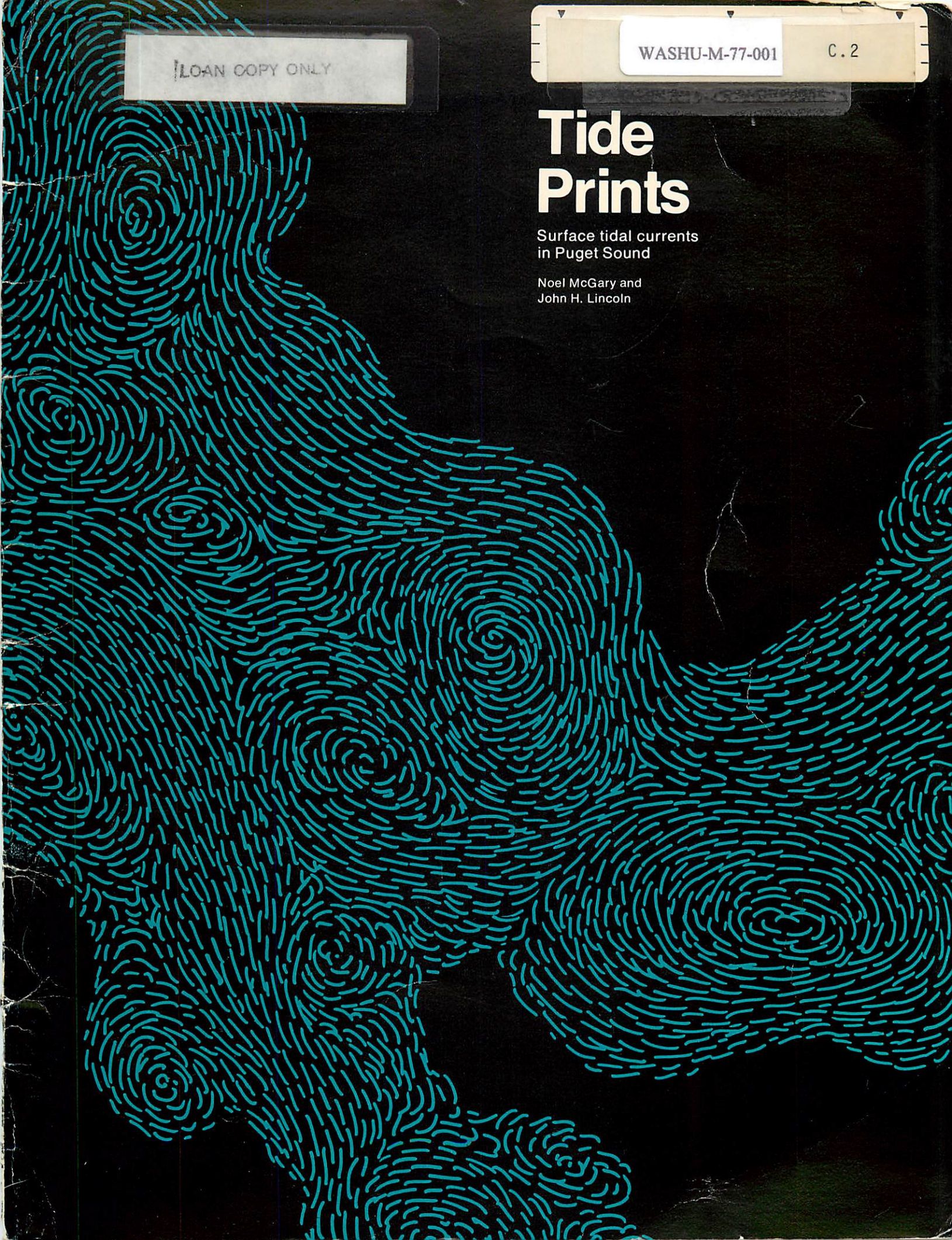
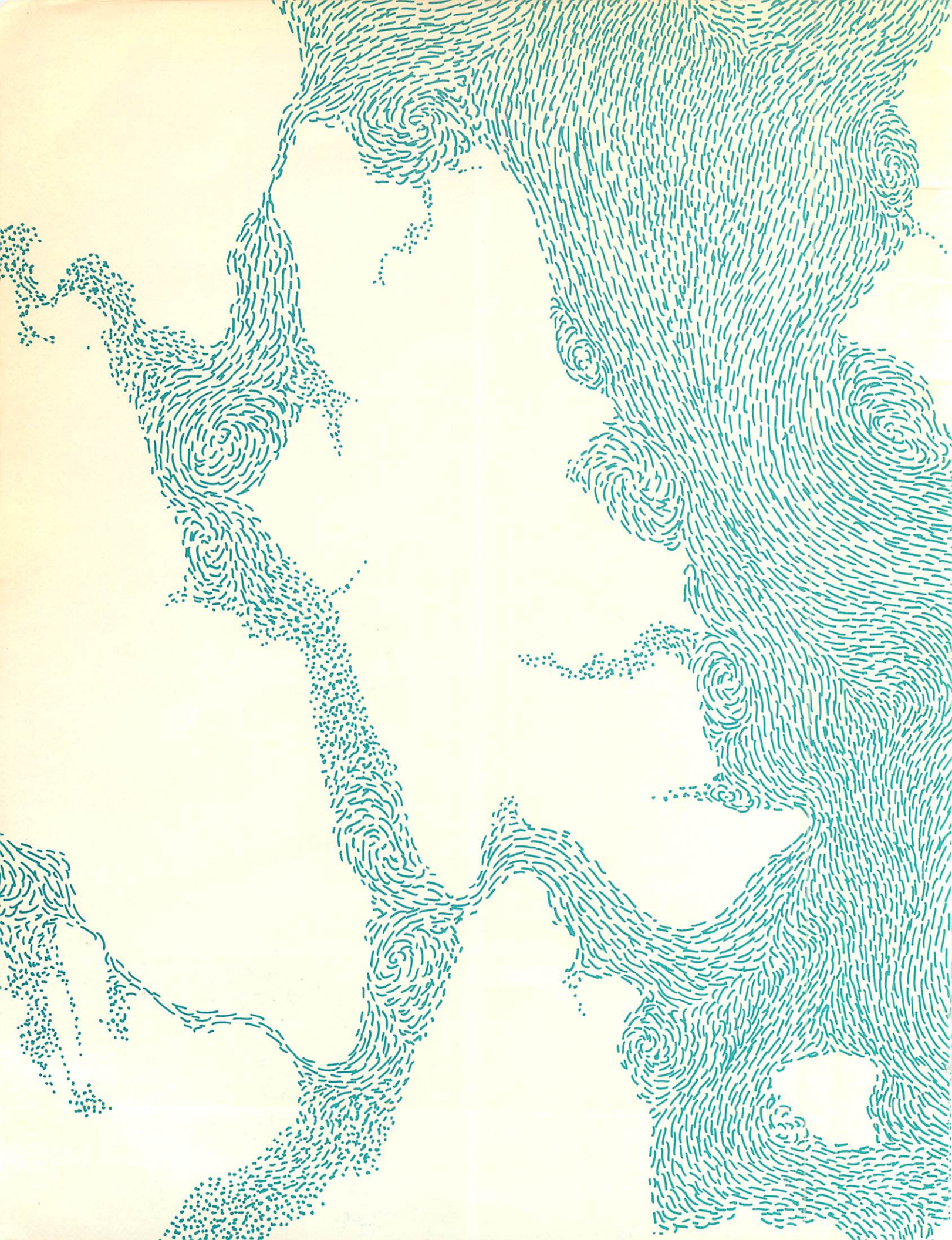
Tide Prints

Surface tidal currents in Puget Sound

Noel McGary and
John H. Lincoln





A WASHINGTON SEA GRANT PUBLICATION

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Noel McGary and
John H. Lincoln

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Foreword

The Puget Sound model, which provided the basis for the charts presented in this atlas, was constructed in 1950 in the Department of Oceanography at the University of Washington. The model's primary function was to provide a bird's eye view of circulation that could not be obtained readily from field observations alone. Beyond its role in basic research, the model has served as a teaching aid and in studies of tides and tidal currents, and in applied research relevant to pollution at various locations. The model has also been a prime attraction at departmental open houses where frequent winners of boat races in the Sound are numbered among its keenest observers.

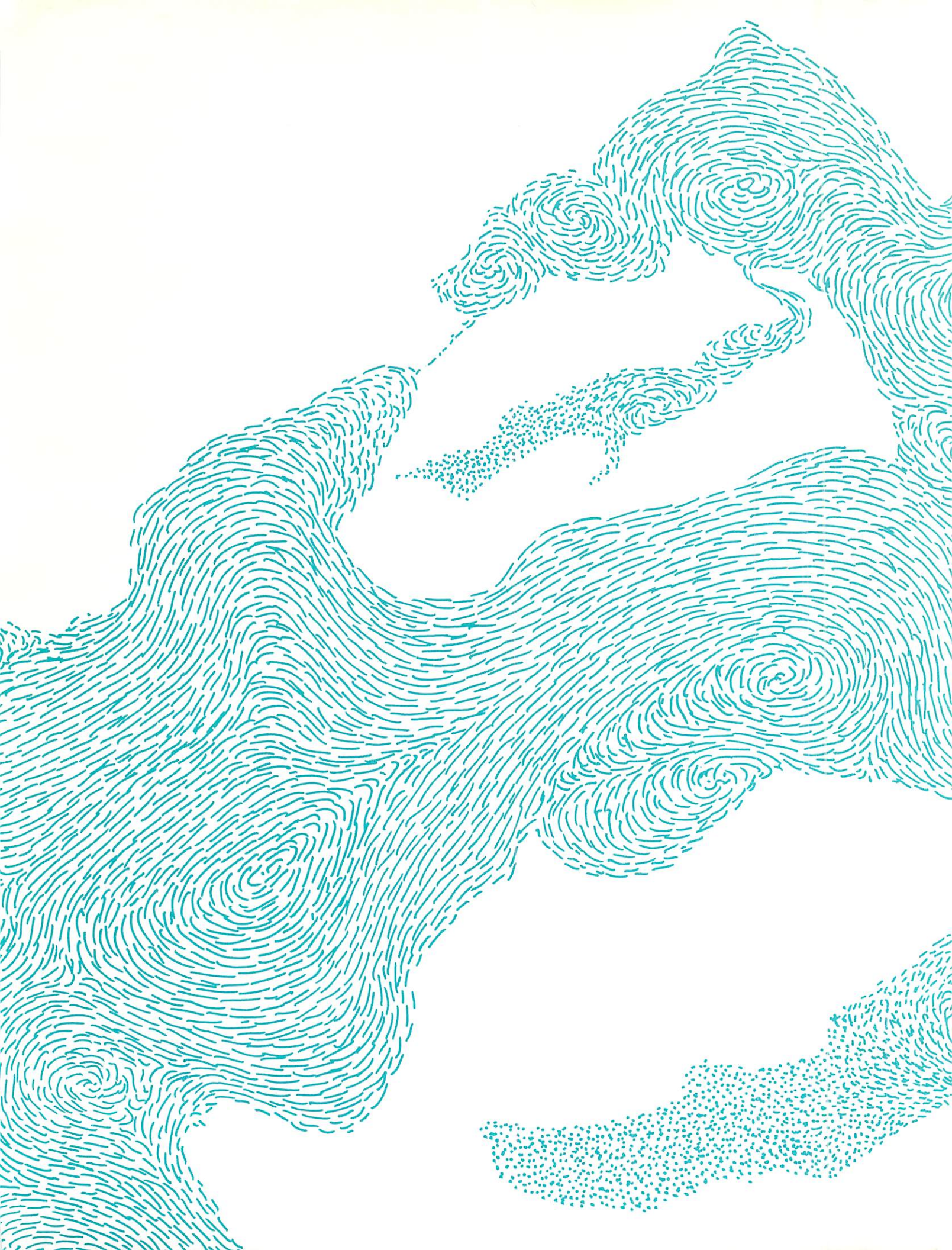
John Lincoln, who took the original photographs as a part of a recent research project, and Noel McGary, who prepared the charts from these photographs, collaborated in the preparation of this atlas. John was involved in the design, construction, and instrumentation of the model and has operated it over many years for a wide variety of studies. Noel, a longtime cartographer for the Department of Oceanography, has made notable contributions to portrayal of bathymetry and water properties of Puget Sound and the North Pacific.

In preparing the various charts, the authors have keyed them to a single reference, the tide stage at Seattle, rather than the tidal currents, as is the case of the conventional current charts, which in the Sound are referenced to two locations of differing flow characteristics. This enables the user to relate the charts to changes in water level easily observable along shore, or to the widely distributed tide tables or tide calendars. It also provides a more comprehensive picture of the system as a whole.

This atlas should be of interest and value to boaters, fishermen, and recreationists, as well as to engineers and scientists concerned with surface currents in Puget Sound.

Clifford A. Barnes *February 1977*

Professor Emeritus
Department of Oceanography
University of Washington



Preface

Undoubtedly, from the time Indians began paddling their canoes on the waters of what is now known as Puget Sound, the ever-present currents have been an enigma to many who have attempted to get from here to there most expeditiously, and to others who, while watching a bit of flotsam or a floating log have wondered, "How did that get here?" or "Why is it going in that direction?" Even now, surprises may await the unwary.

In 1972, we in the Department of Oceanography at the University of Washington had need to understand the circulation in an area where the flows were extremely complex. The Puget Sound model in the Department and field studies had provided us with much data, but we needed more than columns of numbers to describe what was going on—something more graphic.

Photographs proved to be the answer and the model the means. How? In the model, we can make a mess in Puget Sound without concern for environmental impact, so we were able to try out ways impossible or impractical in nature. It occurred to us that a short time-exposure photograph of polystyrene particles floating on the water surface in the model would appear as streaks following the path of simulated surface currents during the exposure time. After several attempts, and after having to scrub out Puget Sound a number of times, some successful photographs were obtained.

Upon seeing these experimental photographs, Dr. Donald F. Winter and Dr. Ronald K. Lam believed that the technique would help solve some research problems with which they were concerned. However, they required coverage of the entire Puget Sound system. With initial funding as a part of their grant from the Environmental Protection Agency, a series of eight photographic mosaics were produced. These photographs showed surface flows at each high, low, and intermediate tide stage of a representative tidal day.

A number of us on the faculty and staff of the Department of Oceanography and the Division of Marine Resources, including Dr. Lam, Dr. Alyn C. Duxbury, Eugene E. Collias, and Patricia Peyton, were convinced that the mosaics would be of wide interest. Their conviction generated enthusiasm for using the mosaics as the basis for a publication that would be interesting and useful not only to oceanographers but also to the thousands of boaters, fishermen, and others to whom Puget Sound is a way of life.

The original photographs, as such, were not suitable for publication because of problems associated with interpretation of sometimes faint streaks and with reproduction. Thus, Noel McGary's line drawings based on my photographs allowed a much clearer representation of the flow lines and enabled additional detail to be added from direct observations in the model.

We wish to thank Dr. Winter for his support in initiating the original project, Dr. Lam for his help in planning and taking the photographs of the model, and Richard Cromoga who produced the many very carefully controlled photographic enlargements from which the mosaics were assembled. The support and guidance of Dr. Alyn C. Duxbury is acknowledged and our thanks given him. We also wish to thank the staff of the Washington Sea Grant Communications Program who were most competent midwives during the gestation and birth of this publication.

Special mention must be made of the contributions by Eugene E. Collias in not only obtaining the funds which made the book possible, but also for his many suggestions and constructive criticisms. Few surpass his knowledge of Puget Sound—a factor which added considerable zest to discussions and arguments that were much help in the development of a publication that is as useful and accurate as the ramifications of the tidal currents permit.

Finally, to the many who love, cherish, protect, enjoy, use, study, or simply look at Puget Sound—here it is. But remember—the tides change, the winds blow, and Puget Sound is restless. If you find that sometime, somewhere, things aren't happening quite the way these charts indicate they should—rejoice. That is what makes it interesting.

John H. Lincoln *January 1977*

Department of Oceanography
University of Washington

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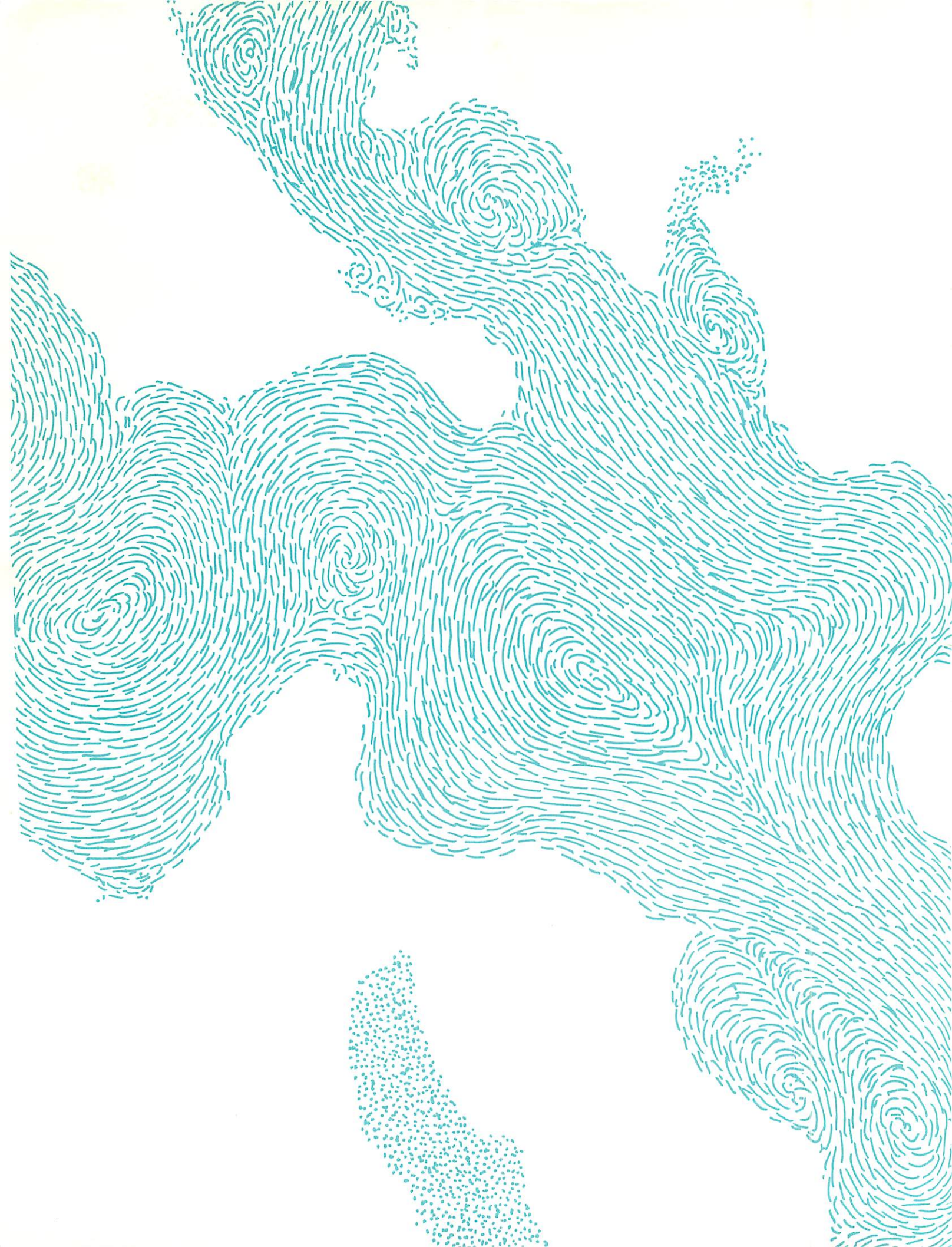


Introduction

These charts—or "tide prints"—portray the surface currents in Puget Sound at eight stages during a tidal day and all are referenced to the tide stage at Seattle. Absolute or true speeds are not shown because of the strong dependence of currents on tide range and height, although the portrayal is designed to indicate approximate relative speeds and flow directions. These charts are intended to supplement the Tidal Current Charts of Puget Sound and the Tidal Current Tables published by the National Ocean Survey of the National Oceanic and Atmospheric Administration. The charts have been prepared as a guide for people concerned with or interested in details of surface flow within Puget Sound.

Surface tidal currents within Puget Sound are complex. Their intricate, continuously changing patterns result from an irregular shoreline, underwater features, and physical characteristics of interconnecting channels. The flow in most locations is related primarily to tide range and height, and secondarily to the winds. Patterns that develop during each ebb tide or during each flood tide generally are similar. Thus, flow characteristics can be indicated suitably by presenting patterns that develop during a representative tidal day, although much larger or smaller tide ranges may result in some modification of the patterns depicted in these charts.

Preparation of the charts

The charts are based on observations made in the Puget Sound oceanographic model at the Department of Oceanography, University of Washington.

The tide-generating equipment of the model was set to repeat continuously the selected tidal-day sequence. Small particles of white polystyrene foam were distributed as uniformly as possible over the surface of the water which had been dyed a dark color to provide suitable contrast for photography. A series of eight two-second, time-exposure photographs was taken during the tidal day, with the start of each exposure precisely timed with reference to the tide stage at Seattle. During the two-second exposure time, the movement of the water caused the floating particles to appear in the photographs as streaks which indicated flow lines. Although the individual streak lengths were a function of current speed, they were not a reliable measure because of image overlapping produced by the great number of closely spaced particles required to obtain suitable detail of the flow patterns.

To obtain complete coverage of the model area, photographs were taken of fourteen sub-areas of the model at each stage of the tidal cycle. The 14 sub-area photographs corresponding to a particular tide stage at Seattle were mounted to produce a composite photograph showing the flow behavior over the entire Puget Sound system at the indicated time. The eight such composites produced represented the following tide stages:

1. Lower low
2. Mid-tide between lower low and higher high (large flood)
3. Higher high
4. Mid-tide between higher high and higher low (small ebb)
5. Higher low
6. Mid-tide between higher low and lower high (small flood)
7. Lower high
8. Mid-tide between lower high and lower low (large ebb)

Next, line drawings based on the composite photographs were prepared to show more clearly the flow patterns. Additional details, based on interpretation of the streak images and on visual observations during and subsequent to the photography, were added where photographic data were insufficient or unclear. Since the streaks did not indicate flow direction (flow in opposite directions appeared the same), this was confirmed by visual observations, and directional arrows were then transcribed onto the charts. This was particularly necessary at or near times of slack water, and for some eddies where the direction of rotation could not be adequately inferred from the photographs.

Limitations

These charts primarily are qualitative representations of the surface tidal flow characteristics or patterns, with an indication of approximate relative speeds and directions of flow. The charts are not intended to be quantitative

representations from which precise speed and direction of flow can be determined. Limitations are imposed by scaling parameters of the Puget Sound model and by the observation and reproduction techniques used in preparing the charts.

Because of the small size of the model, water surface tension significantly affects flow in some areas in it. Thus the charts do not accurately indicate flow behavior near the shoreline, in restricted small bays or inlets, or in shallow areas such as tide flats. Moreover, representation of detail in narrow channels such as Agate Passage or Deception Pass cannot be shown reliably. Water viscosity in the model prevents formation of very small eddies and fine-scale turbulence, but features larger than about 0.1 to 0.2 mile in diameter are represented adequately.

Scaling factors also preclude representation of the effects of wind stress on surface currents —thus, these representations are for calm wind conditions. Wind-driven currents may become significant, but the effect is highly variable, depending on wind speed, duration in a given direction, fetch length, and land topography. Where wind-driven currents become appreciable, they will tend to introduce a small component about 45° to the right of the wind direction.

Finally, relative speed indicated by the length of flow lines and directional arrows should not be considered an accurate measure because it is the result of subjective interpretation of the original photographs.

However, tidal currents and flow characteristics, determined by field observations in Puget Sound, and those observed in the model, when it is operated to represent the same time period, have demonstrated agreement within observational and model limitations.

Use of the charts

These charts have been prepared as an aid in understanding the complex and continuously changing surface flow patterns associated with tides within Puget Sound. They show the principal flow paths; the more prominent convergence lines; and the location, general extent, and direction of rotation of larger scale eddies commonly found in the channels downstream of points and promontories and in certain embayments. The character of the flow, represented by flow lines, is suggested by the lengths of both the flow lines and the directional arrows. Dots indicate areas of very weak currents when direction is indeterminate at the tide stage represented.

Actual speeds are not indicated because of their dependence on tide range and height. Current speeds at specific times and locations can be determined from the Tidal Current Charts of Puget Sound (1) which show speed factors for various locations timed from predicted maximum floods and ebbs at the referenced locations. The use of these speed factors, which are adjusted to the maximum current listed for each tide in the Tidal Current Tables (2), is described in detail in the introduction and explanation for the Tidal Current Charts. This information can then be used to "calibrate" these charts for the particular tide in question.

The Puget Sound system is shown in four overlapping series of eight charts:

NORTHERN SOUND: Admiralty Inlet and the Whidbey Basin from Possession Sound to Deception Pass
MAIN BASIN: Foulweather Bluff to The Narrows
HOOD CANAL: Foulweather Bluff to Lynch Cove
SOUTHERN SOUND: The Narrows and all southern inlets

The tide stage (at Seattle) represented by each chart is indicated on the tide curve on the chart. Flow behavior over the entire system at the indicated time is shown by the appropriate chart of each series. For example: the first chart of each series shows the flow at the time of lower low water at Seattle. Flood current has commenced at the northern entrance near Port Townsend (series A) but has not started in the southern areas near Olympia (series D) where some ebb current still persists in the channels.

The principal flow features, as observed in the model and shown by the charts, are similar during the majority of tide ranges, but the patterns may be slightly altered or modified by

tidal extremes. Very large ranges tend to accentuate some flow features such as a plume-like discharge from a channel into a basin. Large eddies may be carried further downstream and to midchannel or beyond, and stronger currents with associated greater turbulence will develop in most channels. During very small tide ranges, some eddies shown may not fully develop or may not form. In most channels, a true slack or zero current seldom occurs or is of brief duration. Transition between flood and ebb may appear as a rotation in direction during the current minimum, as the passage of a "front," or as a simple reversal in direction. In certain localized areas, flow may be unidirectional, e.g., movement is in the same direction during both ebb and flood but with a variation in speed.

Practical considerations in preparing these charts limited portrayal to only eight tide stages during the day. Because Puget Sound is a dynamic system, flow characteristics are continually changing. Thus, a limited number of charts cannot show in detail the transitions of flow behavior that occur. For example, how an eddy forms, drifts, changes character, and dies out as others form, or how the flow lines change as the current speed increases or decreases during a particular tide. To provide this detail would require a large number of charts made at frequent intervals—ideally, a motion picture.

Tide Prints will provide much information for those who are interested in but probably unfamiliar with the details of Puget Sound tidal currents. For those more familiar with the subtleties of the currents in all or part of Puget Sound, the charts will serve as an aid toward a more detailed understanding.

References

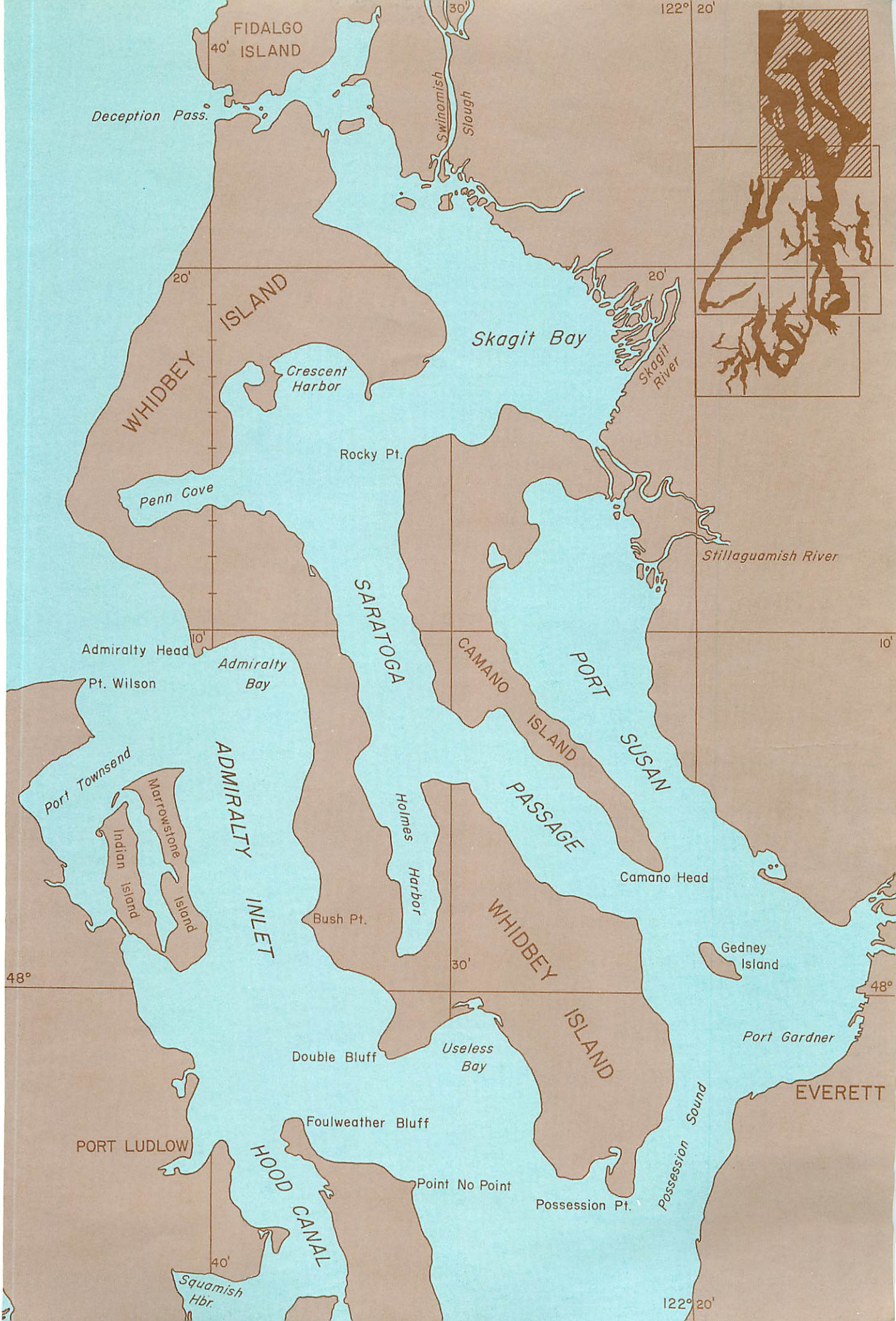
Tidal Current Charts. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey. Puget Sound Northern Part. Serial No. 696 (1947) Puget Sound Southern Part. Serial No. 713 (Second Ed., 1961)

Tidal Current Tables. Pacific Coast of North America and Asia. U.S. Department of Commerce. National Oceanic and Atmospheric Administration, National Ocean Survey. (Published yearly)

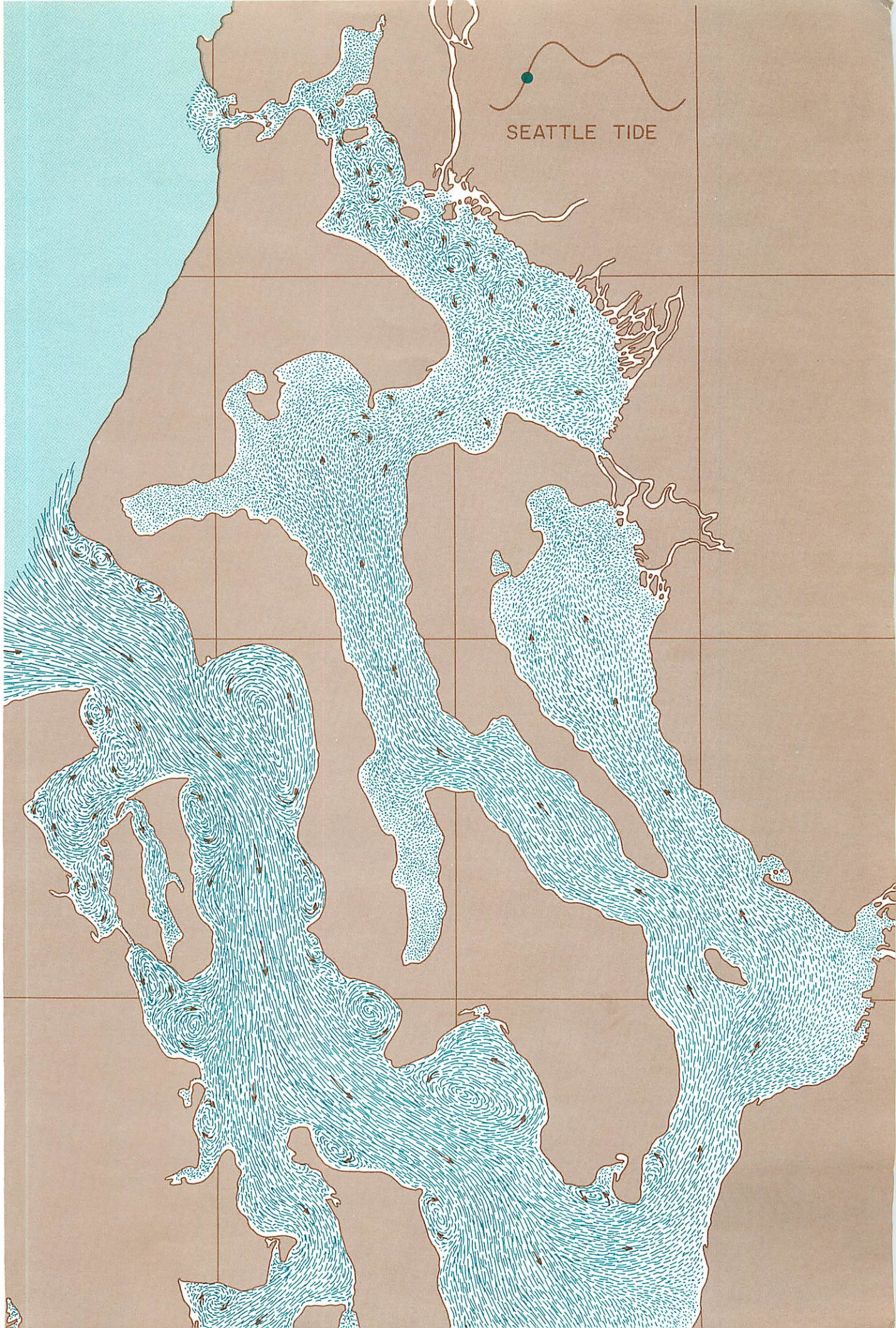
Physical Characteristics of Puget Sound

Water area at Mean High Water	767.6	square nautical miles
Length of shoreline	1,157	nautical miles
Total volume below Mean High Water	26.5	cubic nautical miles
Mean tidal exchange	1.27	cubic nautical miles
Average depth	34	fathoms
Maximum depth (off Point Jefferson)	155	fathoms
Maximum currents		
Deception Pass	9-10	knots
The Narrows	5.5	knots
River Discharge		
Maximum monthly average	367,000	cubic feet per second
Yearly mean	41,000	cubic feet per second
Minimum monthly average	14,000	cubic feet per second

Northern Sound


FIDALGO ISLAND
Deception Pass.
Swinomish Slough
122° 30'
122° 20'
40'
20'
WHIDBEY ISLAND
Skagit Bay
Crescent Harbor
Skagit River
Rocky Pt.
Penn Cove
Stillaguamish River
SARATOGA
CAMANO ISLAND
PORT SUSAN
10'
Admiralty Head
Pt. Wilson
Admiralty Bay
Port Townsend
Marrowstone Island
Indian Island
ADMIRALTY INLET
Holmes Harbor
PASSAGE
Camano Head
Bush Pt.
WHIDBEY ISLAND
Gedney Island
48°
30'
Port Gardner
Double Bluff
Useless Bay
EVERETT
Foulweather Bluff
PORT LUDLOW
HOOD CANAL
Point No Point
Possession Pt.
Possession Sound
Squamish Hbr.
40'
122° 20'


SEATTLE TIDE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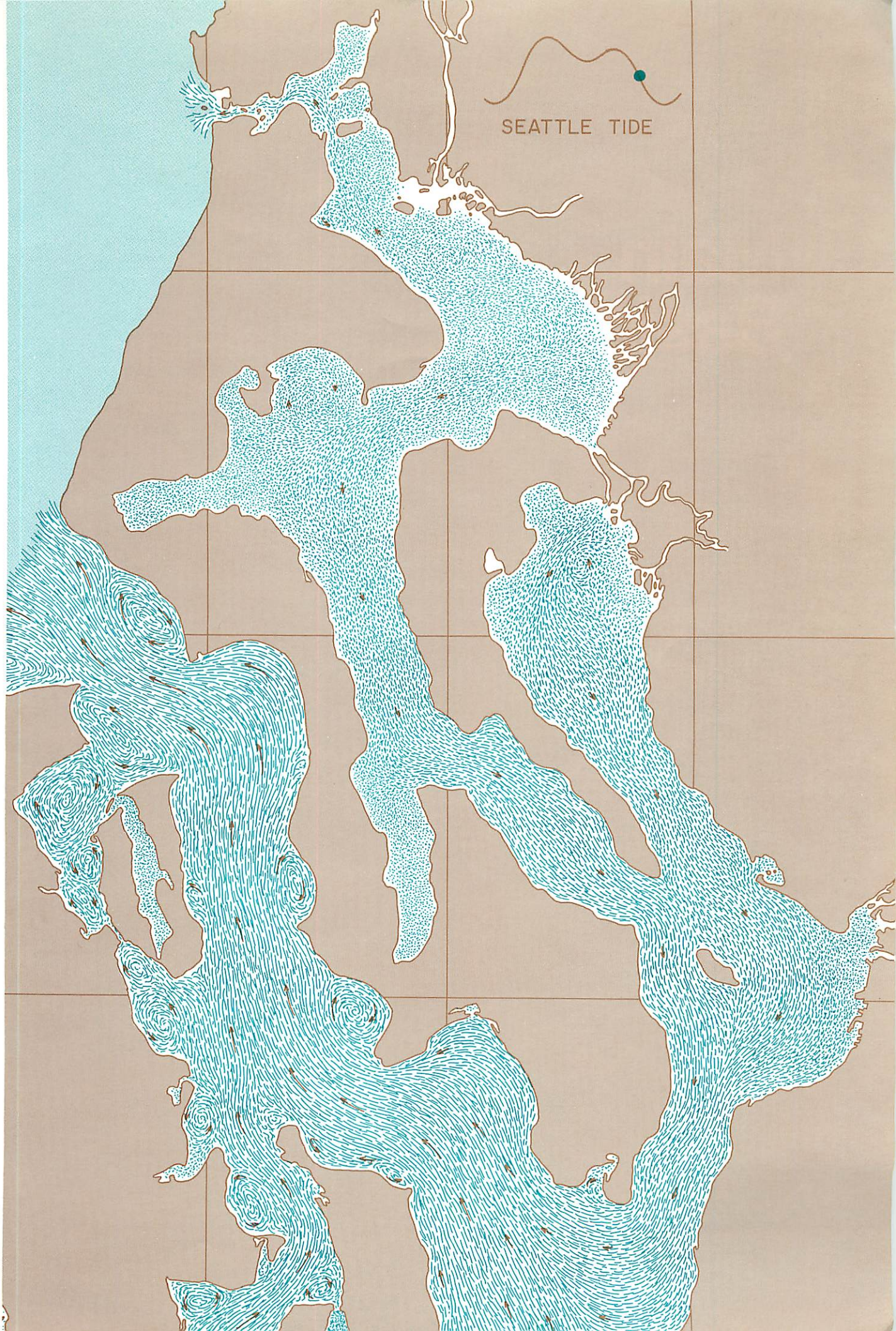
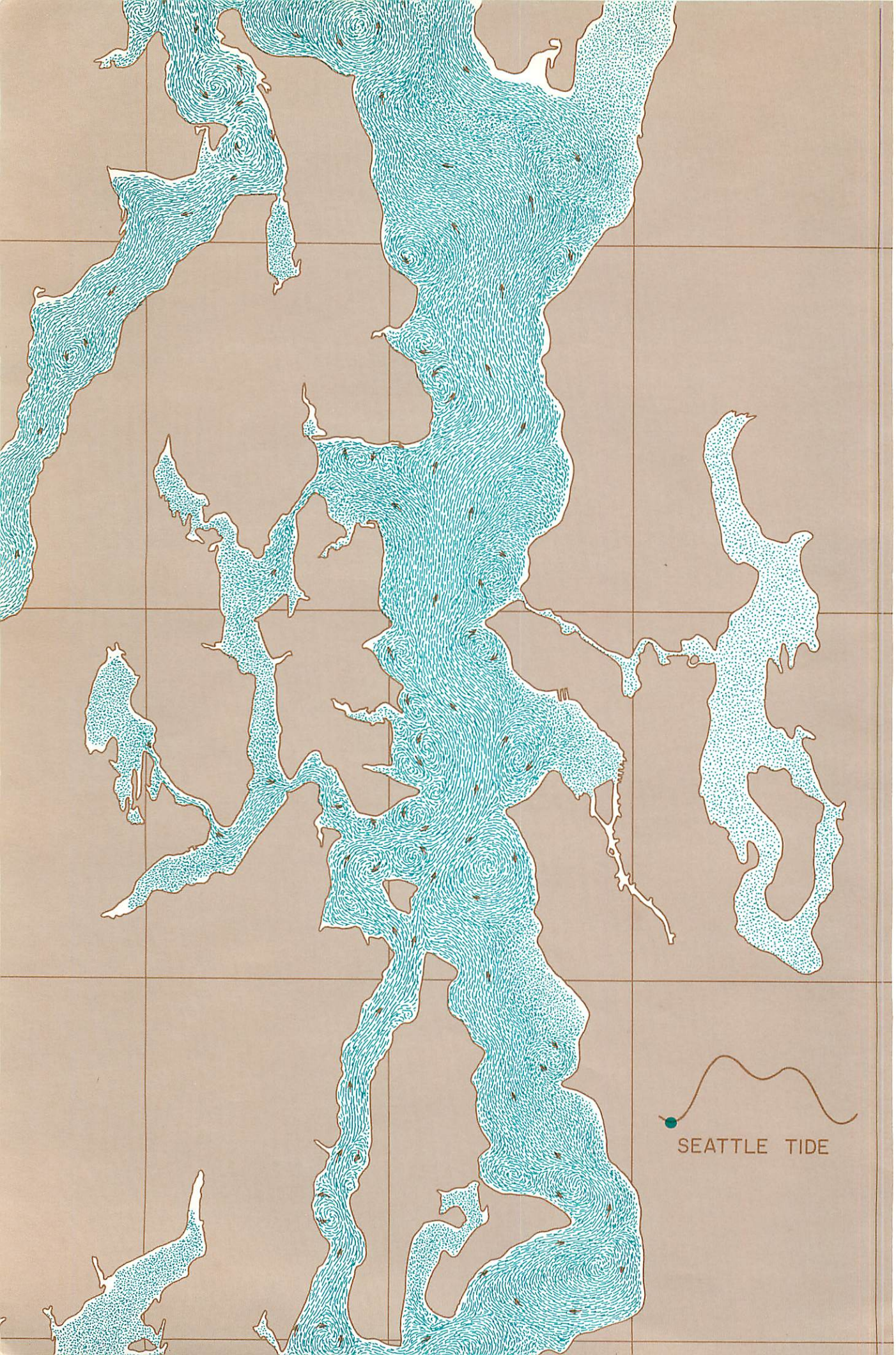

SEATTLE TIDE

Main Basin


PORT LUDLOW
Foulweather Bluff
Point No Point
Possession Pt.
Possession Sound
Head Hood
Squamish Harbor
HOOD CANAL
Port Gamble
Apple Cove Pt.
EDMONDS
Pt. Wells
Pt. Jefferson
Liberty Bay
Agate Pass.
Port Madison
BANGOR
Pt. Monroe
Meadow Pt.
Shilshole Bay
West. Pt.
BAINBRIDGE ISLAND
PORT ORCHARD
Dyes Inlet
SEATTLE
Lake Washington
Elliott Bay
Restoration Pt.
Alki Pt.
Rich Pass.
BREMERTON
Sinclair Inlet
PORT ORCHARD
Yukon Harbor
Blake Island
Duwamish River
Dolphin Pt.
EAST PASSAGE
COLVOS PASSAGE
VASHON ISLAND
Pt. Pully
Pt. Robinson
Maury Island
Quartermaster Hbr.
Pt. Piner
CARR INLET
122° 20'
50'
40'
30'
47° 20'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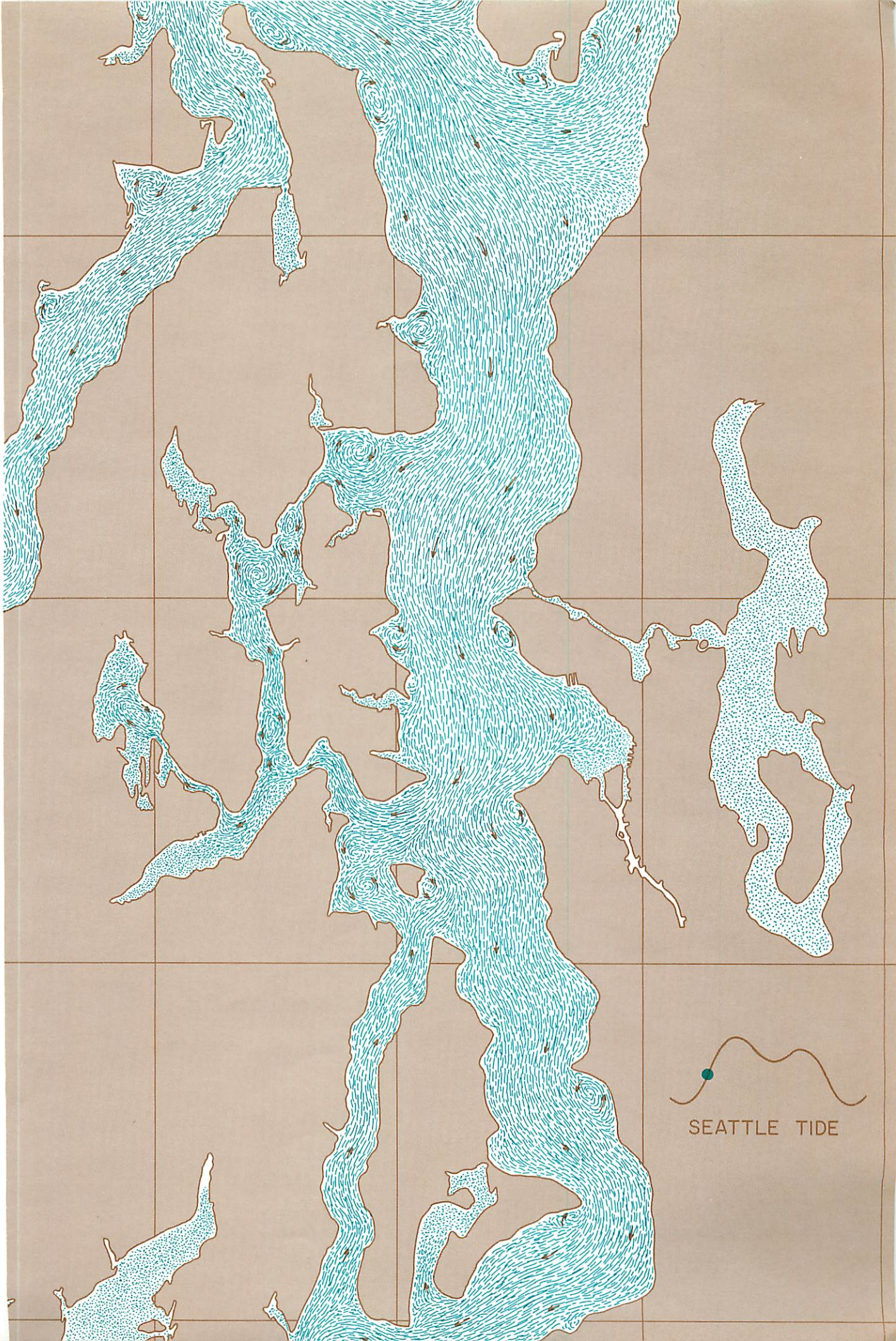
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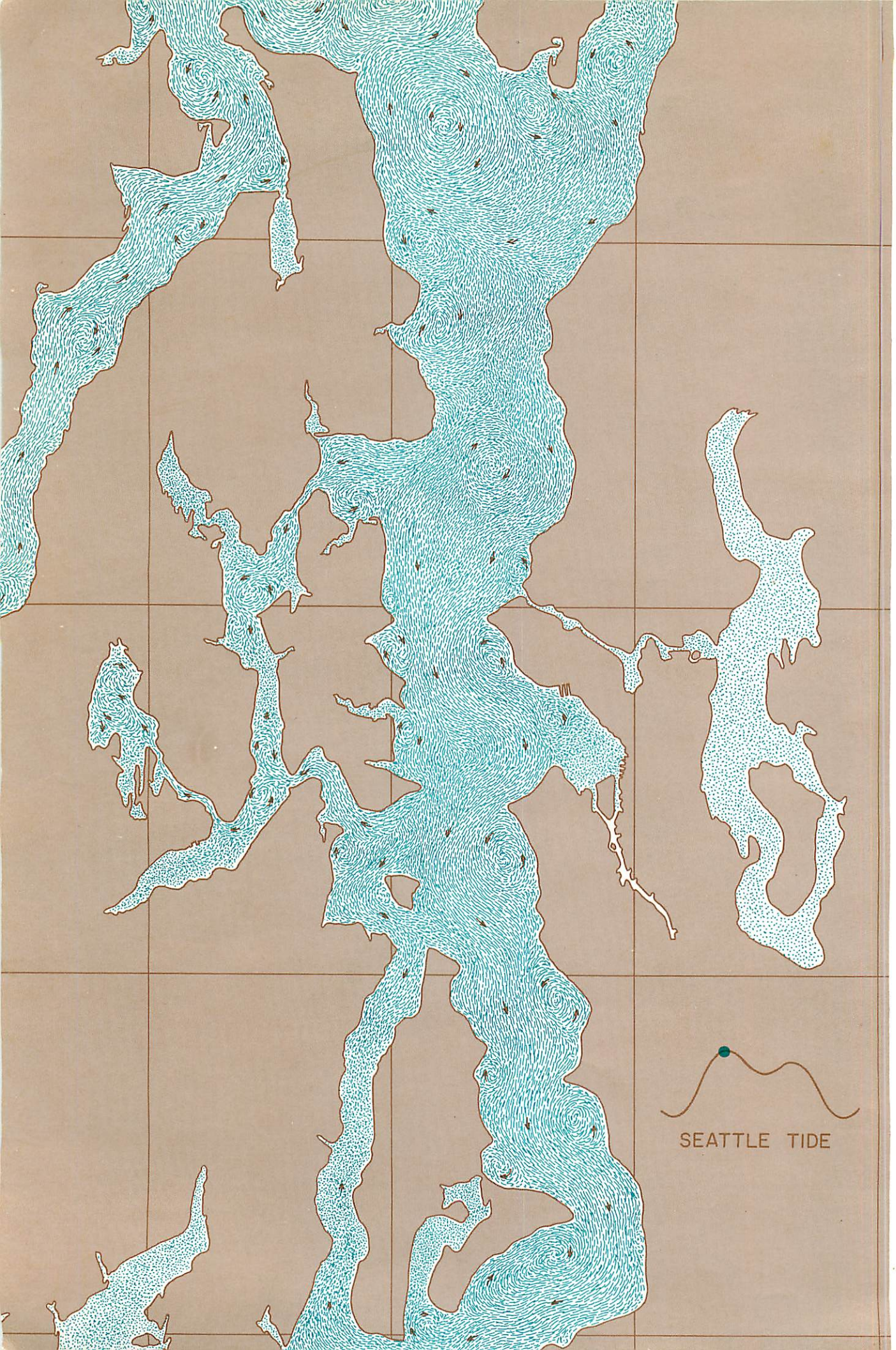
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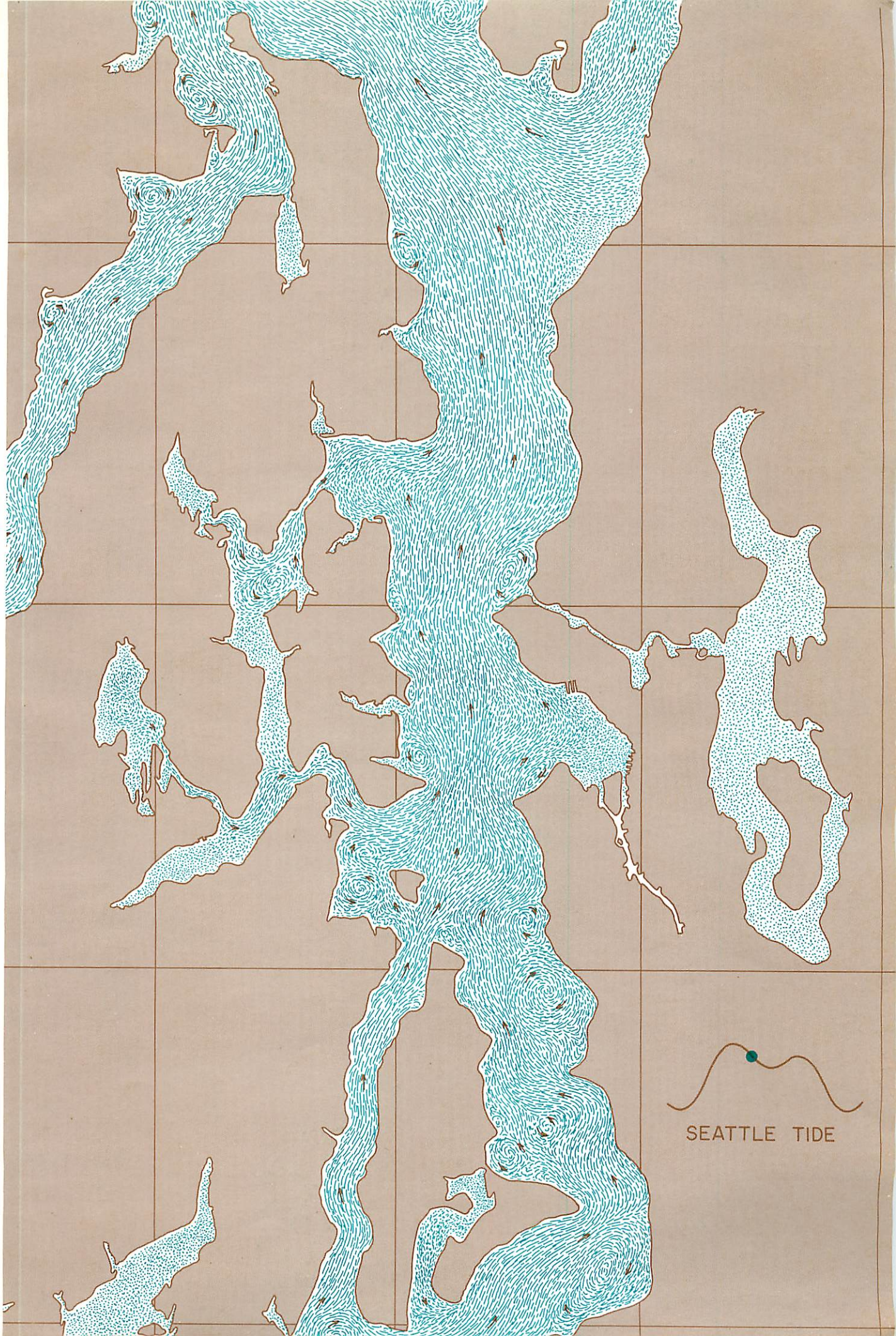
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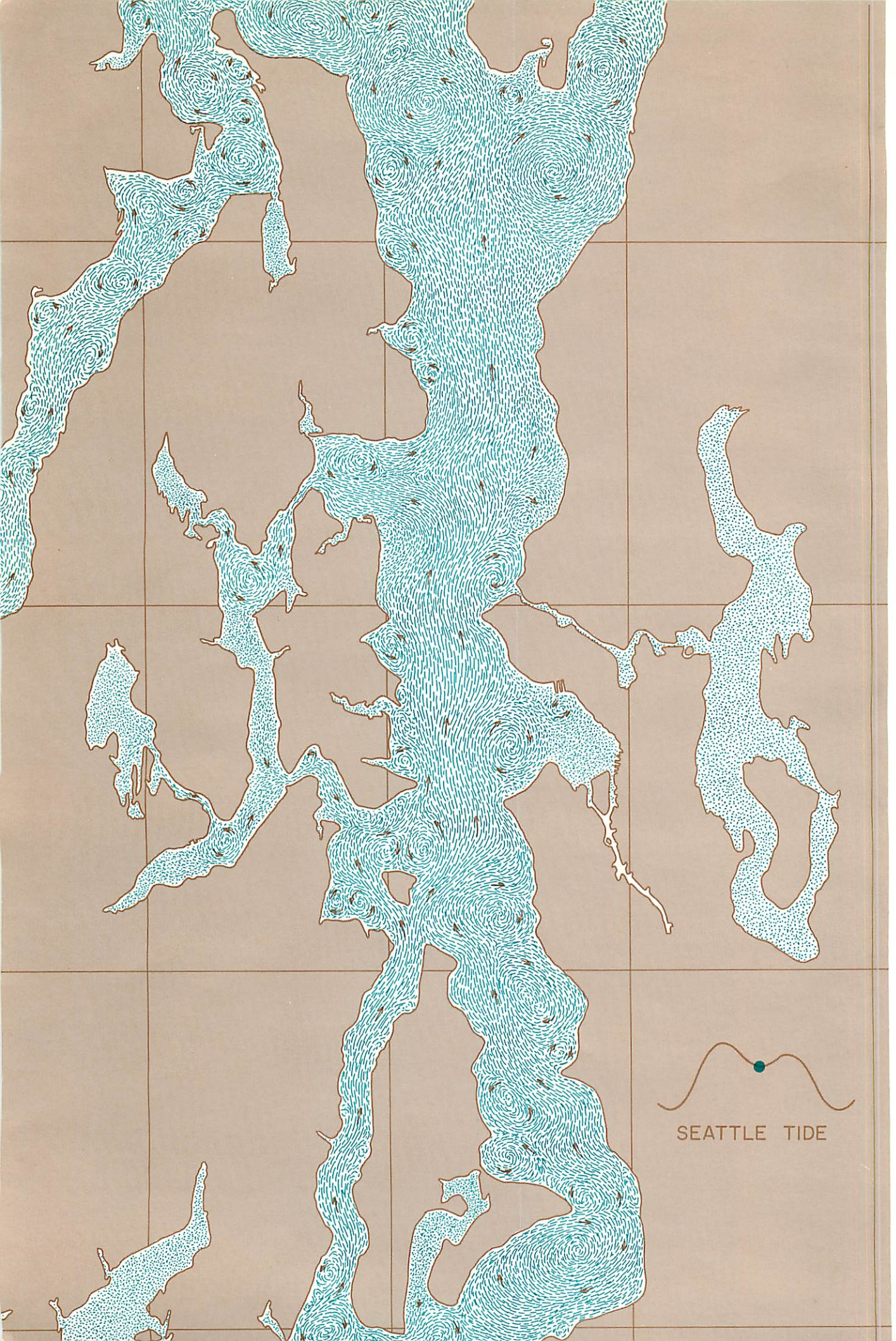
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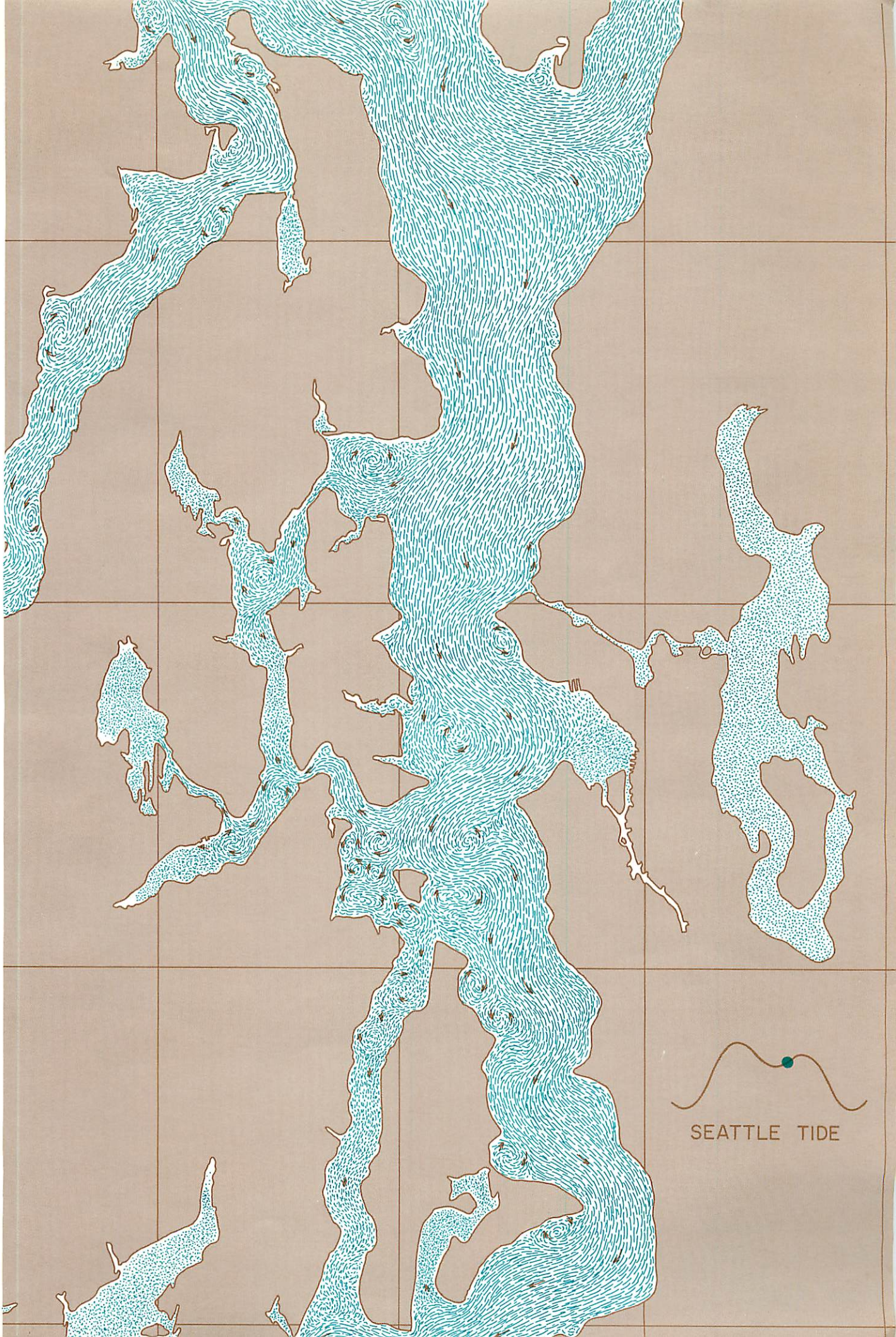
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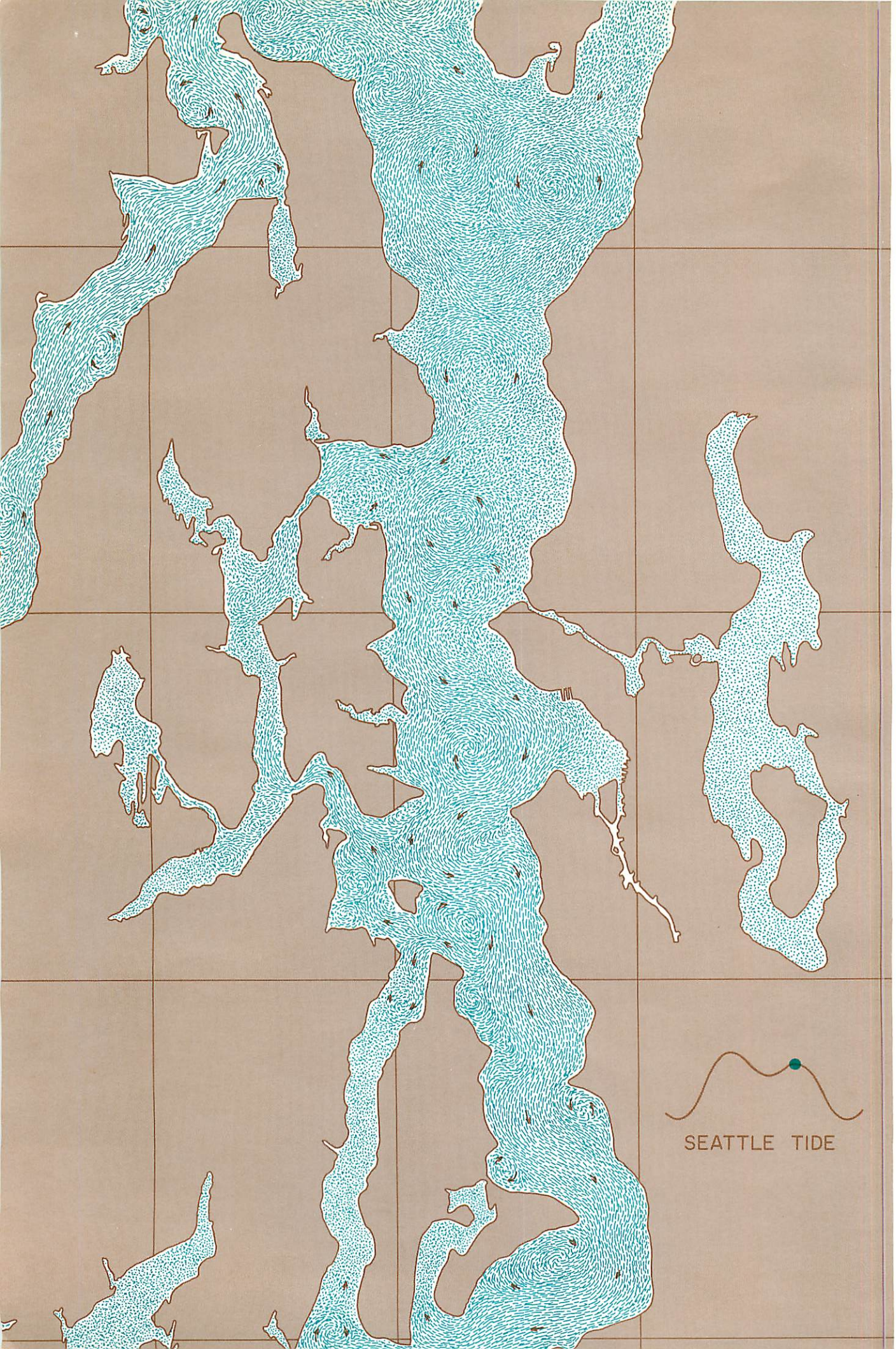
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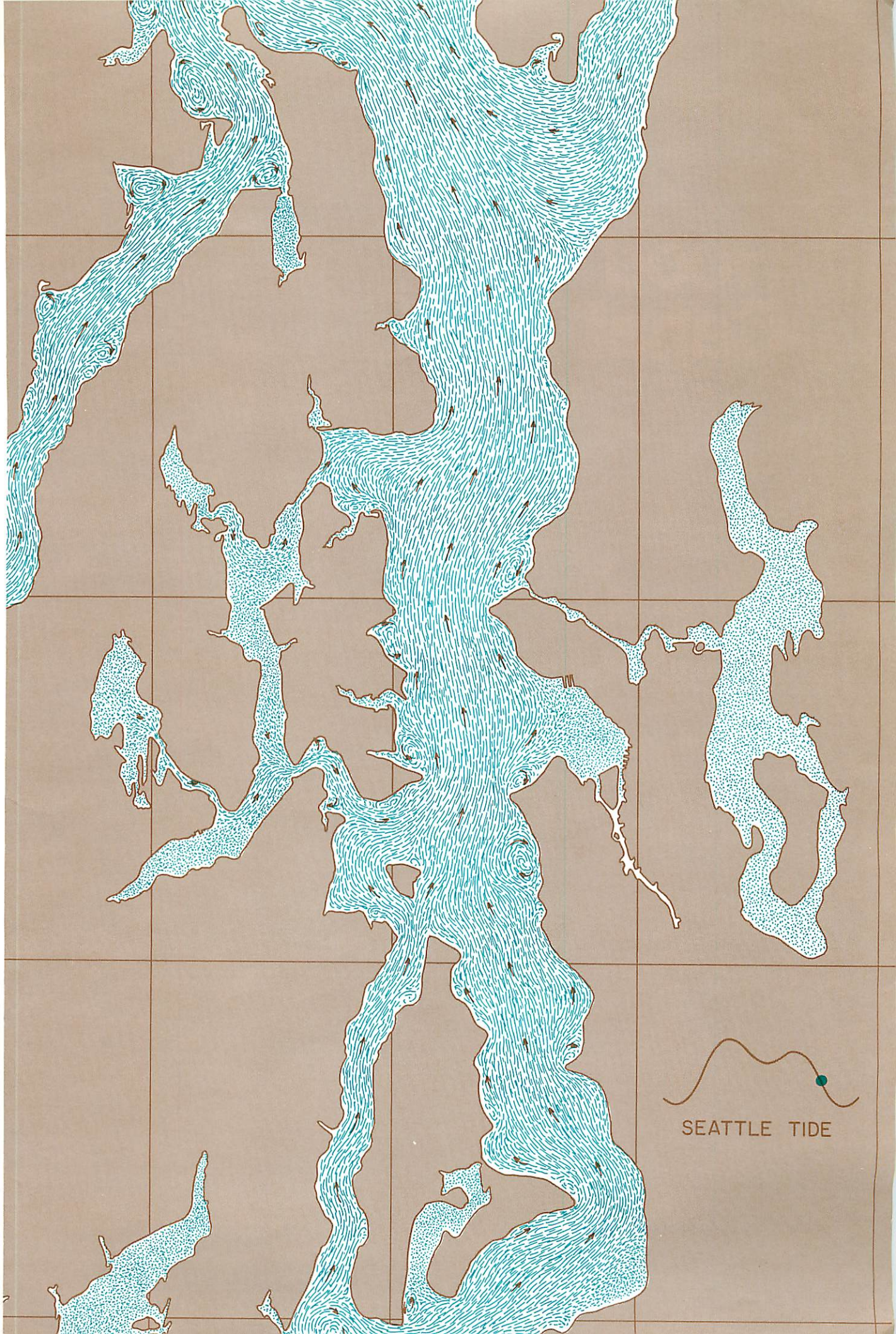
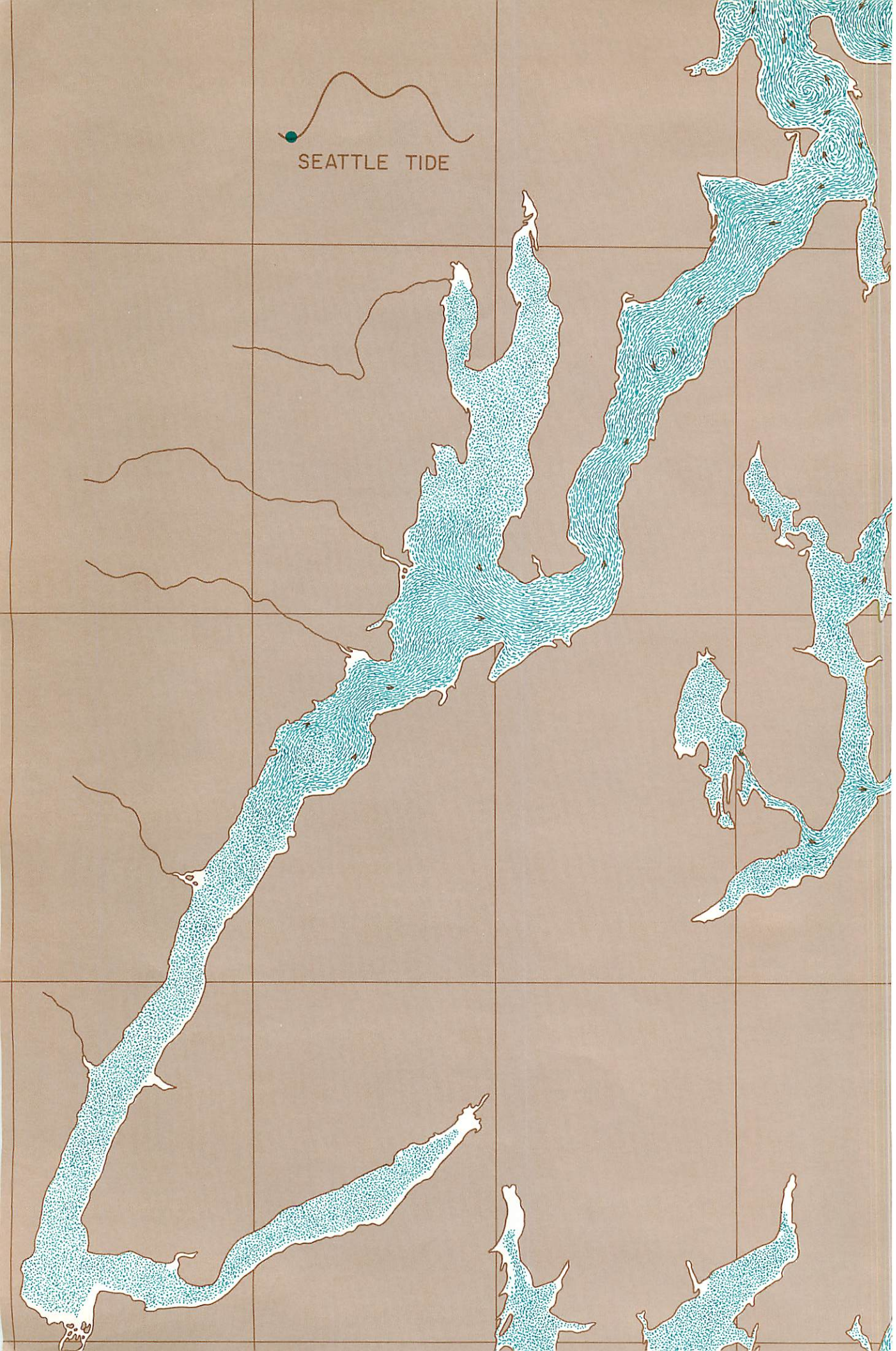

SEATTLE TIDE

Hood Canal


10'
123°
50'
PORT LUDLOW
40'
Hood Head
Squamish Harbor
Port Gamble
Quilcene River
Quilcene Bay
DABOB BAY
TOANDOS PENINSULA
HOOD CANAL
Liberty Bay
Agate Pass
BANGOR
Dosewallips River
Duckabush River
Oak Head
Quatsap Pt.
SEABECK
Hood Pt.
Dyes Inlet
PORT ORCHARD
Hamma Hamma River
Tekiu Pt.
BREMERTON
Sinclair Inlet
PORT ORCHARD
30'
Lilliwaup Creek
HOOD CANAL
Lynch Cove
Musqueti Pt.
THE GREAT BEND
UNION
47° 20'
CASE INLET
CARR INLET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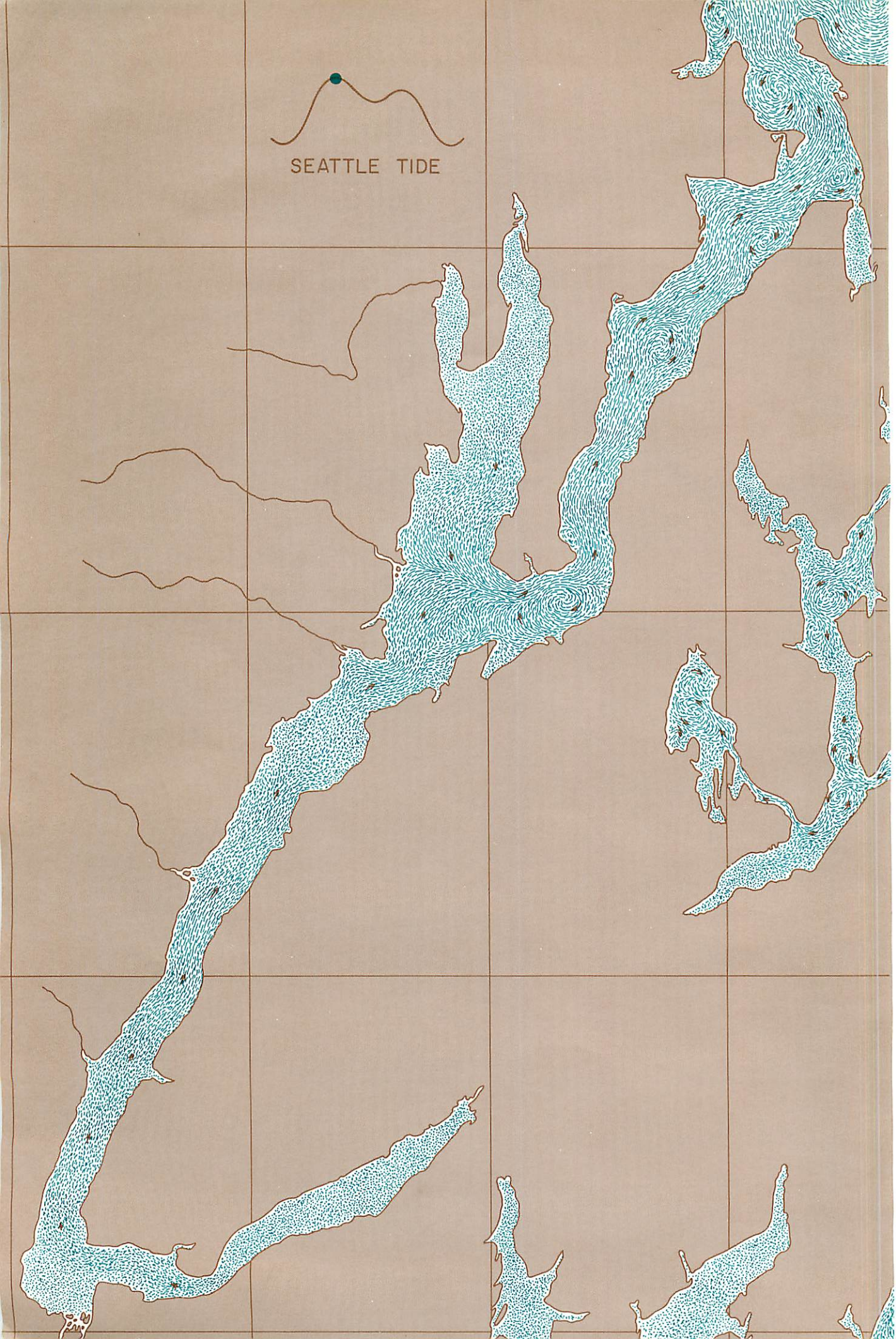
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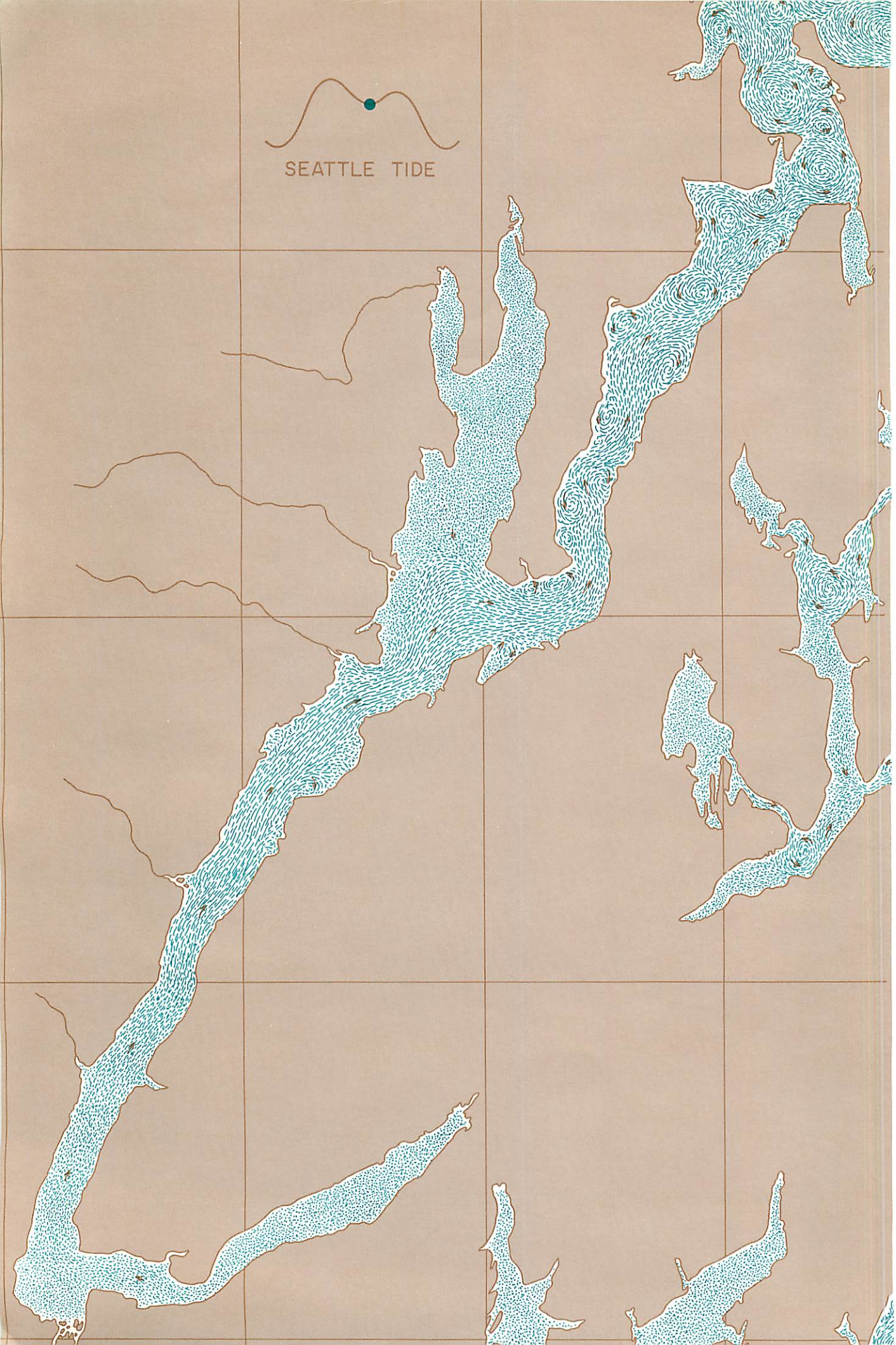
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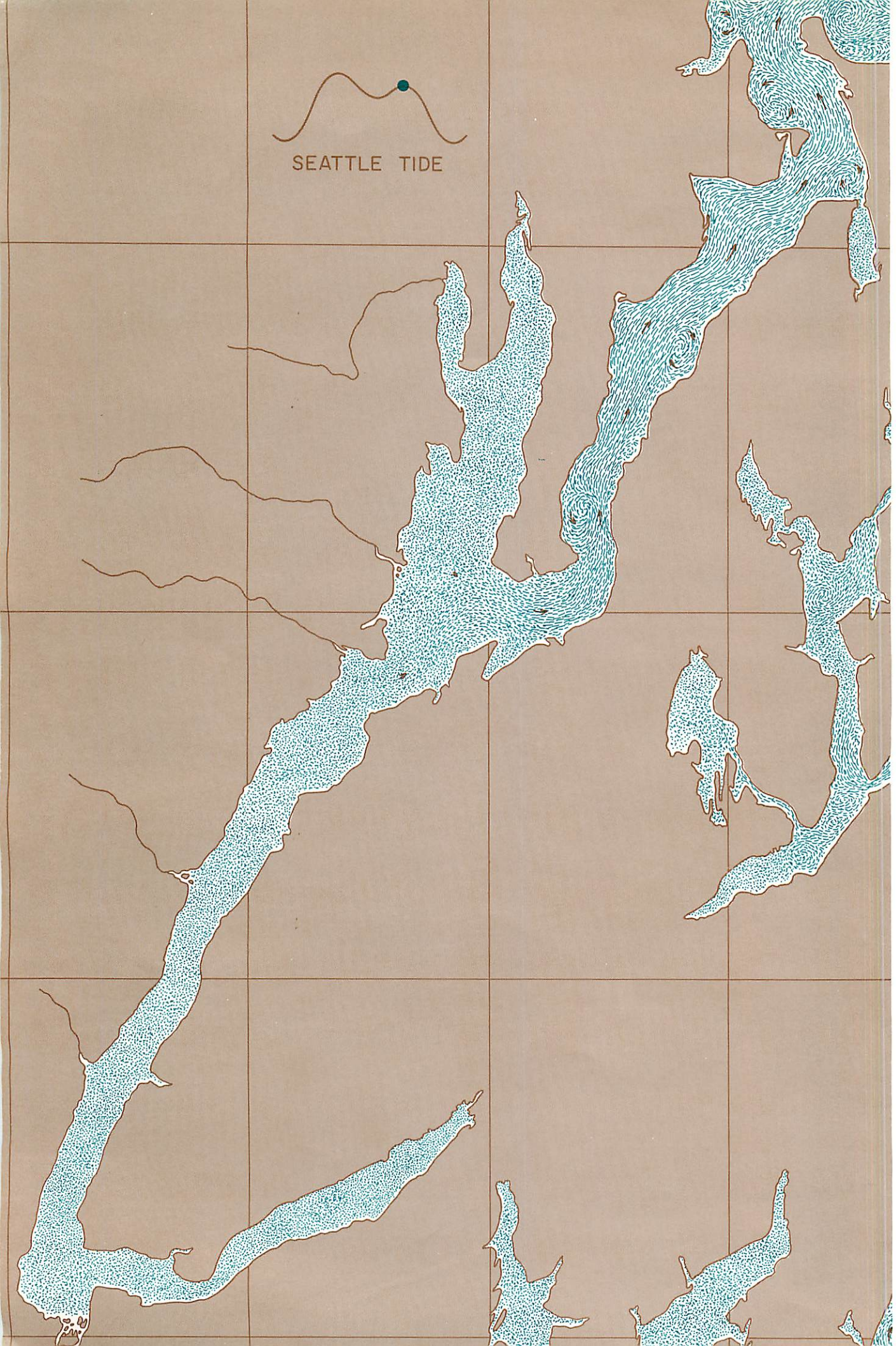
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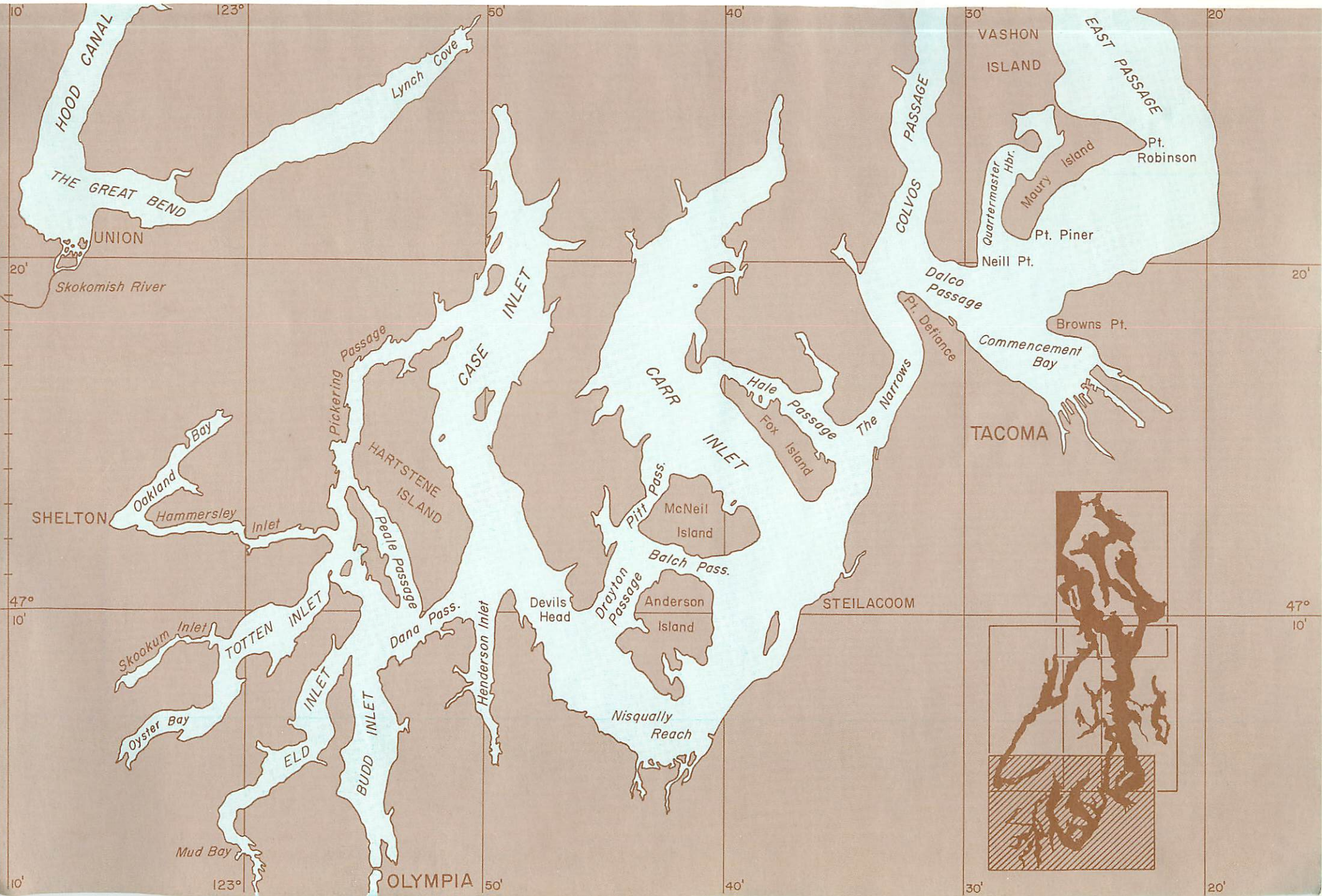
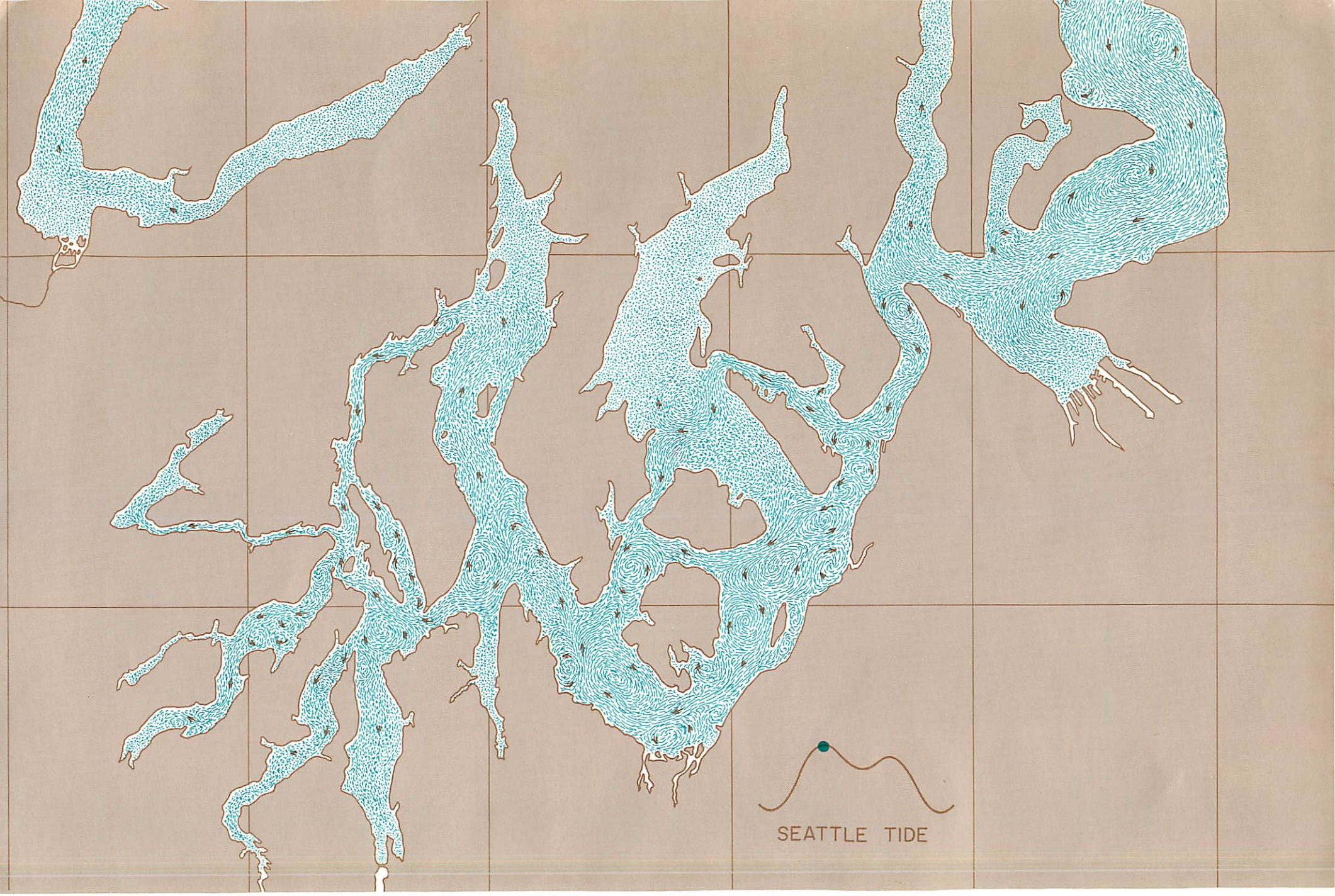
Southern Sound


HOOD CANAL
Lynch Cove
THE GREAT BEND
UNION
Skokomish River
CASE INLET
Pickering Passage
HARTSTENE ISLAND
Oakland Bay
SHELTON
Hammersley Inlet
Peale Passage
TOTTEN INLET
Skookum Inlet
Oyster Bay
ELD INLET
BUDD INLET
Mud Bay
OLYMPIA
Dana Pass.
Henderson Inlet
Devils Head
Drayton Passage
Nisqually Reach
CARR INLET
Pitt Pass.
McNeil Island
Balch Pass.
Anderson Island
Hale Passage
Fox Island
The Narrows
COLVOS PASSAGE
VASHON ISLAND
EAST PASSAGE
Quartermaster Hbr.
Maury Island
Pt. Robinson
Pt. Piner
Neill Pt.
Dalco Passage
Pt. Defiance
Browns Pt.
Commencement Bay
TACOMA
STEILACOOM
47° 10'
123°
50'
40'
30'
20'


SEATTLE TIDE


SEATTLE TIDE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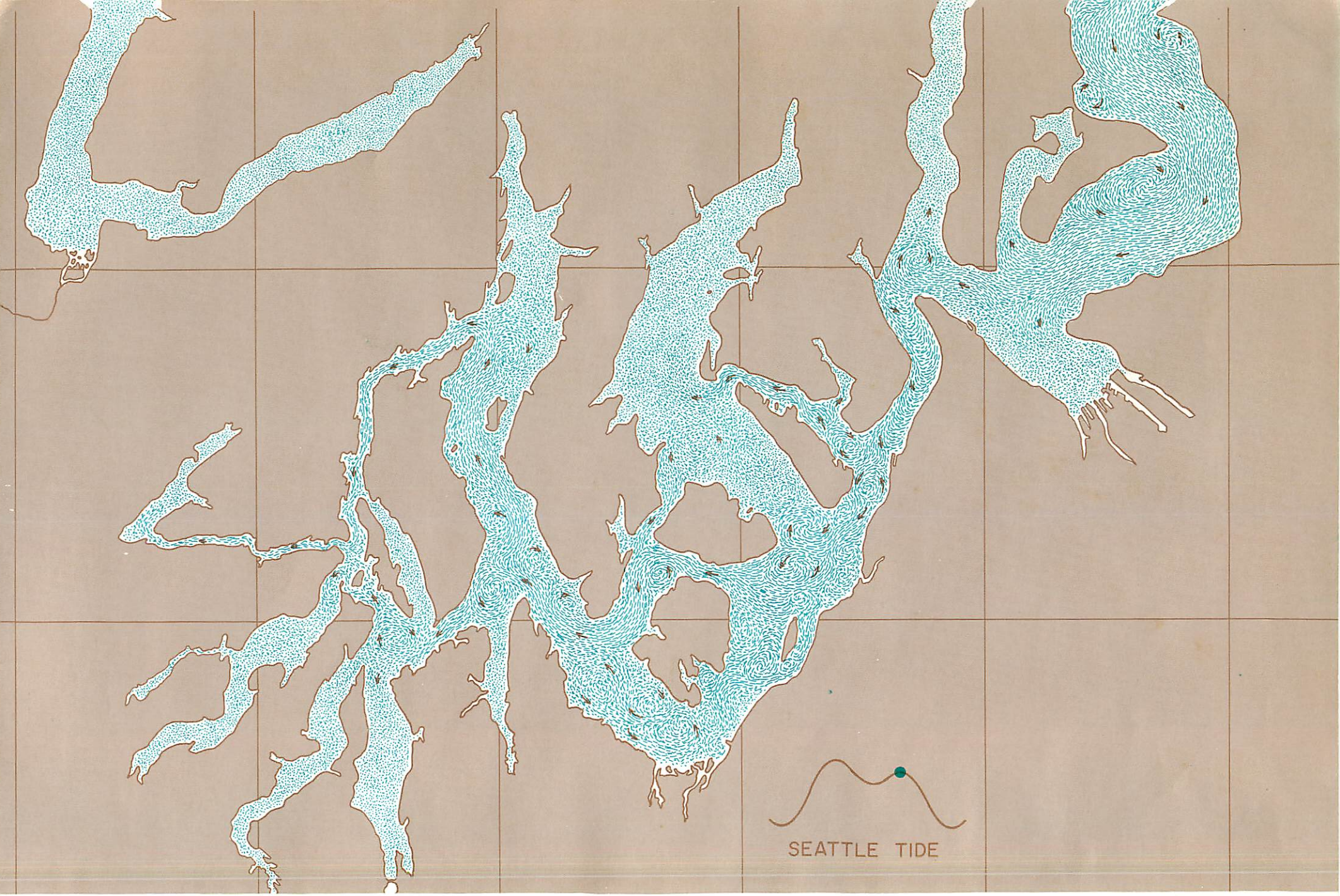
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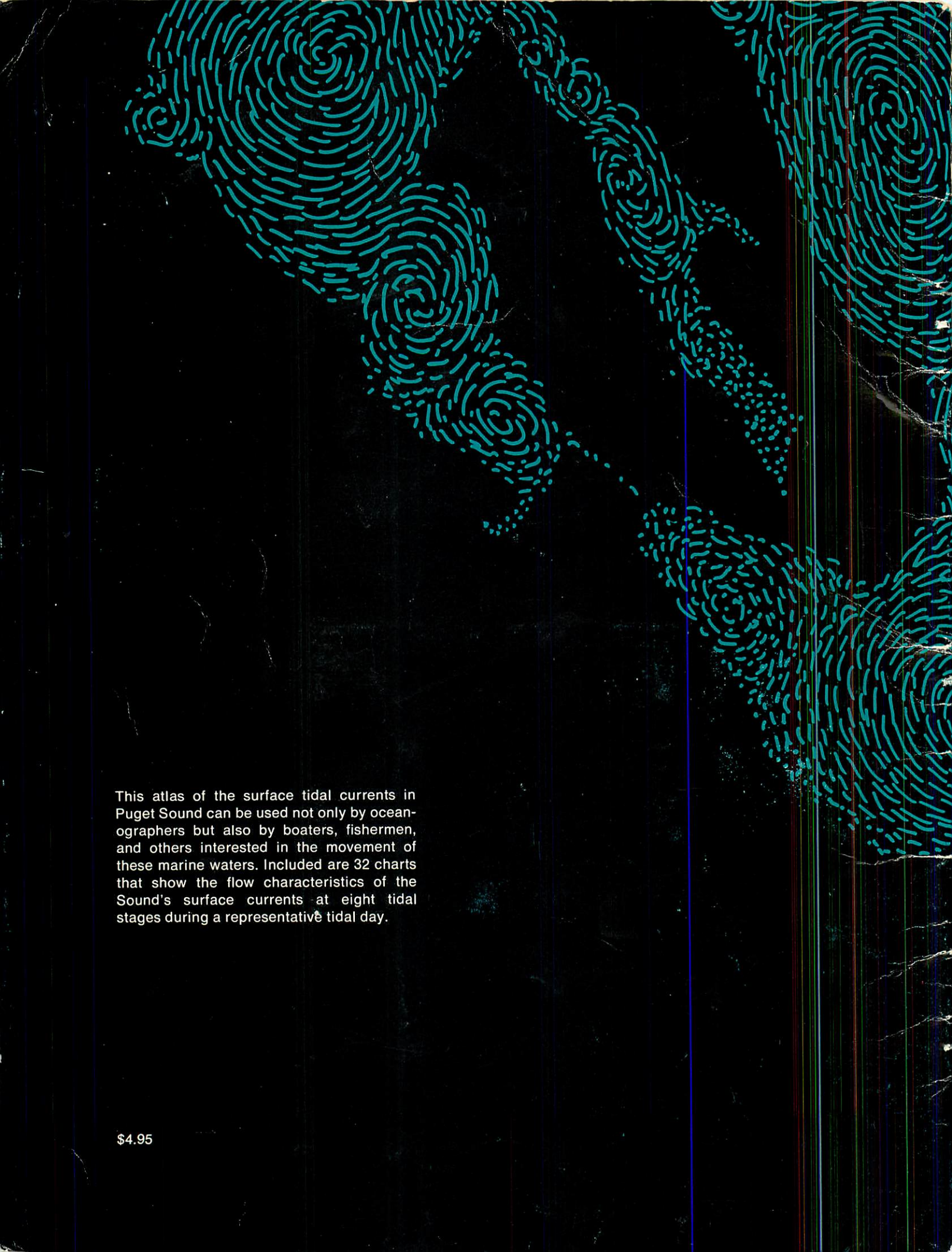

This atlas of the surface tidal currents in Puget Sound can be used not only by oceanographers but also by boaters, fishermen, and others interested in the movement of these marine waters. Included are 32 charts that show the flow characteristics of the Sound's surface currents at eight tidal stages during a representative tidal day.

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