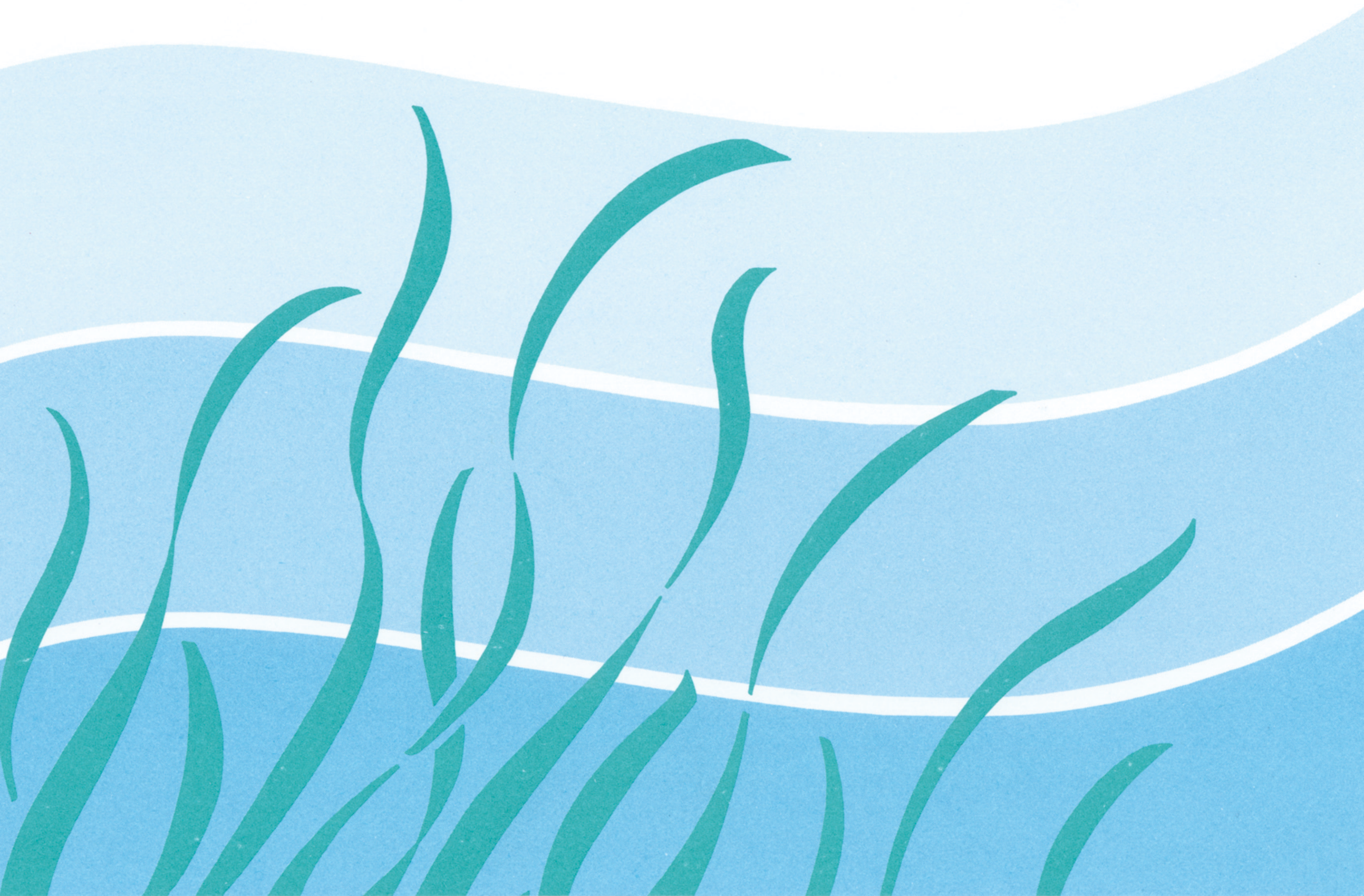
Padilla Bay
National Estuarine Research Reserve

Technical Report No. 10

REVIEW OF WATER QUALITY DATA IN THE PADILLA BAY/BAYVIEW WATERSHED

Douglas A. Bulthuis

October 1993



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ABSTRACT

Bulthuis, Douglas A. 1993. Review of water quality data in the Padilla Bay/Bay View watershed. Washington Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 10, Mount Vernon, Washington. 72 pp.

The published and unpublished data on water quality in Padilla Bay and the Padilla Bay watershed is reviewed and summarized in this report. Few studies have been conducted on water quality in Padilla Bay or its watershed. The limited data available indicate that Padilla Bay usually meets the Washington State water quality standards for Class A marine water. Four areas of concern are the high turbidity of influent sloughs, the rate of nutrient flow to Padilla Bay, the periodic influx of bacterial contamination and the low level, widespread toxicity of the sediments. The limited data available indicates that in the watershed the freshwater in the sloughs is regularly not meeting the water quality standards for fecal coliforms and dissolved oxygen. Turbidity and suspended solids are very high and similar to or above concentrations reported elsewhere in western Washington. Nutrient concentrations are similar to other agricultural watersheds and at concentrations at which eutrophication problems are "likely to exist." Temperature, total dissolved gas and pH of the sloughs almost always meet water quality standards. Most toxic materials that have been measured in the sloughs have not been detected or have been detected at low concentrations.

INTRODUCTION

A summary of the available water quality data in the Padilla Bay/Bay View watershed is an important first step in planning for non-point source pollution control in the watershed. The Skagit County Watershed Ranking Committee judged the Padilla Bay/Bay View Watershed to be the second highest ranking watershed in Skagit County for current and potential nonpoint source pollution issues and impacts (Skagit County Department of Planning and Community Development 1988). This ranking was based on verbal reports and local knowledge of water quality conditions, potential problems and the important beneficial uses, particularly in Padilla Bay. Subsequently, the Skagit County Department of Planning and Community Development initiated Watershed Action Planning for the watershed as prescribed in Washington Administrative Code, Chapter 400-12. This chapter of the code specifies the requirement for a watershed characterization including an assessment of existing water quality. This report is written to fulfill the requirement for a review of existing data on water quality in the watershed.

The Skagit County Watershed Ranking Committee (Skagit County Department of Planning and Community Development 1988) relied primarily on verbal reports of water quality and on the judgement of the various members of its Technical Advisory Committee. Although there have been several investigations of water quality complaints, there is no review of water quality data for the Padilla Bay/Bay View watershed. The purpose of this report is to review published and unpublished reports of water quality data for surface water in the Padilla Bay/Bay View watershed, to summarize the available data, and to compare the available data with State of Washington water quality standards, with State of Washington beneficial uses for these waters, and with other surface waters in selected watersheds in western Washington.

STUDY AREA DESCRIPTION

Padilla Bay and its watershed are located in the north lobe of the Skagit River delta in western Skagit County, Washington (Weisberg and Riedel 1991). The Skagit River has not flowed to the north lobe for at least 5000 years other than during flooding episodes; so that, Padilla Bay is an "orphan" estuary (orphaned from the river that formed it). Topographically and geologically the watershed is divided into two primary features: Holocene river deposits that are less than 20 feet above sea level and Vashon recessional deposits forming Bay View ridge that rises about 200 feet above sea level.

In addition, Vashion Till and older glacially compacted deposits form March Point, the Swinomish upland, and Samish Island, parts of which are in the Padilla Bay/Bay View watershed (Fig. 1).

The Padilla Bay/Bay View watershed is a small coastal watershed of about 23,000 acres. Agriculture is the major land use in the watershed occurring in about 65% of the area (Kelly 1993). Forest and woods cover about 7% of the area and about 15% is vacant or has miscellaneous uses. Commercial and industrial uses cover 7%, and residential uses about 3% of the area. About half of the agricultural land use is in annual commercial crops and the rest in pasture, berries, orchards, or miscellaneous uses (Kelly 1993). Vegetation cover in the watershed, therefore, varies with the season and year. During the 1992/93 winter, more than one half of the acreage in commercial crops had some type of winter cover crop.

The ground water resources of the watershed may be divided by the two major geological features: the ridges and the holocene river deposits. No comprehensive study of the ground water in the watershed has been conducted. However, a preliminary study on ground water resources (Sceva 1950) and the isolated studies for landfills (Hong West and Associates 1990, Sweet, Edwards and Associates 1985, 1987) indicate various small perched aquifers on the ridges (Bay View, March Point, Swinomish upland). A survey of available data to determine ground water resources in Skagit County indicated local low-yield aquifers in the lowland (Pacific Groundwater Group 1992). This later study surveyed the available data on water quality of ground water. The authors indicated potential water quality problems in the area of the watershed because of excess iron or manganese, saline water intrusion (Dion and Sumioka 1984), and wells with known or potential industrial contamination. The ground water in the watershed, thus, appears to be of variable water quality and volume. In some areas where ground water recharges surface water, the ground water is a potential source of contaminants to sloughs.

The only hydrological study of the surface waters of the watershed was conducted by Entranco Engineers as part of a study on pesticide runoff into Padilla Bay (Entranco Engineers and Nelson 1989). For one year, runoff from Joe Leary Slough, and Big and Little Indian Sloughs was recorded. Peak runoff occurred in winter and spring of 1988 with monthly flows of 500 acre-feet from Big Indian Slough and 2000 acre-feet from Joe Leary Slough. Low flows were recorded for July through October when about 50 acre-feet per month discharged from Big Indian Slough and 600 acre-feet per month from Joe Leary Slough. Joe Leary Slough recorded about twice as much runoff per unit acre as Big Indian or Little Indian Sloughs. The cause for this apparent difference between the two sloughs is not known, and the report suggested that it may be a measurement anomaly.

Surface fresh water flow from the watershed into Padilla Bay is primarily via four sloughs: Joe Leary, Big Indian, Little Indian, and No Name. All four sloughs have tide gates at their mouths that significantly alter the flow of water into the bay (Bulthuis 1993). In addition to the tide gates, water is pumped from Big Indian Slough and No Name Slough into the bay during times of high flow. The regulation of water flow through the tide gates causes the sloughs to have a daily rhythm of flow, storing water during a rising tide and discharging water during falling tides. The boundary between freshwater and estuarine water is more sharp and distinct in Padilla Bay than in most estuaries because of the tide gates on the sloughs.

Portions of Padilla Bay have been designated a National Estuarine Research Reserve with the proposed boundaries including most of the intertidal area of the bay and the islands of Hat, Saddlebag, and Dot. The designation of the bay as a National Estuarine Research Reserve emphasizes the important habitat and estuarine resources in the bay and the need to protect those resources. Most of Padilla Bay is intertidal with seagrasses covering about 3,000 hectares (about 7,400 acres), macroalgae about 200 hectares (500 acres), and bare mudflats about 2,000 hectares (5,000 acres) (Bulthuis 1991).

Water movement in Padilla Bay is dominated by the diurnal tides of up to 3 m (10 feet). Most of the marine water in Padilla Bay flows through the distributary channels into Guemes Channel and the deep water areas just west of Padilla Bay and via these channels back into the bay with rising tides. Swinomish Channel has a net northerly flow (McKinley et al. 1959), and thus, also contributes some water to Padilla Bay. Water quality within Padilla Bay, therefore, is determined not only by the freshwater flow from the sloughs, but also by the water quality of Swinomish Channel, Guemes Channel and the waters east of Guemes Island.

BENEFICIAL USES

The beneficial uses for surface water have been defined and listed in the Washington State Administration Code, Chapter 173-201A (Washington State 1992). The surface waters of the state are divided into four classes: AA, A, B, and C. All surface waters not specifically classified in the code are classified Class A. Padilla Bay is listed and classified marine water Class A. The watershed is not specifically listed and, therefore, is considered freshwater Class A. The beneficial uses for Class A include:

- domestic water supply
- agricultural water supply
- industrial water supply
- stock watering
- salmonid migration, rearing, spawning, and harvesting
- clam, crab, and oyster rearing, spawning, and harvesting
- other fish migration, rearing, spawning and harvesting
- shellfish rearing, spawning and harvesting
- wildlife habitat
- primary contact recreation (e.g. swimming)
- sport fishing
- aesthetic enjoyment

A full list of the beneficial uses for Class A waters as defined in the administrative code is listed in Table 1.

WATER QUALITY STANDARDS

Water quality criteria have been set by the State of Washington (Washington State 1992) in order to help protect the beneficial uses that have been identified for each particular class of water. The criteria are not exhaustive, that is, a water body that meets all of the numeric criteria may still not support the beneficial uses. The parameters that have been chosen, however, are those that are relatively easy to measure and those for which enough studies have been conducted to establish a criteria which will protect a beneficial use.

Water quality standards for Class A freshwater are:

Fecal coliform organisms: fecal coliform organism levels shall both 1) not exceed a geometric mean value of 100 colonies/100 mL, and 2) not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL.

Dissolved oxygen: dissolved oxygen shall exceed 8.0 mg/L.

Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

Temperature shall not exceed 18° C (64° F) due to human activities. When natural conditions exceed 18° C, no temperature increases will be allowed which will raise the receiving water temperature greater than 0.3° (0.5°F). Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8° C(5°F).

pH shall be within the range of 6.5 to 8.5 with a human-caused variation within a range of less than 0.5 units.

Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health.

Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

REVIEW OF WATER QUALITY STUDIES IN PADILLA BAY

Padilla Bay supports many of the beneficial uses that have been designated for Class A marine waters, in particular supports waterfowl, fish, and shellfish. Eelgrasses cover about 3,200 hectares (7,900 acres) of Padilla Bay (Bulthuis 1991); juvenile salmon use Padilla Bay during their outward migration to the sea, (Fresh 1979, Simenstad et al. 1988); the young of Dungeness crabs grow in the eelgrass beds of Padilla Bay (Dinnel et al. 1986, 1993); surf smelt, Pacific sand lace, threespine stickleback, sculpins, English sole, shiner perch, and other fish live in or feed in Padilla Bay (Fresh 1979, Simenstad et al. 1988, Dinnel et al. 1990); black brant, mallard, pintail, green-winged teal, wigeon, and other waterfowl use Padilla Bay during spring and fall migration (Jeffrey 1976, Reed et al. 1989); and harbor seals feed and haul out in Padilla Bay (Everitt et al. 1979, 1980). This diversity of plant and animal life in the bay is an indication that the water quality in the bay meets the standards that have been set to protect these beneficial uses.

There have been very few studies, however, that have directly measured water quality characteristics, although some studies have measured potential contaminants in the sediments. The earliest published studies of water quality in Padilla Bay were concerned with potential pollution from the pulp mills in Anacortes and their effect on oysters and oyster growth in Padilla Bay (Saxton and Young 1948, Orlob et al. 1950, Neale 1952, Wagner et al. 1957). These studies concluded that there was no evidence that sulfite waste liquor or other waste discharges from the pulp mills were causing the decline in growth of oysters in Padilla Bay. At the time of the construction and commissioning of the Texaco oil refinery, a pre-operational study included water quality stations in Padilla Bay. This study indicated relatively clear water other than some spent sulfite liquor that was detectable at low concentrations in the bay. The most extensive collection of water quality data in Padilla Bay was the study by Cassidy and McKeen (1986) in which they measured eleven parameters at eleven stations in Padilla Bay every week for one year. The only other data on water samples were a few studies on bacterial contamination (Williams 1975, Luce 1986, Cleland 1991, Walker 1993).

Contaminants in the bay can accumulate in the sediments. The sediments are included in "water quality" as defined by the Washington Administrative Code (Washington State 1992). Therefore, the reports on concentrations of oil, herbicides and pesticides in sediments, and toxicity of the sediments are included in this review in the section on toxic or deleterious material.

Fecal Coliforms

Fecal coliforms have been measured in Padilla Bay in a few studies, but often with only a single station or a few stations close together. The only data collected over a wide area is that by Washington State Department of Health (Cleland 1991, Walker 1993) that measured fecal coliforms at 15 sites near the center of Padilla Bay.

Williams (1975) reported fecal coliform counts of 10, 30, 30, and 32 colonies/100 ml in 4 samples collected at two sites in November 1975 near the entrance of Swinomish Channel to Padilla Bay. Luce (1986) reported one sample of 50 colonies per 100 ml and 3 samples with none detected. Bulthuis (unpublished data) reported fecal coliform counts per 100 ml ranging from <2 to 119 in samples taken approximately monthly from January to October 1992 in Swinomish Slough beneath the Highway 20 bridge (Table 2). The geometric mean of these samples, 11, is below the Washington State criteria for Class A water (14 colonies/100 ml), but 12% of the samples exceed 43 colonies/100 ml compared to the criteria that state no more than

10% of the samples should exceed 43 colonies/100 ml. Thus, Swinomish Slough may be causing bacterial contamination in Padilla Bay.

At fifteen stations near the center of Padilla Bay fecal coliform counts were low on five of six sampling dates in the study by Washington Department of Health (Walker 1993, Table 3, Fig. 2). The geometric means for these stations were less than 14 colonies/100 ml, the criteria for Class A water. However, on December 19, 1991, very high counts were recorded at stations 5, 6, 14, and 15 (Fig. 2, Table 3). The location of these stations indicates that fecal coliforms from Joe Leary Slough were impacting Padilla Bay water quality at that time.

Thus, the limited data on fecal coliforms in Padilla Bay indicate that bacterial contamination is usually low and within the Washington State criteria for Class A water. Periodically, however, Swinomish Slough and Joe Leary Slough contaminate localized portions of Padilla Bay above the criteria.

Dissolved Oxygen

The concentration of dissolved oxygen was generally high and around saturation of the water in Padilla Bay during 1985 - 1986 (Cassidy and McKeen 1986). The only months during which any Padilla Bay samples were below the Class A marine water quality standard of 6.0 mg/L of dissolved oxygen were July, August, and September. During July, one sample out of 147 was below the standard, during August, 4% of the samples, and during September, 6% of the samples were below 6.0 mg/L. During all other months of the year, all measurements of dissolved oxygen in Padilla Bay met the water quality standard. These data indicate that the waters of Padilla Bay are well oxygenated and have adequate dissolved oxygen to support the diverse plant and animal communities in the bay.

Temperature

The temperature of the water in Padilla Bay follows a seasonal trend. Average temperature at a central bay station fluctuated from 17°C (63°F) in July to 7°C (45°F) in December and February (Cassidy and McKeen 1986). The Class A marine water quality criteria states that temperature must be below 16°C (61°F). During June, July, and August, temperature in Padilla Bay was up to 20°C (63°F) and 23°C (73°F) at a few sites. Thus, Padilla Bay does not meet the water quality criteria for temperature during these months. The temperatures in Padilla Bay are higher than the adjacent marine waters during summer because Padilla Bay is so shallow. The sun heats the sediments and shallow waters during summer daytime low tides. Therefore, natural processes rather than man-made changes are the cause for temperatures in Padilla Bay that exceed the water quality criteria.

pH

Marine waters are well buffered with carbonate and bicarbonate ions compared to fresh water. Thus, problems with pH, either too acidic waters or too basic waters, are rare in bays and estuaries. In Padilla Bay, mean pH, measured weekly at eight stations, was within the water quality criteria of 7.0 to 8.5 (Cassidy and McKeen 1986). A few samples were above 8.5 during midsummer. These higher pH values probably were caused by the higher productivity of the seagrasses and macroalgae in the bay. During photosynthesis, plants remove carbon dioxide from the water which lowers the acidity of the water and increases the pH. Thus, pH in Padilla Bay is almost always within the water quality criteria and the few times when pH was above the water quality criteria, the probable cause was natural productivity of the plants in the bay.

Turbidity

Turbidity in Padilla Bay was usually low at all eight bay stations in the study by Cassidy and McKeen (1986). Seasonal means for the eight Padilla Bay stations varied from 5.5 NTU during summer to 1.8 NTU during spring. Fall and winter means were 3.5 NTU. These values indicate relatively clear water in Padilla Bay compared to the sloughs that flow into the bay. The water quality criteria state that the turbidity shall not increase more than 5 NTU over background. The data in the Cassidy and McKeen (1986) report provide the background and there are no previous reports of turbidity in Padilla Bay, so no comparison can be made with the water quality standards.

Nutrients

The plant nutrients, nitrogen and phosphorus, were measured by Cassidy and McKeen (1986) in 1985-1986 and during the summer months of 1992 by Bernhard (1993). Cassidy and McKeen's study indicates that both nitrogen (as nitrate) and phosphorus (as soluble reactive phosphate) are higher during the months of October through March and lower during the spring and summer months of April through September. These seasonal differences may reflect changes in the rate of nutrients flowing into Padilla Bay from the sloughs or differences in the utilization of nutrients by the marine plants - seagrasses, macroalgae and phytoplankton. During summer, marine plants usually grow at a faster rate than during winter, absorbing nutrients from the water. When growth rates are high enough, this absorption of nutrients can decrease the concentration of dissolved nitrogen and phosphorus in the water.

The concentrations of nitrogen as ammonia and of phosphorus as soluble reactive phosphate are higher than reported for the Strait of Georgia but somewhat lower than reported for Bellingham Bay during 1991 (Janzen and Eisner 1993). On the other hand nitrogen as nitrate and nitrite were generally higher in Padilla Bay than in Bellingham Bay (Cassidy and McKeen 1986; Janzen and Eisner 1993).

Bernhard (1993) measured the concentration of nutrients and conducted in situ experiments to determine the nutrients that limit growth of phytoplankton in Padilla Bay during the summer of 1992. She found that nitrogen was the primary nutrient limiting growth of phytoplankton during the warmer months. Thus, any increases in the supply of dissolved nitrogen to Padilla Bay are likely to increase the growth rate of phytoplankton in the bay.

Mats of macroalgae, such as sea lettuce, are one of the early effects of eutrophication in marine bays and estuaries (Bulthuis and Cowdell 1982). A survey of marine plant communities in Padilla Bay during the summer of 1989 indicated large accumulations of macroalgae (mainly sea lettuce) in the southern part of Padilla Bay (Bulthuis 1991). The cause for these large accumulations is not known, but they may be an early indication of eutrophication problems in Padilla Bay. The source of nutrients for these macroalgae may be the sloughs that flow into Padilla Bay as well as the nutrients that flow into the bay from Swinomish Slough and Guemes Channel.

In summary, there are little data on nutrients in Padilla Bay. However, the measurements that have been taken and the measurements on phytoplankton and marine algae indicate that eutrophication is a potential problem in Padilla Bay and that nitrogen may be the primary limiting nutrient.

Toxic or Deleterious Materials

The first published reports on water quality in Padilla Bay were concerned with complaints that sulfite waste pollution from the pulp and paper mill in Anacortes was affecting the oysters in Padilla Bay. Orlob et al. (1950) and Neale (1952) concluded that sulfite waste liquor was not the cause for the decline in oysters in Padilla Bay. However, Sylvester and Clogston (1958) reported low measurable levels of spent sulfite liquor in the water in Padilla Bay. The extent or effects of this material on Padilla Bay were not studied further.

Sediments are often a sink for toxic materials in bays and estuaries and, therefore, most studies of toxic materials in Padilla Bay have focused on contamination of the sediments. In a review of sediments throughout Puget Sound, Barrick (1987) ranked Padilla Bay sediments as having an intermediate level of toxic chemical contamination in the surface sediments. This ranking was based mainly on the concentration of a type of oil: polycyclic aromatic hydrocarbons.

Polycyclic aromatic hydrocarbons can be transported to Padilla Bay via the atmosphere (transportation, oil refineries, incinerator, open burning) or via stormwater runoff from urban, commercial, and industrial areas. Barrick and coworkers extensively analyzed the hydrocarbon content of sediment cores from the Puget Sound region (Barrick et al. 1980; Barrick and Hedges 1981; Barrick and Prahl 1987). At least one of these cores was from Padilla Bay. The concentration of combustion-derived polycyclic aromatic hydrocarbons in Padilla Bay sediments was among the highest found in their study, and the calculated surface accumulation rate of these compounds in Padilla Bay was the highest reported for Puget Sound. On the other hand, a second core taken at the Padilla Bay boundary indicated average concentrations of polycyclic aromatic hydrocarbons and low accumulation rates. Thus, limited data on hydrocarbons indicate some oil contamination of sediments in Padilla Bay.

Trace metals (cadmium, copper, lead, and mercury) were measured in sediments at eight sites in Padilla Bay by Antrim (1985). He reported low concentrations of all metals, consistent with background concentrations of metals throughout Puget Sound.

The March Point landfill is located in the southwest corner of Padilla Bay. Leachate from this former landfill is a potential contaminant of Padilla Bay sediments. Milham (1986) reported only slight and inconsistent concentrations of contaminants in the sediments of Padilla Bay near the landfill, in particular, slightly elevated concentrations of fluoranthene and toluene. These could not be linked directly to the landfill. Johnson (1989) reported that sediments near the landfill and near a Northwest Petrochemical outfall were not contaminated with cresylic acid nor with polychlorinated biphenyl. However, moderately elevated concentrations of phenol were measured. The chemical analyses conducted in these two investigations did not indicate contamination of the sediments by toxic compounds. However, bioassay studies of the sediments near the landfill indicate a high toxicity. Bulthuis and Shaw (1992) reported survival rates of 7% to 40% in sediments of the upper 20 mm near the landfill using the ten day bioassay with the marine amphipod, *Rhepoxynius abronius*. Similarly, Wiggins (1992) reported very high toxicity (up to 100% mortality) of the top 20 mm of sediment near the landfill. However, Wiggins also found that the top 2 mm of sediment were not toxic to *R. abronius*. This indicates that natural sedimentation is "capping" contaminated sediments at this site (Wiggins 1992).

Herbicides and pesticides used in the watershed on agricultural fields, roadsides, lawns, and other sites may enter the bay and accumulate in the sediments or in marine organisms that may be eaten by birds and other predators. Three studies have measured pesticides and herbicides in Padilla Bay or animals from Padilla Bay. Butler (1968) detected only trace amounts or no detectable concentrations of DDT, DDD, and DDE in oysters from Padilla Bay. Mayer and Elkins (1990) reported only trace amounts of dicamba and 2, 4-D in sediments of Padilla Bay in a study that specifically measured fourteen herbicides that were used on crops during the spring and summers of 1988 and 1989. Norman (1991) measured organochlorine contaminants in breast and liver tissue of nestlings and eggs of Great Blue Herons from the Samish Island colony. The concentrations of contaminants were below the levels indicating acute toxic effects. Data from all three reports were limited in the area sampled and the compounds analyzed, but all three indicate low levels of herbicides and pesticides in Padilla Bay.

Bioassays have been conducted on Padilla Bay sediments in several studies. Such assays indicate whether or not the sediments contain some compound toxic to a particular organism, although bioassays do not indicate which toxic compound is present. DeWitt et al. (1989) reported no toxicity from a single sample of sediment in Padilla Bay. Wiggins (1992) reported very high toxicity close to the March Point landfill, but low toxicity at a site about 500 m away. Bulthuis and Shaw (1992) measured toxicity of the sediments at 16 sites that were scattered throughout Padilla Bay. Mean survival of *Rhepoxynius abronius* ranged from 14 to 92 percent. These results indicated slight toxicity of the sediments at sites throughout Padilla Bay. There was no consistent pattern indicating a point source for the toxicity and it was suggested that the sea-surface microlayer may be a mechanism for concentrating contaminants in the intertidal sediments (Bulthuis and Shaw 1992). Gardiner (1992) compared the sea surface film and surface deposit onto intertidal flats in three bays: Commencement Bay (near Tacoma), Padilla Bay, and Discovery Bay (near Port Townsend). Toxicity of each bay was evaluated using three echinoderm (*Dendraster excentricus*) bioassays: 48 hour development test, sperm viability, and alterations in embroyonic mitosis. Padilla Bay samples were intermediate in their toxicity compared to Commencement Bay (numerous samples indicating toxicity) and Discovery Bay (Gardiner 1992). These results indicate that contaminants in the sea surface film and in the intertidal sediments cause some toxicity to marine life in Padilla Bay. These contaminants are most likely transported to the intertidal sediments via the sea surface microlayer.

Summary for Padilla Bay. As a whole, the studies on water quality and biota in Padilla Bay indicate a relatively healthy environment that supports a diverse and rich flora and fauna. Four areas of concern are the high turbidity of influent sloughs, the rate of nutrient flow to Padilla Bay, the periodic influx of bacterial contamination and the low level, widespread toxicity of the sediments.

REVIEW OF WATER QUALITY STUDIES IN THE WATERSHED

Very few studies have been conducted on the water quality of the freshwater of the Padilla Bay/Bay View watershed. The studies that have been conducted were usually short-term studies with a specific objective and no comprehensive study has been made of the waters in the watershed. Most of the studies on freshwater in the watershed have been conducted on Joe Leary Slough or Big Indian Slough. Two studies, Mayer (1989) and Luce (1986) also collected data from Little Indian Slough and No Name Sloughs.

Each of the studies in the watershed is briefly described in chronological order below, with some evaluation of the apparent quality assurance and quality control. This is followed by a brief description of four other watersheds in western Washington that are used for comparison of Padilla Bay/Bay View watershed data for those parameters for which no Washington State Water Quality criteria have been specified. The main body of this section is a discussion, parameter by parameter, of the data extracted from these various reports, along with a comparison with either Washington State Water Quality criteria or comparisons with other sloughs and streams in western Washington when water quality criteria are not specified.

SYNOPSIS OF STUDIES ON PADILLA BAY/BAY VIEW WATERSHED WATER QUALITY

Milham, S. E. 1986. *Site inspection report, Skagit County-March Point landfill, Anacortes, Washington.* This report includes analytical results of four water samples and two sediment samples taken near the March Point landfill. Analyses included volatile organics, EPA priority pollutants, dissolved priority pollutant metals, and total phenols. Very careful attention was given to quality assurance and quality control so that the results can be interpreted with a high degree of confidence. Essentially the study found only slight amounts of contamination and no hazardous concentrations of any of the measured contaminants.

Ecology and Environment. 1986. *Site inspection report of P. M. Northwest dump, Anacortes, Washington.* This report includes metals detected in two surface water samples collected near the site. Soil samples had elevated levels of organic compounds. Based on this limited sampling it is concluded that surface water runoff from the site appears not to be significantly contaminated by the dump. Ground water could become contaminated if organic compounds move laterally.

Luce, T. R. 1986. *Total coliform and fecal coliform levels in Padilla Bay and surrounding water.* The purpose of this student project was to investigate coliform levels in Padilla Bay and in sloughs flowing into Padilla Bay. Twenty two sites were sampled during July and August, most sites were sampled on a weekly basis for six weeks. Total and fecal coliforms were measured by the student in a laboratory at Western Washington University. Appropriate methods were used, duplicate samples were taken at all sites (only the mean's reported), and the methods section indicates careful attention to sample collection and holding times. However, the results should be interpreted with caution as indicative of the concentration of coliforms and should not be considered with the same confidence as samples from a certified laboratory. This report has the most extensive data set of coliform bacteria in the Padilla Bay/Bay View watershed.

Cassidy, P. M. and G. L. McKeen. 1986. *Padilla Bay baseline water quality record.* This study included extensive water quality sampling of Padilla Bay. Weekly samples at twelve sites were collected for one year. Parameters that were measured included dissolved oxygen, temperature, salinity, turbidity, pH, total and carbonate alkalinity, total nitrogen, ammonium, nitrate, nitrite, and total and soluble reactive phosphorus. Most sample sites were in Padilla Bay. However, two sample sites were located near the mouths of Joe Leary Slough and Big Indian Slough. Although the sample sites were on the marine side of the tidal gates, samples taken during low tide were samples of the freshwater flowing out of the tide gates at the time. For this review, the data in Cassidy and McKeen that indicates samples were taken during low tide and are freshwater (salinity less than 5 ppt) were used to indicate water quality in Big Indian and Joe Leary Sloughs. Quality assurance/quality control is not included in the report, but the authors are accomplished water analysts and the data are considered reliable.

Fitzpatrick, K. C. 1989. This letter includes data on metals in a leachate sample from the March Point landfill. While not reported in the letter, there appears to have been good quality assurance/quality control of sampling and analyses. This single sample indicates high heavy metal concentrations exceeding the state's acute toxicity criteria for marine systems.

Entranco Engineers and R. Nelson. 1989. *Padilla Bay Hydrologic Study*. The aim of this study was to measure flow from Joe Leary and Big and Little Indian Sloughs, and to develop a model capable of estimating flow from these sloughs into Padilla Bay based on the amount of rainfall in the watershed. Considerable difficulty with the water level meters, the diurnal pattern of flow through the tide gates, and the general instability of the hydraulic model led to the conclusion that the model would be too unreliable for use on a continuous basis. However, this report includes the only data on flow in the sloughs of the Padilla Bay/Bay View watershed.

Mayer, J. R. 1989. *Potential impact of agricultural pesticide runoff on Zostera marina and Zostera japonica (eelgrass communities) in Padilla Bay, Washington.* This report includes the results of a very careful study to measure the movement of pesticides (primarily herbicides) from crop fields into the sloughs and Padilla Bay. Water and sediment were collected on four dates from 18 sites and analyzed for the chemicals being applied by farmers in the watershed. Very careful attention was given to quality assurance/quality control. The results can be interpreted with a high degree of confidence even though QA/QC was not included in the report. No pesticides were detected other than low concentrations of Dicamba and 2, 4-D in water and in sediments. Ancillary measurements in the water included temperature, dissolved oxygen, pH and salinity.

Skagit County Department of Health. 1990-1992. *Monitoring of Joe Leary Slough near Inman Landfill.* The Skagit County Department of Health is monitoring water and sediments from Joe Leary Slough at three sites. Samples are collected each year during dry weather flow and wet weather flow. Parameters being measured include nutrients, turbidity, organic carbon, phenols, metals, volatile organics, and coliform bacteria. Careful attention is being given to quality assurance/quality control. The results can be interpreted with confidence. Access to the unpublished data was given to the author and are collectively referenced in this report as Skagit County Health 1990-1992, while the data from individual sample dates are contained in references Milat and Pfaff 1990a, 1990b; Noone-Fisher 1991; Columbia Analytical Services 1992.

Bulthuis, D. A. 1993. *Suspended sediments in Joe Leary Slough, a north Puget Sound coastal stream draining an agricultural watershed. Draft report.* This report includes data of a year long study of suspended sediments in Joe Leary Slough. Weekly samples were collected at three sites, hourly samples were collected for 26 hours on four occasions, and a longitudinal survey of Joe Leary Slough with 18 sites from mouth to headwaters was collected on two occasions. Parameters that were measured included total and organic suspended sediments, temperature, salinity and conductivity. Dissolved oxygen was also measured in the longitudinal survey. Careful attention was given to quality assurance/quality control. The results can be interpreted with confidence. The study indicated that suspended sediments in Joe Leary Slough fluctuate widely with season and rainfall, and that concentrations are very high relative to Padilla Bay and to other streams in Western Washington.

DESCRIPTION OF WATERSHEDS USED FOR COMPARISON

Woodland Creek. Woodland Creek, Thurston County originates in the Long - Hicks - Pattison Lakes basin, flows north through residential, commercial, and agricultural areas and eventually feeds into Henderson Inlet. The stream is classified Class AA. (Dickes and Reed 1992).

Portage Creek. Portage Creek is a tributary of the Stillaquamish River located near the City of Arlington in Snohomish County. The watershed covers about 19 square miles. The mainstem of the creek flows from highlands south of Arlington through agricultural lowlands. Elevations range from 540 feet above mean sea level to 20 feet mean sea level near the mouth. Portage Creek is classified "Class A". Land use in the watershed is predominantly agricultural with a forested perimeter. The majority of the lower watershed lies in the fertile Stillaquamish River floodplain and is farmed intensively for dairy and row crop production. The watershed description and data comparisons are from Plotnickoff and Michaud (1991).

Johnson Creek. Johnson Creek watershed covers about 13,500 acres and is located in north central Whatcom County. Johnson Creek flows into the Sumas River that flows northward into British Columbia. Land use in the watershed is dominated by agriculture on alluvial soil in the eastern portion and in the organic soils found in the northwest. Most of the farmland is used as pasture and hayland (80 percent) with some cropland interspersed (7 percent). Dickes and Merrill (1990) compared water quality data from 1980-81 with data collected in 1988-89. During the period between the two sampling years, Best Management Practices were implemented on many of the agricultural lands in the watershed. By 1988-89, 80% of the contracted projects were installed. The watershed description was taken from Dickes and Merrill (1990) and additional data comparisons from Dickes (1992a and 1992b).

Fir Island Sloughs. Fir Island is located in the delta of the Skagit River between the North and South Forks of the river. Brown, Hall, Dry, and Wylie Sloughs drain Fir Island, discharging into Skagit Bay through tide gates. Land use is primarily agricultural. Data for comparison with Padilla Bay/Bay View watershed is taken from the Lower Skagit River Basin Water Quality Study (Entranco 1993).

WATER QUALITY PARAMETERS

Fecal Coliforms

Fecal coliform colonies are a measure of the bacteria in the water. Fecal coliforms grow in the intestine of warm blooded animals and do not grow and reproduce in the water although they may survive. When individual cells or clumps of cells are placed in a favorable environment (human intestine or laboratory incubator) the cells will quickly grow and reproduce. The number of colonies formed within a standard time frame is used to measure the abundance of fecal coliforms. Thus, the reporting units are "colony forming units" or ("CFU" per 100 milliters of water, that is about 1/2 cup).

The only two reports that include data on fecal coliforms are Luce (1986) and Skagit County Health (1990-92). In addition, single samples were collected by Bulthuis and Booth (Washington Department of Ecology). All data on fecal coliforms in the watershed are reported in Table 4. Mean (geometric) fecal coliform counts were 400-500 per 100 mls in Joe Leary Slough in Luce's (1986) study (Table 4). Similar counts were recorded by Skagit County Department of Health in 1990, 1991, and 1992. Luce reported somewhat lower mean counts in Big Indian and No Name Sloughs with means of 136 and 178 (Table 4). In contrast to the other sloughs, Little Indian Slough had much lower counts with a maximum of 50 and a mean of 7.

Water quality standards specify a geometric mean of less than 100 CFU/100 mls and not more than 10% above 200 for Class A waters. Joe Leary, Big Indian, and No

Name Sloughs do not meet these standards in the limited data on coliforms that has been collected (Table 4, Fig. 6). Little Indian Slough was within these standards when it was sampled in July and August 1986.

The mean fecal coliforms for Joe Leary Slough are similar to the highest means reported for five watersheds in western Washington (Fig. 7). The Joe Leary data is from a more limited time period than for the other watersheds and direct comparisons should not be made until a full year of reliable data are collected. Nonetheless, the limited data available indicates significant fecal coliform problems in Joe Leary Slough comparable to Johnson Creek watershed that has a very heavy concentration of dairies.

Dissolved Oxygen

Dissolved oxygen was measured by Cassidy and McKeen (1986) at the mouths of Joe Leary and Big Indian Sloughs weekly for one year. In addition, Mayer (1986) and Bulthuis (1993) measured dissolved oxygen as ancillary data in their studies. Cassidy and McKeen recorded dissolved oxygen concentrations ranging from 2.8 to 10.0 mg/L (Table 5). The lowest concentrations were measured during the warmer months of March to September (Fig. 8). Similarly, Mayer reported lower dissolved oxygen in the sloughs during May, June, and August (Fig. 9).

The water quality criteria for Class A waters states that dissolved oxygen shall exceed 8 mg/L. In only a single sample out of 46 sample/dates was this standard met in Cassidy and McKeen's study (Fig. 8). Similarly, Mayer and Bulthuis' data indicate that all three sloughs that were measured, Joe Leary, Big Indian, and Little Indian, did not meet water quality criteria for dissolved oxygen in all months in which measurements were taken (Fig. 9, Table 4). During May, June, and August, 79% of the samples were below the water quality standard of 8 mg/L (Fig. 9).

The percent violations of the water quality standards are greater than those reported for Woodland and Potage Creeks (Fig. 10). Padilla Bay/Bay View Sloughs violated dissolved oxygen criteria at frequencies similar to Johnson Creek that drains a watershed with a high concentration of dairies and similar to the Fir Island sloughs that drain a watershed like the flat lands of Joe Leary Slough and Big Indian Slough. These data indicate significant dissolved oxygen problems in Joe Leary and Big Indian Sloughs and that these problems also occur in other creeks and sloughs in Western Washington (Fig. 10).

Total Dissolved Gas

The criteria for Class A water states that dissolved gas shall not exceed 110 percent of saturation. Generally the dissolved oxygen in the Padilla Bay/Bay View Sloughs is too low, but samples with percent saturation greater than 100% were recorded by Mayer in Big and Little Indian Sloughs in May 1987 and April 1988 (Table 6). These may have been a result of algal blooms which are capable of supersaturating the water with oxygen.

Temperature

Temperature was measured as an ancillary measurement in almost all studies in the watershed. Annual studies indicate a seasonal pattern of temperature fluctuation (Figs. 11 and 12). Cassidy and McKeen (1986) reported summer temperatures up to 24.4°C (76°F) (Table 5) while Bulthuis reported a maximum of 22°C (72°F) at the mouth of the slough, but a maximum of 19°C (66°F) at Allen West Road bridge (Bulthuis 1993, Fig. 12).

The water quality standard of 18°C (64°F) is more likely to be exceeded during the summer months. This standard was exceeded six times in weekly samples taken from Joe Leary Slough during 1990-91 (Bulthuis 1993). Similarly, 6 of 11 samples taken during June, July, and August at the mouths of Joe Leary and Big Indian Sloughs were above 18°C (64°F) in the study by Cassidy and McKeen (Table 5, Fig. 11).

pH

pH was measured weekly in the mouths of Joe Leary and Big Indian Sloughs in 1985-86 by Cassidy and McKeen (1986), in Joe Leary Slough by Skagit County Health at three sites near the Inman Landfill in 1991, and at several stations in Joe Leary, Big Indian and Little Indian Sloughs in 1987 and 1988 by Mayer (1989). pH ranged from 6.2 to 8.6 in these samples. The water above the mouth of the sloughs was usually slightly acidic in the range 6.6 to 6.9 (Table 7). Little Indian Slough was an exception to this generalization. Samples in Little Indian were usually above 7.0 with one sample as high as 8.6 (Table 7). At the mouth of the sloughs pH was close to neutral (7.0) or slightly above (Tables 5, 7, and Fig. 13).

The high pH's observed in Little Indian Slough in May and June 1987, and in August 1988 by Mayer (Table 7) stand out because almost all of the other pH measurements above the mouths of the sloughs were acidic. Blooms of phytoplankton can cause an increase in pH in freshwater (Wetzel 1975) and such a bloom may have caused the higher pH's observed by Mayer (1989). Evidence in support of this hypothesis is provided by the dissolved oxygen measurements taken at the same time (Table 6). During phytoplankton blooms, the water can become supersaturated (greater than 100%) with dissolved oxygen that is produced through photosynthesis by the algae during the day. The highest pH observed by Mayer was at station L1 in Little Indian Slough on May 19, 1987 (Table 7). At the same time and site the highest concentration of dissolved oxygen was recorded (168%) (Table 6). Both of these high values may have been caused by a phytoplankton bloom in Little Indian Slough.

The water quality standards state that the pH shall be within the range 6.5 to 8.5. Water quality within the sloughs was almost always within this range. The one exception above this range has been discussed above and may have been caused by a phytoplankton bloom. The only times the water was below this range were the three samples taken by Skagit County Department of Health in Joe Leary Slough near the Inman Landfill (Table 7). These low values stand out and seem anomalous compared to the rest of the pH measurements in Joe Leary Slough. Because the three values were taken the same day, they may indicate a short-term decrease in the pH. Another possible explanation is drifting of the pH meter that was used.

The pH values recorded for sloughs in the Padilla Bay/Bay View watershed are similar to those reported for other streams in Western Washington, such as, Woodland Creek, Thurston County (Dickes and Reed 1992); Portage Creek, Snohomish County (Plotnikoff and Michaud 1991); and Johnson Creek, Dakota Creek, Bertrand Creek, and Fishtrap Creek in Whatcom County (Dickes 1992a, Dickes 1992b, Dickes and Merrill 1990).

Turbidity

Turbidity was measured in Joe Leary Slough by Skagit County Department of Health as part of the Inman Landfill monitoring 1990-92, and weekly at the mouths of Joe Leary and Big Indian Sloughs during 1985-86 by Cassidy and McKeen (1986). Turbidity ranged from 16 to 65 NTU at the mouth of the sloughs with a median value of 30 (Table 5). Similar values were reported from both sloughs, although the lowest values were found at Big Indian Slough and the highest values at Joe Leary Slough. These high turbidities were recorded during all months of the year and there was not a strong seasonal trend (Fig. 14). However, mean turbidity for the months of June, July, and August was 46 NTU compared to an average turbidity of 28 during the remaining months. Similar high turbidities were recorded by the Skagit County Department of Health during 1990-1992 in Joe Leary Slough (Table 8).

The water quality standards for Class A waters state that turbidity shall not exceed 5 NTU over background turbidity. Unfortunately, there are no data for background turbidity for these sloughs so no comparison can be made with the water quality standards.

The turbidity in sloughs of the Padilla Bay/Bay View watershed are very high compared to values reported for other streams and sloughs in Western Washington (Fig. 15). Woodland Creek had a median turbidity of 2 NTU. In Portage Creek and tributaries, Plotnikoff and Michaud (1991) measured turbidity at 110 different sites or dates. Out of 110 data points, all but 1 were 14 NTU or less. Only one value was above 14 NTU. This contrasts with the range of turbidities from 15 to 65 NTU (Table 5) and 23 to 99 (Table 8) in the two studies in the Padilla Bay/Bay View watershed. In Johnson Creek watershed in Whatcom County, Dickes and Merrill (1990) compared water quality data from 1980-81 with data collected in 1988-89. During the period between the two sampling years, Best Management Practices were implemented on many of the agricultural lands in the watershed. By 1988-89, 80% of the contracted projects were installed. Median turbidity for all sites in the watershed was 6 NTU in 1980-81 and declined to a median of 2 NTU in 1988-89. Dickes and Merrill attributed the decline to the extensive fencing program implemented to exclude livestock from the creeks and increased bank revegetation. In comparison the median turbidity in Joe Leary and Big Indian Sloughs was 30 NTU in the study by Cassidy and McKeen. Median turbidity in four sloughs on Fir Island ranged from 5 to 18 NTU (Entranco 1993). Mean monthly turbidity in the Skagit River varied from about 6 to 12 NTU from January to October and then was 30 and 20 NTU in November and December (Entranco 1991). Median turbidity in Joe Leary and Indian Sloughs is higher than the median turbidities reported in any of the above mentioned studies of streams and sloughs (Fig. 15).

In summary, the limited data on turbidity in the sloughs of Padilla Bay/Bay View indicates high turbidity in the sloughs compared to other streams and rivers in western Washington. Although there is no "background" data with which to compare these values, the high turbidity would be expected to impair many of the designated beneficial uses.

Suspended Solids

Suspended sediments were measured in Joe Leary Slough during 1990-1991 (Bulthuis 1993). Weekly suspended sediments at three sites ranged from 3 to 199 mg/L. A pronounced seasonal fluctuation in suspended sediments was observed with lower concentrations measured during June through September, and the highest concentrations measured during November and during February through April (Figs. 16 & 17).

The tide gates at the mouth of the sloughs caused daily fluctuations in all parameters that were measured. The concentration of suspended sediments increased when water flowed out of the tide gates and decreased as saline water from Padilla Bay seeped into the slough (Fig. 18). The water height increased slowly when the tide gates were closed, but decreased more quickly when the tide gates were opened. This same pattern of inverse correlation between water salinity and concentration of suspended sediments was observed on all four tidal cycles, winter, spring, summer, and autumn, that were measured (Bulthuis 1993). The water flow (and concentration of suspended sediments) at Allen West Road also fluctuated with the tide.

The concentration of suspended sediments differed by more than ten times from the headwaters of Joe Leary Slough to its mouth at the tide gates with the highest concentrations near the headwaters (Tables 9 and 10). Concentrations of suspended sediments were somewhat lower during the time of high flow compared to low flow.

The suspended sediments are primarily inorganic, ranging from 10% to 58% organic material by dry weight (Tables 9 and 10). Organic weight was higher in the headwaters than near the mouth. In the samples taken in November 1991 all of the sites east of Interstate 5 had an organic content of 50% or greater and all sites west of Interstate 5 had an organic content less than 50% (Table 10).

The source of sediments to the sloughs may include sediments carried with surface flow from fields used for annual crops. Sampling conducted during moderate rainstorms during December 1991, indicated that presence of a cover crop substantially reduced the concentration of suspended sediments in surface runoff, while the construction of a V-ditch substantially increased the concentration of suspended sediments (Fig. 19).

Water quality standards do not include criteria for total suspended sediments. Suspended sediments in Joe Leary Slough are high compared to other streams in Western Washington for which data are available. Mean concentrations in Woodland Creek, Thurston County were 3-5 mg/L at three sites (Dickes and Reed 1992). Mean concentrations at five sites along Portage Creek, Snohomish County ranged from 1.5 to 5 mg/L (Plotnikoff and Michaud 1991). In Johnson Creek, Whatcom County, one site near the headwaters had a mean concentration of 26 mg/L and the remaining four sites downstream had means from 5 to 8 mg/L (Dickes and Merrill 1990). In comparison the mean concentrations at the three Joe Leary sites were 42, 49, and 55 mg/L (Figure 20).

The only sites for which mean concentration of suspended sediments were similar to Joe Leary Slough were the four sloughs on Fir Island.

In summary the limited data on suspended sediments indicate large seasonal fluctuations, and overall, a very high concentration of suspended sediments compared to other streams and sloughs in Western Washington.

Nutrients

The nutrients, nitrogen and phosphorus, can increase growth of plants in freshwater or saltwater. If these growths of algae or higher plants become too great, they can cause serious problems, particularly during the process of their decay. Nutrient loading that leads to excessive growths of algae is considered eutrophication. Excessive growths of algae can lead to poor water quality such as low dissolved oxygen, poor water clarity, poor habitat for fish and other aquatic animals and bad taste and odor of the water. Phosphorus is often the nutrient most limiting in freshwater and nitrogen in marine water. Therefore, the concentration and loading rates of these two nutrients is considered an important indicator of water quality and of the potential for water quality problems to develop.

The nutrients nitrate, ammonium, and phosphorus were measured by Cassidy and McKeen (1986) at the mouths of Joe Leary and Big Indian Sloughs. Nitrate concentrations ranged from 0.003 to 4.8 mg/L and ammonia from 0.03 to 4.7 mg/L (Table 5). Nitrate concentrations were higher during the wet season (November to April) and lower during the dry season (May to October) (Fig. 21). Ammonium did not show the same seasonal distribution, with high concentrations occurring most months of the year (Fig. 22). Total phosphorus ranged from 27 to 1100 ug P/L (Table 5) with little evidence of any seasonal trends other than a few high values in the spring months (Fig. 23). Orthophosphate ranged from 0 to 38 ug P/L with no seasonal trends (Fig. 24).

Water quality standards have been set only for ammonium as a toxicant, and no standards have been set for Washington State for nutrients as potential contributors to algal blooms and eutrophication. However, some indication of the relative level of pollution can be provided by a comparison with other streams in Western Washington and by comparison with a review of nonpoint source watersheds throughout the United States (Omernik 1977).

Total inorganic nitrogen means at various sites on Portage Creek ranged from 2 to 6.5 mg/L during the wet season and from 0.8 to 1.4 during the dry season. Annual means on Big Indian and Joe Leary Sloughs were 1.9 and 2.7 mg/L respectively. Annual station means on Johnson Creek ranged from about 5.5 to 7.5 mg/L of total inorganic nitrogen. No means were calculated for Dakota, Bertrand, and Fishtrap Creeks in Whatcom County, but the concentrations of total inorganic nitrogen ranged from about 0.34 to 13 mg/L of nitrogen. The majority of values were between 2 and 4 mg/L. These are similar to the concentrations in Joe Leary and Big Indian Sloughs where total inorganic N in individual samples ranged from 0.8 to 6.5 mg/L and the majority of values were between 1 and 4 mg/L. Thus, the sloughs in the Padilla Bay/Bay View watershed have similar total inorganic nitrogen concentrations to Portage Creek, Snohomish County and Bertrand, Dakota, and Fishtrap Creeks in Whatcom County but about one half the concentrations reported for Johnson Creek, Whatcom County.

Omernik (1977) summarized nutrient data from 730 nonpoint source type watersheds distributed throughout the United States. For watersheds in the western U.S. with agriculture comprising between 50% and 75% of the land use in the watershed, the average inorganic nitrogen concentration was 1.7 mg/L. The mean concentrations of 1.9 and 2.7 mg/L in Big Indian and Joe Leary Sloughs are only slightly higher than this region wide average.

Total phosphorus means from other Washington streams includes 0.04 to 0.05 mg/L in Woodland Creek, 0.10 to 0.35 for wet season and 0.2 to 0.8 for dry season means on Portage Creek, and a mean concentration on all sites in the Johnson Creek watershed of 0.23 mg/L in 1988; a significant rise from 0.11 in 1980. Big Indian and Joe Leary Sloughs with annual means of 0.20 and 0.38 mg/L total phosphorus are higher than Woodland Creek and similar to Johnson Creek and most sites on Portage Creek, but not as high as the maximum dry weather mean from Portage Creek.

Omernik (1977) reported a mean total phosphorus of 0.17 mg/L and orthosphosphate of 0.07 for watersheds in the western United States with 50% to 75% of land use in agriculture. The Padilla Bay/Bay View watershed is higher than this regional average based on Big Indian and Joe Leary Sloughs with a total phosphorus mean of 0.29 mg P/L and an orthophosphate mean of 0.12 mg P/L.

Although there are no water quality criteria set for nutrients in Washington, Mills et al. (1985; cited in Joy et al. 1991) suggested the following "eutrophication potential" scale for river systems when both nitrogen and phosphorus are present at certain concentrations:

Total phosphorus (ug/L)	Total nitrogen (ug/L)	Significance
13	92	Problem threshold
130	920	Problem likely to exist
1300	9200	Severe problems possible

This "eutrophication potential" scale for river systems may not directly apply to streams and sloughs, but will provide some indication of the potential for eutrophication problems. Comparing Figures 21, 22 and 24 with the above values, indicates that on almost all sample dates the concentrations of nitrogen and phosphorus are above the concentrations at which "problems are likely to exist." Thus, the nutrient concentrations in the sloughs of Padilla Bay/Bay View are similar to other agricultural watersheds and those at which eutrophication problems are likely to exist.

Toxic materials

Herbicide concentrations have been measured in the waters and sediments of the sloughs in the Padilla Bay/Bay View watershed by Mayer and Elkins (1990). Their study tested for the presence and concentration of herbicides before and at the time of the first major rainfall event following application of the herbicides on crops in the watershed. Thus, the concentrations measured were expected to be at their highest at the time of sampling. In the two year study, Mayer and Elkins detected only two herbicides, dicamba and 2, 4-D in the water and sediments during the first year and none were detected the second year. Dicamba was found in the sediments of Big and Little Indian Sloughs, and in the water of the sloughs and in the bay. Concentrations in the water were low, ranging from 10 to 160 μg/L. Low levels of 2, 4-D were also detected in slough waters ranging from undetectable to 1.1 μg/L. During the second year of the study, no herbicides were detected in any water or sediment samples. The sources of the Dicamba and 2, 4-D suggested by Mayer and Elkins (1990) were roadside vegetation management. This is consistent with the reported herbicides used in the

Padilla Bay/Bay View watershed (Claybo 1993). The study by Mayer concluded that no ecologically significant levels of any of the fourteen pesticides studied were found in the water or sediments of Padilla Bay sloughs.

Toxic materials may enter waterways from landfills via movement of ground water. The Inman Landfill, the Whitmarsh dump, and the P.M. Northwest Dump are all located in the Padilla Bay/Bay View Watershed. The Inman Landfill is located on Bay View ridge and has both an active landfill and a closed landfill (Sweet, Edwards and Associates 1985, 1987). The landfill has had monitoring wells placed around its perimeter and residential wells in the vicinity have been tested. On the basis of the available data Parametrix (1992) concluded that ground water within 2 aquifers underlying the site has been impacted by landfill activities. State secondary standards and state carcinogen standards were exceeded in some wells. Sweet, Edwards and Associates (1985) also stated that the discharge for the aquifers was not known, but that "springs and seeps along the northern margin of the site near the top of Bay View Ridge and Joe Leary Slough are the most likely candidate areas for discharge." Contaminants that have been detected in monitoring and domestic wells include iron and manganese (a common impact of municipal solid waste landfills), vinyl chloride, volatile organics and total organic carbon and TOX. It is clear from the studies on Inman Landfill that the landfill is impacting ground water and may be discharging to Joe Leary Slough (Sweet, Edwards and Associates 1985, 1987, Parametrix 1992).

Skagit County Department of Health has been monitoring Joe Leary Slough sediments and water since 1990, testing for any evidence of a wide range of potential toxicants. No significant levels of any of the toxicants has been reported. Most potential toxicants have not been detected including phenols, lead, and 40 volatile organic compounds. Very low levels of zinc and cadmium have been detected, but these appear to be background concentrations. Methylene chloride was detected in several samples but this appears to be a laboratory contamination problem. One group of toxic compounds that is consistently detected in the water above and below the Inman landfill are total organic halides. The concentrations are low, 11-31 mg/L (ppb), and just above the method detection limits.

In addition to the monitoring of Joe Leary Slough by Skagit County Department of Health, there have been a few site investigations of potential toxic sites. Milham (1986) inspected the March Point landfill site to evaluate the site for possible hazardous cleanup. Samples were taken of sediments and water including leachate at the site and of an estuarial stream on the edge of the landfill. No phenols, or acid, base, or neutral extractables were detected in water or sediments. Slight amounts of toluene (51 ppb) and fluoranthene (50 ppb) were found in Padilla Bay sediments, and arsenic was found at 126 ppb in the estuary stream sediments. These concentrations indicate slight contamination of the sediments around the site. The report concluded that the data did not show a significant problem at the landfill site and that no further sampling or remedial action should be taken.

Leachate from this landfill was sampled again in June 1988 (Fitzpatrick 1989). Analysis of the leachate for priority pollutant metals in a single grab sample indicated high levels of some metals (Table 11). The concentrations for cadmium, copper, lead, nickel, and zinc are above the acute toxicity criteria for marine waters. [No data on hardness of the water was provided with the report, and hardness of the freshwater is used to calculate the acute toxicity of metals in freshwater. Therefore, the acute toxicity for marine water is presented in Table 11 as indicative of the levels of contamination.] These very limited data indicate that freshwater leachate from the March Point landfill may be contaminating Padilla Bay water and sediments.

An investigation was conducted of P.M. Northwest Dump by Ecology and Environment (1986). Part of that investigation included samples of surface water upgradient and downgradient of the landfill. The two grab samples indicate only limited contamination of surface waters by metals at the site. Water samples were not analyzed for hydrocarbons although sediment samples from the site indicated hydrocarbon contamination.

SUMMARY OF EXISTING WATER QUALITY PROGRAMS IN THE WATERSHED

There are only two existing (1993) water quality studies that include sampling and analysis of freshwater in the watershed.

One study is the monitoring of Joe Leary Slough near the Inman landfill that is being conducted by the Skagit County Department of Health. This study includes annual dry and wet weather sampling of water and sediments from three sites on Joe Leary Slough. Parameters being measured include temperature, pH, turbidity, total coliforms, fecal coliforms, ammonia, chloride, nitrate, total phosphorus, phenolics, total organic halides, zinc, cadmium, lead and 41 volatile organic compounds. This study is expected to continue in order to indicate whether or not the Inman Landfill is contaminating Joe Leary Slough.

A second study is the Padilla Bay/Bay View watershed monitoring project. The project is described in detail in Anon. (1993). Basically, water monitoring will be conducted at 15 sites with a mixture of low flow sampling and storm event sampling.

Parameters being measured include temperature, conductivity, pH, dissolved oxygen, salinity, fecal coliform, total suspended solids, ammonia, nitrate, nitrite, total kjedhal nitrogen, soluble reactive phosphorus, total phosphorus, oil and grease, metals, acid based extractables and neutrals, chlorinated phenols and the EPA priority pollutant list. Sampling will be conducted during 1993, with no further sampling and analysis planned in future years.

CONCLUSIONS

This review of historical water quality indicates that there is little data on water quality in the Padilla Bay/Bay View watershed. The limited data that has been collected indicates that freshwater in the sloughs is regularly not meeting the water quality standards for fecal coliforms and dissolved oxygen. The turbidity and suspended solids are very high and similar to or above concentrations reported elsewhere in western Washington. Nutrient concentrations are similar to other agricultural watersheds and at concentrations at which eutrophication problems are likely to exist. Temperature is occasionally too high at the mouth of the sloughs during the summer. Total dissolved gas and pH of the sloughs almost always meet water quality standards. Most toxic materials that have been measured have not been detected or have been detected at low concentrations. Limited data indicates that leachate from landfills at toxic levels may be flowing into Padilla Bay and requires further investigation at the Whitmarsh Landfill. Leachate from the Inman Landfill has impacted ground water and may be leaching into Joe Leary Slough. The water quality in the sloughs has resulted in loss of some beneficial uses. In particular, the waters are not suitable for domestic water supply; no longer support migration, rearing, spawning, or harvesting of salmonids or other fish; have decreased value for wildlife; and are not suitable for primary or secondary contact recreation, sport fishing, or aesthetic enjoyment.

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Table 1. Characteristic beneficial uses for Class A waters as defined by Washington Administrative Code (Chapter 173-201A): Water Quality Standards for Surface Waters of the State of Washington (Washington State 1992).

(i)	Water supply (domestic, industrial, agricultural).
(ii)	Stock watering
(iii)	Fish and shellfish: Salmonid migration, rearing, spawning, and harvesting. Other fish migration, rearing, spawning, and harvesting. Clam, oyster, and mussel rearing, spawning, and harvesting. Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting.
(iv)	Wildlife habitat.
(v)	Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).
(vi)	Commerce and navigation.

Table 2. Total and fecal coliforms (colonies/100ml) in Swinomish Slough beneath Highway 20 bridge near the time of low tide. Data from Bulthuis (unpublished).

Date	Sample No.	Time	Sample depth meters	Coliform Total	Coliform Fecal
21-Jan-92	B001	1206	surface	1100	9.1
21-Jan-92	B002	1207	surface	460	<3
27-Jan-92	B003	1824	surface	240	15.
27-Jan-92	B004	1824	surface	240	15.
3-Feb-92	B005	2255	surface	210	43.
3-Feb-92	B006	2255	surface	64	3.6
11-Feb-92	B007	1653	surface	150	23.
11-Feb-92	B008	1655	surface	93	9.1
17-Feb-92	B009	2221	surface	39	3.6
17-Feb-92	B010	2223	surface	39	9.1
24-Feb-92	B011	1629	surface	43	23.
24-Feb-92	B012	1629	surface	210	64.
1-Mar-92	B013	2149	surface	43	3.1
1-Mar-92	B014	2149	surface	75	9.1
21-May-92	B017	1321	surface	8	2.
21-May-92	B018	1321	surface	5	2.
17-Jun-92	B019	1305	surface	2	2.
17-Jun-92	B020	1305	surface	2	<2
15-Jul-92	B021	1224	surface	20	10.
15-Jul-92	B022	1224	surface	22	2.
26-Aug-92	B023	1045	surface	40	15.
26-Aug-92	B024	1045	surface	40	12.
9-Sep-92	B025	910	surface	110	30.
9-Sep-92	B026	910	surface	160	20.
9-Oct-92	B027	1035	surface	150	81.
9-Oct-92	B028	1035	surface	120	119.
Geometric mean					11.2

Table 3. Fecal coliforms (colonies/100 ml) at fifteen stations in Padilla Bay. Each station was sampled twice on each sampling date with 1/2 to 4 hours between the sample times. Data extracted from Walker (1993). Sample stations shown in Fig. 2.

Station No.	22 July 91		23 July 91		24 July 91		19 Dec 91		25 Feb 92		26 Feb 92	
1	1.8	1.8	1.8	2.	1.8	2.	2.	1.8	1.8	1.8	1.8	1.8
2	1.8	1.8	1.8	1.8	1.8	7.8	1.8	1.8	1.8	1.8	1.8	1.8
3	1.8	2.	1.8	1.8	1.8	1.8	4.	7.8	2.	1.8	1.8	1.8
4	1.8	2.	1.8	1.8	2.	6.8	7.8	13.	1.8	1.8	2.	1.8
5	1.8	2.	1.8	1.8	22.	7.8	33.	33.	1.8	1.8	4.5	1.8
6	2.	1.8	1.8	1.8	4.5	7.8	33.	130.	2.	4.	1.8	1.8
7	1.8	1.8	2.	1.8	2.	1.8	11.	4.5	1.8	1.8	1.8	1.8
8	1.8	1.8	1.8	1.8	4.5	1.8	2.	2.	2.	1.8	1.8	1.8
9	2.	2.	1.8	1.8	4.5	2.	1.8	1.8	1.8	2.	1.8	1.8
10	1.8	1.8	1.8	1.8	1.8	1.8	2.	1.8	1.8	1.8	1.8	1.8
11	1.8	1.8	1.8	1.8	1.8	1.8	2.	1.8	1.8	1.8	1.8	1.8
12	1.8	1.8	1.8	1.8	1.8	4.5	2.	1.8	1.8	1.8	1.8	1.8
13	6.8	1.8	1.8	1.8	22.	7.8	13.	4.5	1.8	1.8	2.	2.
14	1.8	1.8	1.8	1.8	1.8	2.	33.	17.	1.8	1.8	1.8	1.8
15	1.8	1.8	1.8	1.8	1.8	13.	110.	240.	1.8	1.8	1.8	1.8

Table 4. Total and fecal coliforms in freshwater sloughs of the Padilla Bay/Bay View watershed. Data from Luce (1986), Skagit County Health (1990-92), Bulthuis (unpublished), and Booth (Ecology, personal communication). TNTC = too numerous to count; n.d. = not determined. The geometric mean was calculated for fecal coliforms for those stations for which two or more samples were taken within a 7 week period in 1986. Location of sample sites are indicated in Figs. 3-5.

Site No.	Slough	Date	Total Coliform (per 100 mls)	Fecal Coliform (per 100 mls)	Fecal Coliform Geometric mean	Source
8	Joe Leary	1-Jul-86	n.d.	950	475	Luce
		8-Jul-86	1200	250		
		15-Jul-86	700	300		
		29-Jul-86	1300	380		
		5-Aug-86	1600	710		
		12-Aug-86	1300	600		
9	Joe Leary	22-Jul-86	1000	740		Luce
10	Joe Leary	22-Jul-86	900	590		Luce
11	Joe Leary	8-Jul-86	2100	500	571	Luce
		29-Jul-86	1300	610		
		5-Aug-86	1400	1200		
		12-Aug-86	800	290		
12	Joe Leary	1-Jul-86	TNTC	350	454	Luce
		15-Jul-86	1000	n.d.		
		29-Jul-86	1400	590		
9	Joe Leary	22-Apr-91	460	240		Skagit Co.
		30-Sep-92	>2400	240		
H2	Joe Leary	22-Apr-91	4600	4600		Skagit Co.
		30-Sep-92	>2400	46		
11	Joe Leary	22-Apr-91	4600	1100		Skagit Co.
		30-Sep-92	>2400	1100		
H2	Joe Leary	15-Dec-92	1100	240		Bulthuis
?	Joe Leary	Nov-90		4,400,000		Booth
13	Little Indian	1-Jul-86	600	40	7	Luce
		8-Jul-86	200	50		
		15-Jul-86	3900	n.d.		
		22-Jul-86	<1	<1		
		22-Jul-86	600	5		
		29-Jul-86	850	25		
		5-Aug-86	15	<1		
		12-Aug-86	100	5		
14	Big Indian	1-Jul-86	500	150	136	Luce
		8-Jul-86	250	50		
		15-Jul-86	450	100		
		22-Jul-86	2900	120		
		29-Jul-86	1700	110		
		5-Aug-86	TNTC	240		
		12-Aug-86	850	360		
15	No Name	1-Jul-86	TNTC	1400	178	Luce
		1-Jul-86	TNTC	TNTC		
		22-Jul-86	<1	<1		
		12-Aug-86	1200	120		

Water quality criteria for these waters states that the geometric mean for fecal coliforms shall not exceed 100 colonies per 100 mls.

Table 5. Water quality in Joe Leary Slough (site 12) and Big Indian Slough (site 10) from June 1985 to May 1986. Data are extracted and modified from Cassidy and McKeen (1986). All samples with a salinity of 5 parts per thousand or less were extracted from the data of weekly samples taken at the mouth of the two sloughs.

Site	Date	D.O. ppm	Temp. °C	Salinity ppt	Turb. FTU	pH	NO3 mg N/L	NH3 mg N/L	Tot. P µg P/L	PO4 µg P/L
10	12/Jun/85	3.0	17.4	1.0	43	7.1	0.54	0.47	222	0.
12	12/Jun/85	3.4	16.4	0.0	35	7.1	0.15	1.36	321	2.5
10	19/Jun/85	6.1	23.0	4.2	46	6.9	0.45	0.84	27	0.
12	19/Jun/85	2.8	20.2	2.0	57	7.0	0.14	1.17	44	0.
12	26/Jun/85	5.2	22.4	2.1	46	7.2	0.10	1.20	245	0.
12	02/Jul/85	3.7	17.0	2.0	60	7.2	0.11	1.28	550	0.
12	10/Jul/85	6.0	24.4	1.6	51	7.3	0.09	1.20	41	0.
12	17/Jul/85	4.0	21.0	1.8	44	7.1	n.d.	2.59	204	11.7
12	31/Jul/85	3.2	16.4	1.8	47	7.2	n.d.	4.70	182	25.6
12	14/Aug/85	5.2	19.8	1.6	45	7.3	n.d.	2.34	20	36.3
12	28/Aug/85	4.7	16.0	1.2	34	7.3	0.44	1.77	143	19.1
12	11/Sep/85	4.1	18.0	3.7	27	7.3	0.30	1.53	139	29.9
12	25/Sep/85	5.4	14.0	1.5	35	7.3	0.00	1.26	316	7.3
10	29/Oct/85	7.0	9.5	3.6	29	6.7	0.39	0.35	175	11.5
12	29/Oct/85	5.3	9.5	1.4	21	6.7	0.86	0.83	450	29.1
10	05/Nov/85	6.7	8.0	4.8	19	7.0	2.50	0.70	196	11.9
10	12/Nov/85	6.2	5.2	3.4	34	7.3	1.45	0.13	108	14.2
10	17/Dec/85	7.8	6.5	5.0	40	7.1	1.60	1.19	209	7.1
12	14/Jan/86	7.5	6.8	5.0	30	7.3	1.89	1.54	194	14.7
12	21/Jan/86	6.1	7.2	2.4	35	7.1	2.51	1.55	247	12.7
12	30/Jan/86	10.0	7.3	4.2	24	7.3	1.24	1.57	371	12.4
10	19/Feb/86	n.d.	2.0	5.0	23	7.2	2.34	1.06	288	8.2
10	26/Feb/86	6.2	8.2	1.7	25	7.1	2.27	0.66	100	20.6
12	26/Feb/86	4.8	8.6	1.3	65	6.7	4.82	1.64	200	26.
12	04/Mar/86	4.3	9.0	3.4	28	6.8	0.68	1.78	355	5.7
10	11/Mar/86	5.1	9.5	3.0	31	7.2	1.05	0.05	245	7.9
12	11/Mar/86	4.3	9.5	1.2	30	7.0	0.76	0.09	475	11.8
10	19/Mar/86	4.2	10.0	3.8	26	7.0	0.99	0.03	240	9.6
12	19/Mar/86	3.8	10.0	1.2	30	7.0	1.19	0.09	632	15.
10	28/Mar/86	7.4	7.5	1.8	20	7.2	1.28	0.05	69	19.8
12	28/Mar/86	6.5	8.5	1.8	20	7.1	1.33	1.52	370	11.8
10	01/Apr/86	5.5	10.0	1.8	28	6.9	1.26	0.71	83	15.4
12	01/Apr/86	4.3	10.0	0.8	52	6.9	2.46	2.25	965	15.9
10	08/Apr/86	5.8	11.3	1.0	35	7.2	0.09	0.93	370	5.3
12	08/Apr/86	4.5	11.0	0.6	37	7.3	0.37	2.65	250	8.3
10	15/Apr/86	7.2	9.5	3.0	23	7.3	1.08	0.48	385	14.7
12	15/Apr/86	5.2	9.5	1.8	26	7.3	1.12	1.72	1066	18.3
10	29/Apr/86	7.8	9.5	2.8	16	7.2	0.18	n.d.	354	14.3
12	29/Apr/86	5.5	9.5	1.8	26	7.3	1.24	n.d.	289	16.5
10	06/May/86	4.8	13.2	2.8	17	6.9	0.92	1.15	211	6.8
12	06/May/86	4.4	11.0	1.6	22	7.0	0.69	0.83	451	12.2
10	14/May/86	6.6	12.0	2.0	20	7.1	0.75	0.60	119	3.5
12	14/May/86	3.6	11.5	1.0	29	7.0	0.48	3.25	714	9.7
10	21/May/86	7.1	14.0	1.4	15	7.1	0.72	0.49	198	3.3
12	21/May/86	4.1	12.5	1.2	21	6.9	1.05	3.45	650	38.3
10	27/May/86	3.8	12.0	3.8	30	7.1	1.40	3.08	242	2.3
12	27/May/86	4.8	19.0	0.6	22	7.1	0.21	3.63	736	6.9

Table 6. Dissolved oxygen and temperature in Joe Leary Slough in the Padilla Bay/Bay View watershed. Data are taken from Mayer (1989) and Bulthuis (1993). Location of sample sites is indicated in Figs. 4 and 5.

Site No.	Date	Temperature	Dissolved Oxygen		Source
			mg/L	% saturation	
J1	19-May-87	12.	9.2	88%	Mayer
	22-Jun-87	16.2	2.3	24%	"
	13-Apr-88	12.5	3.9	37%	"
	7-Aug-88	17.	3.0	32%	"
J2	19-May-87	12.	5.6	54%	"
	22-Jun-87	17.4	4.9	52%	"
	13-Apr-88	12.	5.4	52%	"
	7-Aug-88	18.1	3.8	41%	"
J3	19-May-87	11.	4.0	37%	"
	22-Jun-87	14.6	4.9	49%	"
	13-Apr-88	12.	5.4	52%	"
	7-Aug-88	15.2	4.8	49%	"
J4	19-May-87	11.	3.6	34%	"
	22-Jun-87	14.6	4.8	48%	"
	13-Apr-88	11.	7.5	70%	"
	7-Aug-88	16.	5.0	52%	"
J5	19-May-87	12.	4.6	44%	"
	22-Jun-87	17.	7.8	83%	"
	13-Apr-88	12.	10.2	98%	"
	7-Aug-88	18.2	7.6	83%	"
M1	21-Nov-91	9.	3.6	32%	Bulthuis
M2	21-Nov-91	9.	8.2	73%	"
M3	21-Nov-91	8.8	7.2	63%	"
M4	21-Nov-91	9.5	8.8	79%	"
M6	21-Nov-91	8.7	6.9	60%	"
M7	21-Nov-91	9.	7.6	68%	"
M8	9-Oct-91	9.	4.4	39%	"
	21-Nov-91	8.5	7.5	65%	"
W1	21-Nov-91	9.	9.6	86%	"
W2	21-Nov-91	8.	10.2	89%	"
W3	9-Oct-91	9.	9.5	85%	"
	21-Nov-91	8.5	9.6	84%	"
W4	21-Nov-91	9.	10.8	97%	"
W5	21-Nov-91	9.5	8.5	76%	"
L1	21-Nov-91	8.5	7.6	66%	"
L4	9-Oct-91	12.	7.4	71%	"
L5	9-Oct-91	11.5	6.2	58%	"
	21-Nov-91	7.5	8.6	73%	"

Water quality standards for these waters state that the temperature shall not exceed 18°C and that the dissolved oxygen shall not be less than 8 mg/L.

Table 7. pH in Joe Leary, Big Indian and Little Indian Sloughs in the Padilla Bay/Bay View watershed. Data are taken from Mayer (1989) and Skagit County Department of Health (1990-92). Sample locations shown in Fig. 4.

Slough	Site No.	Date	pH	Source
Joe Leary	J1	19-May-87	6.6	Mayer
"	"	22-Jun-87	6.8	"
"	"	13-Apr-88	6.6	"
"	"	7-Aug-88	6.6	"
"	J2	19-May-87	6.7	"
"	"	22-Jun-87	6.9	"
"	"	13-Apr-88	6.7	"
"	"	7-Aug-88	6.7	"
"	J3	19-May-87	6.7	"
"	"	22-Jun-87	6.8	"
"	"	13-Apr-88	6.7	"
"	"	7-Aug-88	6.7	"
"	J4	19-May-87	6.8	"
"	"	22-Jun-87	6.8	"
"	"	13-Apr-88	6.7	"
"	"	7-Aug-88	6.9	"
"	J5	19-May-87	7.0	"
"	"	22-Jun-87	7.1	"
"	"	13-Apr-88	6.8	"
"	"	7-Aug-88	7.2	"
"	H1	18-Apr-91	6.2	Skagit Co.
"	H2	18-Apr-91	6.3	"
"	H3	18-Apr-91	6.3	"
Big Indian	B1	19-May-87	6.6	Mayer
"	"	22-Jun-87	6.8	"
"	"	13-Apr-88	6.7	"
"	"	7-Aug-88	6.9	"
"	B2	19-May-87	6.7	"
"	"	22-Jun-87	6.7	"
"	"	13-Apr-88	6.7	"
"	"	7-Aug-88	6.7	"
"	B3	19-May-87	6.7	"
"	"	22-Jun-87	6.9	"
"	"	13-Apr-88	6.8	"
"	"	7-Aug-88	6.6	"
"	BL	19-May-87	7.8	"
"	"	22-Jun-87	8.1	"
"	"	13-Apr-88	7.7	"
"	"	7-Aug-88	7.8	"
Little Indian	L1	19-May-87	8.6	Mayer
"	"	22-Jun-87	8.1	"
"	"	13-Apr-88	6.8	"
"	"	7-Aug-88	8.0	"
"	L2	19-May-87	7.2	"
"	"	22-Jun-87	7.9	"
"	"	13-Apr-88	7.0	"
"	"	7-Aug-88	7.9	"

Water quality standards for these waters state that the pH shall be within the range 6.5 to 8.5.

Table 8. Turbidity at three sites in Joe Leary Slough as measured by Skagit County Department of Health (1990-92). Sample locations shown in Fig. 4.

Site No.	Date	Tubidity (NTU)
H2	10-Oct-90	47
H3	10-Oct-90	58
H1	18-Apr-91	93
H2	18-Apr-91	99
H3	18-Apr-91	80
H1	30-Sep-92	23
H2	30-Sep-92	38
H3	30-Sep-92	58

Table 9. Suspended sediments and water quality at 13 sites in Joe Leary Slough on 9 October 1991 at a time of low flow (from Bulthuis 1993). Sample sites are shown in Fig. 5.

Station number	Temp. (C)	Conductivity (uohms)	Oxygen (O2 ppm)	SS mean mg/l	Organic weight mean mg/l	Organic weight mean percent
M4	9.	310		65.0	20.0	30
M5	11.	270		76.0	21.0	28
M6	11.	225		64.0	18.5	30
M7	9.	220		17.0	5.5	16
M8	9.	210	4.4	8.0	3.7	48
W3	9.	205	9.5	14.7	2.9	23
W4	10.5			23.4	4.9	20
W5	11.	202		16.0	4.8	38
L1	9.8	248		13.3	4.5	36
L2	9.	250		10.8	2.7	25
L3	9.	250		4.9	1.2	26
L4	12.	30000	7.4	4.7	1.0	22
L5	11.5	31000	6.2	18.3	10.0	40

Table 10. Suspended sediments and water quality at 18 sites in Joe Leary Slough on 21 November 1991 at a time of high flow following rainfall in the watershed (from Bulthuis 1993). Sample sites are shown in Fig. 5.

Station number	Temp. (C)	Conductivity (uohms)	Oxygen (O2 ppm)	SS mean mg/l	Organic weight mean mg/l	Organic weight mean percent
M1	9.	265	3.6	31.5	20.0	63
M2	9.	350	8.2	32.5	19.0	59
M3	8.8	270	7.2	29.0	15.0	52
M4	9.5	275	8.8	25.3	12.7	50
M5	8.8	270		26.8	11.7	44
M6	8.7	270	6.9	26.5	11.5	44
M7	9.	270	7.6	17.2	6.9	33
M8	8.5	230	7.5	23.5	6.3	27
W1	9.	195	9.6	6.8	1.2	17
W2	8.	160	10.2	9.4	1.8	17
W3	8.5	205	9.6	14.5	3.0	21
W4	9.	300	10.8	14.3	3.5	25
W5	9.5	290	8.5	20.0	5.5	28
L1	8.5	252	7.6	15.8	4.5	30
L2	8.3	248		9.0	3.0	33
L3	8.3	240		7.2	2.2	30
L4	8.	700		6.2	1.8	29
L5	7.5	950	8.6	2.8	0.9	16

Table 11. Concentration of metals (total metal) in a grab sample of leachate collected at the March Point landfill, June, 1988. Data from Fitzpatrick (1989). Acute marine water quality standard from WAC 173-201. U=undetected. Lead was analyzed by two different methods. N.S.=no standard set for this metal.

metal	concentration µg/L	marine water standard µg/L
arsenic	91.	69.
lead	214.	151.1
lead	126.	151.1
thallium	1.8	N.S.
silver	2.2	1.2
antimony	U	N.S.
selenium	U	300.
berylium	8.5	N.S.
cadmium	9.9	37.2
chromium	324.	
copper	357.	2.5
nickel	959.	71.3
zinc	779.	84.6

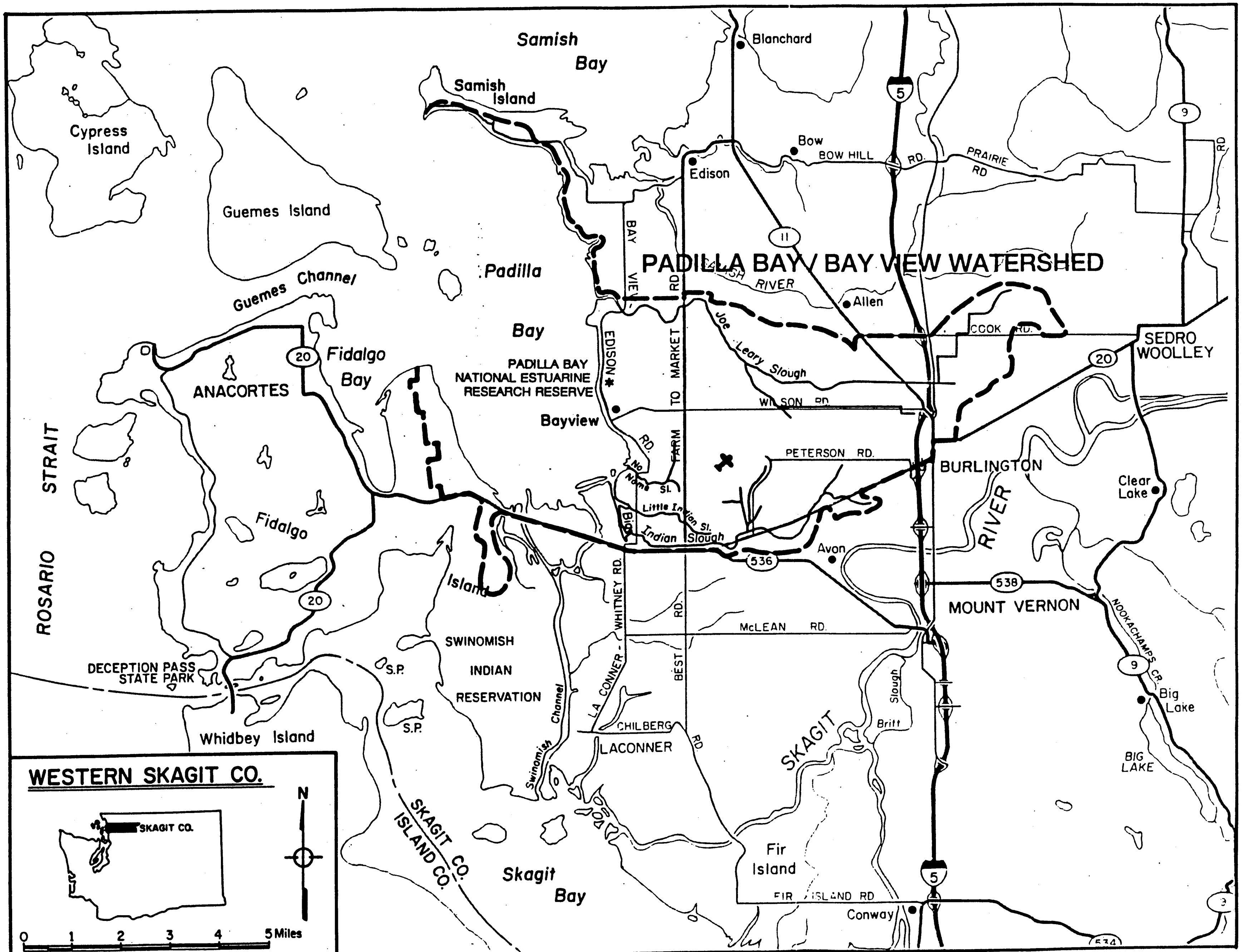


Figure 1. Padilla Bay/Bay View watershed including the major sloughs that flow into Padilla Bay.

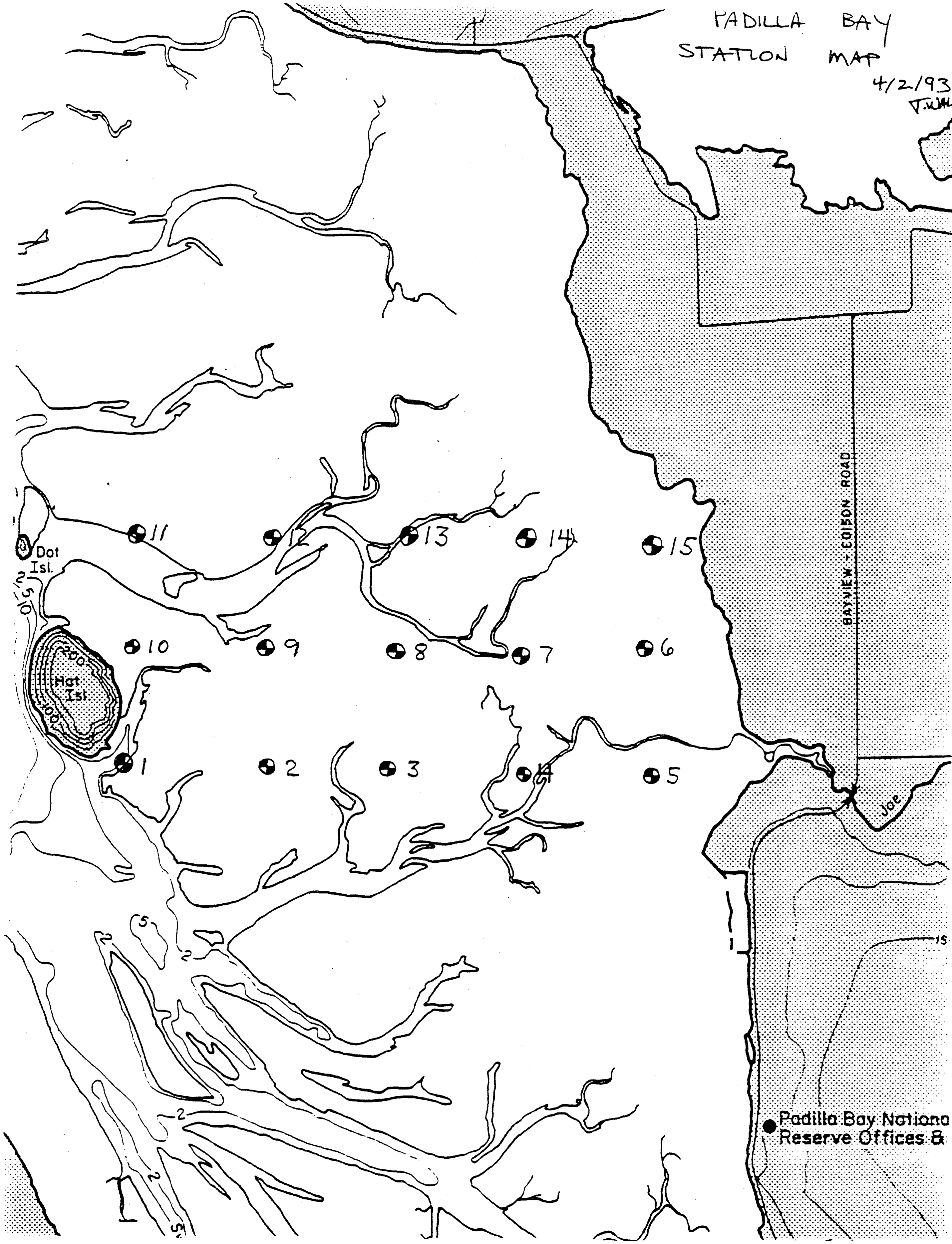


Figure 2. Location of sample sites in Padilla Bay during study by Walker 1993.

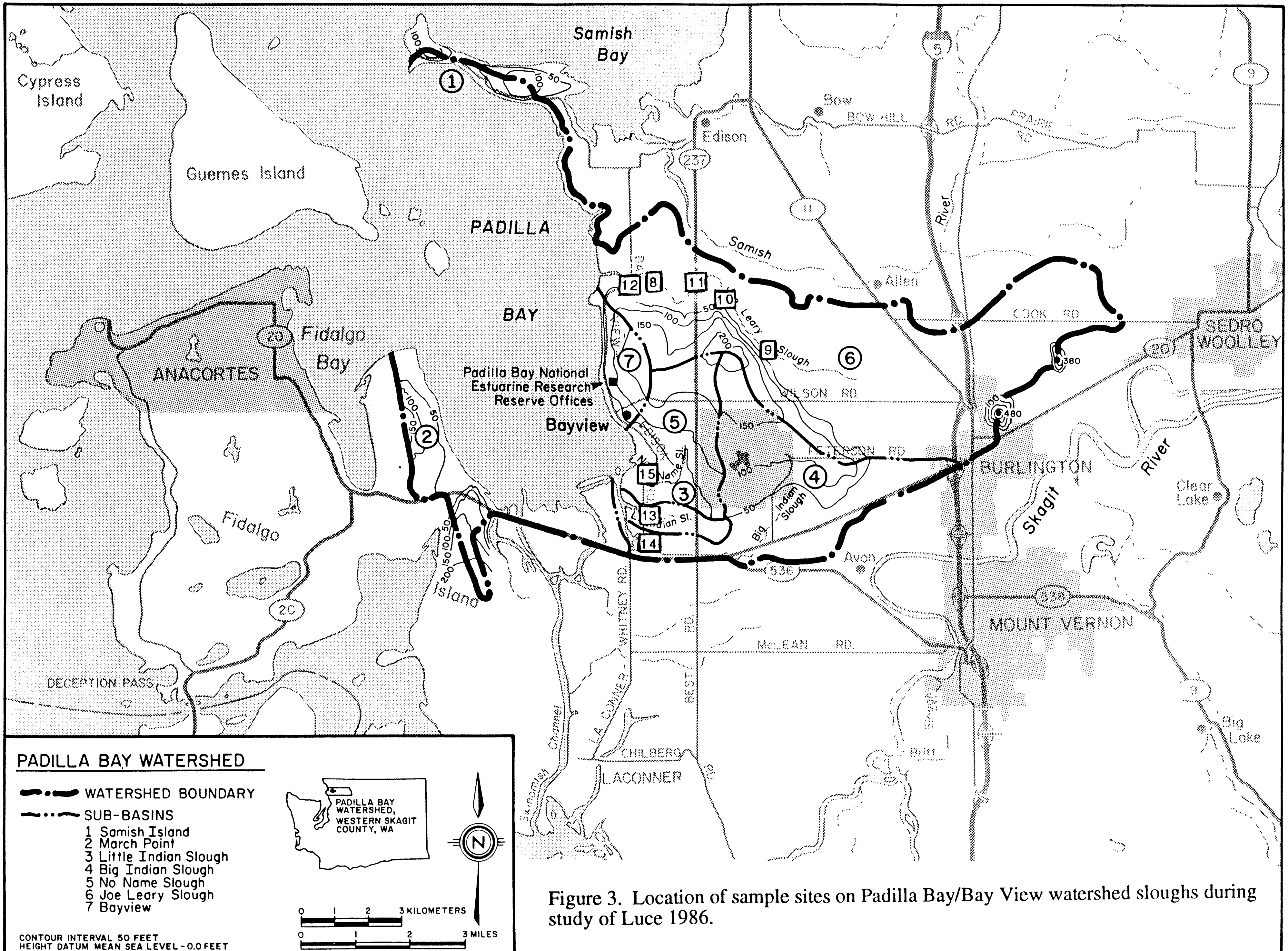


Figure 3. Location of sample sites on Padilla Bay/Bay View watershed sloughs during study of Luce 1986.

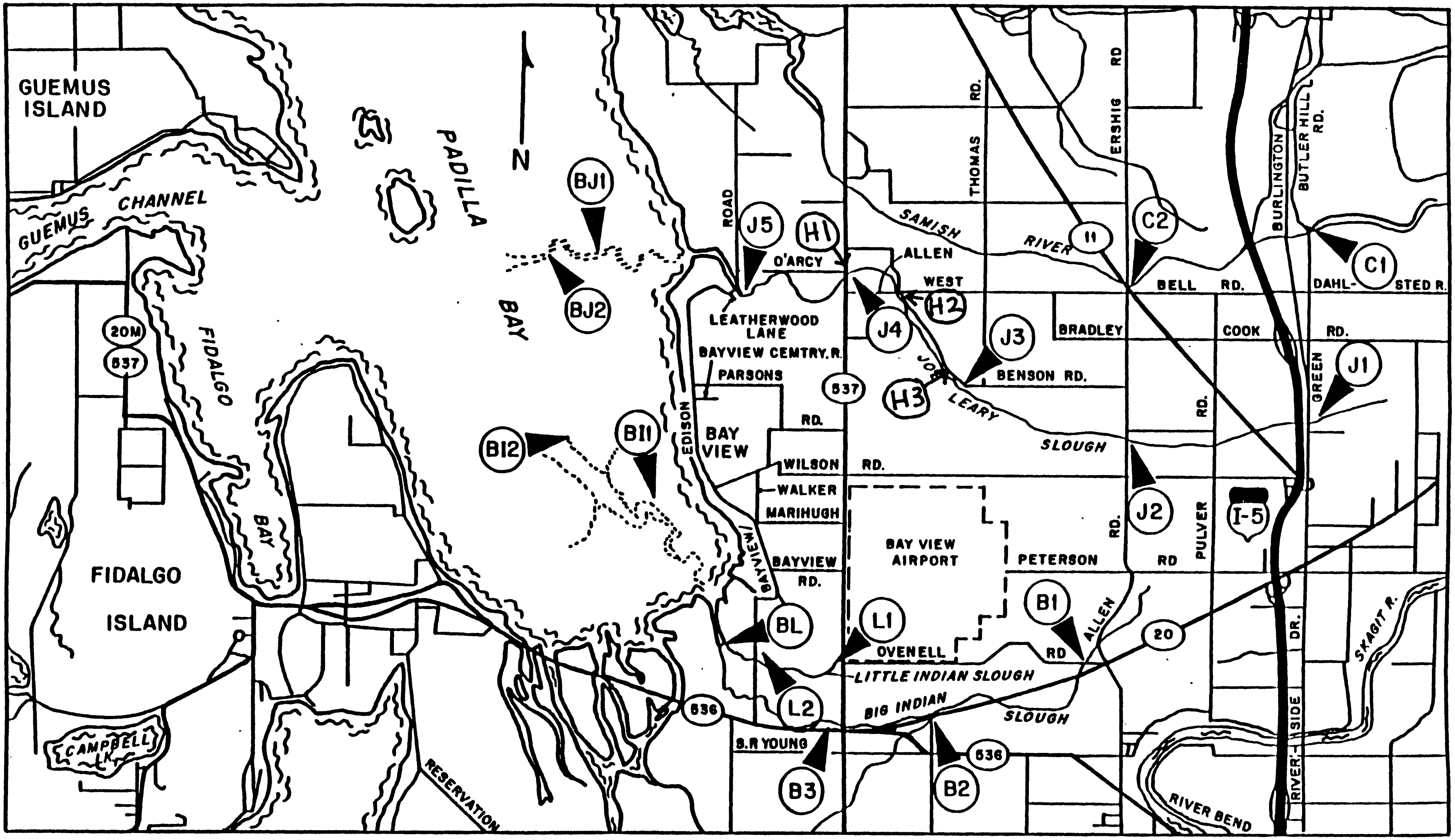


Figure 4. Sample sites in the sloughs of the Padilla Bay/Bay View watershed during the study of Mayer (1989) and Skagit County Health (1990-1992).

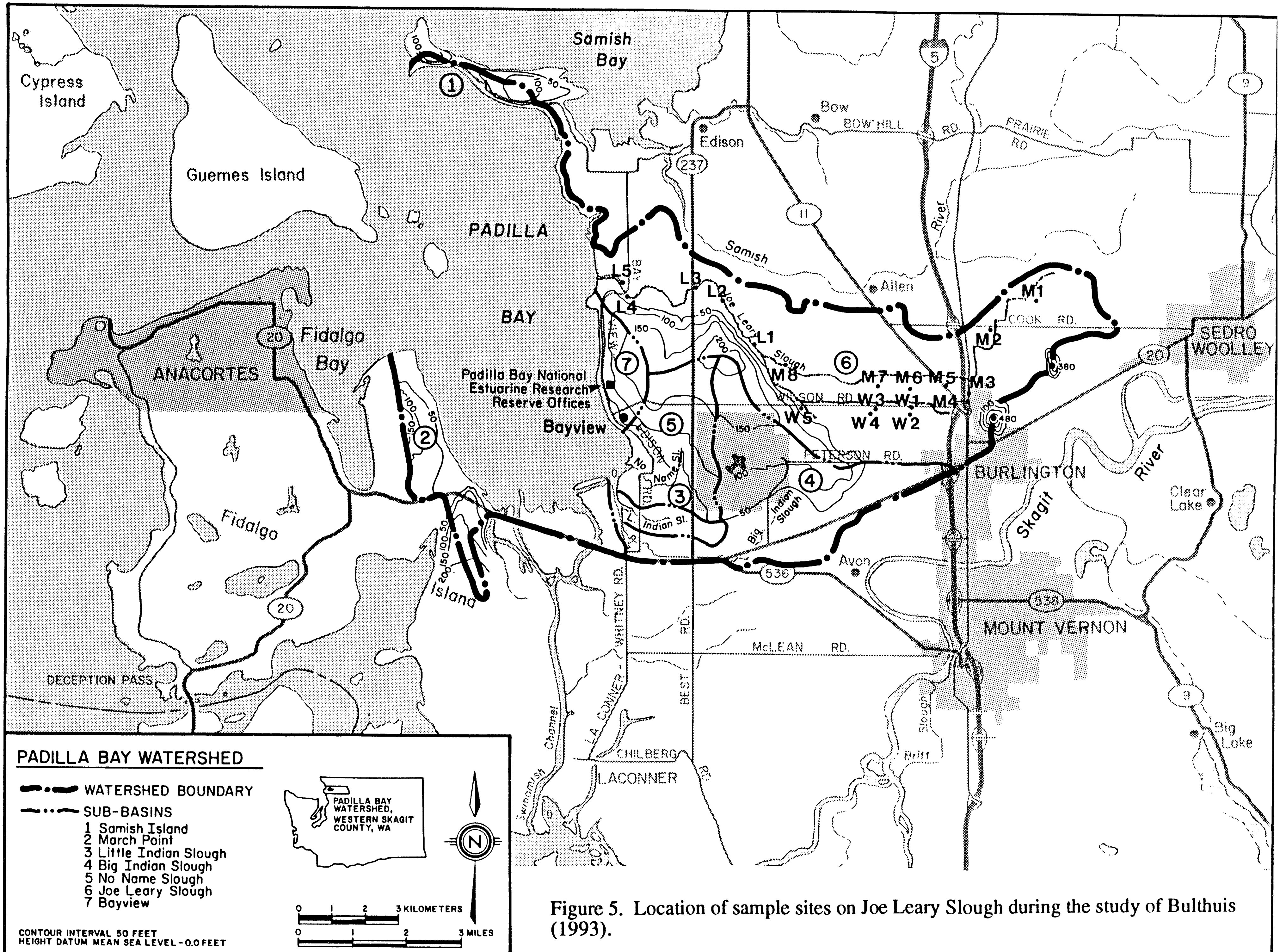


Figure 5. Location of sample sites on Joe Leary Slough during the study of Bulthuis (1993).

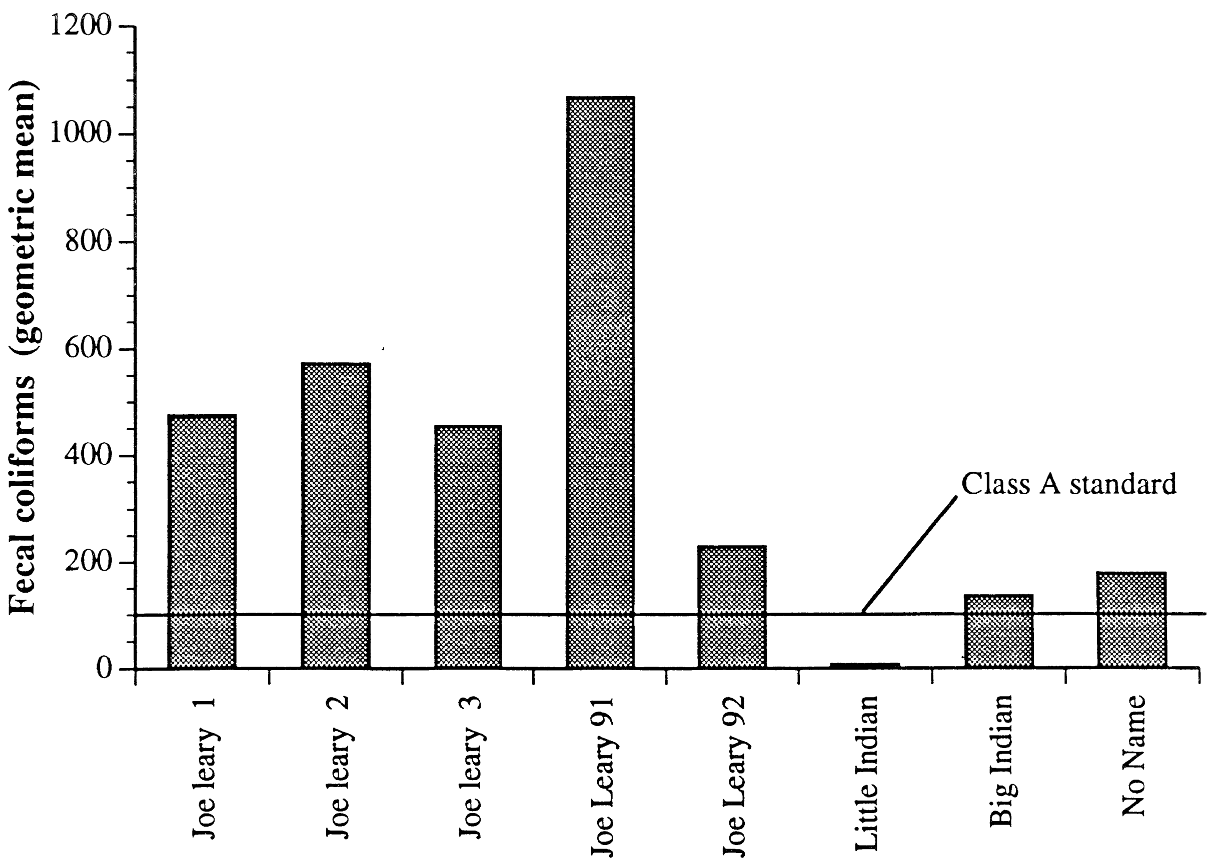


Figure 6. Fecal coliforms (colonies/100 ml, geometric mean) in Joe Leary, Little Indian, Big Indian and No Name Sloughs. Data extracted from Luce (1986) and Skagit County Health (1990-1992). Washington State water quality standard for Class A freshwaters state that the geometric mean shall not be greater than 100 colonies/100 ml.

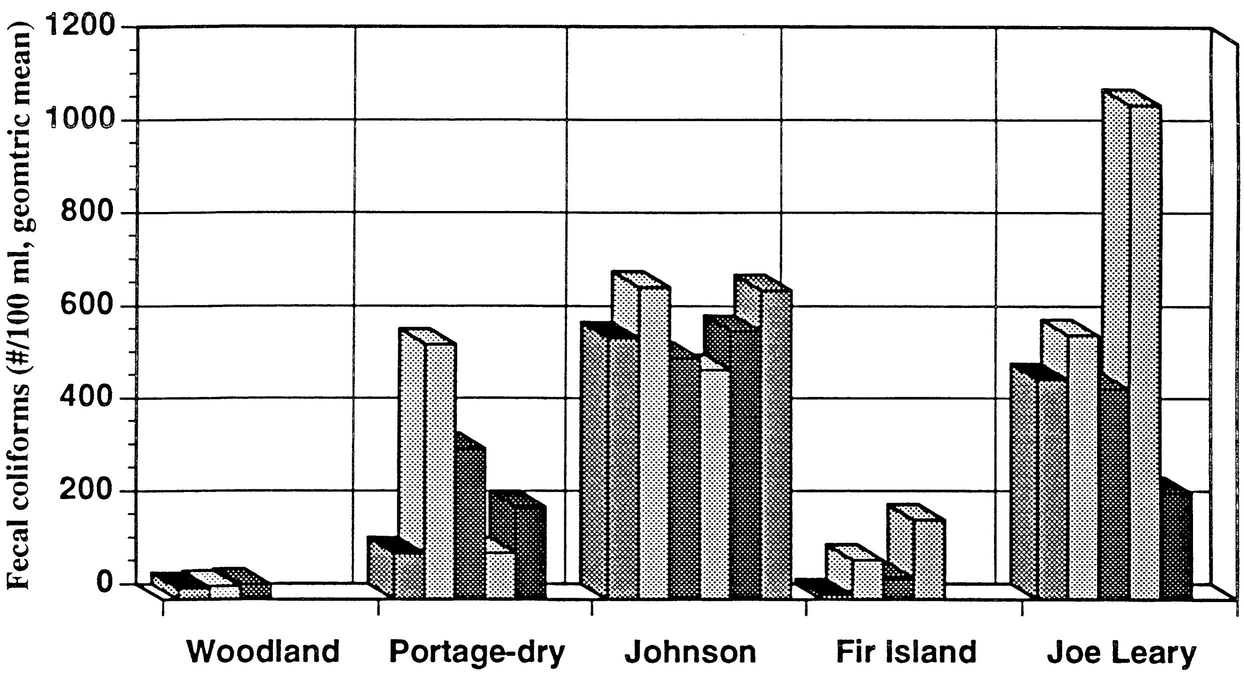


Figure 7. Mean fecal coliforms reported for five creeks and sloughs in western Washington. Sites within a creek are sample sites along the mainstem of the creek or slough except for Fir Island in which sites are four different sloughs and the last two from Joe Leary Slough in which two different years at the same site are displayed. Portage Creek means are for dry weather flow; wet weather data were similar. Data extracted from Dickes & Reed 1992, Plotnikoff & Michaud 1991, Dickes & Merrill 1990, Entranco 1993, Luce 1986, and Skagit County Health (1990-1992).

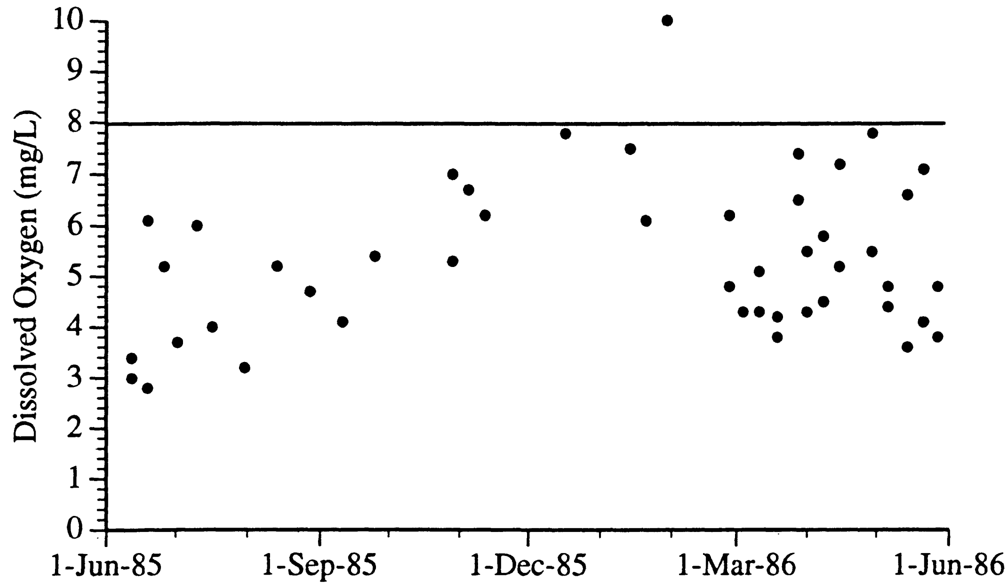


Figure 8. Dissolved oxygen at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)]. Washington State water quality standards for Class A freshwaters state that the dissolved oxygen concentration shall not be less than 8 mg/L.

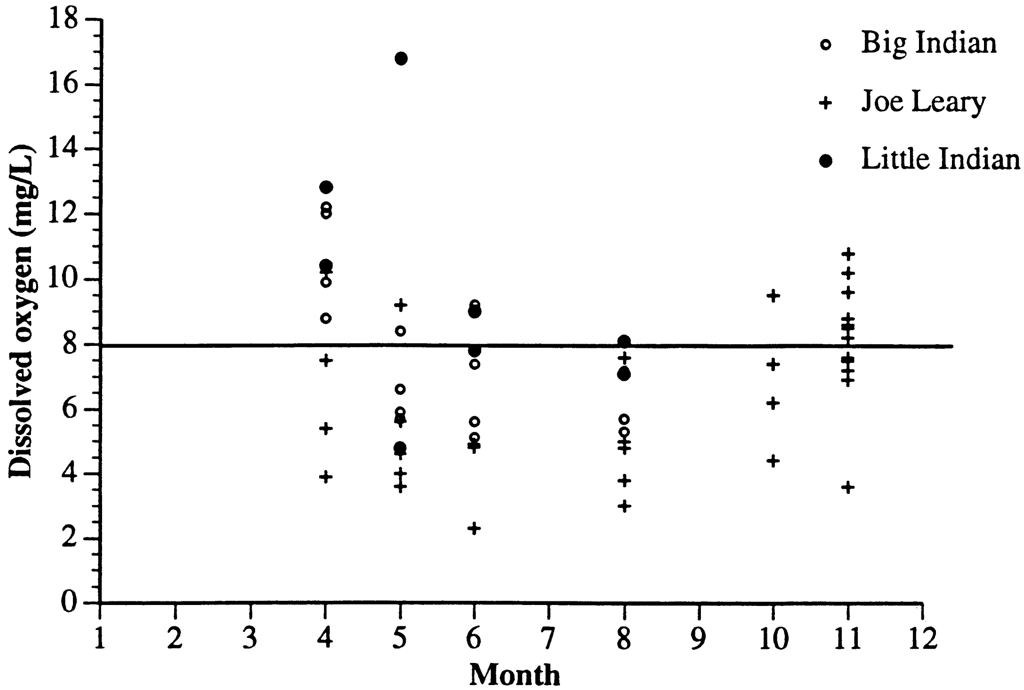


Figure 9. Dissolved oxygen in freshwater sloughs in the Padilla Bay/Bay View watershed. Water quality criteria for these waters states that the dissolved oxygen shall not be less than 8 mg/L. Data are extracted from Mayer (1989) and Bulthuis (1993), location of sample sites are shown in Figs. 4 and 5.

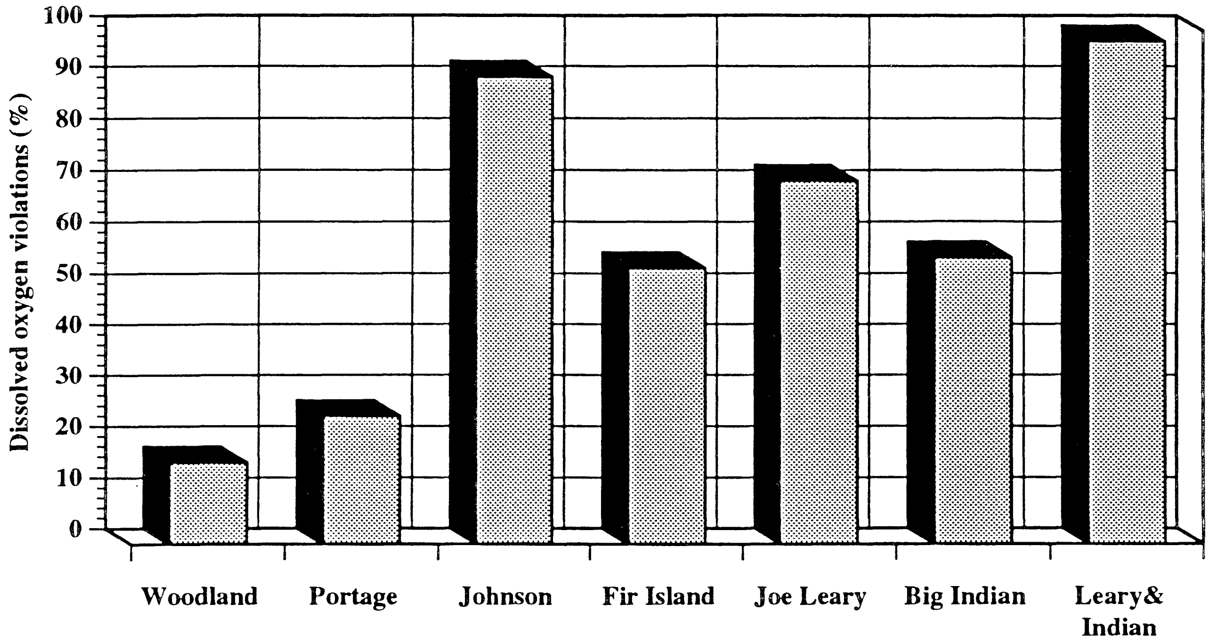


Figure 10. Percent of measurements of dissolved oxygen that were below the Washington State water quality criteria (8 mg/L) for Class A freshwaters. Data extracted from Dickes & Reed (1992), Plotnikoff & Michaud (1991), Dickes & Merrill (1990), Entranco (1993), and from Mayer (1989) and Bulthuis (1993) for Joe Leary and Big Indian Sloughs and from Cassidy & McKeen (1986) for the combined Joe Leary and Big Indian (Leary & Indian) column.

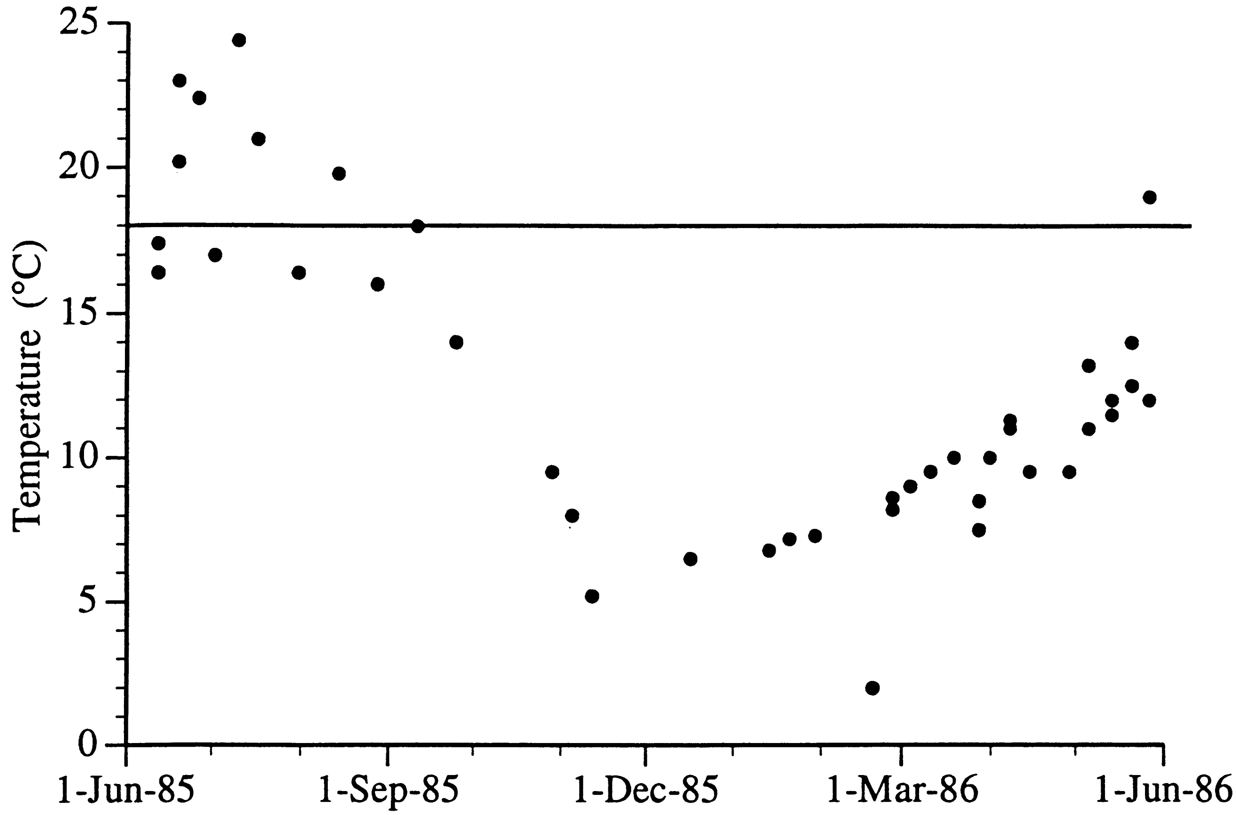


Figure 11. Temperature in degrees Celsius at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)]. The Washington State water quality standards for Class A freashwaters state that temperature shall not exceed 18°C.

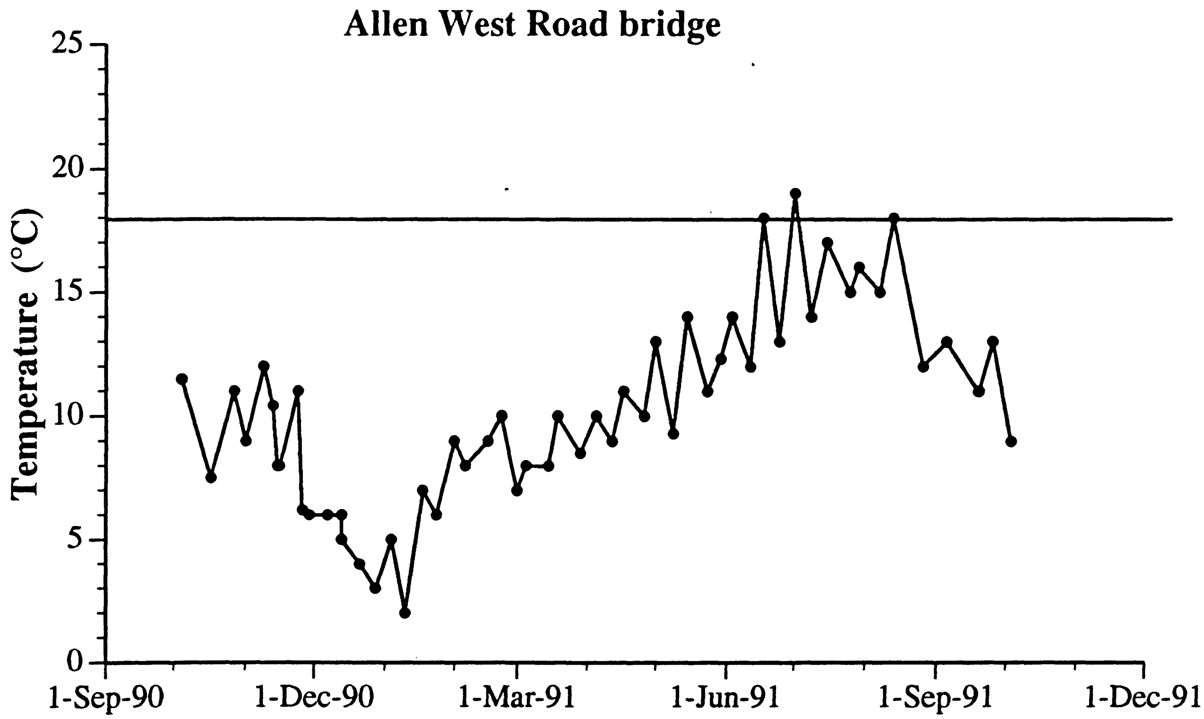


Figure 12. Temperature of Joe Leary Slough at the Allen West Road bridge from October 1990 to October 1991 (from Bulthuis 1993).

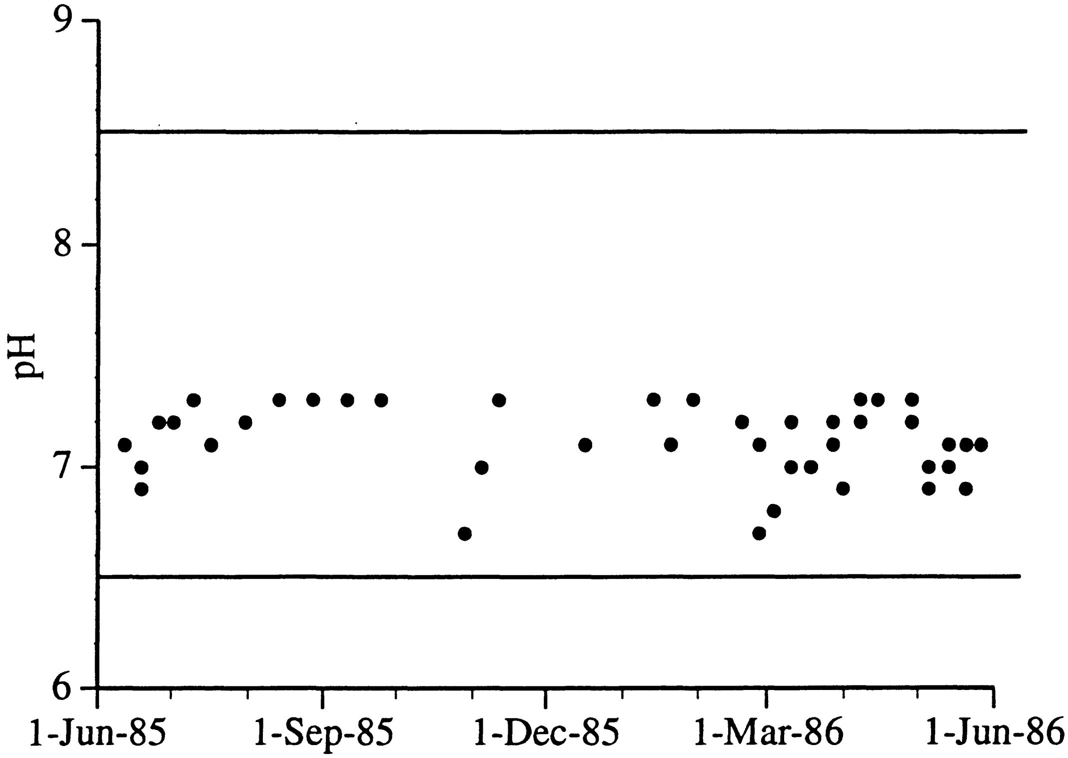


Figure 13. pH at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)]. Washington State water quality standards state for Class A waters that pH of freshwater shall be within the range 6.5 to 8.5.

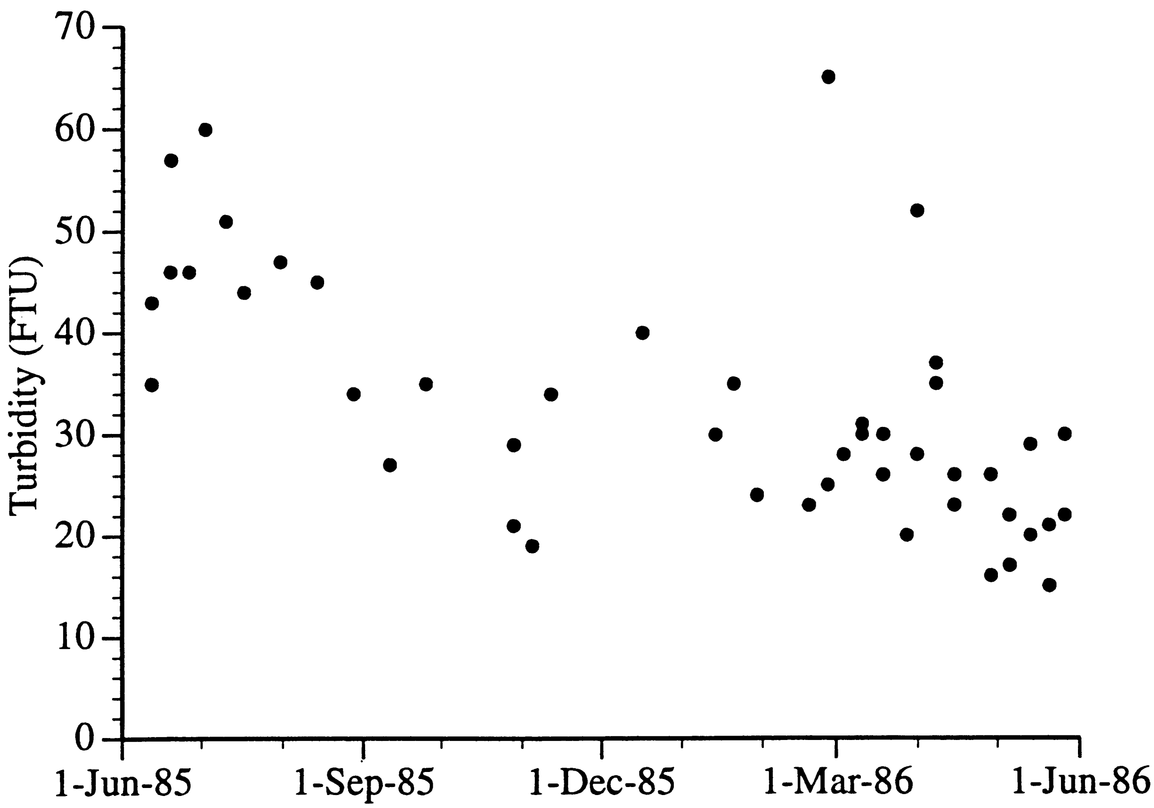


Figure 14. Turbidity at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)].

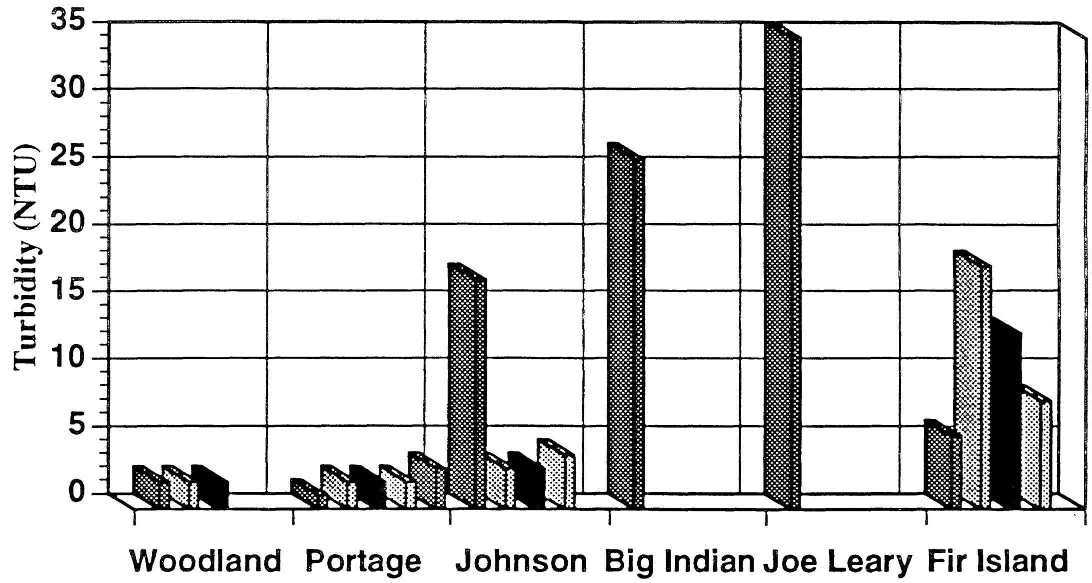
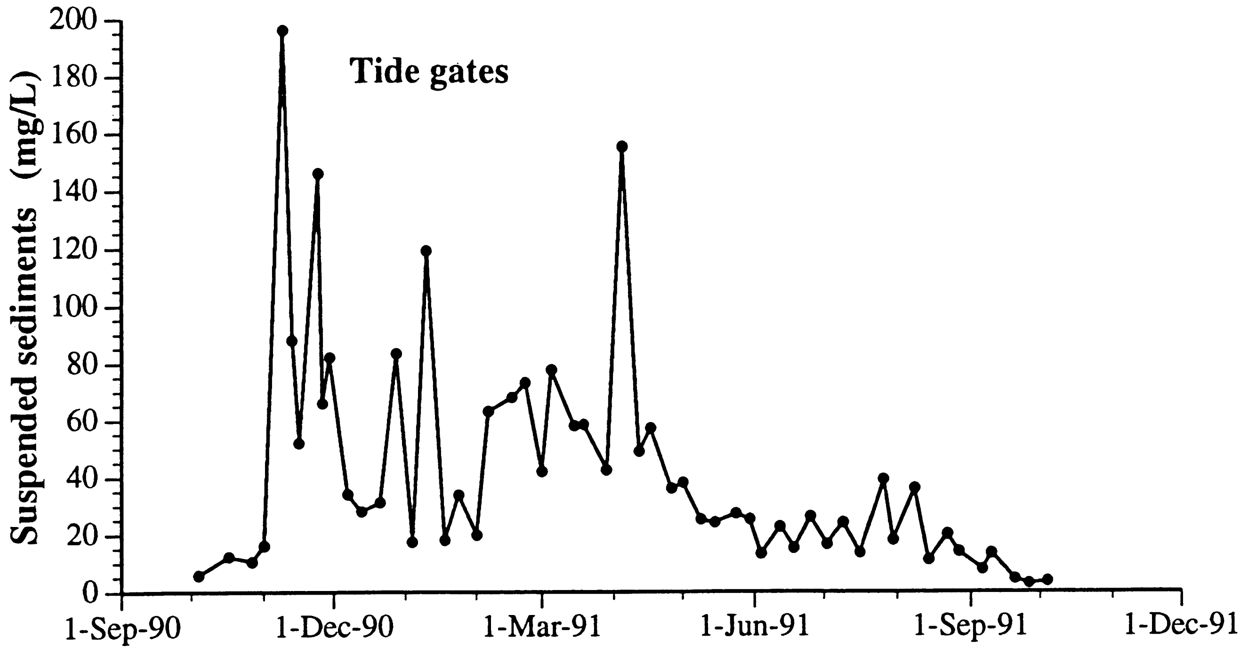


Figure 15. Median turbidity in six creeks and sloughs in western Washington. Medians are based on monthly or weekly samples taken for one year except for Johnson Creek for which samples were taken during 7 months scattered throughout the year and Fir Island for which samples were taken monthly for six months from January to June. Sites within a creek system are samples sites along the mainstem of each creek or slough with the left hand site being the sample site farthest upstream, except for Fir Island where sites are four different sloughs with samples taken at the tide gates. Data are extracted from Dickes & Reed (1992), Plotnikoff & Michaud (1991), Dickes & Merrill (1990), Cassidy and McKeen (1986), and Entranco (1993).



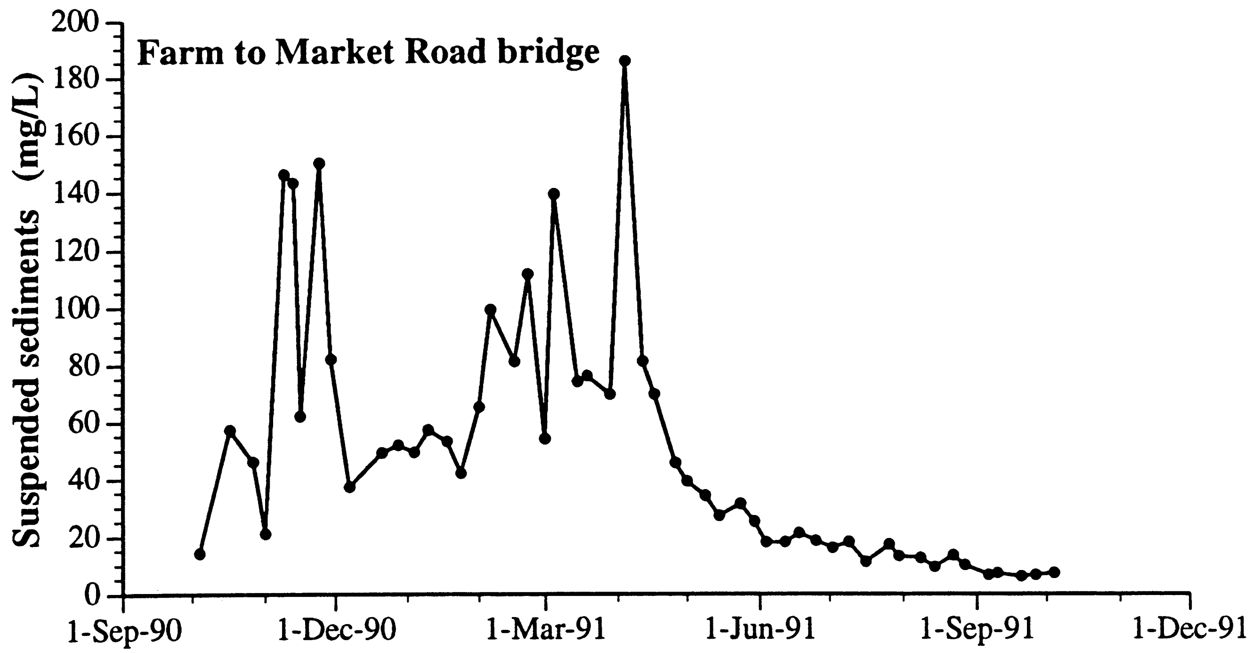


Figure 16. Suspended sediments at the tide gates and Farm to Market Road bridge on Joe Leary Slough from October, 1990 to September, 1991 (from Bulthuis 1993).

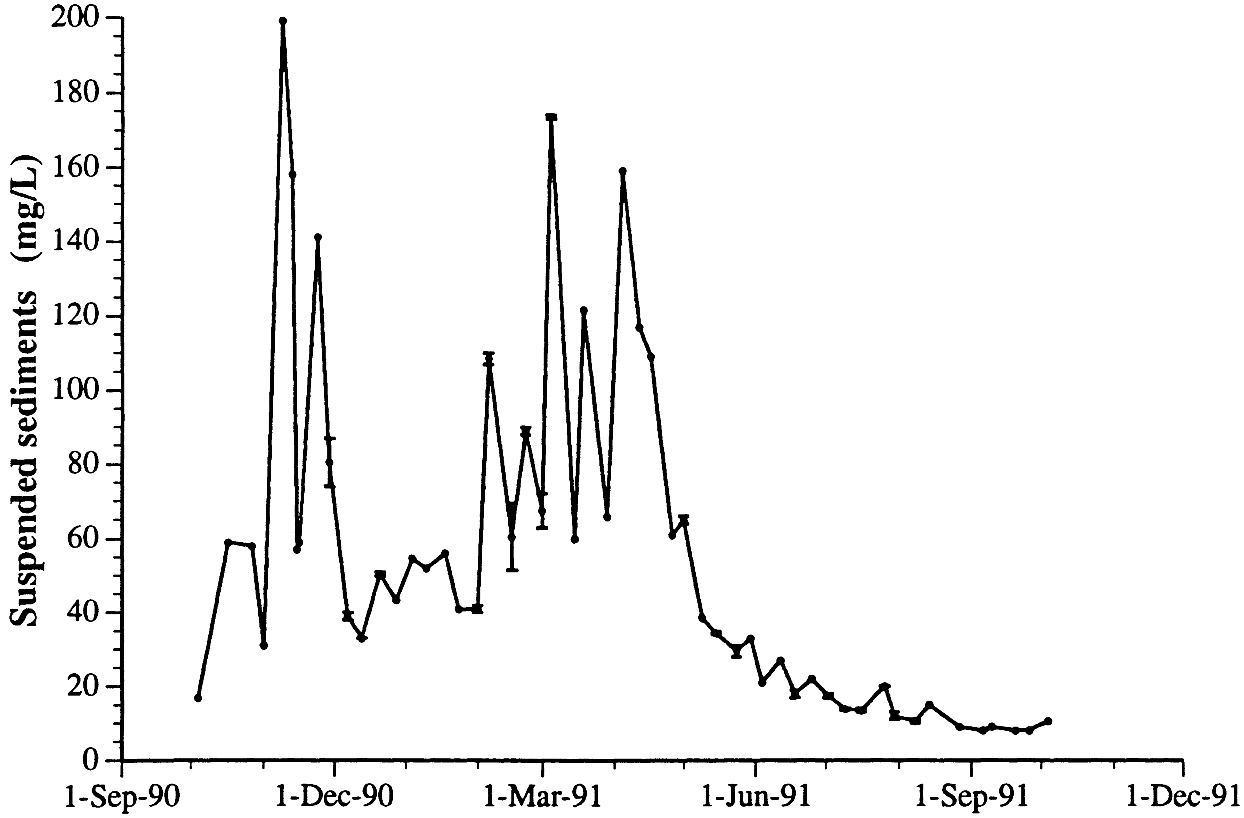


Figure 17. Suspended sediments (mean & s.e. of the mean, n=2) at the Allen West Road bridge from October, 1990 to September, 1991 (from Bulthuis 1993).

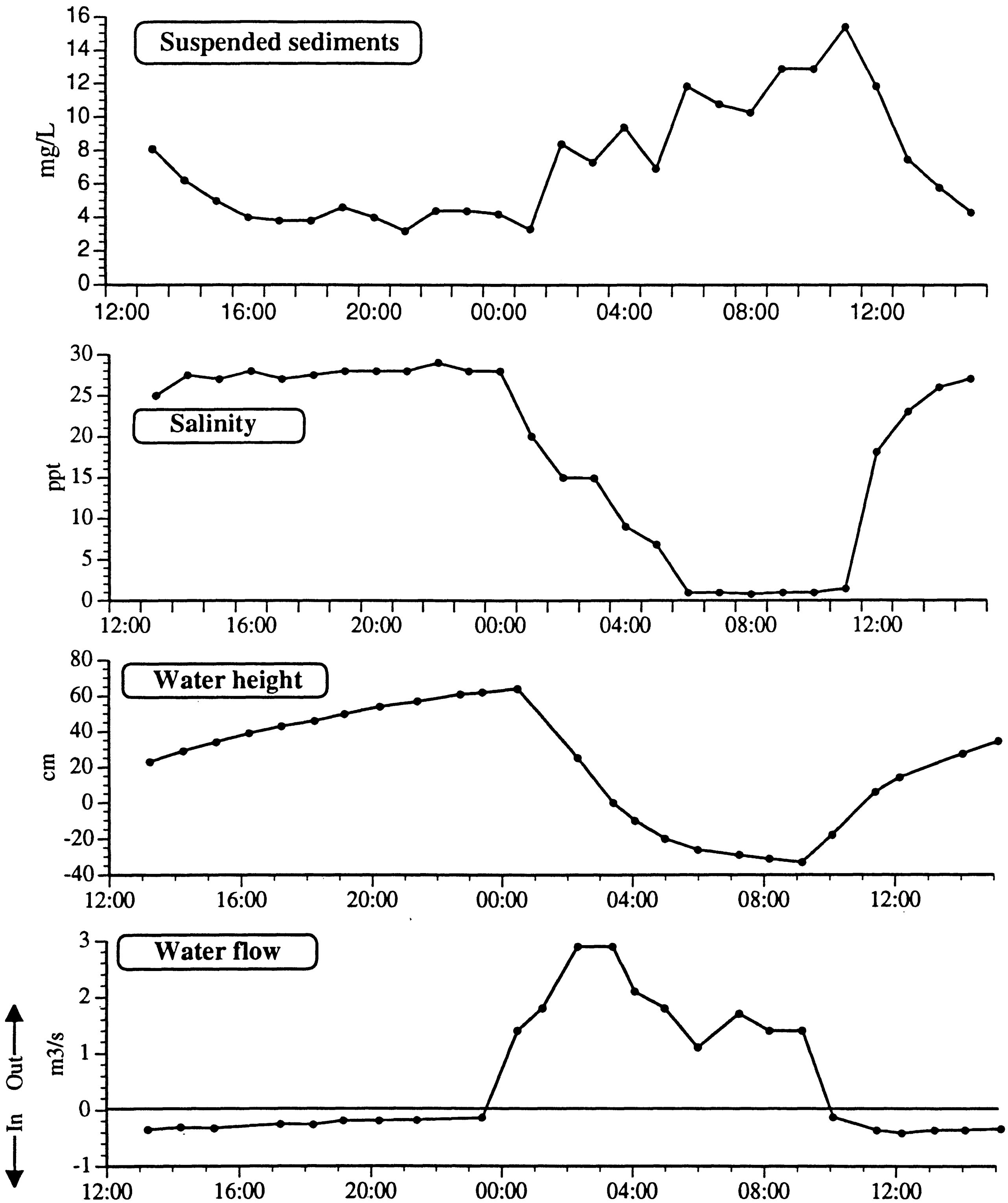


Figure 18. Suspended sediments and salinity (parts per thousand) at mid-water depth on the fresh water side of the tide gates in Joe Leary Slough at hourly intervals on October 11 & 12, 1990. Water height on the fresh water side of the tide gates relative to chart datum and flow "out" of the slough to Padilla Bay and "in" to the slough from Padilla Bay are shown for comparison (from Bulthuis 1993).

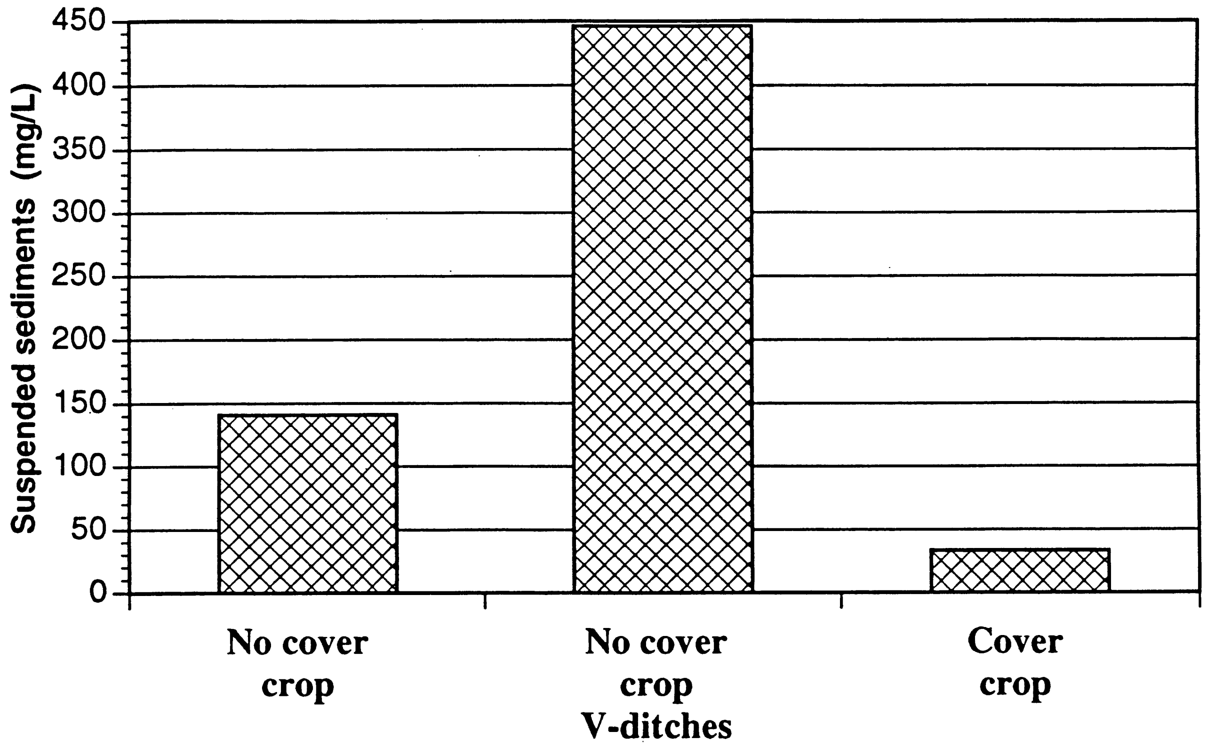


Figure 19. Concentration of suspended sediments in ditches draining fields during moderate rainstorms in December, 1991, in the watershed of Joe Leary Slough, Skagit County, Washington. Each column is the mean of 3 to 6 samples taken of surface water flowing from fields with the indicated type of cover (from Bulthuis 1993).

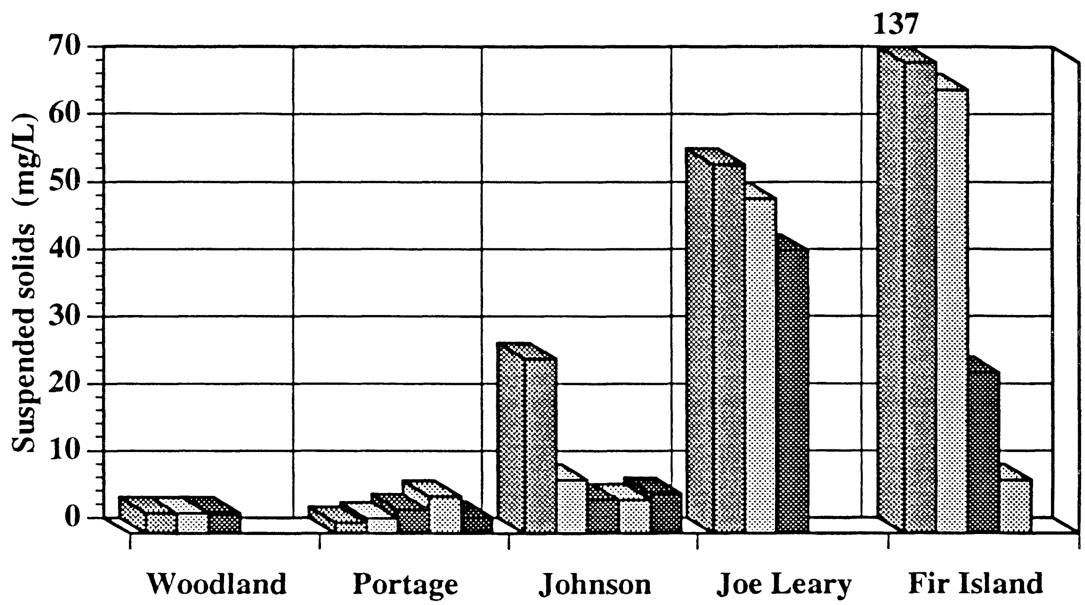


Figure 20. Mean total suspended solids in five creeks and sloughs in western Washington. Means are based on monthly or weekly samples taken for one year except for Johnson Creek for which samples were taken during 7 months scattered throughout the year and Fir Island Sloughs for which samples were taken monthly from January to June. Sites 1 to 3 or 1 to 5 are samples sites along the mainstem of each creek or slough with site 1 being the sample site farthest upstream except for Fir Island where four different sloughs were sampled at the tide gates. The mean total suspended solids for one of the Fir Island Sloughs extends beyond the graph and is displayed numerically. Data extracted from Dickes & Reed (1992), Plotnikoff & Michaud (1991), Dickes & Merrill (1990), Bulthuis (1993), and Entranco (1993).

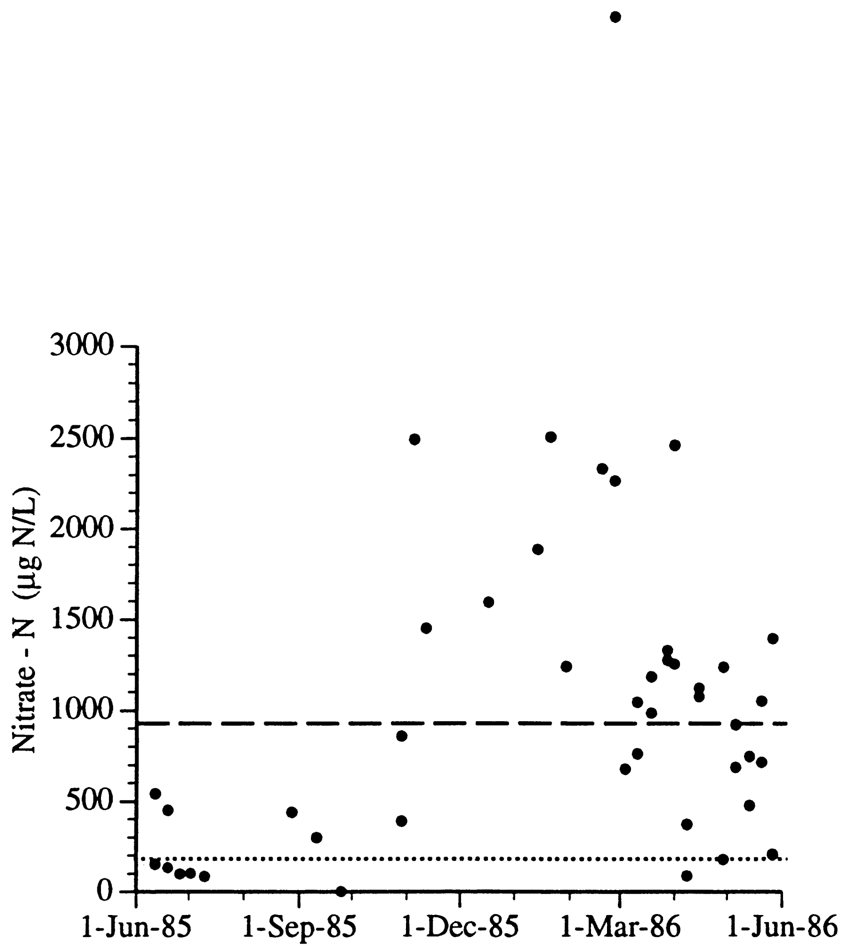


Figure 21. Nitrate nitrogen at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)]. The values of total nitrogen above which Mills <u>et al</u>. (1985) suggested as "problem threshold" (dotted line) and "problem likely to exist" (dashed line) are shown for comparison.

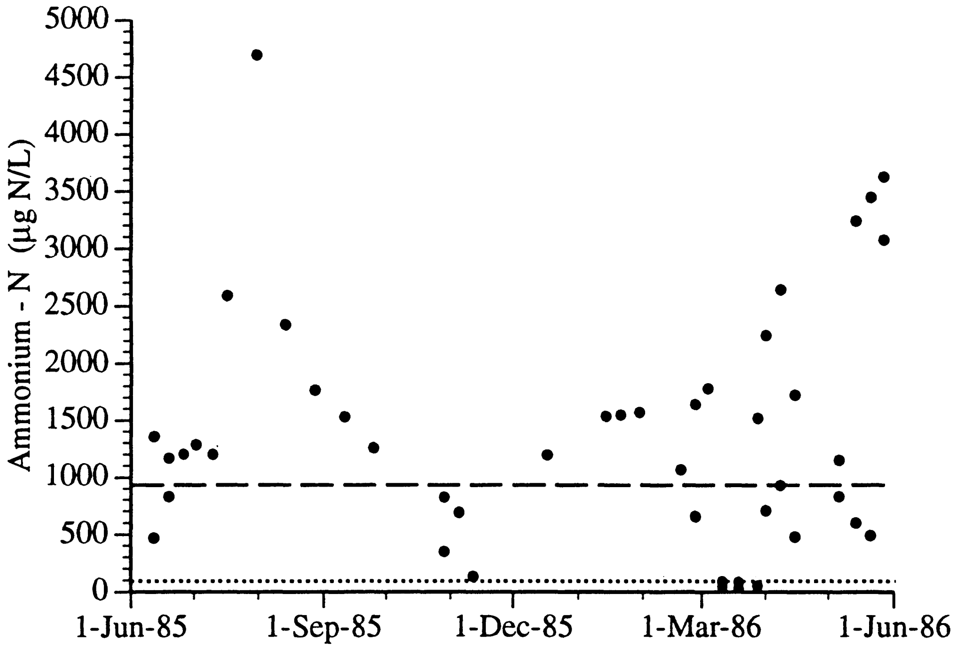


Figure 22. Ammonium nitrogen at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)]. The values of total nitrogen above which Mills et al. (1985) suggested as "problem threshold" (dotted line) and "problem likely to exist" (dashed line) are shown for comparison.

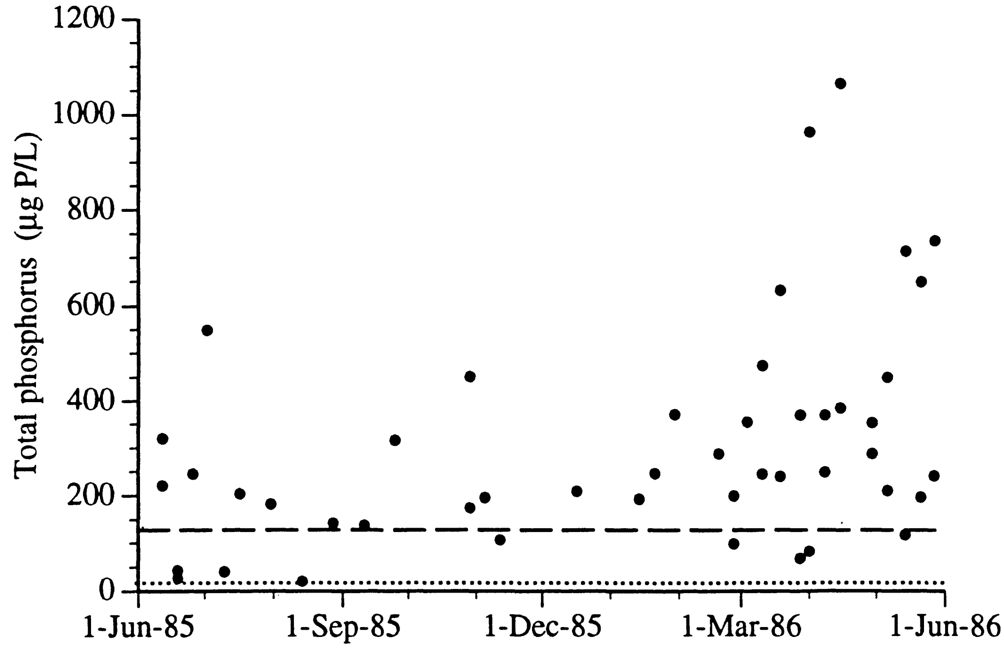


Figure 23. Total phosphorus at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)]. The values of total phosphorus above which Mills et al. (1985) suggested as "problem threshold" (dotted line) and "problem likely to exist" (dashed line) are shown for comparison.

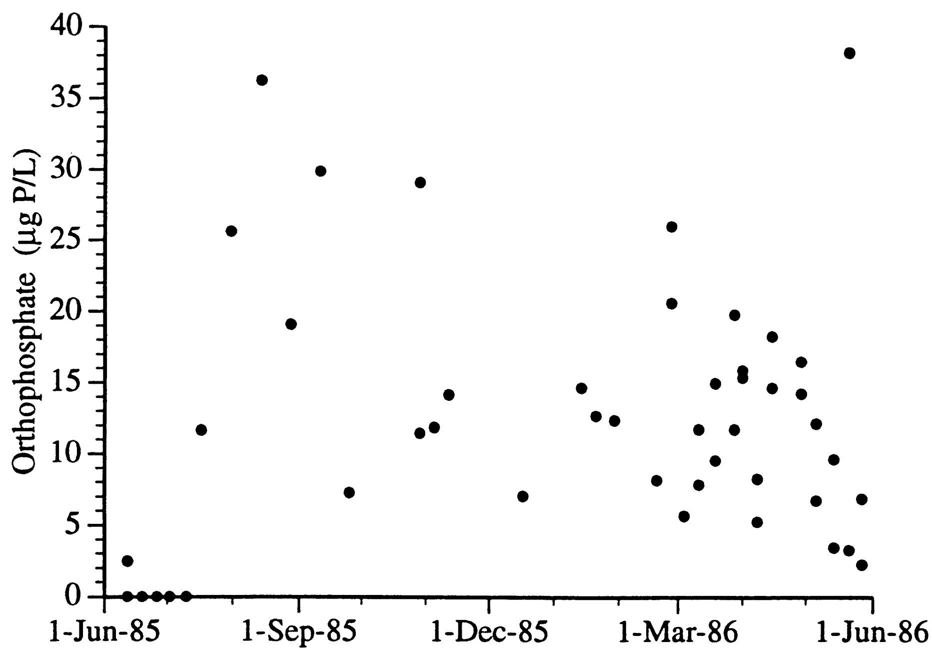


Figure 24. Orthophosphate phosphorus at the mouth of Joe Leary and Big Indian Sloughs [data extracted from Cassidy and McKeen (1986) by including only those data from their weekly samples that indicated freshwater flow out of the tidal gates (salinity 5‰ or less)].