristics (e.g., degree of tidal flushing and proximity to outfalls) and species sampled vary. However, sites in some urban coastal areas in the U.S. have higher levels of tissue contaminants in the biota than those found in sites in the urban areas of the Sound (Weaver, 1984; Landolt et al., 1987; Matta et al., 1987; NOAA, 1987). For example, PCB concentrations in fish from sites in the Hudson River, New York Harbor, San

Diego Harbor, and much of Lake Michigan (especially Waukegan Harbor) exceed those in fish from Elliott and Commencement Bay sites. However, PCB concentrations in fish tissue in Boston Harbor, western Long Island Sound, and San Francisco Bay sites are lower than those in Elliott and Commencement Bay sites.

Risks Due to Contamination by Bacteria and Viruses

Bacterial and viral contamination of water and shellfish can cause a variety of illnesses such as gastroenteritis, skin and eye irritations, nausea, diarrhea, typhoid fever, cholera, hepatitis, and many other diseases. Anthropogenic sources of bacteria and viruses include sewage treatment plant outfalls, CSOs, runoff from urban and agricultural areas, and failing on-site sewage disposal systems. The state has established a water quality standard for fecal coliform bacteria and has routinely monitored commercial shellfish beds for bacterial contamination over the past 40 years (Plews, 1987, pers. comm.). Metro routinely monitors fecal coliform bacteria concentrations near several sewage outfalls, and health department officials have temporarily closed swimming and recreational shellfishing beaches in the area of raw sewage spills from time to time. FDA has monitored fecal coliform bacteria concentrations in the water, sediments, and tissue of shellfish around the Sound since the mid-1970s (Kaysner, 1988, pers. comm.).

Fecal coliform bacteria are not themselves pathogenic but are indicators that pathogenic bacteria and viruses associated with warm-blooded animals (e.g., enteric viruses which can cause human diseases such as hepatitis) may be present. Viral hepatitis in humans may be contracted by eating contaminated shellfish that are raw or undercooked. Viral contamination is not routinely monitored in Puget Sound shellfish or anywhere else in the nation because the procedures are difficult and expensive. Therefore, potential exposure to viruses is inferred from measurements of fecal coliform bacteria. In addition, while chlorine is used to treat bacteria at sewage treatment plants, most viruses that are discharged into the Sound are generally more resistant to chlorine treatment than bacteria. Viruses remain in contaminated shellfish much longer than do fecal coliform bacteria (Canzonier, 1971). Consequently, there is very little information on the health risks associated with viruses in Puget Sound shellfish.

Other disease-causing microorganisms that may be of concern in Puget Sound include enterococci bacteria. Enterococcal bacteria also originate in the intestinal tracts of warm-blooded animals, and some strains have been associated with gastrointestinal illness, particularly among swimmers (Cabelli et al., 1983; Kaysner, 1988, pers. comm.). This is an emerging concern in Puget Sound as well as in other locations throughout the U.S., and there are few data on the health risks associated with enterococcal bacteria in Puget Sound.

Extensive areas, including the eastern shore of Puget Sound from Everett to Tacoma, are closed to all commercial shellfish harvesting because of the number of existing sources of contamination in these areas (such as numerous sewage treatment plants and stormwater outfalls along the shoreline). Areas where commercial harvesting of shellfish was prohibited or restricted in 1987 include a portion of Sequim Bay near the John Wayne Marina (Clallam County), a western portion of Port Susan (Island County), Dosewallips State Park (Jefferson County), and Lynch Cove (Mason County). In addition, the beaches in Oakland Bay (Mason County) and southern Skagit Bay (Island and Snohomish Counties) have recently been downgraded from conditionally approved to restricted for commercial harvest (Lilja, 1988, pers. comm.). In 1986 and 1987 DSHS received 15 requests for classification of new commercial shellfish beds. Five of these were denied because of degraded water quality (three in Hood Canal, one in Dyes Inlet, and one on

Bainbridge Island; Mitchell, 1987, pers. comm.). Table 4-10 and Figure 4-26 show many of the areas in the Sound where commercial shellfish harvesting is limited.

As called for in the Puget Sound Water Quality Management Plan (element SF-4), a recreational shellfish program is currently being developed by Ecology and DSHS in cooperation with other resource agencies, local health and planning agencies, tribes, and environmental groups. The program is inventorying public recreational beaches, developing a monitoring plan to collect water and tissue samples in recreational areas, developing recreational shellfish standards to protect the public's health, and generally addressing issues of closures of recreational areas (including the need for adequate public involvement and education).

In June 1986 the state and EPA began a special monitoring study of 20 recreational shellfish beds that includes sampling for fecal coliform bacteria and chemical contamination about three times per year (Faigenblum, 1987). In general, bacterial contamination was found to be most prevalent in urban areas. However, not all urban areas were contaminated, and not all rural areas were clean. Concentrations of fecal coliform bacteria that exceeded the FDA standard for commercial shellfish beds were found in at least half of the samples from Dash Point State Park (near Tacoma), Dosewallips State Park (Hood Canal), Post Point State Park (near Olympia), Point Vashon (Vashon Island), and Walker Park (near Shelton; Faigenblum, 1987). Although this standard was designed to be applied at the wholesale market level, it is used as a guide for recreational shellfish harvest areas because no standard currently exists for noncommercial shellfish.

Areas of Puget Sound most affected by bacterial (and possibly viral) contamination generally coincide with areas of limited flushing and/or with proximity to sources such as sewage treatment plant outfalls, urban runoff, agricultural runoff, failing on-site sewage disposal systems, or boat discharges. Overall, land use and well-thought-out community development (especially proper siting and maintenance of on-site sewage disposal systems, implementation of BMPs for animal-keeping operations, careful siting of sewage treatment plant outfalls, and urban stormwater control) have the greatest potential to control contamination from bacteria and viruses. Increased sampling efforts will help quantify to what degree sources of contamination are affecting shellfish resources as well as the health of people who recreate and harvest shellfish on Puget Sound beaches.

Paralytic Shellfish Poisoning

In Puget Sound paralytic shellfish poisoning (PSP) is caused by blooms ("red tides") of a phytoplankton species called *Gonyaulax catenella*. This organism produces a neurotoxin which can become concentrated within bivalve shellfish (clams, oysters, and mussels) as they feed. Cooking shellfish does not remove the toxin, and people who eat PSP toxin-contaminated shellfish may experience a tingling sensation in the lips and tongue, followed by numbness, paralysis, and possibly death. *Gonyaulax* plankton blooms can reach toxic levels even if a "red tide" is not visible in the water, and red water can occur that is not toxic. *Gonyaulax* blooms occur from April to November, with each bloom lasting about two weeks (Strickland, 1983). Bivalves consume and digest the toxic algae and retain the toxin in their flesh, but are otherwise unaffected by it because they lack the nerves it affects. The rates and amounts of toxin ingested vary among bivalves, and the species differ in the time required to detoxify once there are no longer significant amounts of toxin in the water. A beach is closed to shellfishing if the toxin level in shellfish reaches 80 micrograms of toxin per 100 grams (3.5 ounces) of shellfish meat (the equivalent of 0.8 ppm). PSP toxins have been found in concentrations below levels of concern in other marine organisms such as limpets, snails, and Dungeness crabs.

TABLE 4-10: PUGET SOUND SHELLFISH BEDS WHERE HARVESTING WAS LIMITED[1] DUE TO CONTAMINATION, 1987

Location	County	Cause[2]
PROHIBITED[3]		
Sequim Bay, near marina*, near state park	Clallam	Marina, nonpoint
Penn Cove, north	Island	STP, nonpoint
Port Townsend*	Jefferson	STP
Quilcene Bay, north	Jefferson	Nonpoint
Appletree Cove, Kingston*	Kitsap	STP
Dyes Inlett, all*	Kitsap	STP, nonpoint, urban runoff
Liberty Bay, east	Kitsap	Marina, nonpoint
Port Gamble, north*	Kitsap	STP
Port Madison, Suquamish Reservation	Kitsap	STP
Sinclair Inlet*	Kitsap	STP, nonpoint
Winslow*	Kitsap	STP
Dougall Point*	Mason	STP
Hartstene Island, north*	Mason	STP
Jarrell Cove*	Mason	Boating
Lynch Cove, Belfair Region	Mason	Nonpoint
Oakland Bay/Hammersley, vicinity of Shelton	Mason	STP, mill, nonpoint
Squaxin Island	Mason	Nonpoint
East shore of Puget Sound, Tacoma to Edmonds*	Pierce, King, Snohomish	STPs, industrial
Carr Inlet, Minter Bay	Pierce	Nonpoint
Glen Cove*	Pierce	Marina, nonpoint
Mayo Cove*	Pierce	Boating
Van Gelden Cove*	Pierce	Nonpoint
Port Gardner*	Snohomish	STP, industry, nonpoint
Port Susan, 1/3 tideflats, near Stillaguamish	Snohomish	STP, nonpoint
Budd Inlet, south of Gull Harbor*	Thurston	STP, nonpoint
Henderson Inlet, south 1/4	Thurston	Nonpoint
Bellingham Bay*	Whatcom	STP, mills, nonpoint
Lummi Bay	Whatcom	STP, nonpoint
RESTRICTED[4]		
Port Susan, west	Island	STPs, nonpoint
Dosewallips State Park[5]	Jefferson	Nonpoint
Oakland Bay	Mason	STP, industry, nonpoint
Carr Inlet, Burley Lagoon	Pierce/Kitsap	Nonpoint
Skagit Bay, southeast	Skagit	Nonpoint
CONDITIONALLY APPROVED[6]		
Penn Cove, south	Island	STP, nonpoint
Fishermans Harbor	Jefferson	Marina
Liberty Bay	Kitsap	Nonpoint, marina
Squaxin Island, northeast	Mason	Nonpoint, boating
Filucy Bay	Pierce	Nonpoint, marina
Eld Inlet, south	Thurston	Nonpoint
Henderson Inlet, mid-portion	Thurston	Nonpoint

Notes:

1. DSHS considers all waters closed to the commercial harvest of shellfish until the Shellfish Sanitation Program has surveyed and classified them. Once surveyed and classified, these classifications may change as conditions improve or deteriorate. There are approximately 80 shellfish areas in Washington which DSHS can't certify or would decline requests for certification due to contamination. Commercial shellfish harvesting is prohibited in all areas located within 0.5 miles (0.8 kilometers) of marinas, sewer treatment plants, and other outfalls.

2. Cause refers to probable sources of contamination that have resulted in a classification other than Approved for a commercial growing area. Nonpoint sources include runoff from urban areas and farms, effluent from failing on-site sewage disposal systems, and other sources of fecal coliform bacteria. STP stands for sewage treatment plan.

3. DSHS defines prohibited growing areas as follows: a growing area is classified prohibited if there is no current sanitary survey or if the sanitary survey or other monitoring program data indicate that fecal material, pathogenic microorganisms, poisonous or deleterious substances, marine biotoxins, or radionuclides may reach the area in excessive concentrations. The taking of shellfish for any human food purposes from such areas is prohibited.

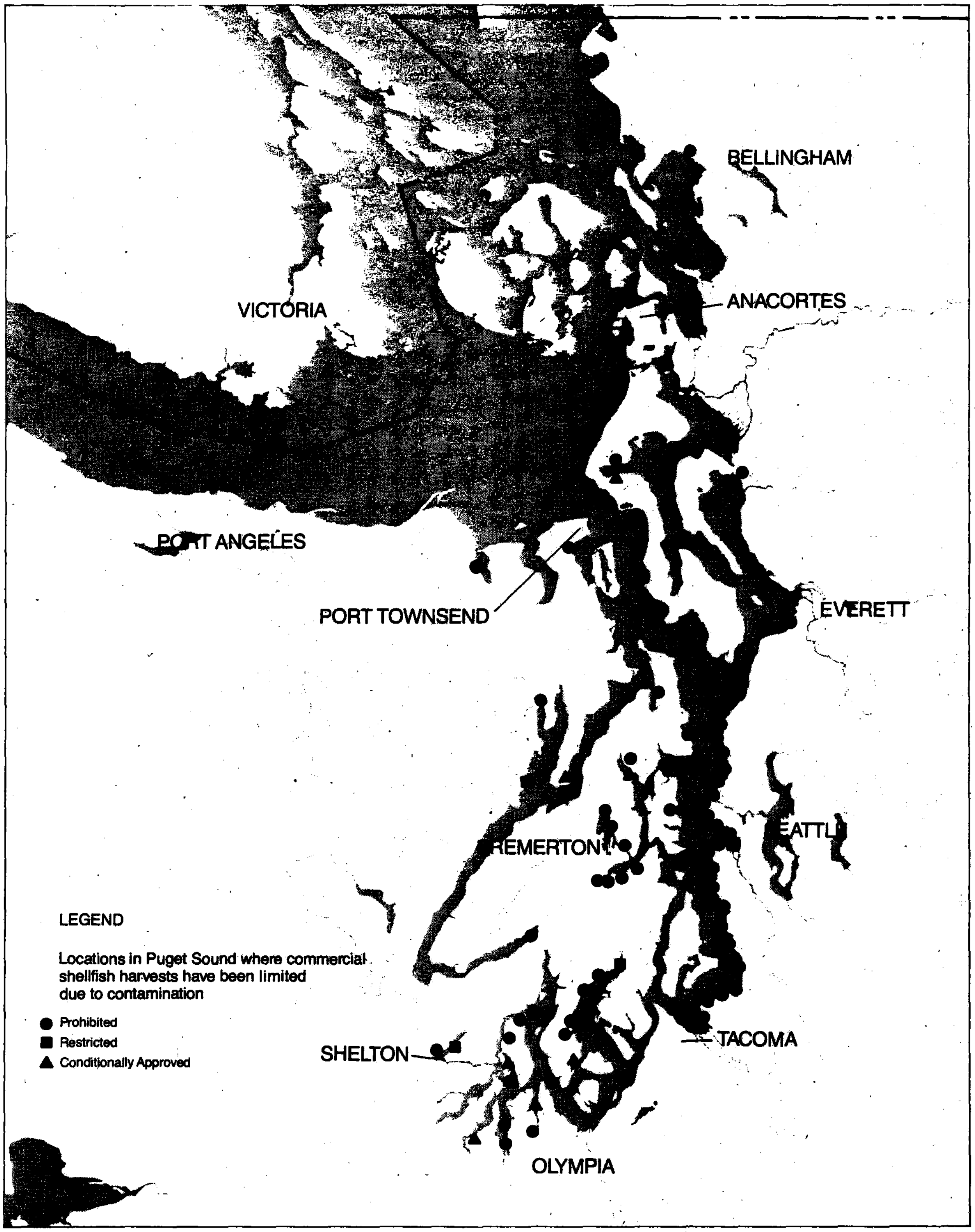
4. DSHS defines restricted growing areas as follows: a growing area may be classified as restricted when a sanitary survey indicates a limited degree of pollution, and relaying or purifying the shellfish will make them safe to market.

5. Because there is no standard for recreational shellfish beds, DSHS presently has no formal jurisdiction over recreationally harvested beds (e.g., at state parks). However, Indian tribes may harvest certain recreational beaches for commercial purposes. In such cases, DSHS may apply the commercial standards to these areas.

6. DSHS defines conditionally approved growing areas as follows: growing areas that are subject to intermittent microbiological pollution are classified as conditionally approved. This option is voluntary and is used when the suitability of an area for harvesting shellfish for direct marketing is affected by a predictable pollution event. The pollution event may be predicated upon the attainment of an established performance standard by wastewater treatment facilities discharging effluent, directly or indirectly, into the area. In other cases, the sanitary quality of an area may be affected by seasonal population, nonpoint source pollution, or sporadic use of a dock or harbor facility.

*These areas are not approved by DSHS for shellfish harvest and are generally located near persistent sources of contamination. This list is not exhaustive.

(Reference: DSHS, 1988)



Reference: DSHS, 1988

Figure 4-26

CONTAMINATED SHELLFISH BEDS
IN PUGET SOUND, 1987

Prior to 1978 when routine testing began, toxic concentrations of the PSP toxin had not been detected in Puget Sound, although there is circumstantial evidence that crew members from the Vancouver expedition of 1792 may have died from eating shellfish in Puget Sound. From 1978 to 1985 the area where significant amounts of toxic plankton in shellfish were found increased, but no further increases have occurred since 1985 (Lilja, 1988, pers. comm.). The only Puget Sound waters that have never been closed because of PSP toxin are in portions of Hood Canal and south of the Tacoma Narrows (the telephone number 1-800-562-5632 can be called to obtain information on beach closures due to PSP in Washington). Low concentrations of the toxin in shellfish (not necessitating closures) have been found in Hood Canal as far south as Bangor (Kitsap County) and throughout most of the southern basin of Puget Sound. In the Puget Sound area, there have been no reported cases of PSP associated with the consumption of commercially harvested shellfish, but there have been several commercial operations that have been temporarily shut down because of the presence of the toxin. There have been two reported cases of PSP from recreationally harvested shellfish in Puget Sound since 1978. The most recently reported case occurred in 1985 (Lilja, 1988, pers. comm.).

"Red tides" that cause PSP are natural phenomena, and it is unclear whether human activities aggravate their spread (Nishitani and Chew, 1984; Kendra and Determan, 1985). Researchers have shown that in certain instances the timing and duration of dense blooms of *Gonyaulax* was controlled, in part, by the availability of nutrients such as nitrogen and phosphorous (Nishitani et al., 1988). Bays tend to support more frequent blooms of this species than channels, and blooms tend to be controlled by low nutrient availability. Under special circumstances in certain bays, the addition of nutrients by human activity might increase the frequency and intensity of *Gonyaulax* blooms (Nishitani et al., 1988). Because of the prevalence of the toxic plankton species in Puget Sound and the persistence of its long-lived cyst, it is not likely that the PSP problem will disappear in the foreseeable future.

SUMMARY AND CONCLUSIONS

This chapter has presented extensive information on the general classes of contaminants; the various physical, chemical, and biological processes that operate in the Sound; the sources and loadings of contaminants in the Sound; the distributions and trends of contamination; and the potential human health risks associated with chemical and biological contaminants in the fish and shellfish of Puget Sound. Chapter 1 of this report summarizes much of this information according to major categories (e.g., toxic contamination, point source pollution, stormwater and combined sewer overflows, nonpoint source pollution and shellfish, and loss of wetlands). Rather than repeat that summary information, an overview of the most critical issues and problems in Puget Sound is given by major geographic area below.

Northern Puget Sound

Northern Puget Sound and the San Juan Islands (including San Juan, Skagit, and Whatcom Counties) are largely rural areas with localized industrial and intense urban development in the vicinity of Anacortes, Bellingham, and the Cherry Point area. Specific areas are exhibiting certain environmental problems in this region. For example:

* Forest practices and agricultural nonpoint pollution is causing problems in parts of Skagit and Whatcom Counties;

* Saltwater intrusion is being detected in the groundwater in some parts of the San Juan Islands (Figure 4-13);

* Sediments in Bellingham Bay have moderate levels of copper and zinc and high levels of mercury (Figures 4-16, 4-18, and 4-19);

* Clam tissue has moderate levels of PAHs in Birch Bay (Figure 4-23);

* There is high amphipod bioassay mortality in Bellingham Bay (Figure 4-24); and

* Commercial shellfish operations are prohibited in Bellingham and Lummi Bays (Figure 4-26).

In addition, extensive wetland losses have occurred in Lummi, Samish, and Skagit Bays, and three major oil spills recently occurred in the vicinity of Anacortes. San Juan County is the second fastest growing county in the Puget Sound area. Rapid population growth may lead to additional water quality and habitat degradation in the future.

Whidbey Island/Strait of Juan de Fuca

This region (which includes Clallam, Island, the northeast portion of Jefferson, and Snohomish Counties) is also largely rural, with the exception of the intense urban/industrial centers of Everett and Port Angeles and the extensive urban/suburban development in southwest Snohomish County. Localized areas are exhibiting the following problems:

* Nonpoint pollution problems are seen in portions of Clallam, Jefferson, and Snohomish Counties;

* Groundwater is contaminated by saltwater, metals and synthetic organic compounds on parts of Whidbey Island (Figures 4-12 and 4-13);

* Sediments in Everett Harbor have moderate levels of PAHs and zinc (Figures 4-14 and 4-18);

* Clam and fish muscle tissue has moderate to high levels of PCBs and PAHs in Port Gardner/Everett Harbor and at Mukilteo (Figures 4-22 and 4-23);

* Bioassay mortality is high in Everett Harbor and Port Angeles (Figure 4-24; Long, 1988b);

* English sole show moderate to high occurrences of liver abnormalities in Everett Harbor (Figure 4-25; Long, 1988b); and

* Harvesting of commercial shellfish beds is prohibited or restricted in southern Skagit Bay, Penn Cove, parts of Port Susan, Port Gardner/Everett Harbor, Port Townsend, and part of Sequim Bay (Figure 4-26).

In addition, extensive losses of wetlands have occurred in the deltas of the Stillaguamish and Snohomish Rivers. Island and Snohomish Counties are also growing very rapidly, which could lead to additional water quality and biological degradation in the future.

Hood Canal

The Hood Canal region includes portions of Jefferson and Mason Counties. Overall this region is one of the least developed areas in Puget Sound, although the shoreline of Hood Canal is extensively developed with summer and year-around residences. Much of the canal has not been analyzed for the presence of contaminants in biota. Sediment levels of PAHs, PCBs, and metals are found in low concentrations in Hood Canal (Figures 4-14 to 4-20). The region is affected by nonpoint pollution from forest practices, small farms, failed on-site sewage disposal systems, and recreational boating as evidenced by prohibited or restricted commercial shellfish beds located in Quilcene Bay, Dosewallips State Park, and Lynch Cove (Figure 4-26). Parts of Mason County are exhibiting rapid population growth which may create additional environmental problems in the future.

Central Puget Sound

This region encompasses the intensely developed areas of King and Kitsap Counties and contains some of the most highly contaminated areas in Puget Sound including Eagle Harbor, Elliott Bay, and Sinclair Inlet. Some of the most concerning environmental issues in this region include:

* Nonpoint pollution effects from stormwater runoff and failed on-site sewage disposal systems;

* Groundwater contaminated by metals and synthetic organic compounds (Figure 4-12);

* Sediments containing high levels of PAHs and PCBs in Eagle Harbor and Elliott Bay (Figures 4-14 and 4-15);

* Sediments containing high concentrations of copper, lead, and zinc in Elliott Bay and Sinclair Inlet (Figures 4-16, 4-17, and 4-18);

* Biota containing high tissue levels of PCBs and PAHs in Elliott Bay, Sinclair Inlet, and Eagle Harbor and vicinity (Figures 4-22 and 4-23);

* High occurrences of liver abnormalities and reproductive failures in English sole from the Duwamish River and Eagle Harbor (Figure 4-25); and

* Large areas that are closed to commercial shellfish harvest including the entire eastern shoreline of central Puget Sound, Eagle Harbor, Sinclair Inlet, Dyes Inlet, Liberty Bay, Port Gamble, and Port Madison (Figure 4-26).

In addition, nearly 100 percent of the wetlands in the Duwamish River estuary have been lost.

Southern Puget Sound

This region includes the southeast portion of Mason County, Pierce, and Thurston Counties. The region is largely rural except along the shorelines and in the vicinity of the intensely developed areas of Lacey, Tumwater, Olympia, and Tacoma. A unique feature of this region are the many long, narrow passages and inlets that tend to receive little circulation or mixing with water from the rest of Puget Sound. The physical configuration of this region thus tends to contribute to some of the nutrient and bacteriological water quality problems that are evident here. Almost all other problems in the region are localized in the urban areas, particularly in and around Commencement Bay. For example:

* Groundwater at specific locations in the vicinity of Tacoma and Olympia is contaminated with various substances (e.g., the pesticide EDB has been found in wells near Olympia, Figures 4-12 and 4-13);

* High concentrations of copper, lead, zinc, and arsenic are found in Commencement Bay sediments (Figures 4-16 to 4-20);

* Biota are contaminated with high levels of PCBs and moderate levels of PAHs in Commencement Bay (Figures 4-22 and 4-23);

* Amphipod bioassay mortality is high in Commencement Bay (Figure 4-24); and

* English sole in Commencement Bay have moderate occurrences of liver abnormalities (Figure 4-25).

Pollutant effects in other areas of the region are largely related to nonpoint pollution from forest and agricultural practices, failing on-site sewage disposal systems, and recreational boating. Many southern Puget Sound areas that were once productive oyster habitats are presently closed to commercial shellfish harvest, including portions of Case Inlet, Oakland Bay, Budd Inlet, and Henderson Bay (Figure 4-26). Because Mason and Thurston Counties are two of the fastest growing counties in the Puget Sound area, increased population pressures may create additional degradation of water quality and biological resources in the future.

Appendix A: Local Water Quality Programs and Success Stories

This appendix contains short discussions of some of the many programs relating to water quality and habitat issues that have been initiated in Puget Sound by county and city governments, tribes, industry, and citizens groups in the last few years. These discussions are not comprehensive, but demonstrate the wide variety of work being done throughout the Sound.

COUNTY GOVERNMENT

The following programs are a non-comprehensive cross-section of activities specifically related to water quality and habitat issues that have been initiated by county governments or local conservation districts in the past few years. An attempt was made to include, within the constraints of space limitations, the most relevant programs in each county. Descriptions of other local programs follow these county programs.

In the past, county government programs related to water quality and habitat improvement have typically been limited because of a lack of funding and other resources. The Puget Sound Water Quality Management Plan is designed to assist county governments in a number of ways. Water quality and habitat protection programs will be better coordinated, technical assistance will be made available to county governments, and the plan provides funding assistance to counties for specific programs such as watershed ranking. Many of the programs discussed below specifically relate to Puget Sound plan elements. Although many programs are still quite new, preliminary program results are encouraging in terms of seeing some significant water quality and habitat improvements.

Clallam County Programs

As a result of recent shellfish bed closures in Sequim Bay, Clallam County initiated a detailed study between August 1986 and June 1987 to determine the effects of nonpoint source pollution on the watersheds that drain into the bay (Brastad et al., 1987). Stream walks, sanitary surveys, and intensive water quality monitoring were used to evaluate sources of bacteriological contamination in each watershed. Results indicated that large agricultural activities (dairy and beef cattle operations) were the most significant contributors of bacterial contamination to the bay, while irrigation ditches were major contributors in two of the project area creeks.

Stormwater and on-site septic systems were not found to be significant nonpoint pollution contributors, and the effect of forest practices could not be determined in the 10-month study period. As a result of the study, the county, conservation district, and citizens groups have initiated an educational program focused on water quality issues and agricultural nonpoint source pollution control measures (e.g., best management practices (BMPs)). More rigid enforcement actions will be taken in two to three years if the educational approach does not result in significant improvements in Sequim Bay water quality. Sequim Bay was designated as an early action watershed under the Puget Sound plan in 1987.

Island County Programs

In 1986 Island County enacted, as part of a comprehensive land use package, a wetland protection and enhancement ordinance directed at halting the county's loss of wetlands and providing for restoration in certain cases. The county is currently modifying the ordinance to further clarify what activities may and may not be conducted at wetland sites, and to more explicitly protect associated saltwater wetlands under county jurisdiction.

The county is heavily involved in water planning. One committee is developing a groundwater management plan to protect the county's sole source aquifer. Another committee is working to coordinate the delivery of water services among the county's many small water districts. And a third is ranking the county's watersheds under the Puget Sound plan's nonpoint program. The county is developing a plan for disposal of septage and solid waste in order to reduce the amount of these wastes that need to be landfilled. One option currently being tested is composting. The county also has a sludge utilization program. Wastewater treatment sludge is periodically applied to two farm sites and one forest site and is regularly monitored.

Jefferson County Programs

Jefferson County has initiated a number of water quality projects in the past few years, including an in-depth study of water quality problems in Dabob and Quilcene Bays and an innovative program for septic system repair and installation. The Quilcene/Dabob Bay water quality investigation was initiated by county health officials after the headwaters of Quilcene Bay were closed to commercial shellfish growing and harvest because of bacterial contamination. Suspected contributors of bacteria in the watershed included failing septic systems, livestock, seals, and other native wildlife. The study revealed that there were several potential sources of the bacterial contamination in the bays, including several creeks that flow through agricultural areas and the population of about 230 seals that reside in Quilcene Bay (Welch and Banks, 1987). Malfunctioning septic systems were also suspected sources of contamination because of the poor soils and high water table in the area. In 1986 the county initiated a program to identify failed septic systems and to financially assist landowners with the design and construction of system repairs. Housing and Urban Development (HUD) grant funds are used to provide no-interest loans to low-income property owners. In 1987 Quilcene Bay was designated as an early action watershed under the Puget Sound plan. In 1988 the county obtained a conservation easement for a pasture that is regularly inundated by tidal action, thus eliminating waste runoff from the field.

In addition to these county projects, the Jefferson County Conservation District has coordinated an award-winning stream enhancement project in the Chimacum Creek watershed. Through a cooperative effort involving private land owners, local industry, agency representatives, schools, and community associations, various projects have been completed including stream stabilization through planting of vegetation and fish habitat enhancement work. In addition, because of the collaborative efforts of land owners, industry, and public agencies, a large sediment catch basin has been constructed for a fraction of its estimated cost on the west fork of the creek near Eaglemount.

King County Programs

Projects with significant implications for water quality in King County are the county's basin reconnaissance program, the Bear Creek Community Plan, a household hazardous waste round-up, and the county's wetland protection program. The basin reconnaissance program was initiated to assess the extent of surface water problems in each of 29 basins in the western, urbanizing portion of the county. Reconnaissance teams looked at sites with problems with erosion, landslides, flooding, pollution, and habitat degradation to determine which areas needed immediate solutions and what the costs of capital improvements would be to solve drainage and water quality problems. The extensive data base generated by this program has resulted in more efficient identification of those basins with the most serious problems that are in need of immediate attention.

The Bear Creek basin was identified as a critical area by the reconnaissance program, indicating that stringent surface water management measures should be required of any development. In response, the Bear Creek Community Plan (King County, 1987) requires that master plan development areas (e.g., Novelty Hill) provide protection for wetlands and wildlife habitat before development can occur. The plan specifically establishes natural resource protection areas to protect wetlands, surface water quality, groundwater recharge, groundwater quality, wildlife, and aquatic resources. These areas include unique and significant wetlands, surface streams, and a 200-foot (61-meter) undisturbed buffer around wetlands, streams, and drainage ways. In addition, vegetation removal, roads, ditches, utility lines, and other disturbances are prohibited within the resource protection areas.

In May 1987 the largest-ever Puget Sound household hazardous waste collection day took place in the Seattle-King County area. The project was coordinated by Metrocenter YMCA, and involved the participation of numerous public agencies, chemical processing firms, and other private corporations. About 117 tons (106 metric tons) of toxic materials were brought into four sites from 4,091 households, including 229 used car batteries, almost a ton of pesticides, and various other products including cyanide capsules, mustard gas, and explosives. In 1988 Metrocenter YMCA was awarded a Public Involvement/Education Fund (PIE-Fund) contract by the Authority to carry out at least two collection events and to develop a detailed procedures manual for coordinating collection campaigns.

King County's wetland protection program is based on the county's Sensitive Areas Ordinance (Ord. 4365). This ordinance prohibits development in wetlands unless special studies show that either the wetland does not serve any of a number of specific functions, or the proposed development would preserve or enhance wetlands functions. To effectively carry out the ordinance, the county conducted a countywide inventory of wetlands and has developed a three-volume notebook that maps and describes (in detail) each inventoried wetland.

Kitsap County Programs

Since 1985 Kitsap County has worked very closely with Pierce County to develop a comprehensive water quality management plan for the Burley Lagoon and Minter Bay drainage basins. Historically, both of these water bodies were productive commercial oystering areas, but increasing bacterial contamination has caused the Washington Department of Social and Health Services (DSHS) to close the shellfish beds. Water quality investigations have indicated that the main sources of the bacterial contamination are failing on-site septic systems and farm animal wastes that wash into Burley Lagoon/Minter Bay (Determan et al., 1985). With the general sources of contamination identified, the water quality plan developed by the two counties has made specific recommendations for programs and policies that will help reduce or eliminate these sources (Naglich, 1987). Included are recommendations for a voluntary maintenance program for on-site septic systems and an education program to better inform noncommercial farmers on proper farm management techniques (e.g., stream fencing and improved drainage and pasture management). In 1987 Burley Lagoon/Minter Bay was designated as an early action watershed. To date significant progress has been made toward implementing the water quality management plan, including stream fencing at over 15 sites and 50 other sites targeted for improvements. In 1987 the county health department found reduced fecal coliform levels in the watershed. However, continued education and remedial action programs, in addition to long-range watershed planning, are still needed.

Mason County Programs

Mason and Thurston Counties carried out a joint water quality study of Totten/Skookum Inlets to investigate bacterial water quality in these highly productive southern Puget Sound water bodies. The inlets historically provided excellent habitat for the Olympia oyster, but have come under surveillance because of degraded water quality due to nonpoint source pollution. Efforts by the two counties, including an ambient monitoring program, a shoreline survey program, and a rainfall event study program, have focused on defining the cause and extent of bacterial contamination in the inlets and recommending solutions to reduce the problem. Specific corrective and educational actions that have resulted from the study include the repair of identified failing on-site septic systems; implementation of BMPs on small farms within the watershed; and public awareness and education efforts including talks and slide shows, recreational shellfish sampling, and educational brochures. Totten/Eld Inlets in Mason and Thurston Counties were designated as an early action watershed in 1987 under the Puget Sound plan.

Pierce County Programs

Water quality programs initiated by Pierce County in the last few years include a wetland management program, continued involvement in water quality management in the Burley/Minter watersheds (see Kitsap County programs above), watershed ranking activities, a coordinated water system planning effort, creation of a natural resources planning division within the county, and creation of a marine resources program by the Tacoma-Pierce County Health Department (see the following description of Tacoma's programs). Their wetland management program was initiated in 1986 and has included a field inventory of wetlands in part of the county and development of an overall wetland management strategy. The program has already heightened agency and the public's awareness of wetland values and has resulted in an improved system for evaluating development proposals that affect wetland resources. The wetland inventory is currently being merged with the county's land use computer system so that requests for development permits are automatically flagged for further evaluation if wetland resources exist on the parcel.

In addition to their watershed planning efforts in the Burley/Minter area, the county has initiated a countywide watershed ranking process as called for in the Puget Sound plan. Public education and public involvement in the ranking process are being stressed. Water resource planning and conservation are being emphasized further in the county's Coordinated Water System Plan which is being developed as a cooperative effort with the state and local water suppliers. In 1988 the Pierce County Conservation District and Puyallup High School were awarded a PIE-Fund contract to co-sponsor a community oil recycling project.

San Juan County Programs

In 1985 a county-sponsored nonprofit group was formed to develop a response plan for emergency oil containment and bird rescue in San Juan County. The San Juan Islands Oil Spill Association (IOSA) saw the need for a local group that could respond quickly and efficiently to an oil spill crisis until appropriate government or/and industry representatives arrived on the scene. The IOSA intends to train emergency response personnel and obtain necessary equipment so that they can respond to, and contain, spills in the first few hours after an event. Rapid response to oil spills is critical to reducing the short- and long-term environmental impacts of these potentially disastrous events. In early 1988 the IOSA was awarded a PIE-Fund contract to continue their work of developing citizens' monitoring and cleanup procedures for San Juan County. Another contract under the Authority PIE-Fund program is a wetland protection project administered by the San Juan Preservation Trust, a private conservation organization. The project will identify important wetlands and then educate local residents and owners of land containing wetlands on the value of San Juan County wetlands and strategies for their protection.

Skagit County Programs

Skagit County has recently initiated a number of programs to deal with localized drinking water contamination and liquid and solid waste disposal issues. The county assisted citizens near Birdsview (located on the Skagit River near Concrete) to apply to become a water district and receive funding for a new water system to replace wells contaminated with EDB, an agricultural pesticide. The county is currently constructing a $14 million solid waste incinerator that is scheduled for startup in July 1988. This incinerator will allow the county to close two of its three operating solid waste landfills. In addition, the county Department of Public Works has applied for a grant from the Washington Department of Ecology (Ecology) to implement a household hazardous waste management plan.

The Skagit County Conservation District has conducted extensive work on nonpoint source pollution problems (particularly dairy waste) in the Nookachamps and Samish River watersheds since 1985. District staff have conducted surveys of water quality and dairy waste management practices to document existing problems and practices, and have come up with additional recommendations for nonpoint source pollution control. In general, BMPs are being implemented to help solve manure management problems in these watersheds, but additional BMPs (e.g., control of silage seepage, wash water collection, grass buffer strips along ditches and streams, and stream fencing) are needed to reduce and possibly eliminate nonpoint pollution from dairy wastes in these watersheds (Skagit Conservation District, 1986, 1987). In 1987 the conservation district, in cooperation with the Washington Department of Fisheries (WDF) and county and state road crews, installed signs at 24 major road crossings of the Samish River, Friday Creek, and Thomas Creek identifying the waterways as salmon streams. The signs are part of the district's public awareness campaign to identify important salmon spawning streams and encourage people to help keep them clean. The sign project is also intended to make people aware that even small creeks can be important for fish habitat.

Snohomish County Programs

In July 1987 Snohomish County formed a new storm and surface water management utility to meet water management needs in the rapidly developing southwest portion of the county. By assessing a users' service fee, the utility has created a fund to be used to design drainage basin plans, inventory and acquire wetlands, design and construct detention basins for stormwater runoff, and make other capital improvements. In 1988 the county plans to develop five detention basins (including the use of two wetlands) in an effort to control stormwater flows, reduce erosion, and consequently reduce the level of silt and pollutants delivered downstream to the Sound. The county was awarded a PIE-Fund contract in 1988 to undertake a series of public involvement activities. These include stormwater detention pond maintenance efforts with the Boy and Girl Scouts, an adopt-a-wetland project, and citizen involvement in basin planning.

The Snohomish County Conservation District, in cooperation with the Tulalip Indian Tribes, the King County Conservation District, and Ecology, has initiated a program to study the effectiveness of agricultural BMPs in the Snohomish/Snoqualmie River system. This research program is attempting to answer in-depth questions about which types of BMPs are most effective in certain situations and what the direct implications will be for reducing fecal coliform bacteria and nutrients and making other water quality improvements in streams and rivers. In addition, the Stillaquamish River was designated as an early action watershed in 1987 under the Puget Sound plan.

Thurston County Programs

Water quality activities conducted by Thurston County in the past few years include establishment of their Office of Water Quality and Resource Management, early action watershed programs in Totten/Skookum and Henderson and Eld Inlets, and a household hazardous waste collection project. The Office of Water Quality and Resource Management was created in October 1986 to provide a focal point for water programs including groundwater, stormwater, and watershed management. The office is involved in coordinating policy development among county departments, coordinating with cities and tribes, developing and monitoring water quality work programs, and conducting public outreach and education with respect to water resource management. Among other activities, the office is coordinating work on the Totten/Skookum Inlets watershed (see above description of this joint project with Mason County) and Henderson and Eld Inlets watersheds. Activities on these watersheds include remedial/corrective action for existing nonpoint pollution sources (on-site septic system failures, stormwater outfall problems, and agricultural waste management problems); ongoing water quality monitoring of marine and fresh waters; and public education and information distribution. Henderson Inlet was designated as an early action watershed in 1987 under the Puget Sound plan. The office is also working in cooperation with the county programs in stormwater management, groundwater management, vegetation management, and the Lacey, Olympia, Tumwater, Thurston (LOTT) sewage treatment program. Watershed management studies in the Nisqually and Deschutes watersheds are also underway.

The Thurston County Conservation District is also actively engaged in projects with direct water quality benefits. The district has been quite successful at working with landowners to voluntarily implement various BMP strategies, particularly the fencing of streams to control animals. The conservation district has helped eight property owners on Henderson Inlet install stream fencing by providing technical expertise, financial assistance (a cost-share program provided 75 percent of the cost of materials), and in some cases organizing for donated labor (through the Washington Conservation Corps program) to help build the fences. By getting the cooperation of the landowners, the district's work has resulted in direct benefits for stream habitat and water quality.

Whatcom County Programs

Whatcom County's Kamm Slough, Tenmile Creek, and Silver Creek watersheds were designated as early action watersheds in 1987 under the Puget Sound plan. The Silver Creek area comprises significant agricultural, industrial, and residential land uses (including Bellingham Airport) and contains substantial undeveloped areas that are currently zoned for industrial use. To respond to needs for comprehensive watershed planning, the Whatcom County Council of Governments organized a watershed committee made up of representatives from diverse interests such as agriculture, tribes, industry, environmentalists, and numerous government agencies with jurisdiction in the area. Watershed planning activities were begun in early 1988, and committee participants have expressed a particular commitment to ensure that the process is representative of all interests in the watershed.

In 1981 the Whatcom County Conservation District devised a plan to cope with the increasing water quality problems in the Johnson Creek watershed. Local farmers, concerned about stream erosion and clogged drainage systems as well as the loss of important coho salmon habitat, cooperated in a site-by-site inventory of the 55 dairies within the watershed. Forty-five of these farms were found to need some form of upgraded BMPs or other capital improvements. Grants, loans, and other assistance were secured from several sources including Ecology, the U.S. Fish and Wildlife Service, the Agricultural Stabilization and Conservation Service, and other agencies. As of early 1988 most of the structural work had been finished and the 10-year project was 80 percent complete. This successful project received the cooperation of 87 percent of the farms in the area.

CITY GOVERNMENTS

Most of the larger cities in the Puget Sound area were contacted to determine what water quality and habitat related programs they had initiated in the last two years. The following descriptions briefly summarize some of those programs.

Auburn

In 1987 the city of Auburn established a surface water utility to fund a municipal water quality program. The program includes stream monitoring within the Green River watershed to establish baseline data and identify problem areas. Stream monitoring is partially funded by a contract from the Authority PIE-Fund. Auburn and the Green River Community College will recruit local primary, secondary, and college students to carry out water quality sampling. A second element established a complaint response system that successfully identified more than 10 commercial polluters in 1987, prevailing upon each to correct polluting practices. A public outreach and education project comprises the third element of the water quality program.

Bellevue

The city of Bellevue's Storm and Surface Water Utility has been involved in a number of water quality projects in the last few years including stream enhancement, inspection of private flood and water quality control systems, surface water pollution identification and response, and an annual household hazardous waste collection day. The utility works with volunteers to construct physical stream improvements, revegetate stream banks, and protect and enhance fish runs in Bellevue's streams. The utility also provides support to 10 schools that are raising salmon in aquariums and egg boxes, and to two schools that are involved in water quality studies on Kelsey Creek. The utility will soon begin to recruit and train streamside residents and businesses to monitor, survey, and enhance stream systems. This work will be done in conjunction with a PIE-Fund project (co-sponsored by the Bellevue Community College, the Urban Wildlife Coalition, and the Bellevue Parks and Recreation Department) that is designed to protect and manage the Mercer Slough wetlands while increasing public awareness of the value of wetlands in general.

The Storm and Surface Water Utility routinely inspects over 1,000 private flood and water quality control systems to see that they are functioning correctly and being properly maintained. Through this process land owners learn about the need for proper and regular maintenance of their systems. The utility also investigates reports of surface water pollution, identifies sources, and requires compliance with local and state water quality standards. Many small pollution sources have been redirected to sanitary sewers or controlled to prevent them from entering storm drains. For example, gas stations built 20 to 30 years ago had floor drains connected directly to storm drains so that oil, grease, antifreeze, solvents, and other products ended up in Bellevue's creeks. Negotiations have resulted in over 90 percent of these stations being connected to sanitary sewers. In 1985 the Storm and Surface Water Utility teamed with Bellevue's fire department to hold the first one-day household hazardous waste collection event in the Northwest. This successful event has been held ever since and plans are underway to implement permanent, ongoing collection services.

Bellingham

Over the past few years Bellingham has been working on improving drainage and restoring habitat in each of the three major creeks that flow through the city. Baffles were installed over storm outflow conduits in the stream channel of Padden Creek. This allowed the return of salmon runs. Funds were provided through the WDF, and the project was initiated and developed by Trout Unlimited, a private conservation organization. A real estate excise tax provided funds for an elaborate hydraulics project on Whatcom Creek that improved drainage and spawning channels and beds for returning salmon. Additionally, earthen dams were installed on upstream areas of tributaries of Padden and Whatcom Creeks to detain runoff during storms and accommodate increased runoff from urban areas downstream. Silver Creek watershed is designated as an early action watershed under the Puget Sound plan, and planning for the area is already underway.

Municipality of Metropolitan Seattle

The Municipality of Metropolitan Seattle (Metro) has initiated a number of projects in the last few years to protect water quality. Metro projects include adoption of plans to control combined sewer overflows and to upgrade its sewage treatment plants to secondary treatment; expansion of its household hazardous waste program; improvement of its industrial pretreatment program; and initiation of a water quality emergency response program. Metro is providing technical water quality expertise to King County as part of the Green/Duwamish early action watershed planning program. Studies indicate that nonpoint pollution sources in the upper reaches of the watershed significantly contribute to water quality problems in Elliott Bay and central Puget Sound. The agency has also developed a project to protect Lake Sammamish from the adverse effects of urban development. Metro is working with Richmond, Bellevue, and King County to educate people and develop facilities, regulations, and techniques that will help protect the lake's water quality. Metro produces three annual reports that summarize these and other activities related to water quality: the Marine Annual Status Report, the Local Lake and Streams Status Report, and a report on the Status of Water Quality in Small Lakes.

Seattle

In October 1987 Seattle issued its draft plan for water quality management in the industrialized Lake Union and Ship Canal. The city's Office for Long Range Planning convened an Interagency Committee, consisting of representatives from city departments, numerous government agencies, and a citizens advisory committee. The committees evaluated existing research and identified gaps in data that require further study. Major problems include saltwater intrusion; low dissolved oxygen at the lake bottom; elevated fecal coliform levels; concentrations of metals, PAHs, and other organic pollutants in sediments; and small populations and lack of diversity of bottom-dwelling animals.

The city's plan coordinates the responsibilities and activities of the myriad agencies having jurisdiction over Lake Union. Programs include planning for better control of combined sewer overflows (CSOs), investigation of groundwater concerns at Gas

Works Park, conservation of industrial water, and study of runoff from the I-5 freeway, among others. The plan also calls for development of industry BMPs and education to promote industries to voluntarily implement BMPs, education of boaters about the hazards of sewage and bilge discharges, and education of lakeside residents about household hazardous waste disposal. The plan specifies further study of several suspected pollution problems in the lake.

Tacoma

In 1985 the Tacoma-Pierce County Health Department established a marine resources program to improve water quality in Commencement Bay. Program activities include discharge monitoring, correction of polluting discharges, and oversight of the sewer utility's pretreatment program. Sediment "hot spots" identified off the Tacoma storm drain outfalls have led investigators to believe that the storm drains are a significant source of toxicants to Commencement Bay. In July 1986 Ecology, the city, and the health department agreed on an approach to characterize, inventory, inspect, and sample areas in the city storm drain system in an effort to trace sources of toxicants that are discharged to Commencement Bay. Since 1986 the program has contacted or inspected 736 businesses, identified 31 problem areas, and mapped 377 storm drains (268 of which are regularly monitored). Ecology has completed additional sediment sampling and contaminant analysis efforts in 14 storm drains in the Hylebos, City, and Sitcum Waterways (see the discussion of the Urban Bay Toxics Control Program in Appendix B of this report).

The Tacoma Metropolitan Park District is continuing development of the Nature Center at Snake Lake. Saved from development by Tahoma Audubon in the early 1970s, the 54-acre (22-hectare) wooded preserve has been the subject of an intensive lake study and wetland restoration program funded in part by the state Centennial Water Quality Fund. Originally fed by a series of small "kettle" lakes, Snake Lake now receives its only freshwater intake from urban stormwater flows. The wetlands tend to cleanse this stormwater as it flows to the South Tacoma Aquifer and Chambers Creek. Beyond its ecological function, the Nature Center provides interpretive information, classes, and field trips to the citizens of Tacoma. The Nature Center is an undeveloped park that is preserved in its natural state in the heart of Tacoma.

OTHER LOCAL PROGRAMS AND SUCCESS STORIES

A wide variety of private organizations, Indian tribes, industries, citizen groups, and individual landowners have initiated or participated in various activities related to water quality issues in the Puget Sound basin in the past few years. Some representative projects are discussed below. Unfortunately, many other important projects could not be discussed here because of lack of space.

Hood Canal Coordinating Council and Hood Canal Land Trust

The Hood Canal Coordinating Council was formed by interlocal agreement in the fall of 1985 to develop a regional strategy for protecting and enhancing water-based resources in the Hood Canal watershed. In September 1986 the Council published its Regional Planning Policy. The regional plan includes recommendations for dealing with nonpoint pollution from such activities as forest and agricultural practices, shoreline and upland development, and boating. A set of "Water Quality Guidelines" was also developed to assist local governments in implementing the regional plan. The guidelines focus mainly on those activities not covered in regular shoreline or comprehensive plans. They are being incorporated into county and tribal policies. Projects currently planned or being accomplished by the Council include fisheries enhancement projects, watershed awareness programs, a demonstration wetland inventory project, shellfish and recreational surveys, boaters' education, a pilot teachers' project, and a regional household hazardous waste round-up.

Another project of importance on the Canal is the Hood Canal Land Trust. It was founded in 1985 as a local, grass-roots organization to preserve and enhance wetlands, wildlife habitat, and open spaces. The Trust has succeeded in preserving over 150 acres (60 hectares) of marsh and upland in the Canal and in southern Puget Sound through acquisition and conservation easements. Wetlands preserved on the Canal (in Lynch Cove) were identified as one of 19 biologically significant sites selected by the Washington Department of Natural Resources (DNR) in the Puget Trough for inclusion in a statewide system of estuarine sanctuaries.

Northwest Indian Fisheries Commission

The treaty Indian tribes of the Puget Sound region are involved in many projects related to assessing and improving the water quality of the Sound. Most treaty tribes are conducting water quality monitoring programs and other water quality-related projects, and also are involved as participants in larger efforts such as the early action watershed program. The Northwest Indian Fisheries Commission has initiated an innovative program to provide financial assistance (using Centennial Clean Water Fund money) for tribal participation in various early action watershed programs around the Sound. In addition, 20 tribes have installed a sophisticated geographic information system that uses computers to map watersheds in their regions.

The Lummi Tribe currently is developing a shellfish monitoring and protection plan that will tie directly into the shellfish and early action watershed programs of the Puget Sound Water Quality Management Plan. The tribe's plan is being developed with the assistance of an U.S. Environmental Protection Agency (EPA) grant. Tribal personnel will test shellfish and water for the presence of contaminants such as fecal coliform bacteria and PSP toxins. Information obtained from the program also will provide a data base to detect changes in upper watershed areas. The Lummi Tribe is also studying the relation of logging history and forest management practices to landslides in the Nooksack River watershed. In conjunction with this study, landslide rehabilitation work is being conducted in two of the five sub-basins being studied by the tribe. These pilot rehabilitation projects are resulting in significant localized improvements in fish habitat and stream water quality.

The Tulalip Tribes have been involved in several fish monitoring programs, including a springtime smolt outmigrant study that investigated the timing, abundance, and habitat use of smolting juvenile salmon in estuarine and marine waters surrounding the Stillaguamish and Snohomish River systems. The program was largely aimed at determining the potential impacts to fish resources from the U.S. Navy's proposed homeport in Everett. In another project, coho salmon smolts from nine different tributaries to the Stillaguamish River system were trapped and tagged to provide information on fish production by habitat area. The program (funded through the Pacific Salmon Treaty) was instrumental in identifying a major fish kill caused by a chlorine spill in Church Creek. Under a joint effort with the U.S. Forest Service (USFS), tribal crews rehabilitated a substantial amount of stream habitat in the Stillaguamish and upper Skykomish watersheds last summer. In early 1988 the Tulalip Tribes were awarded a PIE-Fund contract to develop a volunteer monitoring program for northern Port Susan and the lower Stillaguamish River. The project will coordinate and train volunteers to identify potential pollution problems, document current land use activities, survey and map aquatic habitats, and collect water quality samples. The tribe is also involved in the early action watershed program on the Stillaguamish River.

The Nisqually Tribe has been very active in the development of the Nisqually River Management Plan, a holistic management approach designed to meet the needs of the tribe, timber companies, environmental groups, state agencies, and others. This pilot planning process (which is incorporated into the Timber/Fish/Wildlife (T/F/W) agreement) will run for several years, and will address protection and enhancement of wildlife, fish, timber, and water resources.

Other tribal projects related to Puget Sound water quality issues include: a water quality monitoring program on various creeks draining into the Green River which was conducted by the Muckleshoot Tribe, Metro, and the King County Conservation District; and initiation of a planning process by the Port Gamble Klallam Tribe to develop a centralized sewage treatment plant for their reservation.

Simpson Timber/Simpson Tacoma Kraft

The Simpson Timber Company is working cooperatively with the Squaxin Island Tribe, the Washington Department of Wildlife (WDW), and WDF to protect important fishery resources in Kennedy Creek (located in Mason and Thurston Counties). Through the T/F/W process, the parties are jointly developing a variable width buffer zone for the whole Kennedy Creek basin that should allow for both timber harvest activities and protection of fishery resources.

Simpson Tacoma Kraft Company, with strong encouragement from Ecology, is in the process of addressing several environmental issues in one proposed project called the St. Paul Waterway Area Remedial Action and Habitat Restoration Project. This project includes: 1) rehabilitating an area of contaminated sediments located near the mill in Commencement Bay by capping the area with clean sediments (permits have been approved for this work); 2) completing a new outfall for the secondary treatment plant; 3) collecting and providing secondary treatment for surface runoff from the mill area; 4) containing wood chip spillage; and 5) creating new intertidal habitat for birds and other marine life. Simpson Tacoma Kraft is also diverting treated effluent from Tacoma's wastewater treatment system for use in its plant. This reduces the total amount of fresh water that the plant has to withdraw from groundwater or surface water sources.

The Boeing Company

The Boeing Company is conducting innovative programs related to wastewater treatment, waste discharge reduction, and water conservation. A new "double-loop" wastewater treatment system at Boeing's Everett facility is designed to remove metals and reduce concentrations of toxic organic chemicals (primarily phenols) from 3,000 parts per million (ppm) to less than 1 ppm. This system has significantly reduced the volume of hazardous wastes generated by the facility. The company also commonly recycles process water, and is able to save 900,000 gallons (3.4 million liters) of water a month at their wind tunnel facility by reallocating power to the tunnel's motors. In addition, Boeing initiated an overall water conservation campaign that has resulted in an estimated 10 percent reduction in water usage.

Citizen Action Groups

The Nature Conservancy is an international private, nonprofit conservation organization. Its goals are to identify and protect important natural areas through purchases, easements, and other methods, and to increase public awareness of the need to safeguard natural areas. The Washington chapter of The Nature Conservancy entered into a partnership with the state of Washington in late 1986, launching the Washington Wetland Campaign. The three-year program seeks to preserve the best remaining examples of Washington's native wetlands by purchasing them with funds raised by the Conservancy and matching grants from the state. Acquisitions are selected on the basis of a wetland survey conducted by DNR's Natural Heritage Program. So far the campaign has led to purchase and protection of six native wetlands of statewide significance. These include the Snoqualmie Bog Natural Preserve and additions to an existing wetland preserve at Dabob Bay. The Nature Conservancy seeks to raise $1.3 million for the wetland campaign by April 1989 and to purchase more than 20 additional sites in Washington. The group has preserved thousands of acres in the Puget Sound region, including preserves on the San Juan Islands, on Protection Island, and on the Upper Skagit River.

The Kitsap chapter of the Audubon Society, in conjunction with Trout Unlimited and a number of governmental agencies, has constructed a seven-acre (three-hectare) wetland on the property of one of its members (Bob Wiltermood). The ongoing project is adjacent to Ruby Creek near Port Orchard. The Agriculture Stabilization and Conservation Service provided funds for excavation under its "shallow area for wildlife" criteria. The Suquamish Tribe provided hatch boxes and eggs for a small hatchery that produces 320,000 salmon, and there is additional rearing habitat for coho salmon. Trout Unlimited installed stream structures and overflow swales, and Audubon monitors the 138 species of birds (including 53 nesting species) that inhabit the site. Last year 6,000 willow and dogwood trees were planted to provide shade for the channels and to add to the natural wetland food chain.

The Snohomish County Adopt-A-Stream Foundation was created from a successful county program that set out to educate public schools and community groups about the concept of "habitat stewardship." The foundation has continued this work and expanded to host two Adopt-A-Stream conferences for those interested in developing similar programs around the Sound. An example of their work is Pigeon Creek. This creek, which flows through the city of Everett, was "adopted" in 1982 by the entire Jackson Elementary School and the Salmon Club of Evergreen Middle School. Since then, coho salmon have returned to the creek for the first time in many years. Adopt-A-Stream provided funds for an egg box, aquarium, water quality testing kits, and paint and templates so that "No Dumping" signs could be painted on curbs throughout the creek's watershed. The school children provided the labor and enthusiasm to clean up and inventory the creek and to distribute educational pamphlets. They also successfully lobbied the city council to fund educational signs and to buy property at the headwaters of the creek for stormwater control.

In 1987 The Puget Sound Bank initiated a fundraising program to support educational activities focusing on the health of the Sound. Use of the bank's services, such as cash machine transactions or purchases of personalized checks, triggers an automatic contribution by the bank to an educational fund. The fund is expected to raise between $100,000 and $200,000, and will finance a 30-minute video about Puget Sound for television broadcast and distribution to schools. The fund will also support curriculum materials and educational brochures to be distributed at bank branches. The bank is also actively encouraging employees from its more than 80 branches to become involved in activities related to Puget Sound including Adopt-a-Beach and Adopt-a-Stream programs and litter cleanup events.

Preservative Paint Company, a Seattle-based paint manufacturer, successfully reduced its hazardous waste output by almost half in 1987. Faced with skyrocketing disposal costs, the company instituted an innovative program providing incentives to employees for ideas and efforts to reduce the use and disposal of hazardous wastes used in the paint manufacturing process. For each barrel of waste saved over 1986 amounts, the company contributed to a fund to be distributed among all employees. Employees chose to donate a portion of their incentive fund to two local environmental groups: the Puget Sound Alliance and the Adopt-a-Stream Foundation. The Puget Sound Alliance will use the money to educate and encourage other companies to reduce toxic waste, and the Adopt-a-Stream Foundation will use the funds to expand environmental education and stream enhancement activities in King County.

Appendix B: Activities, Studies, and Research, 1986-1987

This appendix includes capsule descriptions of a mixture of federal, state, local, and private activities, studies, and research that have been conducted in the last few years. The descriptions provide examples of the wide range of programs and activities taking place around the Sound. These activities are too numerous to discuss in total. The topics of these reports include issues relating to habitats and biological resources of Puget Sound as well as to sources of contamination in the Sound and the effects of this contamination. These and other studies are discussed in more detail in the main body of this document. Over 80 papers on recent research and studies were presented at the First Annual Meeting on Puget Sound Research held in Seattle on March 18-19, 1988. The proceedings from that conference (available from the Authority) also provide a good overview of research currently being conducted around the Sound.

Although there is no central repository for the studies discussed in the *State of the Sound Report*, local public libraries may be able to locate many of these studies and reports. Local libraries are connected through a statewide network with the Washington State Library located in Olympia. Other libraries that contain large collections of technical information on Puget Sound include the University of Washington library system, libraries of other colleges and universities around the Sound, and the in-house libraries of local, state, and federal agencies. However, many agency libraries (e.g., the U.S. Environmental protection Agency (EPA) Region 10 library located in downtown Seattle and the National Oceanic and Atmospheric Administration (NOAA) library located on Sand Point Way in Seattle) do not have lending policies so the reports must be reviewed on the premises.

Puget Sound Environmental Atlas (Evans-Hamilton, Inc., 1987)

Recognizing the need for an updated, comprehensive summary of Puget Sound environmental data, the U.S. Army Corps of Engineers (Corps), EPA, and the Puget Sound Water Quality Authority (Authority) funded the development of the *Puget Sound Environmental Atlas*. The atlas contains information on more than 40 topics grouped into the five major categories of physical environment, natural resources, human use patterns, pollution sources and data, and indicators of areas of concern. Data collected from a wide variety of sources were subjected to quality assurance/

quality control (QA/QC) procedures to ensure their accuracy. These data were then computerized and depicted on maps of 12 Puget Sound regions, as well as on enlarged maps of seven extensively sampled urban embayments. A narrative discussion of the information included on the maps is also provided in the atlas, including a discussion of data trends throughout the Sound. The atlas is intended to be used by a wide variety of groups (including students, permit writers, and resource agency personnel) who may need site-specific as well as Soundwide resource information. The document is available for use at the local libraries, as well as at the Corps, EPA, and Authority offices. Efforts are underway to develop the computer capability to produce an updated atlas every few years.

Puyallup River Estuary Wetlands Construction Project (Thom et al., 1987)

In 1985 and 1986 a 9.6-acre (3.8-hectare) wetland system was constructed by University of Washington Fisheries Research Institute scientists in the Puyallup River estuary near Lincoln Street (Tacoma) to mitigate for the filling of wetlands located about one mile downstream. Construction (funded by the Port of Tacoma) of the wetlands included building a new dike to surround the system; rerouting of a buried oil pipeline; excavation of fill material to form intertidal flats and channels; transplanting sedge plants onto the flats; and breaching the dike to connect the river to the wetlands. The construction project resulted in a mixture of wetland and upland habitats designed to attract a variety of species including juvenile salmon, shorebirds, waterfowl, raptors, and small mammals. The system appears to be successfully providing rearing habitat for juvenile salmonids. In addition, shorebirds and waterfowl have used the system in relatively high numbers to date (34 species were observed during the spring and summer of 1986). The wetland construction project mitigates for the habitat loss in the natural system downstream because it is providing habitat for the species it was designed to support.

Puget Trough Coastal Wetlands Study (Kunze, 1984)

This study was conducted as part of the Washington Department of Natural Resources (DNR) Natural Heritage Program to evaluate the most significant coastal wetlands in the Puget Sound area that might be appropriate for inclusion in the statewide system of estuarine sanctuaries. Sites were evaluated in terms of the quality, representation, and diversity of physical and biotic features using botanical and ecological criteria. In addition, supplemental data on wildlife and land use history were used in the evaluation when available. A total of 19 sites were recommended for inclusion into the estuarine sanctuary system, including three in the San Juan Islands, seven in the Hood Canal region, and four in southern Puget Sound. The sanctuary system will help protect these fragile, diminishing coastal wetland systems, as well as provide an opportunity for research and education.

Harbor Seal Populations and Their Contributions to Fecal Coliform Pollution in Quilcene Bay (Calambokidis et al., 1987)

High concentrations of fecal coliform bacteria in northern Quilcene Bay have resulted in the decertification of commercial shellfish beds there. This study evaluated the potential contribution of harbor seals to fecal coliform bacteria concentrations in the bay. Up to 230 harbor seals were counted in Quilcene Bay, though no dramatic seasonal variation in numbers was observed. A variety of bacteria were found in samples of harbor seal feces, predominantly *Bacillus* sp. and *Escherichia coli.* The pathogenic bacteria *Salmonella* and *Yersinia* were not found in any samples. This study indicated that densities of fecal coliform bacteria in the feces of harbor seals are fairly high. Given the number of seals and their relatively high defecation rates, concentrations of seals have the potential to be significant contributors to fecal coliform bacteria concentrations in Quilcene Bay. Potential fecal coliform contributions by harbor seal populations in other parts of the Sound have not been investigated.

Contaminant Transport from Elliott and Commencement Bays (Curl et al., 1987)

Major contaminant sources in Puget Sound are concentrated in urban embayments, but the extent of dispersion of these contaminants is unknown. To begin to understand contaminant transport processes better, NOAA conducted a study to determine whether contaminants could enter the main basin of Puget Sound from Elliott and Commencement Bays. The approach involved mapping water properties (e.g., current, temperature, and salinity) and the contaminant loadings in suspended sediments. The study revealed that particles suspended in freshwater were the primary sources of trace metals and toxic organic compounds in these bays. The Duwamish West Waterway, Denny Way combined sewer overflow (CSO), and Harbor Island were the three principal sources of high concentrations of metals in the surface layer of Elliott Bay. However, no substantial point sources were identified for metals observed in the freshwater layer of Commencement Bay, which were found in much lower concentrations than metals in Elliott Bay surface water.

Most of the contaminated suspended sediments remained in the thin freshwater plume on the water's surface and were transported to the main basin within about five days from Elliott Bay and about two days from Commencement Bay. Rates of resuspension and transport of bottom sediments were minimal in Commencement Bay and near zero in Elliott Bay. It is not known what percentage of the total freshwater sediment contaminant loading remains suspended in the surface layer versus what percentage settles out in the embayments. However, the findings of this study are significant because they show that contaminants found in the surface layer do not remain in the bays but are transported into the main basin.

Southern Puget Sound Water Quality Assessment Study (URS, Inc., 1985, 1986)

Estimates of human population growth indicate that southern Puget Sound will be one of the fastest growing areas in the Puget Sound area. The present population and anticipated growth will put increasing demands on current wastewater systems. URS Corporation prepared three reports for the Washington Department of Ecology (Ecology) to provide a technical basis for deciding where to locate effluent outfalls for wastewater treatment plants in southern Puget Sound. The first report established general guidelines for siting wastewater discharges based on dilution potential and beneficial uses (recreational and commercial) of the Puget Sound waters. The second report characterized the circulation and flushing of southern Puget Sound. The third report addressed anthropogenic (human-caused) pollutant loads, water quality, and circulation in one area of southern Puget Sound known to have ongoing water quality problems: Budd Inlet.

Budd Inlet was found to experience dissolved oxygen (DO) depletion during late summer and early fall. The severity of this problem is typically related to the strength and duration of phytoplankton (algae) blooms and the subsequent DO depletion when the plankton die and decay. To a lesser extent, this seasonal oxygen depletion is also caused by the poor flushing, lower DO concentrations, and high sediment oxygen demand rates that occur naturally at this time of year. Nutrients in the discharge from the LOTT (Lacey, Olympia, Tumwater, Thurston County) wastewater treatment plant near Olympia are believed to increase the intensity of these phytoplankton blooms by 30 to 50 percent compared to normal levels. It was predicted that acceptable DO concentrations could be maintained if the increase in intensity of algae blooms due to LOTT discharge was limited to no more than 10 percent over background conditions. This restriction could be met without reducing flow rate at the LOTT plant by removing at least 90 percent of the nutrient load from April through October. Ecology issued a National Pollutant Discharge Elimination System (NPDES) permit to the LOTT plant in September 1987 that requires (among other things) 90 percent effluent nutrient removal by April 1, 1993.

Duwamish Head Baseline Study (Metro, 1986)

The Municipality of Metropolitan Seattle (Metro) was recently required to eliminate discharges from the Renton Secondary Treatment Plant to the Duwamish River by constructing an effluent transfer system and a 9,500-foot (2,879-meter) long, 600-foot (183-meter) deep outfall in Elliott Bay. Prior to installing the outfall, Metro conducted an environmental baseline study to document existing physical, chemical, and biological conditions in the bay. The study objectives were to document predischarge conditions at the outfall site, document existing levels of contamination and potential pollution sources in shoreline areas near the site, and recommend a postdischarge monitoring program.

Results of the study showed that a band of sediments at a water depth of 100 to 200 feet (30 to 61 meters) between Duwamish Head and Alki Point produced a toxic response in Microtox (a bioluminescent bacteria). The highest concentrations of oil and grease in the sediment were found in the area where the new outfall was to be installed. The highest sediment concentrations of trace organic contaminants (PCBs and PAHs) were detected near Four Mile Rock and Smith Cove. Shellfish from four of six stations south of Alki Point and near West Point did not meet state and federal bacterial standards for commercial shellfish. Bacterial contamination in shellfish appeared to be related to bacterial levels in the sediment and not to bacterial levels in the water. Shellfish from Wing Point on Bainbridge Island had the greatest frequency of high metal contamination, although no samples of shellfish exceeded U.S. Food and Drug Administration (FDA) "action" levels for metals. Recommendations for a postdischarge monitoring included a "Red Flag System" to identify adverse changes in the environment, and the addition of effluent biomonitoring to the existing NPDES treatment plan monitoring program. Metro began discharging from the new outfall in March 1987.

Toxicant Reduction in the Denny Way Combined Sewer System (Romberg et al., 1987)

Frequent wastewater discharges (50 per year) from the Denny Way CSO are a major source of untreated sewage and stormwater to Elliott Bay. The purpose of the Denny Way toxicant reduction program conducted by Metro was to identify and reduce upstream toxicant sources in the Denny Way sewer system, thereby reducing toxicant loading to Elliott Bay during storms. Sampling was conducted in the sewer system to identify chemicals and their sources and in offshore sediments to define existing conditions. A total of 530 businesses were identified as potential toxicant sources, but only a small portion had nonsanitary discharges. Better storage, organization, and labeling practices to prevent spills were recommended for 40 businesses. Installation of pretreatment equipment produced improvements in discharge concentrations for two businesses. Street runoff appeared to be the major source of PAHs, and concentrations of organic pollutants were more variable than concentrations of metals in offshore surface sediments. Ten projects were recommended to reduce the loading of metals and organic chemicals to Elliott Bay from the Denny Way CSO and to accelerate recovery of the offshore environment.

Eagle Harbor Preliminary Investigation (Tetra Tech, Inc., 1986b)

Eagle Harbor, a federal Superfund site, was evaluated in this EPA-funded study to determine the type and extent of sediment contamination in the harbor, and to relate sediment toxicity and water quality to abundances of and effects on bottom-dwelling infauna (organisms living within the sediments). Of the toxic organic contaminants, PAHs were the most frequently detected and at the highest concentrations in the sediments. Total PAHs in three areas of Eagle Harbor (center of the harbor, near the Wyckoff Company facility that produces creosote-treated lumber, and near the state ferry maintenance terminal) exceeded 100 parts per million (ppm) dry weight, with the highest concentration reaching 120 ppm. Concentrations in surface sediments from reference areas in Puget Sound averaged 330 parts per billion (ppb) dry weight. Subsurface sediment PAH concentrations reached 47,000 ppm (4.7 percent) dry weight in the center of Eagle Harbor. The PAHs came from three sources: pure creosote oil, creosote contained in groundwater seepage, and weathered creosote from treated pilings.

Other organic compounds were detected at much lower concentrations in the sediments of Eagle Harbor. Chlorinated compounds were detected near the Wyckoff facility. Metals were detected near the ferry maintenance and passenger terminals; the highest concentrations were observed for copper, lead, zinc, and mercury. Concentrations of six metals exceeded Puget Sound reference concentrations. A limited study of the biological effects of all the above contaminants suggested that sediment contaminants are present at concentrations that can cause short- and long-term reductions in the abundances of benthic infaunal populations. However, the exact cause of the decreased infaunal abundances was not completely determined.

To address the various problems at this Superfund site, EPA has divided the cleanup activities into two separate areas, the Wyckoff Company unit and the Eagle Harbor unit. Cleanup measures being considered for the Wyckoff facility include 1) source controls to ensure that facility operations do not contribute to further site contamination; and 2) product recovery and groundwater cleanup activities to reduce the movement of contaminated materials to the Sound. Cleanup activities in Eagle Harbor include 1) initial chemical sampling of harbor sediments to determine the locations of specific problem areas; 2) full-scale biological and chemical analyses at problem areas; 3) analyses of clam tissue from Eagle Harbor beaches and sampling of nearshore sediments; and 4) an evaluation of parties that may be responsible for the contamination in the harbor. Sediment sampling in the harbor was initiated in March 1988; nearshore fieldwork including clam tissue sampling is scheduled for May 1988.

Development of Sediment Quality Values for Puget Sound (Tetra Tech, Inc., 1986a)

This report presents results of a joint effort between the Puget Sound Dredged Disposal Analysis (PSDDA) and EPA's Puget Sound Estuary Program (PSEP) to develop sediment quality values for Puget Sound. Sediment quality values represent concentrations of chemical contaminants that are associated with adverse biological effects in sediments. These effects are assessed by sediment toxicity, which is determined by measuring amphipod mortality and oyster larvae abnormality, as well as a depression in the abundance of benthic infauna. The sediment quality values are recommended for the following uses: identifying areas that require further testing of sediment quality; ranking potential problem areas; identifying problem chemicals in sediment; identifying acceptable sediments for open-water disposal of dredged material; and setting priorities for laboratory studies for determining cause-and-effect relationships between contaminants and biological effects.

Users' Manual for the Pollutant of Concern Matrix (Tetra Tech, Inc., 1986d)

The users' manual for the Pollutant of Concern Matrix describes how to access extensive information on 52 pollutants in Puget Sound. The information is tabulated on a Lotus 1-2-3 worksheet consisting of a matrix or set of tables. Compounds were included in the matrix on the basis of high toxicity in laboratory studies, environmental persistence, high potential to accumulate in aquatic organisms, existence of known sources, high concentration in sediments, and widespread distribution in Puget Sound. In tabular format, the following details are presented for each pollutant:

* Table 1: Regulatory status; availability of analytical methods for water, sediment, and tissue; and generally attainable analytical detection limits.

* Table 2: Drinking water standards; water quality criteria for freshwater aquatic life, saltwater aquatic life, and human health effects; apparent effects thresholds (i.e., concentrations above which biological impacts are expected); state dangerous waste designations; U.S. Food and Drug Administration action levels for seafood; and other limits.

* Table 3: Specific types of municipal, industrial, nonpoint, and other sources of contaminants.

* Table 4: Presence and effects in sediment, water, wildlife, sea surface microlayer, and fish/shellfish tissue.

* Table 5: Maximum, 90th percentile, median, and minimum concentrations in sediment, animal tissue, and water for both reference ("clean") and non-reference areas.

The study was funded by EPA. Although the two-year-old study is still very useful, it is slowly becoming outdated as new chemicals of concern and importance are discovered in Puget Sound and as the results of the ambient monitoring program become available.

Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound (Tetra Tech, Inc., 1986c)

In the past, collection and laboratory analysis of Puget Sound environmental samples were not standardized. The resulting differences in methods have severely limited comparisons of information collected. The objective of this EPA-sponsored project was to provide and encourage the use of well-defined and consistent methods for environmental sampling and analysis for Puget Sound. Recommendations for study design and data analysis were generally not included in the protocols because these factors can vary widely, depending on study objectives. Recommendations for eight groups of variables were documented: station positioning; conventional sediment, physical, and chemical variables; concentrations of organic compounds in sediment and tissues; concentrations of trace metals in sediment and tissues; benthic infauna; sediment bioassays; pathology of fish livers; and microbiological measurements of bacterial indicators and pathogens. Quality assurance/quality control procedures for collecting and analyzing environmental samples were also included.

PSDDA Draft Technical Appendix Disposal Site Selection Phase 1, Central Puget Sound (Kendall et al., 1988)

This technical appendix to the PSDDA phase 1 draft recommendation presents the information used to identify potential sites for unconfined open water disposal of dredged material. Map overlays were prepared showing navigation activities, recreational uses, cultural sites, aquaculture facilities, utilities, scientific study areas, point pollution sources, water intakes, shoreline land use designations, political boundaries, dredging areas, fish/shellfish harvest areas, threatened and endangered species, fish/shellfish habitat, wetlands, mudflats, vegetated shallows, bathymetry, sediment characteristics, and water currents (many of the overlays are included in the *Puget Sound Environmental Atlas*). Field studies were then undertaken to obtain additional information at potential sites. These included studies to confirm the depositional nature of the central Puget Sound sites; studies of crab, shrimp, and groundfish populations; and food web studies. A companion document specifies the chemical and biological tests that dredged material would have to pass for unconfined disposal.

The Urban Bay Toxics Control Program Action Team Accomplishments (Ecology, 1987d)

In an effort to ameliorate the pollution of Puget Sound and improve the quality of water and sediments, EPA and Ecology joined with other agencies and organizations in 1985 to develop and implement the Urban Bay Toxics Control Program. The program's methodology is based on earlier investigative work conducted by Metro and Ecology. The program is designed to identify existing problems of toxic contamination; identify known and suspected pollutant sources; outline procedures to eliminate existing pollution problems; and identify agencies responsible for implementing corrective actions in selected urban bays in Puget Sound. Four-member action teams were selected by local and federal government agencies for Elliott Bay, Commencement Bay, and Everett Harbor to provide the link between problem identification and source control. An action team is currently being organized for Budd Inlet, and the city of Seattle has developed an action plan for the Lake Union/Ship Canal/Shilshole area. Action plans and teams for Sinclair Inlet and Bellingham Bay will be developed in the future if resources become available. The following summaries outline actions taken since October 1985 in Elliott Bay, Commencement Bay, Everett Harbor, and Budd Inlet.

Elliott Bay: Since November 1985 the action team for this site has made over 221 inspections at 124 locations ranging from active companies to abandoned sites believed to be contributing pollutants to Elliott Bay. These site inspections revealed 42 unpermitted (illegal) discharges and as a result of these investigations, Ecology has issued 86 penalties totalling $44,200 in fines. Most of the priority problem areas are located in the lower Duwamish River adjacent to Harbor Island. Other areas include the Denny Way CSO and the Seattle waterfront near Madison Street.

Commencement Bay: Over 425 potential pollutant sources have been identified within Commencement Bay. Two members of the action team work on contaminated sites and two members work on permitted industries, storm drains, and inspections. Since October 1985 the action team has conducted 134 inspections resulting in 18 enforcement actions, $94,000 in penalty assessments, and nine permit actions. The action team is negotiating with other potentially responsible companies to achieve cleanup of contaminated sites.

Everett Harbor: The action team for this site was formed in March 1987. Field sampling has been completed, and the results will be used to help identify priority problem areas and to develop an action plan. Inspections by the action team and source control activities are ongoing, and two penalties have been assessed for discharging untreated wastewater into the city sewer system.

Budd Inlet: Ecology initiated an investigation to identify possible toxic problems in the inlet, including PAHs, heavy metals, and increases in nutrient and bacteria concentrations. A work group was organized by local and federal government agencies to help form an action team for the area.

Studies of Sea-Surface Contamination in Puget Sound (Hardy et al., 1986)

NOAA-sponsored studies were conducted at the Battelle Pacific Northwest Marine Laboratory to determine: 1) what biota might be found in contact with the microlayer in Puget Sound; 2) what contaminants might be present in the microlayer; and 3) how toxic the microlayer might be (as measured by the effects on the reproductive success of flatfish and the growth of trout cells). The sea-surface microlayer (the upper 50 micrometers or 2×10^{-3} inches of the sea surface) is a highly effective collection area for a variety of organic and metal contaminants. The sea-surface microlayer is also an important biological habitat, especially for eggs and larvae of many fish and shellfish.

Field surveys determined that invertebrate eggs and the egg and fry (young) of fish are found in the surface layer and may be exposed to microlayer contaminants. Toxic compounds, bacteria, and planktonic organisms can be found at higher concentrations in the sea-surface microlayer than in water below the microlayer. In some cases PCB concentrations in the sea-surface microlayer exceeded water quality criteria. About half the samples of fertilized flatfish eggs exposed in laboratory bioassays to urban bay microlayer samples experienced decreases in the number of hatched eggs and increases in larval abnormalities. In addition, urban bay sites generally were found to contain lower concentrations of flatfish eggs during spawning season than rural sites, but this finding may be due to the effects of the freshwater lens that is present in the surface layer of the bays rather than to pollution effects (Long, 1988a, pers. comm.). Human health effects from sea-surface microlayer contamination have not been studied.

Reconnaissance Survey of Eight Bays in Puget Sound (Battelle Pacific Northwest Marine Laboratory, 1986)

This two-year study was conducted for EPA to develop a better understanding of the toxic contamination problems in the following four urban industrialized bays of Puget Sound: Bellingham Bay, Port Gardner-Everett Harbor, the Four Mile Rock-Elliott Bay dump site near Seattle, and Sinclair Inlet near Bremerton. Understanding the contamination in these bays will aid in developing a basis for regulatory action. Preliminary and detailed surveys were conducted in the four industrialized bays and in four baseline (rural) embayments (Samish Bay in Skagit County, Case Inlet in southern Puget Sound, Dabob Bay in Jefferson County, and Sequim Bay in Clallam County). The baseline embayments were chosen to help establish sediment and benthic characteristics in relatively unaffected areas.

For each urban bay, the report describes sediment chemistry and toxicity (measured by amphipod and oyster larval bioassays), numerically dominant benthic infauna, and occurrence of fish and shellfish diseases. The urban bay stations (which were generally selected near potentially affected areas) showed higher levels of sediment contamination and fish/shellfish disease than did stations in the baseline bays (which were generally located in the middle of the bay).

The greatest impacts were found at stations in Port Gardner-Everett Harbor, Sinclair Inlet, and Bellingham Bay. These three bays had the highest levels of metals, PAHs, PCBs, and sediment toxicity. The Four Mile Rock site was the least affected of the urban bays in terms of sediment contamination and toxicity. Sequim Bay was the least contaminated of the baseline bays, with Dabob Bay slightly less pristine. Case Inlet and Samish Bay both showed some indication of degraded sediment quality.

Characterization of Spatial and Temporal Trends in Water Quality in Puget Sound (Tetra Tech, Inc., 1988a)

A long-term trend analysis of water quality was conducted for 14 sites in Puget Sound. The primary purpose of this EPA-sponsored study was to determine whether changes in the ecology of the water column could be related to anthropogenic (human-induced) influences. A secondary purpose of the study was to determine if future monitoring programs should be redesigned for more efficient detection of possible ecological changes. The study focused on the intensity of algal blooms and nutrient concentrations. When the intensity of algal blooms increases, water quality is degraded by increased turbidity and lowered dissolved oxygen (DO) concentrations (which can cause fish kills and odor problems).

Water quality variables analyzed in the study included salinity, water temperature, and concentrations of dissolved oxygen, chlorophyll *a*, nitrate, and phosphate. Pollutants analyzed included concentrations of fecal coliform bacteria (a measure of sewage contamination) and sulfite waste liquor (a measure of pulp mill contamination). The data base for some sites extended back to 1932, although data for most sites extended only to the early 1950s. The population of the Puget Sound region has more than doubled since 1932, which has probably caused an increase in nutrient inputs. However, treatment requirements for wastewater discharges have become more stringent, which may have moderated the effects of population growth.

There was no evidence of basinwide trends in intensity of algal blooms or degradation of water quality. Some regional trends in water quality appear to have been driven by oceanographic factors. For example, in Hood Canal salinities declined while temperature and DO concentrations increased, even though anthropogenic influences have remained relatively low. Significant reductions in concentrations of fecal coliform bacteria and sulfite waste liquor were noted in several areas (e.g., Port Gardner at Everett, Bellingham Bay, and Oakland Bay near Shelton). These improvements generally coincided with improved effluent treatment in these locations. In addition, phosphate concentrations in six urban areas (but no rural areas) have increased since 1973. The cause(s) of these increased phosphate concentrations is unknown. This comparative study was hampered by the diversity of methods that have been used for field sampling and laboratory analyses. Intermittent and infrequent sampling of the water, and changes in the locations of sampling stations, also constrained the usefulness of existing data. The use of consistent sampling protocols at established station locations should alleviate some of these problems in future monitoring programs, thus facilitating trend analyses in the future.

Compendium of Toxic Indicators in Less-Developed Areas of Puget Sound (Tetra Tech, Inc., 1988b)

This EPA-funded study presents an assessment of toxic contamination in less-developed areas of Puget Sound. Studies of toxic contamination are being conducted in contaminated urban areas including Commencement Bay, Elliott Bay, Everett Harbor, Budd Inlet, and Lake Union/Ship Canal. Other studies are anticipated for Sinclair Inlet and Bellingham Bay. However, less-developed areas may also have toxic contamination from sources such as existing or historical industrial facilities, military installations, and chemical spills. The compendium contains information to help determine which of the less-developed areas may be contaminated.

Information was obtained from a wide variety of sources such as government records, government and industrial reports, research papers, and interviews with resource agency personnel and private citizens. The information was organized in a "decision matrix," with a high, medium, or low priority for further study assigned to each site. The next step in characterizing less-developed areas will be to more thoroughly investigate the literature on those areas identified as having high priority for further study. Based on these investigations, field surveys may be conducted to measure toxic chemicals and biological effects in the less-developed areas judged to be most severely degraded.

Potential Toxicant Exposure Among Consumers of Recreationally Caught Fish from Urban Embayments of Puget Sound (Landolt et al., 1987)

There is growing public concern regarding the safety of consuming seafood caught in urban embayments of Puget Sound. A two-year study was conducted by NOAA to estimate the amount of certain contaminants that recreational anglers might ingest by eating fish from urban bays in Puget Sound. The study focused on five main elements: 1) what species people are fishing for, actually catching, and eating from the urban bays; 2) the average ingestion rate of the typical consumer (fish eaten/year); 3) the contaminant levels that are present in the tissue of the species eaten; 4) the effects of cooking on tissue contaminant levels; and 5) average contaminant uptake rate (which is a factor of both typical ingestion rates and tissue contaminant levels). The study found that tissue from recreationally caught fish generally contained low levels of metals (with the exception of arsenic) and organic compounds. Arsenic levels varied greatly among species and geographic locations but were highest in squid and walleye pollock (particularly those collected from Commencement Bay). Although generally present in low concentrations, PCBs were found in all of the recreationally caught fish from the urban bays. Cooking the fish was found to reduce tissue levels of PCBs and other organic contaminants by 50 to 90 percent, but cooking had little or no effect on arsenic concentrations. Cooking slightly increased concentrations of copper, cadmium, mercury, selenium, and zinc and greatly increased concentrations of silver and lead. The study did not attempt to assess the risk associated with eating fish from urban bays, but did provide estimates of contaminant doses being consumed by urban anglers.

National Status and Trends Program for Marine Environmental Quality (NOAA, 1987)

The National Status and Trends Program, initiated by NOAA in 1984, is evaluating the prevalence of toxic chemical contamination of the coastal environment of the United States. The goals of the program are to assess the status and trends in concentrations of toxic chemicals and measures of biological effects. NOAA's approach is to develop a systematic, historic record and to compare trends in the record with each year's worth of new data. Sampling of sediments and tissues of bivalve molluscs and bottom-dwelling fish is performed at over 200 sites, 11 of which are located in Puget Sound. Because the focus of the program is nationwide and representative sites are sampled around the country, no specific area is sampled as thoroughly as might be done in a more regional study.

Data are obtained on 24 chlorinated synthetic organic compounds (mostly pesticides and PCBs), 19 PAHs, 17 elements (mostly metals), along with a suite of biological variables (including incidence of histopathological disorders) and a number of measures of sediment physical characteristics. Preliminary results for the Sound indicate that the highest concentrations of some contaminants were found at sites in urban areas (e.g., PCBs, PAHs, and sewage indicators in Elliott and Commencement Bays). The concentrations of other contaminants did not vary substantially in the Sound (e.g., chromium). Highest contaminant concentrations were found at selected sites in Boston Harbor and Raritan Bay on the east coast, in San Diego Bay in southern California, and in Elliott Bay in Puget Sound. However, the Four Mile Rock site located in Elliott Bay had the highest PAH concentrations of any site in the country.

Neoplastic and Other Diseases in Fish in Relation to toxic Chemicals: An Overview (Malins et al., 1988)

This report summarizes a five-year study conducted by the National Marine Fisheries Service (NMFS) in Puget Sound on the following two issues: the relationships among liver tumors in bottom-dwelling fish (primarily English sole) and the concentrations of toxic chemicals in sediments and fish tissue. Liver tumors in bottom fish appear to be correlated with exposure to or contamination by certain toxic substances. This problem is an emerging concern not only in Puget Sound, but also in Boston Harbor, southern California, and the Great Lakes. In Puget Sound, liver tumors were found most frequently in fish from Eagle Harbor (24 percent occurrence) and the Duwamish Waterway (17 percent occurrence). Significant correlations were found between the prevalence of liver tumors and sediment concentrations of aromatic hydrocarbons (e.g., PAHs). In addition, there were higher concentrations of metabolic breakdown products from nitrogen-containing aromatic compounds in fish livers containing tumors than in normal fish livers.

The report presents preliminary evidence on the cause of liver tumors and the route of exposure. Fragments of aromatic hydrocarbon molecules bind to DNA in the cells of fish livers. The possible connection between these fragments and tumor development is still being studied. One route of exposure occurs when fish take in PAHs in their food. The food of English sole are small bottom-dwelling organisms, and these organisms contain much higher concentrations of PAHs in contaminated areas than in relatively uncontaminated areas.

Acronyms

AET--Apparent effects threshold
Authority--Puget Sound Water Quality Authority
BMP--Best management practice
BOD--Biochemical oxygen demand
Corps--U.S. Army Corps of Engineers
CSO--Combined sewer overflow
DNR--Washington Department of Natural Resources
DSHS--Washington Department of Social and Health Services
EAR--Elevation above reference
Ecology--Washington Department of Ecology
EIS--Environmental impact statement
EPA--U.S. Environmental Protection Agency
FDA--U.S. Food and Drug Administration
IAC--Washington Interagency Committee for Outdoor Recreation
IOSA--San Juan Islands Oil Spill Association
LOTT--Lacey, Olympia, Tumwater, Thurston County
Metro--Municipality of Metropolitan Seattle
MGD--Millions of gallons per day
NCPDI--National Coastal Pollutant Discharge Inventory
NMFS--National Marine Fisheries Service
NOAA--National Oceanic and Atmospheric Administration
NPDES--National Pollutant Discharge Elimination System
NWI--National Wetland Inventory
OFM--Washington Office of Financial Management
PAH--Polycyclic aromatic hydrocarbon
PCB--Polychlorinated biphenyl
PIE-Fund--Public Involvement/Education Fund
PNRBC--Pacific Northwest River Basins Commission
POTW--Publicly-owned treatment works
PPB--Parts per billion
PPM--Parts per million
PPT-Parts per thousand
PSAPCA--Puget Sound Air Pollution Control Agency
PSCOG--Puget Sound Council of Governments
PSDDA--Puget Sound Dredged Disposal Analysis
PSP--Paralytic shellfish poisoning
PSWQA--Puget Sound Water Quality Authority
QA/QC-Quality assurance/quality control
RCW--Revised Code of Washington
SCS--U.S. Department of Agriculture Soil Conservation Service

SCORP--Statewide Comprehensive Outdoor Recreation Plan
SEPA--State Environmental Policy Act
SMA--Shoreline Management Act
TBT--Tributyl tin
T/F/W--Timber/Fish/Wildlife
TSS--Total suspended solids
USCG--U.S. Coast Guard
USFS--U.S. Forest Service
WAC--Washington Administrative Code
WSDA--Washington State Department of Agriculture
WDF--Washington Department of Fisheries
WDTED--Washington Department of Trade and Economic Development
WDW--Washington Department of Wildlife

Glossary

ACUTE EFFECT
Any toxic effect that is produced within a short period of time, generally 96 hours or less. Although the effect most frequently considered is mortality, the end result of an acute effect could be any harmful biological effect.

AEROBIC
Living, active, or occurring only in the presence of oxygen. For example, soil microorganisms which degrade sewage effluent from septic systems need oxygen in order to function.

ALGAE
Aquatic, nonflowering plants that lack roots and use light energy to convert inorganic nutrients such as nitrogen and phosphorus into organic matter by photosynthesis. Common algae include single-celled dinoflagellates, diatoms, seaweeds, and kelp. An algal bloom can occur when excessive nutrient levels and other physical and chemical conditions enable the algae to reproduce rapidly.

AMBIENT MONITORING
Monitoring that is done to determine existing environmental conditions, contaminant levels, rates, or species in the environment.

AMPHIPODS
Small shrimp-like crustaceans such as sand fleas and related forms. Many live on the bottom (i.e., are benthic) and feed on algae and detritus.

ANADROMOUS FISH
Species, such as salmon, which hatch in fresh water, spend a large part of their lives in the ocean, and return to fresh water rivers and streams to reproduce.

ANTHROPOGENIC
Effects or processes that are derived from human activity, as opposed to natural effects or processes that occur in the environment without human intervention.

APPARENT EFFECTS THRESHOLD (AET)
The highest sediment concentration of an individual chemical contaminant which is not associated with adverse biological effects. Samples with concentrations of contaminants above the AET have always shown adverse biological effects.

AQUACULTURE
The controlled cultivation and harvest of aquatic plants or animals (e.g., edible marine algae, clams, oysters, and salmon).

AQUIFER
The underground layer of rock or soil in which groundwater resides. Aquifers are replenished or recharged by surface water percolating through soil. Wells are drilled into aquifers to extract water for human use.

AROMATIC
A chemical substance characterized by the presence of at least one benzene ring. These substances may have a strong smell and are often persistent in the environment due to the stability of the benzene ring.

BASELINE STUDY
A study that seeks to document the existing state of an environment to serve as a baseline against which future changes are measured.

BENTHIC ORGANISMS
Organisms that live in or on the bottom of a body of water.

BEST MANAGEMENT PRACTICE (BMP)
A method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a water body. The term originated from the rules and regulations developed pursuant to Section 208 of the federal Clean Water Act (40 CFR 130).

BIOACCUMULATION
The process by which a contaminant accumulates in the tissues of an organism. For example, certain chemicals in food eaten by a fish tend to accumulate in its liver and other tissues.

BIOASSAY
A test procedure that measures the response of living plants, animals, or tissues to potential contaminants. For example, marine worms have been exposed to the sediments of Puget Sound, and their responses have been used to determine areas in the Sound where the sediments may be harmful to life.

BIOCHEMICAL OXYGEN DEMAND (BOD)
The quantity of oxygen-demanding materials present in a sample as measured by a specific test. A major objective of conventional wastewater treatment is to reduce the biochemical oxygen demand so that the oxygen content of the water body will not be significantly reduced. Although BOD is not a specific compound, it is defined as a conventional pollutant under the federal Clean Water Act.

BIODEGRADATION
The conversion of organic compounds into simpler compounds through biochemical activity. Toxic compounds can sometimes be converted into nontoxic compounds through biodegradation. In some cases complex compounds are first converted into intermediate substances that can be more toxic than the original substance.

BIOMAGNIFICATION
The process by which concentrations of contaminants increase (magnify) as they pass up the food web such that each animal in the food web has higher tissue concentrations than did its food. For example, concentrations of certain contaminants can increase as they are passed from plankton to herring to salmon to seals.

BIOTA
The animals, plants, and microbes that live in a particular location or region.

BIOTRANSFORMATION
The chemical transformation of substances by biological processes. Toxic chemicals ingested by fish may be changed by chemical reactions into other chemicals in the fish. These new compounds may be harmless, or they may be more toxic than the original contaminant.

BIOTURBATION
Biological activity that disturbs and mixes surface and subsurface sediments. If subsurface sediments are contaminated, the continual mixing with surface sediments may contaminate surface sediments as well. Even after a contaminant is no longer entering the surface sediments, it may take a long time for contamination to diminish because of this mixing.

BIVALVE
An aquatic invertebrate animal of the class Bivalvia. Bivalves, such as clams and oysters, have two shells (valves) and most are filter feeders.

BOG

A wetland with poor drainage generally characterized by extensive peat deposits and acidic waters. Vegetation includes sedges, sphagnum moss, shrubs, and trees.

CARCINOGENIC

Capable of causing cancer.

CARNIVORE

An organism, usually an animal, that feeds on animals or the flesh of animals.

CATEGORICAL INDUSTRY and CATEGORICAL STANDARDS

To deal with the tremendous number of individual industrial and commercial operations that may require water pollution standards, EPA has established 34 industrial categories based on a standard industrial classification developed for tax purposes. Some examples are adhesives and sealants, explosives manufacturing, ore mining, pulp and paperboard mills, and textile mills. As part of the settlement of a lawsuit, EPA identified 22 of these industrial categories for which federal pretreatment standards would be developed. An industry in an industrial category for which pretreatment standards have been set is referred to as a categorical industry, and the federal pretreatment standards are referred to as categorical standards.

CERTIFIED SHELLFISH BED

An area where commercial shellfish harvesting is approved by the Washington Department of Social and Health Services (DSHS), based on measurements of fecal coliform bacteria in the overlying waters. Fecal coliform bacteria are used as an indicator of human health risk.

CHRONIC EFFECT

Any toxic effect on an organism that results after exposure of long duration (often 1/10th of the life span or more). The end result of a chronic effect can be death although the usual effects are sublethal (e.g., inhibited reproduction or growth). These sublethal effects may be reflected by changes in the productivity and population structure of the community.

CLEAN WATER ACT (CWA)

Also known as the federal Water Pollution Control Act (33 U.S.C. 1251 et seq.).

CLEANUP ACTIVITIES

Actions taken by a public agency or a private party to correct an environmental problem. Activities can include either the prevention of pollution by the treatment or control of contaminants (for example, treatment of wastewater before discharge), or the removal from the environment of contaminants introduced by past practices (for example, digging up and incinerating soil contaminated with dioxin).

CODE OF FEDERAL REGULATIONS (CFR)

The compilation of federal regulations adopted by federal agencies through the rulemaking process. For example, pretreatment regulations are found in 40 CFR 403.

COLIFORM BACTERIA

A type of bacteria that is coil or helix shaped. Fecal coliform bacteria are those coliform bacteria that are found in the intestinal tracts of mammals. The presence of high numbers of fecal coliform bacteria in a water body can indicate the recent release of untreated wastewater and/or the presence of animal feces. These organisms may also indicate the presence of pathogens that are harmful to humans. High numbers of fecal coliform bacteria therefore limit beneficial uses such as swimming and shellfish harvesting.

COMBINED SEWER OVERFLOW (CSO)

A pipe that discharges untreated wastewater during storms from a sewer system that carries both sanitary wastewater and stormwater. The overflow occurs because the system does not have the capacity to transport, store, or treat the increased flow caused by stormwater runoff.

COMBINED SEWER SYSTEM
A wastewater collection and treatment system where domestic and industrial wastewater is combined with storm runoff. Although such a system does provide treatment of stormwater, in practice the systems may not be able to handle major storm flows. As a result, untreated discharges from combined sewer overflows may occur.

CONTAMINANT
A substance that is not naturally present in the environment or is present in amounts that can, in sufficient concentration, adversely affect the environment.

CONVENTIONAL POLLUTANT
Conventional pollutants as specified under the Clean Water Act are total suspended solids, fecal coliform bacteria, biochemical oxygen demand, pH, and oil and grease. Today a large number of nonconventional and toxic contaminants are of concern in addition to the conventional contaminants.

COPEPOD
A type of herbivorous microscopic crustacean (subclass Copepoda). Copepods are very important in the food chain because they are eaten by many fish or other organisms that are eventually eaten by fish. Calanoid and cyclopoid copepods are pelagic and harpacticoid copepods are benthic.

CUMULATIVE EFFECTS
The combined environmental impacts that accrue over time and space from a series of similar or related individual actions, contaminants, or projects. Although each action may seem to have a negligible impact, the combined effect can be severe.

DEPOSIT FEEDER
Organisms that feed on organic material that is found on and in bottom sediments. Because they ingest sediments directly to extract the organic component, these organisms may concentrate toxic contaminants.

DESORPTION
The movement of substances into solution from particles where they have been sorbed. Opposite of sorption.

DETENTION
The process of collecting and holding back stormwater for delayed release to receiving waters.

DETRITUS
Fragments of detached or broken down organic matter derived from the disintegration of animals and plants.

DISCHARGE, DIRECT OR INDIRECT
The release of wastewater or contaminants to the environment. A direct discharge of wastewater flows directly into surface waters while an indirect discharge of wastewater enters a sewer system.

DISINFECTION
The destruction of infectious agents such as bacteria or viruses. Most wastewater treatment plants use chlorine or bromine for disinfection.

DISPOSAL
Methods by which unwanted materials are relocated, contained, treated, or processed. Unless contaminants are converted to less harmful forms or removed from the material before disposal, they may be released again into the environment.

DISSOLVED OXYGEN
Oxygen that is present (dissolved) in water and therefore available for fish and other aquatic animals to use. If the amount of dissolved oxygen in the water is too low, then aquatic animals may die. Wastewater and naturally occurring organic matter contain oxygen-demanding substances that consume dissolved oxygen.

DOMESTIC WASTEWATER (SEWAGE)
Human-generated wastewater that flows from homes, businesses, and industries.

DREDGING
Any physical digging into the bottom sediment of a water body. Dredging can be done with mechanical or hydraulic machines, and it changes the shape and form of the bottom. Dredging is routinely done in many parts of Puget Sound in order to maintain navigation channels that would otherwise fill with sediment and block ship passage.

DRY WELL
A pit in the ground, often filled with gravel, into which stormwater is routed. The dry well holds the runoff until it percolates into the ground.

ECOSYSTEM
A community of living organisms interacting with one another and with their physical environment, such as a rain forest, pond, or estuary. Damage to any part of a complex system, such as Puget Sound, may affect the whole. A system such as Puget Sound can also be thought of as the sum of many interconnected ecosystems such as the rivers, wetlands, and bays. Ecosystem is thus a concept applied to communities of different scale, signifying the interrelationships that must be considered.

EFFLUENT
The liquid that flows out of a facility or household into a water body or sewer system. For example, the treated liquid discharged by a wastewater treatment plant is the plant's effluent.

ELEVATION ABOVE REFERENCE (EAR)
The ratio between contaminant concentrations at a study site and a noncontaminated reference site. The value of the elevation above reference is not necessarily an indication of harm because the concentration of contaminants that may cause harm is generally not known.

ENVIRONMENTAL IMPACT STATEMENT (EIS)
A document that discusses the likely significant impacts of a development project or a planning proposal, ways to lessen the impacts, and alternatives to the project or proposal. EISs are required by the national and Washington state environmental policy acts.

EROSION
Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical and chemical forces.

ESCAPEMENT
A fisheries management term for the number of anadromous fish which escape capture and reach spawning grounds to reproduce.

ESTUARY
A coastal water body where ocean water is diluted by out-flowing fresh water.

FECAL COLIFORM see COLIFORM BACTERIA

FECES
Waste excreted from animals.

FILTER FEEDER
An organism that feeds on microscopic food by filtering very large volumes of water. Because of the amount of water filtered, these organisms may tend to concentrate toxins. Filter feeders that live on bottom sediments (e.g., clams and oysters) are particularly susceptible to contamination.

FLOCCULATION
The aggregation of small suspended particles into a loose mass caused by ionic changes or changes in solubility. Many contaminants dissolved or carried in fresh water change form through this process when the fresh water enters the salt water of Puget Sound. Flocculation tends to accelerate the settling of particles.

FOREST PRACTICE
Any activity conducted on or directly pertaining to forest land related to growing, harvesting, or processing timber. These activities include but are not limited to: road and trail construction, final and intermediate harvesting, precommercial thinning, reforestation, fertilization, prevention and suppression of disease and insects, salvage of trees, and brush control. Forest practices are subject to regulation by the Washington Department of Natural Resources.

FULL-TIME EQUIVALENT (FTE)
The work one person does in one year--used to estimate costs and people needed to perform certain actions.

FUNGICIDE
A substance that destroys or inhibits growth of fungus.

GROUNDFISH
Fish (also known as bottomfish) that live on or near the bottom of water bodies, for example, English sole.

GROUNDWATER
Underground water supplies stored in aquifers. Groundwater is created by rain which soaks into the ground and flows down until it is collected at a point where the ground is not permeable. Groundwater then usually flows laterally toward a river, lake, or the ocean. Wells tap the groundwater for our use. (See AQUIFER)

HABITAT
The specific area or environment in which a particular type of plant or animal lives. An organism's habitat must provide all of the basic requirements for life and should be free of harmful contaminants. Typical Puget Sound habitats include beaches, marshes, rocky shores, the bottom sediments, intertidal mudflats, and the water itself.

HAZARDOUS WASTE
Any solid, liquid, or gaseous substance which, because of its source or measurable characteristics, is classified under state or federal law as hazardous and is subject to special handling, shipping, storage, and disposal requirements. Washington state law identifies two categories, dangerous and extremely hazardous. The latter category is more hazardous and requires greater precautions.

HEALTH RISK
The risk or likelihood that human health will be adversely affected. Estimating health risks is a complex and inexact practice.

HEPATIC NEOPLASMS
Liver abnormalities in fish which may be caused by sublethal exposure to toxic pollutants.

HERBICIDE
A substance used to destroy or inhibit growth of vegetation.

HERBIVORE
An organism that feeds on plant material.

HOLDING TANK
An enclosed container used as part of a sewage disposal system on a boat. The tank is used to temporarily store sewage for later pumpout at a marina pumpout facility.

HYDROCARBON
An organic compound composed of carbon and hydrogen; for example, petroleum compounds.

HYDROLOGIC CYCLE
The continual cycling of water between the land, the sea, and the atmosphere through evaporation, condensation, precipitation, absorption into the soil, and stream runoff.

IMPERVIOUS
A surface that cannot be easily penetrated. For instance, rain does not readily penetrate asphalt or concrete pavement.

INDUSTRIAL USER
A commercial or industrial facility which discharges anything other than domestic waste to a sewage treatment plant. Industrial users may be subject to pretreatment requirements.

INSECTICIDE
A substance, usually a chemical, that is used to kill insects.

INTERFERENCE
A contaminant can interfere with the normal sewage treatment plant process by diminishing the efficiency of the treatment process. For example, a toxic chemical can kill the beneficial bacteria in a treatment plant and interfere with the biological treatment process, thus causing the release of excessively contaminated effluent.

INTERTIDAL AREA
The area between high and low tide levels. The alternate wetting and drying of this area makes it a transition between land and water and creates special environmental conditions.

LAND USE
The way land is developed and used in terms of the types of activities allowed (agriculture, residences, industries, etc.) and the size of buildings and structures permitted. Certain types of pollution problems are often associated with particular land use practices, such as sedimentation from construction activities.

LEACHATE
Water or other liquid that has washed (leached) from a solid material, such as a layer of soil or debris. Leachate may contain contaminants such as organics or mineral salts. Rainwater that percolates through a sanitary landfill and picks up contaminants is called the leachate from the landfill.

LIVEABOARD
Those using a boat, other than a houseboat, as a primary dwelling.

LOADING
The total amount of material entering a system from all sources.

MARINE SANITATION DEVICE (MSD)
A device installed on a boat to treat or hold sewage. Section 312 of the federal Clean Water Act requires all vessels with installed toilets to have approved MSDs. Federal regulations describe three types of MSDs: Type I and Type II MSDs are treatment devices while Type III MSDs are holding tanks.

MARSH
A wetland where the dominant vegetation is non-woody plants such as grasses and sedges, as opposed to a swamp where the dominant vegetation is woody plants like trees.

MEAN ANNUAL FLOW
The average amount of water that flows past a given point in one year.

MEAN HIGH WATER (MHW)
The average height (over many years) reached by the high tides.

MEAN HIGHER HIGH WATER (MHHW)
The average height (over many years) reached by the higher of two high tides each day. Puget Sound has two high tides and two low tides each day.

METABOLISM
All chemical processes occurring within an organism, including both synthesis and breakdown of organic materials.

METALS
Metals are elements found in rocks and minerals that are naturally released to the environment by erosion, as well as generated by human activities. Certain metals, such as mercury, lead, nickel, zinc, and cadmium, are of environmental concern because they are released to the environment in excessive amounts by human activity. They are generally toxic to life at certain concentrations. Since metals are elements they do not break down in the environment over time and can be incorporated into plant and animal tissue.

MICROLAYER, SEA-SURFACE MICROLAYER
The extremely thin (usually estimated as 50 microns) layer at the top of the water. Contamination of this layer is of concern because many contaminants such as oil, grease, organic toxicants, and pathogens are buoyant in seawater and therefore may concentrate at much higher concentrations in the microlayer than in the water column. The atmospheric deposition of toxicants into the microlayer is also of concern. These contaminant concentrations may pose a danger to fish eggs and other organisms that may come into contact with the water surface.

MICROORGANISMS
Microscopic organisms, (e.g., bacteria, viruses, and protozoans) that are not visible to the unaided eye. Some cause diseases in humans, animals, and plants; some are important because they are involved in breaking down and stabilizing sewage and solid waste.

MONITOR
To systematically and repeatedly measure conditions in order to track changes. For example, dissolved oxygen in a bay might be monitored over a period of several years in order to identify trends in concentration.

MUNICIPAL DISCHARGE
Effluent from a municipal sewage treatment plant.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES)
A part of the federal Clean Water Act, which requires point source dischargers to obtain discharge permits. These permits are referred to as NPDES permits and are administered by the Washington Department of Ecology.

NONPOINT SOURCE POLLUTION
Pollution that enters water from dispersed and uncontrolled sources (such as surface runoff) rather than through pipes. Nonpoint sources (e.g., forest practices, agricultural practices, on-site sewage disposal, and recreational boats) may contribute pathogens, suspended solids, and toxicants. While individual sources may seem insignificant, the cumulative effects of nonpoint source pollution can be significant.

NUTRIENTS
Essential chemicals needed by plants or animals for growth. If other physical and chemical conditions are optimal, excessive amounts of nutrients can lead to degradation of water quality by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae. Some nutrients can be toxic to animals at high concentrations.

OMNIVORE
An organism that feeds on both plant and animal tissue.

ORGANOMETALLIC

A molecule that is part organic (carbon based) and part metal. When a metal binds to an organic molecule it often becomes chemically more available to organisms and therefore has a much greater toxic effect (e.g., methyl mercury).

OXYGEN-DEMANDING MATERIALS

Materials such as food waste and dead plant or animal tissue that use up dissolved oxygen in the water when they are degraded through chemical or biological processes. Biochemical oxygen demand (BOD) is a measure of the amount of oxygen consumed when a substance degrades.

PARALYTIC SHELLFISH POISONING (PSP)

An illness, sometimes fatal to humans, caused by a neuro-toxin produced by a type of plankton called *Gonyaulax*. During certain times of the year and at certain locations, these organisms proliferate in "blooms" (sometimes called red tides) and can be concentrated by clams, mussels, and other bivalves. The nervous system of shellfish is unaffected. Consumption of the shellfish can cause acute illness in humans and other mammals.

PARAMETER

A quantifiable or measurable characteristic. For example, height, weight, sex, and hair color are all parameters that can be determined for humans. Water quality parameters include temperature, pH, salinity, dissolved oxygen concentration, and many others.

PATHOGEN

An agent such as a virus, bacterium, or fungus that can cause diseases in humans. Pathogens can be present in municipal, industrial, and nonpoint source discharges to the Sound.

PELAGIC

Associated with or living in the water column as opposed to the bottom or the shoreline.

PERCOLATE

To pass through a permeable substance. For instance, septic effluent and rainfall percolates through soil.

PERCOLATION TEST

A test that measures the rate at which water can percolate into the soil at a particular location. The test involves digging a small test pit, filling it with water, and measuring how far the surface of the water drops over a given time period. Soil with a low percolation rate, as determined by the test, may be unsuitable for an on-site sewage disposal system.

PERSISTENT

Compounds that are not readily degraded by physical, chemical, or biological processes.

PESTICIDE

A general term used to describe chemical substances that are used to destroy or control pest organisms. Pesticides include herbicides, insecticides, algicides, fungicides, and others. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants and animals.

pH

The degree of alkalinity or acidity of a solution. A pH of 7.0 indicates neutral water while a pH of 5.5 is acid. A reading of 8.5 is alkaline or basic. The pH of water influences many of the types of chemical reactions that will occur in it. For instance, a slight decrease in pH may greatly increase the toxicity of substances such as cyanides, sulfides, and most metals. A slight increase may greatly increase the toxicity of pollutants such as ammonia.

PHENOLS

Aromatic alcohols which are acidic and often toxic.

PHOTOSYNTHESIS
The process by which plants use light energy to make simple sugars and carbohydrates from carbon dioxide and water.

PLANKTON
Small plants (phytoplankton) and animals (zooplankton) that are suspended in the water and either drift with the currents or swim weakly.

POINT SOURCE
A source of pollutants from a single point of conveyance such as a pipe. For example, the discharge pipe from a sewage treatment plant or a factory is a point source.

POLLUTANT
A contaminant that adversely alters the physical, chemical, or biological properties of the environment. The term includes pathogens, toxic metals, carcinogens, oxygen-demanding materials, and all other harmful substances. With reference to nonpoint sources, the term is sometimes used to apply to contaminants released in low concentrations from many activities which collectively degrade water quality. As defined in the federal Clean Water Act, pollutant means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water.

POLYCHLORINATED BIPHENYLS (PCBs)
A group of manufactured chemicals including about 70 different but closely related compounds made up of carbon, hydrogen, and chlorine. If released to the environment they persist for long periods of time and can biomagnify in food chains because they have no natural usage in the food web. PCBs are suspected of causing cancer in humans. PCBs are an example of an organic toxicant.

POLYCYCLIC or POLYNUCLEAR AROMATIC HYDROCARBONS (PAHs)
A class of complex organic compounds, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAHs are commonly formed by forest fires and by the combustion of gasoline and other petroleum products. They often reach the environment through atmospheric fallout and highway runoff.

PRETREATMENT
The treatment of industrial wastewater to remove contaminants prior to discharge into municipal sewage systems.

PRIMARY PRODUCTION
The production of plant matter (plant tissues) from carbon dioxide and water through photosynthesis. By comparison, secondary production is the production of animal tissue. Different plant communities are often compared by measuring their rates of primary production.

PRIMARY TREATMENT
A wastewater treatment method that uses settling, skimming, and chlorination to remove solids, floating materials, and pathogens from wastewater. Primary treatment typically removes about 35 percent of BOD and less than half of the metals and toxic organic substances.

PRIORITY POLLUTANTS
Substances listed by EPA under the federal Clean Water Act as toxic and having priority for regulatory controls. The list currently includes metals (13), inorganic compounds (two), and a broad range of both natural and artificial organic compounds (111). The list of priority pollutants includes some substances which are not of immediate concern in Puget Sound, and it does not include all known harmful compounds.

PUGET SOUND, WATERS OF
As defined in RCW 90.70.005, all salt waters of the state of Washington inside the international boundary line between Washington and British Columbia, and lying east of 123° 24' west longitude (east of Port Angeles).

PUGET SOUND WATER QUALITY AUTHORITY (AUTHORITY)
The state agency which is responsible for development and oversight of the Puget Sound Water Quality Management Plan.

REGULATORY FRAMEWORK
A particular set of laws, rules, procedures, and agencies designed to govern a particular type of activity or solve a particular problem.

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)
The federal law that classifies and regulates solid and hazardous waste.

RESPIRATION
The metabolic processes by which an organism uses oxygen and releases carbon dioxide and other waste products.

REVISED CODE OF WASHINGTON (RCW)
The compilation of the laws of the state of Washington published by the Statute Law Committee. For example, the law that created the Puget Sound Water Quality Authority is incorporated in the code as Chapter 90.70 RCW.

RIPARIAN HABITAT
Terrestrial habitat adjacent to and associated with streams.

SALINITY
A measure of the quantity of dissolved salts in water.

SALMONID
A fish of the family Salmonidae (as distinct from a salmonoid which is merely a fish that resembles a salmon). Fish in this family include salmon and trout. Most Puget Sound salmonids are anadromous.

SANITARY WASTEWATER
Wastewater which includes domestic sewage and may contain pathogens. Sanitary wastewater is not sanitary.

SECONDARY TREATMENT
A wastewater treatment method that usually involves the addition of biological treatment to the settling, skimming, and disinfection provided by primary treatment. Secondary treatment may remove up to 90 percent of BOD and significantly more metals and toxic organics than primary treatment.

SEDIMENT
Material suspended in or settling to the bottom of a liquid, such as the sand and mud that make up much of the shorelines and bottom of Puget Sound.

SEPARATED SEWER SYSTEM
A wastewater collection and treatment system where domestic and industrial wastewater is separated from storm runoff. A separated system consists of independent sanitary wastewater and stormwater systems. The stormwater is generally discharged directly into open water and the sanitary wastewater goes to a treatment plant.

SEPTAGE
The sludge and scum material that is pumped out of a septic tank.

SHELLFISH
An aquatic animal, such as a mollusc (clams and snails) or crustacean (crabs and shrimp), having a shell or shell-like exoskeleton.

SHELLFISH CONTAMINATION
The contamination of certain bivalves (clams, mussels, oysters) which filter water to feed and tend to collect or concentrate waterborne contaminants in their tissues.

SHORELINE DEVELOPMENT
As regulated by the Shoreline Management Act (Chapter 90.58 RCW) the construction over water or within a shoreline zone (generally 200 feet landward of the water) of structures such as buildings, piers, bulkheads, and breakwaters, including environmental alterations such as dredging and filling, or any project which interferes with public navigational rights on the surface waters.

SHORELINE MANAGEMENT ACT (SMA)
The state law (90.58 RCW) that requires local governments to develop a shoreline master program, and requires permits for water and associated land uses. Many local governments promote the protection of wetlands, habitat, and water quality through their shoreline master program.

SILL
An underwater ridge created by glacial deposits that is relatively shallow compared to the rest of Puget Sound. Sills separate the Sound into sub-basins and affect the overall water circulation in the Sound.

SLUDGE, WASTEWATER TREATMENT SLUDGE
Semi-solid matter resulting from the treatment of wastewater. Some of the contaminants (especially toxic metals) that were in the wastewater remain in the sludge after treatment. The treated wastewater can be discharged to the Sound, but the sludge must be disposed of elsewhere. Sludge is usually at least partially dried before disposal and if relatively uncontaminated may be added to soil to increase plant growth.

SMELT
A family of small fishes, some of which spawn on beaches and some of which are anadromous.

SMOLT
A juvenile salmon or anadromous trout that is making its first descent to the sea from the fresh waters where it was born.

SOIL PERMEABILITY
The ease with which gases and liquids penetrate or pass through a layer of soil.

SOLE SOURCE AQUIFER
The single source of groundwater for human use in any one area. Areas with a sole source aquifer have no other source of groundwater; any contamination of the aquifer could contaminate the entire water supply.

SOLUBLE
Able to go into solution, especially in water. Alcohol is very soluble in water whereas oil is not soluble in water.

SORPTION
The combination of processes by which one material takes up and retains another. Includes absorption in which the substance taken up goes into the other material and adsorption in which the substance taken up adheres to the surfaces of solids or liquids with which they are in contact. In aquatic systems many chemicals sorb to sediment particles and are transported by the particles.

SOURCE CONTROL
A practice, method, or technology that is used to reduce pollution from a source; for example, best management practices or end-of-pipe treatment.

SPECIES DIVERSITY
The number of species within a community of organisms. Areas of high diversity are characterized by a great variety of species. A biological community with high diversity is better capable of withstanding environmental disturbances. Pollution tends to reduce biological diversity.

STATE ENVIRONMENTAL POLICY ACT (SEPA)
A state law (Chapter 43.21C RCW) that requires that state agencies and local governments consider environmental factors when making decisions on activities, such as development proposals over a certain size, and comprehensive plans. As part of this process, environmental impacts are documented and opportunities for public comment are provided.

STORM DRAIN
A system of gutters, pipes, or ditches used to carry stormwater from surrounding lands to streams, lakes, or Puget Sound. In practice storm drains carry a variety of substances such as sediments, metals, bacteria, oil, and antifreeze which enter the system through runoff, deliberate dumping, or spills. This term also refers to the end of the pipe where the stormwater is discharged.

STORMWATER
Water that is generated by rainfall and is often routed into drain systems in order to prevent flooding.

SUBTIDAL
Below the ebb and flow of the tide. Used to refer to the marine environment below mean lower low tide.

SUSPENDED SOLIDS
Organic or inorganic particles that are suspended in and carried by the water. The term includes sand, mud, and clay particles as well as solids in wastewater.

SWAMP
A wetland where the dominant vegetation is composed of woody plants like trees, as opposed to a marsh where the dominant vegetation is non-woody plants like grasses.

TECHNOLOGY-BASED STANDARDS
Technology-based effluent standards are developed by considering the effluent quality that can be achieved using various process or treatment technologies, and the costs of those technologies, rather than basing effluent standards on the environmental effects of different loadings of pollutants.

TERATOGENIC
Causing birth defects.

TIMBER/FISH/WILDLIFE AGREEMENT (T/F/W)
An agreement between timber, fish, and wildlife interests that promotes the monitoring and protection of fish and wildlife resources as an integral component of forestry management practices.

TOTAL SUSPENDED SOLIDS (TSS)
The weight of all sized particles that are suspended in water. TSS reduces light penetration in the water column, can clog the gills of fish and invertebrates, and is often associated with toxic contaminants because organics and metals tend to bind to particles.

TOXIC
Poisonous, carcinogenic, or otherwise directly harmful to life.

TOXIC SUBSTANCES AND TOXICANTS
Chemical substances such as pesticides, plastics, detergents, chlorine, and industrial wastes that are poisonous, carcinogenic, or otherwise directly harmful to life.

TREATMENT
Chemical, biological, or mechanical procedures applied to an industrial or municipal discharge or to other sources of contamination to remove, reduce, or neutralize contaminants.

TRIBUTYL TIN (TBT)

An organometallic additive of many marine antifoulant paints used to prevent algal and barnacle growth. Tributyl tin is highly toxic to many marine organisms.

TURBIDITY

A measure of the amount of material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. High levels of turbidity are harmful to aquatic life.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (EPA)

The federal agency which administers many federal environmental laws. EPA Region 10, which includes Puget Sound, is headquartered in Seattle.

UPLAND MANAGEMENT AREA

A mandatory unharvested area for wildlife use and protection in a forest clearcut. These areas typically represent two percent or more of the clearcut area. This term originated from the Timber/Fish/Wildlife agreement.

VOLATILE

Can be readily vaporized at a relatively low temperature.

WASHINGTON ADMINISTRATIVE CODE (WAC)

Contains all state regulations adopted by state agencies through the rulemaking process. For example, Chapter 173-201 WAC contains water quality standards.

WASHINGTON DEPARTMENT OF ECOLOGY (ECOLOGY)

The state agency which is responsible for developing, implementing, and enforcing many environmental protection laws and policies, including the state Clean Water Act and the Shoreline Management Act. Note that the abbreviation DOE is confusing because the federal Department of Energy uses the same term. Ecology is the preferred term for referring to the Department of Ecology.

WATER COLUMN

The water in a lake, estuary, or ocean which extends from the bottom sediments to the water surface. The water column contains dissolved and particulate matter, and is the habitat for plankton, fish, and marine mammals.

WATER TABLE

The upper surface of groundwater or the level below which the soil is saturated with water.

WATERSHED

The geographic region within which water drains into a particular river, stream, or body of water. A watershed includes hills, bottom land, and the body of water into which the land drains. Watershed boundaries are defined by the ridges of separating watersheds.

WELLHEAD

The immediate area around the top of a well. Contamination of the aquifer may occur from surface water if the wellhead is not sealed to prevent flow down the well casing.

WETLANDS

Habitats where the influence of surface or groundwater has resulted in development of plant or animal communities adapted to aquatic or intermittently wet conditions. Wetlands include tidal flats, shallow subtidal areas, swamps, marshes, wet meadows, bogs, and similar areas. Wetlands as defined by the Shoreline Management Act include all land within 200 feet of the ordinary high water mark, floodways, and floodplain areas.

ZONING

To designate by ordinances areas of land reserved and regulated for different land uses.

References

Although there is no central repository for these and other studies discussed in the *State of the Sound Report*, local public libraries may be able to locate many of these studies and reports. Local libraries are connected through a statewide network with the Washington State Library located in Olympia. Other libraries that contain large collections of technical information on Puget Sound include the University of Washington library system, libraries of other colleges and universities around the Sound, and the in-house libraries of local, state, and federal agencies. However, many agency libraries (e.g., the U.S. Environmental protection Agency (EPA) Region 10 library located in downtown Seattle and the National Oceanic and Atmospheric Administration (NOAA) library located on Sand Point Way in Seattle) do not have lending policies so the reports must be reviewed on the premises.

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