Graphic current charts and flow patterns

TIDAL CURRENTS of PUGET SOUND

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of
PUGET SOUND

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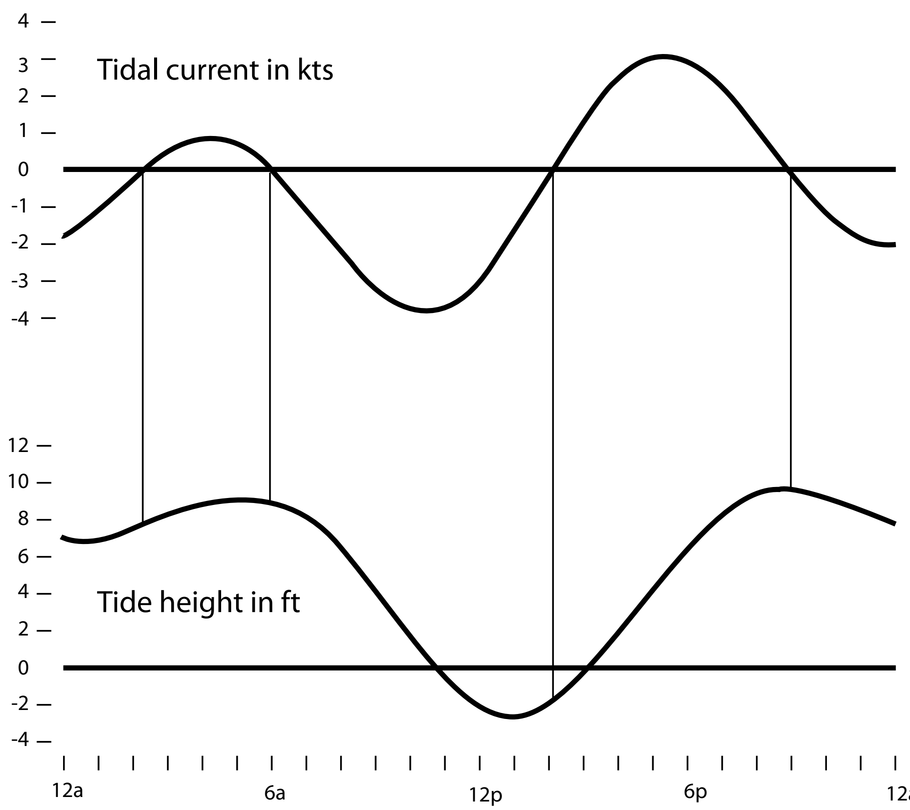

INTRODUCTION

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Tidal current flow is one of the key factors to safe and efficient navigation of all vessels in Puget Sound, from ships to kayaks. Knowing the basics of our Vessel Traffic Services (uscg.mil/d13/psvts) and the associated shipping lanes is another key factor. In some areas of the Sound, currents are very strong and can actually prohibit the progress of a low-powered vessel. In many other situations, a judicious choice of routes or sailing times can significantly save fuel and time underway. Puget Sound is a complex waterway for current flow, resulting in evolving bands and eddies of current that are an ongoing challenge to navigators.

Directions (set) as well as the times and speeds (drift) at the turning points of the tidal currents at numerous locations throughout Puget Sound and adjacent waters are printed annually for each day of the year in an official NOAA publication called *Tidal Current Tables of the Pacific Coast of North America and Asia*. NOAA no longer publishes the printed version, but instead offers it as an electronic document for download. Several private companies offer bound printed copies available at nautical book stores and chart dealers. Most of these outlets also have phone order service if one is not near you. As indicated by the title, this book covers far more than Puget Sound, so many mariners choose to go online to download printable data for their specific region and time of interest. The link is tidesandcurrents.noaa.gov.

The *Tidal Current Tables* tell the times and speeds at the minimum and maximum current flow at the various reference stations, but they leave it up to the user to compute current speeds at the intermediate times using special tables they provide. This can be a time consuming process for an extended voyage because the correction values vary from one reference station to the next. Consequently it is difficult with just these official tables to get an overview of the current flow and how it is changing with time over a larger region. This overview is needed to best plan your voyage, because an exposure to a changing modest current over a longer run can affect your arrival time at a crucial pass that has very strong current. In any event, it is rare we care about the current just at the peak and minimum values listed in the tables.

Fortunately, Puget Sound has two special publications that provide that crucial graphic overview of the current cycle, both of which are presented in full in this booklet. They are of great value to any vessel traveling in Puget Sound, and have been especially valuable to fishermen, racing sailors, tow boat operators, and kayakers who are especially sensitive to the nuances of the current flow.

Tidal Current Charts

The NOAA Tidal Current Charts are a graphical presentation of the data included in the official Tidal Current Tables. They assist the use of the Tables in several ways. First they show you on the chart where most of the reference stations are located. (There have been some changes in station locations over the years that are not reflected on these charts, but the vast majority are the same as presently in use.) These are the places where the current is known and predicted. Currents at regions away from a reference station must be interpolated from neighboring stations. Each chart then shows you the speed and direction of the current at the time represented by that chart. Each chart covers one hour of the current cycle.

Though the current charts are the most convenient for overall planning, if you wish to know the most accurate predictions for a specific station it is best to refer to the *Current Tables* for the most precise speeds and times.

There is a set of charts for the Northern Part of Puget Sound and adjacent waters, and one for the Southern Part of Puget Sound. The Northern Part charts are scaled to the daily current values at Admiralty Inlet (off of Bush Point). To use these charts on a particular day you must have the official current predictions for Admiralty Inlet on that day from one of the sources mentioned above. Likewise, the South Sound charts are scaled to the current data at the Tacoma Narrows, north end. The charts themselves include detailed instructions with examples.

Tide Prints

Tide Prints is the name of a unique tidal current publication that shows how the surface current patterns in Puget Sound evolve throughout the tidal cycle. They show explicitly where and when the large eddies develop and how these eddies migrate around the sound as the tidal cycle evolves. They do not provide specific current speed (other than approximate relative values); their main function is to show flow directions and patterns.

To use these prints on a particular day, you need to know the official tide height predictions in Seattle on that day. Tide heights are readily available in numerous printed publications as well as online from tidesandcurrents.noaa.gov.

Tide Prints — Surface Tidal Currents in Puget Sound is the fine work of Noel McGary and John Lincoln at the University of Washington. The research was supported and first printed by the Washington Sea Grant program in 1977. We join all Puget Sound mariners in thanking the Washington Sea Grant program for giving us permission to reprint this valuable guide to current flow.

The Washington Sea Grant program has been supporting Washington mariners and other concerned users of Washington waterways since 1968 with a full range of services in research, education, and communications. Their recent and planned activities and publications can be seen at wsg.washington.edu.

Comments on Usage

There are important differences in the use of these two resources. Both give a specific page for specific hours of the tidal cycle, but the Current Charts are referenced to *current data* for each hour of the cycle, whereas the Tide Prints are referenced to *tide data* for every 3 hours of the cycle. Also, the Current Charts use different reference stations to index the northern and southern waters, whereas the Tide Prints use Seattle tides to index both northern and southern parts.

Detailed instructions to each resource (including their limitations) are included within them, but here is an example of using them together. Consider use on April 27, 2009 in waters of the Northern Sound. The first step is to look up the peak values of the currents at Admiralty Inlet (Table 1) and also the tide heights at Seattle (Table 2) on this date.

Notice first that the times of peak flow at Admiralty Inlet do not coincide with the mid-tide times at the Seattle station. This highlights the fact that the descriptions used in the Tide Prints refer to the stage of the current, not to the specific times of the peak currents. The example in Table 1 shows that the Current Charts do provide a chart about once each hour, but there could be a bit longer gap near the slack waters, in some cases. If the time you care about is not in the list you make for the current charts as shown in Table 1, then it is a transition time, and you should compare the chart just before with the chart just after the time you care about.

Each page of the Tide Prints (Table 2) can be thought of as applying to the hour and a half before and after the times of the specific pages. Thus you would use the large-ebb Tide Print on page 68 valid at 0920 to represent the details of the current flow on Current Charts of pages 21, 22, and 23 corresponding to times 0822, 0922, and 1022. In this application, the Tide Prints are filling in details on the Current Charts, which is the most common way to use these resources.

On the other hand, if you are looking at a particular flow pattern on one of the Tide Print pages, such as page 62 covering the large-flood tide print valid at about 1650, then you could turn to pages 16 and 17 of the Current charts to see the actual speeds of the currents that are depicted on the Tide Prints page. In this sense you are using the Current Charts to calibrate the Tide Prints.

Both applications are illustrated in Figure 1.

Remember the current speeds printed on the Current Charts are not the average values, but more like an average of the strongest currents of each month. Relative to average currents, the charted floods are slightly enhanced over the ebbs. The average of all floods is about 0.6 times the charted values, and the average of all ebbs is about 0.8 times the charted values. In any event, it is best to use the correction table provided in Current Chart instructions to figure the proper speeds for specific days.

Table 1. Admiralty Inlet Currents, April 27, 2009[1]

Time PDT	*Current Peaks*	*Northern Part Currents Chart Page*
0219	Slack	
(0211)	F-2	15
(0311)	F-1	16
0411	0.8 kts Flood	17
(0511)	F+1	18
(0611)	F+2	19
(0711)	F+3	20
0559	Slack	
(0822)	E-2	21
(0922)	E-1	22
1022	3.8 kts Ebb	23
(1122)	E+1	24
(1222)	E+2	25
(1322)	E+3	26
1406	Slack	
(1519)	F-2	15
1619	F-1	16
1719	3.1 kts Flood	17
(1819)	F+1	18
(1919)	F+2	19
(2019)	F+3	20
2052	Slack	
(2145)	E-2	21
(2245)	E-1	22
2345	2.0 kts Ebb	23

Notes.
1. The shaded areas are found in the Current Tables*. The other values are figured from those in 1-hr steps. At times in between those listed, think of the flow pattern as evolving from the earlier to the later of the two.*

Table 2. Seattle Tides, April 27, 2009[2]		
Time PDT	*Tide Heights*	*Main Basin Tide Prints Page*
0100	6.8 ft Low	65
(0330)	"Small flood"	66
0601	11.1 ft High	67
(0920)	"Large ebb"	68
1310	-3.0 ft Low	61
(1650)	"Large flood"	62
2031	11.7 ft High	63

Notes.
2. The shaded values are found in the Tide Tables. *The other values are interpolated from them as the mid-tide times. The flood and ebb labels describe the stage of the current flow and not precise peak times. Each Tide Print can be thought of as valid for 1 hr and 30 min before and after the times listed. At times in between those listed, think of the flow pattern as evolving from the earlier to the later of the two.*

Time Saving Tip!
Cover a bottom corner of each chart page with a piece of clear tape that you can write on and erase, then you can label the pages with the right times before you depart.

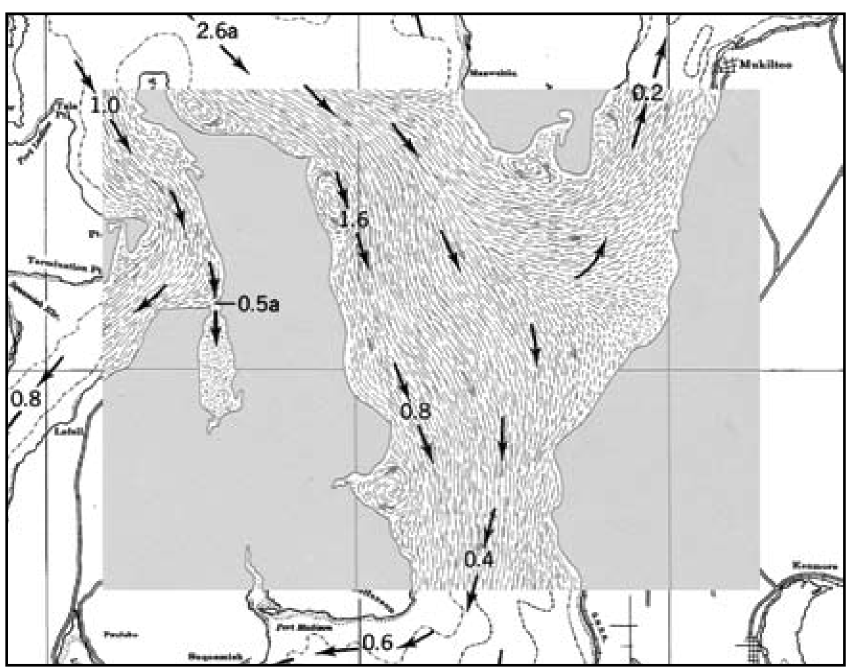
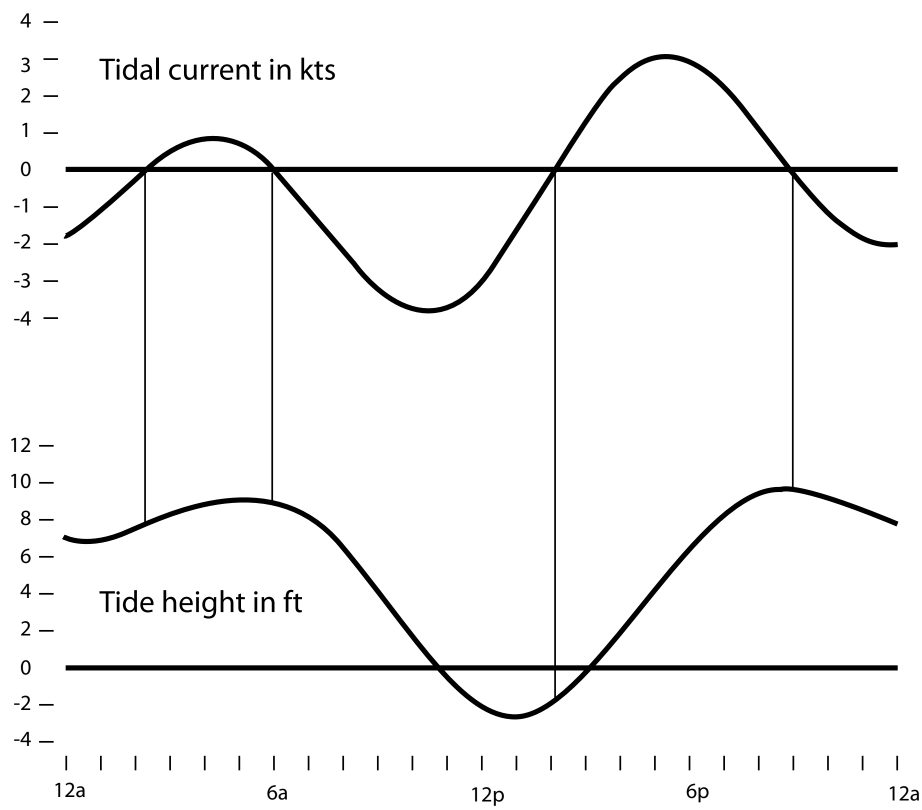


Figure 1. *An overlay of a Tide Print for a large flood onto the corresponding Current Chart to show how these two resources interplay. Eddies are apparent in the Tide Prints as well as more detail on where and how the current flow separates.*

2.
TIDAL CURRENT CHARTS



TIDAL CURRENT CHARTS, PUGET SOUND, NORTHERN PART

These current charts show the direction and speed of the tidal current for each hour of the current at Admiralty Inlet (off Bush Point). They present a comprehensive view of the tidal current movement in the waterways which comprise the northern part of the sound and also supply a means of readily determining for any time the direction and speed of the current at numerous locations throughout those waterways.

The charts, which may be used for any year, are referred to the times of "Maximum flood" and "Maximum ebb" at Admiralty Inlet (off Bush Point), daily predictions for which are included in the Pacific Coast Current Tables published annually by the National Ocean Survey.

The directions of the current are indicated by arrows and the speeds by figures. The speeds, which are expressed in knots, are tropic speeds, that is, the greater flood and greater ebb speeds at the time of the moon's maximum declination. Factors for obtaining the speeds for any time are given below.

Nontidal currents.—These charts depict the flow of the tidal currents under normal weather conditions. Winds and freshets. however, bring about nontidal currents which may modify considerably the speeds and directions shown on the charts.

Use of charts.—There are 12 charts, 6 being referred to "Maximum flood" and 6 to "Maximum ebb." The chart to be used for a given time is determined by obtaining the difference between that time and the time of the nearest "Maximum flood" or "Maximum ebb" for Admiralty Inlet (off Bush Point) as given in the Pacific Coast Current Tables. The chart with the legend that agrees most nearly with this difference is the one to be used.

Having selected the proper chart, the direction and the tropic speed of the current throughout the area are shown by the arrows and figures on that chart.

The tidal current varies from day to day principally in accordance with the phase, distance and declination of the moon; and to obtain the speed for a particular day and hour the speed given on the chart should be modified as follows: Note whether the speed on the chart is accompanied by solid arrows or by dashed arrows. If the arrows are solid, obtain from the current tables the predicted speed of the "Maximum flood" nearest to the time for which the information is sought. If the arrows are dashed, obtain the predicted speed of the nearest "Maximum ebb." With the predicted speed enter the following table and obtain the corresponding correction factor. The speed of the current for the particular day and hour is then determined by multiplying the speed indicated on the chart by this factor.

In taking a flood factor from the table, note that the special factor in the third column of the table is to be used only when the speed on the chart is followed by the letter "a."

Factors for correcting speeds

Flood factors			Ebb factors	
For use with speeds accompanied by solid arrows			For use with speeds accompanied by dashed arrows	
When predicted "Maximum flood" speed (knots) off Bush Point is—	Multiply speed on chart by—		When predicted "Maximum ebb" speed (knots) off Bush Point is—	Multiply speed on chart by—
	Usual factor	*Special factor "a"*		*Factor*
(*)	0. 0	0. 2	0. 3–0. 4	0. 1
0. 3	0. 1	0. 3	0. 5–0. 8	0. 2
0. 4–0. 6	0. 2	0. 4	0. 9–1. 1	0. 3
0. 7–0. 8	0. 3	0. 5	1. 2–1. 4	0. 4
0. 9–1. 1	0. 4	0. 6	1. 5–1. 8	0. 5
1. 2–1. 3	0. 5	0. 6		
			1. 9–2. 1	0. 6
1. 4–1. 6	0. 6	0. 6	2. 2–2. 4	0. 7
1. 7–1. 8	0. 7	0. 7	2. 5–2. 8	0. 8
1. 9–2. 1	0. 8	0. 8	2. 9–3. 1	0. 9
2. 2–2. 3	0. 9	0. 9	3. 2–3. 4	1. 0
2. 4–2. 6	1. 0	1. 0		
			3. 5–3. 7	1. 1
2. 7–2. 8	1. 1	1. 1	3. 8–4. 1	1. 2
2. 9–3. 1	1. 2	1. 2	4. 2–4. 4	1. 3
3. 2–3. 3	1. 3	1. 3	4. 5–4. 7	1. 4
3. 4–3. 6	1. 4	1. 4		
3. 7–3. 8	1. 5	1. 5		

The asterisk (*) in the first column of the table corresponds to the asterisk which appears in the "Maximum flood" speed column of the predictions for Admiralty Inlet (off Bush Point). See instructions on inside of back cover.

The complexity of the current in Puget Sound, particularly the change in the character of the diurnal inequality from place to place, renders it impossible to devise a set of current charts which through a simple method of procedure always gives precise results. Some differences between current-chart values and actual currents encountered are, therefore, to be expected.

The large diurnal inequality usually exhibited by the Puget Sound current makes it very undesirable, except in the case of Port Townsend Canal, to use the speeds given on these charts without correcting them by means of the table of factors.

Off Bush Point, a "Maximum ebb" sometimes precedes a "Maximum flood" by a time interval as small as 5 hours. Consequently a time which is 3 hours after a predicted "Maximum ebb" may be very nearly the same as a time which is 2 hours before a predicted "Maximum flood." If current information is desired for such a time, it is usually advisable to obtain it from the chart designated "THREE HOURS AFTER MAXIMUM EBB OFF BUSH POINT" (E+3).

The current in Port Townsend Canal differs from the current elsewhere in Puget Sound in that it is hydraulic, depending upon tidal differences in water level at the two ends of the canal. It exhibits much less diurnal inequality and has less variation in velocity from day to day than the usual Puget Sound current. The speed for Port Townsend Canal given on each chart therefore is an average (not tropic) speed which requires no correction factor. A notation to that effect appears on each chart.

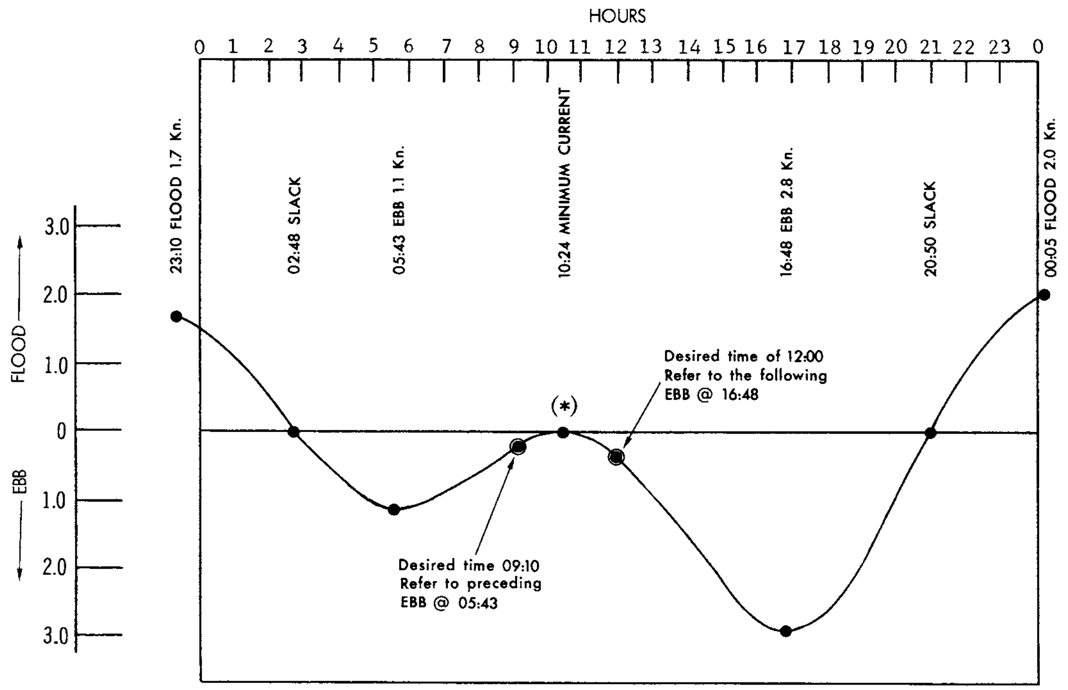
Example.—Suppose the direction and speed of the current in midchannel off Point Wilson are desired for 5 a.m. on a day when the predictions for Admiralty Inlet (off Bush Point) are as follows:

SLACK WATER TIME	MAXIMUM CURRENT TIME	VEL.
H.M.	H.M.	KNOTS
0101	0354	2.3 F
0657	1024	2.8 E
1405	1610	1.2 F
1824	2214	2.8 E

The desired time, 5 a.m., is 1^h 06^m after the "Maximum flood" at 3^h 54^m, this being the nearest predicted maximum strength of current. The data desired will therefore be found on the chart designated "ONE HOUR AFTER MAXIMUM FLOOD OFF BUSH POINT" (F+1). This chart shows that the current in midchannel off Point Wilson is setting east-southeastward. The number (3.3) at that location is the tropic speed of the current in knots. To determine the speed of the current for the particular day and hour, this tropic speed must be modified by a factor given in the table, "Factors for correcting speeds." Since the arrows accompanying this speed are solid arrows the proper factor will be found under the heading "Flood factors," and since the letter "a" follows the speed on the chart the factor is in the "Special factor" column. The predicted maximum flood nearest to 5^h 00^m occurs at 3^h 54^m and its speed is 2.3 knots. For a maximum flood speed of 2.3 knots the table gives a "Special factor" of 0.9 to be applied to the speed on the chart. The approximate speed of the current in midchannel off Point Wilson is then $3.3 \times 0.9 = 3.0$ knots.

As the time 5^h 00^m is more than one hour after the nearest predicted maximum current, which occurs at 3^h 54^m, a more precise value may be obtained by interpolating between values obtained from the two charts designated "ONE HOUR AFTER MAXIMUM FLOOD OFF BUSH POINT" (F+1) and "TWO HOURS AFTER MAXIMUM FLOOD OFF BUSH POINT" (F+2).

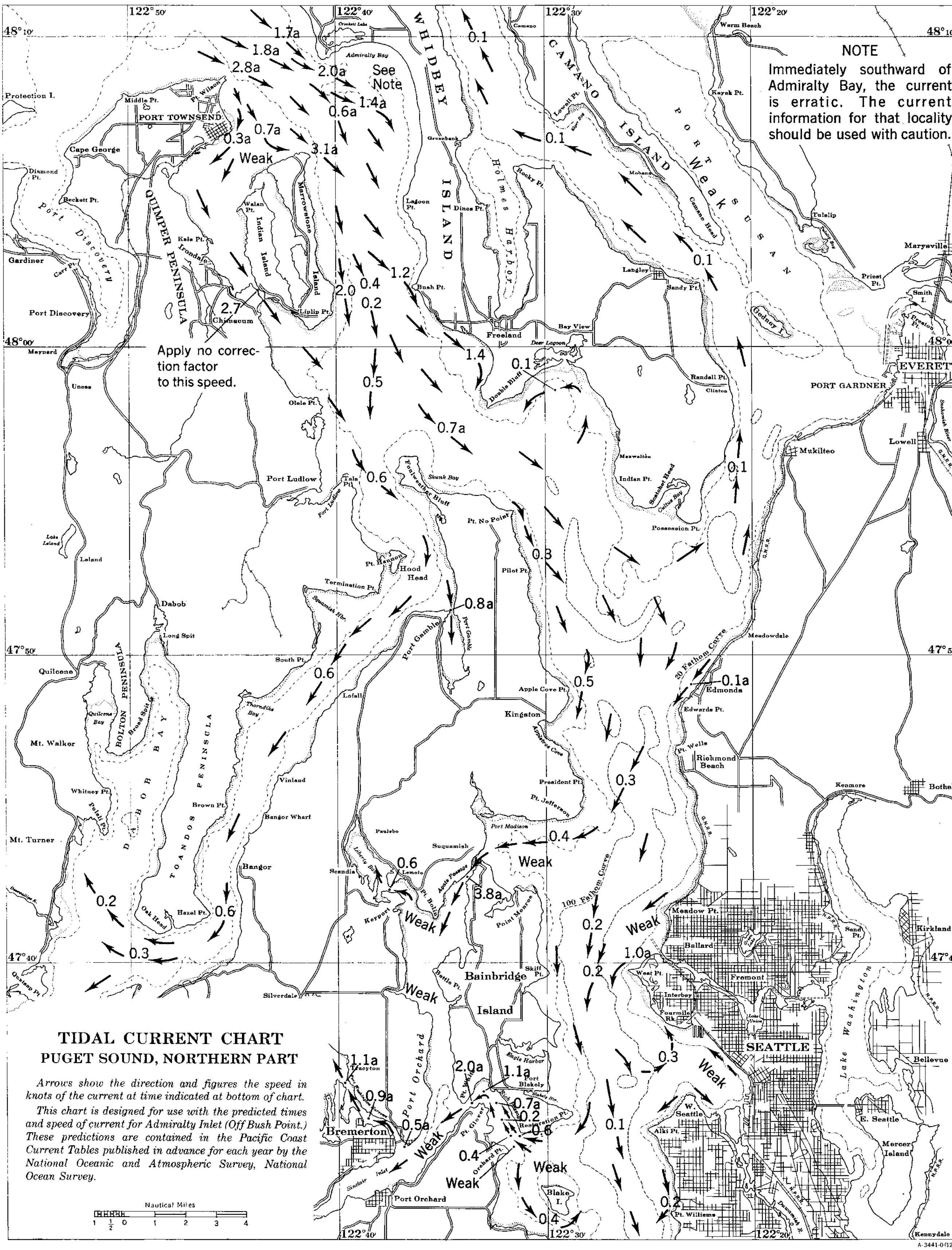
The corrected speed as obtained above from the chart for one hour after maximum flood is 3.0 knots setting east-southeastward, while a corrected speed similarly obtained from the chart for two hours after maximum flood is 1.8 knots setting approximately in the same direction. Interpolating between these values, the current in midchannel off Point Wilson at 5 a.m. is found to set east-southeastward with a velocity of 2.9 knots.



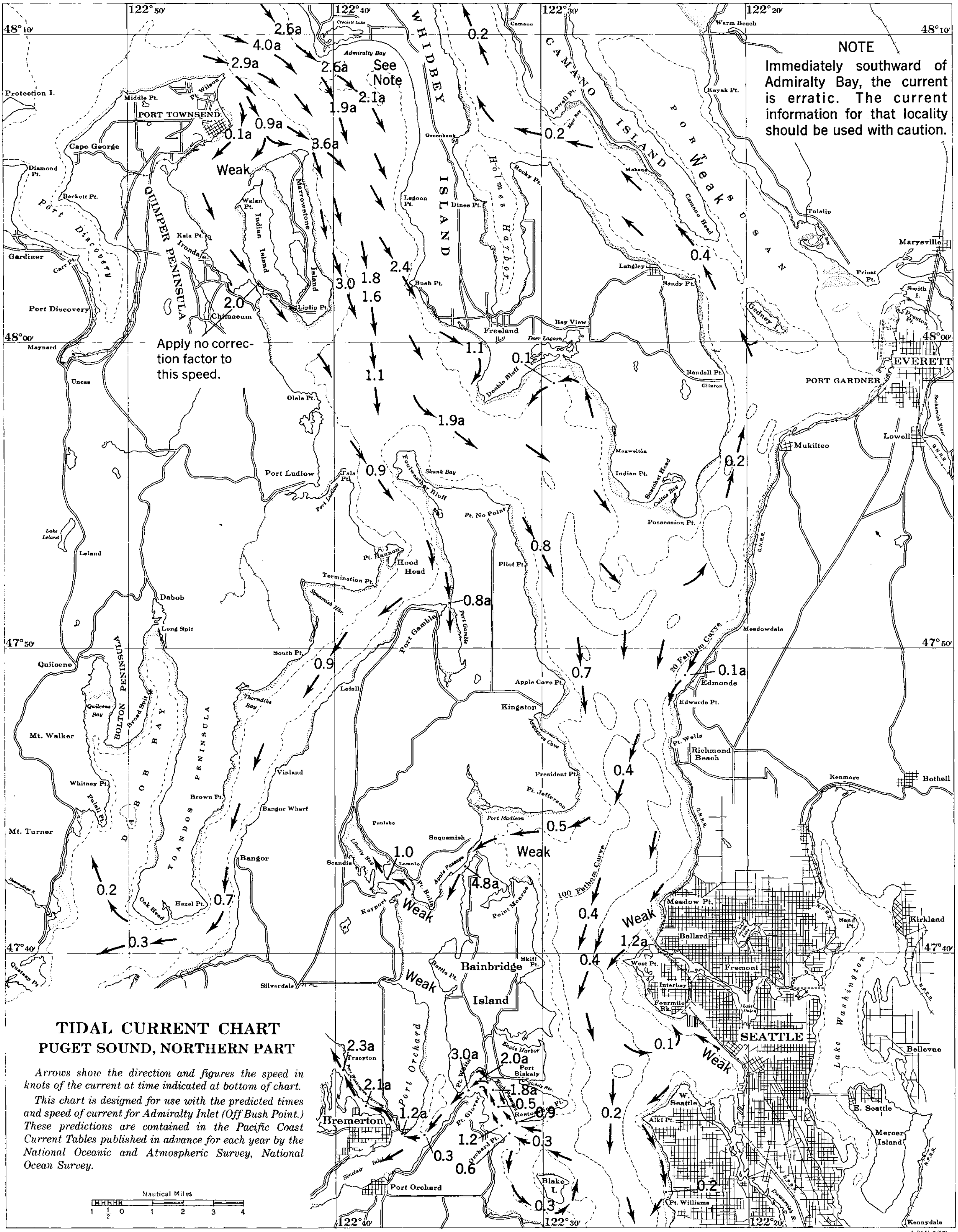
The asterisk (*) indicates the current to be weak and variable and possibly ebbing. In these cases use the Tidal Current Charts that are referred to maximum ebb. The chart to be used is determined in the following manner. When the desired time falls before the perdicted minimum current (*), then refer to the preceding maximum ebb. When the desired time falls after the predicted minimum current (*), refer to the following maximum ebb.

ADMIRALTY INLET (OFF BUSH PT.), WASH.

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	VEL. KNOTS
9	0142	0433	0.9E
W		*0912	(*)
		1547	2.6E
	2004	2310	1.7F
10	0248	0543	1.1E
TH		*1024	(*)
		1648	2.8E
	2050		
11		0005	2.0F
F	0337	0636	1.4E
		*1129	(*)
		1739	3.0E
	2134		



TWO HOURS BEFORE MAXIMUM FLOOD OFF BUSH POINT. (F–2)



ONE HOUR BEFORE MAXIMUM FLOOD OFF BUSH POINT. (F−1)

TIDAL CURRENT CHARTS, PUGET SOUND, SOUTHERN PART

These current charts show the hourly directions and speeds of the tidal current in Puget Sound)southern part). They present a comprehensive view of the tidal current in the entire area and also provide a means for readily determining for any time the direction and speed of the current at various locations throughout many of the inlets and passages of the sound. The directions of the current are indicated by arrows and speeds in knots by figures. Observations of the current from the surface to a maximum depth of 20 feet were used in compiling these charts.

The charts may be used for any year and are referred to the times of "Maximum Flood" and "Maximum Ebb" at The Narrows (north end), Puget Sound. Daily predictions for this station are included in the publication "Tidal Current Tables, Pacific Coast of North America and Asia", published annually by the National Ocean Survey.

Non-tidal currents—These charts picture the flow of the tidal currents under normal weather conditions. Strong winds and freshets, however, bring about nontidal currents which may modify considerably by speeds and directions shown on the charts.

Use of charts—There are twelve charts; six are referred to "Maximum Flood" and six to "Maximum Ebb". The chart to be used for a desired time is determined by the difference between that time and the predicted time of the nearest "Maximum Flood" or "Maximum Ebb" for the Narrows (north end), as published in "Tidal Current Tables, Pacific Coast of North America and Asia". The chart with the legend that agrees most nearly with that difference is the one to be used.

Factors for correcting velocities:—The speeds shown on the charts represent the current at the time of tropic tides. They are the greater flood and greater ebb speeds at the time of the moon's maximum declination. However, the tidal current varies from day to day, principally in accordance with the phase, distance and declination of the moon. Therefore to obtain speeds for the particular day and hour, the plotted speeds on the chart must be modified accordingly. This is done by selecting from the tidal current tables the predicted speed of the "Maximum Flood" or "Maximum Ebb" to which the chart is referred. With this predicted speed enter the appropriate column of the following table and obtain the corresponding correction factor. The speeds on the tidal current chart are then multiplied by this factor to obtain the required speeds.

For the west end of Hale Passage and the north end of Peale Passage, the given average speeds of the current should not be modified by the use of the factors from the table.

The complexity of the current in Puget Sound, particularly the difference in speed between the two flood currents or the two ebb currents of each day, renders it impossible to construct a set of current charts which, through a simple procedure, always give accurate predictions. Some differences between the current as derived from these charts and actually encountered are, therefore, to be expected.

Factors for Correcting Speeds

When the predicted speed in The Narrows (north end) is—	Multiply speed on chart by—
Knots:	*Factor*
0.2—0.5	0.1
0.6—0.9	0.2
1.0—1.3	0.3
1.4—1.7	0.4
1.8—2.1	0.5
2.2—2.5	0.6
2.6—2.9	0.7
3.0—3.3	0.8
3.4—3.7	0.9
3.8—4.1	1.0
4.2—4.5	1.1
4.6—4.9	1.2
5.0—5.3	1.3
5.4—5.7	1.4
5.8—6.1	1.5

CAUTION NOTE: In The Narrows a "Maximum Ebb" often precedes a "Maximum Flood" by a time interval much shorter than the average interval of about 6 hours. When this interval becomes as short as 4 or 5 hours, two different charts may apply to the same times, and a different result for the current at these times will be obtained from each chart. (See instructions on inside back cover).

Example.—Suppose the direction and speed of the current in midchannel east of the south end of Fox Island are desired for 1:00 P.M. (1300 hrs.) on a day when the predictions for The Narrows (north end) as given in the "Tidal Current Tables, Pacific Coast of North America and Asia" are as follows:

SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
01 18	04 12	4.4F
07 33	10 38	3.3E
13 52	16 31	3.5F
19 32	22 46	3.6E

The desired time 1300 hrs., is $2^h\ 22^m$ after the nearest predicted maximum ebb at $10^h\ 38^m$. Therefore the chart to be used is the one designated "TWO HOURS AFTER MAXIMUM EBB AT THE NARROWS" (E+2). This chart indicates that the current in midchannel east of the south end of Fox Island is setting north-northeastward (ebbing) with a tropic speed of 1.6 knots. To determine the speed of the current for the particular day and hour, this tropic speed must be modified by a factor given in the table "Factors for correcting speeds". From the Tidal Current Tables the speed of the current at 1038 (time of maximum current used as reference) is 3.3 knots. For a predicted maximum speed of 3.3 knots, the table gives a factor of 0.8 to be applied to the speed on the chart. The approximate speed of the current in midchannel east of the south end of Fox Island is therefore $1.6 \times 0.8 =$ 1.3 knots.

As the time $13^h\ 00^m$ is somewhat more than two hours after the nearest maximum current, which occurs at $10^h\ 38^m$, a more precise prediction may be obtained by interpolating between values obtained from the two charts designated "TWO HOURS AFTER MAXIMUM EBB AT THE NARROWS" (E+2) and "THREE HOURS AFTER MAXIMUM EBB AT THE NARROWS" (E+3).

The corrected speed as obtained above from the chart for two hours after maximum ebb is 1.3 knots setting north-north-eastward, while a corrected speed similarly obtained from the chart for three hours after maximum ebb is 0.6 knot setting approximately in the same direction. Interpolating between these values, the current in midchannel east of the south end of Fox Island at 1 p.m. is found to be setting north-northeast-ward with a speed of 1.0 knot.

All persons using these charts are invited to send information or suggestions for increasing their usefulness to the Director, National Ocean Survey, NOAA, U.S. Department of Commerce, Rockville, Maryland 20852.

EFFECT OF THE MOON'S DECLINATION ON THE USE OF TIDAL CURRENT CHARTS

The Puget Sound, Southern Part Tidal Current Charts are calculated using the average flood duration is 6^h19^m and the yearly average ebb duration is 6^h06^m as tabulated in Table 1. The speeds were calculated using the average tropic speeds.

These charts are calculated for conditions when the tidal cycles are divided into six hourly intervals as shown in Figure 1. Each hourly chart is referred to the time of maximum current.

The duration of flood and ebb varies throughout the month in accordance with the moon's phases (see Figure 2). Equatorial currents occur semimonthly as a result of the moon's being over the equator. At these times the tendency of the moon to produce a diurnal inequality in the current is at a minimum. There are no problems during these periods when the floods and ebbs have durations that allow the selection of the normal six hourly charts. At tropic tides when the moon is in its maximum north or south declination the current exhibits a maximum diurnal inequality. At these times the lesser flood and ebb durations do not permit the selection of the proper chart.

Caution must be taken to insure that the chart selected will be referred to the predicted maximum current.

EXAMPLE: The speed and direction of the current are required east of Munson Pt. in Hammersley Inlet for 13^h20^m on a day when the predictions for The Narrows (North End) Puget Sound as given in the "Tidal Current Tables, Pacific Coast of North America and Asia" are as follows:

Slack Water Time H M	Maximum Time H M	Current Velocity Knots
0226	0444	1.1E
0744	1020	1.9F
1240	1629	3.5E
2024	2328	3.8F

(See figure 3)

INSTRUCTIONS: Even though the desired time of 13^h20^m is closer to the maximum flood (10^h20^m) than the maximum ebb (1629), we note that the current at The Narrows (North End) is ebbing (Figure 3). The chart to use is E−2. More precise results may be obtained by interpolating between the two charts designated E−2 and F−2.

(E−2) 0.6 x f0.9 = 0.54 knots flooding @ 14^h20^m
(F+2) 1.9 x F0.5 = 0.95 knots flooding @ 12^h20^m

The approximate speed of the current east of Munson Pt. at 13^h20^m is 0.8 knots, flooding.

Note that the short duration of the two lesser flood and ebb phases did not permit the division of six hourly intervals as shown in Figure 3. At these times of short duration the tidal current charts should not be used.

TABLE 1
GREENWICH Intervals

Slack	Flood	Flood Duration	Slack	Ebb	Ebb Duration
H M	H M	H M	H M	H M	H M
07:32	10:17	06:19	01:26	04:14	06:06

Average Tropic Speed (Knots)

Flood	Ebb
4.1	3.8

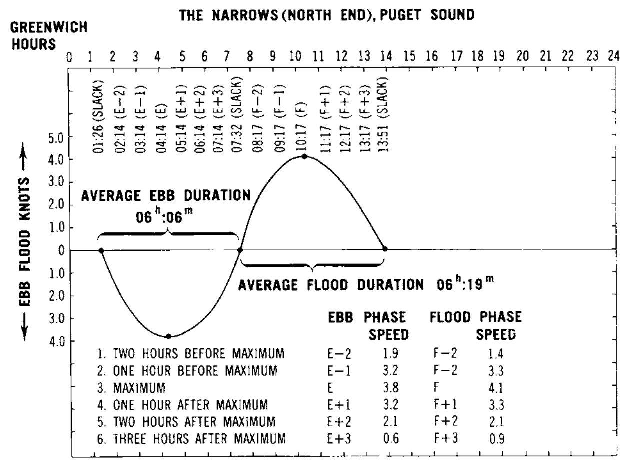


FIGURE 1

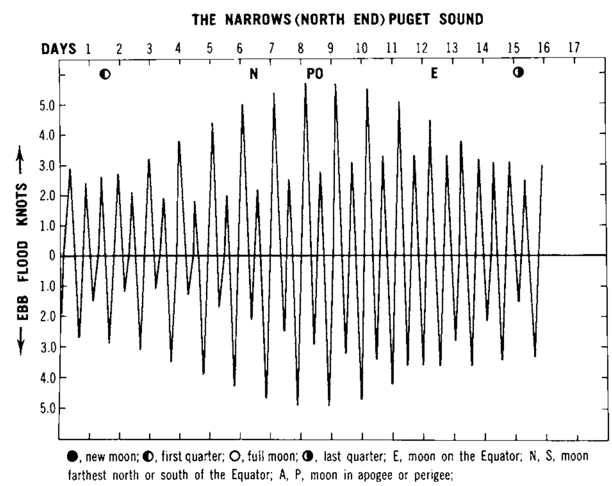


FIGURE 2

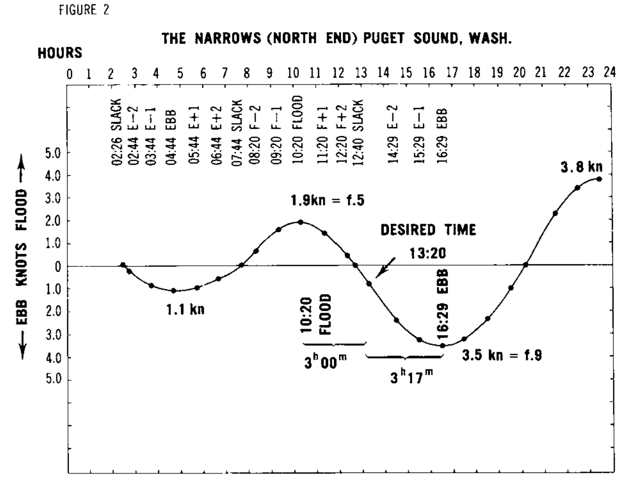
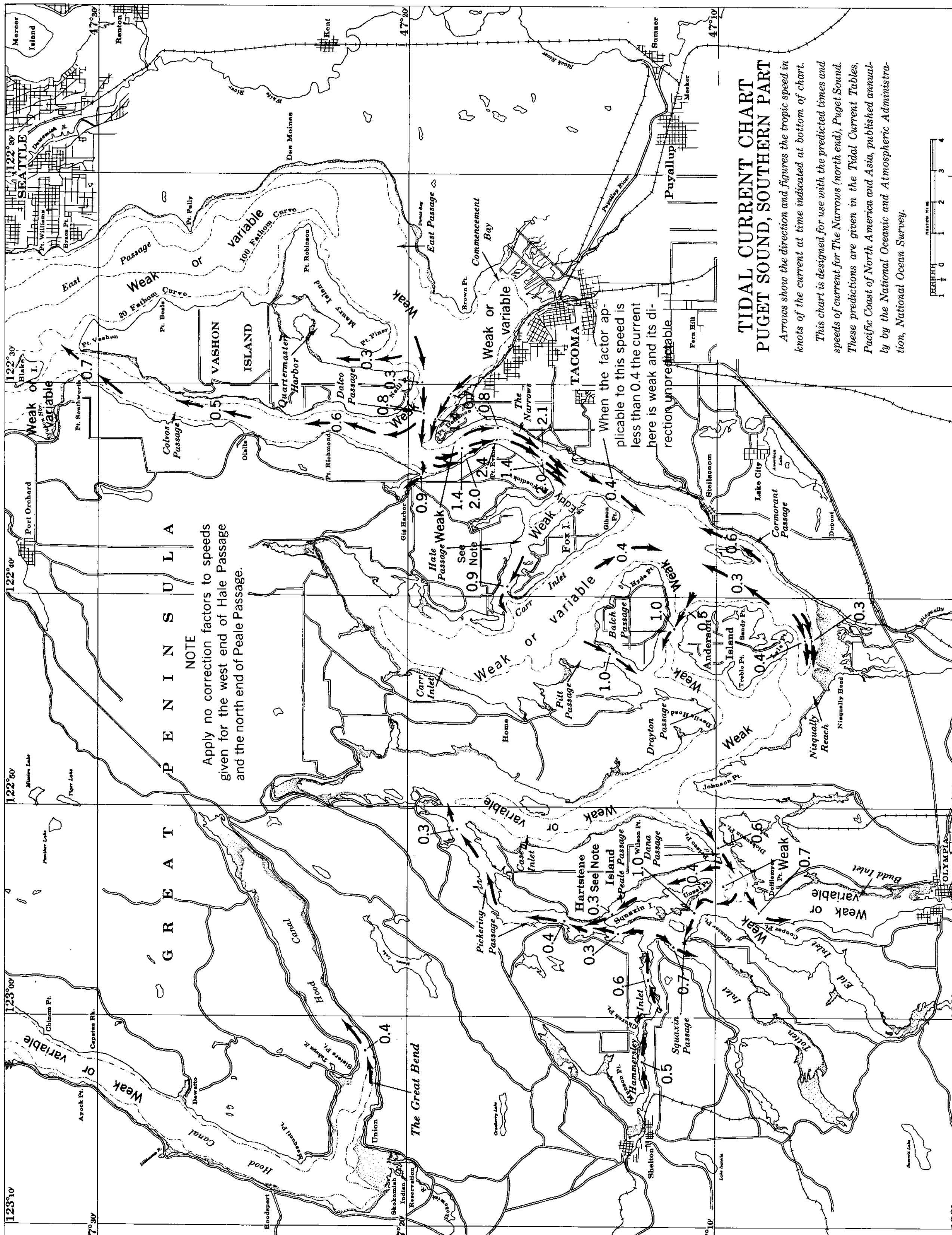
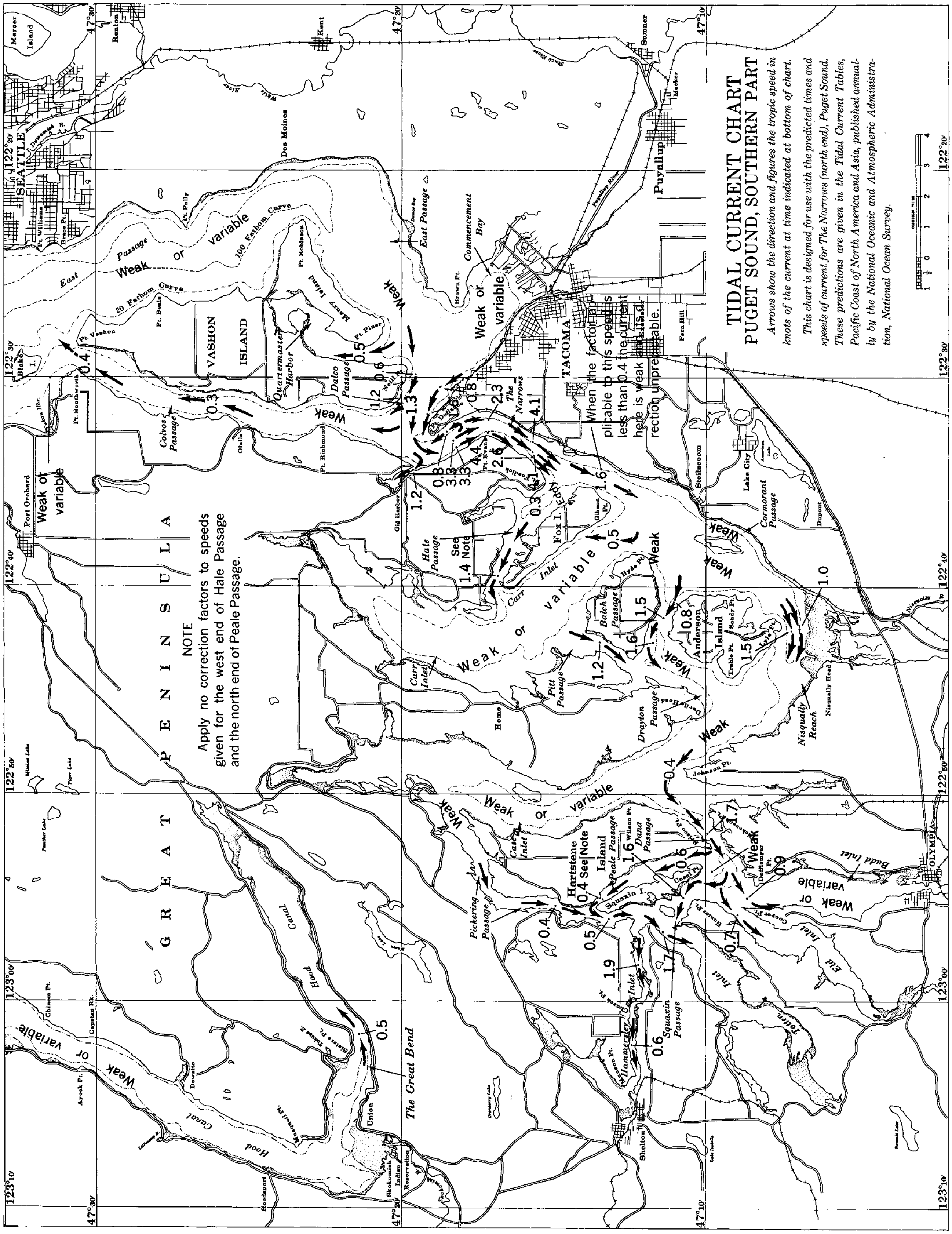


FIGURE 3

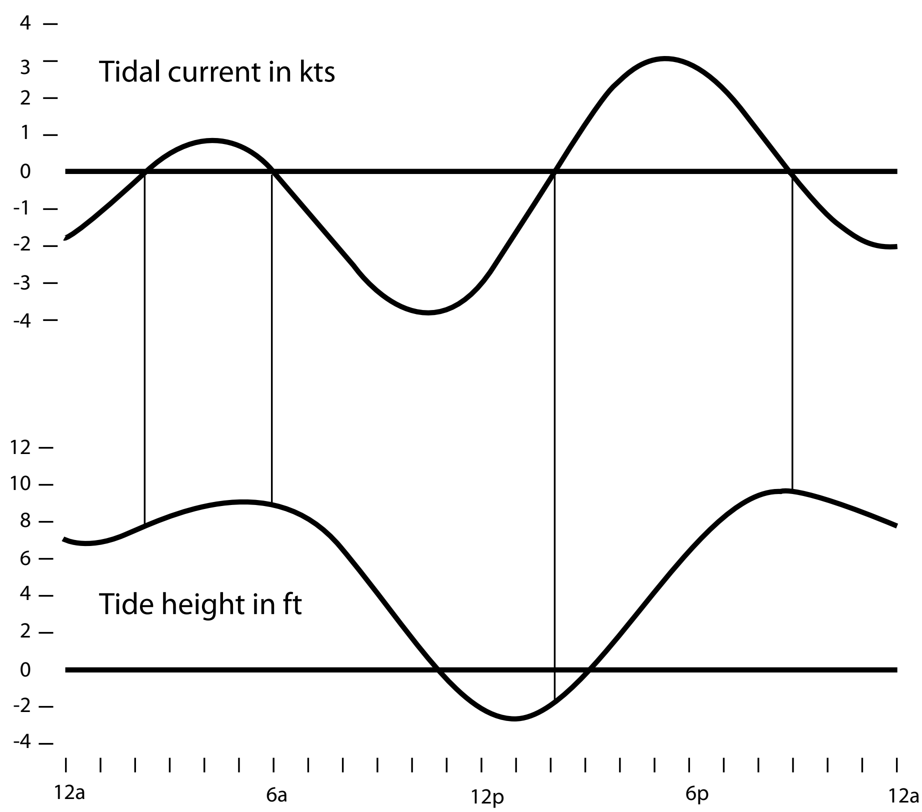


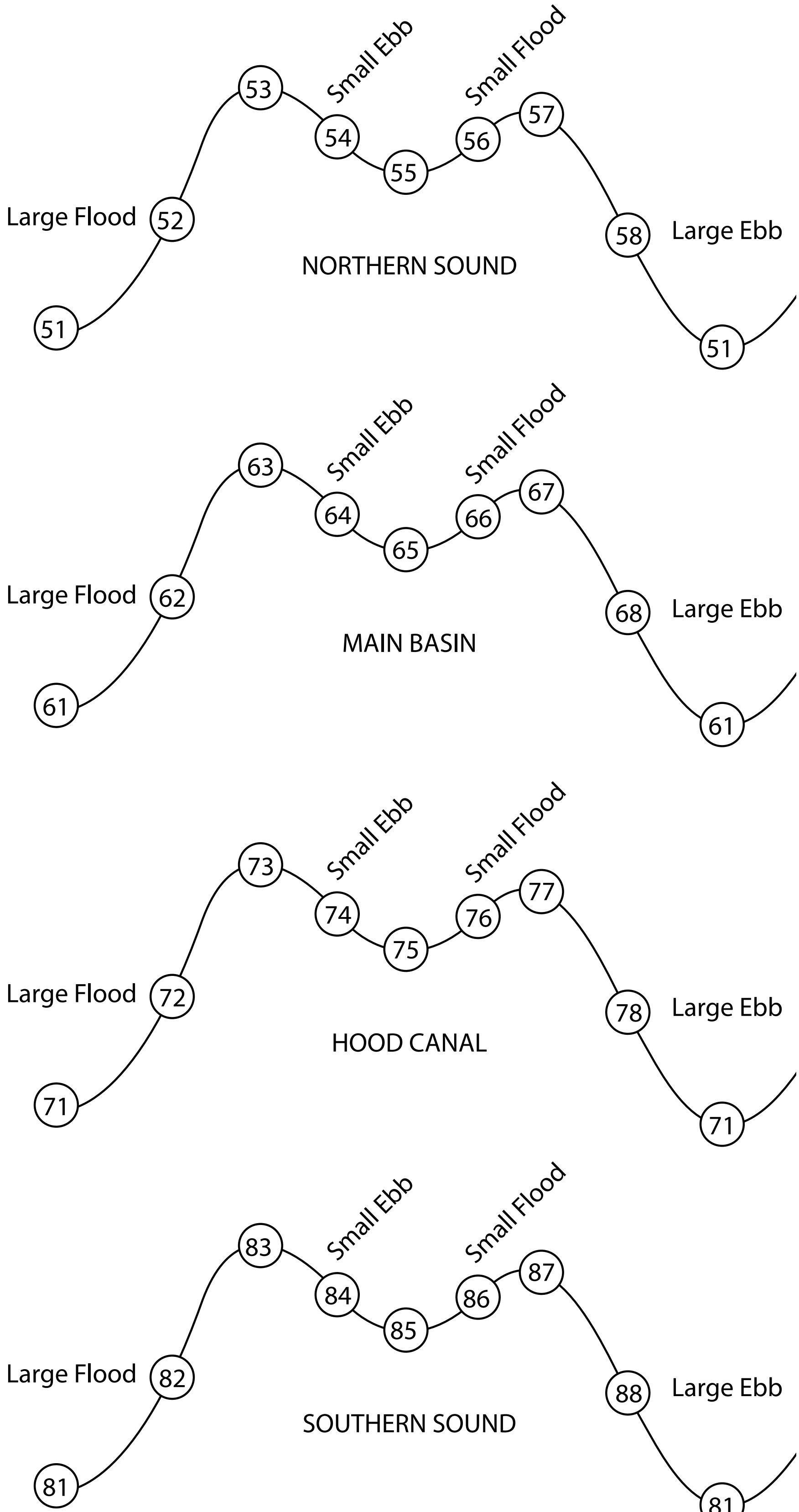
TWO HOURS BEFORE MAXIMUM FLOOD AT THE NARROWS (F−2)



ONE HOUR BEFORE MAXIMUM FLOOD AT THE NARROWS (F–1)

3.
TIDE PRINTS





This graphical presentation of the Table of Contents is not part of the original publication.

Contents

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 develop-

ment 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

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 secondarilyto the winds. Patterns that develop during each ebb tide or during each flood tidegenerally 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

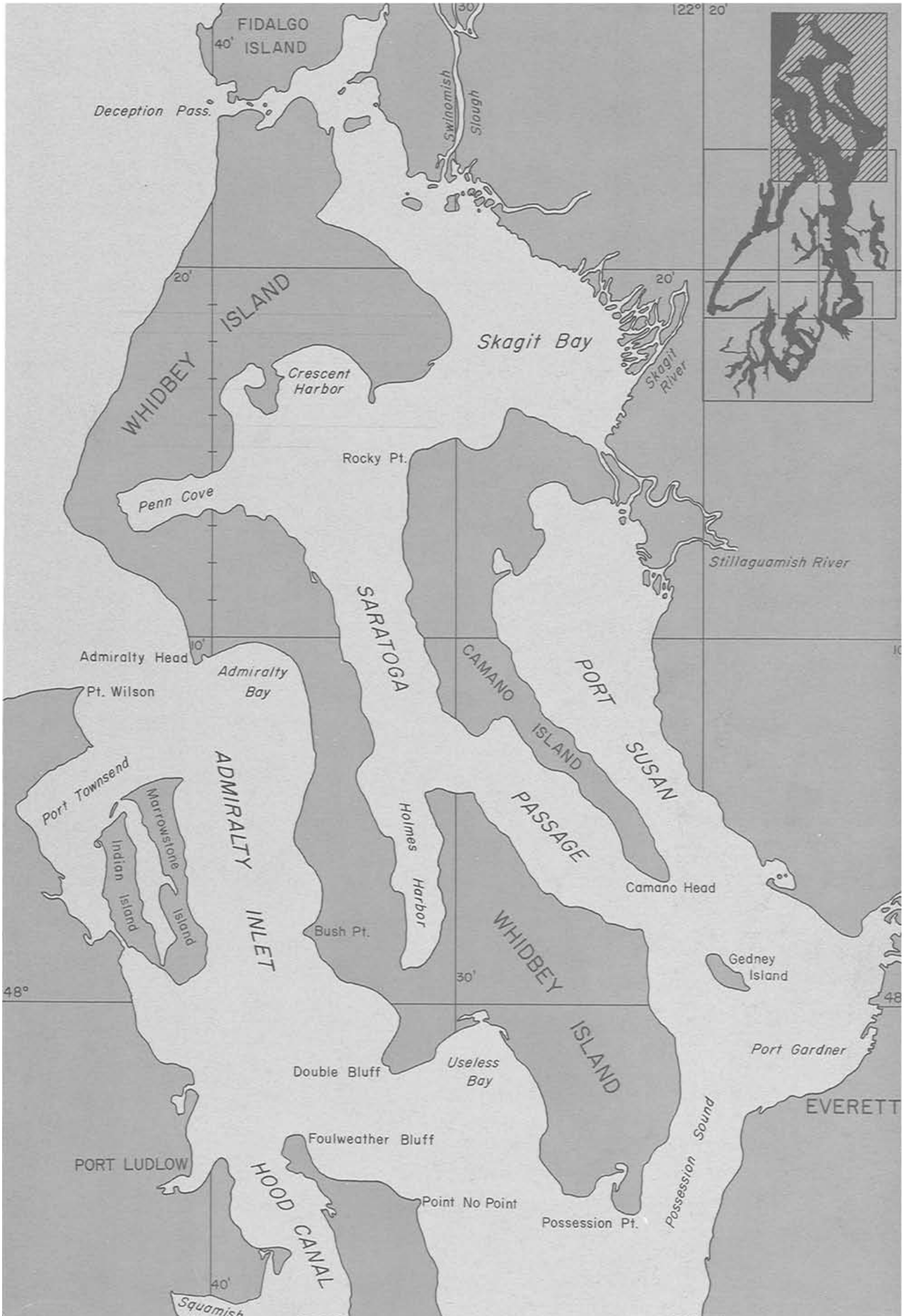
Maximum currents

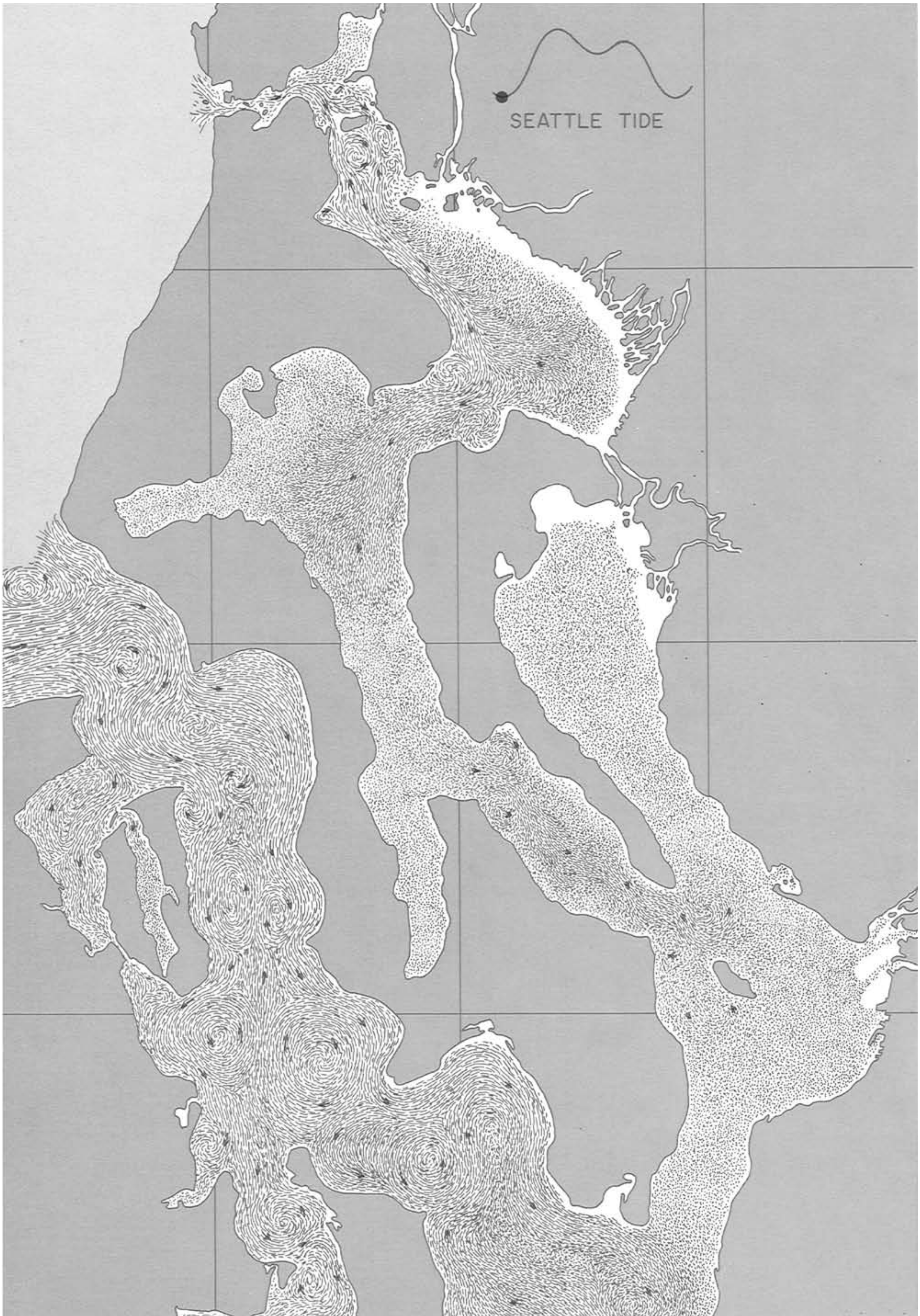
Deception Pass	9-10 knots
The Narrows	5.5 knots

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

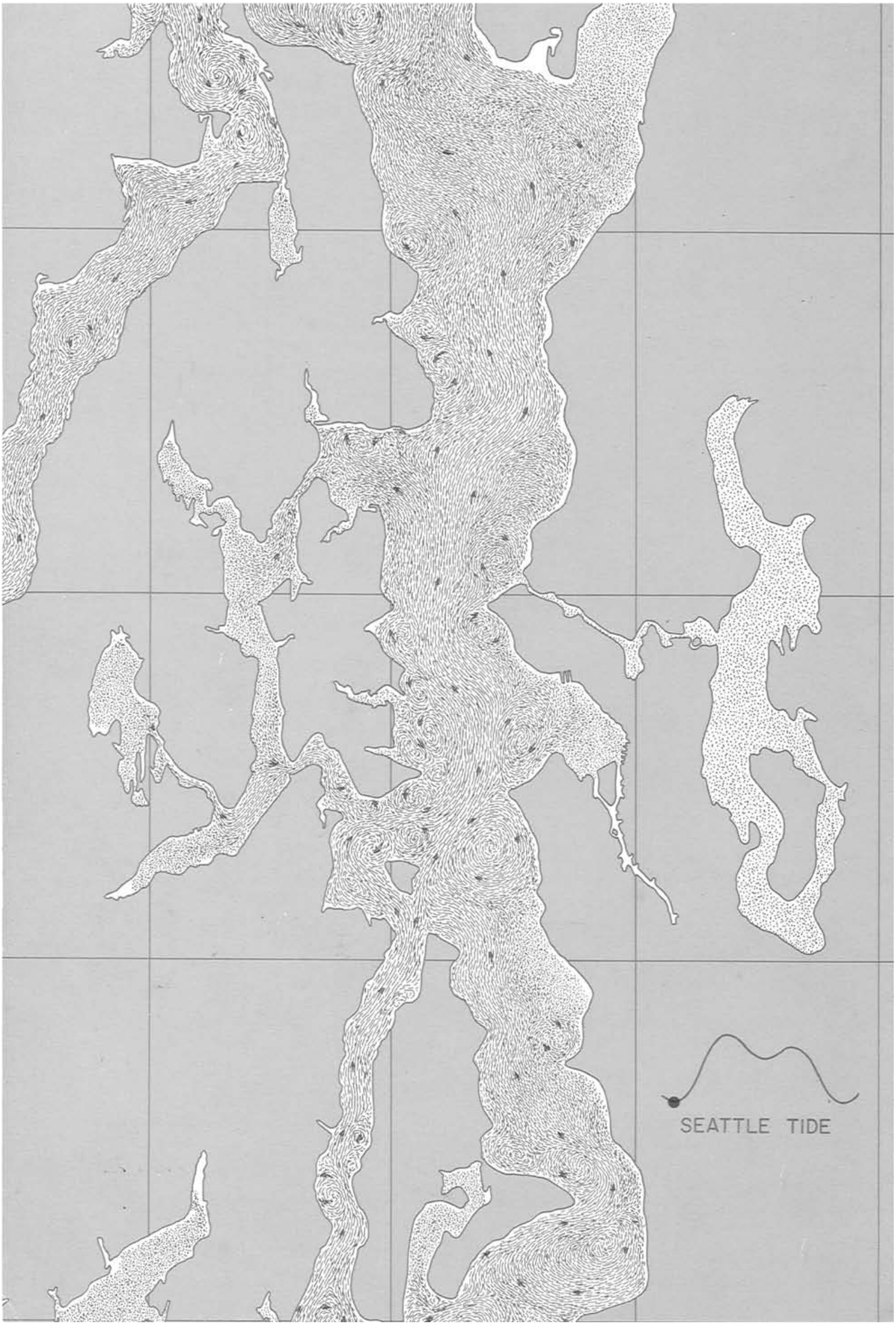
NORTHERN SOUND

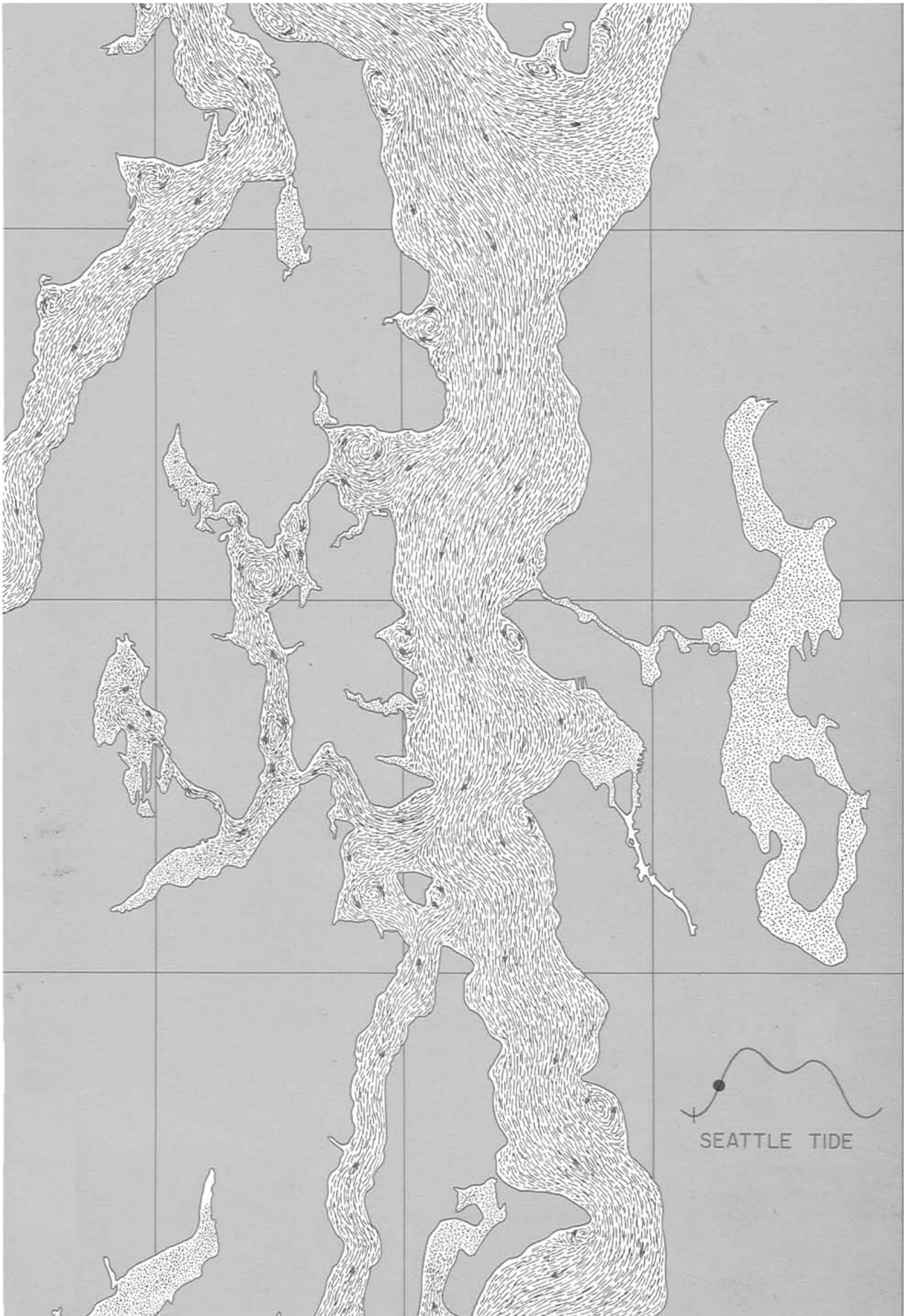

FIDALGO ISLAND
Deception Pass
Swinomish Slough
WHIDBEY ISLAND
Crescent Harbor
Skagit Bay
Skagit River
Rocky Pt.
Penn Cove
Stillaguamish River
SARATOGA
CAMANO ISLAND
PORT SUSAN
Admiralty Head
Admiralty Bay
Pt. Wilson
Port Townsend
Marrowstone Island
Indian Island
ADMIRALTY INLET
Holmes Harbor
PASSAGE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


SEATTLE TIDE


SEATTLE TIDE

MAIN BASIN


SEATTLE TIDE

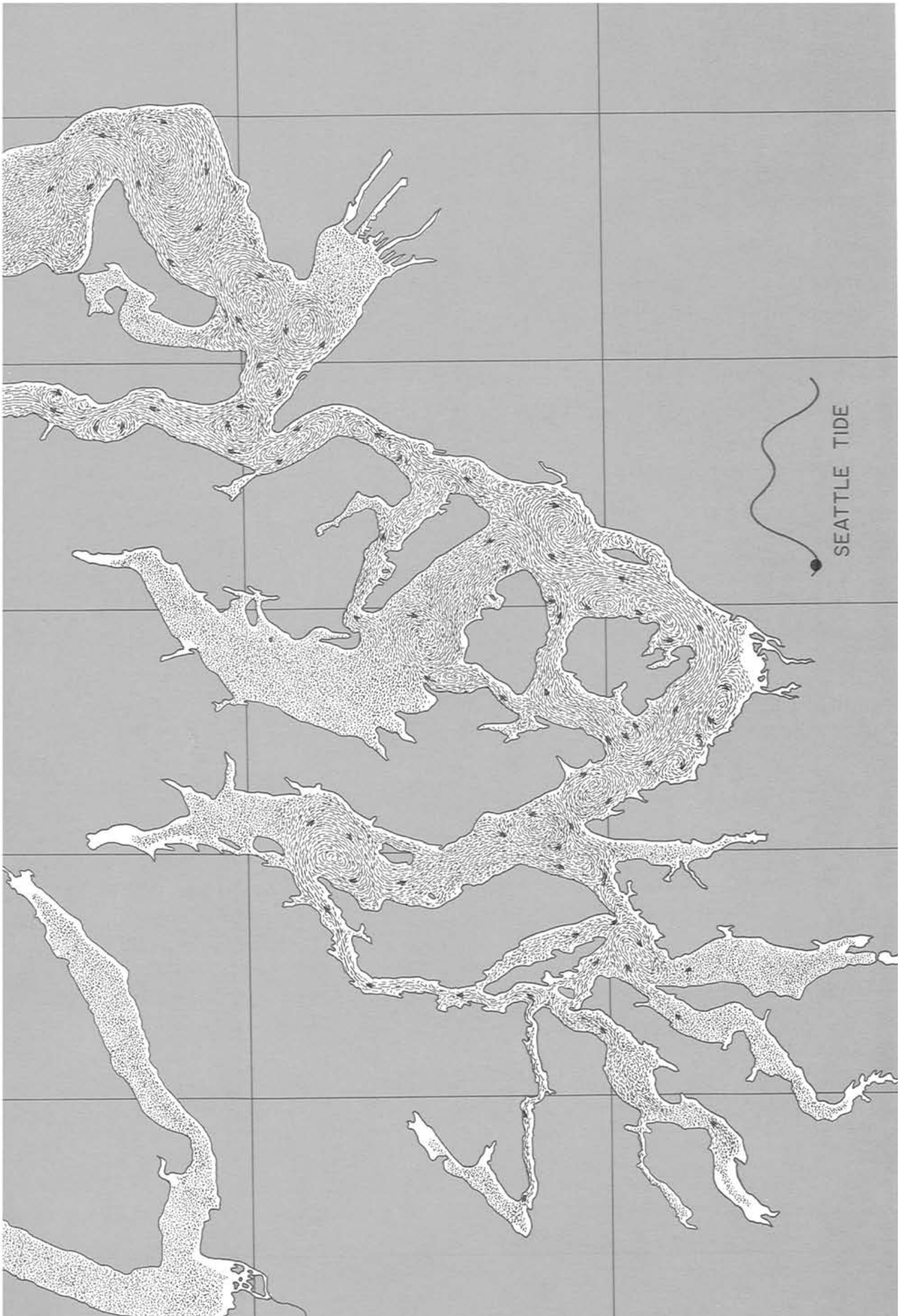

SEATTLE TIDE

HOOD CANAL


SEATTLE TIDE


SEATTLE TIDE

SOUTHERN SOUND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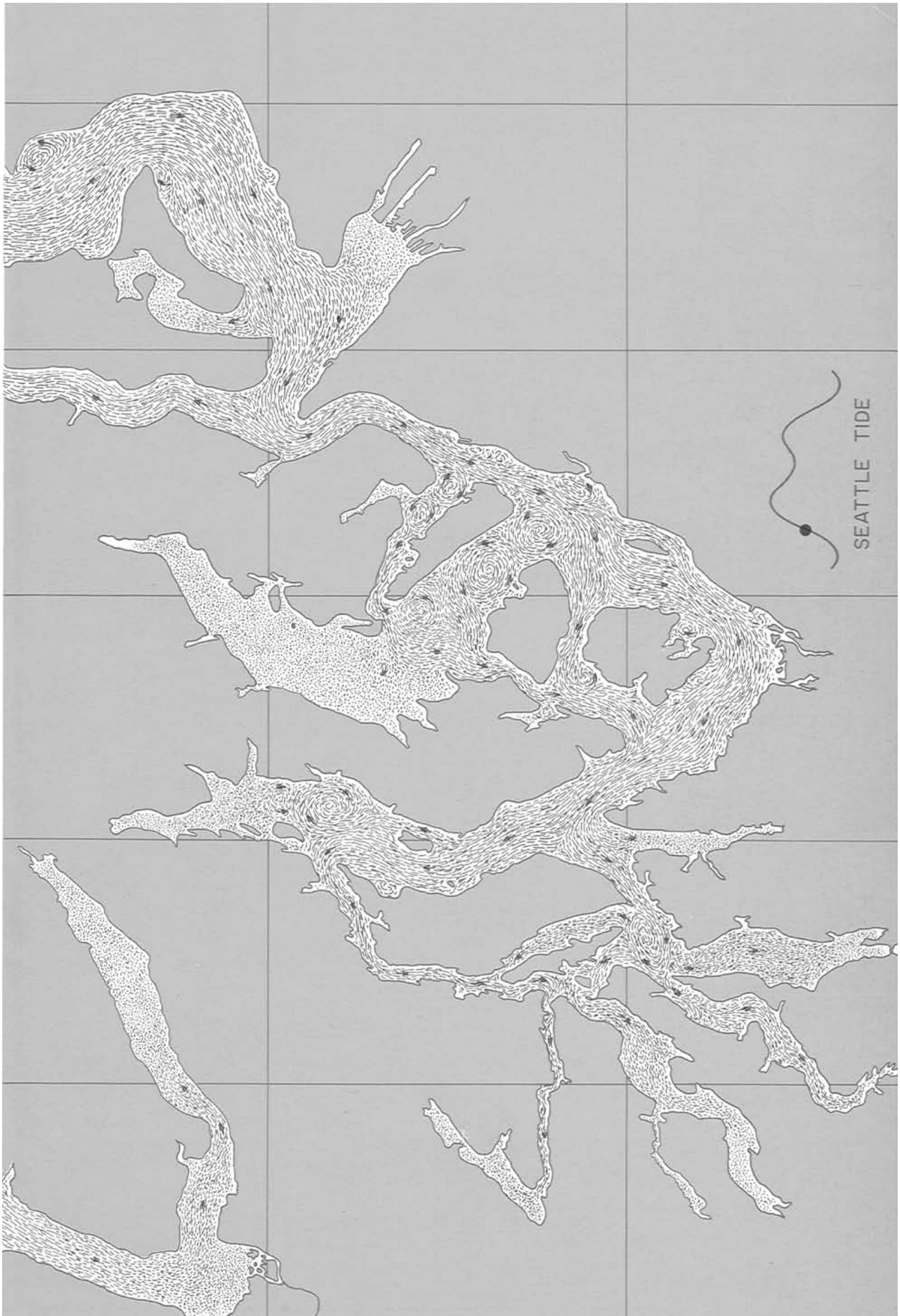
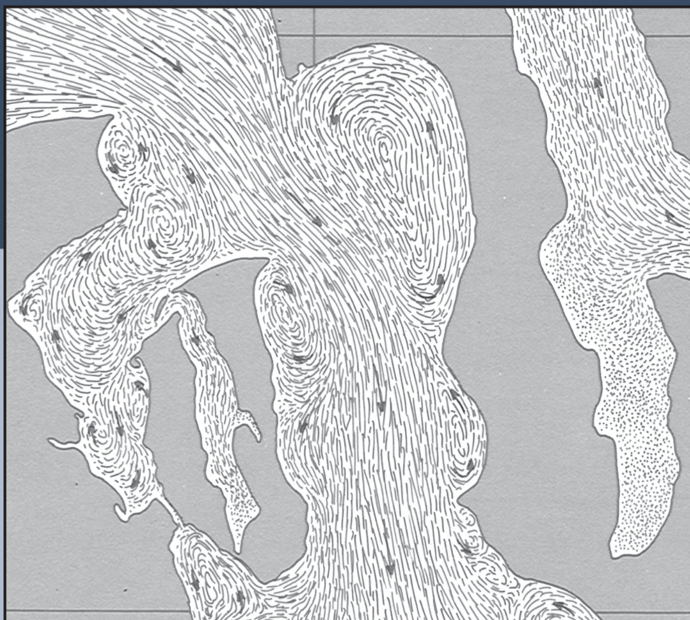
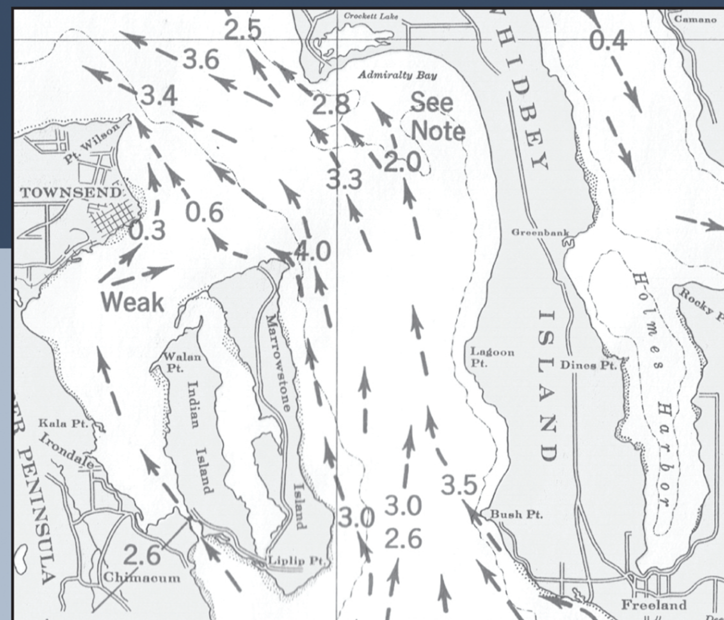

SEATTLE TIDE

Tide Prints

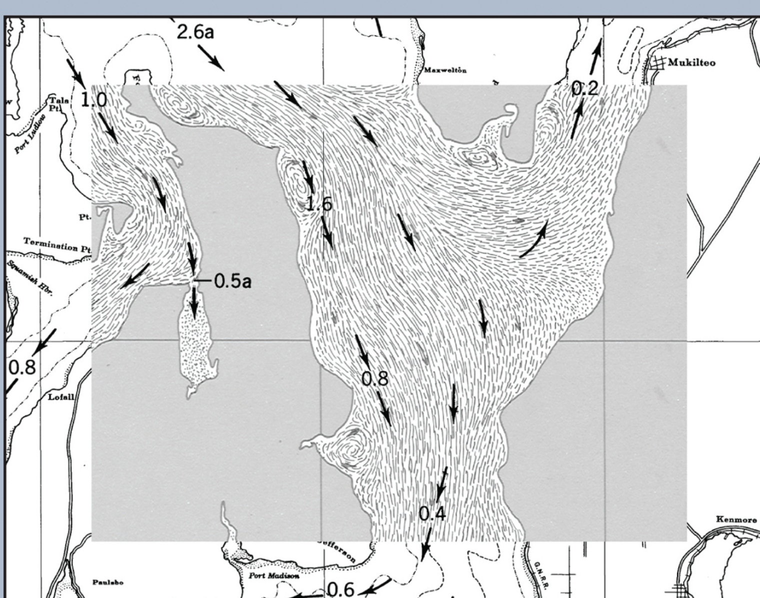


Tide Prints show the flow patterns and how they evolve throughout the current cycle. There is one print for every 3 hours throughout the cycle. They are indexed to the *tide height* in Seattle.

Current Charts



Current Charts show the values of the currents at each reference station. There is one chart for every hour throughout the cycle. They are indexed to the *tidal current* at Admiralty Inlet.



Comparing Tide Prints and Current Charts shows the locations of eddies and bands of current, and how these bands and eddies move and interact as the current cycle evolves.

• These are both perpetual publications, good for any year.

• Tide data at Seattle and current data at Admiralty Inlet (off Bush Pt) and at Tacoma Narrows (north end), are needed to assign specific times to each page of these charts and prints.

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