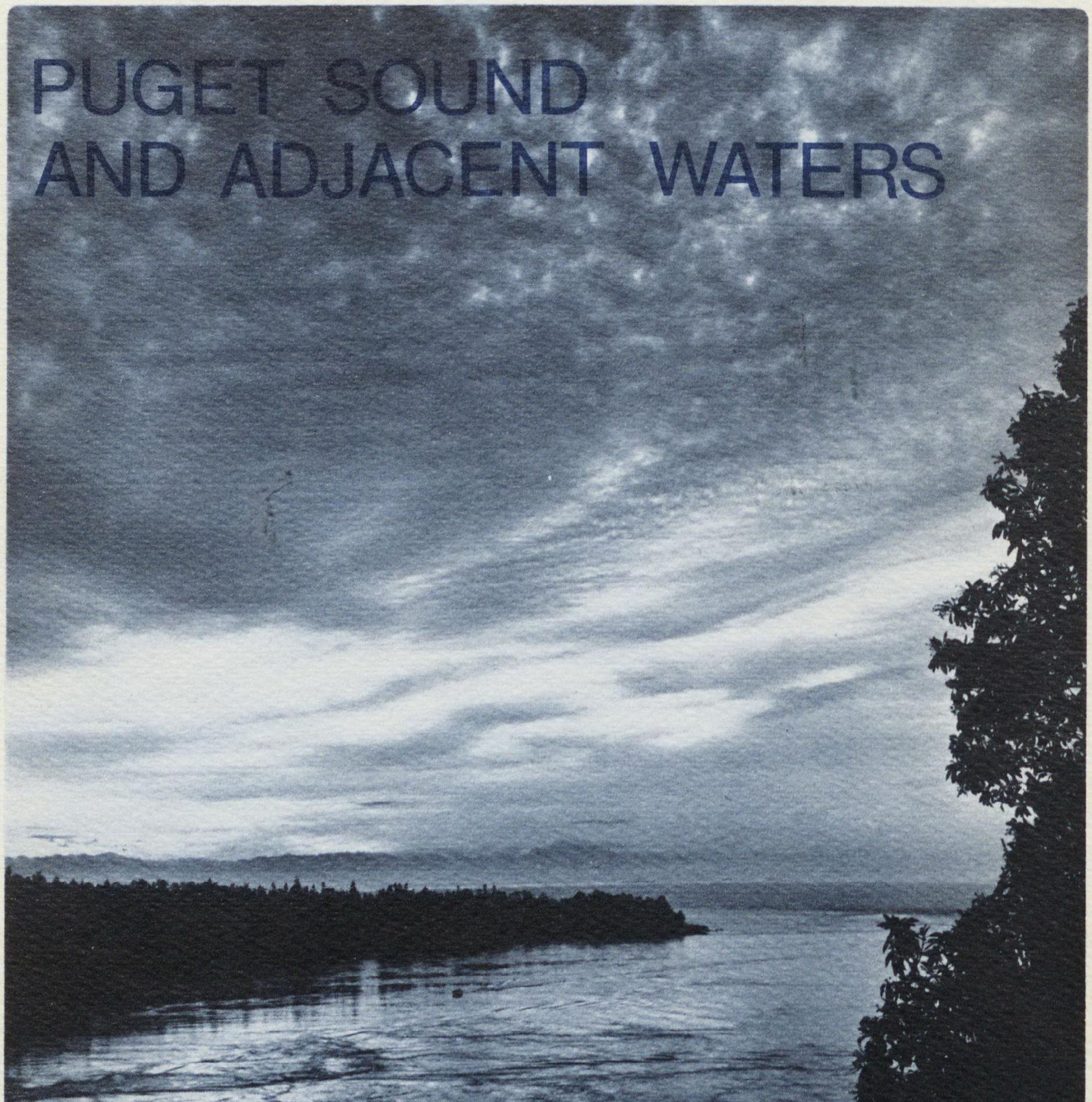
data review for ecologic modeling



May 1974

data review for ecologic modeling

PUGET SOUND AND ADJACENT WATERS

prepared for the

Environmental Protection Agency

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U. S. DEPARTMENT OF THE INTERIOR
OFFICE OF WATER RESOURCES RESEARCH

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I INTRODUCTION

OBJECTIVES AND SCOPE OF STUDY

The Puget Sound drainage area is approximately 3,600 square miles and is bounded on the east by the Cascade Mountains, on the west by the mountains of the Olympic Peninsula and on the south by the lowlands of Puget Sound-Willamette Trough. On the northwest the boundary is open to the coastal waters of Canada and the United States at the Strait of Georgia, Rosario Strait, and the Strait of Juan De Fuca.

Figure I-1 shows the location of Puget Sound and the Adjacent Waters in northwest Washington near the Canadian border. The Study Area encompasses essentially all those inland waters east of Rosario Strait and south of Admiralty Inlet. The north-south extent of the Study Area from Bellingham at Bellingham Bay to Olympia at the southern portion of Puget Sound is approximately 170 miles, forming the largest protected harbor on the west coast. By comparison, San Francisco Bay spans only 40 miles north to south.

Puget Sound is a large, glacially formed estuary. It is segmented into numerous steep sided channels ranging from 300 to 600 feet in depth. These waters are characteristically stratified with upper layers flowing seaward and lower layers flowing inward. A multitude of bays and inlets branch from the channels, and usually contain extensive delta areas formed by tributary rivers. Over a dozen major streams with a total average discharge of approximately 45,000 cfs flow into the Puget Sound Study Area.

In 1972, the Office of Water Resources Research (OWRR), U.S. Department of the Interior, Washington, D.C., authorized Water Resources Engineers (WRE) of Walnut Creek, California, to modify and apply mathematical water quality and ecologic models to the Puget Sound and Adjacent Waters in Washington. This authorization (contract #14-31-001-9056) was a continuation of a previous OWRR contract (#14-31-00001-3385) with WRE to develop water quality and ecologic models [Chen and Orlob, 1972]. Funds for the present contract are being provided by the Environmental Protection Agency and technical monitoring is being administered from the Seattle Regional Office of EPA.

The general objectives of this contract are to provide EPA, the state and local planning organizations with a mathematical simulation capability that will assist them in:

1) evaluating water quality management strategies,
2) establishing priorities for abatement facilities,
3) estimating future productivity of the Sound,
4) determining the capacity of the studied waters to assimilate wastes,
5) setting reasonable water quality standards,
6) controlling the rate of eutrophication.

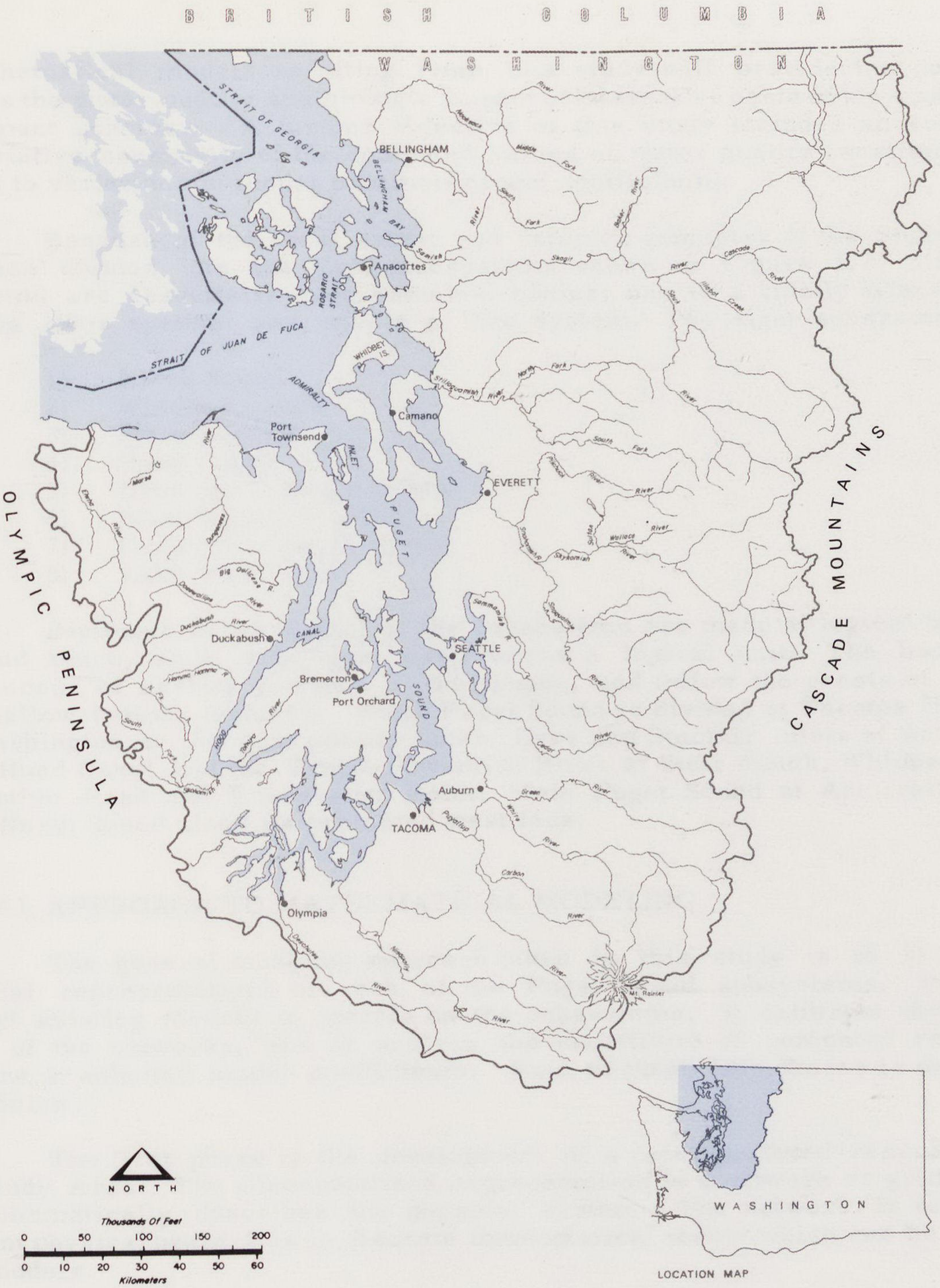

Figure I-1
Puget Sound and Adjacent Waters

The mathematical models resulting from this study will provide the capability to assess the water quality and biologic impact of alternative basin-wide wastewater management schemes. A further objective of this study includes an evaluation of the relative sensitivity of the computed values of water quality constituents and biomass to variations in model parameters and coefficients.

Because of the areal extent and complex geometry of the Study Area, it has been divided into the eight subsystems shown in Figure I-2. Six of the subsystems are essentially deep estuarial bodies; one is a tidally affected non-branching river system; and one is a lake system. The eight subsystems are:

1) North Sound
2) Whidbey Island
3) Main Puget Sound
4) Hood Canal
5) Dyes and Sinclair Inlets
6) South Puget Sound
7) Green-Duwamish River
8) Lake Washington

Divisions between each of the subsystems are made at logical boundary points and hence, each subsystem itself forms a logical unit. The boundaries usually occur at narrow portions of the sounds, and follow the crests of sills or other shallow bottom features. South Puget Sound is divided at Tacoma Narrows; Lake Washington at the government locks; Dyes and Sinclair Inlets at Bainbridge Island; Hood Canal and the Green-Duwamish River at their mouth; Whidbey Island at Deception Pass and Possession Point; Main Puget Sound at Admiralty Inlet; and the North Sound along its protected west face.

GENERAL APPROACH TO MATHEMATICAL MODELING

The general modeling approach taken in this study is to 1) develop conceptual representations of each of the Puget Sound subsystems, 2) modify and adapt existing models to operate on the subsystems, 3) calibrate the models to each of the networks, and 4) analyze the sensitivity of computed results to variations in selected model coefficients. Each of these four phases is described briefly below.

The first phase is the development of a conceptualized representation of the Study Area. The conceptualized representation is a network or grid system which schematically describes the physical system. The network is needed to represent physical properties in discrete mathematical terms which can be utilized by the models.

One network will be developed for each of the subsystems and for the entire Puget Sound system. Special consideration is needed at the boundaries between the subsystems to assure a proper description of hydraulic behavior and mass fluxes between the subsystems. At each of the boundaries except the North Sound, it is possible to specify the hydraulic behavior and mass fluxes with good

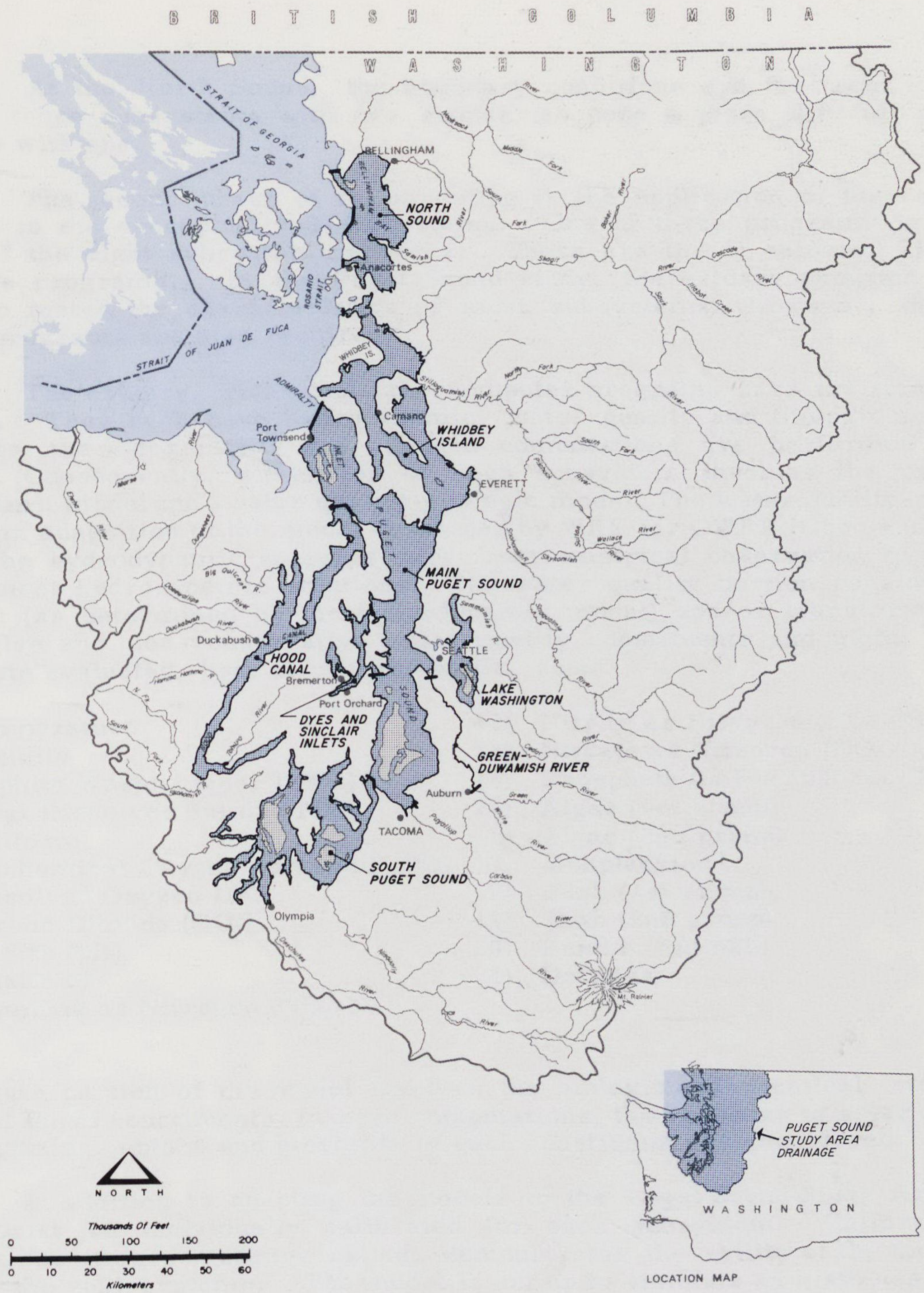

Figure I-2
Puget Sound Study Area and Subsystems

accuracy. At the North Sound, the boundary conditions are far from ideal. In addition, those subsystems with two boundaries pose a more difficult problem than those with one.

The second phase of the modeling is the application of the computer programs to the conceptualized subsystems. One of three programs is applied to each of the eight subsystem networks. These are the 1) estuary, 2) river, and 3) lake programs. In the Puget Sound study, the estuary program can be adapted to match the characteristics of most subsystems. However, the river and lake programs are also required.

The estuary, river and lake computer programs have the same basic structure. They each have hydrodynamic, water quality and biologic portions. In practice, the water quality and biologic computations are performed simultaneously. Consequently, simulation of each subsystem involves the use of a hydrodynamic model and a water quality-ecologic model. The water quality-ecologic model is an adaptation of the model developed by WRE for OWRR [Chen and Orlob, 1972]. The hydrodynamic analyses vary from empirical observation to explicit finite element hydrodynamic solutions. The water quality portion considers the movement (as determined by the hydrodynamic model) and/or transformation of conservative and non-conservative water quality constituents and biota. The 21 constituents evaluated, both abiotic and biotic, are:

1) Temperature
2) Toxicity
3) Sulphite Waste Liquor (SWL)
4) Total Dissolved Solids (TDS)
5) Coliform
6) Biochemical Oxygen Demand (BOD)
7) Dissolved Oxygen (DO)
8) Carbon Dioxide (CO_2)
9) Acidity (pH)
10) Alkalinity
11) Ammonia as Nitrogen (NH_3-N)
12) Nitrite as Nitrogen (NO_2-N)
13) Nitrate as Nitrogen (NO_3-N)
14) Phosphate as Phosphorus (PO_4-P)
15) Algae (1st group)
16) Algae (2nd group)
17) Zooplankton
18) Fish (1st group)
19) Fish (2nd group)
20) Benthic Animals
21) Detritus

The ecologic portion of the model involves the biologic and chemical interaction of many of the 21 constituents. In these computations, the response to solar energy, growth, grazing, uptake and mortality of each constituent are considered.

In addition to adapting the models to the Puget Sound Study Area, the models must be individually calibrated for each subsystem. Calibration or validation, as it is sometimes called, demonstrates the ability of the models to represent the real systems. The model is set up to simulate an historical period in time. The degree to which the model results agree with the historical data determines the degree of model validity. Because the models developed in this study are expected to be valid throughout a one year period, a validation period of one year is dictated. Each of the subsystems will be calibrated individually using identical validation periods for each subsystem if possible.

In the final phase of model adaptation, sensitivity analyses are conducted to determine the relative importance of individual model parameters and coefficients. The purpose of such an analysis is to determine which parameters need to be most accurately defined to assure reliable and meaningful results.

PURPOSE AND SCOPE OF DATA REPORT

The purpose of the data report is to review and determine the availability and adequacy of data required to successfully calibrate the models to the Puget Sound area and to validate them. The data considered in the scope of the data report includes all hydrologic and meteorologic data, water quality data, and biologic data required to simulate one year of historic hydrodynamic and biologic activity in each subsystem. For the most part, all historical data known to be available has been surveyed during the preparation of this report.

The data report that follows consists of a summary chapter describing the types of data required to calibrate the models, the availability, frequency and reliability of data, and recommended calibration periods. Following the summary chapter are two chapters specifying the source, reliability and period of record for each data type. The first of these chapters covers meteorological, hydrological and waste discharge data. The latter covers oceanographic data for the Puget Sound Study Area. Included in this last chapter is the data on tides, water circulation, and chemical and biological water quality.

ORGANIZATION AND ACKNOWLEDGMENTS

The data review reported herein was conducted under the responsibility and direction of Mr. Harry M. Nichandros of WRE, Walnut Creek, California. Dr. Gerald T. Orlob, prinicipal consultant to WRE, served as principal investigator and provided general guidance and enthusiasm.

Mr. Eugene E. Collias of the University of Washington, Department of Oceanography, has helped immeasureably in uncovering some of the most valuable water quality data. Many others in government and private industry gave their time and services to help locate additional sources of data.

WRE wishes to acknowledge the assistance of Mr. John Yearsley, Project Officer, of EPA's Seattle office and Mr. Kenneth D. Feigner, also of EPA for their assistance in locating and accumulating the massive amounts of data required. Additionally, WRE wishes to acknowledge Dr. Stanton J. Ware, OWRR, for his guidance and support through this first phase of the Ecologic Modeling of Puget Sound and its Adjacent Waters.

II DATA SUMMARY

This chapter contains a summary of data required and data available to calibrate and validate the ecologic model for Puget Sound and Adjacent Waters.

The types of data assembled include all data needed to validate the operation of the model. Water quality in this survey report refers specifically to the 21 water quality and biologic constituents that are to be simulated in this study. All periods of record were considered in the data survey. However, more recent periods (since 1950) were concentrated on because of the greater amount of data in the latter years and the greater likelihood of using one of these years as the calibration period. Data is required throughout the Study Area at specific points in time and space. These points are discussed below.

DATA REQUIREMENTS

The model will be calibrated through a one-year period with calibration check points every three months. This will assure that the model performs well throughout the four seasons of the year. The four seasons identified in Figure II-1 correspond to the hydrologic seasons typical of the northwestern United States. Winter is characterized by heavy rains and large runoff. Spring represents a period of lesser rainfall and little snow melt; hence lower stream flows. Summer brings the late snow melt from the higher elevations which results in high streamflows. Fall is a period of relatively little rainfall and the lowest streamflows.

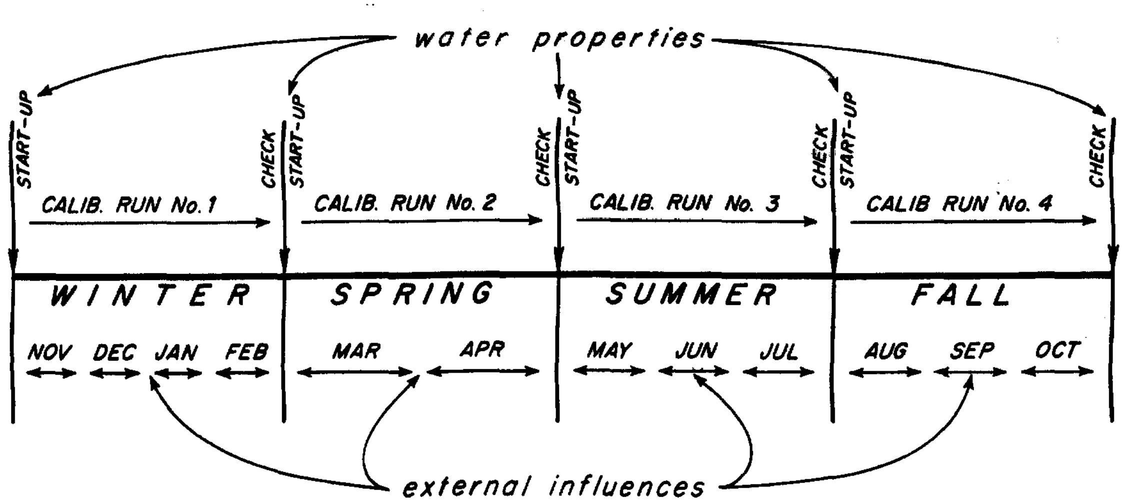

Figure II-1
Calibration Procedure for Each Subsystem

Figure II-1 can be used to aid in the visualization of the calibration process. A calibration run begins by specifying as input data the prototype water properties (physical, chemical and biological properties) existing at the beginning of the season. Theoretically the model is operated for a prototype period of three months under the influence of all the external factors such as sunlight, wind, tides (and the resultant water circulation), and river inflows. At the end of the run, the water properties computed by the model are compared to the prototype water properties. The agreement between the predicted and the actual response of the system determines the degree of validation.

In practice, the model need not be run through the full three months of the calibration season. Generally, seasonal averages of the driving variables can be used (meteorology, hydrology, system boundary conditions, etc.), and it is sufficient to run only long enough to assure that the system has stabilized to such an extent that the seasonal trends can be projected. Usually a run of 30 days is sufficient. Consequently, the data representing the external influences to the subsystems need be specified only as the seasonal average.

The required calibration data must be available over a year's time; however, they need not be continuous. Data representing water properties are needed only at the five points corresponding to the beginning and ending of each seasonal calibration run. Data representing the external influences can be specified as the seasonal average.

In addition to conforming to the temporal requirements discussed above, data must be compatible with the grid or network utilized by the mathematical models. A brief, general description of the network structure is provided here to aid in visualizing the spatial variations in data allowed. In the horizontal plane, a grid is structured to define surface water properties approximately every 2 to 4 miles. Consequently, the values of input data need only be estimated at intervals of 4 to 10 miles to provide adequate calibration. In the vertical plane, the network varies depending upon the vertical stratification of the subsystem waters. In unstratified areas, each value on the horizontal plane is representative of the water column throughout its depth. In stratified areas, additional water properties are required at 4 or 5 depths. Adequate representation is obtained with one value at each depth every 4 to 10 miles along the deep water portion of the Sounds.

The types of data required for the models fall into the following broad categories: meteorologic, hydrologic, waste discharge and oceanographic. These categories are explained below.

Seasonal average values of the following types of meteorologic data are required: solar radiation, cloud cover, wind velocity, relative humidity, air temperature, and precipitation. Solar radiation and cloud cover data must represent the average morning, afternoon, evening and night conditions in order to compute the diurnal response of phytoplankton to solar inputs.

Hydrologic data refer specifically to discharge and water quality of inflows to the study area from the surrounding drainage areas. Seasonal averages are satisfactory for these data. The average freshwater inflow is used to calculate the change in water volume and waste movements within the subsystem. Likewise the inflow water quality is used to compute the increase in concentrations of the various constituents.

The waste discharge data requirements are identical to those for hydrologic data. The average discharge and discharge quality of all municipal and industrial dischargers surrounding the Study Area are needed.

Included in oceanographic data are geometric, tidal, hydrodynamic and oceanographic water quality data. Geometric data are used to define the boundaries, mean depths and average water surface elevations of each water body in the Study Area. These data, of course, do not vary with time.

Tidal data represent the variation in tides at the open boundaries of each subsystem. The monthly average tidal pattern for each season is one of the driving forces for the hydrodynamic models. Additional tidal data (at interior nodes) can be used to check simulated tidal fluctuations against the actual fluctuations. Tidal bench marks are also need to reference all tide gages to a common datum.

Hydromechanical data (current patterns) describe the movement of water within the subsystems. The primary purpose of these data is to validate the hydrodynamic portion of the model by allowing comparison to be made of model generated movements against the actual water movements. The data may also aid in the adaptation of a hydrodynamic model to Puget Sound by allowing some complex model variables to be empirically replaced by known current patterns. Average current pattern data is needed for each season. Because the circulation is the principal mechanism affecting the status of all water quality and biological parameters, the hydromechanical data are of primary importance to the success of the modeling project. The need for accurate circulation data cannot be over-emphasized.

The purpose of the oceanographic water quality data is to provide both a starting point and a final verification point for the water quality and ecological portions of the model. These water parameters must be available at the beginning and end of each season's calibration run. For each of these times the concentrations of each of the following water quality and ecologic properties must be known at all of the node points:

1) Temperature
2) Toxicity
3) Sulphite Waste Liquor
4) Total Dissolved Solids
5) Coliform
6) Biochemical Oxygen Demand
7) Dissolved Oxygen
8) Carbon Dioxide
9) Acidity
10) Alkalinity
11) Ammonia as Nitrogen
12) Nitrite as Nitrogen
13) Nitrate as Nitrogen
14) Phosphate as Phosphorus
15) Algae (1st group)
16) Algae (2nd group)
17) Zooplankton
18) Fish (1st group)
19) Fish (2nd group)
20) Benthic Animals
21) Detritus
22) Secchi Disc Reading

The hydrodynamic data and the oceanographic water quality data are the most essential data required in this study.

DATA AVAILABILITY

In the Puget Sound Study Area, the availability of data varies from unavailable to complete. Figure II-2 represents a subjective analysis of the availability of each major class of data from 1930 to the present. An overall assessment of availability of data would rank it as very sparse to partial. Important physical, chemical and biological oceanographic data are completely missing in early years. In recent years such data are more available but still incomplete. Circulation data (physical oceanographic data) are very sparse, being unavailable at times, even in later years. Only one comperehensive study collected oceanographic data over an extensive area. Less important, but still essential, meteorological and hydrological data are more abundant in later years. Navigation charts provide all the data needed to define the geometrics of the Study Area. These data can be used for any selected calibration period. Following is a more detailed summary of the availability of each class of data.

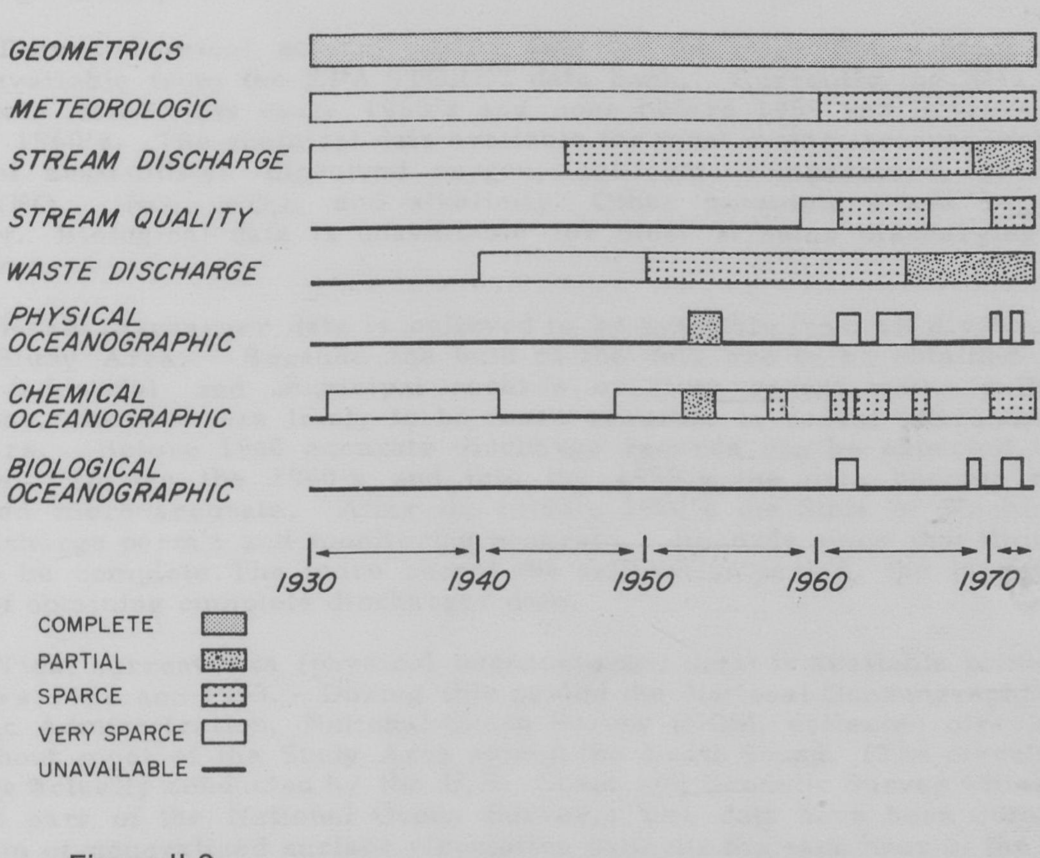

Figure II-2
Overview of Data Availability for the Puget Sound Study Area

Sufficient meteorological data are available from 1960 to the present to satisfy model requirements as set forth above. The weakest portions of the meteorological data are the cloud cover and wind velocity data. These data are not readily available before 1960. After 1960 cloud cover and wind velocity data are available at a few scattered stations. Conditions between stations can be estimated with acceptable accuracy. Periods of no data can be represented by average weather conditions.

Hydrologic (streamflow) data are adequate throughout most of the period since about 1945. Prior to this date the data are less than adequate in nearly all subsystems. Many major stream gaging stations were installed in the period from 1943 to 1947. Consequently, after the mid-1940's the data improve. Since this time, records for most subsystems are good but several major streams in the study area still remain ungaged. After the late 1960's most major streams have continuous recording devices installed at strategic locations. These data are rated as partial throughout the Study Area.

In most cases adequate streamflow records can be synthesized or otherwise estimated as long as records are available for the majority of the streams. Hence the adequacy of hydrologic data should not weigh heavily in the choice of calibration periods.

Recent chemical stream quality data for the Puget Sound Study Area is readily available from the EPA STORET data bank. Currently the data bank has little data before the early 1960's and none before 1959 and it lacks data in the later 1960's. The chemical data available for most major streams include, in order of availability: dissolved oxygen, coliform, temperature, salinity, nutrients (PO_4, NO_2, NO_3), and alkalinity. Other parameters are reported sporadically. Biological data is unavailable for most streams discharging into the study area.

Waste discharger data is believed to be available from all dischargers within the Study Area. Because the bulk of the data are to be obtained from individual industrial and municipal records or from recent water pollution investigations, the data are likely to be more accurate in recent years than in earlier years. Before 1940 accurate discharge records can be expected to be unobtainable. During the 1940's and into the 1950's the data become more available and more accurate. After the middle 1960's the State of Washington began a discharge permit and monitoring program. Records since that time are expected to be complete. The more recent the calibration period, the larger the likelihood of obtaining complete discharger data.

Tidal current data (physical oceanographic data) is available primarily for the years 1952 and 1953. During this period the National Oceanographic and Atmospheric Administration, National Ocean Survey (NOS), collected circulation data throughout most of the Study Area except the North Sound. (The circulation studies were actually conducted by the U.S. Coast and Geodetic Survey which has now become part of the National Ocean Survey.) The data have been compiled into the form of generalized surface circulation patterns for each hour of the tidal cycle. These patterns are valid for spring and summer but less applicable during seasons of high surface discharge. A limited amount of subsurface current data is also available.

The majority of chemical oceanographic data have been collected on cruises from 1932 to 1942 and 1947 to 1966. In addition, several major studies conducted in the 1960's and 1970's have provided considerable data of limited areal extent. The data usually collected, however, have been limited primarily to temperature, salinity, dissolved oxygen and sulfite waste liquor. Very few field investigations have considered nutrients and other water quality constituents.

An extensive data collection effort from October 1952 to September 1954 included chemical data for most of the Study Area. In additional efforts from 1957-1958 and 1960-1961 data were collected for the western portion of South Puget Sound and the North Sound, respectively. Together these periods provide adequate data on water temperature, salinity, dissolved oxygen, phosphate and sulfite waste liquor.

Biological oceanographic data is, for the most part, unavailable except in very recent years. Some of the more recent studies, especially since 1965, have included the effects of pollutants on phytoplankton, zooplankton, and other very specific types of fauna. Most water quality investigations have been concerned with benthic animals and bottom sediments. The data for this are relatively good. A good deal of biological oceanographic data will have to be generalized and accepted as "average" values.

RECOMMENDED VALIDATION PERIOD

Reviewing Figure II-2, it is seen that data availability generally improves in later years. However, several notable exceptions make the physical and chemical oceanograhic categories most complete in the early 1950's. Further, in each subsystem there is no period for which substantial data are available in all categories. It is therefore necessary to select a calibration period based upon the data availability of certain primary categories and then pool information from other categories and other years in an attempt to represent the simulation of a typical period. The physical, chemical and biological categories are most essential to the calibration of the ecologic models. Other data may be averaged and otherwise pooled from other periods to provide a satisfactory data base.

For the North Sound, the calibration period should be selected to coincide with the chemical oceanographic data collected in that subsystem from May 1960 through April 1961. Calibration will thus begin in the summer season as shown in Figure II-1. The Lake Washington Subsystem was calibrated in a very perfunctory fashion by Chen and Orlob [1972]. Further analysis of this subsystem, including model sensitivity analysis, will use data representing the period from 1968 to 1970 as used in the calibration procedure.

The remainder of the Study Area data was collected during the 1953 and 1954 water years. Additional data for the western portion of South Puget Sound was collected during the 1958 water year. The remaining Study Area is comprised of five contiguous subsystems: Whidbey Island, Main Puget Sound, Hood Canal, Dyes and Sinclair Inlets, and South Puget Sound. Because these subsystems are contiguous several advantages can be gained by selecting a single common calibration period. The major advantage, of course, is to facilitate the simultaneous calibration of all subsystems. The period selected for these five subsystems is November 1952 through October 1953. This period, which represents the winter and fall seasons of 1953, corresponds to the period of nearly complete physical and oceanographic data throughout these subsystems. It also corresponds to a water year with fairly typical hydrographic conditions.

III

METEOROLOGICAL, HYDROLOGICAL, AND WASTE DISCHARGE DATA

METEOROLOGICAL DATA

Meteorological data is reported from many stations surrounding the Puget Sound Study Area. The locations of 40 such stations are shown in Figure III-1, which also indicates the data available from each station. These stations encompass the region from Bellingham to Olympia and from Port Angeles to Everett. Additional stations are in the Puget Sound drainage, but only those stations in the immediate vicinity of the Sound are shown. Table III-1 lists the stations and the associated period of record through 1972 for temperature, precipitation, wind velocity and cloud cover. Figure III-1 and Table III-1 were compiled from the National Oceanographic and Atmospheric Adminstration (NOAA) recent climatological data summaries [USDC, 1972], local NOAA representatives [Beech, 1973], and the University of Washington [Lincoln and Collias, 1970].

Nearly all stations report daily precipitation and minimum and maximum temperatures. Recording stations (as indicated on Figure III-1) report hourly. Eighteen stations report hourly wind velocity; 13 of these also report cloud cover data. However, several of these stations either operate intermittently or have very short periods of record. The most comprehensive meteorologic data in the area is recorded at the Seattle-Tacoma Airport (Seatac). Data available from Seatac includes hourly temperature, precipitation, wind velocity, maximum possible sunshine, actual sunshine, solar radiation, and cloud cover. Additional wind velocity data is available from the Washington Marine Atlas for southern [Jamison, 1972a] and northern [Jamison, 1972b] inland waterways. The atlas denotes seasonal average wind magnitude and direction throughout the Study Area.

Twenty-seven of the stations listed in Table III-1 are indexed by NOAA. Data from these stations are available from the NOAA offices in either Seattle or Asheville, North Carolina. Stations marked U of W are supplementary stations operated by the University of Washington, Department of Oceanography. These stations operated for a brief period from early 1969 through January 1, 1972. Data from the University stations may be obtained from the Department of Oceanography in Seattle. The other stations are either airports or U.S. Coast Guard light stations. Information from these sources is available in unpublished form from the NOAA office in Seattle or directly from the station operator.

HYDROLOGICAL DATA

All of the major streams discharging into the Puget Sound Study Area have established stream gaging stations. Nearly all of these stations are located sufficiently close to the river mouth to give a reasonably accurate indication of discharge into the Sound. Figure III-2 shows the location of gaging stations. The stations are keyed to Table III-2 which shows the data source, station

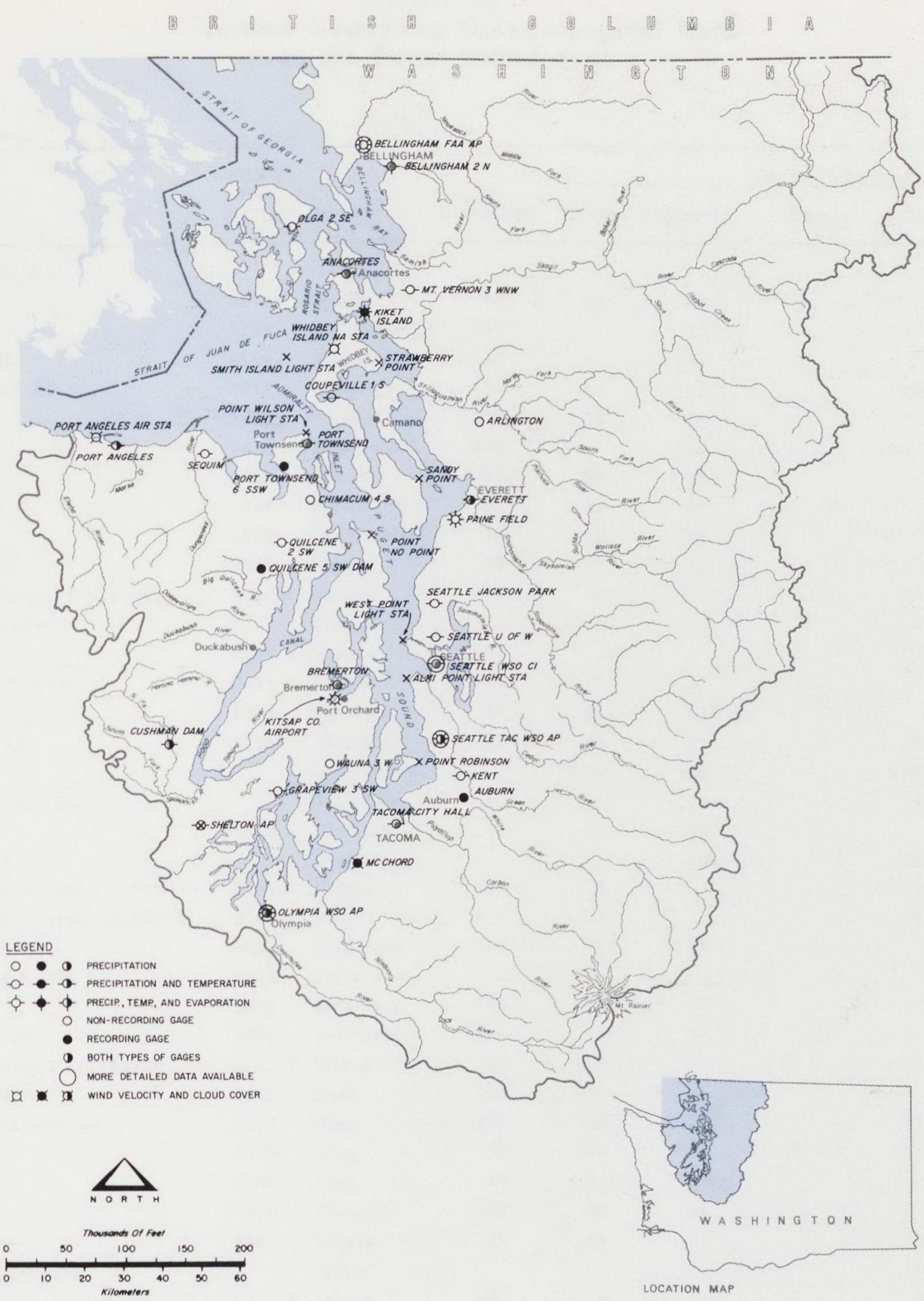

Figure III-1
Locations of Stations Reporting Meteorological Data in the Puget Sound Area

TABLE III-1
Stations Reporting Meteorological Data in the Puget Sound Area

Station	USWB Index No. (1)	County	Elevation	Years of Record				
				Temp.	Precip.	Evap.	Wind	Cloud Cover
Alki Point Light Sta		King						
Anacortes	0176	Skagit	30	62	89			
Arlington	0257	Snohomish	100		34			
Bellingham 2 N	0564	Whatcom	140	59	61	6		
Bellingham FAA AP	0574	Whatcom	150	29	32		10+	10+
Bremerton	0872	Kitsap	162	29	74			
Chimacum 4 S	1414	Jefferson	250		44			
Coupeville 1 S	1783	Island	50	58	70			
Cushman Dam	1934	Mason	750	42	49			
Everett	2675	Snohomish	60	58	58			
Grapeview 3 SW	3284	Mason	30	64	64			
Kiket Island (closed 1/1/1972)	U of W	Skagit	<30	4	4		4	
Kitsap Co. Airport		Kitsap		8+			2	2
McChord	5148	Pierce	292				10+	10+
Mount Vernon 3 WNW	5678	Skagit	14	17	17			
Olga 2 SE	6096	San Juan	80	81	83			
Olympia WSD AP	6114	Thurston	195	31	31		10+	10+
Paine Field		Snohomish		∿30	∿30		∿30	∿30
Point Wilson Light Sta		Jefferson					1	1
Port Angeles	6624	Clallam	99	69	95			
Port Angeles Air Sta		Clallam			10+		10+	10+
Point No Point (closed 1/1/1972)	U of W	Kitsap	<30	3			3	
Point Robinson (closed 1/1/1972)	U of W	King	<30	3			3	
Port Townsend	6678	Jefferson	100	74	95			
Port Townsend 6 SSW	6693	Jefferson	160					
Quilcene 2 Sw	6846	Jefferson	123	51	52			
Quilcene 5 SW Dam	6851	Jefferson	1028					
Sandy Point (closed 1/1/1972)	U of W	Island	<30	3			3	
Seattle Jackson Park	7459	King	335	11	11			
Seattle-Tacoma WSD AP	7473	King	400	28	28		10+	10+
Seattle U of W	7478	King	97	48	62			
Seattle WSO CI	7488	King	14	82(2)	95(2)			
Sequim	7538	Clallam	180	40	54			
Shelton	7584	Mason	22	41	41		5	5
Smith Island Light Sta		Island					5	5
Strawberry Point (closed 1/1/1972)	U of W	Island	<30	3			3	
Tacoma City Hall	8286	Pierce	267	82	97			
Wauna 3 W	9021	Pierce	17		31			
West Point Light Sta		King					1	1
Whidbey Islands N A Sta		Island			10+		10+	10+

(1) U of W indicates University of Washington operated station. Blank indicates privately operated.
(2) Closed in October.

number, average flow rate and periods of record. Unless otherwise stated all the United States Geological Survey (USGS) stations report flow rate daily throughout the specified period of record.

Figure III-2 and Table III-2 were compiled from the USGS surface water records [USDI, 1971 and 1972] and from a STORET data summary [EPA, 1973]. The data from the USGS is reported in the annual USGS publication <u>Water Resources Data for Washington, Part I, Surface Water Records</u>. Copies of the report for any year may be obtained from the Water Resources Division, USGS, Tacoma, Washington. The data in STORET is available from the STORET data terminal in the EPA office, Seattle, Washington.

The Skagit and the Snohomish Rivers are the principal tributaries to the Study Area. Each of these rivers carry one third the total basin discharge. The Nooksack, Stillaguamish and Puyallup Rivers each carry an additional 8 to 10 percent of the total discharge. Sufficient data is available to estimate discharge at the mouth of the Nooksack, Samish, Skagit, Sammamish, Cedar, Green, Puyallup, Nisqually, Deschutes, Skokomish, Hamma Hamma and Duckabush Rivers. This list includes all the major rivers except the Stillaguamish and the Snohomish. Data availability for these and other rivers is discussed below.

Lengthy records of excellent data are available for several tributaries to the Stillaguamish River. However, the only station located on the Stillaguamish is a partial-record station at Arlington. This station reports only crest stages which most likely can be related to flow rate using unpublished USGS stage-discharge curves. The reliability of discharge estimates of the Stillaguamish River at the mouth will be adequate.

Discharge from the Snohomish River can be estimated with reasonable accuracy after February 1973 using records from the station near Monroe. Discharge estimates are hampered because no information is available for the Pilchuck River which is tributary to the Snohomish below Monroe. Before February 1963, the three stations upstream from Monroe must be relied upon.

No data is available for the Tahuya, Big Quilcene and Dosewallips Rivers. However, judging by the closely related Duckabush and Hamma Hamma Rivers, the discharge from the Big Quilcene and Dosewallips will be small and easily estimated with little error. The small Tahuya River discharges must also be estimated; but with less apparent accuracy than the other two rivers.

Many insignificant rivers and creeks not shown in Figure III-2 discharge into the Study Area and also into the reported rivers below gaging stations. For the most part these streams which might carry as much as 200 cfs are ungaged. Individually their effect is minor (amounting to less than 0.5 percent of the total basin discharge) compared to the larger rivers. However, the total volume of water discharged to the Study Area by these streams may be significant. Estimates of this discharge can be made from precipitation data described earlier.

River water quality data is available from many of the same stations where stream discharge measurements were taken. Figure III-3 shows the

Figure III-2
Locations of Stations Reporting Surface Water Discharge
Into the Puget Sound Area

TABLE III-2
Surface Water Gaging Stations Surrounding
The Puget Sound Study Area

Subsystem River/Station	USGS No.	DOE No.	Ave. Flow cfs	Records First	Records Last	Source[1]	Remarks
NORTH SOUND							
Nooksack River							
At Ferndale	12213100		4251	10/66	cur	G	Records excellent or good
At Deming	12210500	01C120	3384	7/35	cur	G	10/57-9/64 discharges above 3500 cfs only
Samish River							
Nr Burlington	12201500		243	7/43	9/71[2]	G	Records excellent
WHIDBEY ISLAND SUBSYSTEM							
Skagit River							
Nr Mt. Vernon	12200500	541035	16820	10/40	cur	G	
Stiliaguamish River Basin							
Pilchuck Cr. Nr Bryant	12168500		281	8/29	cur	G	Records gap prior to 9/52. Records excellent
N. Fork Nr Arlington	12167000	05A110	1880	7/28	cur	G	Records excellent or good
At Arlington	12167400			59	cur	GP	Stages only
S. Fork Nr Granite Falls	12161000	541041	1079	7/28	cur	G	Records excellent
Snohomish River Basin							
Nr Monroe	12150800		10430	2/63	cur	G	Records excellent 1951-1963 annual high stage on file (some in WSP 1932)
Snoqualmie R. Nr Carnation	12149000	07D070	3823	10/28	cur	G	Records excellent
Skykomish R. At Golden	12134500	541046	3983	9/28	cur	G	Records excellent
Wallace R. At Gold Bar	12135000			7/46	cur	G	Records good
LAKE WASHINGTON SUBSYSTEM							
Sammamish River							
Nr Woodinville	12125200		344	1/64	cur	G	Records good
Cedar River							
At Renton	12119000		711	8/45	cur	G	Records good
MAIN PUGET SOUND SUBSYSTEM							
Green River							
At Tukwila	12113350		1159	10/60	cur	G	Records good
Nr Auburn	12113000	541052	1365	8/36	cur	G	Records excellent
Puyallup River							
At Puyallup	12101500	10A050	3390	5/14	cur	G	Records good

TABLE III-2
(Continued)

Subsystem River/Station	USGS No.	DOE No.	Ave. Flow cfs	Records First	Records Last	Source	Remarks
SOUTH PUGET SOUND SUBSYSTEM							
Nisqually River							
Nr McKenna	12088400		1834	8/41	cur	G	No records 8/63-2/69. Records excellent
Muck Cr. At Roy	12090200		68	5/56	9/72	G	
Kennedy Creek							
Nr Kamilche	12078400		61	2/60	9/71	G	Records excellent
Deschutes River							
Nr Rainier	12079000	13A150	269	6/49	cur	G	Records good
HOOD CANAL SUBSYSTEM							
Skokomish River							
Nr Potlatch	12061500	16070	1406	7/43	cur	G	Records excellent
Hamma Hamma River							
Nr Eldon	12054500		364	6/41	6/71[2]	G	Records excellent
Duckabush River							
Nr Brinnon	12054000		420	6/38	cur	G	Records good and fair
Dosewallips River							
No stations							
Big Quilcene River							
Nr Quilcene	12052500		200			G	8/26-9/27, 6-9/51, 8/71-7/72 only

[1]G = USGS

P = USGS partial-record station. A stage-discharge relation for each gage is developed from discharge measurements made by indirect measurements of peak flow or by current meter. The date of the maximum discharge is not always certain but is usually determined by comparison with nearby continuous-record stations, weather records, or local inquiry. Only the maximum discharge for each water year is given. Information on some lower floods may have been obtained, and discharge measurements may have been made for purposes of establishing the stage-discharge relation, but these are not published herein. The years given in the period of record represent water years for which the annual maximum has been determined.

[2]Currently operates as a partial-record, see note 1 above.

locations of selected water quality sampling stations. These stations are tabulated in Table III-3, listing the major rivers for which stream quality data is available, and the dates during which certain selected parameters were measured. Those chosen; namely, PO_4, NO_2, NO_3, dissolved oxygen, coliform, temperature, alkalinity, and salinity are the parameters sampled most frequently. Other constituents are measured on a less frequent and sporadic basis. The table shows a fairly consistent sampling of temperature, salinity, dissolved oxygen, and coliform and somewhat less consistent sampling for nutrients and alkalinity.

Data for stream quality is obtained primarily from the EPA STORET data bank which contains data from many sources including the USGS, EPA, Municipality of Metropolitan Seattle (METRO) and Washington State Department of Ecology. Table III-3 was compiled from a STORET [USEPA, 1973] data dump in 1973. At the time the data dump was taken, data was available from STORET back to approximately 1959 excluding parts of 1966 and 1967 data from the USGS. Because EPA is currently updating and extending the data bank to include more periods of record, more data will be available in coming months. It can be expected that the 1966-1967 gap in USGS data will be filled by that time.

In addition to the STORET data, several river water quality investigations have been conducted. Most of these, done for the Washington Pollution Control Commission, are old and consider essentially the same basic parameters abundant in the STORET files. One study of note was conducted by Welch [1969] on the Duwamish River. He investigated phytoplankton blooms and dissolved oxygen from 1964 to 1966 at five sampling points. Except for the study mentioned above, no comprehensive stream biological data is known to be available.

WASTE DISCHARGE DATA

Over 150 agencies and industries discharge wastewater into the Puget Sound Study Area. Summary information concerning these dischargers have been compiled and reported in the Washington Marine Atlas for southern [Jamison, 1972a] and northern [Jamison, 1972b] inland waterways. The information presented in this section comes from these volumes.

Table III-4 lists the municipal wastewater dischargers. This group comprises about half the total number of dischargers in the study area. The table shows that the level of treatment provided by each agency varies from no treatment to secondary treatment. The average flow rates vary from a negligible 0.03 mgd to 18.0 mgd.

Table III-5 lists the industrial dischargers in the Puget Sound area. The table includes the discharger name, the annual average discharge rate and a short description of either the type of industry or the quality of wastewater discharged. Generally, the larger discharges involve cooling water. Ordinarily the only quality change for such cases is a rise in temperature. Some of the industries listed in Table III-5, such as food processing companies, discharge very little wastewater and affect the 21 water quality parameters only slightly.

Figure III-3
Location of Stations Reporting Surface Water Quality in the Puget Sound Area

TABLE III-3
Surface Water Quality Stations in the Puget Sound Study Area

Subsystem River/Station	PO_4	NO_3	NO_2	DO	Colif.	Temp.	pH	Alka.	Salinity
NORTH SOUND SUBSYSTEM									
Nooksack River									
At Ferndale									
1961-65	X	X				X	X	X	X
1965-66				X	X				
1970				X	X				
1971	X	X	X	X	X				
Samish River									
Nr Burlington									
1959-66	X	X		X	X	X	X		X
1967-69					X	X	X	X	X
1970	X	X		X	X	X			
1971	X	X	X	X	X	X			
WHIDBEY ISLAND SUBSYSTEM									
Skagit River									
Nr Mt. Vernon									
1959-66	X	X		X	X	X	X	X	X
At Conway									
1970-71	X	X		X	X	X			X
Stillaguamish River									
At Stanwood									
1970-71	X	X	X	X	X				
Nr Silvana									
1959-66	X	X		X	X	X	X		X
1966-67				X	X	X	X		X
1968				X	X	X	X	X	X
1970-71	X	X	X	X	X	X			X
Snohomish River Basin									
At Snohomish									
1961-66	X			X	X	X	X		X
1967-69						X	X	X	X
1970-71	X	X	X	X	X	X	X	X	X

TABLE III-3
(Continued)

Subsystem River/Station	PO_4	NO_3	NO_2	DO	Colif.	Temp.	pH	Alka.	Salinity
Pilchuck River									
At Snohomish									
1970-71	X	X	X	X	X				
LAKE WASHINGTON SUBSYSTEM									
Issaquah Cr (Sammamish R.)									
Nr Mouth									
1964-65	X			X	X	X	X		X
1966-68				X	X	X	X	X	X
1969-70						X	X	X	X
1970-71		X	X	X	X	X	X		X
Cedar River									
At Renton									
1959-66	X	X		X	X	X	X		X
1970-72		X	X	X	X	X			X
1973				X	X	X			
MAIN PUGET SOUND SUBSYSTEM									
Green River									
At Tukwila									
1962-63				X	X	X			
1964-68				X	X	X	X	X	X
1969-70				X	X	X			
Nr Kent									
1970-71				X	X	X	X	X	X
Puyallup River									
At Puyallup									
1960-67	X	X		X	X	X	X		X
1970		X	X	X	X	X	X		X
1971		X	X	X	X	X	X	X	
1972		X	X	X	X	X	X		X
SOUTH PUGET SOUND SUBSYSTEM									
Nisqually River									
At Nisqually									
1972-73	X	X	X			X			

TABLE III-3
(Continued)

Subsystem River/Station	PO_4	NO_3	NO_2	DO	Colif.	Temp.	pH	Alka.	Salinity
At McKenna									
1959-65	X			X	X	X	X	X	X
1967-70				X	X	X	X	X	X
Deschutes River									
At Henderson Blvd.									
1971-72		X	X	X	X	X	X	X	X
Nr Olympia									
1962-65	X			X	X	X	X	X	X
1966-70				X	X	X	X	X	X
1971-72		X	X	X	X	X	X	X	X
HOOD CANAL SUBSYSTEM									
Skohomish River									
Nr Potlatch									
1960-61	X			X	X	X	X		X
1962-65	X			X	X	X	X	X	X
1966-70						X	X	X	X
1971-73	X	X	X	X	X	X			X
Hamma Hamma River									
Nr Eldon									
1961-65	X					X	X	X	X
1966						X	X	X	X
1967-68						X	X	X	X
1971		X	X						
1972-73				X	X	X			X
Duckabush River									
Nr Brinnon									
1960-62	X			X	X	X	X		X
1963-65				X	X	X	X		X
1966				X	X	X	X		X
1971		X	X	X	X	X			X
1972				X	X	X			X
Dosewallips River									
At Brinnon									
1959-66	X	X		X	X	X	X	X	X
1967-69						X	X	X	X
1971-73		X	X	X	X	X		X	X

TABLE III-4
Municipal Wastewater Dischargers in the Puget Sound Area

No.	Agency	Type of Treatment	Average Flow in mgd
1	LaConner	S	1.5 3.0 peak
2	Skagit Co. S.D. #1	Spt	.025
3	Anacortes	P	1.3
4	Skyline	P	0.5
5	Lynwood Center		
12	Bellingham (present)	P	4.5 Municipal 3.1 Industrial Included in municipal
13	Post Pt. (Projected)	P	10.0 Municipal 6.0 Industrial
14	Ault Field	S	.55
15	Crescent Harbor - Capehart Housing - Seaplane Base	S	.55
16	Oak Harbor	P	.2 Design .32 Average
17	Penn Cove Sewer District	P	0.1
18	Coupeville	P	.15
19	Langley	P	.15
20	Stanwood	S	1.5 peak
21	Marysville	S	.9
22	Everett	S	18.0
23	Muhilteo	P	.25
24	Olympus Terrace	S	.5
25	Alderwood Water District	S	1.5
26	Lynwood	P	4.0
27	Edmonds	P	8.3
28	Richmond Beach	P	2.5
29	Des Moines	P	1.5
30	Redondo	P	.86
32	Miller Creek	P	2.0
33	Salmon Creek	P	1.6
34	Vashon Sewer District	S	.017
35	West Point (Metro)	P	.35
36	Carkeek Park (Metro)	P	3.1
37	Alki Point (Metro)	P	7.5
38	Annapolis Sewer District		.37
39	Bangor USN	S	.08
40	Bremerton (Charleston)	P	5.0
41	Bremerton (Manette)	P	2.9
42	Keyport	S	.055
43	Keyport - Navy	S	.13
44	Silverdale	P	.23
45	Port Gamble (Pope & Talbot)	S	.04 peak
46	Port Orchard	P	.5
47	Poulsbo	P	.25
48	Winslow	P	.03
49	Manchester	P	0.3
50	Brownsville	S	0.6
51	Beans Point Sewer District #7	S	0.2
52	Kingston	P	0.2
53	Suquamish	P	0.4
59	Port Townsend		
60	Port Ludlow		
61	Fort Flagler State Park		
63	Shelton	P	1.7 Average 1.0 Minimum 4.5 Maximum
64	Shelton Imhoff	Imhoff Tank	.03 Domestic .7 mgd Storm
65	Twanoh	Spt	.045
66	Alderbrook Inn	Spt	
67	Marstene Development	P	
68	Rustlewood Development	STP	
69	Olympia	P	6.5 mgd dry
70	Reserve Fleet	Spt	
71	Point Definance City Park	Raw	
72	Tacoma City - Northside	P	4.57
73	Tacoma City - Southside	P	.85
74	Tacoma City - Central	P	24.0
76	Navy Imhoff Tank	Spt	
77	Steillacoom	P	.8
78	Westside Water District	Lagoon	
79	Fort Lewis	P	.167
80	Ketron Island	STP	.239
81	Taylor Bay Estates	S	
82	McNeil Island	STP	.239
83	Day Island		
84	Salmon Beach Development	Raw	
88	Dash Point State Park	Spt	
99	Lake Stevens S.D.	S	1.47
100	Bay View State Park	S	.035
101	Messenger House		.008
102	Shelter Bay Recreational Development	S	.06
103	Seashore Villa	S	
104	Beverly Beach	S	
105	Olympia Golf and Country Club	Spt	
106	Carlyon Beach	Spt	
110	Indian Island	S	
112	Fairhaven	Raw	

P - Primary
S - Secondary
Spt - Septic Tank
STP - Sewage Treatment Plant
mgd - Million Gallons/Day

TABLE III-5
Industrial Waste Dischargers in the Puget Sound Area

No.	Industry	Type of Discharge	Average Flow in mgd
2	Pope & Talbot Lumber Mill	Cooling Water	.12
3	Guilford Packing Company	Intermittent discharge	Int.
4	Scott Paper Company		6.46
5	Farwest Fisheries Division of Whitney Fidalgo		.6 max.
6	Fisherman's Packing Corporation	Seasonal	.06 max.
7	Moore Clark Company	Intermittent, seasonal	.5
8	Texaco Refinery	pH - 7.1, 4.3 mgl oils	3.0
9	Shell Refinery	pH - 6.8, 4.6 mgl oils	2.1
10	Allied Chemical		.032 max.
11	Standard Oil	Cooling water	.33
12	Chevron Asphalt Company	Cooling water 0-25 ppm oils, 0-1 ppm phenol	.72 .02
13	Scott Paper Company - Everett Sulfite Pulp and Paper Mill	Main sewer Paper composite	24.5 6.4
14	Weyerhaeuser Company	Sulphite Pulp, Mill Bleach Mill Creek Main sewer Deep diffuser	6.9 .3 7.9 11.9
15	Simpson Lee Paper Company - Kraft Pulp & Paper Mill		9.1
16	Weyerhaeuser Company	Mill B } Lumber Mills	1.6
17	Weyerhaeuser Company	Mill C } Lumber Mills	
18	Weyerhaeuser Company - Kraft Mill	Sweet Sewer Lagoon Effluent	3.2 23.8
19	Weyerhaeuser Company - Kraft Mill, Sulfite Mille		26.5
20	Georgia-Pacific Corporation - Pulp & Board Mill }	Untreated Treated	18.0 24.0
21	Georgia-Pacific Corporation - Paper Mill }		
22	Lynden Umatilla Foods		1.09
23	Bellingham Cold Storage		.75
24	Bumble-Bee Seafoods		.33
32	Puget Sound By-Products - Rendering Plant	Aerated Lagoon	0.3
33	ITT Rayonier		35.7
34	Dahl Fish Company		.15
35	Pen Ply		.1
36	Crown Zellerbach		9.7
37	Crown Zellerbach	Domestic Industrial	.015 19.0
38	ITT Rayonier	Solids removal and pH control	1.16
39	Simpson Insulating Board Plant	Primary clarifiers	3.26
40	American Smelting and Refinery	pH and heavy metals	10.34
41	St. Regis	Bark Pulp & paper main sewer	28.75 1.33
42	Sound Oil Refining		.08
43	Penn Walt Chemical Company		9.5
44	Hooker Chemical No. 1 Plant No. 2 Plant	pH, Cl residual and temperature controlled	4.3 12.4
45	Tacoma Boat		.006
46	Boise Cascade & West Tacoma Newsprint Division	S, Cl	8.0

TABLE III-5
(Continued)

No.	Industry	Type of Discharge	Average Flow in mgd
54	San Juan Island Cannery	Seasonal (.09 Cooling Water)	.92
55	New England Fishing Company	Seasonal	.26
56	Moore-Clark Company	(.03 Cooling Water)	.036
57	Glacier Sand & Gravel	Mostly wastewater	3.6
58	Tacoma Narrows Lumber	Cooling water	.001
59	United Grain	Intermittent flow with screening	.05 max.
60	Fore Terminal	Washup water from animal tallow storage	minor
61	Buffelin Woodworking	Cooling water	.22 max.
62	Cascade Pole	Phenal, pH, and total oils control	.011
63	Chicago, Milwaukee, St. Paul Railroad	Oil removal e ipment	.012
64	Dickman Lumber	Cooling water	.04
65	Hygrade Meats	Mostly Cooling	.001
66	Consumer Central Heating	Cooling water only	.012
67	Kaiser Aluminum	pH and Fl problem	
68	Menasha Container Corporation	Cooling water	.05
69	North Pacific Plywood	Circulating system	.25
70	Puget Sound Plywood	Pond saw - Septic Tank Cl effluent	.174
71	Reichhold Chemical Company	pH-Phenol problems, heavy metals	1.7
72	Stauffer Chemical Company	Low pH-super phosphate	.2
73	U.S. Gypsum	Oils and temperature controlled	.032
74	U.S. Oil & Refinery		.241
75	Woodworth Company	Scrubber operation	.125
76	Olympia Oyster	With screening	.013
77	Cascade Poles	Enclosed system	seepage
78	Delson	Sawdust and bark	.025
79	Hardel Mutual Plywood Company	Glue residue-recycling	
80	Werburger Winery		int.
81	Werburger Winery		int.
82	Simpson Timber Company - Olympic Plywood Plant	Cooling water	.1
83	Simpson Sawmill No. 3 Simpson Sawmill No. 4 Simpson Power Plant	Cooling water Cooling water Cooling water	.09 .196 18.0
84	Simpson Veneer Plant	Cooling water	.795
85	Bornstein Seafoods		.47
86	North Pacific Ocean Products		.28
87	Vita Food Products		.02
88	Sea Pac.		.10

mgd - Million Gallons/Day
max - Maximum
ave - Average
Cl - Chlorine
mgl - Milligrams/liter
ppm - Parts per million

The municipal and industrial dischargers listed in the previous two tables are located on the six subsystem maps shown in Figures III-4 through III-9. The maps are North Sound, Figure III-4; Whidbey Island, Figure III-5; Main Puget Sound, Figure III-6; Hood Canal, Figure III-7; Dyes and Sinclair Inlets, Figure III-8; and South Puget Sound, Figure III-9.

More detailed wastewater discharge data is available from the State of Washington, Department of Ecology (DOE) in Redmond. Information on discharge rates and effluent quality is available for dischargers included in the DOE discharge permit and monitoring program which began in the mid 1960's. Information prior to that period may be obtainable directly from the dischargers.

An index of all waste dischargers presently discharging into the Study Area and the quality of their wastewater can be found in the waste inventory of EPA s Surveillance and Analysis Division [USEPA, 1973]. In addition, a limited amount of waste discharge data are available indirectly from the special water pollution investigations conducted for certain bays and estuaries. Most of these sources of data have been published by the Washington Pollution Control Commission and are discussed and referenced in Chapter IV.

It is anticipated that the accuracy and availability of such data will decrease with their age. Most municipal wastewater agencies maintain extensive records of their effluent quality and flow rate. Industrial dischargers are likely to have estimates of their discharge and possibly of effluent quality.

Detailed discharge data will be amassed from the DOE, EPA and the dischargers for the model calibration and validation periods. The sufficiency or lack of discharge data in any period will not be the controlling factor in the determination of model calibration and validation periods.

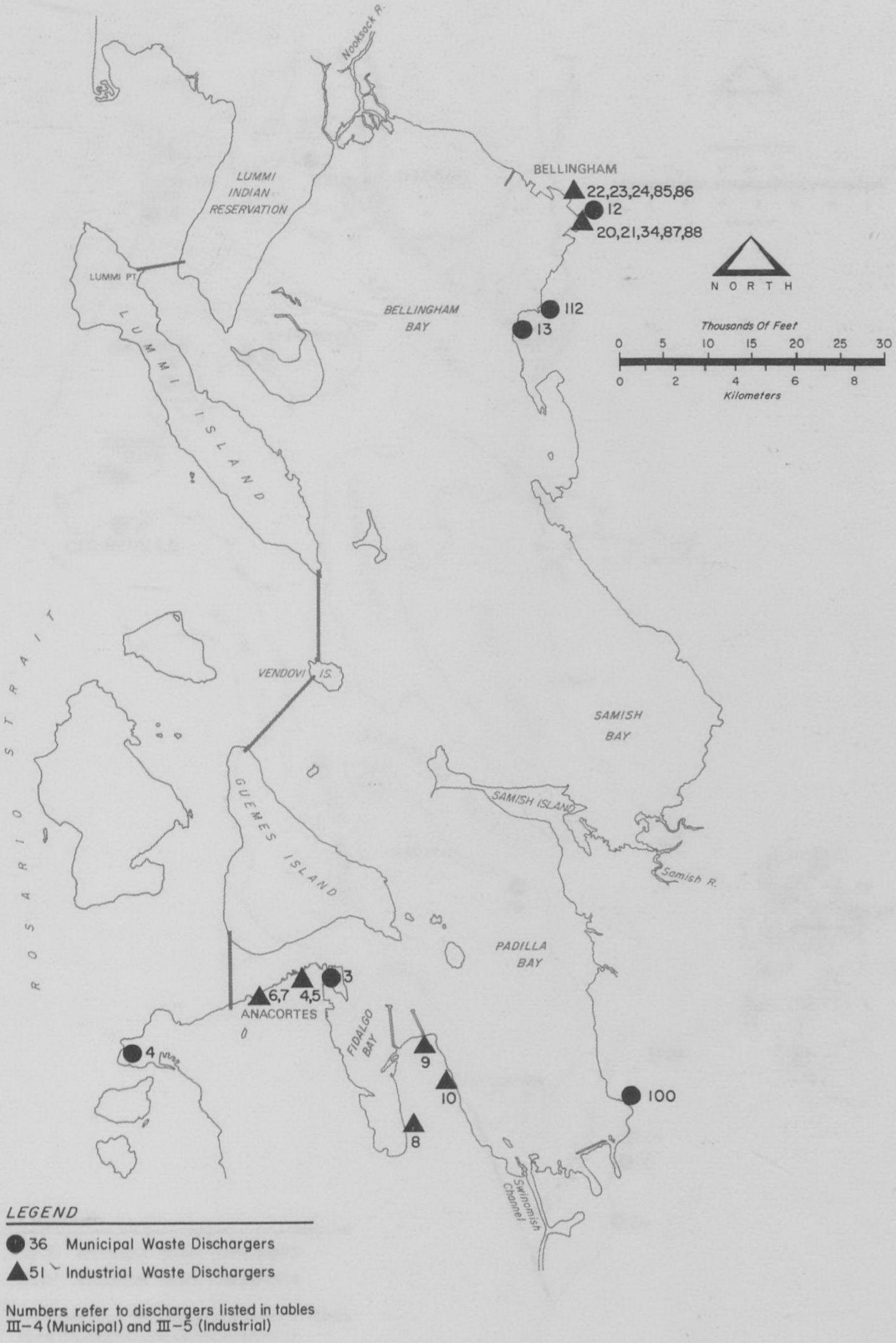

Figure III-4
Municipal and Industrial Waste Dischargers in the North Sound

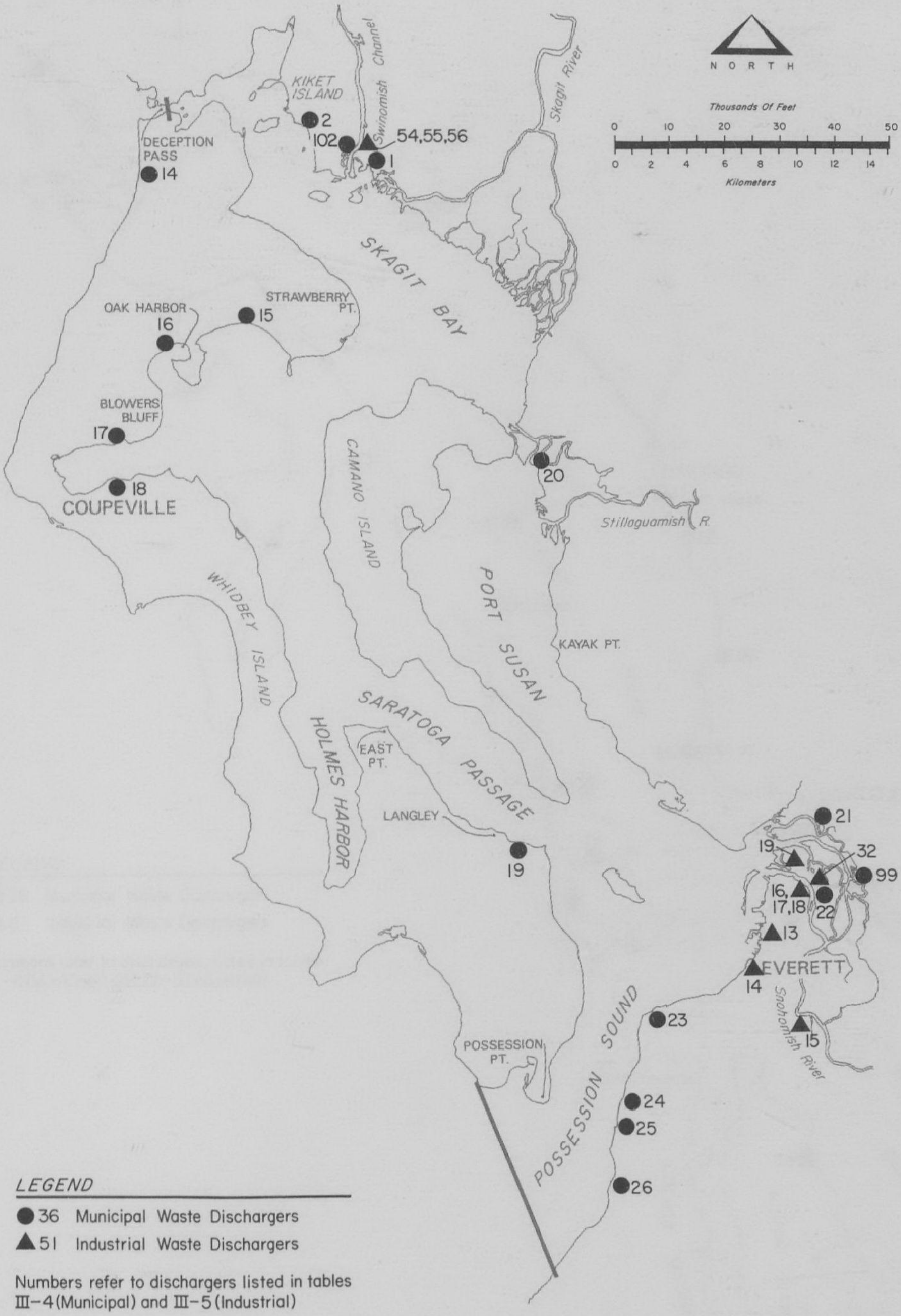

Figure III-5
Municipal and Industrial Waste Dischargers in Whidbey Island Subsystem

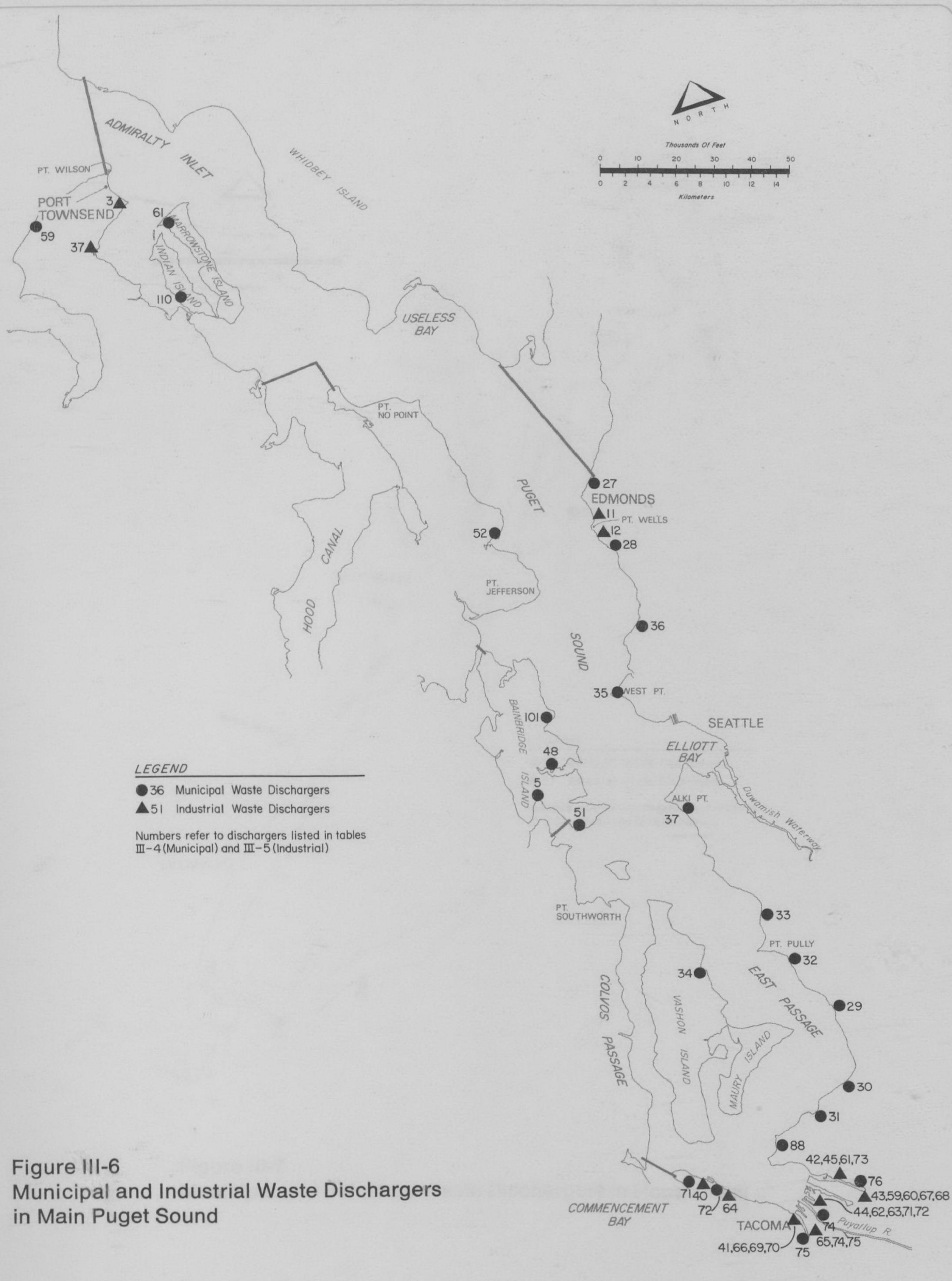

Figure III-6
Municipal and Industrial Waste Dischargers in Main Puget Sound

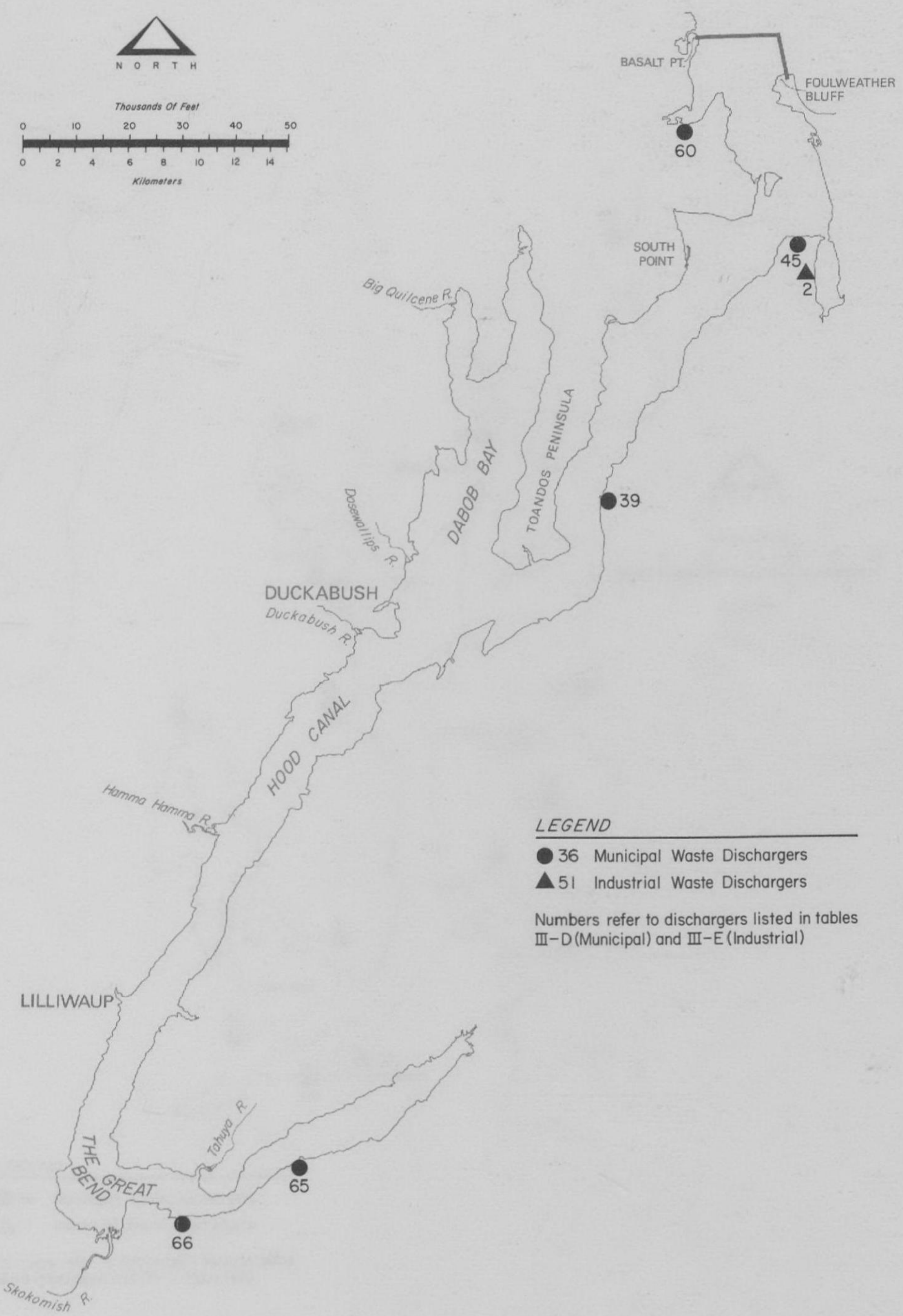

Figure III-7
Municipal and Industrial Waste Dischargers in Hood Canal

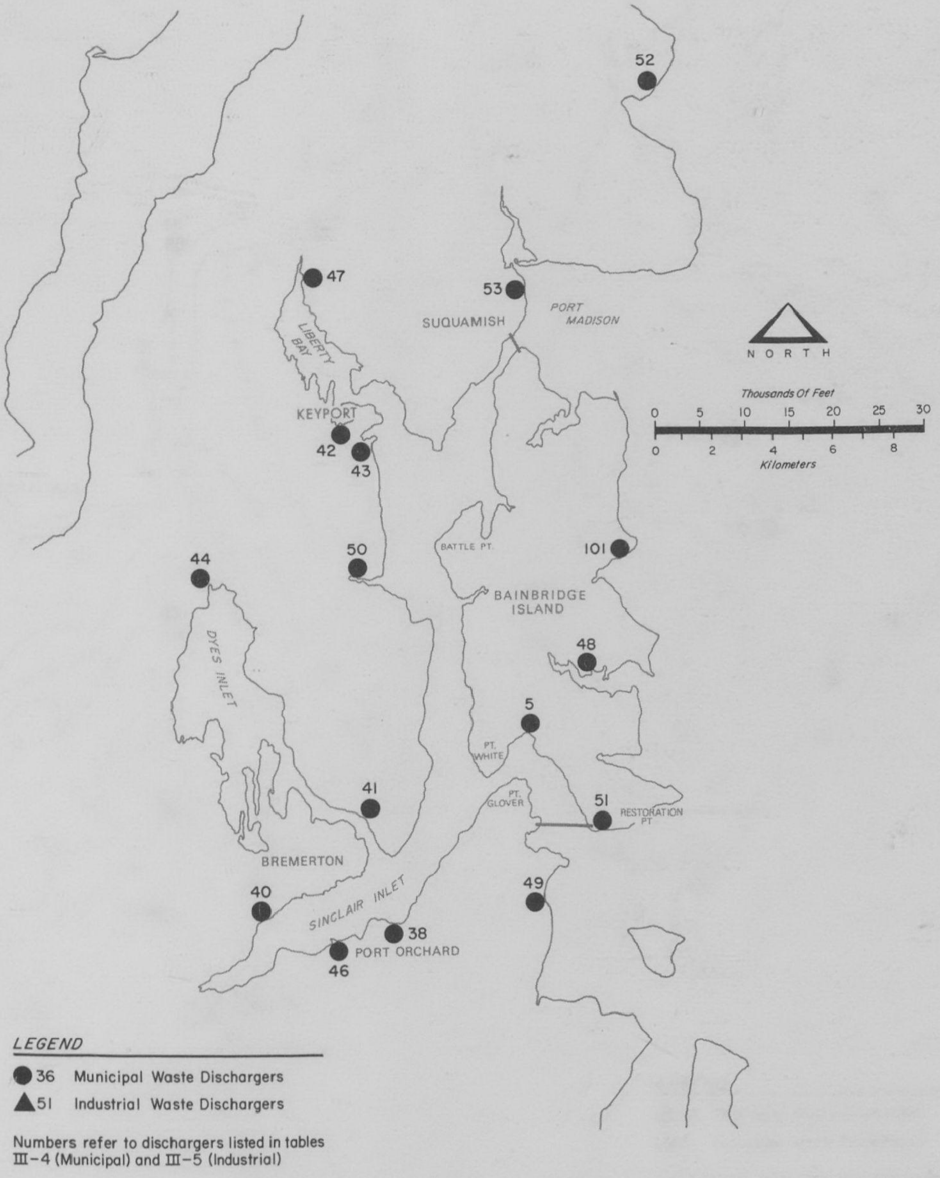

Figure III-8
Municipal and Industrial Waste Dischargers
in Dyes and Sinclair Inlets

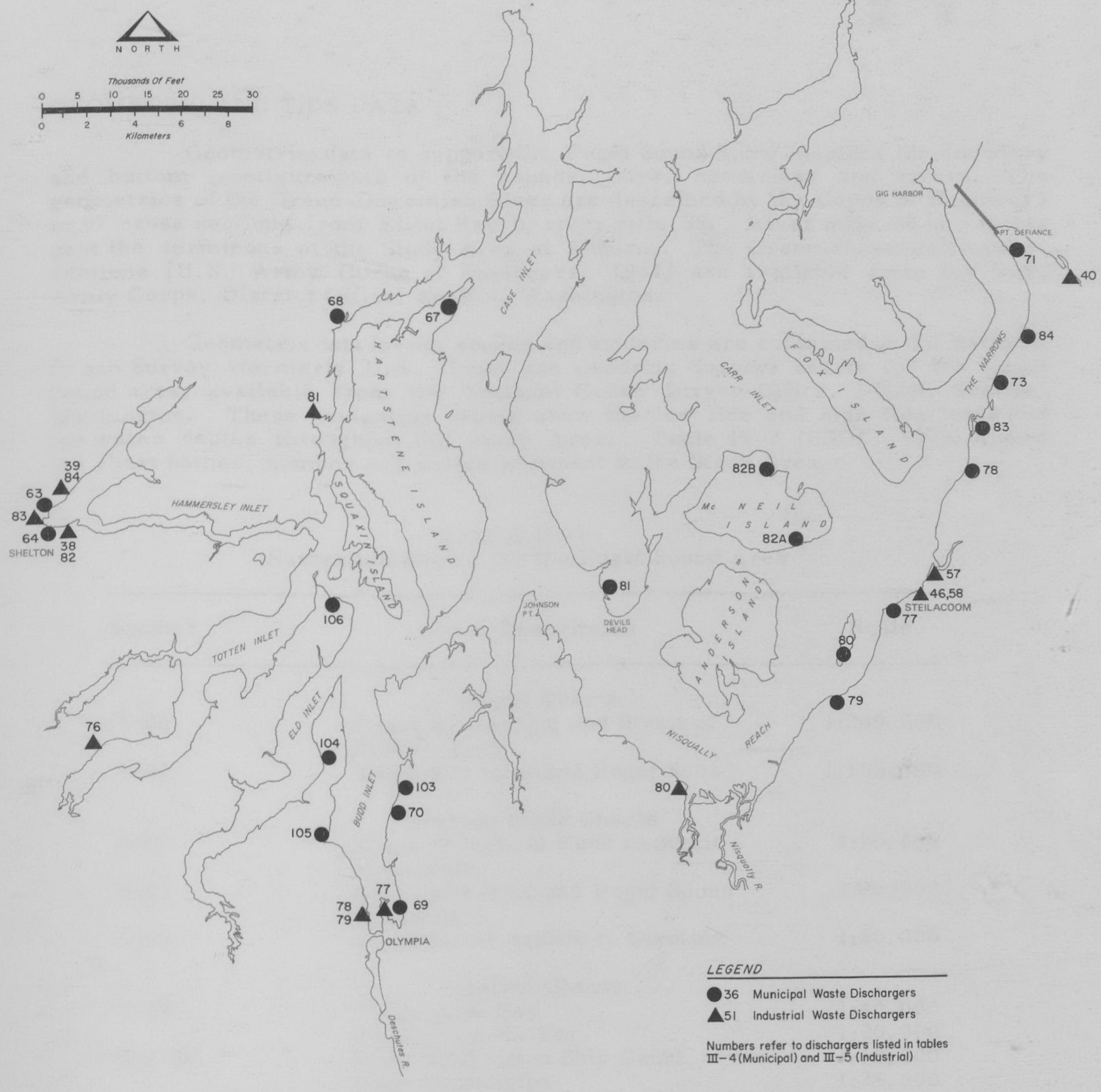

Figure III-9
Municipal and Industrial Waste Dischargers in South Puget Sound

GEOMETRIC AND TIDE DATA

Geometric data to support the Puget Sound Study includes the boundary and bottom configurations of the sounds, bays, estuaries, and rivers. The geometrics of the Green-Duwamish River are described by the Corps of Engineers in 97 cross sections from Elliot Bay to river mile 35. River mile 35 is 3 miles past the terminous of the Study Area at Auburn. The Green-Duwamish cross-sections [U.S. Army Corps of Engineers, 1961] are available from the U.S. Army Corps, District Office, Seattle, Washington.

Geometric data for the sounds and estuaries are contained on the National Ocean Survey (formerly U.S. Coast and Geodetic Survey) charts for the Puget Sound area, available from the National Ocean Survey Office, NOAA, Seattle, Washington. These navigation charts show the low tide and high tide lines and the water depths throughout the Study Area. Table IV-1 (USDC, 1973) shows the chart names, number and scales pertinent to the Study Area.

TABLE IV-1
Navigation Charts for the Puget Sound Area

Number	Chart Description	Scale
	General Charts	
6300	Strait of Georgia and Strait of Juan de Fuca	1:200,000
6401	Admiralty Inlet and Puget Sound	1:150,000
	Medium Scale Charts	
6380	Strait of Juan de Fuca to Strait of Georgia	1:80,000
6450	Admiralty Inlet and Puget Sound to Seattle	1:80,000
6460	Puget Sound-Seattle to Olympia	1:80,000
	Detailed Charts	
6378	Bellingham Bay	1:40,000
	Bellingham Harbor	1:20,000
690-SC	Lake Washington Ship Canal	1:10,000
	Lake Washington	1:25,000

Variations in the tide are recorded at tide gauges. Three primary, or continuously recording, tide gauges in the area are operated by the National Ocean Survey and are located at Seattle, Friday Harbor and Neah Bay. Of these only the Seattle gauge is within the Study Area. Neah Bay is west of the Strait of Juan de Fuca. Friday Harbor is in the San Juan Islands. Eleven supplementary stations were established and operated by the University of Washington Department of Oceanography. All tide gauges are located on Figure IV-1 and tabulated on Table IV-2. As shown in the figure, the stations are uniformly distributed throughout the Study Area.

TABLE IV-2
Water-Level Measurement Stations
Near and in the Puget Sound Study Area

Primary Stations (1)

Location
Seattle
Friday Harbor, San Juan Island
Neah Bay, Strait of Juan de Fuca

Supplementary Stations (2)

Location	Date Installed	Date Discontinued
Cornet Bay	30 December 1968	1 April 1972
Reservation Bay	30 December 1968	early 1972
Fort Townsend	20 March 1968	early 1972
Charles Island	13 April 1968	early 1972
Seabeck	21 June 1967	early 1972
Tacoma	30 December 1969	early 1972
Haines Boathouse	25 September 1969	early 1972
Tulalip	18 December 1969	early 1972
Forbes Point	26 September 1969	early 1972
La Conner	25 March 1970	early 1972
B.N. railroad bridge	2 July 1970	early 1972

(1) Station operated by NOAA, National Ocean Survey
(2) Stations installed by Department of Oceanography, University of Washington.

Tide gauge data is referenced to a common datum by tidal bench marks. In the Puget Sound Study Area there are at least 45 tidal bench marks referencing mean sea level [USDS, 1954] to the 1929 datum. These are fairly uniformly distributed throughout the Study Area.

Tidal bench mark data as well as primary tidal variation data are available from the Director, NOAA, National Ocean Survey, Washington, D.C. Supplementary water level measurement data is available from the University of Washington Department of Oceanography in Seattle.

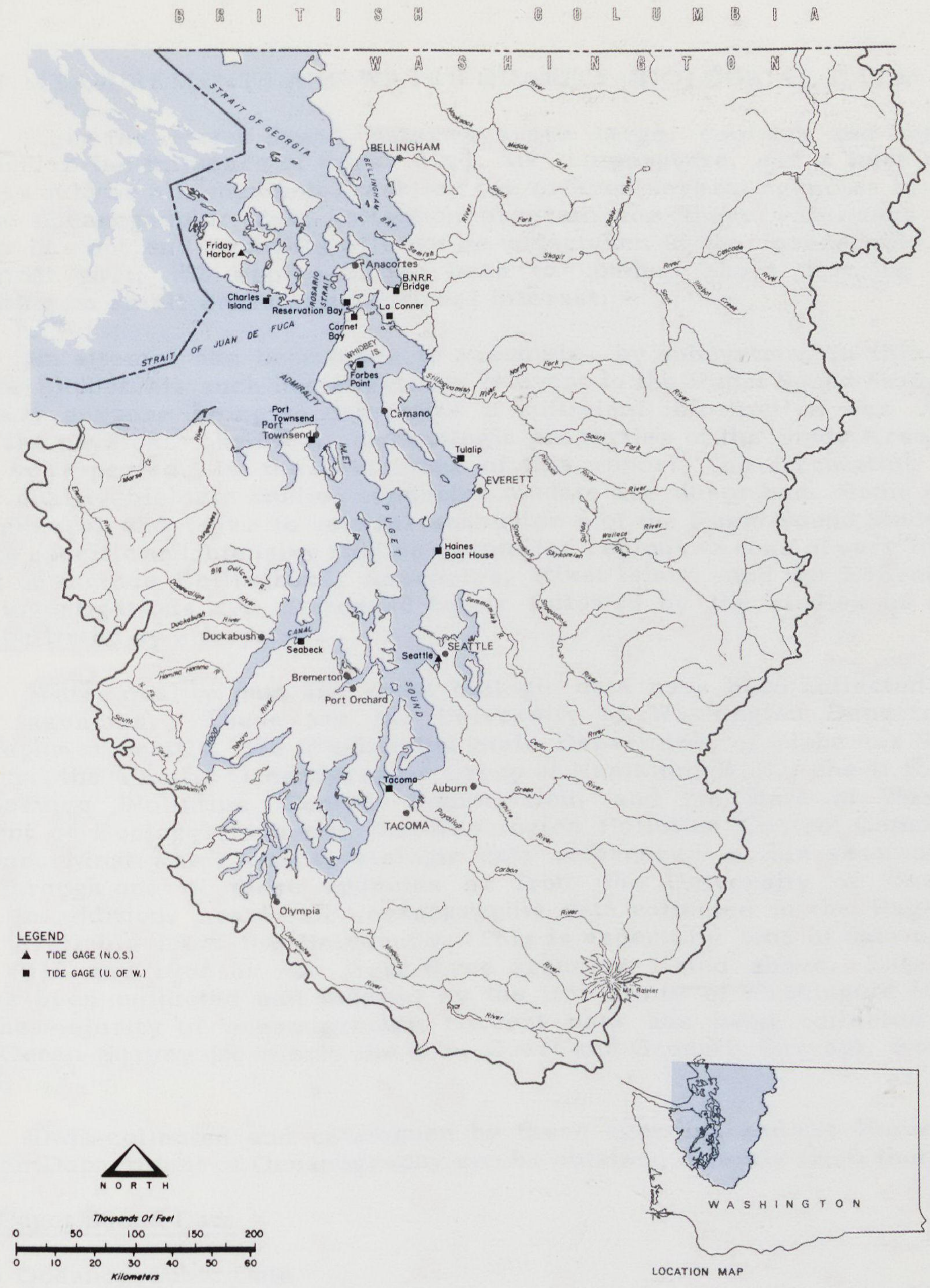

Figure IV-1
Locations of Tide Gauge Stations
Near and in the Puget Sound Study Area

CURRENT MEASUREMENTS AND WATER QUALITY-BIOLOGICAL DATA

Since the Puget Sound waterways are large, complex and constantly changing under the influence of tides, wind, air temperature, and a host of other factors, it would be a monumental task for one or even several agencies to conduct a complete oceanographic data collection program for these waterways. Such a program has not and probably will not be undertaken in the foreseeable future. For the most part, the approach has been to conduct short duration studies concentrating on small areas of exceptional interest.

An attempt has been made to assemble, by subsystem, in this section of the Data Report all such investigations relevant to the Puget Sound Study Area. The primary purpose being to determine if sufficient information was available to define the physical, chemical, and biologic properties of the Study Area waters for a one year period. In the remainder of this report, the circulation studies and water quality-biologic studies conducted to date are described. Some of these are very general and refer to several subsystems of the Puget Sound Study Area. Others are specific and intensive studies of smaller regions. Areas of very intensive investigation include Bellingham, Anacortes, Kiket Island, and the Everett area. General investigations are discussed below followed by the studies of smaller areal scope listed by subsystem.

Water quality data and some biologic data have been collected by five principal agencies. These are the University of Washington Department of Oceanography in Seattle, the Washington State Department of Fisheries Shellfish Laboratory, the Pacific Oceanographic Group at Namaino, B.C., the U.S. Public Health Service Pollution Control Commission, and the State of Washington Department of Ecology (formerly the Washington Pollution Control Commission) in Redmond. Most water quality-biologic data referenced in this section can be obtained through one of these agencies or from the University of Washington Library. In addition, nearly all oceanographic data collected in the Puget Sound region is available from the University. This is especially true of data collected between 1932 and 1966 by the first three agencies listed above. Data in this period has been collected and indexed by the University of Washington [Collias, 1970]. The majority of oceanographic current data has been collected by the National Ocean Survey (formerly the U.S. Coast and Geodetic Survey), Rockville, Maryland.

Data collected and catalogued by these agencies and the University of Washington Department of Oceanography can be obtained directly from them.

General Puget Sound Data

Chemical Oceanographic Data

By far the most comprehensive reference to the water quality-biologic data of Puget Sound and vicinity can be found in The Index to Physical and Chemical Oceanographic Data of Puget Sound and Its Approaches, 1932-1966, by Collias [1970]. The index is a comprehensive catalog of nine important water quality parameters measured in all six estuarial subsystems during the period 1932 to

1966. The 35 years of observation covered encompass most of the periods of intensive data collection in the Puget Sound area. Little data was collected prior to 1932, and between 1942 and 1947. Data collection has been more frequent since 1947.

The index lists the location, depth, date, time, and the parameters measured at each station in the Study Area. The number of stations indexed in each subsystem are listed in Table IV-3. Unless otherwise stated, the stations are evenly distributed throughout the subsystem and the temporal coverage is adequate. The nine parameters catalogued by Collias are temperature, salinity, DO, dissolved organic phosphate, SWL, NO_2, NO_3, silicate and alkalinity. These parameters comprise nearly all the chemical data required for the calibration studies.

TABLE IV-3
Water Quality Sampling Stations Catalogued by Collias [1970]

Subsystem	Number of Stations	Areal Coverage	Comments
North Sound	43	Good	
Whidbey Island	24	Fair	Good in Holmes Harbor
Main Puget Sound	34	Fair	Good near Bainbridge
Hood Canal	39	Fair	Good in Dabob Bay
Dyes and Sinclair Inlets	4	Fair	Poor temporal coverage
South Puget Sound	67	Good	

According to Collias and Sullivan [1973], three comprehensive data collection programs encompassing most of the Puget Sound Study Area have been conducted during the 1932-1966 period covered by the index. The most extensive program included South and Main Puget Sound, Hood Canal, and Whidbey Island Subsystems. Data was collected at regular intervals for two years from October 1952 through September 1954. A similar data collection program for the western portion of South Puget Sound was conducted from August 1957 to October 1958. North Sound data was collected most intensively from April 1960 to May 1961. Collectively, these three periods of comprehensive data collection provide chemical oceanographic data throughout all estuarial subsystems except Dyes and Sinclair Inlets. However, the data available [Collias and Sullivan, 1973] during these sampling periods is limited to temperature, salinity, dissolved oxygen, and phosphates. The sampling locations for the three data collection programs are shown in Figure IV-2.

Studies not covered in the data index are referenced in that report and more extensively in the <u>Bibliography of Literature-Puget Sound Marine</u>

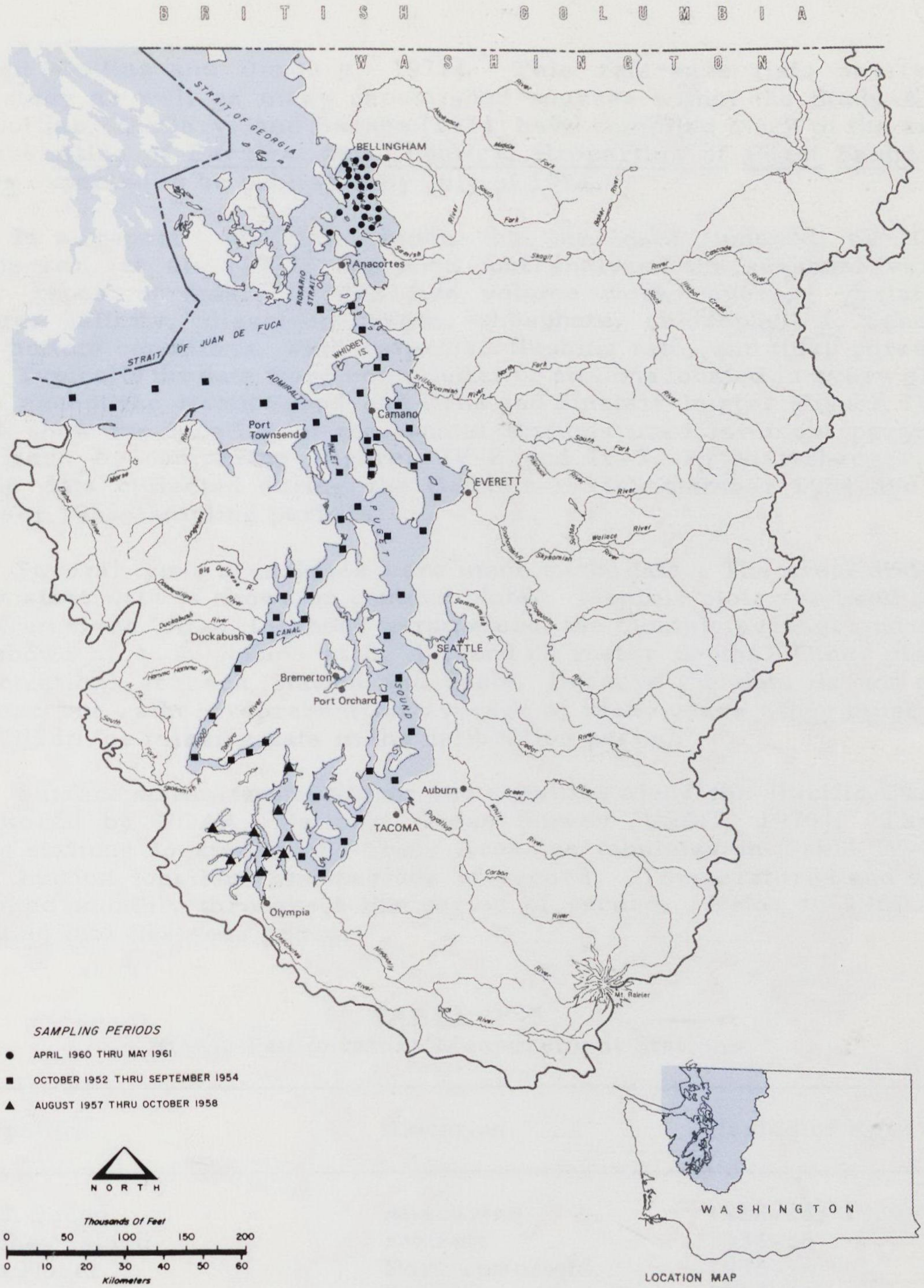

Figure IV-2
Locations of Sampling Stations
for Three Major Oceanographic Water Quality Studies

Environment [Collias and Duxburg, 1971]. This reference lists nearly every published study as well as many unpublished sources within the Study Area. In additon, Collias, McGary, and Barnes [1974] have compiled much of the available data into the Atlas of Physical and Chemical Properties of Puget Sound and Its Approaches expected to be published by July of 1974.

In a report utilizing much of the data indexed by Collias, Friebertshauser, et al. [1971] compiled and analyzed the seasonal variations of several types of data. In this five volume work, average variations of temperature, salinity, dissolved oxygen, phosphate, chlorophyll a, Secchi disk readings, bottom conditions, wind patterns, flushing rate, and tidal currents are presented. Typically the data were compiled at 65 stations located in every estuarial subsystem except the North Sound and Dyes and Sinclair Inlets. Figure IV-3 and Table IV-4 show the location of the typical stations used for most parameters. As can be seen by comparing Figures IV-2 and IV-3, Friebertshauser, et al. utilized the data collected during the October 1952-September 1954 and August 1957-October 1958 sampling periods.

Several types of analyses were made on the data. The areal distribution of time-constant data is shown on contour plots. Monthly plots are used for time varying parameters. Also, for these parameters, the monthly average and expected range is shown at each station at 0, 10, and 20 meter depths. Other plots show annual fluctuations at each station and depth. Because the data do not apply to any one year but rather represent an average of many years, they must be used mainly to fill in for missing data in the calibration period.

Surface water temperatures and densities along the Pacific Coast have been monitored by NOAA, National Ocean Survey [USDC, 1970]. The seven monitoring stations located in the Study Area are tabulated in Table IV-5. This table lists station locations and periods of record. Temperatures and densities are presented monthly throughout the period of record. Prior to 1965 records are combined into five year groups.

TABLE IV-5
NOAA Temperature Measurement Stations

Subsystem	Location	Period of Record
North Sound	Anacortes	1922-24, 1934-35
Whidbey Island	Everett	1934-35
Main Puget	Port Townsend	1935-36
	Seattle	1922-69
	Tacoma	1934-35
Dyes and Sinclair Inlets	Bremerton	1934-35
South Puget Sound	Olympia	1923-24, 1934-35

TABLE IV-4
Data Collection Stations Summarized by
Friebertshauser, et al. [1971]

SAMPLING LOCATIONS		SAMPLING LOCATIONS	
1	Head of Eld Inlet	34	West Point
2	Flapjack Point	25	Point Jefferson
3	Cooper Point, S.W. of	36	Point No Point
4	Burns Point	37	Possession Point
5	New Kamilche	38	Point Gardner
6	Windy Point, N.E. of	39	Camano Head, E. of
7	Henderson Inlet, Middle of	40	Port Susan, Middle of
8	Cannery Point	41	Port Susan, Head of
9	Church Point, W. of	42	Camano Head, W. of
10	Shelton	43	East Point
11	Chapman Cove, N.W. of	44	Holmes Harbor
12	Bud Inlet Buoy No. 12	45	Holmes Harbor, Middle of
13	Gull Harbor	46	Demock Point
14	Hunter Point	47	Strawberry Point, N. of
15	Arcadia	48	Goat Island
16	Graham Point	49	Dewey
17	Dougall Point	50	Deception Island (Juan de Fuca)
18	Johnson Point	51	Bush Point
19	Herron Island	52	Port Townsend
20	Rocky Point	53	Tala Point
21	Allyn	54	South Point
22	Devils Head	55	Hazel Point
23	Nisqually Reach	56	Dabob Bay, Head of
24	Gordon Point	57	Bolton Peninsula, E. of
25	Days Island	58	Tabook Point
26	Still Harbor II	59	Pleasant Harbor
27	Green Point	60	Tekiu Point
28	Wauna	61	Eagle Creek
29	Brown Point	62	Musqueti Point
30	Spring Beach	63	Tahuya River
31	Point Vashon	64	Lynch Cove, Middle of
32	Point Pully	65	Lynch Cove, Head of
33	Alki Point		

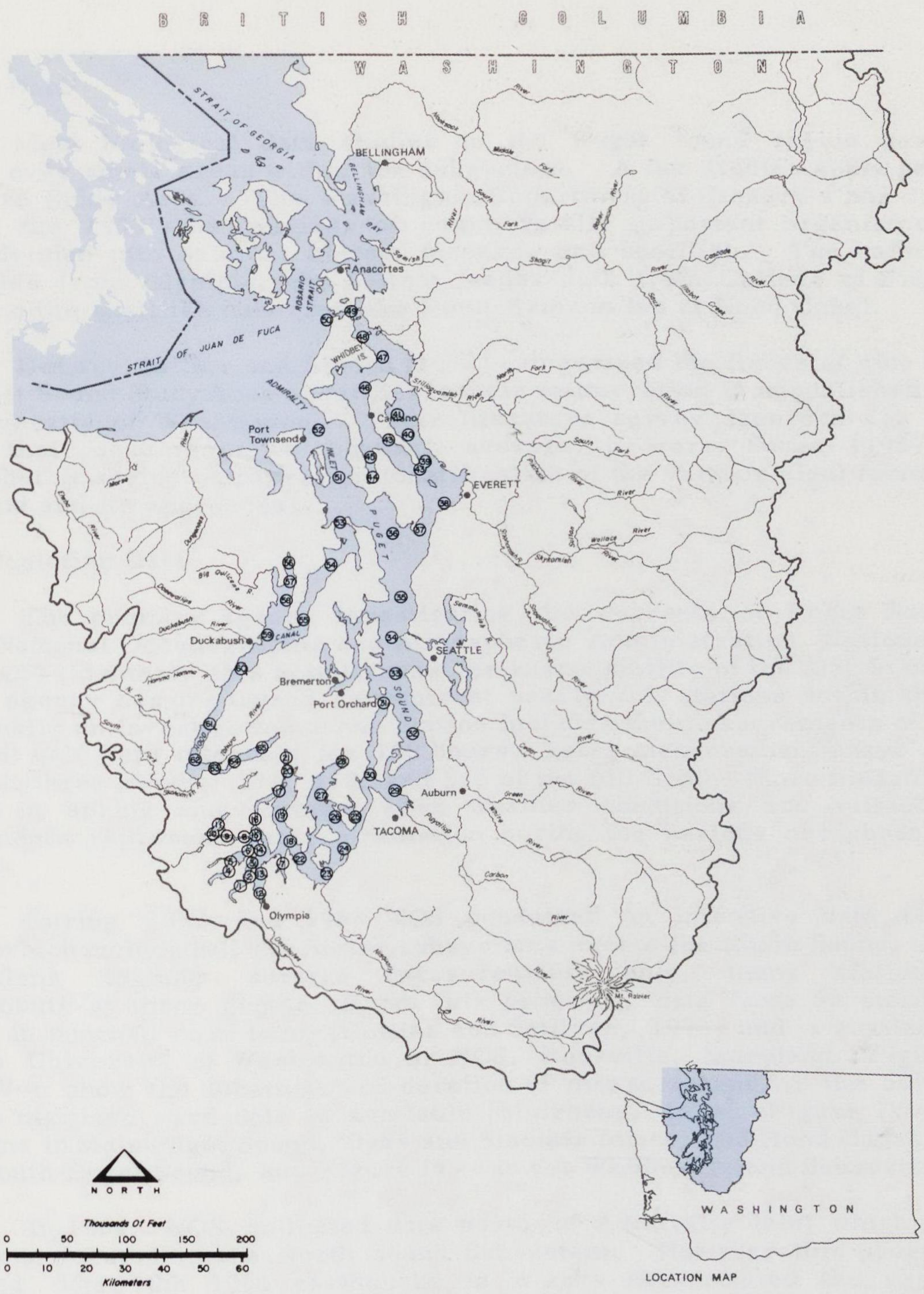

Figure IV-3
Locations of Data Collection Stations
Summarized by Friebertshauser, et al. (1971)

Biological Data

Most biological data studies in the Puget Sound region have been conducted over small areas within the subsystem. A few studies apply generally to the entire Study Area. The Washington Department of Fisheries has collected data since the 1930's on landings of commercially important organisms. The files are divided into salmon, bottom feeders, and shellfish. The salmon data are available from Olympia, the bottom feeder data from College of Fisheries, Seattle, and the shellfish data from the Point Brinnon lab at Hood Canal.

DeLacy, Miller and Borton [1972] categorized the fishes of nine regions of the Puget Sound Study Area according to their enumeration in unpublished reports of the University of Washington. Their literature survey recorded 211 species and rated their occurrence as abundant, average, or rare. Scagel [1957, 1966] has published a series of papers on identification of the various algal forms found in the Sound and its approaches.

Water Circulation Data

The primary agency investigating the currents of Puget Sound has been the National Oceanographic and Atmospheric Administration, National Ocean Survey (NOS) (formerly this activity was the responsibility of the USC&GS). Since 1908 this agency has measured currents at nearly 200 stations within the Study Area. Usually an investigation at one station includes the measurements of surface currents at half-hour intervals for 100 hours. Later measurements have included currents at three depths: 1/6, 1/2, and 5/6 of the full depth. More measurements are taken in spring and summer when weather conditions are suitable. Few measurements represent water circulation during the periods of highest stream discharge.

During 1952 and 1953 NOS conducted an intensive data collection program which included all the major subsystems except the North Sound. Although most stations include surface measurements only, many stations have measurements at three depths. From this program, data from 50 stations was prepared in punched card form [Collias and Sullivan, 1973] and is available from either the University of Washington or NOS, Rockville, Maryland. Figure IV-4 through IV-6 show the locations and duration of measurement for the 50 stations for which digitized card data is available [Muirhead, 1974]. Figure IV-4 shows the stations in Main Puget Sound, Dyes and Sinclair Inlets, and Hood Canal, Figure IV-5 in South Puget Sound, and Figure IV-6 in the Whidbey Island Subsystem.

In 1964, NOS collected data north of Admiralty Inlet which included five stations located in the North Sound Subsystem. However this program was terminated after the 1964 earthquake in Alaska necessitated the use of the equipment elsewhere. Consequently, the data has not been put into final form. In the latter part of 1973, NOS initiated a five year program to collect an extensive amount of tidal current data throughout the Study Area, Admiralty Inlet and the San Juan Islands. The study will not be complete until the late 1970's.

In addition to the data described above, NOS has prepared a general summary of surface currents measured in the 1952-1953 program. This general

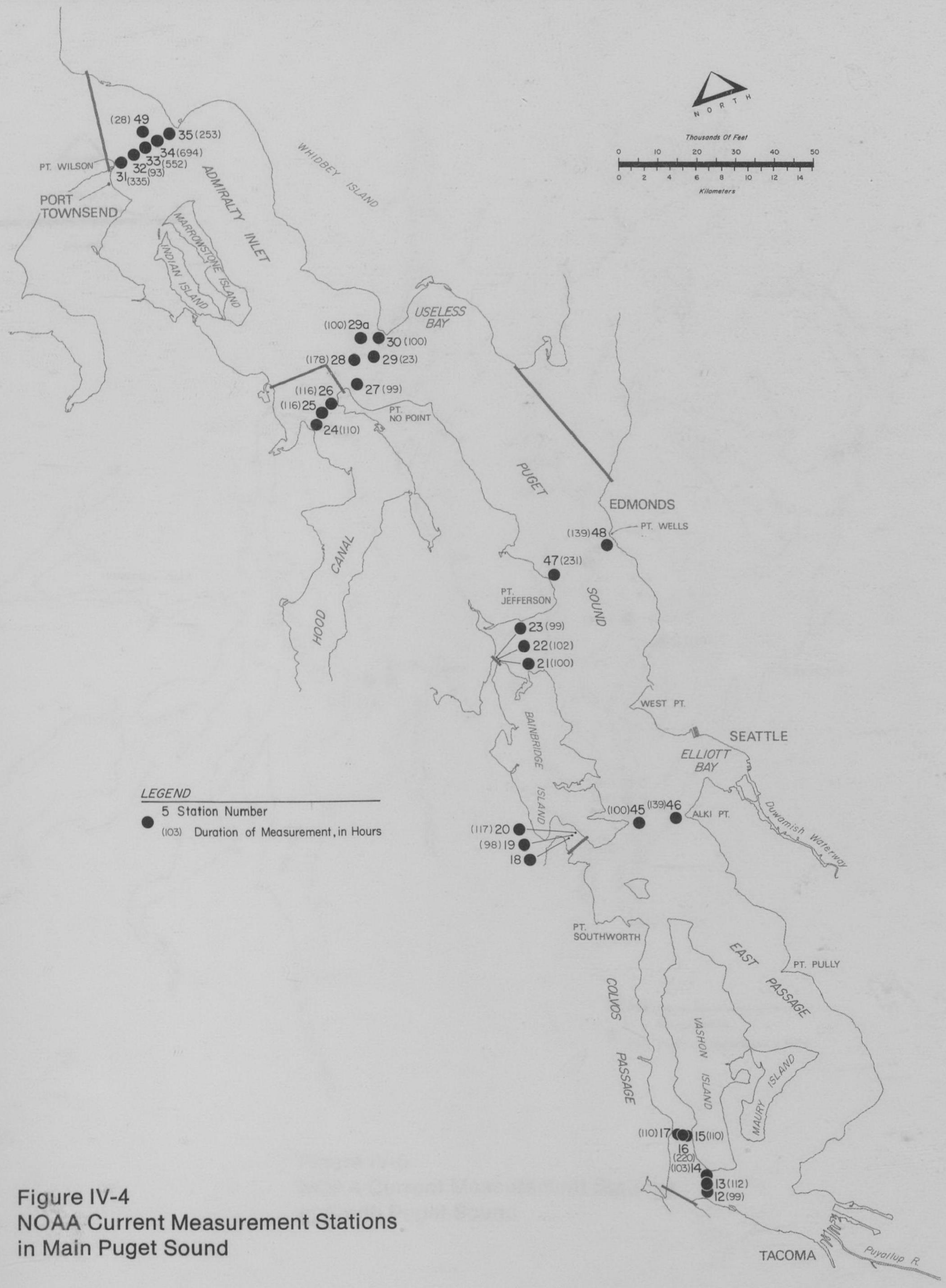

Figure IV-4
NOAA Current Measurement Stations in Main Puget Sound

Figure IV-5
NOAA Current Measurement Stations
in South Puget Sound

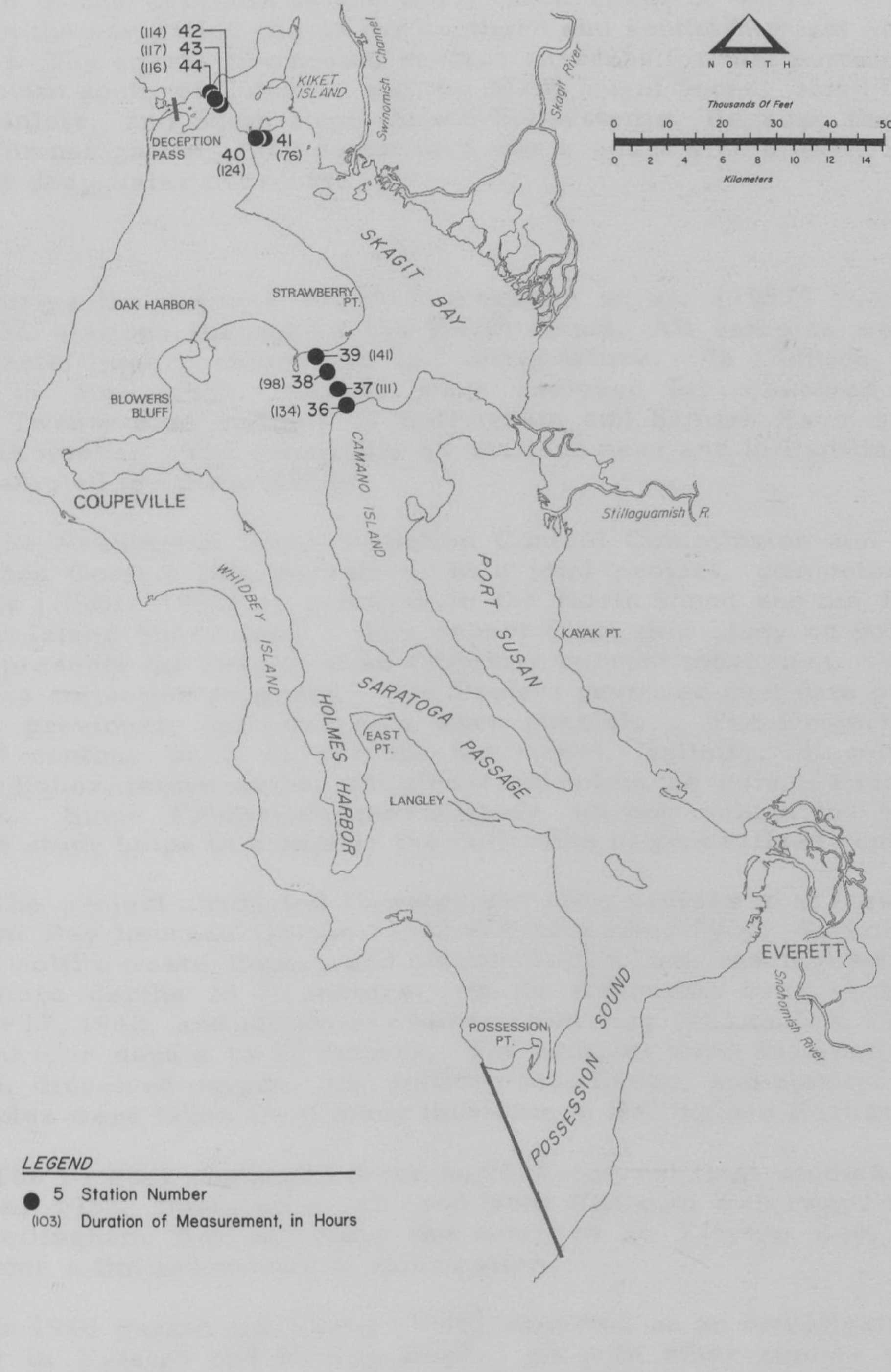

Figure IV-6
NOAA Current Measurement Stations in Whidbey Island Subsystem

approximation of the currents in the Study Area south of 48° 11' North Latitude is available in the navigation charts for northern and southern Puget Sound [USDC, 1961a, 1961b]. The charts give hourly surface currents for that portion of Whidbey Island Subsystem south of Camano, and for Main Puget Sound, Hood Canal, Dyes and Sinclair Inlets, and South Puget Sound Subsystems. Because the charts are generalized for navigation, they do not take into account wind effects, high stream discharge, or deep water currents.

North Sound

During the summer of 1957 Wagner, et al. [1957] collected water samples at 52 stations throughout the North Sound. All samples were analyzed for sulfite waste liquor, chlorinity, and temperature. In addition, 16 stations established in Bellingham Harbor were analyzed for dissolved oxygen and coliforms. Twenty-nine stations in Bellingham and Samish Bays were sampled weekly for six weeks. The remaining 23 stations near and in Padilla and Fidalgo Bays were sampled for three weeks.

The Washington State Pollution Control Commission and the Federal Water Pollution Control Adminstration, in a joint project, conducted a comprehensive study [USDI, 1967] of pollution in the North Sound and the Everett area (see Whidbey Island Subsystem). The report from this study on pulp and paper mill wastes presents the results of an extensive current movement, water quality-biological data collection program. The Project reviewed past data programs and made use of previously collected data when possible. The Project's summary analysis and contour plots of current movement, salinity, dissolved oxygen, sulfite waste liquor, temperature, and pH are not unlike the work of Friebertshauser et al. [1971]. Since Friebertshauser's study did not include the North Sound, the Project's study helps to complete the collection of generalized contour plots.

The project conducted 16 water sampling cruises to at least 17 stations in Bellingham Bay between October 1962 and December 1964. Salinity, dissolved oxygen, pH, sulfite waste liquor, and clarity (Secchi disc reading) were measured at nine or more depths to 70 meters. In the Anacortes area, a single cruise on November 17, 1962, and additional cruises from July 1963 to July 1964, sampled 54 stations at four depths to 25 meters. The samples were analyzed for salinity, temperature, dissolved oxygen, pH, sulfite waste liquor, and clarity. Other water quality samples were taken from many locations in Bellingham Harbor.

The Project conducted three surface-current float studies. In October and November 1962, floats were released from Whatcom Waterway, the northeast corner of Bellingham Bay and near the entrance to Fidalgo Bay. These float studies provide a limited amount of information.

In 1948 Saxton and Young [1948] reported on an investigation of sulfite waste liquor in Fidalgo and Padilla Bays. As with other studies sponsored by the Washington Pollution Control Commission, their study included the collection of circulation and temperature data.

In August 1958, the Washington Pollution Control Commission [Wagner and Ice, 1958] released floats in Guemes Channel (south of Guemes Island) and

Padilla and Fidalgo Bays to determine current patterns during various tidal phases. Special attention was given to the area of the Scott Paper Company pulp mill outfall (Industry #4, Table III-5 and Figure III-4). Tidal currents through Swinomish Channel into Padilla Bay were estimated by McKinley [1959] in a study for the Washington State Department of Fisheries.

Two studies concerning benthic organisms in and near the North Sound include those of Shelford et al. [1935] and Jamison [1970]. Shelford's comprehensive study, conducted during the summers of 1926, and 1928-1930, was mainly in the San Juan Islands. However, 10 sampling stations were located near Samish Bay in the North Sound. Jamison's work involved the effect of aluminum plant effluent on epibenthos at Cherry Point just north of the North Sound. His research was conducted between April 1968 and May 1969.

A recent study identifies the fish population of the North Sound Subsystem. Tyler [1964] studied the migration of three species of young salmon and other fishes through Bellingham Bay north of Eliza Island from April to June of 1963. He sampled at approximately 40 beach seine stations and four east-west townet traverses plus one traverse within Chuckanut Bay.

Whidbey Island

It is likely the water quality of Everett Harbor and the Port Gardner area in the southern portion of the Whidbey Island Subsystem has been investigated more frequently than any other area in Puget Sound and its approaches. The first pollution investigation was sponsored by the State Department of Game in the summer of 1937. They measured certain water quality parameters and established pollution zones. In the summer of 1938, the Washington Pollution Control Commission measured water quality while the Everett pulp mills were closed down.

Subsequently, the Commission conducted a more extensive study [Townsend and others, 1941]. This water quality study by Townsend extended from August 1939 and October 1940 and included the Port Gardner area, the Everett area and part of Possession Sound. Most water quality samples were taken on the surface near the harbor. However, many others were taken at depths and within an area of 10,000 yards of the harbor including the Snohomish River mouth and sloughs.

The samples were analyzed for temperature, dissolved oxygen, BOD, pH, chlorinity, sulfite waste liquor, and plant pigments (plant pigments can be related to chlorophyll a). Townsend obtained information on the variation in these parameters with depth and distance from Everett Harbor. He also related the variation in the parameters to salmon migrations in the Snohomish, Duwamish, and Puyallup Rivers.

Townsend's study included observation of tidal currents and wind induced movements of pollutants near the harbor. Sixteen floats were released during flood and ebb tides in August and September 1940.

In 1942 Cheyne and Foster [1942] published an overview of the pollution of Everett Harbor. This overview presents the results of past investigation and is intended to supplement Townsend's report.

In the fall of 1949, Orlob and others [Orlob, 1950; and Eldridge and Orlob, 1951] studied the effects of pollution in the Port Gardner, Everett and Snohomish River mouth areas. Samples taken in these areas were measured for temperature, chlorides, pH, dissolved oxygen, sulfite waste liquor, and coliforms. They also investigated bottom sediments and benthic life. In the spring of 1951 Orlob and others [1951] reinvestigated pollution in the Everett area. They sampled 12 stations in the harbor and 5 stations in the bay at the surface and at several depths and measured dissolved oxygen, sulfite waste liquor and chloride concentration. Their results give some indication of the stratification of the Everett area waters to 300 feet.

From August 22-25, 1958, the Washington Pollution Control Commission [Wagner, Livingston, and Ice, 1958] conducted a float study to determine circulation patterns southwest of Everett Harbor. They released several floats about 2,000 feet off shore at various depths down to 68 feet. Circulation was predominantly counter-clockwise throughout the tidal cycle.

The Washington Pollution Control Commission [1962] conducted another water quality study of the Snohomish River-Port Gardner Bay region during August 1960 and September 1961. They sampled 17 stations near the port and the river for temperature, salinity, dissolved oxygen, and sulfite waste liquor.

During the period 1962-1964, Weyerhauser Company [Smith, 1973] investigated circulation patterns at the entrance to Everett Harbor about 3,000 feet from shore. They released floats at various depths and locations. Although the study results are unpublished, data is available from Weyerhauser in Everett.

Another study (referred to as the Project) of the Everett area was conducted jointly by federal-state pollution control agencies [USDI, 1967] to determine the pollution of pulp and paper mills. The Project included 11 monthly oceanographic cruises in the Everett area between May 1962 and May 1963. As in the Bellingham and Anacortes studies observations of temperature, salinity, dissolved oxygen, sulfite waste liquor, pH, and Secchi disc readings were made at several depths. The Everett study included 10 depths to 150 meters. Additional samples were taken in Everett Harbor in April and May 1963.

Bottom deposits and benthic organisms in the Everett area were measured by the Project in three studies from May 1962 to September 1964. Plankton productivity was measured between August 1964 and July 1965, inclusive. Bacterial samples were taken once each month during March, April and May 1965. Other measurements were made e.g. pelagic fish eggs and oyster larvae. The Project utilized information on salmon migration obtained in the studies conducted by the University of Washington during 1962, 1963, and 1964.

Currents in the Everett area were investigated by the Project in two dye studies at the Snohomish River mouth and the entrance to Everett Harbor in July 1964. Dye movements in the Everett area were also investigated on the University of Washington's Puget Sound physical model.

Whidbey Island Subsystem currents were also measured in a circulation study by Cannon [1973] in the summer of 1970. Measurements were made in June in Port Susan, in July in the channel from Saratoga Passage to Deception Pass, and in August and September on the sill entering Port Susan near Everett.

The northern portion of Whidbey Island Subsystem has been studied extensively since 1970 by the University of Washington for Seattle City Light and Snohomish County Public Utility District. The investigations concern the proposed Kiket Island Nuclear Power Plant. Two important investigations were made by the University. The first by the Department of Oceanography was to determine currents and other physical and chemical properties of the Skagit Bay region. The second by the College of Fisheries involved the chemical and biological properties of the area.

During most of 1970 Lincoln and Collias [1970] investigated the water quality and currents in and near Skagit Bay. From February to October of that year they collected salinity, temperature, density, dissolved oxygen and micronutrients (phosphate, nitrate, and silicate) and determined their variability with location, depth and time.

Also within this period they collected information on current movements. They measured currents with current meters at fixed locations and depths with drogues, surface drift poles, and dye. The results of this phase of the study include generalized current movements in the northern Whidbey Island Subsystem.

Strober and Salo, from the University of Washington, College of Fisheries, conducted a three year study [Strober and Salo, 1973] for the proposed Kiket Island Nuclear Power Plant. It included the collection of surface water data on temperature, clarity, dissolved oxygen and salinity. The sampling includes generally that portion of the Whidbey Island Subsystem north of Hope Island (Hope Island lies just south of Kiket Island) and east of Deception Pass. Measurements were on 1/4 square nautical mile sections from March through August of 1970, 1971, and 1972. The apparent sampling frequency was 7-10 days. Temperature and salinity were recorded year around from stations near Kiket Island at the mouth of Swinomish Channel.

Strober and Salo's main emphasis was on the collection of biological data, especially juvenile salmonoid migrations (1970-1972), pelagic eggs and larval fish (January 1971-April 1972), Dungeness crab (1970-1972), benthic fauna (grab samples December 1971 and February 1972; trawling August 1970-October 1971; predator stomach samples June 1971), and marine fish (August 1970-August 1972). They also qualitatively evaluated zooplankton species at Kiket Island. Sampling was usually performed at regular intervals throughout the period and usually at 6 to 8 stations or along trawling lines. Stations are located north of Hope Island exclusively except the pelagic eggs and larval fish sampling stations. In this case, three stations were in southern portions of the Whidbey Island Subsystem. Areal coverage and duration of sampling appears to have been very complete.

Strober and Salo also investigated several chemical-biological responses: oxygen uptake by bottom sediments, thermal tolerance of several species, and toxicity of chlorine and heat to salmon.

In addition to the published works discussed above, Snider and Craddock of the Montlake National Marine Fisheries Service lab have been sampling the zooplankton in Possession Sound northwest of Everett. Their data are being analyzed and should be available by the end of 1973. T.S. English [1973] of the University of Washington Department of Oceanography has collected zooplankton data in the Everett area. He has stated that the data have not been published and are presently not available.

Main Puget Sound

The Municipality of Metropolitan Seattle (METRO) has an ongoing water quality sampling program which began in October of 1965. They take monthly samples in five areas in the vicinity of their municipal waste discharges to measure temperature, dissolved oxygen, salinity and total and fecal coliforms. Samples are always taken at the surface and nearly half the stations are also sampled at depth.

METRO samples the following discharge locations: Richmond Beach, 10 stations; Carkeek, 7 stations; West Point, 10 stations; Alki Point, 10 stations; Elliot Bay, 5 stations. These correspond to municipal discharge points 28, 36, 35, and 37 respectively on Figure III-6. At Elliot Bay, station samples are taken semi-monthly, and an additional 4 stations are sampled for coliforms only. An additional 12 stations at West Point are sampled weekly. Two stations at West Point and one at Richmond are measured also for filterable solids.

In 1970 and 1972 METRO made a series of comprehensive tests at depth and at the surface. In the West Point test, samples taken every 2 hours for 24 hours were measured for temperature and fecal coliforms. Similar 12 hour tests were made at Richmond Beach, Carkeek, and Alki Point. These samples were measured for temperature, dissolved oxygen, turbidity, NH_3, NO_2, NO_3, PO_4, and fecal coliforms.

In the summer of 1950, Orlob et al. [1950] conducted an investigation of pollution in Commencement Bay at the mouth of the Puyallup River in the southern portion of Main Puget Sound. They collected samples of bottom deposits at 40 stations and examined them for hydrogen sulphide and bottom organisms. Coliform organisms were measured periodically from May through September of 1950 at 6 stations within Commencement Bay. A few salinity measurements were taken at these stations. Orlob's study also included the investigation of current movements within Commencement Bay. The results show the general movement of water during a flood and an ebb tide, May and June 1950.

The University of Washington has conducted many oceanographic studies to collect data on the near surface and deeper currents of Puget Sound. The majority of investigations considered the currents of Main Puget Sound. However, South Puget Sound and Hood Canal are also represented. Current measurements from June 1948 through November 1955 comprise the bulk of the measurements and are tabulated by the University in Technical Report 271 [Collias, 1971]. Although measurements were taken continuously throughout the measurement period, they are reported every 10 to 15 minutes in Technical Report 271. Figure IV-7 shows the location of each of the 31 measurement stations tabulated. Table IV-6 shows the date and duration of each station. Nearly all of the Main Puget Sound stations are located in three groups: either near Point Jefferson, Hood Canal Inlet or in the Strait of Juan de Fuca near Admiralty Inlet.

Cannon and Laird [1972] investigated currents and other water properties in Main Puget Sound Subsystem during February of 1972. A current meter was placed near West Point in the main channel. Numerous salinity-temperature-depth (STD) surveys were made near the current meter and throughout the main channel into the Strait of Juan de Fuca. Cannon called this supporting data the most comprehensive STD data obtained from the main channel.

On April 29 and June 22, 1971, Miller [1971] and Paine and Roe [1971] studied two facets of the marine community in Main Puget Sound. As part of the Dumas Bay Park environmental impact statement, Miller sampled the fishes of Dumas Bay 15 miles west of Commencement Bay. He included species numbers and lengths of captured fishes. Paine and Roe studied the marine intertidal organisms. Their studies were conducted on April 15, May 13, and May 25, 1971. The intertidal organisms were identified and their relative abundance noted.

The Duwamish Bay and Estuary was studied by Salo [1968]. In it models were developed for salmon mortality. Most of Salo's report is devoted to salmon migrations through the area but species and number of other fishes encountered during trawling in the estuary and control areas of Port Gardner and Skagit Bay are also included.

Ting [1965] includes data on benthic communities from 48 locations in the South Sound and Port Madison in the central basin. His benthos sampler collected an area of several square meters and captured fish and invertebrates which occupied a zone from a meter above the surface to a few centimeters deep in the substrata. His work in Port Madison was on November 21, 1961, February 1, 1962, June 26, 1962, July 12, 1962, and October 24, 1962. A map of his sampling stations accompanies this text.

Lie [1965] made a comprehensive study of species diversity relationships of benthic animals on a traverse across Puget Sound roughly on a line from West Point to Suquamish north of Bainbridge Island. Phytoplankton productivity was also observed at a station near the midpoint of his traverse. His work was conducted during 1962-1963.

Hood Canal

Current measurements have been taken in Hood Canal at three stations. As mentioned in the section for Main Puget Sound, these measurements have been tabulated by Collias [1971]. These stations have been located on Figure IV-7 and are indexed in Table IV-6. Referring to Figure IV-7, stations are located at the mouth of the Canal and near South Point.

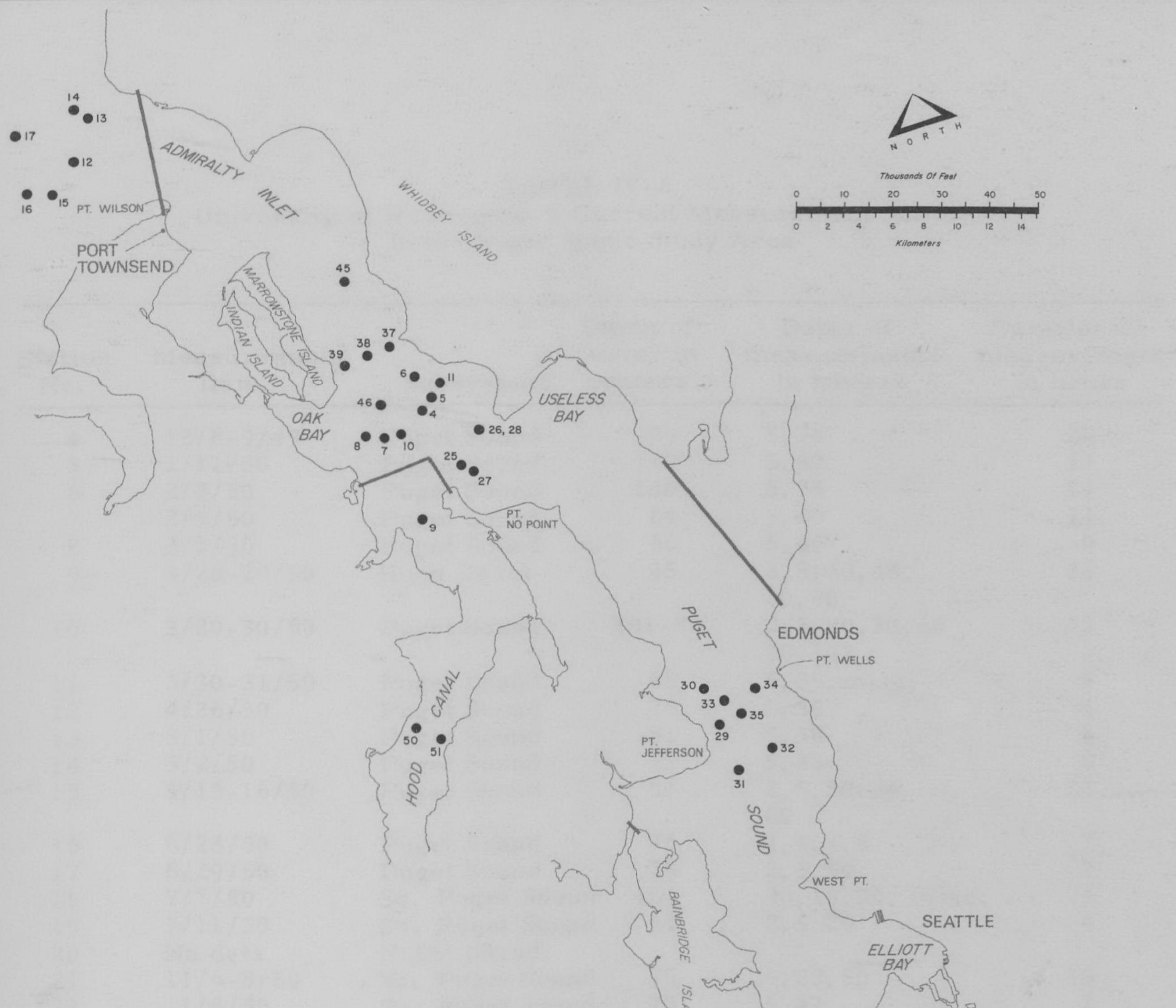

Figure IV-7
Locations of University of Washington
Current Measurement Stations
in Main Puget Sound and Hood Canal

TABLE IV-6
University of Washington's Current Measurement Stations
In the Puget Sound Study Area

Station No.	Measurement Date	Subsystem	Depth of water in meters	Depth of measurements in meters	Duration of measurement in hours
4	12/8-9/49	Puget Sound	99	5, 74	20
5	1/11/50	Puget Sound	110	5, 80	11
6	2/8/50	Puget Sound	100	5, 75	11
7	2/9/50	Puget Sound	64	5, 40	11
8	3/1/50	Puget Sound	66	5, 40	9
9	3/28-29/50	Hood Canal	95	2, 5, 30, 45, 60, 90	24
10	3/29-30/50	Puget Sound	101-80	2, 5, 20, 30, 60 90, 102	12
11	3/30-31/50	Puget Sound	68	5, 36, misc.	5
12	4/26/50	Puget Sound	76	5, 50	4
13	5/1/50	Puget Sound	81	5, 58	6
14	5/2/50	Puget Sound	71	5, 48	9
15	5/15-16/50	Puget Sound	51	2, 5, 20, 34 40	24
16	6/28/50	Puget Sound	76	2, 5, 4, 8	7
17	6/29/50	Puget Sound	73	2, 5, 50	9
18	7/7/50	So. Puget Sound	160	30, 10, 50, misc.	4
19	7/11/50	So. Puget Sound	54	2, 5, 29	4
20	No data	Puget Sound			
21	11/6-8/50	So. Puget Sound	75	5, 25, 50	38
22	11/8/50	So. Puget Sound	70	5, 47	2
23	No data	So. Puget Sound			
24	11/9-10/50	So. Puget Sound	61	5, 40	16
25	4/30-5/2/51	Puget Sound	48	5, 50	38
26	5/2-3/51	Puget Sound	50	5, 50, 60	24
27	5/21-22/51	Puget Sound	60	1, 5, 40, 10, 20, 40	20
28	5/23-24/51	Puget Sound	60	60, misc.	10
29	1/31/52	Puget Sound	196	bottom, misc.	3
30	2/6/52	Puget Sound	189	5, bottom	4
31	7/21/52	Puget Sound	58	5, 20, 30, 50	2
32	7/21-22/52	Puget Sound	220	3, 5, 10, 20, 30, 40, 50, 80, 100, 150	20
33	9/30-10/1/52	Puget Sound	200	5, 20, 50, 100, 150, bottom	15
34	10/1-2/52	Puget Sound	182	5, 20, 50, 100, 150, bottom	24
35	6/26-27/53	Puget Sound	185	5, 20, 50, 100, 150, bottom	24

TABLE IV-6
(Continued)

Station No.	Measurement Date	Subsystem	Depth of water in meters	Depth of measurements in meters	Duration of measurement in hours
37	11/30-12/1-3/53	Puget Sound	117	S, 10, 20, 40, 80	74
38	11/30-12/1-3/53	Puget Sound	110	S, 10, 20, 40, 80	74
39	11/30-12/1-3/53	Puget Sound	47	S, 10, 20, 40	74
42	6/1-4/54	Puget Sound	117	S, 10, 20, 30, 40, 70, 100	75
43	6/1-5/54	Puget Sound	110	S, 10, 20, 30, 40, 70, 100, 110	102
44	6/1-4/54	Puget Sound	47	S, 10, 20, 40	18
45	6/4-5/54	Puget Sound	114	S, 10, 20, 40, 70	26
46	6/4-5/54	Puget Sound	122	S, 10, 20, 40	26
47	7/19-20/54	So. Puget Sound	108	3-5, 30	25
48	6/20-21/54	So. Puget Sound	145	3-5, 30	23
49	6/22-23/54	So. Puget Sound	90	3-5, 30	24
50	12/6-8/54	Hood Canal	51	2, 5, 10, 20, 30, 50	52
51	12/8-10/54	Hood Canal	55	2, 5, 10, 20, 30, 50	51
52	1/31-2/1/55	So. Puget Sound	120	7.5, 30	26
53	2/1-3/55	So. Puget Sound	150	3, 7.5, 30	26
54	2/3-4/55	So. Puget Sound	90	7.5, 30	26
55	2/19/55	Puget Sound	104	2, 10, 20, 30, 50, 100	10
56	4/29-30/55	Puget Sound	95 approx.	2, 5, 10, 20, 30, 60, 90	25

Only a few biological data studies have been attempted in Hood Canal. Barlow [1958] determined spring changes in phytoplankton abundance. Kollmeyer [1962] investigated water quality and circulation in Dabob Bay. The College of Fisheries at the University of Washington has conducted experimental shrimp trawling in Dabob Bay at the north end of Hood Canal. One of several unpublished reports [Elder, 1965] includes the results of experiments conducted along two trawling lines in January 1965.

Dyes and Sinclair Inlets

No additional water quality-biological data or water circulation data are specifically included in the Dyes and Sinclair Inlets Subsystem.

South Puget Sound

Collias [1971] tabulated ten current measuring stations in South Puget Sound from 1948 to 1955. As described for the Main Puget Sound Subsystem, Table IV-6 lists the date and duration of measurements at each station. The ten stations located in Figure IV-8 lie along a line from the Tacoma Narrows up to Carr Inlet.

In South Puget Sound, Ting [1965] extensively sampled 52 stations in Eld Inlet for benthic organisms. His work was done in 1963. Lie [1965] collected benthic organisms along a line east of Hartstene Island and phytoplanton data at a station in southern Case Inlet during 1963 and 1964. The techniques of both Ting and Lie have been described in the section for Main Puget Sound.

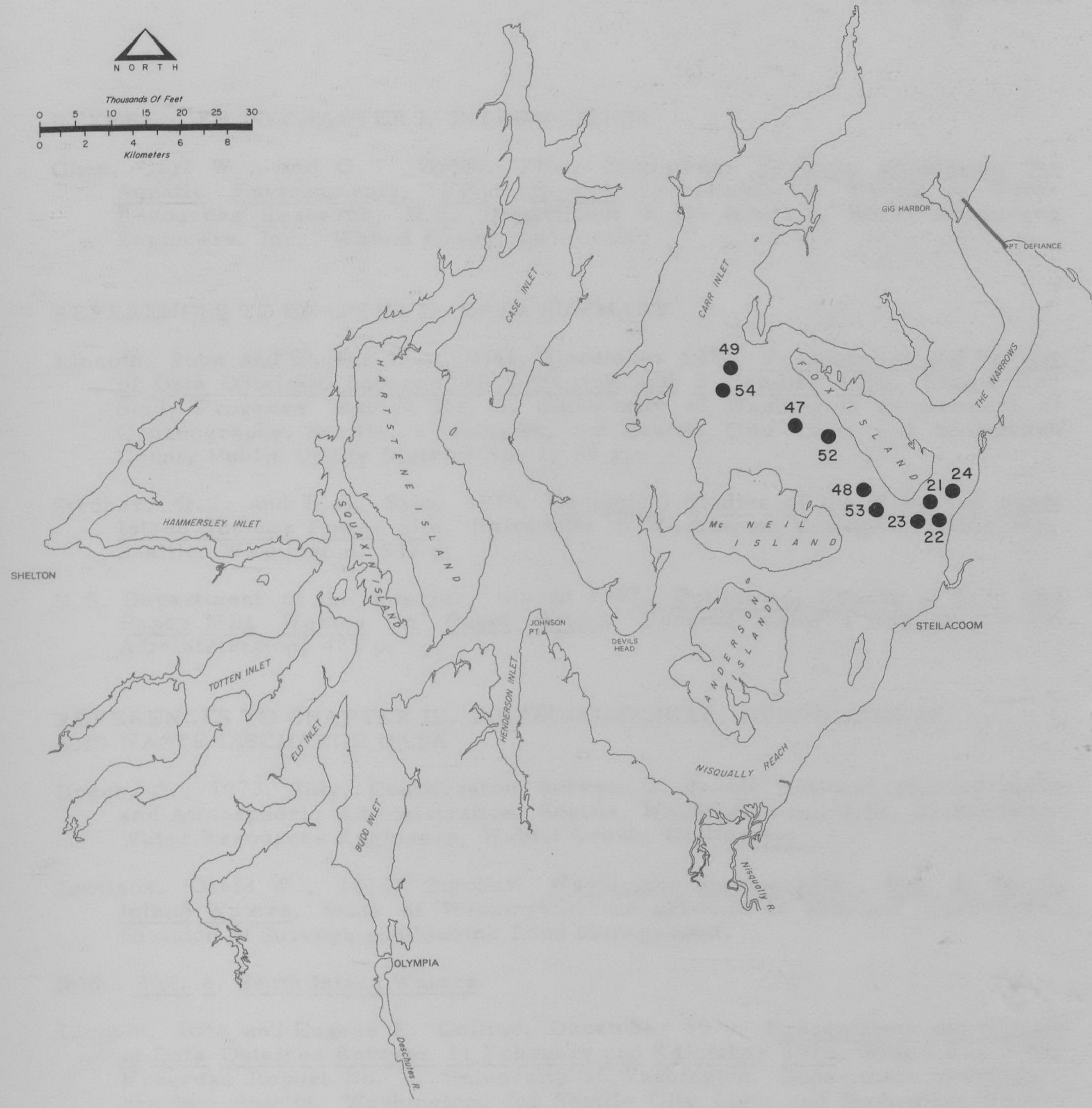

Figure IV-8
Locations of University of Washington Current Measurement Stations in South Puget Sound

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