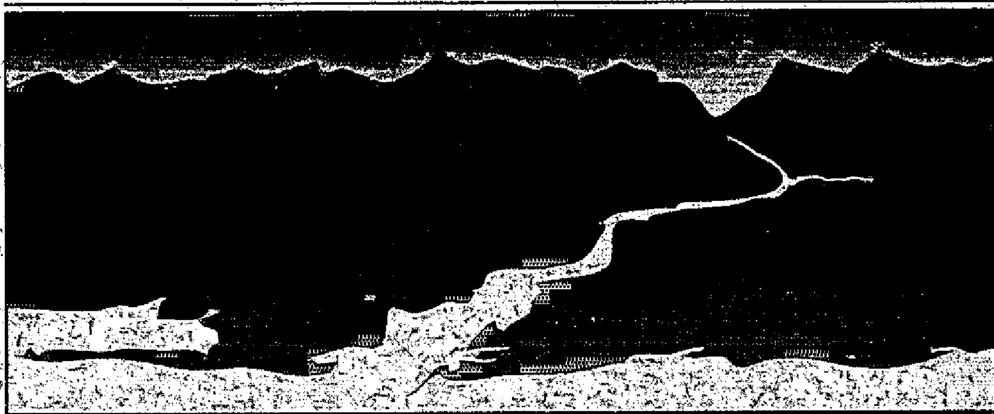
FINAL REPORT
TC 0253-01

LOWER COLUMBIA RIVER



BI-STATE PROGRAM

THE HEALTH OF THE RIVER 1990-1996

INTEGRATED TECHNICAL REPORT

MAY 20, 1996

Prepared By:
TETRA TECH

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Prepared For:

The Lower Columbia River
Bi-State Water Quality Program

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EXECUTIVE SUMMARY

The Columbia River is the second-largest river in the United States, and the central artery of the Pacific Northwest. It flows 1,200 miles from the Canadian Rockies to the Pacific, draining a quarter-million-square-mile area of North America, including portions of seven states and British Columbia. It is at once a scenic treasure, a key to the ecological balance of the region, and an economic necessity for millions, many of whom rarely think about the river and have little idea of its importance to them.

For several decades, concern has been growing among groups intimately involved with the river that its health may be seriously threatened by the pressure of the region's rapidly growing population. The river is asked to provide water for homes, industry, power generation, and agriculture; to support fishing, recreation, and transportation; and to carry the waste products of all these activities and more.

Since 1990, state and local agencies and private interests in Oregon and Washington have worked together on a large-scale scientific study to assess the health of the lower Columbia River. This study, the Bi-State Program, came about as a result of the concern many groups have about pollutants in the river and the effect those pollutants might be having on wildlife and human health. The Bi-State Program has generated over fifty technical reports in its six years, all of which are briefly summarized in the *The Health of the River*.

The Lower Columbia River Basin

Because of the difficulty and expense of studying a river system as vast as the Columbia, the Bi-State Program focused on the lower part of the river, from Bonneville Dam to the Pacific, a stretch of 146 river miles (Figure 1). The basin of the lower Columbia River includes the basins of the lower tributaries, the largest of which are the Willamette, Cowlitz, Kalama, Sandy, and Lewis rivers. This area is only 7 percent of the greater Columbia basin, but it is far more populated and industrialized than the rest of the basin. The eight counties bordering the lower river (three in Oregon and five in Washington) had a combined population of well over one million in 1994.

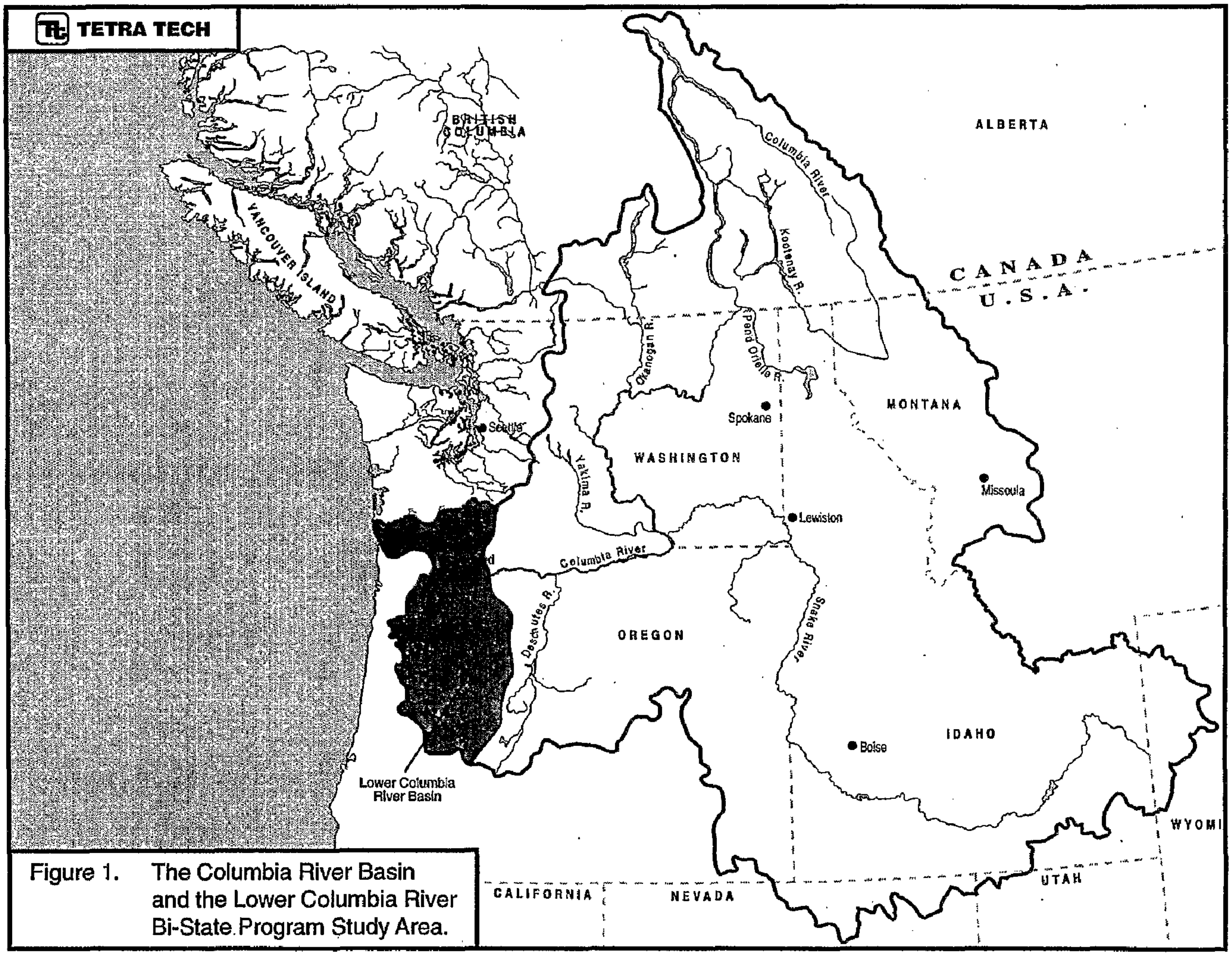

Figure 1. The Columbia River Basin and the Lower Columbia River Bi-State Program Study Area.

The Bi-State Program

This has been a six-year public-private partnership, jointly administered by the Washington Department of Ecology and the Oregon Department of Environmental Quality and advised by a Bi-State Steering Committee. Steering Committee members came from the many groups that take an active interest in the health of the River: environmentalists, Native American tribes, the pulp and paper industry, private citizens, public ports, local governments, commercial and recreational fishing interests, the Northwest Power Planning Council, and federal agencies dealing with environmental issues.

The Bi-State Program was paid for by citizens of Washington and Oregon (1/3 each), the pulp and paper industry (1/6), and public ports (1/6). The study was conducted by private contractors and State and Federal agencies.

Beneficial Uses. Viewpoints differ on how to define the health of a river. Even the experts disagree about just what constitutes a healthy river, and the understandable special interests of many groups complicate the picture further. The Bi-State studies have relied on legally defined "beneficial uses" as a starting point for judging the river's health. These are specific uses of the river by people and wildlife which are defined in state laws and regulations and which the state agencies are charged with protecting. Table 1 combines Oregon's and Washington's beneficial uses and groups them into categories. The few minor differences be-

TABLE 1. BENEFICIAL USES OF THE LOWER COLUMBIA RIVER

Water Supply	■ Public and private drinking water supply
Agriculture	■ Irrigation ■ Stock watering
Fish and Wildlife	■ Migration and spawning of salmon, steelhead, etc. ■ Use by other fish and aquatic plants and animals ■ Wildlife usage, e.g., fish-eating animals ■ Preservation of significant and unique habitats (e.g., marshes, nesting areas, and Natural Heritage Sites)
Recreation	■ Water contact sports ■ Fishing and hunting ■ Aesthetic quality
Commercial	■ Hydroelectric power ■ Navigation and transportation ■ Marinas and related commercial activity ■ Commercial fishing

tween the two states' lists of uses did not pose a problem to conducting the studies. This combined list provides the framework for the balance of the Executive Summary.

The Phases of the Bi-State Program. Under the guidance of the Steering Committee, the Bi-State Program unfolded in four phases:

- Compiling existing data (1990-1991)
- Reconnaissance surveys (1991-1993)
- Baseline studies (1993-1996)
- Advanced studies (1995-1996)

Existing data were gathered and studied so that researchers could start with what was already known about the river and its problems. Earlier studies had been conducted by different researchers charged with studying different areas of the river, during different seasons, for different purposes, using widely differing approaches and techniques. This earlier data was used as a starting point in designing Bi-State studies that would provide a coherent picture of water quality conditions in the lower Columbia River.

Reconnaissance Surveys were broad preliminary surveys designed to provide information on existing environmental conditions and pollutants of concern by sampling and analysing water, sediment, and fish. The initial reconnaissance survey gathered information primarily in and along the main channel during low water flow conditions (September-November 1991).

Backwater areas and sloughs were not sampled during the 1991 survey. These areas, considered critical because they are important breeding and foraging areas for wildlife, were sampled during a second reconnaissance survey conducted in June-August 1993. These two reconnaissance surveys were the first environmental studies to examine the entire lower Columbia River broadly, rather than focusing on a particular type of pollution, beneficial use, or interest group.

Baseline Studies were specific studies suggested by the results of the reconnaissance surveys. They were designed to fill gaps in the information gathered so far. Four of these were planned:

- *Ambient Monitoring* - regular water testing over the course of a year at the mouths of the lower Columbia's major tributaries and four other sites along the main channel.

- *Pollutant Work Assignment* - a planned intensive investigation of specific pollution "hot spots"; this was not done as a baseline study for financial reasons.

- *Fish and Wildlife Health* - a close look at the impact of pollution on some key species:

bald eagle, mink, river otter, some edible fish species, and crayfish.

- *Human Health* - a preliminary look at possible human health risks of eating fish from the river.

Advanced Studies were in-depth studies of priority problem areas based on the findings of all previous phases. One advanced study has been completed, a human health risk assessment that examines in depth the health risks of eating fish from the river. Nearing completion at the time of this publication is a study undertaken by the Oregon Department of Environmental Quality to identify sources of pollutants found in the river.

Table 2 relates the major final Bi-State Program reports, which are summarized in *The Health of the River*, to the beneficial uses they were designed to evaluate:

TABLE 2. BI-STATE REPORTS AND BENEFICIAL USES

Reconnaissance Surveys	All beneficial uses
Ambient Monitoring Study	Water supply; fish and wildlife; recreation
Fish Health Assessment	Fish and wildlife; recreation
Fish Enzyme Study	
Mink and River Otter Study	
Contaminants in Bald Eagle Eggs	
Habitat Mapping	
Human Health Risk Assessment	Water supply; recreation; commercial
Identification of Pollutant Sources	All beneficial uses

Standards. Water quality is most often assessed by comparing measurements to a standard, criterion, or reference level. The mere presence of a pollutant is not an adequate measure in many cases, because many substances we consider pollutants occur naturally in waters and soils. For some persistent man-made pollutants it is no longer possible to expect complete absence; the remains of banned pesticides such as DDT will be with us for decades longer.

It is the task of regulatory agencies to set standards for the maximum amount of a pollutant considered safe, based on best scientific knowledge. Unfortunately, there is much that is not known about the toxicity of pollutants, and standards are lacking in many cases. Bi-State Program findings are related to legally defined standards wherever possible; where no legal standard exists, findings are related to current best scientific judgement. The term "reference level" is used in general discussions to refer to both categories, i.e., legally defined standards and best scientific judgment. In all discussions of particular findings, the legal status of the reference level is clearly stated.

The reports summarized in *The Health of the River* incorporate the important findings of all earlier reports. A full list of Bi-State reports is attached to *The Health of the River* as Appendix A. If you would like to find out more about any particular report, first look in Chapter 2 of the *The Health of the River* for a more complete and technical summary of findings of that report. To obtain a copy of an earlier report, contact:

Department of Ecology
Publications Distribution
P.O. Box 47600
Olympia, WA 98504-7600
(360) 407-7472

THE FINDINGS OF THE BI-STATE PROGRAM REPORTS

The rest of this executive summary presents the basic findings of the Bi-State Program reports that relate to each beneficial use. Table 3 indicates whether there was evidence of impairment for each beneficial use assessed. For a more technical discussion of a given beneficial use, see Section 3 of the *The Health of the River*; for more information about a specific Bi-State Program report, see Section 2 of that report.

TABLE 3. ASSESSMENT OF BENEFICIAL USES OF THE LOWER COLUMBIA RIVER

	Not Assessed	No Evidence of Impairment	Evidence of Impairment
Water Supply	X		
Agriculture	X		
Fish & Wildlife:			
Chemical			X
Biological			X
Habitat			X
Recreation:			
Fishing			X
Water Sports			X
Æsthetics		X	
Commercial Uses	X		

River Health Rating: Fish and Wildlife. Many of the pollutants identified in the Bi-State Program studies may have a negative effect on wildlife. Because wildlife effects were among the most significant of the Bi-State Program findings, they will be discussed in some detail. Possible negative effects on wildlife can be determined by chemical, biological, and habitat measurements.

Chemical Measurements. Wildlife can be affected by chemical pollutants in the water itself, in streambed sediment, or in the tissues of contaminated prey animals. These three forms of pollution will be discussed separately.

Both Oregon and Washington have state water quality standards designed to protect aquatic life. Under the provisions of the Clean Water Act, states must review their water quality standards every three years in order to incorporate the most recent scientific findings and to reflect evolving priorities within society.

Pollutants in water are typically very dilute and hard to measure accurately, even with sophisticated laboratory techniques. For instance dioxins and furans, a group of chemicals commonly referred to simply as dioxin, are known to be present in the river but are difficult to measure without collecting a very large volume of water. They have been detected in Columbia River fish at levels exceeding standards designed to protect human health, causing the EPA to classify the quality of Columbia River water as "limited." More precise testing is needed before the river's water can be fully assessed. Despite the limitations of some test results, the evidence suggests that Columbia river water contains potentially harmful levels of heavy metals, organochlorine pesticides, dioxins and furans, and other organic compounds.

Many pollutants tend to collect in sediments, making them easier to detect there than in water. Oregon and Washington do not have legal standards for safe levels of pollutants in freshwater sediment. Using reference levels from current scientific literature, it appears that sediments at a number of places in the lower Columbia contain pollutants, including heavy metals, organochlorine pesticides, dioxins and furans, and other organic compounds, at levels that may be harmful to wildlife.

Pollutants in animal tissues are of particular concern in relation to fish-eating wildlife, such as eagles and river otters, that may eat contaminated prey. Because of their chemical nature, many pollutants tend to concentrate in animal tissues even more than in sediments, making them comparatively easier to detect. Again, legal standards are lacking for evaluating the levels detected. However, using available reference levels in the scientific literature, fish-eating wildlife in the lower Columbia basin appear to be contaminated by organochlorine pesticides and a range of other organic chemicals. These pollutants, especially dioxins and furans, DDE (a metabolite of DDT), and PCBs are found in a number of locations in the lower Columbia.

Biological Measurements. Biological studies look at such factors as an animal's health and numbers, community structure, range, and breeding success rather than just the presence or absence of pollutants. Bi-State Program studies of this type examined bottom-dwelling organisms, how sediments affect micro-organisms, the health of certain fish species, the population and habitat of mink and otter, and the reproduction of bald eagles nesting on the river.

All of these studies showed evidence of negative impacts caused by pollution. The mink and otter study found evidence that man-made organic pollutants are negatively affecting river otter (not enough mink were caught to generalize about their condition). The bald eagle study contributed to the growing body of evidence that PCBs, DDE, and dioxins and furans tend to accumulate in fish-eating eagles, and cause thinning of the eggshell. However, populations and productivity of these birds have increased in recent years.

Habitat Measurements. Some of the most profound effects on wildlife come not from chemical pollutants but from loss and degradation of habitat. One striking example is the Columbia River estuary, where dredging, filling, diking, and channeling began in the 1880s. Over half of the tidal swamp and marsh area of the estuary has been lost since then.

The best-known habitat alteration of the Columbia River is the development of the river for hydroelectric power generation. Building dams has not only limited the migration of salmon and other fish; the resulting slower current flows and warmer water temperatures have also favored warm water fish at the expense of coldwater species such as trout and salmon. Some of the new species have been introduced intentionally, and have become popular with sport fishers, complicating the picture. The decline of salmon stocks has been lamented for over a century; many runs are extinct, and others are listed as threatened or endangered.

There is strong evidence that fish and wildlife in the lower Columbia River basin are being exposed, via water, sediments, and prey, to a range of pollutants known to cause adverse effects. These include heavy metals, dioxins and furans, PCBs, DDT and its metabolites, and other pesticides. The use of the river by wildlife has also been seriously limited by loss and degradation of habitat. This is particularly true in the estuary, and throughout the river for migratory fish such as salmon.

The use of the river by wildlife is not supported.

River Health Rating: Recreation. The recreational uses of the river which have been evaluated in the Bi-State Program are sport fishing, water sports (swimming, boating, diving, windsurfing, etc.), and æsthetic enjoyment of the river. These are discussed separately. For sport fishing to be protected as a use, the fish must be safe to eat, since many fishers eat their catch. The human health risk assessment found that people who eat fish from the river over a long period of time may be exposed to unacceptable risks, according to EPA guidelines. The main pollutants of concern are PCBs, dioxins, DDT and its metabolites, and arsenic.

The use of the river for fishing and shellfishing is not supported.

A major concern in using the river for water sports is whether there are unacceptably high levels of pathogenic bacteria present at certain times of year. According to current standards and analytic methods, Columbia River water is occasionally unsafe for water sports in a few areas, especially in the more heavily populated stretch between Portland/Vancouver and Longview. The safety of water for water contact sports needs research to improve techniques of testing and monitoring.

The use of the river for water sports is not fully supported.

Æsthetic quality is subjective and thus hard to define. The only æsthetic factors considered in the Bi-State Program are water odors, transparency, and the presence of excessive amounts of algae that forms a scum and gives off unpleasant odors. Such an algal scum is usually a sign of eutrophication caused by pollution of water with chemicals that act as fertilizers (primarily nitrogen compounds and phosphorous). The Bi-State Program studies did not find that nuisance algae was a problem in the Columbia River.

> ***The æsthetic enjoyment of the river is not compromised by excess algae; other æsthetic factors were not assessed.***

River Health Rating: Commercial Uses. The use of the Columbia River for hydroelectric power generation, navigation and transportation, and marinas and related commercial activities was not considered by the Bi-State Program. Historically, the river has been shaped to support these uses at the expense of the fishing industry, wildlife, and, some would say, æsthetic enjoyment. The only commercial use considered was commercial fishing. None of the pollutant levels measured in commercially caught fish during these studies were high enough to result in U.S. Food and Drug Administration restrictions on interstate marketing. Commercial fishing has clearly been limited by the decline in stocks, particularly of salmon. However, this beneficial use was not assessed by the Bi-State Program.

> ***The commercial uses of the Columbia River were not assessed.***

River Health Rating: Water Supply. The purity of drinking water was not chosen as a topic of study in the Bi-State Program. Over 95 percent of the water used for human consumption along the lower Columbia is taken from upstream protected basins or from wells rather than directly from the Columbia River. In the few cases that water is taken directly from the river, it goes through normal treatment for purification and disinfection. There are no drinking water reference levels for the quality of water prior to treatment.

> ***The use of Columbia River water for drinking was not assessed.***

River Health Rating: Agriculture. The suitability of Columbia River water for agricultural uses was not studied in this program. No specific evidence that the water was unsuitable for these uses was discovered during the review of existing information.

> ***The use of Columbia River water for agricultural uses was not assessed.***

1.0 INTRODUCTION

The states of Oregon and Washington are concerned that the water quality of the lower Columbia River has been impaired by toxic pollutants which have entered the river via a number of historical and existing pollutant sources. This concern has been expressed both by state officials and the general public. Prior studies and data collected by government, industries, and educational institutions were aimed at specific purposes narrower than assessing the overall health of the river. The lack of an integrated assessment of the lower Columbia—from Bonneville Dam to the river mouth—and the growing public concern about the river's condition led to the creation of a broad bi-state water quality program.

The Oregon and Washington state legislatures created the Lower Columbia River Bi-State Water Quality Program in 1990 to compile and collect water quality information on the lower Columbia River and make recommendations based on its findings. The Bi-State Program developed a plan designed to characterize water quality in the lower Columbia River, identify problems, determine whether beneficial uses of the river are impaired, and develop solutions to problems identified (Bi-State Committee 1990).

A number of studies have been completed to accomplish the Bi-State Program's legislative mandate. These studies have characterized historical and current levels of contaminants found in lower Columbia River water, streambed sediment, and animal tissues (fish, crayfish, mink, river otter, and bald eagle eggs), and the sources and amounts of pollutants entering the river from point and non-point (diffuse) pollutant sources. The beneficial uses of the lower river designated by Oregon and Washington have been documented and are used as a basis for interpreting the results of the studies. A series of recommendations have been made to address concerns about potential harmful effects of river contaminants on fish and wildlife populations and human health.

This report provides an overview of the objectives and major conclusions of the Bi-State Program studies, plus recommendations for managing water quality in the lower Columbia.

1.1 LOWER COLUMBIA RIVER STUDY AREA

The Columbia River, the largest river entering the northeastern Pacific Ocean, is the second largest river in the United States in terms of volume discharged. The river's drainage basin of 255,000 mi^2 (660,480 km^2) covers portions of seven western states and one Canadian province (Figure 1). The river flows approximately 1,200 mi (1,950 km) from its headwaters in southeastern British Columbia, Canada. After crossing the U.S.-Canadian border, the river flows generally south and west across the Columbia Plateau of eastern Washington, then west along the border of Oregon and Washington to its outlet in the Pacific Ocean. Major tributaries to the mainstem of the river include the Kootenay, Pend Oreille, Okanogan, Spokane, Yakima, Snake, Deschutes, and Willamette Rivers.

The Lower Columbia River Bi-State Program study area includes the Columbia River and its basin from Bonneville Dam at river mile (RM) 146 [river kilometer (RK) 235] to the mouth, including the basins of the lower river tributaries (Figure 1). The study focused primarily on the river's mainstem, but also considered inputs of contaminants from major tributaries. The five largest tributaries to the lower river are the Willamette, Cowlitz, Kalama, Sandy, and Lewis rivers.

The Columbia River basin below Bonneville Dam makes up about 7 percent of the total drainage area of the Columbia River (Figure 1). At Bonneville Dam the river is relatively narrow, as little as 0.2 mi (0.3 km) wide directly below the dam. A number of large islands along its course separate the main channel from backwater areas. The channel widens to a mile (1.6 km) or more at some locations. At RM 46 (RK 74) the river separates into two channels that pass around Puget Island, with the navigation channel following the Oregon side. Below Puget Island [RM 37 (RK 60)] the river opens into a broad estuary with a number of islands and interconnected channels. Below about RM 25 (RK 40) the estuary opens into an even wider expanse of bays and tide flats with distances between the Oregon and Washington shores ranging to about 5 mi (8 km) in some locations. At its mouth the river passes between two jetties approximately 2 mi (3 km) apart as it enters the Pacific Ocean.

The flow of the lower Columbia River is strongly influenced by climatic variations and tides. The tidal influence on water surface elevation is evident all the way to the base of Bonneville Dam, RM 146 (RK 235). During periods of low flow, tides may cause river flow to reverse up to about RM 80 (RK 128). However, the upstream limit of tidal salinity intrusion is approximately RM 23 (RK 37). The lowest river flows generally occur during September and October, when rainfall and snowmelt runoff are low. Highest flows occur in spring (April to June) due to snowmelt runoff from the Cascade and Rocky Mountain ranges to tributaries of the upper Columbia. High flows also occur between November and March due to heavy winter precipitation in the tributary basins of the lower river, primarily the Willamette in Oregon and the Cowlitz in Washington. The hydrology of the basin is described in more detail in Section 2.2.3 of this report. The following overview focuses on the study area, i.e., the lower Columbia basin (shaded area in Figure 1).

The basin was inhabited by aboriginal peoples for at least 10,000 years before the first European-Americans, Captain Robert Gray and his crew, arrived at the mouth of the Columbia River in 1792. The first European-Americans to arrive overland and explore the area were Lewis and Clark in 1805. These explorers were soon followed by the fur trappers and traders of the American Fur and Hudson's Bay companies that came to exploit the rich beaver, otter, and mink resources of the basin.

In 1846, after 28 years of joint occupation of this territory, Great Britain renounced all claims to lands south of the current U.S.-Canadian boundary. Less than 10 years later the Oregon and Washington Territories were formed and Washington Territorial Governor Isaac Stevens had negotiated treaties with Columbia River basin tribes, whose members often traveled great distances to fish along the lower Columbia River and its tributaries. These treaties resulted in cession of 80-90 percent of tribal lands and the transfer of Native Americans to established reservations. Significantly, "[t]he right of taking fish, at all usual and accustomed grounds and stations...in common with all citizens of the Territory" was preserved by the tribes.

In 1859 Oregon became the 33rd state. The new inhabitants had, from the beginning, exploited the river for its bounty of salmon and its readily available water for irrigation. In the 1870s the first regulations directed at controlling the commercial salmon fishery were enacted by the state of Oregon and the Washington Territory, and in 1877 the first salmon hatchery opened (and soon closed) on the Clackamas River, tributary to the Willamette River in Oregon. By 1883 there were forty canneries operating on the Columbia River, packing 634,300 cases or approximately 35 million pounds of canned Chinook salmon that year. In 1889 Washington became the 42nd state.

Along with fish processing and agriculture, lumber mills and wood pulping and papermaking plants were established in the basin. The first pulp mill along the lower Columbia River was established in 1884 in Camas, Washington. This plant was followed by others in Vancouver, Washington (1923); St. Helens, Oregon (1926 and 1930); and Longview, Washington (1927 and 1931). Today, six pulp and paper mills are located along the lower Columbia River: Camas, Vancouver, and Longview (two plants), Washington, and St. Helens and Wauna, Oregon.

Another significant development in the basin was the extensive dredging, diking, and filling of the river which began as early as 1885 with the initiation of the South Jetty at the mouth of the river. The river was diked and filled to create a single channel for navigation and to minimize the need for costly dredging operations. The impact of dredging and filling was greatest in the broad estuarine portion of the lower river, where over half of the tidal swamp and marsh areas have been lost since 1870.

Development and exploitation of the basin's resources entered a new phase in the 1930s when the federal government got involved in dam construction for irrigation, flood control, river transportation, and hydropower production in the basin. In 1935 a 35 ft (11 m) deep navigation channel was completed from the mouth of the river to Portland, Oregon. [The channel depth is currently maintained at 40 ft (12 m).] In 1937 the Bonneville Power Administration was formed and in 1938 the Bonneville Dam, the first federal dam on the Columbia River mainstem, was completed by the U.S. Army Corps of Engineers at a site 146 mi (235 km) from the mouth of the river. The second federal dam, Grand Coulee, was completed in 1941 by the Bureau of Reclamation at a site 470 mi (756 km) above the Bonneville Dam. By 1970 the federal dam system of over 40 dams was essentially complete. The current system has a storage capacity of 20 million acre-ft of water, produces more than 19,000 megawatts of electricity, and provides passage for commercial shipping as far as Lewiston, Idaho on the Snake River, over 460 miles (740 km) from the Pacific Ocean.

The ready supply of hydroelectric power and the military needs of World War II brought two large industries to the Columbia River basin. Aluminum is essential for the construction of aircraft and large amounts of electrical power are required to smelt it, so aluminum smelting operations were located along the lower Columbia during the war. The Columbia River also supplied cooling water for nuclear reactors at the federal Hanford facility, over 200 miles (322 km) upriver of Bonneville Dam, where plutonium was produced for one of the two atomic bombs that brought an end to World War II. Plutonium production began in 1944 and continued until 1987, reaching a peak during the 1960s.

The adverse impacts of rapid development and exploitation of the basin's resources did not go unnoticed. In the late 1800s the decline of the salmon stocks was already being lamented and, over the following decades, various regulations were enacted by Oregon and Washington to manage the salmon resource. However, salmon stocks continued to decline and in 1980 the U.S. Congress passed the Pacific Northwest Electric Power Planning and Conservation Act, which reshaped the management of power production in the basin and legislated the protection, mitigation, and enhancement of salmon and steelhead stocks. The act also created the Northwest Power Planning Council, an eight-member body formed of appointed representatives of the states of Idaho, Oregon, Montana, and Washington. But salmon stocks have continued to decline, and several Columbia River salmon species have been listed as endangered. The National Marine Fisheries Service is developing a plan to restore declining salmon runs.

Water pollution problems started to become evident in the Willamette River and the lower Columbia as development accelerated through the early decades of this century. The discharge of untreated organic-rich industrial and municipal wastewaters resulted in lowered levels of dissolved oxygen, which can be fatal to fish, and aesthetically unpleasant filamentous bacterial growth. A number of regulations were enacted by the states to control organic pollution in the lower river and its tributaries. Primarily as a result of secondary wastewater treatment requirements established in the Federal Water Pollution Control Act of 1972, the conventional water pollution problems of oxygen-demanding organic wastes had been controlled in the Willamette and lower Columbia rivers by the mid-1970s.

Increased awareness of and concern for the potential harmful effects of less visible toxic pollutants, including metals, synthetic organic compounds, and radionuclides, has led to additional studies and regulations. Most recently, the Columbia River basin has been graded "water quality limited" by the U.S. Environmental Protection Agency due to the discharge of dioxins and furans from nine chlorine-bleaching pulp mills in the basin, including 5 mills in the lower basin. Discharge limits for dioxin have been established at the pulp mills that use the chlorine bleaching process.

The growing population of the lower Columbia River basin places increasing demands on the area's land and water for industrial, agricultural, forestry, commercial, and residential uses. The river supports a commercial, recreational, and tribal fishery that has expanded to include not only salmon and steelhead, but sturgeon and a number of resident freshwater species.

The three counties that border the lower Columbia River on the Oregon side (Clatsop, Columbia, and Multnomah) had an estimated population of almost 690,000 in 1994. Major population centers include Portland (approximately 450,000), Gresham (approximately 75,000), Astoria (approximately 10,000), and St. Helens (approximately 8,000). The five counties that border the river on the Washington side (Clark, Cowlitz, Pacific, Skamania, and Wahkiakum) had an estimated population of over 400,000 in 1994. Major population centers on the Washington side include Vancouver (approximately 50,000), Longview (approximately 32,000) and Camas/Washougal (approximately 11,000).

These people share the lower Columbia River with a variety of wildlife, including state- and federally-listed threatened and endangered species of mammals, fish, birds, amphibians, reptiles, insects, and plants. A number of locations along the lower river have been set aside for wildlife protection, including the Lewis and Clark National Wildlife Refuge [RM 16-36 (RK 26-58)], Julia Butler Hansen Wildlife Refuge for the Columbian White-tailed Deer [RM 35-38 (RK 56-61)], Ridgefield National Wildlife Refuge [RM 87-93 (RK 140-150)], and the Sauvie Island Wildlife Management Area [RM 86-100 (RK 138-161)]. These refuges provide protected tidelands, marshes, and riparian areas for wildlife habitat. However, the U.S. Fish and Wildlife Service has expressed concern about organic contaminants found in lower Columbia River water, sediments, and biota, and the effects these contaminants may have on fish-eating wildlife.

1.2 THE LOWER COLUMBIA RIVER BI-STATE PROGRAM

Continued public concern about the water quality of the lower Columbia River led the legislatures of Oregon and Washington to fund a four year program to evaluate the water quality in the river from Bonneville Dam to the Pacific. The legislatures also directed the states' environmental agencies (Washington Department of Ecology and the Oregon Department of Environmental Quality) to enter into an Interstate Agreement to establish the Bi-State Lower Columbia River Water Quality Program and to create the Bi-State Lower Columbia River Steering Committee. The Interstate Agreement identifies the interest groups that serve on the Steering Committee and provides a scope for the types of water quality studies and recommendations that are required of the program. The agreement also requires public involvement in the Steering Committee's deliberations. Funding for the program came from the states of Oregon and Washington ($800,000 each), Oregon and Washington Public Ports ($400,000), and the Northwest Pulp & Paper Association ($400,000) for a total budget of $2,400,000.

The Bi-State Program recognized that the resources available to the program would not allow a detailed investigation of the much larger areas of the Columbia basin above Bonneville Dam, which could be the source of some problems identified in the lower river. Therefore, the program focused on identifying and understanding problems and their sources in the river below the dam. The Bi-State Program also recognized that solutions to some of the problems identified would have to address sources above the dam.

The Bi-State Program was composed of the Washington Department of Ecology and the Oregon Department of Environmental Quality, the Steering Committee (appointed by those two agencies), and a Peer Review Panel (formerly the Scientific Resource Panel). The Steering Committee was co-chaired by one representative from each state, selected by the Steering Committee. The Steering Committee included representatives from the following groups and interests:

- Commercial and recreational fishing
- Environmental organizations
- Federal agencies
- Native American tribes
- Northwest Power Planning Council
- Public at large
- Public ports
- Pulp and paper industry
- State and local governments

See Figure 2 for a list of current Steering Committee members and their organizational affiliations.

The Bi-State Program had the following goals:

- To identify water quality problems
- To determine if beneficial/characteristic uses are impaired
- To develop solutions to water quality problems
- To make recommendations on a long term Bi-State framework.

The Bi-State Program was to accomplish these goals by carrying out the following tasks:

- Involve the public through education and by inviting public participation
- Develop work plans that identify the studies needed to characterize the river's water quality
- Evaluate existing data and conduct reconnaissance surveys
- Carry out further studies of water quality (baseline studies)
- Conduct advanced studies and recommend an approach for long-term monitoring
- Make recommendations to regulatory agencies.

Lower Columbia River Bi-State Steering Committee

Funding Organizations

Oregon Dept. Environmental Quality
- Andy Schaedel - *member*
- Kevin Downing - *alternate*
- Cordelia Shea - *staff*
- Don Yon - *staff*
- Bill Young - *staff*

Washington Dept. Ecology
- David Peeler - *member*
- Bill Backous - *alternate*
- Neil Aaland - *staff*
- Helen Bresler - *staff*
- Brian Offord - *staff*

Public Ports
- Jerry Heller - *member*
- Rollie Montagno - *member*
- Glenn Vanselow - *member*
- Bob Friedenwald - *alternate*
- Daniel James - *alternate*

Pulp and Paper Industry
- Herman Amberg - *member*
- Llewellyn Matthews - *member*
- Al Whitford - *member*
- Anthony Bell - *Alternate*
- Steve Hudson - *alternate*
- Carol Whitaker - *alternate*

Federal Agencies

U.S. Geological Survey
- Stuart McKenzie - *member*
- Joe Rinella - *alternate*

U.S. Environmental Protection Agency
- John Gabrielson - *member*
- Jack Gakstatter - *member*
- Bill Sobolewski - *alternate*

U.S. Fish & Wildlife Service
- Jeremy Buck - *member*
- Carol Schuler - *member*
- Colleen Henson - *alternate*

Interest Groups

Local Government
- Earl Blumenauer - *member*
- Nelson Graham - *member*
- Mike Lindberg - *member*
- Jeff Bauman - *alternate*
- Mark Bautista - *alternate*
- Nan Henrikson - *alternate*
- Dave Kliewer - *alternate*

Native American Tribes
- Michael Farrow - *member*
- Wilbur Slockish - *member*
- Elmer Scott - *member*
- Anton Minthorn - *alternate*
- John Platt - *alternate*
- Ray Slockish - *alternate*

Recreational Fishing
- Steve Willie - *member*
- Curtis Macfarlane - *alternate*

Commercial Fishing
- Bob Eaton - *member*
- Ralph Ennis - *member*
- Thane Tienson - *alternate*

Environmental Organizations
- Nina Bell - *member*
- Jean Cameron - *member*
- Cyndy deBruler - *member*
- Gayle Killam - *alternate*
- Kirsten Metzger - *alternate*
- Eugene Rosolie - *alternate*
- Lynda Sacamano - *alternate*

NW Power Planning Council
- Ted Bottiger - *member*
- Joyce Cohen - *member*
- Andre L'heureux - *alternate*

Public Representation

Citizen-At-Large
- Jim Bergeron - *member*
- Carol Carver - *member*
- Dan Chandler - *member*
- June Spence - *member*
- Carolyn Dunn - *alternate*
- Jon Graves - *alternate*
- David Kruger - *alternate*
- Duane Smith - *alternate*

Figure 2. Lower Columbia River Bi-State Steering Committee Representation and Membership.

The Steering Committee formed three types of internal work groups to accomplish the program goals: individual Technical Work Groups, a Recommendations Work Group, and the Public Participation Work Group. Technical Work Groups consisted of individuals with specific areas of technical expertise. The Recommendations Work Group formulated recommendations for specific activities arising from the findings of the studies. The Public Participation Work Group addressed questions of involving the public in the review process and communicating findings to the general public. Public involvement in the Bi-State Program has included open Steering Committee meetings, quarterly reports, meeting announcements, news releases, and educational materials. Public forums have been conducted throughout the study area to address public concerns and provide information developed by the program.

Technical reports produced by the Bi-State Program have been reviewed by members of the Bi-State Program Steering Committee and have been made available to the public. Prior to 1994, reports were reviewed by members of a Scientific Resource Panel. In 1994, the Bi-State Program Steering Committee replaced this panel with a scientific Peer Review Panel.

Technical studies conducted by the Bi-State Program have included the collection and evaluation of historical information, reconnaissance-level water quality studies, baseline studies, and advanced studies. The results of these studies have undergone critical review by the Scientific Resource Panel or the Peer Review Panel, plus additional scientific peer reviewers. The results of Bi-State Program technical studies and recommendations for future studies are the focus of this report.

1.3 REPORT ORGANIZATION

The balance of this report is organized into the following three sections. Section 2.0 provides an overview of the studies conducted during the four-year Bi-State Program. This section includes an explanation of the types of studies that were conducted: 1) Compilation/characterization of existing data, 2) Reconnaissance surveys, 3) Baseline studies, 4) Advanced studies, and 5) Data management. Section 3.0 provides an integrated assessment of the health of the lower Columbia River based on the data generated during the Bi-State Program studies. Section 4.0 contains recommendations for future studies based on the technical studies conducted by the Bi-State Program.

2.0 LOWER COLUMBIA RIVER BI-STATE PROGRAM STUDIES

This chapter is an overview of the objectives and findings of each of the Bi-State Program studies. The Bi-State Program studies are divided into five categories:

- Compilation/characterization of existing data
- Reconnaissance surveys
- Baseline studies
- Advanced studies
- Data management

Section 2.1 describes the topics studied within this program and their relationships to each other and to the overall program goals. Sections 2.2 through 2.6 summarize the specific studies conducted within each of the categories listed above. Individual reports are listed in Appendix A, which is divided into sections corresponding to the five categories above.

2.1 STUDY TOPICS

This section provides an overview of the approach taken by the Bi-State Program in studying the health of the lower Columbia River. Figure 3 is a diagram of this approach.

In 1991, the Bi-State Program conducted a number of studies designed to review and compile existing information on the health of the lower Columbia River. This compilation included all existing studies and monitoring data available on pollutants in the river and known pollutant sources, an extensive survey of the river's hydrology and geology, potential biological indicators of the river's health, designated beneficial uses of the river as legally defined by both states, and designated biologically sensitive areas along the river. These studies indicated that while there was a substantial amount of data available on the levels and actual or potential sources of contaminants in the river, there was great disparity in the methods used to analyze contaminants, the types of chemicals analyzed, and the time periods and areas of the river covered by the different studies. This compilation underlined the need for a comprehensive, river-wide survey.

The results of these studies were used to design a reconnaissance survey of the river which was undertaken in 1991 in low water conditions. The low water made some backwater areas of the river inaccessible. After careful review of the results of this survey, a backwater reconnaissance survey was undertaken in 1993 to supplement the findings of the initial reconnaissance survey. These reconnaissance surveys provided

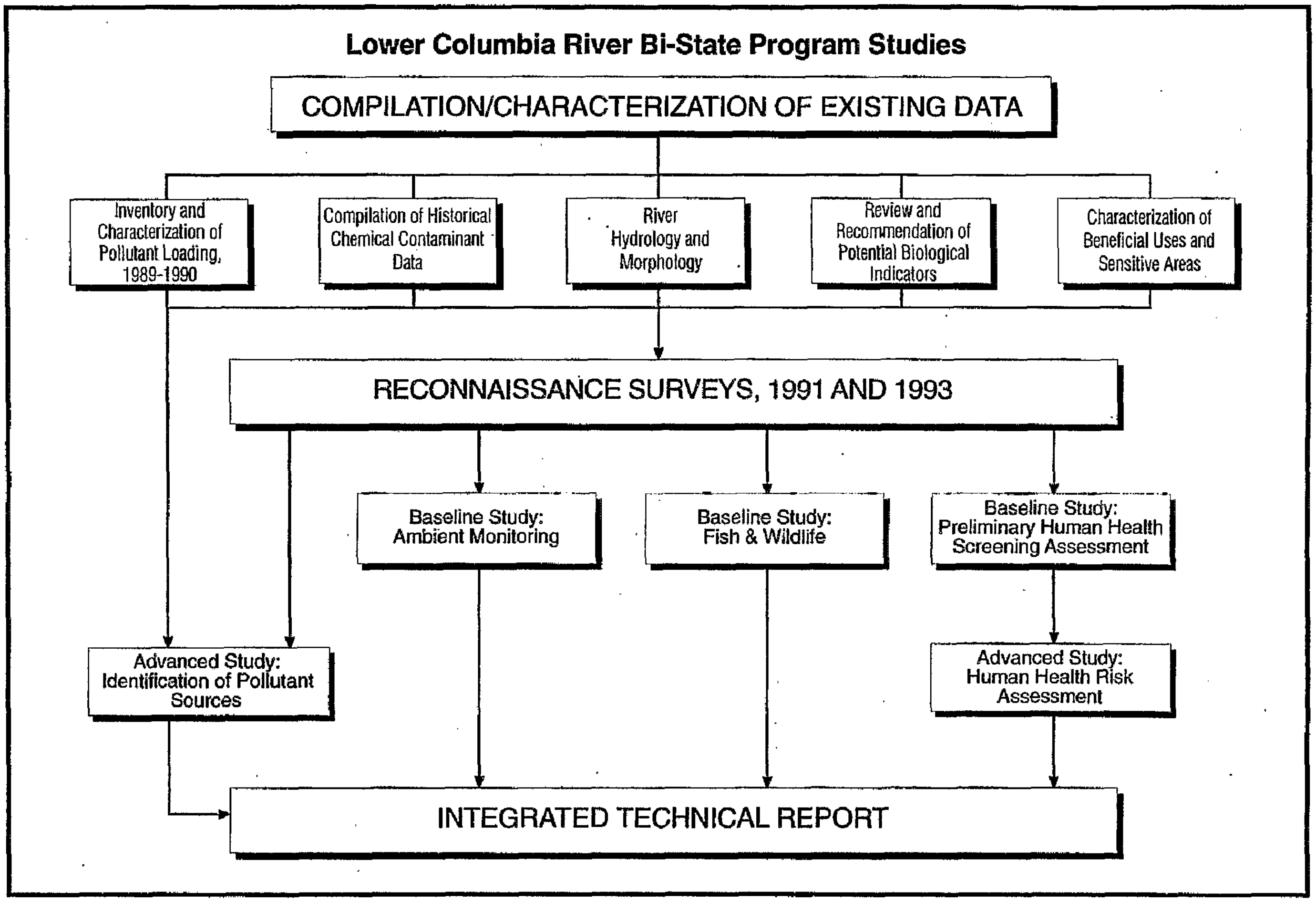

Figure 3. Flow Chart of the Lower Columbia River Bi-State Program Studies.

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the first broad-based information on the health of the entire lower Columbia River.

The next stage of the Bi-State study program was to conduct baseline studies based on the results of the reconnaissance surveys. These studies addressed specific areas for which it was felt that the baseline data provided in the reconnaissance surveys needed to be supplemented or refined. These study areas include:

- **Ambient water quality monitoring**: Monthly water contaminant monitoring conducted by the U.S. Geological Survey, with help from Ecology and ODEQ, along the mainstem and at the mouths of major tributaries for one year.

- **Pollutant work assignment**: A design, not implemented, to investigate areas with the highest identified levels of contaminants in sediments and animal tissue.

- **Fish and wildlife health**: A variety of activities designed to document pollution impacts to aquatic and terrestrial organisms, focusing on a variety of species: bald eagle, mink, river otter, both game and non-game fish species, and crayfish.

- **Human health**: A preliminary screening study of the potential human health risks of river pollutants.

The information gained in the reconnaissance surveys and baseline studies, including the results of peer and public review, was used to design a series of advanced studies in areas of particular concern. To date, only one advanced study has been completed, a human health risk assessment, based on the human health screening study plus additional data. This study estimates the risks to human health associated with eating fish caught in the lower Columbia.

All of these studies are summarized in this Integrated Technical Report. For more detailed information about any specific topic, please refer to the individual report.

2.2 COMPILATION/CHARACTERIZATION OF EXISTING DATA

This stage of the study began with a thorough review of previous studies and other data available on the lower Columbia River. From this, an initial assessment of pollution sources, problem areas, and contaminants was prepared. This information was used in designing reconnaissance surveys, which were in turn used as baseline data and a starting point for designing further assessments. Other areas in which data were reviewed included the physical and hydrologic characteristics of the river, potential biological indicators, designated beneficial uses, and designated biologically sensitive areas along the river in both states. Physical and hydrologic data provided the basis for a conceptual model of contaminant transport processes that could be used to develop a mathematical water quality model of the river. A list of potential biological indicators was recommended for possible use in river monitoring programs. Beneficial uses and sensitive areas in the lower Columbia were classified in terms consistent with the statutory framework of Oregon and Washington to guide the design of the reconnaissance survey and to serve as the basis for assessing impairment of beneficial uses of the river.

2.2.1 Compilation and Evaluation of Existing Water Quality Data

The first Bi-State Program task was to compile, review, and synthesize existing water quality data in order to assess potential problems areas in water, sediment, and biota (Appendix A, Section 1.1). This task focused on historical data (1980-1990) on contaminant levels in these three media, plus population data on benthic (bottom-dwelling) fish and other organisms. Existing reports and databases were catalogued into a library database and then screened for relevance and quality. Selection criteria differed slightly for each medium, but generally consisted of 1) availability of raw data, 2) stations located in Columbia River mainstem, and 3) use of appropriate methods.

Of the numerous reports and databases compiled, only 11 water quality, 18 sediment, and 2 biota studies were considered acceptable. Fish and benthic community studies were generally descriptive and did not allow assessment of potential problem areas. Potential problem areas were identified based on data from acceptable studies. In general, these areas were located in the vicinity of larger urban and industrial areas along the river. This initial screening did not assess overall river health due to the limited spatial coverage of the studies surveyed, which tended to focus on particular areas of the river, especially urban and industrial locations. Comparison among studies was difficult because studies used different field and laboratory methods and focused on different suites of contaminants. This first task underlined the need for a comprehensive river-wide reconnaissance survey.

2.2.2 Inventory and Characterization of Pollutants

The second task of the program was to compile information on pollutant sources to the lower Columbia (Appendix A, Section 1.2). Three types of pollutant sources were evaluated:

- **Point sources**: Discrete sources with permits to discharge directly to the river, usually from a pipe.

- **Non-point sources**: Diffuse discharges from surface runoff, tributaries, combined sewer overflows (CSOs), atmospheric deposition, and accidental spills.

- **In-place sources**: Landfills, hazardous waste sites, septic systems, and marinas and moorage areas located along the river.

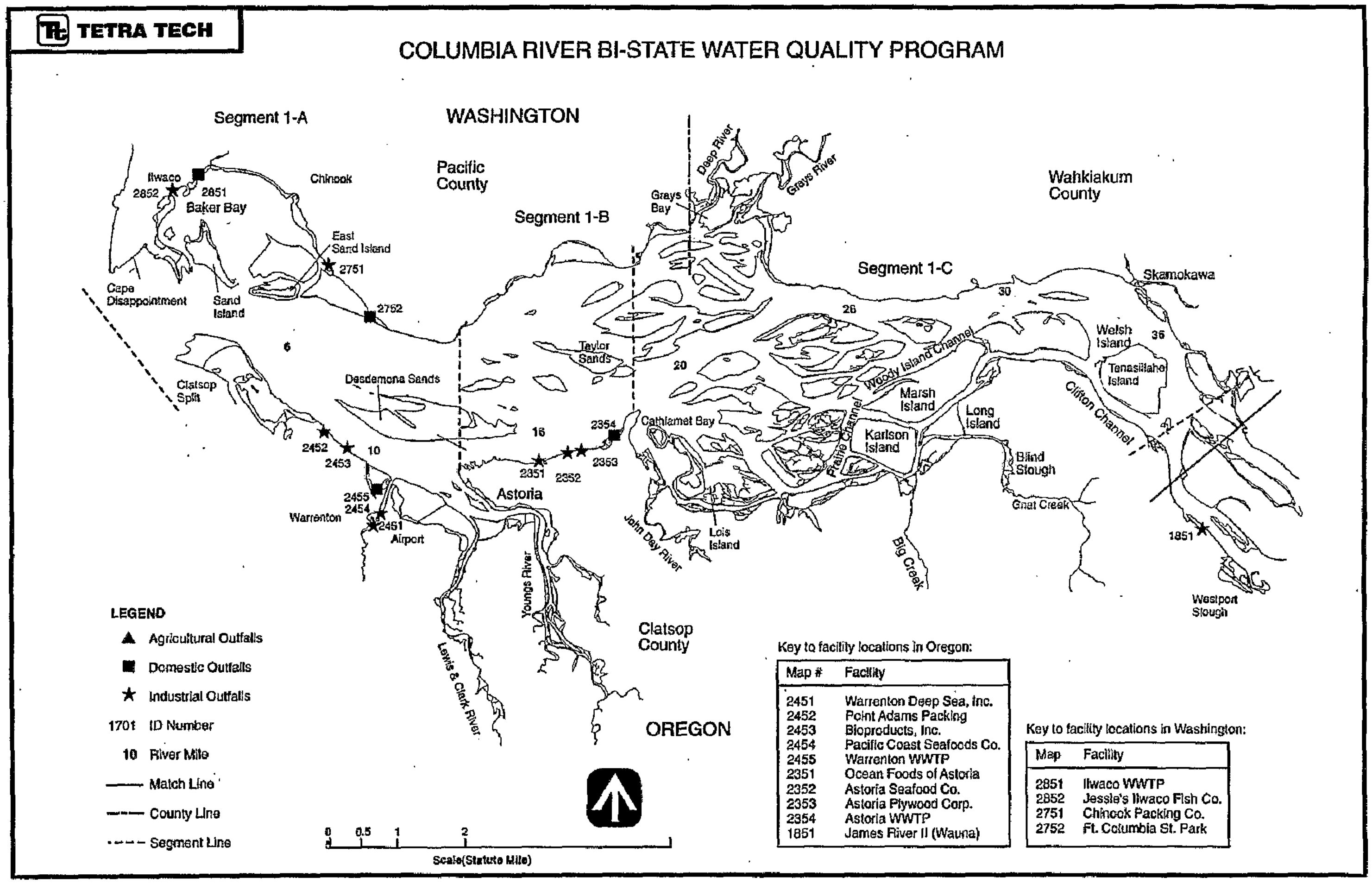
The goal of this task was to locate and characterize contaminant sources and identify the types of contaminants discharged to the river by various sources, with emphasis on the more environmentally toxic substances. One goal of the pollutant characterization process was to identify specific pollutants that are of special concern because of their environmental toxicity. Sources could be compared for potential impact, and this information used in designing the reconnaissance study.

A total of 54 point sources discharging directly to the lower Columbia were identified and characterized (Figures 4-7). The sources include 19 municipal wastewater treatment plants (WWTPs), 3 fish hatcheries, and 32 major industrial dischargers.

Major industrial discharges include treated process wastewaters from three aluminum, two chemical, and six pulp and paper plants; the Trojan Nuclear Plant was formerly a discharger. Minor industrial sources include non-process wastewaters from four chemical, eight seafood, and six wood products facilities. Quantitative estimates and comparisons of the amount or rate of pollutants entering the river were only possible for a limited number of point source pollutants. This information was generally limited to water flow, total suspended solids (TSS), and biochemical oxygen demand (BOD). Data for inorganic constituents, metals, and organic pollutants from specific point sources were even more limited..

Non-point sources considered included surface water runoff, combined sewer overflows (CSOs), atmospheric inputs, and accidental spills. No quantitative data were found for these sources except for accidental spills. There was limited quantitative data available for accidental spills of pollutants, primarily petroleum. It is possible that a few very large spills may account for much of the petroleum pollution.

Tributaries, including input from the upper Columbia River, were also considered non-point sources. Pollutants in these tributaries are derived from both point and non-point sources in their drainage areas. An extensive review of the pollutant sources to tributaries feeding the lower Columbia River was beyond the scope of this task, but was addressed in an advanced study; see Section 2.5.2. Monitoring data collected at the mouths of the major rivers was compared with point source data. The five largest



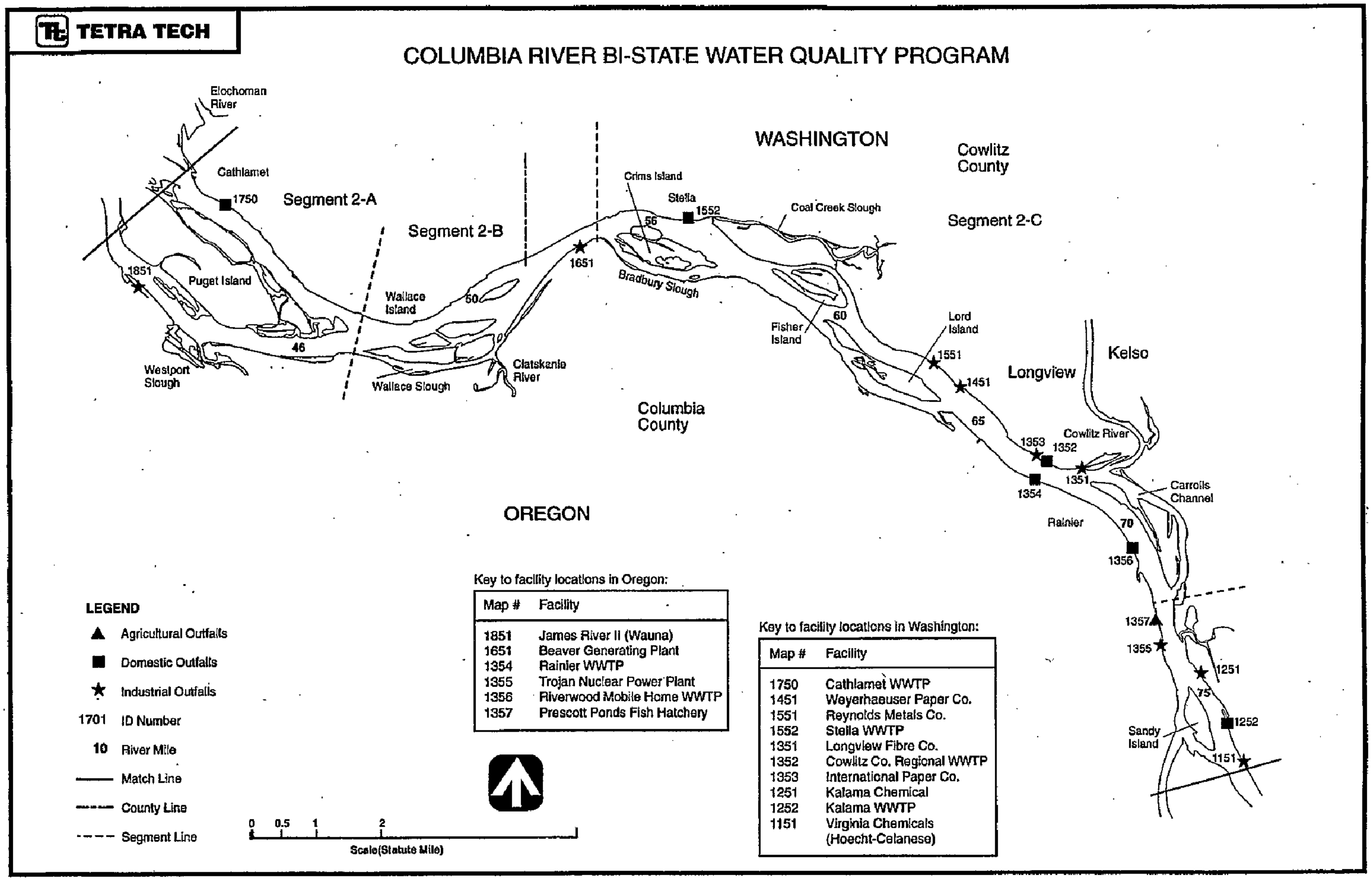
Key to facility locations in Oregon:

Map #	Facility
2451	Warrenton Deep Sea, Inc.
2452	Point Adams Packing
2453	Bioproducts, Inc.
2454	Pacific Coast Seafoods Co.
2455	Warrenton WWTP
2351	Ocean Foods of Astoria
2352	Astoria Seafood Co.
2353	Astoria Plywood Corp.
2354	Astoria WWTP
1851	James River II (Wauna)

Key to facility locations in Washington:

Map	Facility
2851	Ilwaco WWTP
2852	Jessie's Ilwaco Fish Co.
2751	Chinook Packing Co.
2752	Ft. Columbia St. Park

Figure 4. Locations of NPDES-Permitted Point Source Dischargers in the Lower Columbia River (RM0-40).



Key to facility locations in Oregon:

Map #	Facility
1851	James River II (Wauna)
1651	Beaver Generating Plant
1354	Rainier WWTP
1355	Trojan Nuclear Power Plant
1356	Riverwood Mobile Home WWTP
1357	Prescott Ponds Fish Hatchery

Key to facility locations in Washington:

Map #	Facility
1750	Cathlamet WWTP
1451	Weyerhaeuser Paper Co.
1551	Reynolds Metals Co.
1552	Stella WWTP
1351	Longview Fibre Co.
1352	Cowlitz Co. Regional WWTP
1353	International Paper Co.
1251	Kalama Chemical
1252	Kalama WWTP
1151	Virginia Chemicals (Hoecht-Celanese)

Figure 5. Locations of NPDES-Permitted Point Source Dischargers in the Lower Columbia River (RM40-80).

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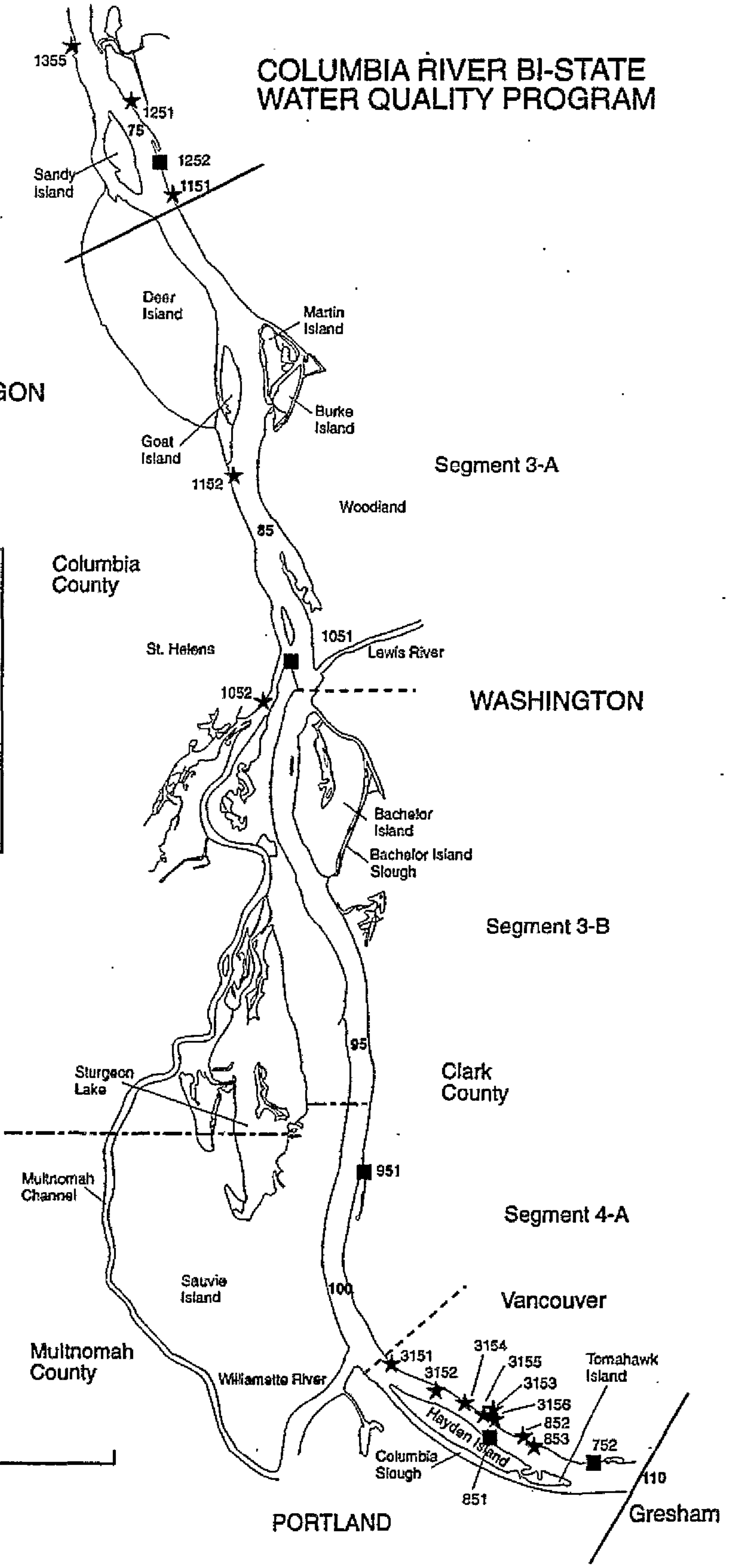


Key to facility locations in Oregon:

Map #	Facility
1355	Trojan Nuclear Power Pl.
1152	Chevron Chemical Co.
1051	St. Helens WWTP
1052	St. Helens Veneer Mill
851	Portland WWTP

Key to facility locations in Washington:

Map #	Facility
1251	Kalama Chemical
1252	Kalama WWTP
1151	Virginia Chemicals (Hoecht-Celanese)
3151	ALCOA
3152	GATX Terminal Corp.
3153	Fort Vancouver Plywood
3154	Northwest Packing
3155	Vancouver (Westside) WWTP
3156	Great Western Malting
852	Boise Cascade Corp.
853	Ideal Basic Industries
752	Vancouver (Eastside) WWTP
951	Salmon Creek WWTP

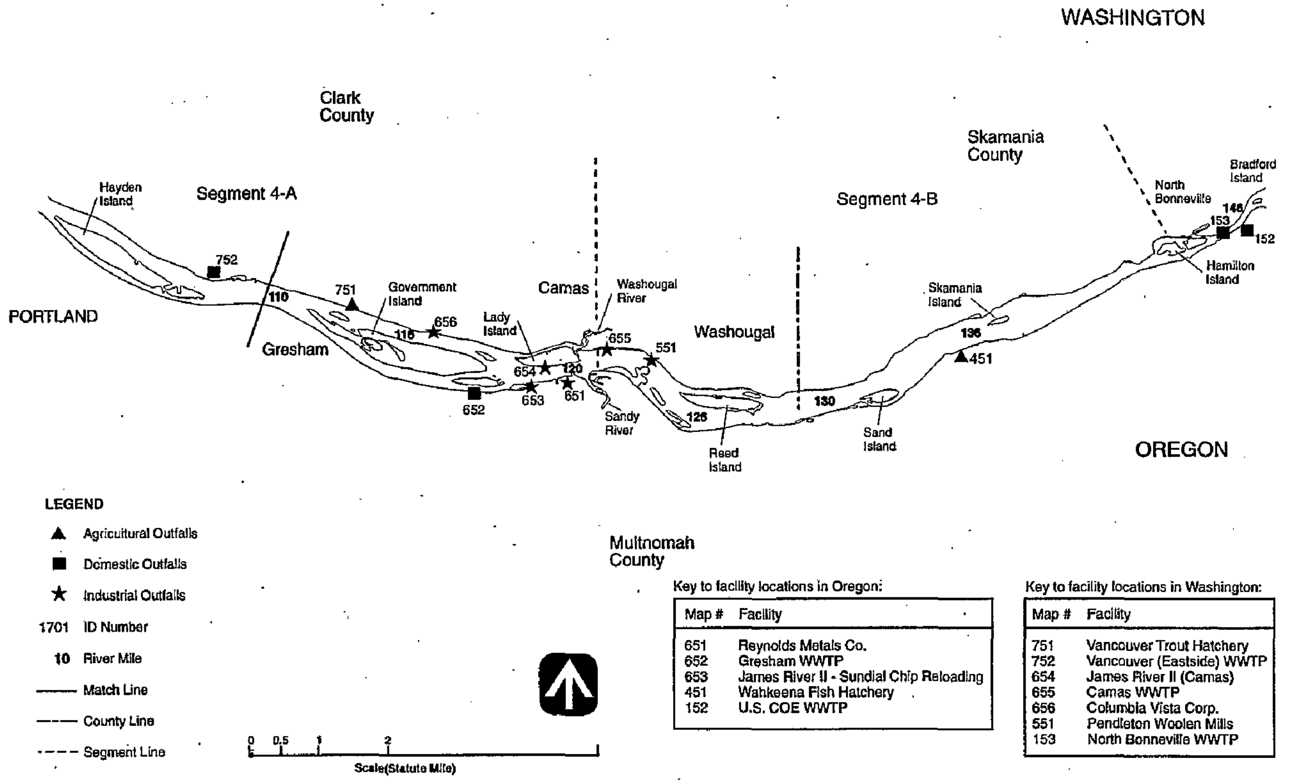
LEGEND

- ▲ Agricultural Outfalls
- ■ Domestic Outfalls
- ★ Industrial Outfalls
- 1701 ID Number
- 10 River Mile
- ——— Match Line
- —-—- County Line
- - - - - Segment Line

0 0.5 1 2

Scale(Statute Mile)

Figure 6. Locations of NPDES-Permitted Point Source Dischargers in the Lower Columbia River (RM80-110).



Key to facility locations in Oregon:

Map #	Facility
651	Reynolds Metals Co.
652	Gresham WWTP
653	James River II - Sundial Chip Reloading
451	Wahkeena Fish Hatchery
152	U.S. COE WWTP

Key to facility locations in Washington:

Map #	Facility
751	Vancouver Trout Hatchery
752	Vancouver (Eastside) WWTP
654	James River II (Camas)
655	Camas WWTP
656	Columbia Vista Corp.
551	Pendleton Woolen Mills
153	North Bonneville WWTP

Figure 7. Locations of NPDES-Permitted Point Source Dischargers in the Lower Columbia River (RM110-146).

tributaries to the lower Columbia River are the Willamette, Cowlitz, Lewis, Sandy, and Kalama rivers. The Willamette River is the largest of the five, with an annual volume almost twice as great as that of the other four combined. Quantitative information on the tributary contributions was generally limited to water flow, TSS, inorganic constituents (including nutrients), and metals; no data on BOD or organic pollutants were identified. More detailed information on contaminant loads in the Willamette River can be found in Tetra Tech 1992d.

Potential in-place pollutant sources identified included seventeen hazardous waste and Superfund sites and eighteen landfills within one mile of the river (Figures 8-11). The limited data available for these sites allowed for only a qualitative characterization. These sites are primarily located in the Longview and Portland/Vancouver area, suggesting that the potential for river impacts from these sources is greatest near these urban areas. The information available for septic tanks, marinas, and moorage areas was even more limited.

Although not necessarily an indication of the relative pollutant inputs from point sources, the relative portion of wastewater discharged from various point source facility types is compared in Figure 12. Wastewater discharge from pulp and paper mills accounts for over half (52 percent) of the total point source discharge to the lower river, and wastewater discharge from major municipal sources accounts for about a third (32 percent). Taken together, the six pulp and paper mills along the lower Columbia River and the WWTPs for Astoria, St. Helens, Portland, and Gresham in Oregon, and Longview and Vancouver in Washington account for 84 percent of the wastewater discharged from permitted point sources directly to the lower Columbia. The next largest source of wastewater, major chemical industry discharges, accounts for less than 8 percent of the total wastewater discharge.

The actual volume of wastewater from these sources is very small compared to river volumes. Such volumes are measured in millions of gallons per day (MGDs). Total annual average point source wastewater discharge is 500 MGD, less than 2 percent of the discharge from the five largest lower Columbia tributaries (30,000 MGD) and less than half a percent of the upper Columbia discharge (120,000 MGD). This total discharge amount is roughly equivalent to 75 percent of the discharge from the Kalama River (653 MGD)—the fifth largest tributary to the lower Columbia River (see Figure 12).

2.2.3 Hydrology and Morphology of the Lower Columbia River

The third task of the program was to summarize existing data on the river's hydrology and

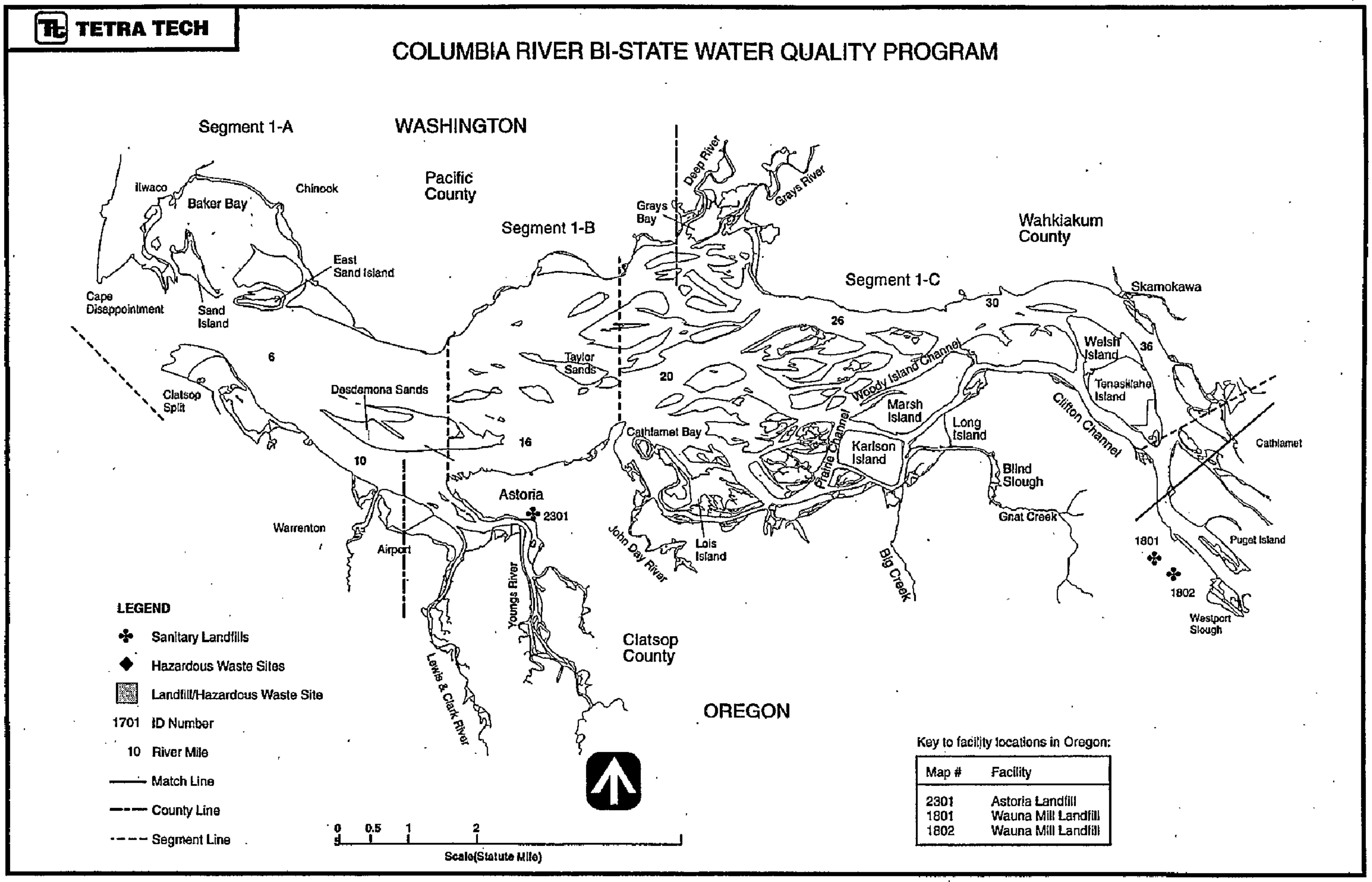
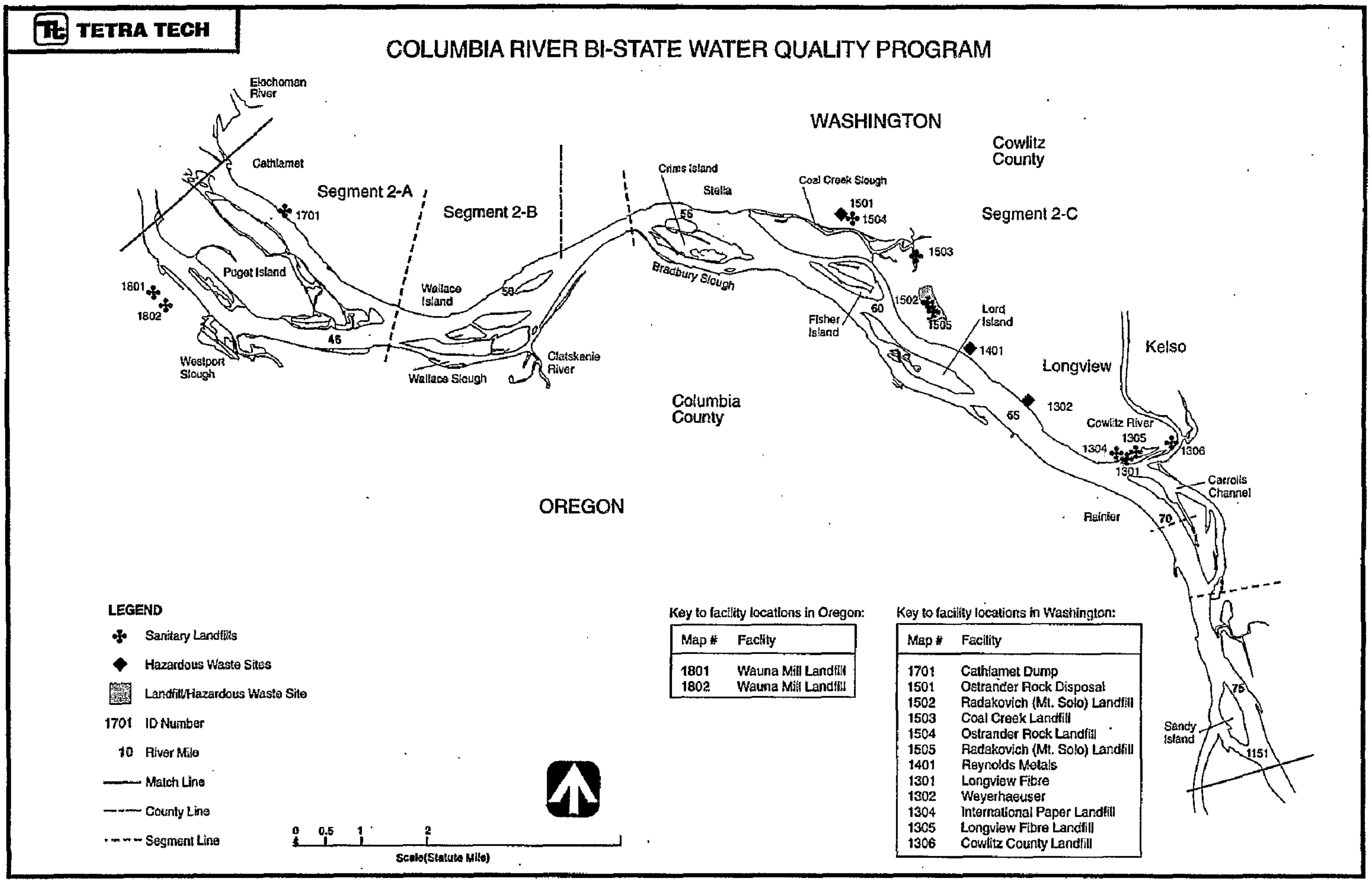


Figure 8. Locations of Landfills and Hazardous Waste Sites Adjacent to the Lower Columbia River (RM0-40).



Key to facility locations in Oregon:

Map #	Facility
1801	Wauna Mill Landfill
1802	Wauna Mill Landfill

Key to facility locations in Washington:

Map #	Facility
1701	Cathlamet Dump
1501	Ostrander Rock Disposal
1502	Radakovich (Mt. Solo) Landfill
1503	Coal Creek Landfill
1504	Ostrander Rock Landfill
1505	Radakovich (Mt. Solo) Landfill
1401	Reynolds Metals
1301	Longview Fibre
1302	Weyerhaeuser
1304	International Paper Landfill
1305	Longview Fibre Landfill
1306	Cowlitz County Landfill

Figure 9. Locations of Landfills and Hazardous Waste Sites Adjacent to the Lower Columbia River (RM40-80).

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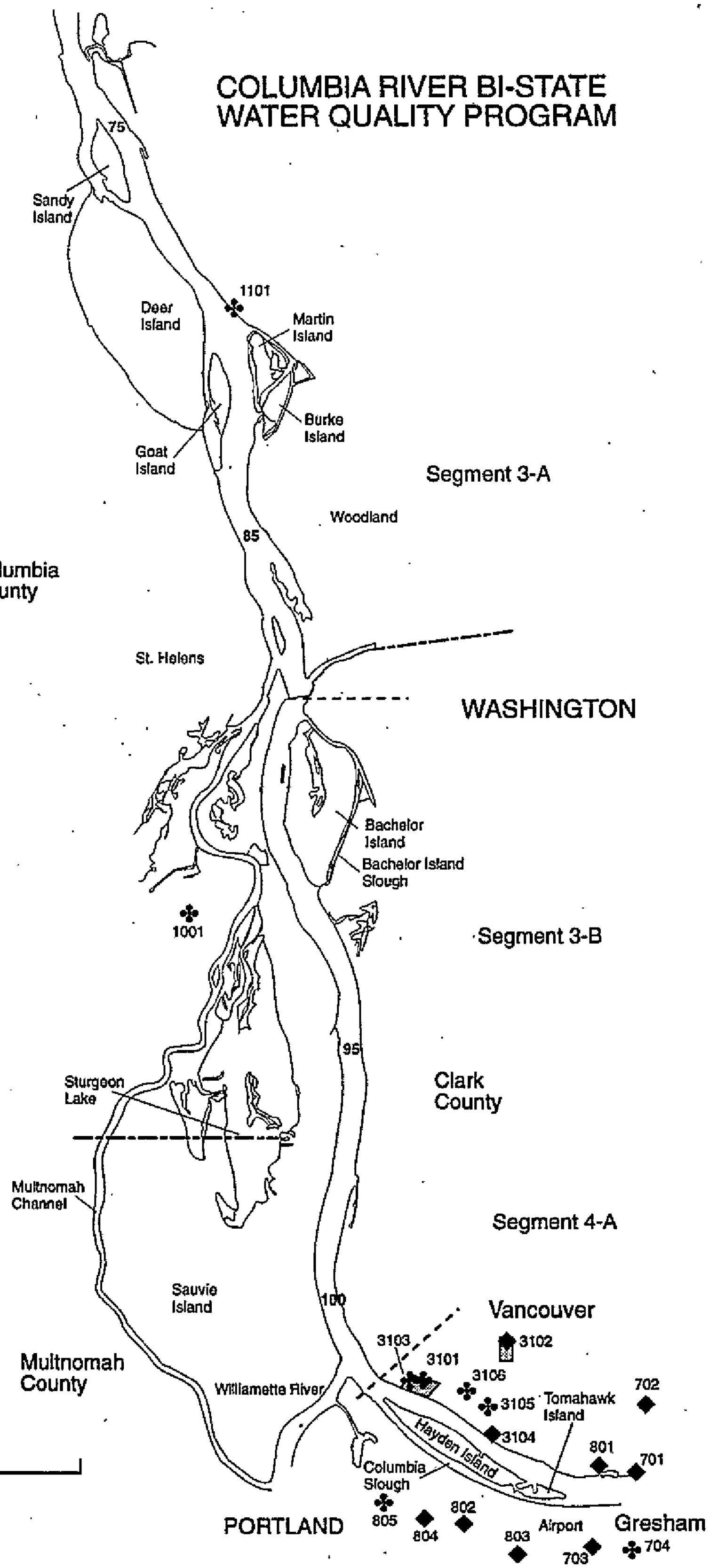
Key to facility locations in Oregon:

Map #	Facility
1001	St. Helens Municipal Landfill
802	Malarkey Roofing Co.
803	Allied Plating
804	Columbia Steel/Joslyn Sludge Pond
805	St. Johns Landfill
703	Nu Way Oil Co.
704	Riedel Landfill

Key to facility locations in Washington:

Map #	Facility
1101	Kalama Municipal Landfill
3101	Columbia Marine Lines
3102	Burlington Northern
3103	ALCPA Smelter
3104	Port of Vancouver
3105	City of Vancouver Sludge Ash Landfill
3106	Boise Cascade Limited Purpose Landfill
801	Frontier Hard Chrome, Inc.
701	Tidewater Barge Lines
702	Custom Care Cleaners



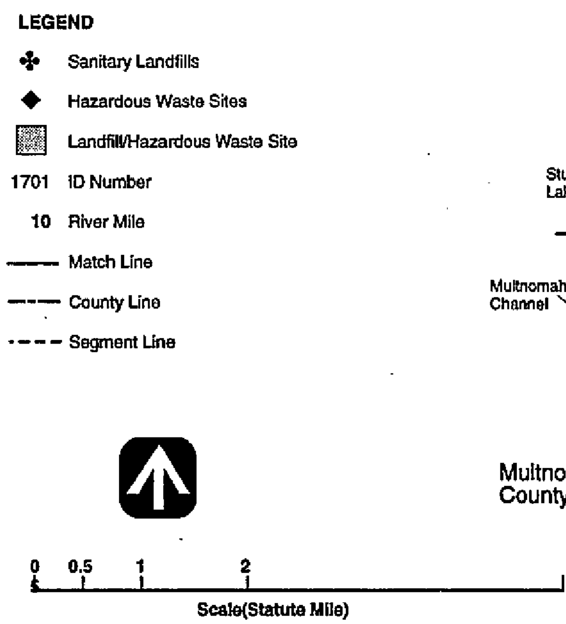


Figure 10. Locations of Landfills and Hazardous Waste Sites Adjacent to the Lower Columbia River (RM80-110).

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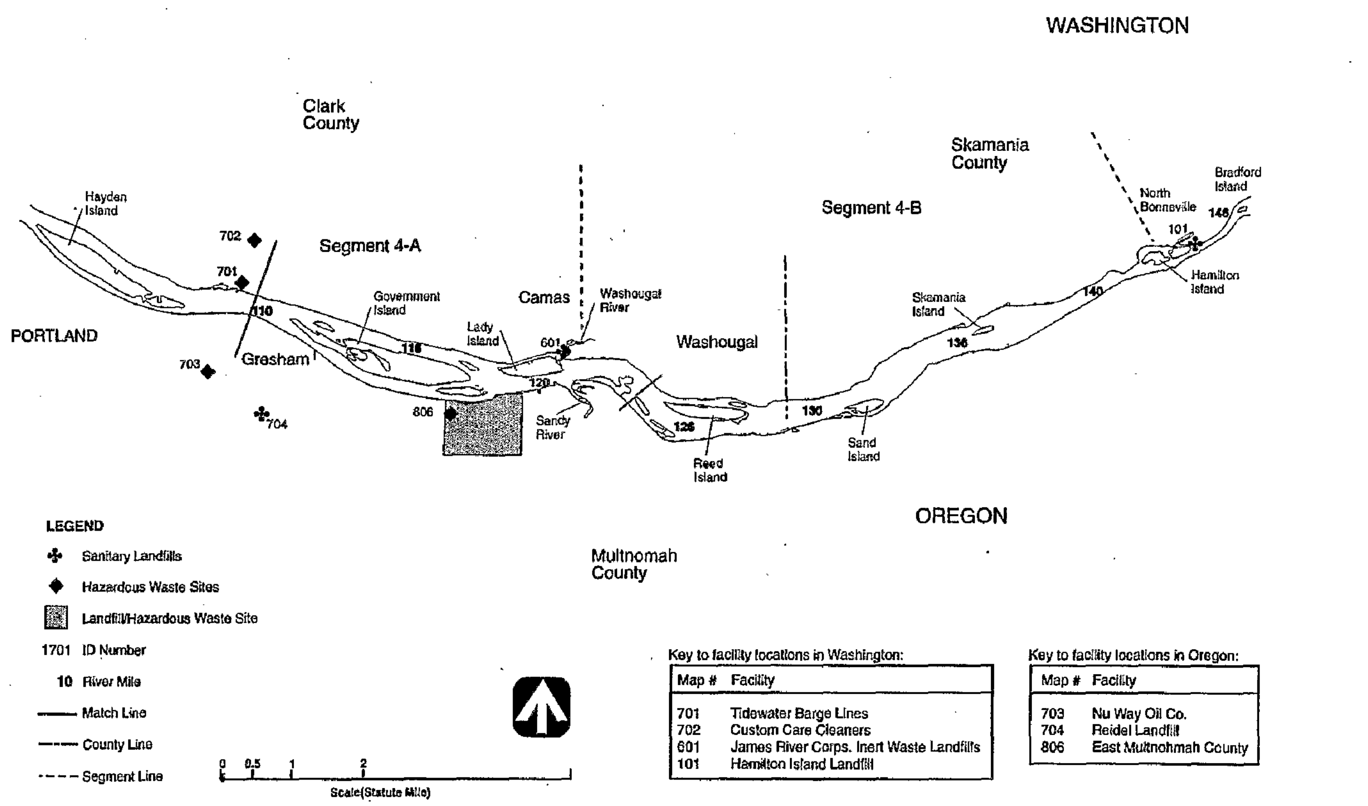
COLUMBIA RIVER BI-STATE WATER QUALITY PROGRAM



Key to facility locations in Washington:

Map #	Facility
701	Tidewater Barge Lines
702	Custom Care Cleaners
601	James River Corps. Inert Waste Landfills
101	Hamilton Island Landfill

Key to facility locations in Oregon:

Map #	Facility
703	Nu Way Oil Co.
704	Reidel Landfill
806	East Multnohmah County

Figure 11. Locations of Landfills and Hazardous Waste Sites Adjacent to the Lower Columbia River (RM110-146).

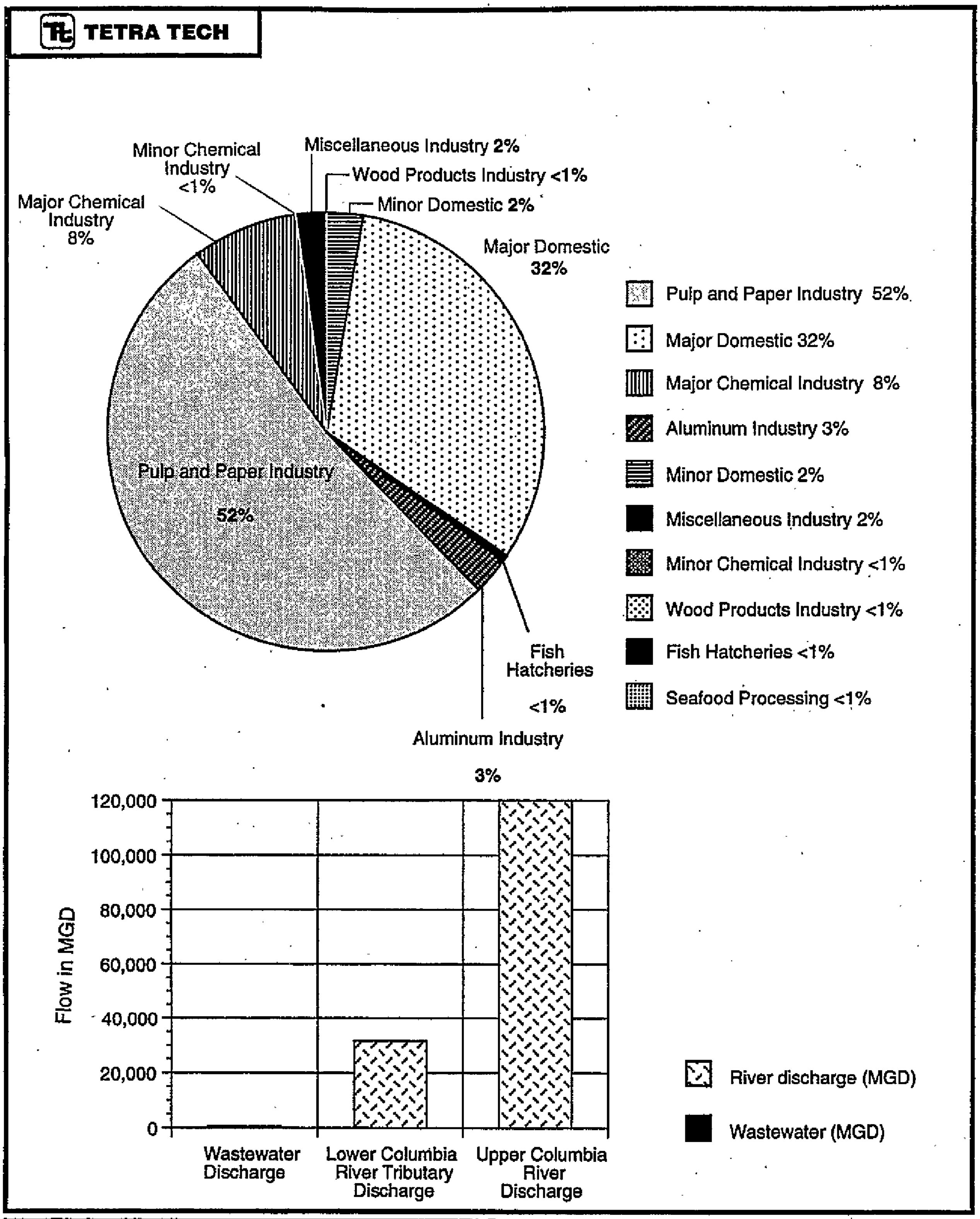


Figure 12. Annual Point Source Discharge to the Lower Columbia River

morphology and recommend conceptual and numerical models to predict the fate and transport of contaminants in the river (Appendix A, Section 1.3). Hydrology and morphology of the river were divided into four general categories: 1) hydrologic, 2) hydraulic, 3) sediment transport, and 4) channel morphology.

2.2.3.1 Hydrologic Characteristics. As stated in Section 1.0, the Columbia River is the second largest river in the United States in terms of volume discharged. The river drains approximately 255,000 mi^2 (660,480 km^2) of seven western states and one Canadian province (Figure 1). Average flow on the mainstem above Bonneville Dam is about 194,000 cubic feet per second (cfs) (5,490 m^3/sec). Additional flow accounting for nearly 25 percent of the total runoff enters the river below Bonneville Dam, contributed by a number of tributaries, including the Sandy, Willamette, Lewis, Kalama, and Cowlitz Rivers. Average discharge at the mouth of the estuary approaches 260,000 cfs (7,360 m^3/sec). Although flow is regulated by an extensive multipurpose reservoir system, the river has two distinct flood seasons. The largest flows are associated with springtime snowmelt from mountains east of the Cascade Divide between April and June. Wintertime rainstorms in areas west of the Cascade Divide cause higher winter flows from November through March. The lowest discharges occur during September and October.

The Willamette River is the major tributary on the lower Columbia River, discharging into the river at Columbia RM 101 (RK 162) and via the Multnomah Channel at RM 86 (RK 138). The Willamette River average annual discharge approaches 35,000 cfs (990 m^3/sec). Maximum daily discharge in the Willamette during the winter has reached 280,000 cfs (7,930 m^3/sec).

2.2.3.2 Hydraulic Characteristics. The dominant hydraulic characteristic of the lower river is the relatively high velocity of the river during most conditions. Velocities greater than 5 ft/sec (1.5 m/sec) occur during average flood stage even though the bed slope in the river is low (approaching 0.001 percent), largely due to high discharge and low resistance to flow. Downstream velocities are moderated at low flow [flows less than 150,000 cfs (4,250 m^3/sec)] by tidal conditions. During low river flows and neap tides, salinity intrusion (measured at river bottom) can extend up to Pillar Rock, RM 27 (RK 43), and during higher flows [about 300,000 cfs (8,500 m^3/sec)], salinity can extend up to RM 14 (RK 22) (for comparison with Figure 12, 1 cfs = 0.6465 MGD). Hydraulic conditions in the estuary are complex, with three-dimensional flows through deep channels of variable salinity, which meander past shallow bays, flats, and islands in a wide coastal plain-type estuary. These conditions make the measurement and prediction of current directions and velocities (necessary to predict contaminant transport) extremely difficult. Hydraulic conditions upstream of the estuary tend to be relatively less complex, with a typical uni-directional flow. However, even above the estuary, the presence of multiple channels, tributary influence, and tidal moderation must be considered in selecting a model to simulate contaminant transport and fate.

2.2.3.3 Suspended Sediment Transport. Suspended sediment transport and fate is important because of the affinity of many contaminants to fine sediments. The lower Columbia River transports significant amounts of sediment which are sand-sized and smaller. Sediments are transported either in suspension (mostly fine silt and clay) or as bed load (primarily sand). Throughout the lower Columbia, fine sediments are deposited only in low energy environments located in sloughs, back channels, and the estuary. The total load of fine-grain sediments in the lower Columbia averages approximately 10 million tons/year. Following the eruption of Mt. St. Helens in 1980, the suspended load measured at Longview [RM 67 (RK 107)] increased by an estimated 40 percent. It is estimated that 20 to 35 percent of the suspended sediments transported to the estuary from upstream are retained, approximately 2 to 3.5 million tons/year. In addition, between 1 and 2 million tons of sand per year enter the estuary as bed load. Bed sediments show seasonal variations in texture, tending to be finer near the end of a low flow period and coarser after a high discharge. Approximately 35 percent of the total sediment load (3-4 million tons/year) is deposited in the estuary. Sediment which reaches, but is not deposited, ultimately contributes to the sediment budgets of areas both north and south of the river's mouth.

2.2.3.4 Channel Morphology. The lower Columbia river is an extremely straight alluvial channel with numerous mid-channel bars and islands. Most of the bank material in the lower river is non-cohesive silty sand and is extremely susceptible to bank erosion. High current velocities are directed toward erodible banks, resulting in a high rate of bank erosion. As river velocity slows in the estuary, it deposits much of its sediment load. This sediment deposition process has resulted in the formation of a wide, multi-channeled river, with bifurcations and diverse sediment sizes.

The information summarized above was used to develop a conceptual model, which was then used to recommend modeling approaches for the river. A three-dimensional model was recommended for the estuary, a two-dimensional model in an intermediate region, and a one-dimensional model with two-dimensional modeling for site-specific reaches in the riverine portion of the lower Columbia. Two approaches were also recommended: 1) a conservative approach using models that have already been applied and verified on parts of the Columbia River, and 2) a state-of-the-art approach using more sophisticated but untested models.

2.2.4 Recommended Biological Indicators

The major steps of the biological indicators task were 1) compile and review pertinent literature and interview scientists experienced with the Columbia River and/or biological indicators, 2) characterize habitats and communities of the lower Columbia River based on historical data, 3) select candidate biological indicators for study in the Reconnaissance Survey, 4) identify major ecological zones of the river based on the reconnaissance data, and 5) reassess recommended biological indicators to determine which indicators would be most useful and applicable for long-term water quality monitoring in the lower Columbia River (Appendix A, Section 1.4).

The following section summarizes the results of the first four objectives of this task. Final recommendations for biological indicators are discussed in Section 3.0 of this report.

The lower Columbia River is a highly dynamic system consisting of a freshwater riverine reach and an estuarine/marine reach. The biological communities present in the river are diverse in response to a wide variety of environmental conditions. These communities can be characterized according to sediment type, flow characteristics, and salinity. Representative biological communities include lotic and demersal fishes, benthic and epibenthic macroinvertebrates, and algae and vascular aquatic plants. The greatest number of species and habitat types occur in the estuary.

The complexity of the river and the diversity of potential contaminants require that any approach used to monitor biological health integrate biological and chemical measurements into a thorough appraisal of environmental conditions. Because there are many areas of concern, no one species will serve as an adequate biological indicator. The use of several species and varying endpoints (mortality, morbidity, or other measurable change) is needed to provide a thorough evaluation of environmental conditions.

Fish and benthic invertebrates have the broadest distribution within the lower Columbia River, and are primary candidates for use in a long-term biological monitoring program. Assessments should be performed at the individual, population, and community levels to provide both site-specific and systemwide information. Valuable information would also be gained through the use of field and laboratory bioassays. This integrated approach will help identify water quality problems in the lower Columbia and support effective management of all Columbia River resources and beneficial uses.

2.2.5 Beneficial Uses and Sensitive Areas

The objectives of the fifth task were to determine the beneficial and characteristic uses and sensitive areas of the lower Columbia River, and to describe these in terms applicable to both States (Appendix A, Section 1.5). People and animals that live along the lower river use it in many differing ways. These uses are referred to by Oregon as "beneficial uses" and by Washington as "characteristic uses." Water quality standards have been adopted by the two states to protect these uses. These beneficial and characteristic uses include public health, public water supplies, agricultural uses, industrial uses, and recreational activities as well as the protection and propagation of a balanced population of shellfish, fish, and wildlife. Therefore, the first objective of this task was to identify and define in consistent terms the beneficial and characteristic uses of the lower river as designated by both Oregon and Washington for use in the Bi-State Program.

2.2.5.1 Oregon Beneficial Uses. Oregon Administrative Rules (OAR) have established water quality standards in the lower Columbia River Basin (OAR 340-41-202, 442, 482). Three separate reaches of the river are covered under these regulations: mouth of river to RM 86 (RK 138); RM 86 to 120 (RK 138-192); RM 120-147 (RK 192-235). Beneficial uses are consistently defined for the three areas with the exception that hydropower is not listed for the mouth to RM 86, and salmonid fish spawning is not listed from RM 120-147 because no tributaries enter this reach. The Oregon beneficial uses are listed below:

- Public Domestic Water Supply
- Resident Fish and Aquatic Life
- Private Domestic Water Supply
- Wildlife and Hunting
- Industrial Water Supply
- Fishing
- Irrigation
- Boating
- Livestock Watering
- Water Contact Recreation
- Anadromous Fish Passage
- Aesthetic Quality
- Salmonid Fish Rearing (trout)
- Hydropower
- Salmonid Fish Spawning (trout)
- Commercial Navigation and Transportation

These beneficial uses are the basis for water quality management in the Oregon portion of the lower Columbia River.

2.2.5.2 Washington Designated Uses. The state of Washington has classified surface water based on water quality characteristic uses. The Washington Administrative Code (WAC) has classified the lower Columbia River as "Class A (excellent) Quality". Water quality for this classification must meet or exceed the requirements for all, or substantially all, of the uses listed in the regulations (WAC 173-203). Six characteristic uses are listed below:

- **Water Supply**: Domestic, industrial, and agricultural irrigation
- **Stock Watering**
- **Fish and Shellfish**: Salmonid migration, rearing, spawning, and harvesting: other fish migration, rearing, spawning, and harvesting; and oyster, and mussel rearing, spawning, and harvesting
- **Wildlife Habitat**
- **Recreation**: Primary contact recreation, sport fishing, boating, and aesthetic enjoyment
- **Commerce and Navigation**

These characteristic uses are the basis for water quality management in the lower Columbia River in Washington.

2.2.5.3 Bi-State Program Uses. The beneficial uses of the lower river as defined by both states were then summarized into the following five main groups for use in the Bi-State Program:

- Water supply
- Agriculture
- Fish and wildlife species and habitat
- Recreation
- Commercial

These combined uses are summarized in Table 4 and discussed below.

TABLE 4. BENEFICIAL USES OF THE LOWER COLUMBIA RIVER, AS DEFINED FOR THE BI-STATE PROGRAM

Water Supply	■ Public withdrawals and wells ■ Private withdrawals and wells ■ Industrial withdrawals and wells
Agriculture	■ Withdrawals for irrigating crops, pastures, orchards, and public lands ■ Withdrawals for stock watering
Fish and Wildlife	■ Anadromous fish passage ■ Salmonid spawning and rearing ■ Resident fish and other aquatic life usage ■ Wildlife usage, e.g., fish-eating animals ■ Preservation of significant and unique habitats (e.g., marshes, nesting areas, and Natural Heritage Sites)
Recreation	■ Hunting, fishing, and boating ■ Water contact recreation ■ Aesthetic quality
Commercial	■ Hydropower production ■ Navigation and transportation ■ Marinas and related commercial activity ■ Commercial fisheries

2.2.5.4 Water Supply. The major municipal users of the lower Columbia River are Vancouver and Camas in Washington and St. Helens in Oregon, which use wells along the river for municipal water. The Alcoa aluminum plant in Vancouver, Washington, is the largest private user for domestic and heat exchange supply. Two of the largest industrial users of both surface and well water are the Weyerhaeuser pulp and paper plant and the Reynolds aluminum plant in Longview, Washington.

2.2.5.5 Agriculture. There are few agricultural lands within one mile of the lower Columbia River. There are extensive agricultural lands in the Columbia Basin as a whole, mainly in the upper basin. The largest agricultural water user in the lower basin is the Bachelor Island Ranch [RM 87-88 (RK 139-141)]. There is also agricultural activity on Sauvie Island [RM 87-101 (RK 139-162)].

2.2.5.6 Fish and Wildlife. Both resident and anadromous fish use the entire length of the lower Columbia River. Several areas of the river provide prime habitat for fish and shellfish. The mouth of the Columbia River contains large concentrations of fish and Dungeness crabs, and the Cowlitz, Kalama, Willamette, and Sandy rivers are popular places for recreational fishing.

Wildlife use is prevalent throughout the river, but wildlife refuges, junctions with tributaries, and the estuary support large concentrations of a wide range of species. Sensitive wildlife species that inhabit the lower river include amphibians, mink, river otter, water birds, and several species of raptors, including bald eagles and osprey. The bald eagles and osprey feed primarily on fish from the river. Amphibians are particularly sensitive to the absorption of contaminants through their skin; species of concern in the lower Columbia include the red-legged frog and the Olympic salamander.

2.2.5.7 Recreation. Recreational uses along the lower river include swimming, wind surfing, water skiing, and fishing. Areas that are heavily used include Jones Beach [RM 45 (RK 72)] for wind surfing, Youngs Bay [RM 12 (RK 19)] for primary contact activities, and Skamokawa [RM 33 (RK 53)] for primary contact activities and fishing.

2.2.5.8 Commercial. Commercial uses of the lower Columbia include navigation and transportation, marinas and related uses, and commercial fisheries. Of these uses, commercial fishing is by far the most sensitive to water quality changes. The locations where commercial fishing is concentrated vary considerably from year to year. Fish species that are economically important include salmon, steelhead, sturgeon, smelt, and shad.

2.3 RECONNAISSANCE SURVEYS

A reconnaissance survey is a preliminary assessment which identifies current environmental conditions and contaminant levels in a study area. When coupled with knowledge of historical studies and information on potential pollutant sources, a reconnaissance survey can indicate potential environmental problems and reveal data gaps to guide future studies. They are thus typically broad in scope, attempting to sample a large number of contaminants, potential problem areas, and environmental media (e.g., water, sediments, and aquatic biota). The reconnaissance surveys of the lower Columbia River conducted for the Bi-State Program (Appendix A, Section 2.0) were designed to:

- Provide a preliminary assessment of contaminant levels in water, streambed sediments, and tissues of river biota.
- Begin to address data gaps identified in an evaluation of existing water quality data.
- Tentatively identify areas of greater contamination within the study area.
- Provide recommendations for baseline studies to be conducted in subsequent years of the Bi-State Program.

These reconnaissance studies were designed to gather data to aid in the development and design of future environmental investigations and monitoring programs for the river (Appendix A, Section 2.1).

2.3.1 Reference Levels

In order to assess the potential effects of measured levels of contaminants on humans, aquatic biota, and wildlife, the level of a particular contaminant associated with adverse health effects is needed as a reference. Federal and state agencies have developed legal standards for some contaminants, but in many cases a standard has not yet been instituted. In these cases, findings are compared to criteria recommended by the EPA or to guidelines taken from the work of other widely respected researchers. Neither criteria nor guidelines are legally binding. The term *reference level* as used in this document includes all standards, criteria, and guidelines used in evaluating reconnaissance survey data to provide a preliminary assessment of environmental conditions in the river.

The reference levels used in evaluating reconnaissance survey data were derived for assessing impacts on aquatic biota and wildlife. For addressing human health concerns, the Bi-State Committee decided to use a basin-specific risk-based approach. The resulting study, the Human Health Risk Assessment, is discussed in Section 2.5.1 of this report. The human health component of the reconnaissance surveys is an assessment of potential human health effects from water contact recreation throughout the lower river and shellfish harvesting in the estuary, based on measuring indicator bacteria levels in the water.

The sources of the reference levels used in the reconnaissance surveys are as follows:

Water

- Oregon water quality standards and action levels (Oregon Administrative Rules - OAR, Chapter 340, Division 41).
- Washington water quality standards (Washington Administrative Code - WAC Chapter 173-201A).
- U.S. EPA water quality criteria for the protection of aquatic life (U.S. EPA 1986 and updates; U.S. EPA 1993a).

Streambed Sediment

- Long and Morgan's (1990) Effects Range-Low (ER-L) and Effects Range-Medium (ER-M) concentration.
- Ontario Ministry of the Environment's Lowest Effect Levels (Provincial Sediment Quality Guidelines - Persaud et al. 1993).
- New York Department of Environmental Conservation's draft sediment criteria (Newell and Sinnott 1993).
- The five draft U.S. EPA freshwater sediment criteria (U.S. EPA 1993b,c,d,e,f).

Aquatic Biota

- Tissue contaminant criteria for the protection of carnivorous fish and fish-eating wildlife (Newell et al. 1987; Lemly 1993).

2.3.2 The Two Reconnaissance Surveys

The first reconnaissance survey (Appendix A, Section 2.1) which focused on open water areas along the mainstem of the river and tributary mouths, was conducted September-November 1991. Water samples were collected from 45 locations, sediments from 54 locations, and fish and crayfish tissue samples from 20 locations in the lower Columbia River. Species sampled and tissues analyzed included whole-body composite samples of carp, crayfish, largescale sucker, and peamouth, plus steaks from white sturgeon. Chemical analyses included a variety of field (i.e., water temperature) and conventional (e.g., water hardness, sediment organic carbon, tissue lipid content) variables, indicator bacteria, metals, organic compounds including organotins, and radionuclides. The types and abundance of benthic organisms were also recorded at the 54 sediment sampling locations.

The Backwater Reconnaissance Survey (Appendix A, Section 2.3) was conducted June-August 1993 at 15 backwater locations in the lower Columbia River. These areas were not accessible during the low water conditions of the first reconnaissance survey, and there was concern that contaminant concentrations could be higher in there areas where fine sediments are deposited (fine sediments have a greater affinity for metals and organic contaminants). This survey also measured contaminant levels in water, sediment, and aquatic biota. Since many aquatic and wildlife species utilize backwater areas as nursery and/or feeding areas, contamination in these locations is of special concern.

In addition to the 1991 and 1993 reconnaissance surveys, the Washington Department of Ecology conducted sampling of indicator bacteria at several locations along the mainstem of the river in 1992 (Ehinger 1993; Hallock 1993). These data supplemented the indicator bacteria data collected for the reconnaissance surveys. The reconnaissance survey data for trace metals concentrations in water were also supplemented by an Ecology study conducted in 1990 (Johnson, A., and B. Hopkins, 30 April 1991, personal communication).

2.3.3 Reconnaissance Survey Findings

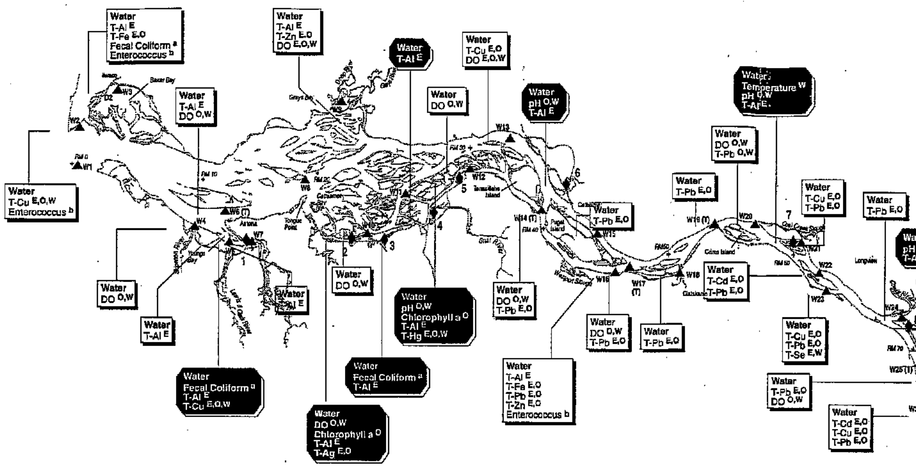
A summary of the findings of these reconnaissance surveys are outlined below by medium. See the individual reports listed in Appendix A, Section 2.0, for more detail.

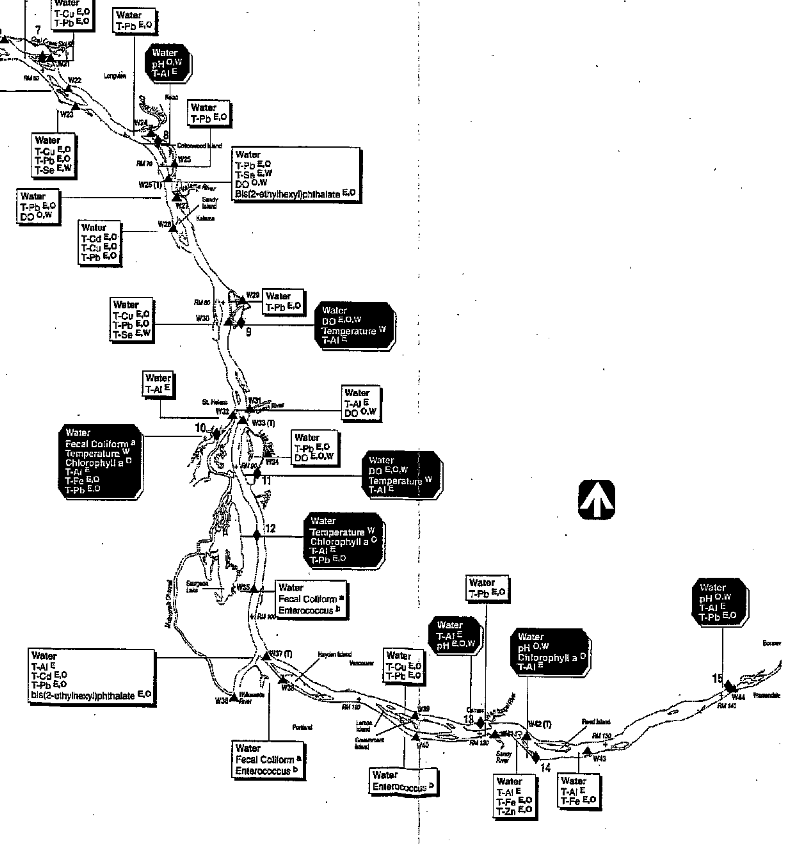
2.3.3.1 Water. It is difficult to generalize about water quality from samples taken at a single point in time because of the dynamic nature of a large river system. Also, levels of contaminants are often so dilute as to be difficult to detect (they are often relatively more concentrated in sediments and tissues). In spite of these difficulties, analysis of water samples can yield important information about environmental conditions because most of the reference levels with regulatory authority (i.e., standards and criteria) were written for water.

Potential water quality problems were indicated by several results from the two surveys (see Figure 13 for more detail, e.g., sites of contamination and sources of reference levels used).

- **Temperature**—The Washington standard of 20° C was exceeded at 4 of 15 stations in 1993. Near exceedances were observed in 1991. High temperature has been recognized as a problem in the lower Columbia in previous studies.

Figure 13. Locations of Concern, Because Samples Exceeded State or Federal Water Quality Standards or Action Levels for the 1991 and 1993 Lower Columbia River Reconnaissance Surveys.





Analytes	Number of Stations Where Reference Levels Were Exceeded	
	1991	1993 [c]
CONVENTIONALS		
Chlorophyll a	0	5
Dissolved Oxygen	5	1
Dissolved Oxygen (% Saturation)	11	2
pH	0	8
Temperature	0	4
INDICATOR BACTERIA		
E. coli	d	0
Enterococcus	6	0
Fecal Coliform	3	3
METALS		
Total Recoverable Aluminum	11	15
Total Recoverable Cadmium	3	0
Total Recoverable Copper	7	1
Total Recoverable Iron	4	1
Total Recoverable Lead	21	3
Total Recoverable Mercury	0	1
Total Recoverable Selenium	3	0
Total Recoverable Silver	0	1
Total Recoverable Zinc	3	0
ORGANIC COMPOUNDS		
Bis(2-ethylhexyl)phthalate	2	d
Total Number of Stations Sampled	45 (6) [e]	15

1991 Water Sampling Results

1993 Water Sampling Results

a Indicator Bacteria Sampling Locations Exceeding Washington State Fecal Coliform Criteria for the Protection of Human Health

b Bacteria Sampling Locations Exceeding U.S. EPA Criteria

c Exceedances based on comparison to the average (geometric mean for indicator bacteria) of the three field replicate samples collected in 1993.

d Not Sampled

e Six Stations Were Sampled for Indicator Bacteria and Organic Compounds

E Exceeded U.S. EPA Freshwater or Marine Chronic Water Quality Standards for the Protection of Aquatic Life

O Exceeded Oregon State Freshwater or Marine Chronic Water Quality Standards for the Protection of Aquatic Life

W Exceeded Washington State Freshwater or Marine Chronic Water Quality Standards for the Protection of Aquatic Life

▲ 1991 Water Column Sampling Stations (45 Sites)

◆ 1993 Areas Sampled for Water (15 Sites)

(T) 1991 Water Transect

T-Pb Total Recoverable Lead

D-Pb Dissolved Lead

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- **Nutrients**—Suitable measurements were available for 1993 only. The concentrations of phosphorus and nitrogen were high enough in 1993 to cause nuisance levels of phytoplankton if other conditions (e.g., light and water residence time) are suitable.

- **Chlorophyll** ***a***—Measurements were made only in 1993. Oregon's action level for chlorophyll *a* (a surrogate measure of phytoplankton biomass) was exceeded at 5 of 15 stations in 1993.

- **Dissolved Oxygen**—Minimum reference levels were not met at a few stations from the Portland/Vancouver area to the mouth of river in both surveys. The worst exceedances were observed below Skamokawa Creek (RM 32.5) and in Burke Slough (RM 81) (see Figure 13).

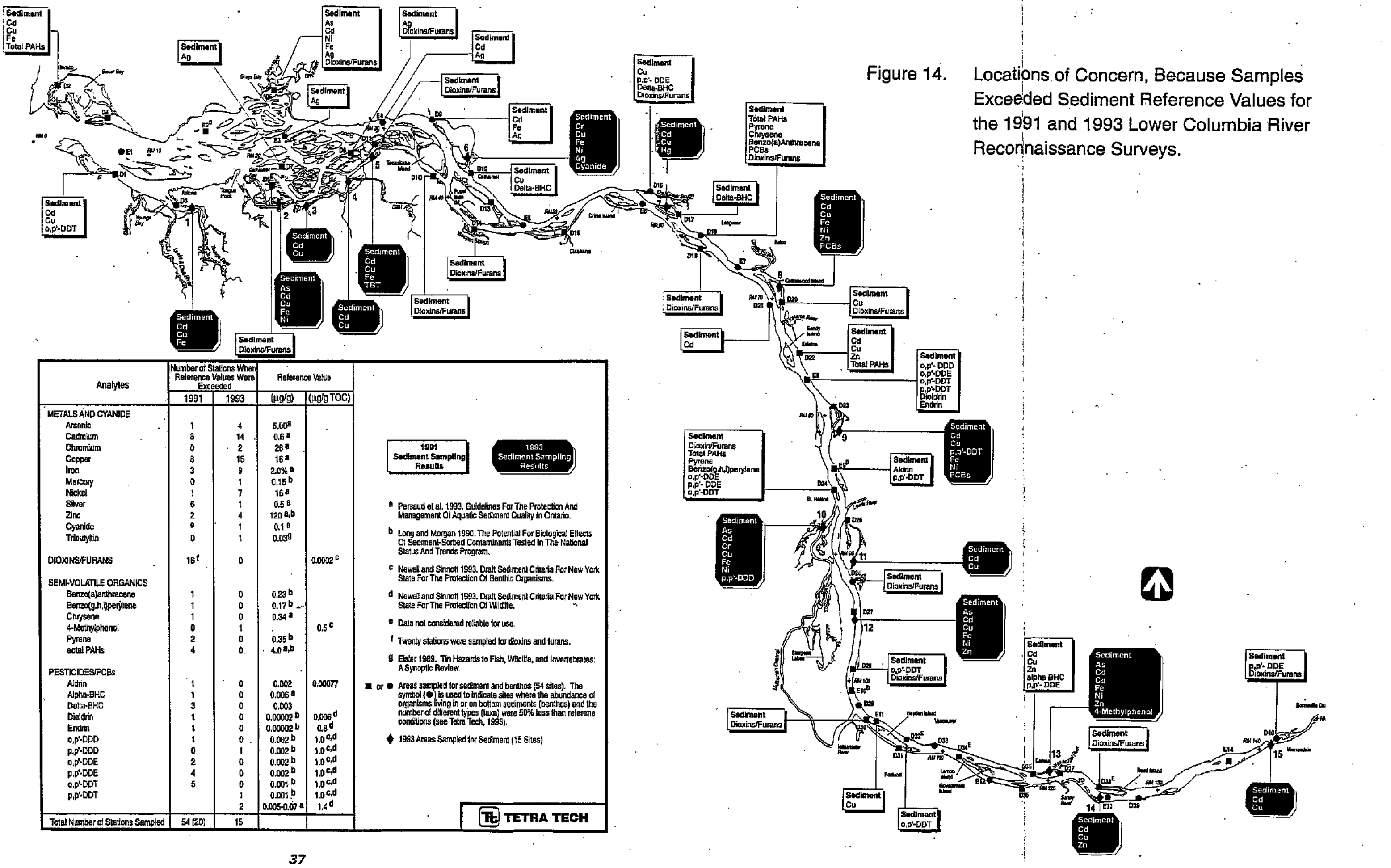
- **Trace Metals**—Reference levels were exceeded for aluminum, iron, cadmium, copper, lead, selenium, zinc, and silver. Copper and lead exceeded reference levels comparatively frequently, and deserve further evaluation. Additional testing is also recommended for silver and mercury due to difficulty in achieving the very low detection limits necessary for comparison with the reference levels (see Figure 13).

- **Bacteria**—The state standards for protecting human health (both for water contact recreation and shellfish harvesting) were exceeded, especially between Portland and Longview. Better monitoring and evaluation of appropriate indicators is needed.

2.3.3.2 Streambed Sediments. Streambed sediments can be good indicators of water quality because they can attract contaminants, integrating inputs over a period of time. Because of this concentration, contaminants in streambed sediment are also generally easier to detect than contaminants in water. However, reference levels for assessing the environmental significance of sediment contamination are still being refined.

Only trace metal concentrations were higher in the finer-grained backwater sediments (1993 survey) compared to the more open-water sediment stations sampled in 1991. These higher metals concentrations were generally due to the natural association of metals with finer-grained sediment, although some locations did appear to have elevated concentrations potentially related to human inputs. The expected higher concentrations of organic pollutants in backwater sediments were not observed in the 1993 survey.

Figure 14. Locations of Concern, Because Samples Exceeded Sediment Reference Values for the 1991 and 1993 Lower Columbia River Reconnaissance Surveys.



Analytes	Number of Stations Where Reference Values Were Exceeded		Reference Value	
	1991	1993	(µg/g)	(µg/g TOC)
METALS AND CYANIDE				
Arsenic	1	4	6.00[a]	
Cadmium	8	14	0.6[a]	
Chromium	0	2	26[a]	
Copper	8	15	16[a]	
Iron	3	9	2.0%[a]	
Mercury	0	1	0.15[b]	
Nickel	1	7	16[a]	
Silver	6	1	0.5[a]	
Zinc	2	4	120[a,b]	
Cyanide	e	1	0.1[a]	
Tributyltin	0	1	0.03[g]	
DIOXINS/FURANS	16[f]	0		0.0002[c]
SEMI-VOLATILE ORGANICS				
Benzo(a)anthracene	1	0	0.23[b]	
Benzo(g,h,i)perylene	1	0	0.17[b]	
Chrysene	1	0	0.34[a]	
4-Methylphenol	0	1		0.5[c]
Pyrene	2	0	0.35[b]	
ectal PAHs	4	0	4.0[a,b]	
PESTICIDES/PCBs				
Aldrin	1	0	0.002	0.00077
Alpha-BHC	1	0	0.006[a]	
Delta-BHC	3	0	0.003	
Dieldrin	1	0	0.00002[b]	0.006[d]
Endrin	1	0	0.00002[b]	0.8[d]
o,p'-DDD	1	0	0.002[b]	1.0[c,d]
p,p'-DDD	0	1	0.002[b]	1.0[c,d]
o,p'-DDE	2	0	0.002[b]	1.0[c,d]
p,p'-DDE	4	0	0.002[b]	1.0[c,d]
o,p'-DDT	5	0	0.001[b]	1.0[c,d]
p,p'-DDT		1	0.001[b]	1.0[c,d]
		2	0.005-0.07[a]	1.4[d]
Total Number of Stations Sampled	54 (20)	15		

[a] Persaud et al. 1993. Guidelines For The Protection And Management Of Aquatic Sediment Quality In Ontario.

[b] Long and Morgan 1990. The Potential For Biological Effects Of Sediment-Sorbed Contaminants Tested In The National Status And Trends Program.

[c] Newell and Sinnott 1993. Draft Sediment Criteria For New York State For The Protection Of Benthic Organisms.

[d] Newell and Sinnott 1993. Draft Sediment Criteria For New York State For The Protection Of Wildlife.

[e] Data not considered reliable for use.

[f] Twenty stations were sampled for dioxins and furans.

[g] Eisler 1989. Tin Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review.

■ or ● Areas sampled for sediment and benthos (54 sites). The symbol (●) is used to indicate sites where the abundance of organisms living in or on bottom sediments (benthos) and the number of different types (taxa) were 50% less than referene conditions (see Tetra Tech, 1993).

◆ 1993 Areas Sampled for Sediment (15 Sites)

- **Sediment Toxicity**—The sediments from the 15 backwater areas sampled in 1993 do not appear to be toxic as measured by amphipod and Microtox tests, with the possible exception of one station located in the estuary in Youngs Bay.

- **Benthic Community**—Approximately one half of the samples analyzed in 1991 for benthic community structure had reduced diversity compared to reference conditions. However, there were no significant correlations between concentration of contaminants and richness and abundance of taxa. Benthic community structure is more likely a function of physical habitat characteristics.

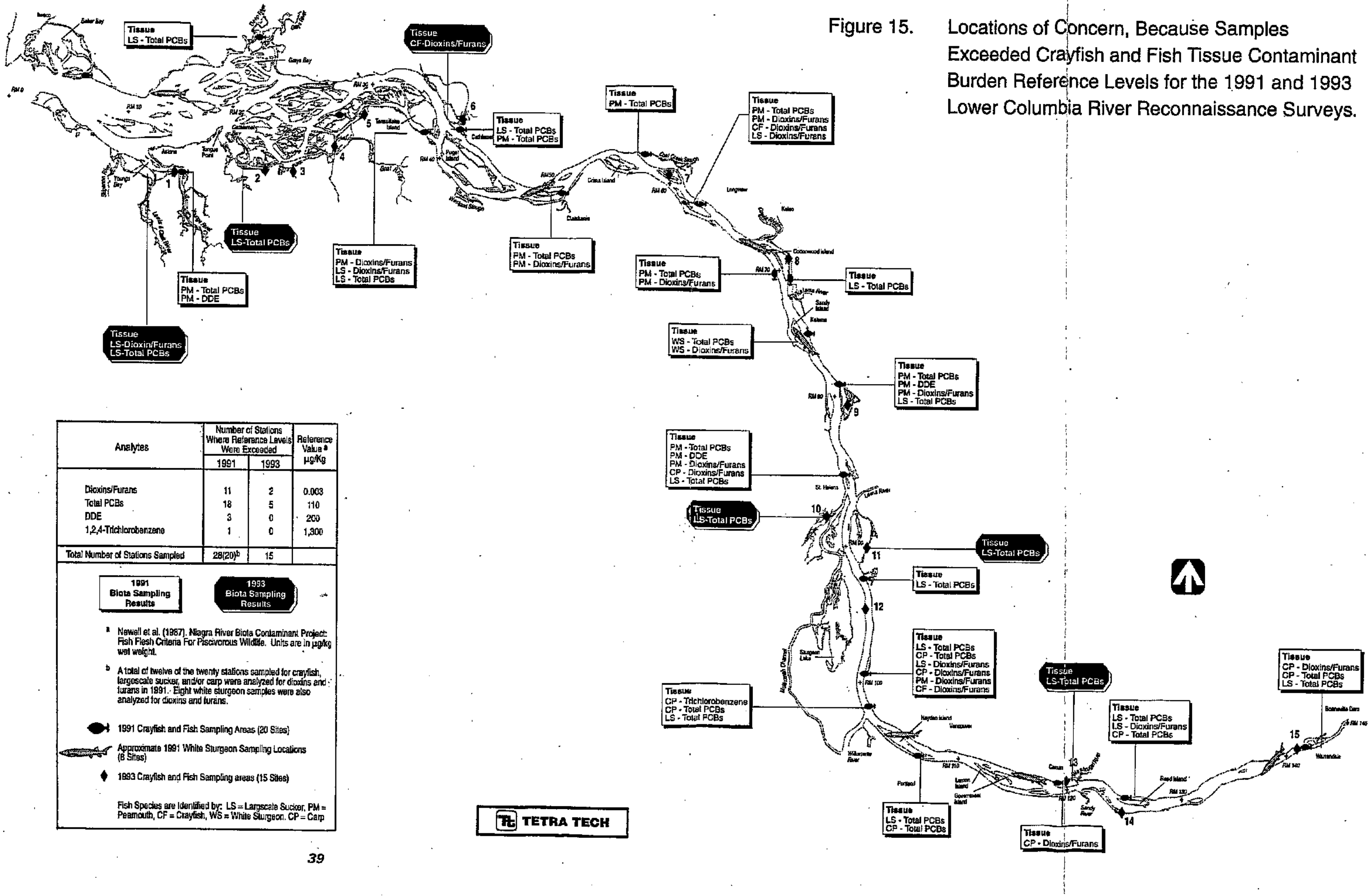
2.3.3.3 Fish/Crayfish. Contaminant levels in fish and shellfish tissue may also be good indicators of environmental quality because a number of contaminants tend to concentrate in aquatic biota and are, therefore, relatively easier to detect. These contaminants can be cause for concern because of the potential for adverse effects on the organisms themselves and on the people and wildlife species who eat them. For example, Anthony et al. (1993) have suggested that the relatively low breeding success of bald eagles in the Columbia River estuary may be due to the accumulation of DDT, PCB, and dioxin and furan compounds from contaminated prey species. However, the environmental significance of contaminants in aquatic biota is difficult to evaluate because reference levels for this kind of contamination are almost completely lacking. The reference levels used in the reconnaissance studies were for the protection of carnivorous fish and fish-eating wildlife. As indicated above, a risk assessment of human consumption of lower Columbia River fish and shellfish species was conducted as a separate study and is discussed in Section 2.5.1 of this report.

The following chemicals were found in excess of reference levels, or were frequently detected in the river (see also Figure 15 for greater detail):

- **Trace Metals**—Barium, cadmium, chromium, copper, lead, mercury, and zinc were frequently detected, with highest concentrations found in crayfish. The only available reference level (for selenium) was not exceeded.

- **Pesticides and PCBs**—Both DDT and its metabolites and PCBs were detected both surveys, mainly in whole fish. Concentrations of DDT and its metabolites were generally not above reference levels, but PCB levels exceeded reference levels at several sites in both years.

Figure 15. Locations of Concern, Because Samples Exceeded Crayfish and Fish Tissue Contaminant Burden Reference Levels for the 1991 and 1993 Lower Columbia River Reconnaissance Surveys.



Analytes	Number of Stations Where Reference Levels Were Exceeded		Reference Value[a] µg/Kg
	1991	1993	
Dioxins/Furans	11	2	0.003
Total PCBs	18	5	110
DDE	3	0	200
1,2,4-Trichlorobenzene	1	0	1,300
Total Number of Stations Sampled	28(20)[b]	15	

1991 Biota Sampling Results

1993 Biota Sampling Results

[a] Newell et al. (1987). Niagra River Biota Contaminant Project: Fish Flesh Criteria For Piscivorous Wildlife. Units are in µg/kg wet weight.

[b] A total of twelve of the twenty stations sampled for crayfish, largescale sucker, and/or carp were analyzed for dioxins and furans in 1991. Eight white sturgeon samples were also analyzed for dioxins and furans.

1991 Crayfish and Fish Sampling Areas (20 Sites)

Approximate 1991 White Sturgeon Sampling Locations (8 Sites)

1993 Crayfish and Fish Sampling areas (15 Sites)

Fish Species are Identified by: LS = Largscale Sucker, PM = Peamouth, CF = Crayfish, WS = White Sturgeon, CP = Carp

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- **Dioxins and Furans**—These compounds were detected frequently in 1991, but less frequently and at lower levels in backwater locations in 1993. Exceedances in 1991 were 11 of 20 samples; in 1993, 2 of 15 samples. These compounds were most frequently detected in whole fish and less frequently in crayfish.

- **Butyltins**—Measurements were only made in 1993. These compounds were frequently detected in fish, especially in the estuary (butyltins were formerly used in marine paints). No reference levels were available for comparison.

- **Radionuclides**—Measurements were only made in 1993. Plutonium 239/240 and cesium 137 were frequently detected in whole fish, but not in crayfish. No reference levels were available for comparison.

2.3.4 Reconnaissance Survey Recommendations

Recommendations based on the results of the two reconnaissance surveys (Appendix A, Section 2.2) included:

- Sample both sediments and biota, in addition to water in future studies. The importance of sampling all media was shown by the fact that PCBs were not detectable in water using standard laboratory methods, were rarely detected in sediments, but were frequently detected in fish tissue samples above reference levels, indicating potential adverse effects to fish-eating wildlife.

- Although backwater areas should continue to be tested and monitored as part of an overall program of river monitoring, this study did not find justification for focusing special attention on these areas at the exclusion of other river habitats.

- Focus attention on areas near and downstream of urban and industrial areas.

- Focus future water column sampling for metals on copper and lead, and assess the potentially toxic forms and concentrations of these metals. Assess mercury and silver concentrations in water with more sensitive laboratory methods.

- Continue to measure sediment variables such as grain size distribution and organic carbon content in future studies, because these variables can provide valuable insight into the distribution and potential toxicity of measured contaminants.

- Sample aquatic biota and terrestrial animals that feed on aquatic biota in order to determine bioconcentration [uptake of contaminants (minus elimination) directly from water to organism only], bioaccumulation (uptake of contaminants by organisms via food and water), and biomagnification factors. These issues should be incorporated in this bullet statement."

2.4 BASELINE STUDIES

Baseline studies were designed by various Bi-State work groups using recommendations made following completion of the reconnaissance surveys. The baseline studies chosen by the Bi-State Program were grouped into the following categories:

- Ambient Monitoring Study
- Pollutant Work Assignment Study
- Fish and Wildlife Studies
- Human Health Study.

Work Groups were formed to direct the work conducted for each study category. The study objectives, main conclusions, and recommendations of these studies are described below (see Appendix A, Section 3.0).

2.4.1 Ambient Monitoring Study

The ambient monitoring study was conducted in 1994 by the U.S. Geological Survey (USGS) with assistance from the Washington Department of Ecology and the Oregon Department of Environmental Quality. Its purpose was to assess ambient water quality conditions and contaminant loads from the upper river and from lower river tributaries (Fuhrer et al. 1995). The goals of this study were to define existing water quality conditions, characterize water quality problems by magnitude and type, and provide a basis for designing and operating pollution prevention, pollution abatement, and resource management programs. Ambient monitoring programs should also evaluate the effectiveness of existing programs for controlling pollution and detecting water quality trends. If water-quality problems are identified, the monitoring program should provide data for evaluating management options, initiating corrective actions, evaluating the effectiveness of these actions, and making refinements to the corrective actions if necessary. The goals of the Bi-State Program ambient monitoring study included four specific tasks:

- Assess the temporal variation of water-quality constituents in water (filtered water for trace elements, including metals and organic compounds; unfiltered water for conventional variables) and suspended sediment (trace elements only).

- Assess the suitability of surface water for maintaining aquatic life and protecting human health.

- Assess the contribution of major subbasins (Cowlitz and Willamette River basins) to the measured instream loads of selected water quality constituents in the Columbia River.

- Assess long-term trends in constituent concentrations for stations with adequate historical data.

Additional goals included:

- Collect quality-control data for interagency comparisons of data among USGS, Oregon Department of Environmental Quality, and Washington Department of Ecology.

- Produce an interpretive report to include analysis of current and historical water-quality data collected in the lower Columbia River basin (Fuhrer et al. 1995).

The ambient monitoring study included collecting water quality data [water temperature, dissolved oxygen, pH, specific conductance, suspended sediment, field alkalinity, major ions, nutrients, organic carbon, fecal-indicator bacteria (fecal coliform, enterococcus, and fecal streptococci), chlorophyll *a*, trace elements, adsorbable organic halides (AOX), and pesticides] at four main-stem stations and six tributary stations, plus daily mean streamflows at the four main-stem stations.

Sampling was conducted at these mainstem stations by the USGS:

1) Columbia River at Warrendale (RM 141)

2) Columbia River at Vancouver (approximately RM 101)

3) Columbia River between St. Helens and the confluence with the Cowlitz River (approximately RM 85)

4) Columbia River at Beaver Army Terminal (RM 53.8)

Sampling was conducted by U.S.G.S., ODEQ, and Ecology at the following tributary stations:

1) Sandy River
2) Willamette River at Portland
3) Multnomah Channel near mouth
4) Lewis River
5) Kalama River
6) Cowlitz River

Sampling at these stations supplemented data collected as part of the USGS National Stream Quality Accounting Network (NASQAN) and National Water Quality Assessment (NAWQA) programs. Sampling for field-measured and conventional variables (temperature, specific conductance, dissolved oxygen, pH, alkalinity, suspended sediment, and chlorophyll *a*) was conducted monthly and during high flows. Quarterly water-column samples were also collected to measure the concentrations of dissolved and suspended trace elements, organic carbon, and dissolved pesticides. Samples for these analyses were collected during winter-storm high flow (December-April), winter base flow (March-April), spring snow-melt high flow (April-June), and summer low flow (July-September).

The overall findings of the first year of the ambient monitoring study included the following:

- The Washington standard for water temperature (20° C) was exceeded consistently at the mainstem stations during July and August, coincident with seasonal high air temperature and low stream flow. Significant historical upward trends in water temperature were noted for the Columbia River at Warrendale and the Willamette River at Portland.

- No samples were below the minimum dissolved oxygen standards (90 percent saturation, 8 mg/L) at the mainstem stations sampled. Historically, less than 25 percent of recorded results have been below the standard.

- No exceedances of the 120 percent total dissolved gas standard (based on a current variance from the 110 percent standard) were noted in the ambient monitoring survey data. Historically, the highest concentrations of total dissolved gas occur from April through July. Relatively high values in July and August 1994 occurred because of increases in spilled water to aid the outmigration of anadromous fish.

- No significant historical trends were noted in suspended sediment concentrations. Suspended sediment load calculations suggest that seasonal deposition and resuspension of suspended sediments may be occurring in the lower river.

- The Willamette River is a significant source of nutrients to the lower Columbia River. Measurements taken above the lower river tributaries (Warrendale, RM 141) show a significant historical downward trend in the concentrations of total phosphorus, total dissolved solids, and specific conductance.

- Median trace element concentrations were similar to background concentrations measured in inland waters throughout the U.S. and the world. However, dissolved arsenic concentrations exceeded water quality criteria for the protection of human health in 15 of 16 samples collected from four sites in the Columbia River. Dissolved chromium was frequently detected, but not at levels exceeding water quality criteria. Exceedances were noted for dissolved mercury, but these concentrations were suspected of bias due to field or laboratory contamination.

- Arsenic, chromium, and copper were transported primarily in the dissolved phase, and aluminum, iron, and manganese primarily in the suspended phase. Zinc was predominantly in dissolved form at low flow, and in suspended form at high flow. The Willamette River is an important contributor of aluminum, iron, manganese, and silver; the Cowlitz River is an important contributor of aluminum, antimony, and nickel. The Yakima River was an important contributor of arsenic.

- Twenty of the 47 measured pesticides were detected at least once. Pesticides were detected at seven of the ten stations sampled. All twenty of the detected pesticides and some of the highest concentrations were measured at the Portland station on the Willamette River. None of the pesticides tested for were detected in the Sandy, Kalama, or Cowlitz rivers. Atrazine, a triazine herbicide, was the most frequently detected compound, followed by metolachlor and simazine. The Willamette River was an important contributor of atrazine.

The USGS report summarized the technical information gathered as part of the Bi-State Program, and included a presentation to water quality managers designed to assist them in identifying water quality problems and issues affecting beneficial uses (Fuhrer et al. 1995). This summary was also intended to help in designing future data collection efforts. The USGS suggested that if all basic water-quality data were stored in one database, these data would be more accessible to the public and to Federal, State, local, and tribal agencies (Fuhrer et al. 1995). A conceptual framework for designing and implementing conceptual water quality mass balance models was also provided, as a basis for designing and refining water quality monitoring programs.

The USGS recommended that the following be given immediate consideration (Fuhrer et al. 1995):

- Initiating coordinated inter-agency quality assurance/quality control programs to evaluate accuracy, precision, bias, and contamination issues.

- Supplementing the Bi-State Program database with other water quality data, including data on land and water use, precipitation quantity and quality, contamination from point and nonpoint sources, and the quantity of fertilizers and pesticides used in the basin.

- Supplementing the Bi-State Program database with data from ongoing water quality programs managed by other agencies (e.g., U.S. Army Corps of Engineer's measurements of river flow at Bonneville Dam, and of total dissolved gas, dissolved oxygen, water temperature, and atmospheric pressure along the lower river).

Overall, the USGS concluded that the proposed NASQAN 1995 sampling in the lower Columbia River basin should continue ambient monitoring activities conducted under the Bi-State Program in 1994 (Fuhrer et al. 1995). This program will sample every other month at the Columbia River near Beaver Army Terminal and at the Willamette River at Portland. Sampling frequency at these stations will likely increase during certain times of the year to evaluate the effects of various land use activities (e.g., agricultural pesticide application).

2.4.2 Pollutant Work Assignment Study

The goal of this work assignment was to provide additional data on specific problem areas, groups of pollutants, and probable sources of contaminant levels detected during the reconnaissance surveys. Studies were designed to confirm contaminant problems identified from single samples collected from isolated locations, determine the extent of contaminant problems at "hot spot" locations (locations where more than one sample or contaminant indicated potential problems), and attempt to trace the sources of "hot spot" contaminants identified during the reconnaissance surveys. This work was begun as a baseline study and continued as an advanced study (see Appendix A, Section 3.2).

2.4.3 Fish and Wildlife Studies

The following baseline studies (Appendix A, Section 3.3) were conducted to address the effects of contaminants and habitat loss on the fish and wildlife of the lower Columbia River:

- Fish and wildlife literature review
- Fish health assessment
- Fish enzyme activation study
- Mink and river otter study
- Contaminant study of bald eagle eggs
- Geographical Information System (GIS) and maps of historical and existing wildlife habitat.

2.4.3.1 Fish and Wildlife Literature Review. The first task the Fish and Wildlife Work Group undertook was compiling and synthesizing existing information on fish and wildlife of the lower Columbia River (Columbia Basin Fish and Wildlife Authority/WILD Systems 1996). The goal of this task was to identify data gaps and make recommendations for future fish and wildlife studies (Appendix A, Section 3.3.1).

The fish and wildlife literature review focused on the following species, representative of various trophic levels in the lower Columbia River:

- Freshwater phytoplankton (*Asterionella formosa*)
- Estuarine zooplankton (*Eurytemora affinis*)
- Freshwater tube-dwelling amphipod (*Corophium salmonis*)
- Anadromous juvenile chinook salmon (*Onchorhynchus tshawytscha*)
- Bottom-feeding freshwater fish [largescale sucker (*Catostomus macrocheilus*)]
- Mink (*Mustela vison*)
- River otter (*Lutea canadensis*)
- Bald eagle (*Halieetus leucocephalus*).

For each of these species, the literature review examined habitats, life histories, feeding habits, population dynamics and trends, and the extent and effects of contaminant accumulation.

For largescale sucker, mink, otter, and bald eagle, the literature review also assessed the role of habitat alteration in population declines and dynamics of the food web. This literature review is a valuable resource for any future studies that focus on these key species and their interrelationships.

2.4.3.2 Fish Health Assessment. The two main objectives of the fish health assessment (Appendix A, Section 3.3.2) were to:

- Characterize the health of fish assemblages and resident indicator fish species in the lower Columbia River.
- Draw conclusions, if possible, about the impacts of water quality and/or habitat loss on fish health in the lower Columbia River.

Fish health was characterized by applying the following three biological assessment techniques:

- Fish community assessment based on the Index of Biotic Integrity (IBI) (Karr et al. 1986) and U.S. EPA Rapid Bioassessment Protocol V (RBP V) (Plafkin et al. 1989).
- Autopsy-based fish health/condition assessment of largescale sucker (Goede 1993) and Health Assessment Index (HAI) procedure outlined by Adams et al. (1993).

- Juvenile fish skeletal abnormality assessment.

The fish health assessment study was designed to characterize fish health and community differences among three habitat types (main channel, urban/industrial, and backwater) and the following four major river segments, which are based on physical and hydrologic characteristics:

- Segment 1 (37 river miles) — from the mouth to Tenasillahe Island
- Segment 2 (35 river miles) — from Tenasillahe Island to the Cowlitz River
- Segment 3 (30 river miles) — from the Cowlitz River to the Willamette River
- Segment 4 (44 river miles) — from the Willamette River to Bonneville Dam.

Due to delays in issuing fish collection permits for endangered salmon species, sampling was conducted much later in the year than proposed in the sampling plan (December rather than late summer/early fall). This delay resulted in smaller catches of fish (at some stations no fish were captured) than in previous surveys on large river systems which employed similar methods (e.g., Hughes and Gammon 1987; Sanders 1992; Tetra Tech 1995). These other surveys were conducted in late summer or early fall. It is likely that many Columbia River resident fish species are more easily captured during the warmer months when they are more active (see Appendix A, Section 3.3.2).

Fish Community Assessment. The effects of habitat on fish community could not be tested because not enough fish were caught in some habitats to calculate a meaningful IBI value. In addition, habitat type stations yielding enough fish for IBI calculation were unevenly distributed among the river segments. It was possible, however, to test the effects of river segment and habitat type by pooling data from several stations. No fish were collected from river segment 1, so the effects of this segment could not be tested. The results of analysis of variance (ANOVA) tests on the pooled data indicated no significant effect of habitat on IBI scores. IBI scores from river segment 3 were significantly lower (indicating poorer community health) than the IBI scores from river segments 2 and 4. River segment 3 had more frequent exceedances of reference levels for pollutants in water, sediments, and tissues than did segments 2 or 4. This may partly explain the lower IBI scores.

Fish Autopsy Assessment. It was not possible to test the effects of habitat type with this technique because an insufficient number of largescale suckers were captured at main channel stations. The Health Assessment Index (HAI) scores for the urban/industrial stations were significantly lower (indicating better condition) than the HAI scores for backwater stations. However, all mean HAI scores from this study were lower than at sites known to be associated with chemical contamination (Adams et al. 1993). Analysis of water, sediments, and tissue collected near fish health stations during the reconnaissance surveys did not indicate a higher degree of contamination at either urban/industrial or backwater habitats.

Juvenile Fish Skeletal Abnormality Assessment. The effects of river segment on the incidence of skeletal abnormalities could not be tested for any single species due to the small number of fish captured in river segments 3 and 4. Also, due to the delay in sampling, very few small juvenile fish were captured. Overall, the incidence of skeletal abnormalities was very low (less than 2.3 percent) for all species and river segments. There did not appear to be any meaningful relationship between river segment and overall incidence of abnormalities. Using the limited data available, the incidence of skeletal abnormalities was compared with contaminant level data; no meaningful relationships were observed. This lack of a statistical relationship could be due to 1) the overall low incidence of skeletal abnormalities, 2) the timing of sampling, 3) the use of species (e.g., three-spine stickleback) whose response to stressors is unknown, and 4) the larger size of the fish examined in this study (due to the timing of sampling) compared to the range for which this assessment technique has been used. It is possible that many of the more deformed fish would have died or become prey by this time of year.

The utility of these three techniques for assessing fish health on the lower Columbia River and the relationship of fish health to habitat and contaminant concentrations cannot be fairly assessed until the sampling can be repeated during summer when juveniles of the target species are more likely to be captured in sufficient numbers for statistically valid comparisons.

2.4.3.3 Fish Enzyme Activation Study. The National Marine Fisheries Service (NMFS) conducted an assessment of exposure to polynuclear aromatic hydrocarbons (PAHs) in the same largescale suckers collected as part of the autopsy-based fish health/condition assessment described above (Collier et al. 1996). This was done by measuring cytochrome P4501A (CYP1A)-dependent enzyme activities (i.e., AHH, aryl hydrocarbon hydroxylase) and biliary levels of fluorescent aromatic compounds (FACs). Both CYP1A activities and FAC concentrations have been shown to be indicative of exposure to aromatic organic compounds. These PAH-exposure assessment methods have been developed and field tested by the staff of the Environmental Conservation Division of the Northwest Fisheries Science Center.

Analysis of variance (ANOVA) was performed on log-transformed data followed by Fisher's Protected Least Significant Difference (PLSD) test to determine if there were any significant differences among the sites sampled (significance level set at 0.05). No overall site differences were noted for levels of biliary FACs or hepatic CYP1A. Nor was there a significant linear relationship between individual measurements of bile and AHH activities. Many of the female fish showed signs of ovarian development, and significant sex differences were noted, with females having significantly lower AHH activity than males. In general, the largescale sucker data did not indicate marked exposure to PAHs. No significant between-site differences were noted for biliary FACs or hepatic AHH activities, and AHH activities were lower than previously reported values for other benthic fish in moderately and severely contaminated environments. However, the levels of biliary FACs were relatively high compared to reference levels measured in lower Columbia River white sturgeon upstream of an oil spill (Krahn et al. 1986). In the absence of adequate dose-response data for largescale sucker, the FAC data cannot be interpreted as showing evidence of exposure.

Problems encountered in the fish enzyme activation study led the researchers to recommend changes to improve future studies. Note that several of the suggestions address the difficulties in collecting suitable numbers of fish caused by the fish collection permitting delays described in Section 2.4.3.2 above. These suggestions are:

- *A priori* determination of suitable reference sites for comparison.
- Sampling earlier in the year to avoid sampling females undergoing gonadal maturation.
- Collection of fish from main channel locations to determine if these sites are suitable as reference sites.
- Collection of more fish and fish of both sexes at each site.
- Chemical analyses of stomach contents and surficial sediments to determine the presence of PAHs in the fish's habitat.

2.4.3.4 Mink and River Otter. In late summer of 1994 and winter of 1994-95, the National Biological Service (NBS) undertook an assessment of mink and river otter habitat, body condition, and contaminant concentrations (Henny et al. 1996). Eight random 9-mile strata along the lower Columbia River were evaluated for mink and river otter abundance and habitat condition. The habitat assessment was based on a slightly modified form of the habitat suitability index (HSI) developed by Allen (1986).

During the winter, licensed fur trappers were contracted to provide skinned frozen mink and river otter carcasses trapped along the lower Columbia River [within approximately 400 m (1,310 ft) of the river] between RM 11.0 and 119.5 for necropsy, tissue histopathology, and contaminant analysis. A few mink and river otter scats were also collected in the study for analysis. In addition, reference mink and river otter carcasses and scats were collected in Idaho and Oregon and analyzed for comparison with the study results for the lower Columbia River. Canine teeth were extracted from all animals for aging.

A total of 30 river otter (*Lutra canadensis*) were collected from the Columbia River between RM 11.0 and 119.5. Six otter were collected from a reference area located in the Coast Range of Oregon. Two mink (*Mustela vison*) were collected from the lower Columbia (both in the vicinity of RM 88) and four reference mink were collected at Malheur National Wildlife Refuge in eastern Oregon. Mesentery fat and livers from the animals were analyzed for 20 organochlorine pesticides and their metabolites, 43 non-orthosubstituted PCB congeners, PCB Aroclors, and 15 dioxin and furan compounds. Liver and kidney from the same animals were analyzed for 10 metals (aluminum, cadmium, chromium, copper, lead, manganese, mercury, nickel, vanadium, and zinc). River otter scats were pooled into five samples representing several animals at each location along the Columbia River between RM 27 and 134. Reference area scats were collected from the Wizard Falls Fish Hatchery on the Metolius River in central Oregon and along the Clearwater River in northern Idaho.

The concentrations of organochlorine compounds (PCBs, pesticides, dioxins, and furans) were generally higher in livers from all age classes of Columbia River otter and mink compared to reference area samples. A pattern of increasing concentration of pesticides and PCBs with age in river otter was apparent although not all increases were statistically significant. No significant differences were noted between Columbia River and reference area river otter liver and kidney concentrations of chromium, copper, iron, manganese, mercury (liver only), and vanadium. Zinc concentrations in liver and kidney from Columbia River otters did not increase with age, but the concentration in male kidneys, age class 2+, was higher for the reference area than for the lower Columbia River. Although cadmium concentrations increased significantly with age in liver and kidney of river otter from the Columbia, the concentrations measured were similar to those measured in reference area organs. Statistical comparisons were not possible for aluminum and lead because of the infrequent detection of these metals, but the highest concentrations of these metals were measured in river otter collected from RM 119.5. This location is near a large aluminum refining facility in Oregon and a pulp and paper mill in Washington. Metal concentrations in the few mink showed no obvious differences between Columbia River and reference area samples, with the possible exception of nickel which was relatively higher in kidney collected from Columbia River mink. River otter scat contaminant concentrations from the two reference areas were always lower than the Columbia River sample from RM 87-108, but similar to or lower than the lowest Columbia River sample concentration, taken from RM 27.

Contaminant concentrations in river otter were evaluated as a function of RM of capture for age classes 0, 1, and 2+ to evaluate the spatial distribution of contamination. Significant linear regression coefficients were rarely found for pesticide and Aroclor PCB concentration as a function of RM for age class 0 (DDE and DDD), never correlated with RM in age class 1, but almost always correlated with RM in age class 2+. In all cases tissue contaminant concentrations decreased from RM 119.5 (just above the Portland-Vancouver area) to RM 11.0. This significant relationship for age class 2+ animals is consistent with their life history. The lack of correlations in age class 0 may be due to lower concentrations in young animals. Age class 1 animals are typically dispersers and wanderers that may have been collected far from their place of birth. After year two, river otters establish a home range and become more sedentary. Some significant relationships were found for non-orthosubstituted PCB, dioxin, and furan concentrations with RM. Two coplanar PCBs [PCB-126 (3,3',4,4',5-PCB) and PCB-169 (3,3',4,4',5,5'-PCB)], two dioxins (1,2,3,7,8,9-HxCDD and OCDD), and several furans (2,3,4,7,8-PCDF, total PCDF, 1,2,3,4,7,8-HxPCDF, 1,2,3,6,7,8-PCDF, and total HxPCDF) showed significant correlations with RM, with the highest concentrations measured at the upstream sampling location in the Portland-Vancouver area. Age class 1 (the dispersers) showed the opposite relationship with RM for 2,3,7,8-TCDF and total TCDF. Known PCDD and PCDF point sources exist downstream from Portland-Vancouver. The general pattern of contaminant concentrations in river otter scat was consistent with the trend with river mile noted above, but relatively lower concentrations were noted in scat collected from RM 134 (upstream from Portland-Vancouver), above the area near RM 119.5 where many of the highest river otter tissue contaminant concentrations were measured.

Necropsy and histopathology results indicated a number of significant statistical relationships with contaminant concentrations in tissues. For example, hepatic effects were noted that were possibly related to PCB contamination. Baculum (penis bone) length and weight of Columbia River age class 0 river otters was significantly different (smaller or shorter) than reference area animals of the same age class. Mean testes weight was also smaller for lower Columbia River vs. reference area specimens, although the difference was not statistically significant. Histopathological study of the testes also identified differences at the cellular level. Reproductive organs of all young males from the Columbia River were adversely affected, but organs of older males did not show significant size differences when compared to reference area animals, suggesting that developmental problems (endocrine disruption) may be temporary. It is not known of if older male's reproductive organs were functioning normally. Concentrations of organochlorine insecticides, PCBs, and to a lesser extent PCDDs and PCDFs in the liver of river otters were highly correlated with each other and many were significantly related to baculum and testes size or weight. Young river otters from the Columbia River represent the first free-living mammal population showing dose-response (xenobiotics and measured in the liver) hypoplasia of male reproductive organs.

In general, the river otters collected from RM 119.5 had the highest tissue contaminant levels, and some metals (i.e., aluminum and lead) that were seldom found elsewhere. Three of the four river otters collected from this location showed a number of gross abnormalities, including a missing kidney and adrenal gland, a multilocular cystic abscess, and no testes in one young male.

The results of the mink HSI scores indicated that the suitability of habitat for mink in many areas assessed was excellent. However, very few mink were found and although no population estimate could be made the population is clearly very low. The authors' best estimate of the river otter population was 286 (±47) animals with no evidence of fewer animals in the area of highest tissue contaminant concentrations. This is the highest published estimate of river otter density in North America, although estimates of river otter density in other similar habitats (large rivers) were not available.

Comparison to historical tissue contaminant data on mink and river otter of the lower Columbia River collected over 15 years ago (Henny et al. 1981) indicates a major decline in PCB concentrations over time. Historically, some individual mink contained PCB concentrations known to make adult female mink in laboratory studies incapable of producing young. The environmental significance of the current contaminant levels measured in tissue and scat samples from mink and river otter in the lower Columbia River was assessed by comparing these data to effects-based contaminant reference levels developed by other investigators. Although the two mink contained contaminant levels below threshold effects concentrations, some river otter contained concentrations that exceeded threshold and even critical levels in tissue or levels of concern in scat. However, these reference levels may not be appropriate for river otter. The reference levels for tissue were developed for mink, which are generally considered extremely sensitive to PCBs, dioxins, furans, and other dioxin-like compounds. The levels of concern for scat concentrations were derived for European otter (*Lutra lutra*), a related species of unknown sensitivity compared to *Lutra canadensis*.

The authors conclude that river otter in the vicinity of RM 119.5 are in a critical or almost critical category based on reference level comparisons, abnormalities noted during necropsy, and histopathological observations of individuals collected from this area. The authors hypothesize that the few relatively uncontaminated mink sampled during the study may be individuals that have recently entered the lower Columbia River in attempt to recolonize.

Several future research areas are proposed. Animals were not live-captured in this study which eliminated the option of collecting blood to evaluate steroid concentrations, as well as the option for histopathology of unaltered (non-frozen) organs and tissue. Additional research is planned with trapper-caught and live-captured animals from the Columbia River and elsewhere throughout the Pacific Northwest and includes further studies with the contaminants initially investigated plus other known endocrine disrupters (e.g., alkylphenols, phthalate esters). This research will emphasize a general evaluation of health, hormone concentrations, hormone receptor characteristics, and sperm counts and quality. The addition of river otters from other locations with differing contaminant combinations will allow further evaluating of contaminants that not appear to be related to the observed reproductive organ hypoplasia in young males, and future evaluation of the distribution and magnitude of the problem in the Northwest.

It is suspected that the observed hypoplasia is temporary because 1) all you males sampled from the Columbia River had hypoplastic reproductive organs, and 2) reproductive organs of adult males appeared normal in size. Unless all adults currently living the Columbia River were produced outside of the system, a scenario which seems unlikely, there appears to be no other conclusion. Tracking young male river otter using radio-telemetry could provide information on movement patterns, survival, and organ development (e.g., are young males remaining within the Columbia River system with baculums and testes eventually attaining normal size?).

2.4.3.5 Contaminant Study of Bald Eagle Eggs. The U.S. Fish and Wildlife Service initiated a two year study in 1994 with partial funding from the Bi-State Program to assess bald eagle nesting success and contaminants in bald eagle eggs found along the lower Columbia River (U.S. Fish and Wildlife Service 1996). Previous studies have indicated that although the number of nesting pairs of bald eagles along the Columbia River estuary has increased each year since 1980, the five-year average productivity has been about half that of the state-wide averages for bald eagles nesting in Oregon and Washington (Isaacs and Anthony 1993). During studies conducted in 1986, 1987, and 1991, elevated concentrations of PCBs, DDE, and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) were found in bald eagle eggs collected near the river (Anthony et al. 1993). Elevated concentrations of PCBs and DDE were also measured in blood obtained from eight- to ten-week-old nestlings and eagle carcasses collected near the river (Garret et al. 1988; Anthony et al. 1993). Prey items (primarily fish) collected from the river also had detectable concentrations of DDE, PCBs, and other chlorinated organic compounds (Anthony et al. 1993). Concentrations of DDE, PCBs, and 2,3,7,8-TCDD in eggs were high enough to cause concern regarding possibly lowered breeding success. Eggshell thinning, commonly attributed to DDE, was prevalent in most eggs and shell fragments collected from eagles along the river. However, eggshell thinning in this case does not correlate with lowered breeding success.

Analyses of fresh and addled eggs collected in April and May 1994 indicate that concentrations of DDD, DDE, total PCBs, and hexachlorobenzene are lower than mean concentrations measured before 1988 (U.S. Fish and Wildlife Service 1995). However, the measured DDE and total PCB concentrations were still above levels associated with reduced productivity of bald eagles in other areas. The mean mercury residue level in these eggs was similar to the mean concentration found in 13 eggs collected along the river in 1985 to 1987. However, these levels did not exceed concentrations associated with adverse effects on bald eagle productivity. The concentrations of polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and individual PCB congeners were also higher than adverse effects levels in the 1994 sample.

The relative dioxin-like toxic contribution of these compounds was made by means of an additive model of toxicity using toxic equivalency factors (TEFs) and toxic equivalents (TEQs); both mammalian (I-TEF; Ahlborg et al. 1992) and avian (C-TEF; Bosveld et al. 1995) TEF models were used. This analysis indicated that much of the dioxin-like toxicity of PCDDs and PCDFs was due to 2,3,7,8-TCDD; 69 percent for the mammalian model and 40 percent for the avian model. Measuring the TEFs for PCB congeners indicated that PCB 118 (2,3',4,4',5-PCB) contributed the most dioxin-like toxicity (33 percent) in the mammalian model and PCB 126 (3,3',4,4',5-PCB) contributed the most toxicity (54 percent) in the avian model.

The H4IIE rat hepatoma cell bioassay was used to assess exposure to planar halogenated hydrocarbons (PHHs), a class that includes PCBs, PCDDs, and PCDFs. This bioassay was used to screen bald eagle eggs for total dioxin-like activity (i.e., 2,3,7,8-TCDD equivalents or TCDD-EQ). The potency of PHH mixtures in the H4IIE cells has been correlated to the hatching success in double-crested cormorants from the Great Lakes (Tillitt et al. 1992). The analyses conducted on tissue samples collected in 1994 indicated PHH levels comparable to less contaminated sites in the Great Lakes. However, the levels of PHHs that might cause early life stage toxicity in bald eagles is unknown at this time. Further analysis and assessment of TCDD-EQs will be conducted on eagle eggs collected in 1995.

Eggshell thinning has been associated with environmental contamination and with reduced reproductive success of birds. Eggshell thickness measured in 1994 and 1995 was generally less than the mean of eggs collected in the Pacific Northwest prior to the use of DDT, although one egg was 12 percent thicker than the pre-DDT average. Linear regression analysis indicated no significant relationship between breeding success and eggshell thickness among breeding pairs ($r=-0.06$, $n=19$, $P=0.79$) (U.S. Fish and Wildlife Service 1996).

The general trend in the annual mean concentration of DDD, DDE, total PCBs, and hexachlorobenzene concentrations in bald eagle eggs has been a decrease from concentrations measured in the lower Columbia River from 1985 to 1987. Five-year productivity (measured as the five-year running average number of young bald eagles per occupied territory) for the lower Columbia River region from 1993 to 1995 was higher than in any previous year assessed since 1984. This level of reproductive success is higher than predicted using a regression relationship between productivity and DDE concentration in bald eagle eggs. A number of nesting sites have been established by newly arrived breeding pairs since 1990. The youth and recent arrival of these birds could cause them to have lesser contaminant accumulations, explaining some of the equivocal relationships among productivity, eggshell thickness, and contaminant levels measured at these sites. Analysis of contaminant levels in eggs of newly established breeding pairs collected in 1995 will provide positive or negative evidence of this influence.

In summary, the relationship between organochlorine compounds and reproduction of bald eagles nesting along the lower Columbia has not yet been fully evaluated. Preliminary data indicate that eagles nesting along the river continue to accumulate levels of DDE and PCBs that impair reproduction. Data also indicate that eagles are accumulating PCDD and PCDF compounds, but additional information is needed to assess their relative contribution to overall toxic effects. No correlation was found between reproductive success and eggshell thickness, and reproductive success did not fit the prediction based on the measured concentration of DDE in eggs. The extent to which these equivocal findings are influenced by the presence of newly established nesting pairs that have not yet accumulated contaminants at levels that affect reproduction has not yet been determined. A complete analysis of five-year productivity averages, eggshell thickness, and contaminant levels will be included in the final USFWS report due in 1996.

2.4.3.6 GIS and Map of Historical and Existing Habitat. This mapping project was a large cooperative effort among state and federal agencies and other organizations involved in the Bi-State Program. It included the development of maps and a geographical information system (GIS) of historical and existing wetlands, riparian vegetation, and important and critical fish and wildlife areas within two miles of the mainstem of the lower Columbia River (U.S. ACOE 1996). The goals of this task were as follows:

- Compile existing wetland, riparian habitat, wildlife habitat, and fish habitat mapping data.
- Review historical and current aerial photos to define habitat changes through time.
- Expand existing GIS mapping of the Columbia River estuary to extend coverage up to Bonneville Dam.
- Prepare a report summarizing results of habitat mapping and identifying significant riparian and wetland habitats.
- Make updated and expanded GIS habitat map database available to agencies and public bodies.

These tasks were undertaken as separate work projects led by the Columbia River Estuary Study Taskforce (CREST) and the U.S. Army Corps of Engineers (U.S. ACOE). The CREST study team expanded the map coverage of historical (1851-1887) wetlands habitats of the estuary developed by Thomas (1983) (RM 0-46.5) to include the area of the river to RM 105 (RK 168) and a portion of the Willamette River (Graves et al. 1995). The U.S. ACOE developed PC ARC/INFO (computer-based mapping) data layers for a number of habitat types found within two miles (3.2 km) of the river mainstem (where possible) from aerial photographs taken in 1948, 1961, 1973, 1983, and 1991 (U.S. ACOE 1995). These data were analyzed to produce estimates of changes in the expanse of these habitats from 1948 through 1991. Habitat changes in the Columbia River Estuary (RM 0-46.5) between the 1880s and 1991 were also estimated. The U.S. ACOE study team identified significant undisturbed habitats and areas with the potential for habitat rehabilitation or enhancement. The database was expanded to include the 18 ft (5.5 m) water depth contour (believed to be important in delineating juvenile salmon habitat) and National Wetland Inventory maps developed by the U.S. Fish and Wildlife Service (USFWS). Additional information not yet appended to the existing GIS includes the federally authorized navigation channel, river mile markers, hydrography, political boundaries, major roads and rail lines, and state parks. The U.S. ACOE also surveyed 15 other state, regional, and federal resource management and mapping agencies and concluded that no other agency had mapping data that would be redundant to that produced for the Bi-State Water Quality Program. A brief summary of the study approaches and results from the CREST and U.S. ACOE studies is provided below.

Historical Habitats of the Lower Columbia River. The CREST study effort (Graves et al. 1995) was based on six U.S. Coast Survey charts published in 1870-1888. These charts were based on field surveys of the river from the mouth to Portland conducted in 1851-1887. Thomas (1983) used these charts to map seven habitat types in the estuary [river mouth to RM 46.5 (RK 74.4)]:

- Deep Water - Areas of water depth greater than 18 ft (5.5 m).
- Medium Depth Water - Areas of water depth between 6 and 18 ft (1.8-5.5 m).
- Shallows and Flats - Water depths of 6 ft (1.8 m) or less extending to the edge of tidal marsh or swamp vegetation or to mean higher high water (MHHW).
- Tidal Marshes - Emergent vegetation and low shrubs.
- Tidal Swamps - Shrub and forest dominated wetlands extending up to the line of non-aquatic vegetation.
- Non-tidal Water/Wetlands - Floodplain lakes and non-tidal emergent or forested wetlands.
- Upland-Uplands without wetland vegetation.

The maps developed by Thomas (1983) were converted to digital coverage in PC ARC/INFO. The habitat types above RM 46.5 to 105 (RK 74.4-168) were delineated by Christy and Putera

(1992) into 18 types using Thomas' (1983) types as coarse definitions. Two final work products were produced. The first was a complete PC ARC/INFO map and database of the seven habitat types (coarse definition) from the river mouth to Portland (Graves et al. 1995). The acreage of historical habitat types along the river from the mouth to Portland, estimated from the GIS system is as follows:

Habitat Type	Acres (Hectares)
Deep Water	54,100 (21,900)
Medium Depth Water	59,300 (24,000)
Tidal Marshes	25,600 (10,400)
Shallows and Flats	67,800 (27,400)
Tidal Swamps	11,500 (4,700)
Non-Tidal Water/Wetland	29,700 (12,000)
Uplands	19,600 (7,900)
Total	267,600 (108,300)

A second ARC/INFO map and database contained information on the 18 habitat types in the area from Puget Island (RM 46) to Portland (RM 105).

The percentage of the total area represented by each habitat type is given below:

Habitat Type	Percentage of Total Area
Water Shallow (6-18 ft)	22.16
Water Deep (>18 ft)	20.21
Flats and Shallows (<6 ft)	16.76
Tidal Marsh	9.56
Tidal Swamp	8.57
Riparian Forest	6.00
Prairie and Pasture	5.77
Floodplain Lake	2.39
Tidal Willow Swamp	1.59
Tidal Cottonwood Swamp	1.52
Emergent Marsh	1.42
Willow Swamp (no tidal influence)	1.29
Tidal Spruce Swamp	1.17
Upland	0.95
Oak and Fir Forest	0.50
Oak, Fir, Ash Savannah	0.08
Urban	0.03
Sand Bank Unvegetated	0.02

Expanded GIS Habitat Mapping. The U.S. ACOE study team reviewed aerial photographs dating back as far as 1929 to select five photographic record dates that would be most suitable for comprehensive coverage of the river from the mouth to Bonneville Dam. The dates selected were September/October 1948, November 1961, August/September 1973, September 1983, and September/October 1991. Habitats were then delineated using a hybrid system of two classification schemes: 1) the scheme developed for the U.S. ACOE study of riparian habitats and wildlife along the Columbia and Snake Rivers (U.S. ACOE 1976) and 2) the Cowardin classification scheme used for the USFWS's National Wetlands Inventory. The hybrid system included the following categories:

- **Barren Land (1):** Unvegetated sandy beaches, quarries, dunes, rock lands, etc. (At least 95 percent barren).
- **Open Water (2):** At least 6.6 ft (2 m) deep. Further sub-classifications are possible and include marine subtidal (2Ms), marine intertidal (2Mi), estuarine subtidal (2Es), estuarine intertidal (2Ei), riverine tidal (2Rt), riverine lower perennial (2Rl), riverine upper perennial (2Ru), lacustrine limnetic (2Ll), lacustrine littoral (2Lt), palustrine (2P).
- **Grassland (3):** At least 95 percent grassland.
- **Wetland/Marsh (4):** Tidal and non-tidal, cattail, sedge, grass, salt or freshwater marsh, and water shallow enough to support emergent marsh vegetation [less than 6.6 ft (2 m) deep]. Further subclassifications are possible and include marine subtidal (4Ms), marine intertidal (4Mi), estuarine subtidal (4Es), estuarine intertidal (4Ei), riverine tidal (4Rt), riverine lower perennial (4Rl), riverine upper perennial (4Ru), lacustrine limnetic (4Ll), lacustrine littoral (4Lt), palustrine (4P).
- **Shrub/Scrub (5):** At least 95 percent shrub/scrub.
- **Savanna-like (6):** Grassland with less than 25 percent scattered trees.
- **Coniferous Forest, Low (7L):** Forest density between 26 and 70 percent cover.
- **Coniferous Forest, High (7H):** Forest density greater than 70 percent cover.
- **Broadleaf Forest, Low (8L):** Forest density between 26 and 70 percent cover.
- **Broadleaf Forest, High (8H):** Forest density greater than 70 percent cover.
- **Mixed Forest, Low (9L):** Greater than 20 percent mixed with low (26-70 percent cover) forest density.
- **Mixed Forest, High (9H):** Greater than 20 percent mixed with high (greater than 70 percent cover) forest density.
- **Agricultural Land (10):** Field crops, orchards, and pasture.

- **Urban/Developed (11):** Residential, industrial, transportation, etc.

- **Forested Wetland (12):** Palustrine.

The expanses of the 33 delineated habitat types (including subclassifications) were digitized, attributed, and georeferenced in a PC ARC/INFO GIS database. The GIS was then used to summarize the expanse of each of these habitats in three river units [Lower Unit (mouth to RM 46.5), Middle Unit (RM 46.5 to 105.5), and Upper Unit (RM 105.5 to RM 146.8)] for each of the five photographic records analyzed.

The U.S. ACOE study team also defined and identified significant existing habitats that were 1) undisturbed (no apparent human impacts), and 2) candidates for rehabilitation or enhancement to improve their value as habitat. These areas of minimally-disturbed habitat were estimated to cover approximately 194,790 acres (77,915 ha) or 31 percent of the total habitat mapped.

To make comparisons between the CREST-defined habitats in the estuary (RM 0-46.5) for the 1880s and the U.S. ACOE-defined habitats, the CREST-defined habitats were lumped into one of the 12 major U.S. ACOE categories. However, none of the CREST habitat classifications fell into either the Shrub/Scrub or Agricultural habitat categories of the U.S. ACOE. Comparing estuarine habitat in the 1880s with that in 1991 indicates that significant losses of Wetland/Marsh, Broadleaf Forest, Grassland, and Forested Wetland have occurred, and have mostly been countered by increases in Urban/Developed Land and Open Water (Figure 16). The current level of agricultural habitat is also undoubtedly much greater than that existing within the estuary during the late 1800s.

The U.S. ACOE habitat data can also be compared for each study unit to evaluate habitat trends between 1948 and 1991 (Figure 17). Since 1948, the most notable habitat changes seem to have occurred in the Middle and Upper Units of the lower Columbia River. For example, rapid rises are evident in the coverage of Urban/Developed habitat in both the Middle and Upper Units. Decreases in other habitat types are most notable for Open Water, Wetland/Marsh, Shrub/Scrub (Upper Unit only), Coniferous Forest, Broadleaf Forest, and Agricultural habitat. Only the coverage of Forested Wetland habitat appears to be increasing.

2.4.4 Human Health

To determine whether contaminant levels in the river pose a risk to human health, the Bi-State Program convened a work group of human health experts in March 1993 to provide specific recommendations regarding how a human health risk assessment should be conducted for the lower Columbia River. This work group recom-

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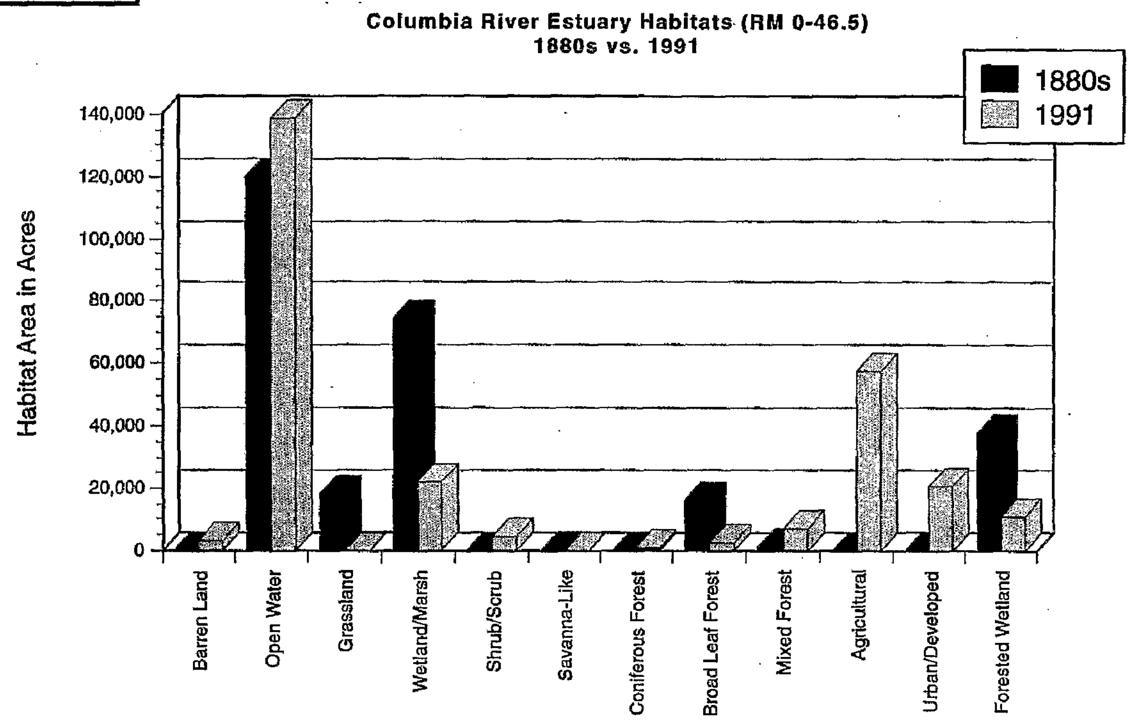

Source: U.S. ACOE (1995)

Figure 16. Changes in Habitat Coverage in the Lower Columbia River Estuary, 1880s vs. 1991.

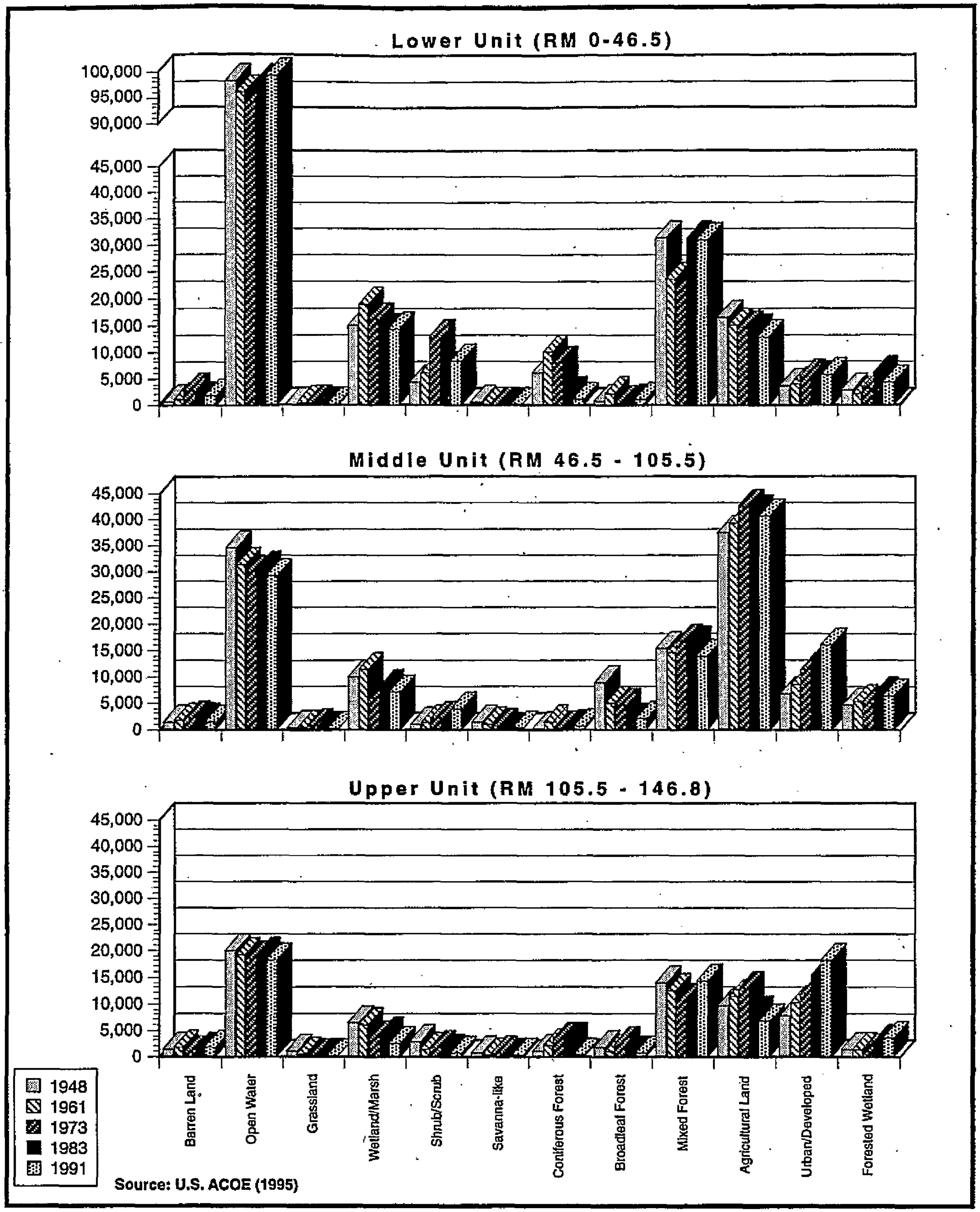

Figure 17. Changes in Habitat Coverage (acres) in the Lower Columbia River - 1948, 1961, 1973, 1983, and 1991.

TETRA TECH

mended an initial screening analysis of fish and crayfish tissue contaminant levels measured during the 1991 Reconnaissance Survey using risk-based screening methods recommended by the U.S. EPA (1993). The objectives of this screening analysis were to:

- Determine whether contaminant levels in fish may potentially pose an unacceptable risk to human consumers.

- Identify the contaminants potentially of greatest concern.

The screening assessment (Appendix A, Section 3.3.6) determined that 1) there was potential threat to human consumers from fish and crayfish harvested from the lower Columbia River, and 2) the contaminants of greatest potential concern (those contributing more than one percent to the total potential risk) were primarily dioxins/furans, PCBs, and chlorinated pesticides. Based on the results of the risk-based screening analysis, the Bi-State Steering Committee members determined that human health risk assessment was a priority area for an advanced Bi-State Program Study. This risk assessment is described below in Section 2.5.1.

2.5 ADVANCED STUDIES

As indicated in Section 2.1, a series of advanced studies were planned using information obtained in the reconnaissance surveys (see Section 2.3) and the baseline studies (see Section 2.4). To date, only one advanced study has been completed, the Human Health Risk Assessment, and one is in final stages of completion, Identification of Pollutant Sources.

2.5.1 Human Health Risk Assessment

The results of the human health risk screening assessment described in Section 2.4.4 indicated a priority need for a more in-depth assessment. This assessment utilized the fish tissue data collected in the two reconnaissance surveys, plus data collected specifically for this purpose in a special study conducted in 1994-95. This assessment evaluated the potential human health risk from consuming fish caught in the lower Columbia (Appendix A, Section 4.1).

2.5.1.1 Survey Design and Methods.

The reconnaissance surveys, conducted during the summers of 1991 and 1993, while not specifically designed as human health risk assessment surveys, did include chemical analyses of whole-body samples of carp, crayfish, largescale sucker, peamouth, and filets of white sturgeon that could be used for such an assessment. The five different species collected during the reconnaissance surveys were selected because their feeding habits and high fat content meant that chemicals which were present in sediments could potentially bioaccumulate in their tissue. One of the objectives of these two surveys was to determine the concentrations of chemicals in the fish tissue to which fish-eating wildlife, such as mink and bald eagles, could be exposed.

The human health risk assessment survey was designed specifically to calculate risk to human health associated with the consumption of carp, largescale sucker, white sturgeon, steelhead trout, coho salmon, and chinook salmon from the river. The inclusion of both game and non-game species was intended to represent the fishing and dietary practices of many different populations, not just recreational fishers with boats.

A total of 104 fish samples were analyzed during the three surveys. Samples were analyzed for metals, semi-volatile organic compounds, dioxins and furans, and pesticides and PCBs.

The risk assessment process involves five steps: 1) hazard identification, 2) exposure assessment, 3) toxicity assessment, 4) risk characterization, and 5) uncertainty analysis.

Hazard identification is determining which chemicals are potentially of concern. This was done by screening the tissue contaminant database for chemicals which have been previously detected at concentrations high enough to warrant concern regarding human health (Appendix A, Section 3.3.6).

Exposure assessment is determining how much fish people eat at a time and how often they eat it (ingestion rate), for how many years they eat fish (exposure duration), and what parts of the fish are eaten (fillet, eggs, etc.). For this project, exposure durations of 30 and 70 years were chosen to represent resident and subsistence fishers, respectively, of the lower Columbia River Basin. The study used ingestion rates recommended by the Human Health Risk Work Group which ranged from almost zero to 40 meals per month (300 g/day). This broad range of ingestion rates was selected to assist individuals, health departments, and regulatory agencies in making their own assessments of health risk based on these findings plus what they know about the fish eating habits of local populations.

Toxicity assessment is calculating a dose for each chemical that could result in adverse health effects to humans. Dose is defined as mass ingested (amount divided by body weight) over a specified period of time. Toxicity data for almost all of the chemicals analyzed for this project have been published by U.S. EPA.

Risk characterization integrates the information from the toxicity assessment with the information from the exposure assessment to estimate the potential for consumers of lower Columbia River fish to experience adverse health effects. Each fish species was evaluated separately, as were data from each of the surveys. Estimates were made for both cancer and non-cancer effects. Both kinds of estimates assume that consumption rate and measured chemical concentrations remain constant over the entire exposure duration. Cancer risk estimates are the probability of getting cancer from eating fish, e.g., 1 chance in 1,000,000 over a lifetime. Non-cancer health effect estimates are calculated as a hazard quotient (HQ), a number which shows how much of a given chemical fish consumers are ingesting, compared to the maximum dose considered safe. HQs for different chemicals affecting the same organ or system (e.g., central nervous or immunological system) were added together, producing an overall Hazard Index (HI) for that system.

Uncertainty analysis addresses the fact that this process requires that assumptions be made, many of which are inherently uncertain, and describes how this uncertainty affects the resulting estimates. Assumptions used in the risk assessment were based on U.S. EPA guidance, current literature, and best scientific judgement.

2.5.1.2 Risk Assessment Findings.

Acceptable levels of risk are typically determined by public health agencies. The risk estimates provided in the risk assessment were designed to aid these agencies in making the necessary decisions. States differ in what they consider to be an acceptable level of cancer risk. Cancer risk is defined in term of "excess risk," i.e. the amount of risk added by being exposed to a certain chemical. The U.S. EPA uses lifetime excess cancer risks ranging from 1 chance in 10,000 to 1 chance in a million of developing cancer as guidelines when determining whether chemical exposures represent a potentially unacceptable level of risk to public health.

Carcinogenic risk values from individual chemicals were added in order to derive an overall total risk for each fish species. For *filet* samples, the risk estimates were highest for carp, followed in decreasing order by sturgeon in 1991, sturgeon in 1995, sucker, chinook, coho, and steelhead. The total carcinogenic risk from these last three species was at least ten times lower than from the other species. None of these salmonid species reside permanently in the river, most having returned from the ocean within a few weeks of their capture. For *whole-body* samples, the risk estimates were highest for carp, followed in order of decreasing risk by peamouth, sucker, and crayfish. At the U.S. average per capita fish consumption rate (6.5 g/day) and the median exposure duration

(30 years), the excess cancer risk estimates for filet samples were all between 1 in 10,000 and 1 in 1,000,000. For whole-body samples, the cancer risks from carp and peamouth were slightly greater than 1 in 10,000. The risk estimates for the whole-body samples were generally higher than the risk estimates for the filet samples. At consumption rates more typical of recreational fishers, risk was approximately 10 times higher.

For non-cancer health effects, Hazard Indices (HI) relating to the central nervous system (CNS), human development, and the immune system, were calculated for each species. At 6.5 g/day, the HI were all under 1.0 (the calculated "safe dose" for a given kind of exposure). The HI for the three salmonid species were lower than HI for other species, particularly regarding the developmental and immune system endpoints. These two endpoints also showed the largest difference between HI for whole-body (higher) and filet samples (lower). There was little difference between whole-body and filet samples for the central nervous system HI.

Public health agencies typically make risk management decisions based on the total carcinogenic risk and noncarcinogenic health effects for each species. State environmental agencies, on the other hand, must also be aware of the individual chemicals and chemical classes which contribute the most to the overall risk so that trends can be monitored and solutions to problems can be implemented. The chemicals contributing the most to excess cancer risk were dioxins/furans, PCBs, arsenic, and to a lesser extent, organochlorine pesticides (particularly DDT and its derivatives). As with cancer risk, the potential for noncancer health effects from the consumption of fish was attributed to a relatively small number of toxic chemicals. For the CNS HI, the large majority of the value was attributable to metals, primarily mercury. For the developmental HI, PCBs were responsible for the majority of the total for all species except crayfish in 1991 (PCBs were not detected in these samples). The metals cadmium and selenium were also significant sources of developmental HI, contributing as much as 50 percent to the total in some cases. All of the immunological HI was due to PCBs and dieldrin.

2.5.1.3 Uncertainty Analysis. Some of the key areas of uncertainty in this risk assessment are: 1) lack of toxicity values [reference doses (RfDs)] for some chemicals, most importantly lead and dioxins/furans, 2) representativeness of the samples used to characterize exposure, 3) use of one-half detection limit for non-detect values, and 4) the limited number of samples analyzed for some species. The effect of each of these areas on the resulting risk estimates is discussed below.

Except for lead and dioxins/furans, the risk of adverse health effect from most of the chemicals without published toxicity values was not assumed to be great, although these chemicals could not be evaluated quantitatively. U.S. EPA has not reached a consensus on a RfD for lead.

Pohl et al. (1995) have proposed a RfD of 0.7 pg/kg-day for 2,3,7,8-TCDD. Using this proposed RfD as a basis, HQs were calculated for all detected dioxins/furans based on their relative toxicities. At 6.5 g/day, the sum of the HQs for the detected dioxin/furan congeners was less than 0.6, with the exception of peamouth in 1991, for which the sum was 1.07. By this analysis, dioxins/furans are a major contributor to the developmental HI, contributing between 17 and 95 percent. The HI calculated by this method was slightly greater than 1.0 for some species collected in 1991 and 1993 (e.g., carp, largescale sucker, and peamouth).

The concentrations in the whole-body and hatchery samples may not have been representative of the concentrations normally consumed by humans. The lipid (fat) content of a whole-body sample is typically higher than that in a filet sample because of lipid-dense organs such as the liver and gonads. Many of the organic compounds evaluated in this risk assessment accumulate in lipid-rich parts of the fish because of their hydrophobic nature. So the contaminant concentration in a filet might be lower than the concentration in the whole body of the same species. Thus the risk estimates for whole-body fish in this report could overestimate the risk to fish consumers who normally only eat filets.

This risk assessment makes the conservative assumption that skin and fatty areas of the fish are not removed during fileting and that there is no net reduction in contaminant concentrations during cooking. Fishermen who prepare fish by skinning and trimming away the fatty areas of filets may reduce their exposure to the lipophilic contaminants by as much as 60 percent (Gall and Voiland 1990). It has also been shown (Zabik and Zabik 1995, Skea et al. 1979) that cooking fish can reduce contaminant concentrations by as much as 50 percent, depending on the cooking method. Because the effects of preparation and cooking were not considered in this risk assessment, it is likely that chemical concentrations and subsequently calculated risks were overestimated.

The salmon samples that were analyzed in 1995 were collected at three different hatcheries. The degree to which these salmon are representative of salmon that are typically consumed by people is affected by several factors, including 1) the differences between salmon from different hatcheries, 2) the differences between wild and hatchery salmon, and 3) the length of time the salmon reside in the river. The first two sources of uncertainty cannot be evaluated using available data. Because most of the salmon caught by recreational fishers are caught near the mouth of the river (WDFW/ODFW 1994), the fish collected at the hatcheries probably resided in the lower Columbia River for a longer period of time than the majority of the fish caught by recreational fishers, and thus had more time to take up contaminants from the water via respiration. Given that many of the chemicals were not detected in salmon or were detected at very low concentrations near the detection limit, the degree to which the concentrations in these fish are different from those in fish caught nearer the mouth of the river is probably minor.

Risk assessors generally take one of three approaches for evaluating non-detected values: assume a non-detect is zero, assume it is equal to the detection limit (conservative approach), or assume it is one half the detection limit. Which approach to take is an ongoing discussion among risk assessors. For most of the species collected in 1991 and 1993, the zero-detection limit and full-detection limit risk calculations are less than 20 percent lower and higher, respectively, than the half-detection limit calculations. Because public health agencies typically make decisions based on order of magnitude differences in risk estimates, the treatment of non-detect values is probably not a major issue in this assessment.

U.S. EPA (1993) has recommended that 3 or more fish samples be analyzed for a given fish species in a risk assessment. This recommendation was followed for all species except carp in 1995, for which only 1 sample could be collected and analyzed. Although 3 or more samples were analyzed for most species, the risk estimates are based on datasets which may differ in the degree to which they are representative of the true mean chemical concentrations for a species at the time they were analyzed.

2.5.2 Identification of Pollutant Sources

The Inventory and Characterization of Pollutants (Section 2.2.2) resulted in a list of approximately 100 "chemicals of concern." The Oregon Department of Environmental Quality (ODEQ) has studied potential sources of these chemicals, plus loads and levels of conventional parameters, and assembled what is currently known about sources and quantities of pollutants entering the lower Columbia. While this is ongoing work, a draft report has been prepared. At the time of this publication, not report that could be generally released was available.

2.6 DATA MANAGEMENT

Data management was a particularly important issue to the Bi-State Program for several reasons. The program generated a considerable amount of original field investigation data to address key program objectives. The program also generated a number of work plans, technical reports, letters, memos, brochures, and meeting minutes. A large amount of historical literature and data was compiled, annotated, and reviewed in technical reports. However, there is currently no central electronic archive for Bi-State Program data, which is found in electronic form in databases, GISs, and spreadsheets in a variety of formats. These data are currently not very accessible to the public or to various state and federal agencies (Appendix A, Section 5.0).

The reports generated from these data have been archived at the Washington Department of Ecology Publications Office. These reports are available upon request, some at a nominal fee, by writing to the following address:

Department of Ecology
Publications Distribution
P.O. Box 47600
Olympia, WA 98504-7600

The Publications Distribution section can be reached by phone at (360) 407-7472.

The main purpose of the data management task was to identify important criteria and factors to consider in evaluating data management systems for the Bi-State Program. This assessment involved three steps:

- Data management needs assessment
- Data management systems evaluation and recommendations
- Data management systems demonstration.

2.6.1 Data Management Needs Assessment

The data management needs assessment identified key programmatic and technical issues relating to the effective management of Bi-State Program data, and developed a list of required and preferred elements that could be used to evaluate the ability of existing data management systems to meet the needs of the Bi-State Program. This list of evaluation criteria was further refined through discussions with work group members, and short-, medium-, and long-term data management objectives for the Bi-State Program were identified:

- Short-term (2 months to 1 year) data management objectives are to manage the data that have been collected or compiled through the program itself (e.g., reconnaissance survey data).

- Medium-term (1 to 5 years) data management objectives include managing, analyzing, and distributing data collected by the program and other related data about the lower Columbia River, and encouraging the distribution of this information to interested parties, including the public and other agencies.

- Long-term (greater than 5 years) data management objectives of the Bi-State Program are to ensure cooperative sharing of all available information on the lower river, in order to improve environmental decision making.

These time scales and elements were then used to evaluate existing data management systems for use by the Bi-State Program.

2.6.2 Data Management System Evaluation and Recommendations

The data management systems evaluation and recommendations report had two major objectives:

- Evaluate existing data management systems according to the criteria developed by the needs assessment, as modified through work group meetings.

- Develop recommendations for data management systems to meet short-, medium-. and long-term data management needs.

Recommendations were made for each time scale based on the evaluation of each system in light of the required, preferred, and technical elements defined during the needs assessment. The recommendations for each time scale are summarized below:

- **Short-term:** An existing data transfer format or archive is the recommended approach. The Puget Sound Ambient Monitoring Program (PSAMP) data transfer formats are recommended. The Oregon GIS standards are recommended for GIS data.

- **Medium-term:** Three approaches were identified, and recommendations for each alternative approach were made.

  - Maintain data in the archive format selected for the short-term option. PSAMP format was recommended.

  - Place Bi-State Program data into an existing data management system that is managed and maintained by the Bi-State Program. PSAMP and NOAA's Coastal Ocean Mapping, Planning and Assessment System (COMPAS) systems are possible choices.

- Place Bi-State Program data into an existing system that is managed and maintained by another organization. If a federal system is selected, EPA's Ocean Data Evaluation System (ODES) is recommended. If a local system is selected, then the Northwest Power Planning Council's and BPA's Columbia River Coordinated Information System (CRCIS) is a suitable alternative.

- **Long-term:** Develop a committee of State and Federal data experts to explore the use of wide-area networks.

2.6.3 Data Management Systems Demonstration

A demonstration of the PSAMP data management system and data transfer formats was conducted by Data Management Work Group participants in November 1993. The demonstration focused on the short-term option: the selection of PSAMP data transfer formats as the standard to be used in the future. In addition, the PSAMP system was used to demonstrate some of the capabilities that would be useful for medium- and long-term Bi-State Program needs. A consensus was reached by the work group and committee members present to make a recommendation to the Bi-State Steering Committee that PSAMP data transfer formats be required for any future contract deliverables.

3.0 THE HEALTH OF THE LOWER COLUMBIA RIVER

The overall health of the lower Columbia River is difficult to determine quantitatively using existing scientific methods. Existing methods can assess and predict the impacts of environmental changes on the health of individual organisms, but the science of assessing and predicting changes at the ecosystem level is far less well developed. This is especially true of effects due to chronic exposure to low levels of contaminants, and effects due to habitat alterations (Shindler 1985; Emery and Mattson 1986; Chapman 1991). The "health" of an ecosystem can also depend on the perspective of the evaluator. A river with dams for navigation, power production, irrigation water, and flood control might seem "healthy," that is useful or desirable, to a shipper, industrialist, or farmer. However, that same condition could seem unhealthy from the perspective of anadromous salmon or people dependent on these fish for their livelihood. As with many issues of ecosystem management (i.e., resource management), there is a sensitive interplay among various public and private interests, public policy, and scientific understanding. The environmental legislative history in the U.S. reveals this interplay.

The legislative mandate of the Federal Water Pollution Control Act (FWPCA) Amendments of 1972 was the attainment of "fishable, swimmable" waters. In accordance with these amendments and the Clean Water Act Amendments of 1977, 1981, and 1987, a two-pronged approach was developed by congress to protect the health of the nation's waters as defined by water quality criteria and specific "beneficial uses" of these waters that are to be protected through compliance with the established water quality criteria. Appropriate beneficial uses and water quality criteria are designated by individual states for specific water bodies (see Section 2.2.5 of this report). These beneficial uses are to be protected or achieved through the implementation of technology-based water pollution controls (i.e., best available technology or BAT) for municipal and industrial point sources. Where established water quality criteria for the protection of the designated beneficial uses are still exceeded after implementation of BAT-wastewater treatment controls, additional controls (i.e., beyond BAT) on point and diffuse non-point sources may be warranted if the impairment of beneficial uses is due to human impacts.

Although the initial development of water quality criteria focused on individual chemical constituents, increased emphasis is being placed on a more holistic view which includes the biological, chemical, and physical integrity of the ecosystem as outlined in the original FWPCA Amendments of 1972. This integrated approach incorporates whole-effluent toxicity testing, sediment toxicity testing, and biological assessments along with the current chemical-specific water quality criteria approach to provide a more comprehensive evaluation of overall ecological integrity. However, ecological integrity is not typically defined as a specific beneficial use of a water body. The protection of ecological integrity, however, should provide protection for the animals, plants, and humans that depend on the aquatic environment for chemical, physical, biological, and perhaps in the case of humans, aesthetic or even spiritual support.

The protection of ecological integrity (if it can be clearly defined for regulatory purposes) may conflict with other designated beneficial uses of the river. The types of designated beneficial uses for a water body typically include public water supply, propagation of fish, shellfish, and wildlife, power production, as well as recreational, agricultural, industrial, and navigation uses. These uses are not independent activities, but affect each other, sometimes negatively and sometimes positively. For example, water withdrawals for public water supply and agriculture can reduce the amount of water available to dilute pollutants, directly impacting fish and other aquatic organisms and wildlife habitat. However, maintenance of water quality suitable for public consumption may also prove beneficial to fish and wildlife. Because of the complicated relationships among these various uses, there is no single set of suitable criteria that would ensure the maintenance of all beneficial uses. However, the public and private interests often demand that all of these uses be protected year-round.

The assessments of the Bi-State Program are based on the beneficial (or characteristic) uses of the Columbia River that are protected by Oregon and Washington laws and regulations (see Table 1 and Section 2.2.5). Studies have targeted the following specific beneficial uses:.

- **Water Supply:** While not studied in depth, a preliminary assessment of the suitability of the river as a source of drinking water has been made using available data.
- **Fish and Wildlife:** Suitable chemical and physical habitat in and along the river for the uses of migratory fish, resident fish, and wildlife associated with aquatic habitats. These uses include habitat, propagation and rearing of young, and migratory passage.

- **Recreation:**
  - Fish of suitable quality for human consumption to support a recreational fishery.
  - Suitable water quality for primary water contact recreation (i.e., skin diving, swimming, water skiing, jet skiing, and wind surfing).

- **Commercial:** Fish of suitable quality for human consumption to support a commercial fishery.

Bi-State Program studies evaluating potential adverse impacts to these beneficial uses have focused on using chemical-specific criteria, standards, and guidelines. Although biological assessment techniques have also been applied, the utility of these techniques has been limited by: the physical variability of such a large river system for application of benthic invertebrate community evaluations on a river-wide scale (Tetra Tech 1992a), the sampling delays encountered in the fish health assessment conducted in December 1994 (Tetra Tech 1995a), and the limited number of the sediment toxicity tests conducted during the Backwater Reconnaissance Survey (Tetra Tech 1995b).

The support of these designated beneficial uses is evaluated below using available criteria, standards, guidelines, and some qualitative professional judgement. Where established state standards are not available, the assessment may be based on criteria or guidelines provided by federal programs in the U.S. or Canada, or from states other than Oregon and Washington. The evaluation draws on all of the data collected as part of the Bi-State Program (including sediment toxicity bioassays, biological assessments, and habitat studies) to provide a comprehensive assessment of the "health" of the river.

3.1 WATER SUPPLY

The purity of drinking water was not chosen as a topic of study in the Bi-State Program. However, a preliminary assessment of this topic can be made using available data. According to Oregon and Washington water withdrawal permits, over 95 percent of water withdrawals along the lower Columbia River for human consumption are from wells (Tetra Tech 1992b). Private wells and systems withdrew 13,400 gallons per minute (GPM) for domestic single, domestic multiple, and domestic general uses. Approximately 186,000 GPM are withdrawn for domestic municipal water uses.

In Oregon the City of Rainier uses Columbia River water as a seasonal water supply (summer and fall) and the City of St. Helens uses river water as the primary water source year round. Although most of the potable water is supplied by wells along the lower Columbia River, the supply of water for drinking is a beneficial use designated by both states. Therefore, the quality of lower Columbia River water should be maintained to allow its continued and future use as a drinking water supply.

Criteria have not been established by either state to strictly evaluate if this use is supported. The drinking water standards established by the two states are based on Maximum Contaminant Levels (MCLs) established by the EPA and only apply to the quality of water following treatment using best available technology. Primary MCLs are enforceable standards based on health effects, organoleptic effects, treatment feasibility, treatment costs, and analytical detection limits. Secondary MCLs are nonenforceable guidelines used to evaluate adverse effects to the taste, odor, or appearance of water.

None of the trace metals or organic compounds analyzed in water for the Bi-State Program have exceeded established primary drinking water MCLs, with the possible exception of one sample collected at RM 53.8 which indicated a mercury concentration of 3.6 μg/L (MCL= 2 μg/L). However, this very high concentration was considered to be due to field or laboratory sample contamination. Measurements of aluminum, iron, and pH have exceeded secondary MCLs, but these water quality parameters are amenable to conventional treatment methods. The measured concentrations of fecal coliform bacteria and turbidity also preclude the use of Columbia River water for human consumption without prior treatment. However, fecal coliform bacteria and turbidity can be reduced using conventional treatment methods. Overall, there is no evidence that the beneficial use of domestic water supply is not protected by the existing quality of the river water, if treated using best available technology.

3.2 FISH AND WILDLIFE

The lower Columbia River and the adjacent wetland and riparian areas support a wide variety and a great abundance of fish and wildlife. In general, few criteria, standards, or guidelines are available for assessing adverse effects to aquatic organisms or terrestrial and avian species that depend heavily on nearby water habitats. As stated above, the primary focus of the Bi-State program studies has been on evaluating chemical contamination in the lower river and assessing the potential of this contamination to have adverse effects on aquatic organisms and wildlife. The results of these evaluations are synthesized below along with the biological assessments and habitat studies that were also conducted as part of the Bi-State Program. The evaluation is divided into chemical criteria (including standards and guidelines), biological assessments, and habitat studies. The conclusions from these separate evaluations are then combined to provide an overall assessment of whether or not the beneficial use of the river by fish and wildlife is protected.

3.2.1 Chemical Criteria

Most of the available guidance for assessing impacts to fish and wildlife concern physical properties and chemical concentrations measured in the water column. Only three of these criteria are for the protection of wildlife: EPA water column criteria for selenium, DDT, and PCBs (U.S. EPA 1992). Chemical-specific reference levels for contaminants in sediments and aquatic biota are fewer in number. The reference levels for sediment are based on two separate endpoints: 1) levels that may have an adverse effect on benthic organisms and 2) levels that would lead to accumulation in aquatic organisms at levels that would be harmful to carnivorous fish and wildlife. The criteria for levels of contaminants in aquatic organisms are also those concentrations which may be harmful to carnivorous fish and wildlife. Using the criteria, standards, and guidelines summarized by Tetra Tech (1995b), the potential for adverse impacts to aquatic organisms and wildlife is provided below for each medium: water, sediment, and aquatic biota.

3.2.1.1 Water Column. Although more criteria have been developed for the concentrations of contaminants in the water column, accurate analysis of many toxic constituents is difficult and relatively expensive to perform, especially analyses of trace metals and organic compounds.

Metals--The difficulty of measuring relatively low concentrations of metals in ambient waters has been noted in a number of investigations (e.g., Shiller and Boyle 1987; Windom et al. 1991) and is now recognized as a serious obstacle to achieving water quality-based control of metal pollution (U.S. EPA 1995). The accurate measurement and evaluation of water column concentrations of metals in the lower Columbia River has been a recurring problem (e.g., see discussion by Velz 1984, pp. 340-352). In addition, the EPA has been redefining the guidance for measuring metals in water and applying these data to water quality criteria (U.S. EPA 1995). EPA guidelines now recommend the use of dissolved metals concentrations and criteria (rather than total recoverable metals) for assessment of compliance with water quality standards. The State of Washington has already adopted standards for dissolved metal concentrations of cadmium, copper, lead, nickel, silver, and zinc. At the time most of the water samples for the Bi-State Program were analyzed, water quality standards were still based on total recoverable metals. The concentrations of total recoverable metals (primarily aluminum, iron, copper, and lead) in a number of samples analyzed for the Bi-State Program have exceeded water quality standards of Oregon and/or Washington. The concentrations of total recoverable selenium and silver have very infrequently exceeded standards.

The metals aluminum and iron are not considered priority toxic pollutants by EPA. Therefore, the EPA has not determined dissolved concentration standards for these metals. Oregon has adopted the EPA-recommended total recoverable criteria for these metals. However, the measured concentrations of aluminum and iron are typical of unpolluted waters. These metals are primarily associated with the very fine particulate clays that are transported with the suspended sediments of the river. Furthermore, no reliable measurements of dissolved metal concentrations have exceeded state standards or EPA criteria for dissolved metals concentrations (Tetra Tech 1995b; Fuhrer et al. 1995; Johnson and Hopkins 1991).

The existing database does not provide convincing evidence that aquatic organisms (including fish) and wildlife are significantly impaired by the concentrations of metals in the water column of the lower Columbia River. Additional high quality data are needed to better assess the potential acute and chronic effects of water column metals concentrations on aquatic organisms and wildlife. What is also needed is a consistent framework of Bi-State standards or guidelines for accurately measuring and evaluating the concentrations of metals in the water column of the river.

Organic Compounds. Organic compounds are very difficult to measure in ambient water using conventional methods. Limited measurements of semi-volatile organic compounds, chlorinated pesticides, and PCBs were made as part of the 1991 Reconnaissance Survey. In several instances the reported detection limit for a compound (lowest concentration at which it could reliably be detected) was greater than the established criteria or standard. These compounds included pentachlorophenol, hexachlorocyclopentadiene, forms of DDT and derivatives, heptachlor, alpha-chlordane, aldrin, dieldrin, mirex, parathion, toxaphene, endrin, methoxychlor, and PCBs. Only one compound was detected at a concentration greater than the chronic criterion for the protection of aquatic organisms. This compound [bis(2-ethylhexyl)-phthalate] was detected at two of the five stations sampled. However, this compound is also a common laboratory contaminant. The USGS also measured the water concentration of 47 organic pesticides (and metabolites) during their ambient monitoring study conducted in 1994. Although 20 of the 47 pesticides were detected in at least one sample, of the dissolved concentrations of the pesticides for which criteria for the protection of aquatic life were available (chlorpyrifos, dieldrin, Lindane, malathion, and parathion), only Lindane was detected and it did not exceed the criterion. However, the detectable presence of these compounds may be reason for some concern given the significant degree to which they may biomagnify in aquatic organisms.

Overall, the available data do not indicate that the water column concentrations of organic compounds typically exceed levels that would indicate potential toxic effects to aquatic organisms or wildlife. However, few measurements that achieve adequate detection limits for comparison to criteria have been made. For example, adequate measurements of the water column concentration of 2,3,7,8-TCDD have not been made. Instead, the river has been declared "water quality limited" because concentrations of this compound in fish have exceeded screening thresholds for human consumption. Dioxins (e.g., 2,3,7,8-TCDD) and related compounds may also be involved in the impairment of bald eagle reproduction in the Columbia River estuary, although this relationship is not clear (see below). Therefore, additional monitoring of water concentrations of specific organic compounds using methods that can accurately quantify them at levels of concern may be warranted.

Other Water Column Properties. In addition to metals and organic compounds, other water column properties have been measured in Bi-State Program studies to evaluate effects on fish and wildlife. These properties include water temperature, dissolved oxygen, pH, and total dissolved gas. The criteria for these properties are primarily for the protection of fish. Exceedance of Washington's water temperature standard of 20° C occurs routinely during summer months. Although it is not clear to what extent exceedance of the standard is due to human-induced causes vs. natural conditions, the high temperature of the lower river during summer has implications for the relative success of coldwater and warmwater fishes. Exceedances of standards for dissolved oxygen and pH have also been noted, but these occurrences have not exhibited a river-wide trend associated with significant pollution sources. With one possible exception [i.e., low dissolved oxygen in Burke Slough which may have been associated with discharges from a dike pumping station (see Tetra Tech 1995b)], these exceedances have been relatively minor and may be primarily associated with natural variation of primary production and ecosystem respiration.

The State of Oregon has recently proposed new standards for dissolved oxygen of 11 mg/L for the lower Columbia River up to river mile 120 (Harding, R., 5 February 1996, personal communication). This represents a significant change from their previous standard, which required oxygen concentrations of greater than 90 percent saturation. The modification is designed to protect spawning salmon, one of the designated beneficial uses for this portion of the river. Had this standard been in effect at the time of two reconnaissance surveys, it would have been violated at almost all of the stations.

The new standard may require a use-attainability study at a future date to determine if the designation of this portion of the river as salmon spawning habitat is appropriate. If it is determined that this beneficial use is not supported, the applicable dissolved oxygen standard would be 6.5 mg/L.

The levels of total dissolved gas have been a chronic problem in the lower river since the construction of Bonneville Dam. The discharge of water over the dam spillway entrains ambient air resulting in supersaturation of atmospheric gases, primarily nitrogen and to a lesser extent dissolved oxygen. Supersaturation of gases in the river can cause gas bubble trauma in fish, which can result in serious injury and death. Concentrations of total dissolved gas have routinely exceeded the 110 percent saturation standard, although a variance has been granted by Oregon and Washington to allow the concentration to reach 120 percent. This was done to allow more water to be spilled during juvenile salmon downstream migration and hopefully increase their chances of survival. No measurements made by the USGS during 1994 exceeded the interim standard of 120 percent (Fuhrer et al. 1995). Nonetheless, management of the river for both hydropower and fish migration will continue to warrant concern for this water quality variable.

3.2.1.2 Streambed Sediment. While contaminants in water are often so dilute as to be difficult to measure, contaminants tend to collect in sediments over time, resulting in levels that are relatively easy to quantify using conventional analytical techniques. However, few criteria, standards, or guidelines are available to evaluate the significance of sediment contamination levels. Although Washington has developed marine sediment management standards and is in the process of developing freshwater sediment quality standards for the protection of benthic organisms, neither Oregon nor Washington has yet adopted formal freshwater sediment standards to protect aquatic life. In the absence of relevant state or federal standards or criteria, sediment data collected as part of the lower Columbia River reconnaissance surveys were evaluated using guidelines for contaminant levels associated with adverse effects on benthic organisms from NOAA's National Status and Trends Program (Long and Morgan 1990), Ontario Ministry of the Environment's Provincial Sediment Quality guidelines (Persaud et al. 1993), New York's sediment quality criteria (Newell and Sinnott 1993), and EPA draft sediment criteria for five non-polar organic compounds (U.S. EPA 1993a,b,c,d,e,f).

Metals. A number of sediment metals exceeded reference levels in one or both reconnaissance surveys, including arsenic, cadmium, chromium, copper, iron, mercury, nickel, silver, and zinc. However, some reference levels (primarily the Ontario values) are lower than the concentrations that would be expected in uncontaminated soils and sediments of the lower Columbia River (e.g., for chromium and copper).

Because sediment metals concentrations tend to vary with the percent of fine sediment in a sample and the natural occurrence of metals, it is difficult to assess the significance of these exceedances. Tetra Tech (1995b) used a sediment normalization technique to identify locations with elevated metals concentrations possibly caused by human inputs. Elevated concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc were identified at a number of backwater and mainstem locations. Comparison of the maximum metals concentrations to the metal content of presumably uncontaminated soils in the U.S. and in fine sedimentary rocks (i.e., shales which likely represent the uncontaminated metals content of fine sediments) (Krauskopf 1979) also indicated exceedances of background levels of arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, and zinc at a number of locations.

Overall, the available data on sediment metal concentrations suggests that adverse effects to benthic organisms may be occurring at a number of locations in the lower Columbia River. No guidelines are available to evaluate the potential effect of sediment metals on wildlife. The development of suitable evaluation criteria and monitoring guidelines specific to the lower Columbia River would greatly improve the confidence in this preliminary assessment based on guidelines developed from other areas.

Semivolatiles. In general, few semi-volatile organic compounds were detected in sediments in either survey. The measured concentrations of PAHs exceeded guideline levels at locations near St. Helens and Longview. Elevated concentrations of PAHs near Longview were also measured in a previous study conducted by the Washington Department of Ecology (Johnson and Norton 1988). The concentration of 4-methylphenol measured in Camas Slough in 1993 exceeded the New York State reference level for the protection of benthic organisms. Overall, the potential impairment to fish and wildlife due to semi-volatile compounds is relatively low and appears to be localized to urban and industrial areas.

Pesticides/PCBs. Pesticides and PCBs were detected infrequently in sediments in the reconnaissance surveys. Reference guidelines for several pesticides were exceeded at various locations in the river. At least one exceedance occurred for aldrin, alpha-BHC, delta-BHC, dieldrin, endrin, DDT derivatives and metabolites, and PCBs. Overall, the available pesticide/PCB data suggest river-wide impairment of aquatic organisms and wildlife in the lower Columbia River. However, the relatively low concentrations measured and wide distribution of these compounds suggests that their sources are diffuse inputs due to historical uses of these restricted-use and banned chemicals. Their continued presence in sediments of the lower river attests to their persistence and the possibility of continued inputs from erosion of soils contaminated with these compounds. For example, Rinella et al. (1992) have documented the continued erosion of DDT compounds and derivatives from agricultural lands of the Yakima basin, a tributary to the Columbia River above Bonneville Dam.

Dioxins/Furans. Dioxins and furans were sampled at fewer locations than other contaminants due to the high cost of analysis. The concentrations of these compounds in sediments exceeded the New York State guideline for the protection of wildlife at locations throughout the river, both above and below major chlorine-bleaching pulp mills. The available data indicate potential impairment of wildlife. There are no guidelines available for assessing effects of these contaminant levels on benthic organisms.

Butyltins--These compounds (used historically as anti-fouling paints on boats and ships) were detected relatively frequently in sediments throughout the river. A single tributyltin concentration exceeded the proposed standard of 30 μg/kg (Eisler 1989). The concentrations reported in this study are within the range of sediment butyltin concentrations classified as lightly to moderately contaminated in a study of two estuaries in Great Britain (Dowson et al. 1992). Although the use of organotins in anti-fouling paints was controlled by legislation enacted in 1988 in the U.S., and decreasing trends in water concentrations have been demonstrated in some areas (Huggett et al. 1992), sediments in the lower Columbia River appear to harbor butyltin compounds and may serve as a reservoir of these contaminants for continued release to the water column and accumulation by aquatic organisms. The compounds are still used on some foreign vessels.

Radionuclides. The radionuclides cesium 137 and plutonium 239/240 were detected relatively frequently in sediments. Although no reference levels are available to evaluate the potential environmental significance of radionuclide data, the levels measured are similar to concentrations measured in sediments above the Hanford military reserve in Washington, the largest potential source of these radionuclides. The concentrations measured in areas removed from direct radionuclide inputs are presumed to be the result of the accumulation of fallout from historical above-ground nuclear weapons testing.

3.2.1.3 Aquatic Biota. Aquatic biota integrate the inputs of contaminants that tend to bioaccumulate in the tissues of organisms. As with sediments, these contaminants can be detected with relative ease using conventional laboratory methods. However, even fewer criteria, standards, or guidelines are available to evaluate these findings than are available for evaluating the findings of contamination in sediments. The few reference values that are available are for the protection of carnivorous fish and fish-eating wildlife. Guidelines for tissue contaminant levels are available for 4 semivolatile compounds, 17 pesticides, total PCBs, dioxins and furans, and selenium (Newell et al. 1987; Lemly 1993).

Metals. None of the fish and crayfish tissue samples analyzed for the Bi-State Program exceeded either of the available selenium guidelines (to prevent adverse effects on carnivorous fish and fish-eating wildlife, and to protect the health and reproductive success of freshwater and anadromous fish) (Lemly 1993). Therefore, no adverse effects to the fish themselves or to animals which prey on them are expected due to the levels of selenium measured in these fish. Guidelines are not available to assess the potential for adverse effects of the other metals measured in fish and crayfish of the lower Columbia River.

Semivolatiles. Reference levels for tissue concentrations of semivolatile organic compounds were available for hexachlorobenzene, hexachlorobutadiene, pentachlorophenol, and 1,2,4-trichlorobenzene. Hexachlorobenzene was detected in fillet samples of largescale sucker, and hexachlorobenzene and hexachlorobutadiene were detected in fillet samples of white sturgeon, steelhead, and carp. The concentrations detected were well below the reference levels for these compounds. Pentachlorophenol has not been detected in any sample of fish analyzed for the Bi-State Program. The concentration of 1,2,4-trichlorobenzene exceeded the reference level in one whole-body carp sample collected in the Portland/Vancouver area in 1991. Overall, adverse effects on fish-eating wildlife are expected to be minimal due to the measured levels of these compounds. No reference levels are available to assess the potential for adverse effects of the other semivolatile compounds measured in fish and crayfish of the lower Columbia River.

Pesticides/PCBs. DDT and its metabolites and PCBs were detected relatively frequently in fish and crayfish analyzed for the Bi-State Program. Infrequently detected pesticides included alpha-BHC, beta-BHC, Lindane, heptachlor, aldrin, endosulfan I, dieldrin, endrin, methoxychlor, parathion, methyl parathion, and mirex. The available reference levels were exceeded relatively frequently for PCBs, especially in whole-body samples of largescale sucker and peamouth. The reference levels for DDT compounds and derivatives were also exceeded in a few samples of peamouth. The available data indicate impairment of fish-eating wildlife due to consumption of PCB-, and to a lesser extent, DDT-contaminated fish.

Dioxin/Furans. The reference level for toxic effects to fish-eating wildlife from consumption of dioxin- and furan-contaminated prey species was also exceeded relatively frequently. The available data indicate impairment of fish-eating wildlife due to consumption of prey species contaminated with dioxin and furan compounds.

Butyltins. Although butyltin compounds were detected relatively frequently in largescale sucker and carp samples collected in 1993, there are no reference levels or guidelines available to evaluate the environmental significance of these data. One area of the lower river (RM 29-36) had the highest concentrations of these compounds in both tissues and sediments, and may warrant further study.

Radionuclides. Eight long-lived radionuclides were analyzed in fish tissue samples collected in 1993; plutonium 239/240, plutonium 238, and cesium 137 were detected. No radionuclides were detected in crayfish samples. No reference levels for radionuclide concentrations in aquatic biota have been established in either the U.S. or Canada, so no assessment of the potential adverse effects to aquatic organisms or wildlife is possible.

3.2.1.4 Synthesis of Chemical Criteria Assessment. Overall, the available chemical contaminant data indicate some impairment of the use of the lower Columbia River by aquatic organisms and wildlife. Based on the frequency of exceedances of the available reference levels and the distribution of the areas where exceedances have been noted, river-wide impairment of fish-eating wildlife is predicted due to the presence of PCB, DDT and its metabolites, and dioxin and furan compounds in fish and sediments. This prediction is consistent with ongoing studies conducted by the U.S. Fish and Wildlife Service on the reproductive success of mink, river otter, and bald eagles of the lower Columbia River (see Section 2.4.3.5).

Although several metals were detected in water and sediment, it is not currently possible to state whether the levels detected impair the uses of the river by aquatic organisms. Conclusions regarding the water column metals data depend primarily on the criterion used (total recoverable vs. dissolved) and the accuracy of the available data. An accepted framework for analyzing and evaluating water column metals concentrations is needed before impairment due to metals concentrations measured in the water column can be adequately addressed.

Trace metals are introduced to sediments naturally from the weathering of rocks as well as from human activities such as mining. Measurable levels of metals tend to be naturally higher in finer sediments. An attempt was made to identify sediments with human-induced increases in metal content. Metals that were identified as anthropogenically elevated at one or more locations and that also exceeded available reference levels included arsenic, cadmium, chromium, copper, nickel, and zinc.

The State of Washington has developed a regulatory program for managing contaminated marine sediments and is in the process of developing a program for freshwater sediments. These programs utilize a tiered chemical and bioassay testing scheme similar to one that will be recommended in EPA's Contaminated Sediment Management Strategy. The limited sediment toxicity data collected in 1993 as part of the Bi-State Program (Tetra Tech 1995b), and tests conducted in 1987 by Ecology at port areas of the lower river (Johnson and Norton 1988) have not indicated acute sediment toxicity, although toxicity was evidenced at one location in Youngs Bay using the Microtox test (Tetra Tech 1995b).

The State of Washington's approach to managing marine sediment contamination does not address the bioaccumulation of contaminants and resultant effects on fish, wildlife, or humans. Additional sampling and analysis, including additional acute and chronic sediment toxicity bioassays (perhaps using sensitive resident species such as the amphipod *Corophium salmonis*), would help fill this gap.

3.2.2 Biological Assessments

A limited number of biological assessments have been conducted as part of the Bi-State Program. These assessments have included identification and enumeration of benthic organisms in sediment samples collected in 1991, a limited number of sediment toxicity tests conducted in 1993, fish health assessments conducted in 1994, studies of mink and river otter populations and habitat in 1994 and 1995, and studies of the reproductive success and contaminant levels of bald eagles nesting along the lower river in 1994 and 1995.

Although inter-station differences in benthic community structure were noted in 1991, these differences were attributed to the variation and dynamic nature of the physical habitats sampled (Tetra Tech 1993). The sediment toxicity tests did not indicate significant acute toxicity at the 15 locations sampled, although one location did evidence toxicity as measured by the Microtox bioassay (Tetra Tech 1995b). The cause of this toxicity could not be determined.

The fish health assessments conducted in 1994 were relatively inconclusive, primarily due to the few fish that could be collected during winter (Tetra Tech 1995a). The enzyme activation studies conducted on the largescale sucker collected during the same survey did not indicate exposure to excessive levels of PAHs (Collier et al. 1995). This finding is consistent with other data collected during the Bi-State Program that indicated only moderate PAH contamination in the lower Columbia River, primarily in the vicinity of urban and industrial areas (Tetra Tech 1995b).

A study recently completed on mink and river otter (Henny et al. 1996) indicates that river otter in the vicinity of RM 120 may be in a critical category based on contamination reference levels, abnormalities noted during necropsy, and histopathological observations.

The contaminant and reproduction studies conducted on bald eagles nesting in the lower Columbia River have provided evidence of reproductive abnormalities due to the accumulation of PCBs, DDT compounds and metabolites, and dioxins and furans. However, there has in fact been an increase in productivity and total population of these birds. No correlation was found between breeding success and eggshell thickness measured in 1994 and 1995. There is evidence that PCBs, DDT compounds and their metabolites, and dioxins and furans in some combination may be causing embryo mortality and abnormality, and behavioral abnormalities in parents among bald eagles. More study is needed in this areas.

3.2.3 Habitat Assessments

An assessment of habitat loss in the Columbia River estuary has been made as part of studies directed by the Columbia River Estuary Study Task Force (CREST) and the U.S. Army Corps of Engineers. These studies indicated that extensive dredging, diking, and filling of the river began as early as 1885. Diking and filling activities were directed at creating a single channel for navigation and minimizing the need for costly dredging operations. In the estuarine portion of the lower river over half of the tidal swamp and marsh areas have been lost since 1870. An assessment of the effect of this loss on fish and wildlife has not been made.

The hydroelectric system developed on the Columbia River has also altered the habitat of the lower river by regulating flows and water levels and limiting the passage of migratory fish (Dynesius and Nilsson 1994; Johnson et al. 1995). Reduced current velocities and warmer water temperatures have increased the relative abundance of resident and introduced warm water fish species at the expense of cold water species such as salmon (Zimmerman and Parker 1995).

Riparian and wetland habitat has been altered extensively in the lower river and the abundance and distribution of fish and wildlife has changed since humans began altering the river significantly in the late 1800s. The value of the river to fish and wildlife has clearly been affected by these changes. The growing popularity and economic value of recreational fisheries for introduced warmwater species such as smallmouth bass and walleye complicate assessment of habitat changes (Zimmerman and Parker 1995). Evaluations of habitat alteration/degradation/loss could also be based on more recent benchmarks (e.g., "no net loss" or "no net change"). Further consideration should be given to evaluating habitat information as it relates to the support of beneficial uses.

3.2.4 Synthesis

The available data do not provide evidence that contaminant levels in water, sediment, or biota are sufficient to cause river-wide impairment of aquatic organisms. However, exceedances of sediment reference levels for metals suggest possible localized adverse effects to benthic organisms at a number of locations along the river. The data do provide evidence that contaminant levels of some organic compounds measured in fish tissue and sediments, specifically PCBs, DDT compounds and derivatives, and dioxins and furans, are high enough to cause adverse effects in fish-eating wildlife. Additional studies of fish-eating bald eagles, mink, and river otter support this conclusion. Overall, the available evidence indicates that the use of the river by fish-eating wildlife is not fully supported.

3.3 RECREATION

Beneficial recreational uses evaluated as part of the Bi-State Program include fishing, water contact recreation, and the aesthetic quality of the water. The degree to which these uses are currently supported is evaluated below.

3.3.1 Recreational Fishing

To assess the adverse effects to human health, a health risk screening assessment was performed for recreational and subsistence exposure to the contaminant levels measured in lower Columbia River fish. [Note: subsistence is not a currently designated beneficial use of the river.] This study indicated that people who eat relatively large amounts of fish from the river over a long period of time would be exposed to risks that exceed those deemed acceptable by the EPA. These findings were confirmed in the 1995 Risk Assessment (Tetra Tech 1995), which evaluated fish tissue contaminant data from both reconnaissance surveys and from the advanced risk assessment field survey. The contaminants that contributed the most to the estimated health risks were PCBs, dioxins and furans, DDT compounds and derivatives, and inorganic arsenic.

Water quality criteria for the protection of human health are also predicted to be exceeded frequently for PCB, DDT compounds and derivatives, 2,3,7,8-TCDD (dioxin), and arsenic using the available fish tissue contaminant data and the bioconcentration factors (BCFs) used by EPA to establish the water quality criteria. Less frequent exceedances are predicted for PAHs, dieldrin, heptachlor epoxide, and Lindane. The data indicate that the beneficial use of the river for recreational fishing is not fully supported.

Although not identified explicitly in Table 4, recreational shellfishing is a protected "characteristic" use of Class A waters of the State of Washington. The limited indicator bacteria data collected in the Columbia River estuary as part of the Bi-State Program indicate that state water quality standards for microbial contamination established for the protection of human health due to consumption of shellfish are not met in the estuary. Direct sampling and analysis of shellfish tissue quality (of shellfish actually or potentially harvested for human consumption) would provide more direct information on the suitability of these shellfish for human consumption. The extent of the recreational shellfish harvesting areas potentially affected should be identified and future monitoring should focus on these areas.

Note that factors other than chemical and bacteriological water quality affect recreational fisheries. These factors include the growing popularity of a recreational fishery for both warm and cool water fish species and declines in anadromous salmon and sturgeon populations. These changes in fish populations are primarily related to changes that have occurred throughout the Columbia River basin and require a basin-wide approach for their management (e.g., National Marine Fisheries Service recovery plan for endangered Snake River sockeye and chinook salmon).

3.3.2 Water Contact Recreation

Reference levels for assessing the safety of water bodies for contact recreation are based on the number of colonies of certain indicator bacteria found in water samples. For water that meets the reference level, it is assumed that the risk of gastroenteritis due to accidental ingestion of water during swimming and other water sports is relatively low. The indicator bacteria are presumed to be surrogate measures of the presence and abundance of pathogenic bacteria and viruses in general. However, there is an ongoing debate about the correctness and utility of the recommended U.S. EPA criteria (e.g., Fleicher 1991) and the utility of the current indicator bacteria in general (e.g., Toranzos 1991). Recently developed analytical methods (e.g., Gilgen et al. 1995) may facilitate the direct detection of pathogens that are the most common causes of disease as a result of recreational water uses. Data collected for

Bi-State water quality studies indicate that exceedances of existing state water quality standards and U.S. EPA criteria are expected at a few locations in the lower river, mainly between Portland/Vancouver and Longview, indicating potential risk for gastroenteritis from ingestion of Columbia River water during contact recreation. The existing Bi-State Program database and standards indicate that recreational bathing use of the river is not a fully supported beneficial use.

The sources of the indicator bacteria measured have not been identified, but likely include municipal and industrial point sources, and non-point sources associated with urban and agricultural runoff. Non-point sources of indicator bacteria may be more significant following summer storms and after the fall rains begin. Water column concentrations of indicator bacteria tend to be high in late fall when rainfall intensity and duration is greater and contact recreation less common (Ehinger 1993). Further studies of indicator bacteria in the lower Columbia River should focus on the relatively drier peak recreational period. The most suitable indicators of the presence of human pathogens (or methods for the direct detection of pathogens), the risks for contraction of various types of illness, and suitable protocols and monitoring for the regulatory application of these criteria should also be established. For example, the State of Oregon has recently replaced the standard based on fecal coliforms with the *E. coli* standard recommended by the EPA. No exceedances of the EPA-recommended criteria for *E. coli* or enterococcus were noted at any of the 15 backwater stations sampled in June and July 1993, a summer period when recreational use of the river would be relatively high.

The Washington State Department of Health (WSDH) has recommended that indicator bacterial sampling results be coupled with additional information (including sanitary surveys) and actions (including limiting bather densities to avoid contamination of the water by the bathers themselves) to ensure the health of public bathing areas (WSDH 1991). By sampling for the most appropriate indicators and specific pathogens at popular water contact recreation areas, health risks due to exposure to river water during water contact activities can be assessed. Evaluation of the impairment of recreational water use would be greatly improved by expanding the existing monitoring program (currently the USGS and DEQ each routinely sample one location on the lower Columbia River) and adopting better indicators of fecal contamination in receiving waters (e.g., *E. coli*). Further improvements in monitoring and assessment can be made as scientific advances in pathogen detection and risk assessment are developed.

3.3.3 Aesthetics

The aesthetic quality of a river is hard to define and measure because of differing perceptions and expectations. Measurable qualities related to aesthetics include water odors, color, and transparency, and the presence of nuisance algae that takes the form of floating scums. These often result from high levels of dissolved nutrients (N, P, and K), a condition known as eutrophication. The only aesthetic variables evaluated during the Bi-State Program were eutrophication and the presence of nuisance algae.

The development of nuisance algae is controlled by light, temperature, pH, nutrient supply, predation, and residence or retention time. Any one of these factors may limit biomass or production; even in conditions favoring production, biomass may be kept relatively low by grazing zooplankton. When production is not controlled, algae may form aesthetically displeasing scums on the water surface and unpleasant odors from rotting. Decaying algae may also reduce dissolved oxygen due to microbial degradation. Lower dissolved oxygen levels may in turn affect other aquatic organisms (see Section 3.2).

The State of Oregon uses the level of the algal pigment chlorophyll *a* as a surrogate measure of algae in the water column: 15 μg chlorophyll *a*/L indicates a possible need for additional studies. (Additional studies would be required because this surrogate does not directly measure nuisance algae.) The chlorophyll *a* action level has been exceeded in the mainstem of the lower Columbia River (see data report sheets of Fuhrer et al. 1995) and in backwater areas (Tetra Tech 1995b). However, species identification performed on samples collected from the mainstem of the lower river indicate that the most abundant forms of phytoplankton are diatoms, with the more noxious blue-green algae being less abundant (Williams and Scott 1962; Haertel et al. 1969; Beak Consultants 1978; Tetra Tech 1993). The State of Washington does not currently have nuisance algae standards or guidelines.

Although data indicate that nutrients are present in sufficient quantity to elevate algal biomass, nuisance algae has not been observed. This phenomenon has been noted in previous studies of the Columbia River (Hileman et al. 1975; Lara-Lara et al. 1990a). In the Columbia River mainstem, algal biomass appears to be controlled by the flushing action of water released from dams (Robeck et al. 1954; Haertel et al. 1969; Dahm et al. 1981).

Algal bloom in a large river is further controlled by short retention times and light limitation in deep turbid reaches. Lara-Lara et al. (1990a) cite light limitation and detention time as primary factors in controlling phytoplankton productivity in the Columbia River estuary. Due to the relatively high flushing rates and the rapid transition from fresh to saline water, freshwater phytoplankton cells are lysed at the freshwater-brackish water boundary. The combined effects of rapid flushing, loss of phytoplankton biomass due to cell lysis, and light limitation from elevated turbidity cause the rate of primary productivity in the Columbia River estuary to be one of the lowest in North America (Lara-Lara et al. 1990a,b).

The available data do not indicate impairment of the aesthetic enjoyment of the lower Columbia River due to nuisance algae. However, additional studies may be warranted to monitor trends in nutrient levels [e.g., Fuhrer et al. (1995) identified a downward trend in total phosphorus in the mainstem of the river] and identify significant nutrient sources [the Willamette appears to be the largest tributary source (Hileman et al. 1975; Tetra Tech 1992c; Fuhrer et al. 1995)]. If warranted, additional sampling could be conducted in backwater areas to assess nuisance algae levels in areas with more limited water exchange.

3.4 COMMERCIAL

Although there are a number of designated commercial uses of the lower Columbia River (e.g., hydropower and navigation), the only commercial use addressed by the Bi-State Program studies has been the suitability of commercially harvested fish for human consumption.

3.4.1 Commercial Fishing

The regulation of the quality of commercial food and feed is managed by the Food and Drug Administration (FDA) using FDA action levels for pesticides that are no longer registered for use, including persistent organochlorine pesticides, and EPA tolerance values for registered pesticides that are currently in use. The FDA action levels are only guidelines and consider human health effects on one side and the costs of restricting the commerce of foodstuffs on the other. Only pesticides with FDA action levels have been measured in fish and crayfish sampled as part of the Bi-State Program. None of the levels measured have exceeded the FDA action levels with the exception of PCBs (Aroclor 1254) measured in one composite whole-body largescale sucker sample (2.7 mg/kg) which exceeded the FDA action level of 2.0 mg/kg (FDA action levels apply to both whole-body and filet samples). FDA action levels for the pesticides aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, heptachlor epoxide, and toxaphene were not exceeded in any Bi-State fish sample. An FDA guideline ("level of concern") for dioxins and furans of 25 pg TEC/g for Great Lakes fish and an action level of 1.0 mg/kg of mercury were also not exceeded in any fish or crayfish sample.

Although the concentrations of contaminants measured in lower Columbia River fish do not appear to exceed levels that would result in restrictions on the interstate marketing of these commercially caught species, restrictions have been placed on the commercial harvest of species in the lower Columbia River due to the listing of the Snake River sockeye and chinook salmon as endangered. Although the commercial fishery may not be impaired due to chemical contamination, impairment is evident in the decline observed in the commercial fishery, much of which may be due to habitat degradation. As noted in the comments on impairment of the recreational fishery, these declines are primarily related to changes that have occurred throughout the Columbia River basin. Mitigation of these changes requires a basin-wide management approach.

Although not explicitly identified as a beneficial use by the Bi-State Program (see Table 4), commercial shellfishing could also be considered a potential beneficial use of the lower river. However, no commercial shellfishery for oysters or clams occurs in the Columbia River estuary. The limited indicator bacteria data collected in the Columbia River estuary as part of the Bi-State Program indicate that state standards established for the protection of human health due to consumption of shellfish are exceeded in the estuary. As stated above for potential impairment of recreational shellfishing uses due to bacterial contamination, direct sampling and analysis of shellfish tissue quality (of shellfish actually or potentially harvested for human consumption) would provide more direct information on the suitability of these shellfish for human consumption. The extent of the commercial shellfish harvesting areas potentially affected should be identified and future monitoring should focus on these areas.

3.5 IDENTIFICATION OF IMPAIRED BENEFICIAL USES

This section is a summary assessment of the "health" of the river, based on comparing all available criteria, standards, and guidelines, and professional judgement with the body of information compiled during the Bi-State Program.

- Water Supply
  - Drinking water supply - Not impaired if treated with best available technology before consumption.
  - Industrial supply - Not assessed.
- Agriculture
  - Not assessed.
- Fish and Wildlife
  - Fish-eating wildlife uses impaired due to contamination of water, sediment, and

biota with PCBs, DDT and its metabolites, and dioxins and furans.

- Fish and wildlife also affected by habitat alterations. Studies assessing effect of habitat degradation/alteration not conducted at this level of detail. Additional sampling warranted.

- Potential impairment of benthic organisms due to metal concentrations in sediment. Additional sediment testing, including sediment toxicity bioassays may be warranted.

- **Recreation**
  - Recreational fishing - Impaired due to levels of PCBs, DDT and its metabolites, dioxins and furans, and arsenic measured in fish.
  - Primary contact recreation - Impaired due to measured levels of indicator bacteria in a few water samples collected near contact recreation areas. Further analysis recommended, including monitoring and evaluation guidance.
  - Secondary contact recreation - Not assessed.
  - Aesthetic quality - Smell and taste not assessed; not impaired due to eutrophication or abundance of blue-green algae.
  - Hunting and boating - Not assessed.

- **Commercial**
  - Commercial fisheries - Not assessed, but habitat degradation/alteration has resulted in declines of migratory salmon populations. Basin-wide management needed to address this problem.
  - Navigation and transportation - Not assessed. However, management activities to improve salmon populations may conflict with these uses.
  - Marinas and other commercial activities - Not assessed. Marinas, some of which rely on recreational boat traffic, may be in conflict with management activities designed to improve salmon populations.
  - Hydropower production - Not assessed. Hydropower production may be in conflict with management activities designed to improve salmon populations.

3.6 RECOMMENDATIONS

- Identify and analyze all beneficial uses of the lower Columbia River, including potential beneficial uses not currently protected.

- Develop strategies for approaching beneficial uses that are or appear to be in conflict.

- Review all standards, criteria, and assessment methods currently used for resource management and decision making. Make changes necessary to ensure that all standards, criteria, and assessment methods are common to both states and in keeping with current scientific knowledge (e.g., bacteriological indicator organisms).

- Develop specifically measurable criteria as needed to evaluate how well each beneficial use is supported.

- For beneficial uses not fully supported, establish a plan with measurable goals and concrete action steps to maximize support.

- Continue to disseminate technical and nontechnical information regarding all these processes widely, and perform outreach to other potential parties of interest.

4.0 PROGRAM RECOMMENDATIONS

This report has characterized water quality in the lower Columbia River, identified problems, and determined the degree of impairment of beneficial uses of the river. Developing long-term solutions to the problems identified requires more specific information, first to determine precisely what actions and policy changes are required, and then to guide implementation and monitor progress on an ongoing basis. The needed information can be supplied by the following activities:

- Problem confirmation and source identification
- Fate and transport assessment
- Criteria and standards development
- Ambient monitoring and assessment
- Fish and wildlife monitoring and assessment
- Human health monitoring and assessment

The breadth of the recommended studies will require interagency cooperation beyond that already achieved by the Bi-State Program. However, cooperation should not be limited to governmental and regulatory agencies. The success of any proposed plan of action will also require cooperation from public, private, tribal, and academic interests. The scope and purpose of the recommended studies is outlined below. A summary of the recommended studies is provided in Table 5.

4.1 PROBLEM CONFIRMATION AND SOURCE IDENTIFICATION

The Bi-State Program studies have indicated that the highest levels of sediment contamination generally occur in the vicinity of urban and industrial areas along the river, although contamination in excess of reference levels does occur elsewhere in the lower Columbia. Studies of bald eagle and river otter demonstrate that these animals are accumulating a number of contaminants at potentially harmful levels. In the case of river otter, the highest levels of contamination were measured above the Portland/Vancouver area in the vicinity of two major industrial discharges. However, the Bi-State Program data on fish and crayfish contaminant levels do not provide any clear indication of

TABLE 5. SUMMARY OF PROGRAM RECOMMENDATIONS
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Problem Confirmation and Source Identification

- Conduct chemical fingerprinting of individual PCB, dioxin, and furan congeners in sediments and animal tissues and from suspected point and nonpoint sources of these compounds.
- Use existing air pollution monitoring and control programs to help determine the pollutant sources and loading contributions.
- Evaluate the role of dredging and resuspension of contaminated sediments in the bioaccumulation/ bioconcentration of contaminants.

Fate and Transport Assessment

- Link contaminant sources to problem areas using fate and transport models.
- Model food chain bioaccumulation and bioconcentration in aquatic organisms to evaluate the effects of any proposed source control or cleanup activities. The model(s) should also be suitable for the evaluation of alterations in food chains or habitat on contaminant accumulation in biota and should include the calculation of biomagnification factors for comparison with other studies.

Criteria and Standard Development

- Use latest wildlife toxicological studies and conduct others as needed to help determine acceptable contaminant levels in aquatic organisms and wildlife.
- Use results of sediment bioassays and conduct others as needed to evaluate toxic effects on sensitive indigenous benthic organisms (e.g., the amphipod *Corophium salmonis*).
- Using best available toxicology, develop sediment quality standards for the protection of benthic organisms and fish tissue quality standards for the protection of fish-eating wildlife.

Ambient Monitoring and Assessment

- Continue the USGS ambient monitoring program and coordinate this program with ongoing water quality studies managed by other agencies (e.g., U.S. ACOE measurements of river flow, total dissolved gas, dissolved oxygen, water temperature, and barometric pressure below Bonneville Dam). Attempt to incorporate monitoring data collected for compliance purposes.
- Couple ambient monitoring data with data on land and water use, precipitation quantity and quality, point and nonpoint source water quality, and the quantity of fertilizers and pesticides used in the basin.
- Perform synoptic sampling efforts at time of maximum concern for water quality conditions.

TABLE 5. SUMMARY OF PROGRAM RECOMMENDATIONS
(Page 2 of 2)

Fish and Wildlife Assessment

- Link habitat attributes to wildlife abundance for developing guidance on habitat mitigation, rehabilitation, and enhancement activities.
- Use existing studies documenting habitat loss in conjunction with studies identifying activities causing habitat loss to help focus regional management activities.
- Conduct additional fish health studies during summer months using fish autopsy and enzyme assay procedures.
- Use acid volatile sulfide/simultaneiously extracted metals (AVS/SEM) method in conjunction with sediment toxicity tests. If significant mortality routinely occurs, trace causes of toxicity by means of toxicity identity evaluation.
- Continue the USFWS bald eagle study. Focus on linking feeding habits and the duration of residency in the estuary with contaminant levels in eggs. Conduct additional assays to assess the relative contribution of the contaminants measured to reproductive impairment.
- Continue the NBS mink and river otter study. Focus on live trapped animals, assessment of the relative sensitivity of mink vs. river otter to contaminants, and assessment of factors contributing to depressed numbers of mink in the lower river.
- Supplement these data with fisheries and wildlife management data available from ongoing research and data collection activities conducted by Oregon and Washington fish and wildlife departments, Bonneville Power Administration, NMFS, U.S. ACOE, and the USFWS.
- Develop and implement an Ecological Risk Assessment program that utilizes the ambient data to assess the ecological health of the river.

Human Health Monitoring and Assessment

- Continue contaminant monitoring of popular recreational and subsistence fish species to assess the effects of resource management decisions on the quality of aquatic food resources harvested from the lower Columbia River.
- Perform regional survey of fish consumption practices.
- Collect fish tissue contaminant data for walleye, bass, and additional runs of salmon.
- Analyze fish samples for coplanar PCB congeners.
- The health agencies of Oregon and Washington should conduct a health analysis to determine whether the cancer and non-cancer effects of eating fish outweigh the known beneficial health effects.
- The health agencies of Oregon and Washington should prepare and disseminate instructional materials to the public identifying consumer behaviors that will reduce their exposure to contaminants contained in Columbia River fish.
- Conduct monitoring and assessment of bacterial indicators, specific pathogens, and conduct health risk assessments designed to provide rational water quality standards for the protection of recreational water uses. The bacterial monitoring program should include routine monitoring of popular swimming areas and mouths of tributaries and continued sampling through the onset of wet weather to identify the effects of "first flush".

Interagency Cooperation

- Develop and adopt standards and protocols for collecting, storing and transfering data, including geographic referencing, field and laboratory methods, and data storage and transfer formats.
- Develop and adopt an integrated data management system to facilitate data sharing among resource management agencies and the public.

trend with river mile or proximity to urban and industrial areas. The lack of clear relationships between fish contaminant levels and proximity to major contaminant sources may be due to seasonal migration, feeding habits, metabolic characteristics of the species sampled, transport of contaminants away from the source, variability in biomagnification, and insufficient sample size.

Confirm problem areas identified during the reconnaissance survey by conducting additional sampling, and identify the sources of the contaminants found. Controlling the identified sources of these contaminants should be the first priority. Control of some of these contaminants has already begun (i.e., dioxins and furans from pulp and paper mills). However, source identification should not be limited to point sources of these contaminants. Contaminant source evaluation should also include identification and quantification of nonpoint and in-place contaminant sources, including tributary inputs and input from the river above Bonneville Dam.

In-place contaminants, such as those that may be found in sediments, are often overlooked as a potential source. Resuspension of these sediments by storms or dredging can be a significant factor in the bioaccumulation and bioconcentration of contaminants by aquatic organisms. Laboratory and field studies should be conducted to evaluate the relative contribution from these phenomena to the overall contaminant loading for a particular site.

Contaminants discharged to air from industrial facilities may represent a significant source that has not been evaluated extensively in previous monitoring efforts. Data from existing air pollution and control programs should be used to supplement the data collected from other media.

One way in which the source of sediment contamination can be determined is through the use of chemical fingerprinting. Certain chlorinated organic compounds, such as PCBs and dioxins/furans, are found in hundreds of different configurations called congeners. The concentration pattern of the various congeners within a sample ("fingerprint") may in some cases be unique to a particular source. Sources may be identified by comparing the fingerprint of a suspected source with the fingerprint of a sediment sample. This technique can also be used on contaminanted animal tissues.

4.2 FATE AND TRANSPORT ASSESSMENT

To evaluate the significance of the various contaminant sources identified in the study recommended above, and to assess the significance of these sources to the contaminant levels measured at the identified problem areas, conduct fate and transport assessments. These assessments should consider relevant hydrodynamics, sediment transort, and food chain bioaccumulation, tracing specific contaminants in each medium. It is important to study both physical and biological dimensions of contaminant fate and transport. These studies should be designed so that the proposed pollution control measures can also be assessed.

4.3 CRITERIA AND STANDARDS DEVELOPMENT

Develop criteria that precisely define what levels of contamination warrant action. Such criteria would provide goals for reducing inputs from contaminant sources and cleaning up problem areas. Ideally, criterion development should be based on protecting specific lower Columbia River beneficial uses, and not be limited to adopting existing Oregon or Washington State water quality standards. Sediment criteria for protecting benthic organisms and fish tissue criteria for protecting fish and fish-eating wildlife are needed. Standards for benthic organisms may need to be developed by performing sediment bioassays using a variety of benthic invertebrates. In order to develop fish tissue standards, toxicological studies should be performed to determine safe levels of contaminants for various wildlife species.

Coordinate this criterion development with the fish and wildlife monitoring and assessment programs described in Section 4.5 below.

4.4 AMBIENT MONITORING AND ASSESSMENT

Implement a long term ambient monitoring and assessment program to give early warning of problems not previously identified. This program will provide data for the ongoing evaluation of water quality management decisions and the assessment of pollution source control activities. Focus the ambient monitoring program primarily on the quality of water and sediment.

To maximize the utility of monitoring data, encourage interagency cooperation (see Section 4.7) in monitoring efforts. Currently, many different agencies collect monitoring data on a regular basis. Incorporating these data into a single comprehensive program would yield more valuable information than any single agency could collect independently. Include data collected by municipal and industrial entities for environmental compliance purposes in this comprehensive program. These data are uniquely suited to assessing point sources.

The river should not be studied independently of the surrounding environment. Supplement the data collected from the analysis of sediments, water, and biota from the river with data on processes that contribute contaminants from outside the river, such as land and water use, agricultural practices, and precipitation quantity and quality.

The river is part of a dynamic system that changes over very short periods of time. In some seasons, day-to-day fluctuations in conditions may affect contaminant levels more than proximity to sources. Periodically conduct synoptic sampling, in which samples are collected simultaneously from multiple sites, at times when the concern for water quality is highest.

4.5 FISH AND WILDLIFE MONITORING AND ASSESSMENT

Closely coordinate fish and wildlife monitoring and assessment activities with the ambient monitoring program recommended above. Fish and wildlife monitoring and assessment should include:

- Wildlife habitat assessment
- Fish health and habitat assessment
- Fish population monitoring and trend analysis
- Bald eagle reproduction, habitat, and contaminant assessment
- Mink and river otter population, habitat, and contaminant assessment.

These assessments and the monitoring programs developed from them can guide the process of mitigation, rehabilitation, and enhancement of wildlife habitats and populations.

4.6 HUMAN HEALTH MONITORING AND ASSESSMENT

Because the human health risk assessment identified a potential for adverse human health effects resulting from consumption of lower Columbia River fish, human health monitoring and assessment is recommended. Continue to monitor and assess the chemical quality of recreational, subsistence, and commercial fish and shellfish resources of the lower Columbia River. Conduct comparative studies of the human consumers of fish and shellfish harvested from the lower Columbia River and elsewhere to verify the effects predicted by the risk assessment.

Risk estimates that have been made to date are subject to uncertainty from a variety of sources. Areas of uncertainty that could be reduced with the collection of additional data include: 1) fish consumption rate, 2) representativeness of fish tissue contaminant data, and 3) more specific identification of PCBs.

A regional survey of the fish consumption rates of people who live along the lower Columbia River has not been performed. Consumption data are critical for accurately estimating the extent to which fish consumers are exposed to fish tissue contaminants. Any survey of fish consumption practices should be designed to obtain the following data on the fish consumed: 1) quantity, 2) species, 3) capture locations, 4) seasonal variability in consumption, 5) preparation methods, and 6) cooking methods. The people surveyed should include both recreational fishers and subsistence fishers.

The human health risk assessment performed for the Bi-State Program included limited data on some species of sportfish, particularly walleye, bass, and salmon. No contaminant data for walleye and bass were collected, and only three composite samples of both chinook and coho salmon obtained from hatcheries were analyzed. Since one of the objectives of the risk assessment was to characterize health risks to recreational fishers, the limited data for these important game species represents an important data gap. To eliminate this data gap, future data collection efforts should target walleye and bass during the summer months and different runs of salmon at several times of year. Collect salmon from locations frequented by recreational fishers (e.g., Buoy 10 fishery).

The carcinogenic and noncarcinogenic risk estimates for PCBs are based on a single slope factor and reference dose, respectively. Each of the seven Aroclor mixtures analyzed for the risk assessment is composed of a different assemblage of some of the 209 PCB congeners, which vary in toxicity. A toxicity equivalence factor (TEF) approach similar to that used for dioxins and furans has been developed for coplanar PCB congeners (U.S. EPA 1992). Consider use of this approach in analyzing these congeners for future risk assessments so that a more precise estimate of risk can be made.

Because contamination with bacterial and viral pathogens has been identified as a potential human health problem in the lower river, monitor and assess human pathogens. Develop appropriate indicators for the presence of pathogens, identify the health risks associated with the types of pathogens identified, and attempt to identify the sources of these pathogens. The goal of this program should be developing standards to protect the use of the lower Columbia River for contact recreation.

4.7 INTERAGENCY COOPERATION

Effectively implementing the programs outlined above will require a high degree of interagency cooperation. Several of the baseline Bi-State Program studies have demonstrated that there is a wealth of data, knowledge and expertise among the local, state, and federal agencies charged with managing lower Columbia River resources. Interagency cooperation will also be needed to develop standard data collection protocols. Develop an integrated data management system that facilitates data access and sharing among resource management agencies and the public. Because recreational and commercial fisheries management can be effectively addressed only at the basin wide level, very broad interagency cooperation will be needed to address fisheries management issues in the lower Columbia River.

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APPENDIX A

LOWER COLUMBIA RIVER BI-STATE PROGRAM BIBLIOGRAPHY

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LOWER COLUMBIA RIVER BI-STATE PROGRAM BIBLIOGRAPHY

1.0 COMPILATION/CHARACTERIZATION OF EXISTING DATA

1.1 Compilation of Existing Data

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