AN OBSERVATIONAL STUDY OF CURRENT AND TURBIDITY IN SOUTHWEST ROAD, ST. THOMAS U.S. VIRGIN ISLANDS

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ABSTRACT

Observations of current patterns and suspended loads were made at a prospective sand mining site in Southwest Road, St. Thomas to assess the dispersion of mining discharge. Twelve drogue experiments were conducted at different conditions of wind and tide, i.e. ebb and flood, spring and mean-neap, between December 1979 and October 1980. Additionally, ten surface and bottom drifters were released fortnightly and eight water samples were collected weekly from near-surface and near-bottom water for gravimetric analysis of total suspended load.

Drogue observations reveal a primary tidal circulation with a predominate westward movement. The pattern is modified by geometry of the Road whereby flood flow converges toward the west end of St. Thomas and ebb flow diverges eastward around islands and reefs. Currents are faster in surface water of central reaches, up to 1.0 knot, than inshore or offshore near Saba Island. These areas have a secondary circulation governed by the local geometry, the wind and by phasing of tidal currents. Both primary and secondary circulations are stronger and better organized during spring range and diurnal tide than during neap range and semi-diurnal tide. The drogue observations show that the circulatory regime for mining discharge is highly variable. Worse case conditions occur in nearshore zones when southeast winds (> 10 knots) exert an opposing influence over weak ebb flow and drive surface water onshore.

Natural loads of suspended solids are relatively low. The mean load of near-surface and near-bottom water for an 11-month period was 0.75 mg/l and the range was 0.03-2.85 mg/l. Differences between stations were very small, however concentrations at nearshore station 4 were higher than average between February and June 1980, a time of intense airport construction and runoff.

1. INTRODUCTION

The uncertainity of environmental impacts created by offshore mining has been a major deterrant to exploiting sand and gravel deposits. Of special concern is where does the mining discharge go? How far does it extend and what are the suspended loads in relation to natural or background concentrations? To answer these questions requires a knowledge of the current regime affecting the dispersion and resedimentation of suspended material and a knowledge of the natural variations in the suspended load. This report provides a data base as input for a numerical model of sediment dispersion as well as new knowledge to assess the natural physical conditions at the prospective mining site.

State of Knowledge

The circulation and turbidity in Southwest Road and vicinity has been sparingly studied. In 1970-71 surveyors of the National Ocean Survey (formerly U.S. C. & G.S.) recorded distinct reversing tidal currents of 0.5 to 2.0 knots at a 100-hour station in Savana Passage. By contrast, a undirectional northwestward, or semipermanent drift which occasionally reverses, at 0.2 to 0.7 knots, was recorded at a 100-hour station 2 km south of Saba Island. As Part of ERTS-1 ground truth, Colburn (1975) of Grumman Ecosystems occupied 17 current meter stations during a six week period in St. Thomas Harbor and the area east of Southwest Road. Although most of the records were not reduced, Colburn reports a diurnal reversing current sets from the southeast to the northwest. This trend was observed by Insular Environments (1975) from a 48-hour near-bottom record in Southwest Road 1.6 km west of Red Point. In 1977, Tetra-Tech oceanographers (Tetra-Tech, 1977) tracked drogues and made current profiles in Southwest Road around Truman Airport and about 2.0 km offshore. These observations, acquired as input to a numerical flow model, revealed an inshore diurnal reversing flow that is stronger and of longer duration to the northwest than to the southeast.

As part of an intensive environmental survey of Perseverance Bay, inner Southwest Road, Nichols and Towle (1977) occupied 8 anchor stations at two conditions of wind and waves. These observations display tidal currents with a distinct reversing and at times a slightly rotary character. Superimposed on the tidal currents there is a weak semi-permanent current driven westward by the wind or thermohaline forces.

Observations of suspended solids concentrations and turbidity levels have been made monthly by the Virgin Islands Department of Conservation and Cultural Affairs for more than five years at several inshore stations between Brewers Bay and Water Island. Additionally, diurnal and tidal variations are reported by Nichols and Towle (1977) at 16 anchor stations in Perseverance Bay and offshore of Truman Airport. As part of an effort to monitor water quality during and prior to airport construction the DCCA, Division of Natural Resources, has observed light and turbidity levels monthly at 16 inshore and reef stations from November 1978 to the present (Rogers, 1980). These data reveal the effects of storms and airport construction. Although prior observations in Southwest Road provide information for inshore and reef zones, as well as adjacent areas to the east and west, information at prospective mining sites in central reaches of the Road is lacking.

Objectives

This report aims to provide new information and the oceanographic observations necessary to assess the dispersion and resedimentation of mining discharge. The objective is resolved into two subobjectives which provide an organizational plan for different tasks of the project: (1) to determine the path and speed of water movement at the prospective mining site and throughout Southwest Road, (2) to determine the natural variation and range of suspended solids concentrations (turbidity) on the prospective mining sites over an annual period. It is of special interest to assess the circulation pattern and suspended solids at various "worse case" conditions of wind, waves and tide and to compare the variations in these conditions with ambient or "normal" conditions. The worst case conditions selected represent conditions of high energy and of reefward and shoreward movement.

2. FIELD OBSERVATIONS

Observational Approach and Scope

To delineate the drift path and speed of water movement, free drifting drogues and drifters were deployed. These devices record the displacement or trajectories of marks representing tagged water parcels from an initial point or points. By repetitively establishing the position of a drogue as it moves along, a procedure called tracking, the current speed and direction is determined.

The environmental conditions selected for drogue experiments consist of:

1. Ambient: a period of moderate northeast to east and southeast trade winds with wind speeds greater than eight knots during, and 24 hours prior to, the experiment.

2. Worse Case "A": a period of minimal wind from any direction with speeds mainly less than eight knots during and 24 hours prior to the experiment. This condition favors slow currents and minimal effluent dispersion.

3. Worse Case "B": a period of moderate east to southeast winds with speeds greater than eight knots during and 24 hours prior to, the experiment. This condition favors a "southeast chop" and onshore surface drift.

A third worse case condition, strong southeast to southwest winds associated with a passing tropical storm or hurricane, was planned but did not materialize during the project period. Additionally, the experiments were designed to meet contrasting ebb (eastward) and flood (westward) tidal currents as well as different ranges of the tide which affect strength of the tidal currents: (1) spring range (>26cm); (2) mean or neap range (<26cm). Tidal ranges are based on predicted tidal heights of the National Ocean Survey (NOS) and direction of tidal current was predicted on a preliminary relation of current observations to predicted high and low waters of NOS (Nichols and Towle, 1977).

Another technique is to release drift bottles and bottom drifters at known points and times. When bottles and drifters are found ashore or recovered from the seabed some time later, they record the end point of a path of movement. Although inexpensive and deployed in large numbers only a small percentage of bottles and drifters are recovered and they do not indicate the entire path or the history of water movement.

To determine the load of particulate material suspended in the water, the material was separated from the water by filtration through a membrane filter. This approach is preferred to optical measurements of turbidity because it is more accurate and free of variations caused by varying particle size and composition of the material. Additionally, filtration is a standard technique widely used in oceanographic observations and thus allows comparison with other data.

The observational area covers Southwest Road proper and its environs to Porpoise Rock on the east and close to Savana Island on the west (Figure 1). Four stations were positioned in central reaches of the Road, three of which lie on potential sand deposits delineated by the U. S. Geological Survey (U.S.G.S., 1979), Figure 1. These stations were marked with temporary buoys and occupied at different times: (1) weekly for water samples analyzed for suspended solids (turbidity), (2) twice a month for release surface and bottom drifters at stations 2 and 4, and (3) intermittently, according to selected wind and tide conditions, for release of drogues. The sampling and measurements extended from December 5, 1979 to October 30, 1980.

Equipment and Field Procedures

The drogues consisted of free-drifting floats with a vane of the "window-shade" type (Figure 2). The mast is constructed of a thin fiberglass staff with a small flag and a cyalume light stick attached to the mast.

To measure the current path and speed, drogues were tracked hourly or more frequently, by sighting positions on known landmarks or buoys with

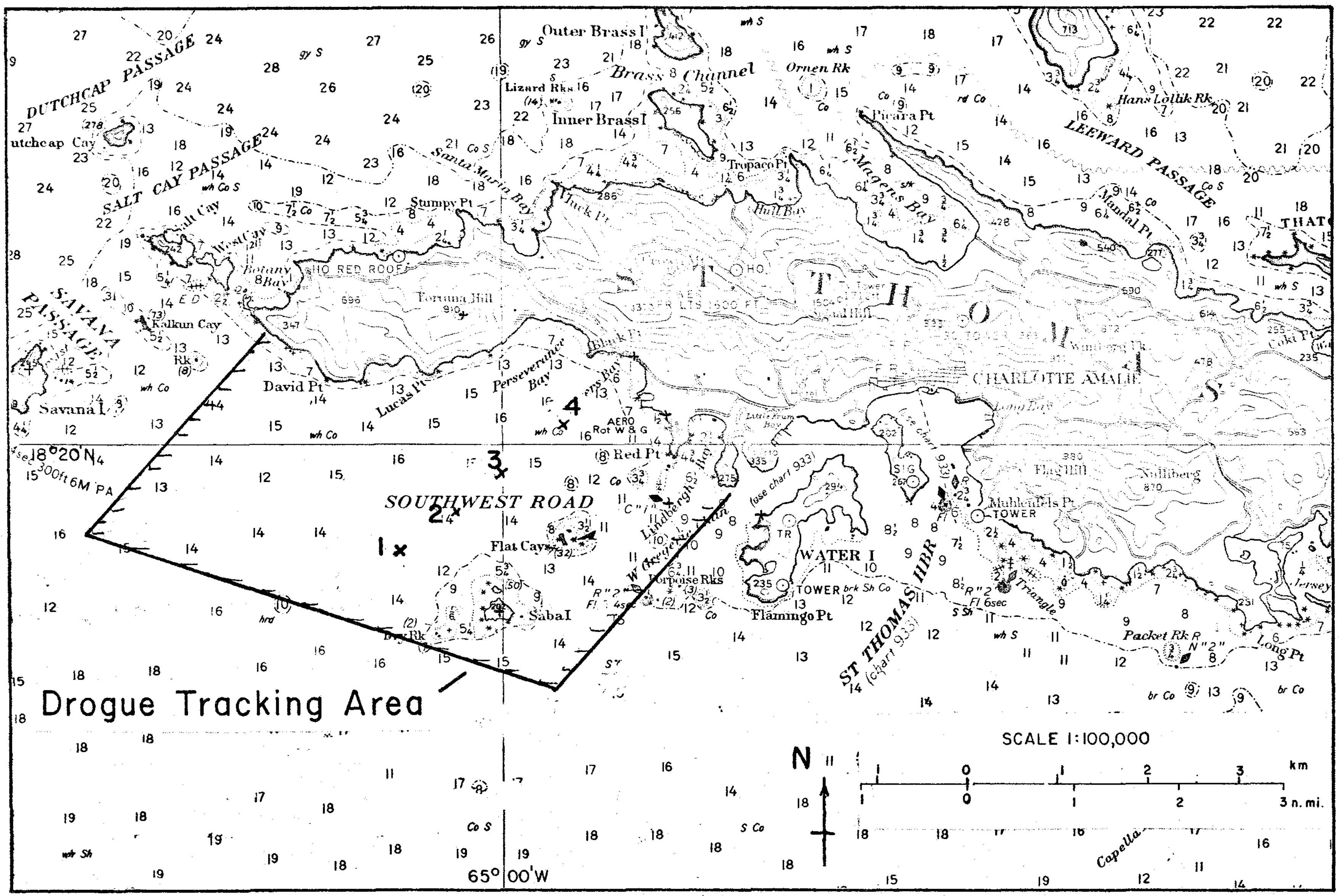

Figure 1. Location of sampling stations and drogue release stations in relation to drogue tracking area, Southwest Road, St. Thomas. Landmarks used for positioning noted by (+).

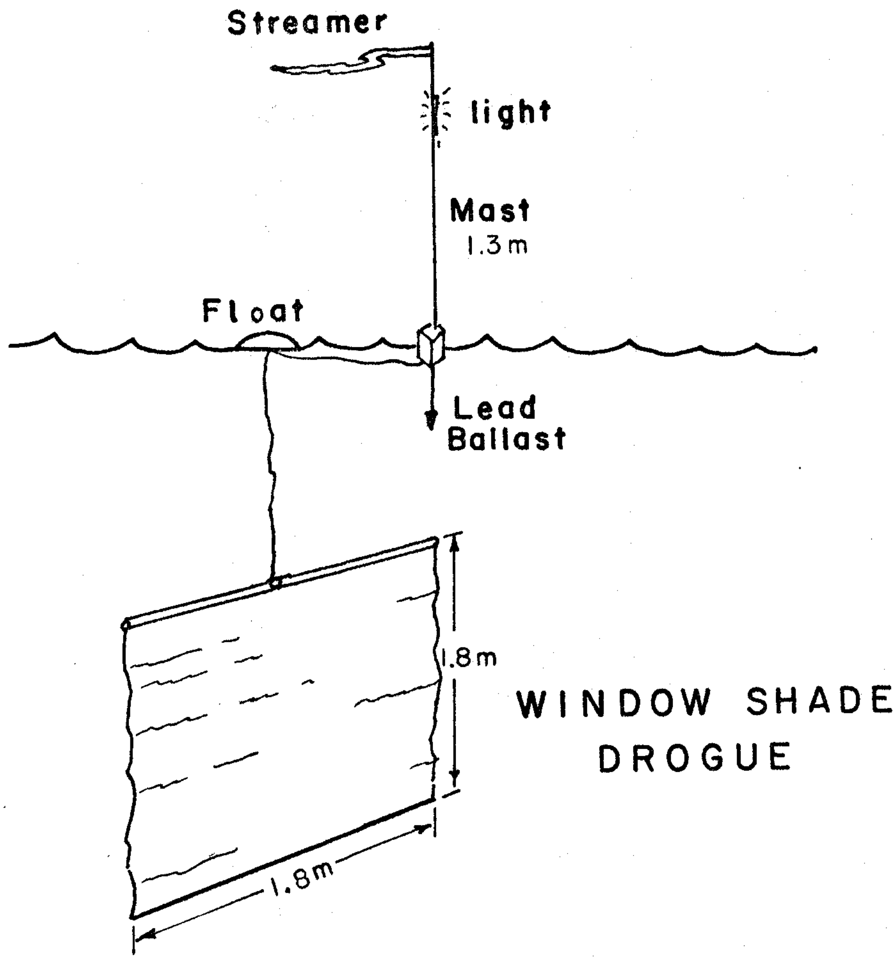

Figure 2. Schematic configuration of window shade drogue.

a sextant or hand-bearing compass. Most of the same landmarks or buoys were used for all experiments.

Drogue experiments were planned to meet the desired conditions of wind and tide according to local predictions previously described. Some predicted conditions of wind did not materialize, or changed during the experiment; however deployment continued once it began. Drogues were released either: (1) close to high water for ebb (eastward) excursions; or (2) close to low water for the beginning of flood (westward) excursions. The drogues were started at nearly the same time (< $\pm$ 1 hour) at each of the four key stations (Figure 1) and tracked from 3 to 13 hours, i.e. for one-half a semi-diurnal tide cycle, or for 12 to 14 hours, a full semi-diurnal tide cycle, or until they departed the tracking area. The drogues were normally released in pairs, near-surface (2 meters below the surface), and near-bottom (2 to 4 meters above the bottom) at the release station. By using two tracking boats to follow two pairs of drogues per excursion, most drogues could be tracked almost simultaneously.

Surface drifters consisted of drift bottles containing information cards that could be filled in and returned by a finder for a small reward. They were released four at a time, twice a month at stations 2 and 4.

Bottom drifters consisted of Woodhead seabed drifters, a polythene umbrella 18 cm in diameter, and a stem 54 cm long ballasted with a brass ferrule to provide a slight negative buoyancy. A label on the umbrella provided space for recovery information and notice of reward. Bottom drifters were released four at a time, twice a month at stations 2 and 4.

Samples for analysis of suspended material were obtained with a 5-liter Van Dorn water bottle from near-surface water, approximately one meter below the surface, and from near-bottom water, approximately one meter above the bed. Because wave action caused the sampling boat to roll and pitch, the actual sampling depths occasionally varied ± 1 meter. To avoid deterioration, samples were processed within 12 hours after collection by Millipore filtration using 0.45 μ pore size filters. Procedures follow Strickland and Parsons (1979) and procedural details are given in Appendix A.

Ancillary meteorlogical, wave and tidal data were collected at least every two hours during the drogue experiments. Wind speed was measured with a Sims handheld anemometer while wind direction was determined with a streamer and hand bearing compass. To determine wind conditions 24 hours prior to the experiments, hourly wind records were acquired from the National Weather Service Station at Truman Airport located near Southwest Road. The direction of significant waves was measured by sighting along crests with a compass while height and length were estimated visually. Tidal heights were mainly derived from predicted NOS tide tables for Charlotte Amalie and supplemented by marigrams from a bubble tide gauge installed in St. Thomas Harbor.

Data Reduction and Compilation

Observational data of the drogue experiments were recorded on standard forms. Sextant fixes were plotted on a 1:24,000 scale base chart using a 3-arm protractor while compass bearings were plotted on the same chart using parallel rules and the chart compass plot. The drogue tracks were established by connecting points representing the time of successive positions and then reduced to a 1:46,000 scale base chart (Appendix B).

Accuracy

The accuracy of tracking drogues is limited mainly by errors in identifying and sighting landmarks and buoys. Prior to drogue observations all landmarks were identified both in the field and on a 1:24,000 scale U.S.G.S. topographic map (Fig. 1). Positions of many landmarks were verified by sighting and triangulation between landmarks. Position of most landmarks is better than ± 80 m over a maximum distance of 5 km. Drogue tracking may result in an error of ± 2° for each sextant or compass bearing over a maximum distance of 4 km. This is equivalent to about ±150 m. Most sightings however, were accomplished within 2 km and the resulting error is less than ± 85 m. Therefore, average velocities determined over a excursion of 5 km are subject to an error of about 3.4 percent. Laboratory analyses of suspended material using the established procedure with five liters of sample water, yields a precision of ± 0.08 mg/l while the overall working accuracy is better than ± 0.5 mg/l.

3. RESULTS

Drifter Data

Table 1 gives the release and recovery times and locations for surface and bottom drifters. Of the 430 drifters released between December 20, 1979 and October 25, 1980 only seven were recovered. Six were surface drift bottles while one was a bottom drifter. Recovery locations range from nearby Perseverence Bay, St. Thomas to Grand Turk Island, Bahamas. All recovery locations are west of the release stations. Because the number of recoveries are limited, less than two percent, the drifters indicate little about the circulation in Southwest Road. Low

Table 1. Surface and Bottom Drifter Data for Drifters Recovered.

Release Date	Release Location	Drifter Number and Depth	Recovery Date	Recovery Location	Recovery Position
13 Jan 80	Station 2 SW Road	0002 Surface	8 Mar 80	Zoni Beach NE Culebra Isld.	Lat. 18°20'15"N Long. 65°17'55"W
23 Jan 80	Station 4 SW Road	0038 Bottom	20 Mar 80	West Cay, NE Beach, St. Thomas	Lat. 18°21'35"N Long. 65°02'35"W
20 Feb 80	Station 4 SW Road	0075 Surface	31 Jul 80	Perseverance Bay, St. Thomas	Lat. 18°21'08"N Long. 64°59'52"W
3 May 80	Station 2 SW Road	0162 Surface	5 Jul 80	West Beach, Fortuna Bay, St. Thomas	Lat. 18°20'55"N Long. 65°02'15"W
3 May 80	Station 2 SW Road	0165 Surface	17 Jul 80	East Bay, Grand Turk North Isld., Bahamas	Lat. 21°26'N Long. 71°05'W
30 Jul 80	Station 4 SW Road	0291 Surface	31 Jul 80	Perseverance Bay, St. Thomas	Lat. 18°21'09"N Long. 64°59'55"W
5 Mar 80	Station 2 SW Road	0081 Surface	5 Aug 80	South Caicoc Island, Bahamas	Lat. 21°31'N Long. 72°22'W

recoveries were anticipated because the "receiving" shores are limited and consist of rocky cliffs rather than beaches. Also, the shores are fringed by coral reefs in which bottom drifters can be trapped. The drifter results suggest that onshore drift is limited and movement toward resort beaches at Brewers Bay and Water Island is infrequent.

Drogue Observations

Table 2 summarizes the drogue release time, environmental conditions and observed current for each drogue experiment. The plots given in Appendix B show the detailed track, release and termination time for each drogue.

The most significant feature of the drogue tracks is their back and forth excursions directed mainly northwest-southeast. This movement represents a reversing current produced by the tide. The flood is one that sets to the west which is the direction of propagation of the oceanic progressive tide wave. The ebb is one that sets in the opposite direction, to the east. The movement is distinctly periodic with a change from ebb to flood about every 3 to 8 hours during semi-diurnal mixed tides and about 11 to 13 hours for diurnal tides. The change from ebb to flood is accompanied by a relatively short period (~<0.5 hr) of slack water during which the speed approaches zero.

During flood tide and light wind most drogue paths are relatively straight and tend to converge toward the west end of St. Thomas (Figure 3). The drogue skirts the coast without stranding ashore. Near-surface speeds reach an average of 0.86 knots (43 cm per sec) over a 3.2 hour excursion whereas near-bottom speeds are slower, up to 0.54 knots (29 cm per sec).

TABLE 2. Index and Summary to Drogue Experiments, 29 December 1979 to 10 October 1980.

		PREDICTED TIDE		OBSERVED WIND		OBSERVED CURRENT		
DATE/TIME	RELEASE STATION	RANGE, CM	DOMINANT DIRECTION*	DOMINANT DIRECTION	SPEED, KNTS.**	DOMINANT CONDITION & TIDE	DOMINANT DIRECTION*	AVERAGE SPEED, KNTS.***
29 Dec 79 1730-2355	3,4	26	Ebb	ENE	8-10	Ambient, Spring	Ebb	0.50
1 Jan 80 1805-0000	1,2	31	Ebb	E to ESE	8-10	Ambient, Spring	Ebb	0.36
3 Jan 80 0410-0955	3,4	36	Flood	E to ESE	4-6	"Low" Wind, Spring	Flood	0.19
4 Jan 80 0457-1000	1,2	28	Flood	E to ESE	9-10	"Low" Wind, Spring	Flood	0.56
5 Jan 80 0930-1544	2,3,4	25	Ebb	SEXE to SEXS	12-17	Ambient, Mean	Flood	0.16
8 Jan 1980 1236-1600	1	9	Ebb	ESE	11	Ambient, Neap	-	-
12 Jan 80 0945-1505	3,4	3	Flood	E	10-14	Ambient, Neap	Flood	1.02
13 Jan 80 0930-1430	1,2	3	Flood	ENE to ESE	11-12	Ambient, Neap	Flood	0.74
22 Feb 80 0815-1500	1,2	10	Flood	NEXN to E	10-11	"Low" Wind, Mean	Flood (Ebb)	0.94 (0.57)
4 Apr 80 1620-2235	1,2	33	Flood	EXS to SEXS	6-11	SE Wind, Spring	Flood	0.72

TABLE 2 (Continued). Index and Summary to Drogue Experiments, 29 December 1979 to 10 October 1980.

DATE/TIME	RELEASE STATION	PREDICTED TIDE RANGE, CM	PREDICTED TIDE DOMINANT DIRECTION*	OBSERVED WIND DOMINANT DIRECTION	OBSERVED WIND SPEED, KNTS.**	DOMINANT CONDITION & TIDE	OBSERVED CURRENT DOMINANT DIRECTION*	OBSERVED CURRENT AVERAGE SPEED, KNTS.***
5 Apr 80 1735-2301	3,4	30	Flood	ESE to SE	6-10	SE Wind, Spring	Flood	0.30
19 Jun 80 0833-1258	1,2	4	Flood	ESE	12-13	SE Wind, Neap	Flood	0.74
1345-1845	1,2	6	Ebb	ESE to SEXE	8-13	SE Wind, Neap	Ebb	0.15
20 Jun 80 0913-1555	3,4	6	Flood	ESE to SEXS	12-15	SE Wind, Neap	Flood	0.48
1522-2004	3,4	4	Ebb	EXS to SEXE	7-12	SE Wind, Neap	Flood	0.22
26 Jun 80 0526-1235	1	27	Ebb	EXN to SEXE	8-15	SE Wind, Spring		
1314-1915	1,2	33	Flood	EXN to SE	10-15	Ambient, Spring	Flood	0.86
29 Jun 80 0643-1430	3,4	28	Ebb	SE to SXE	8-10	SE Wind, Spring	Flood	0.26
1511-2150	3,4	35	Flood	EXN to ESE	8-10	Ambient, Spring	Flood	0.70
15 Aug 80 1058-1623	3	6	Ebb	EXN to SEXE	6-11	"Low" Wind, Neap	Ebb	0.16

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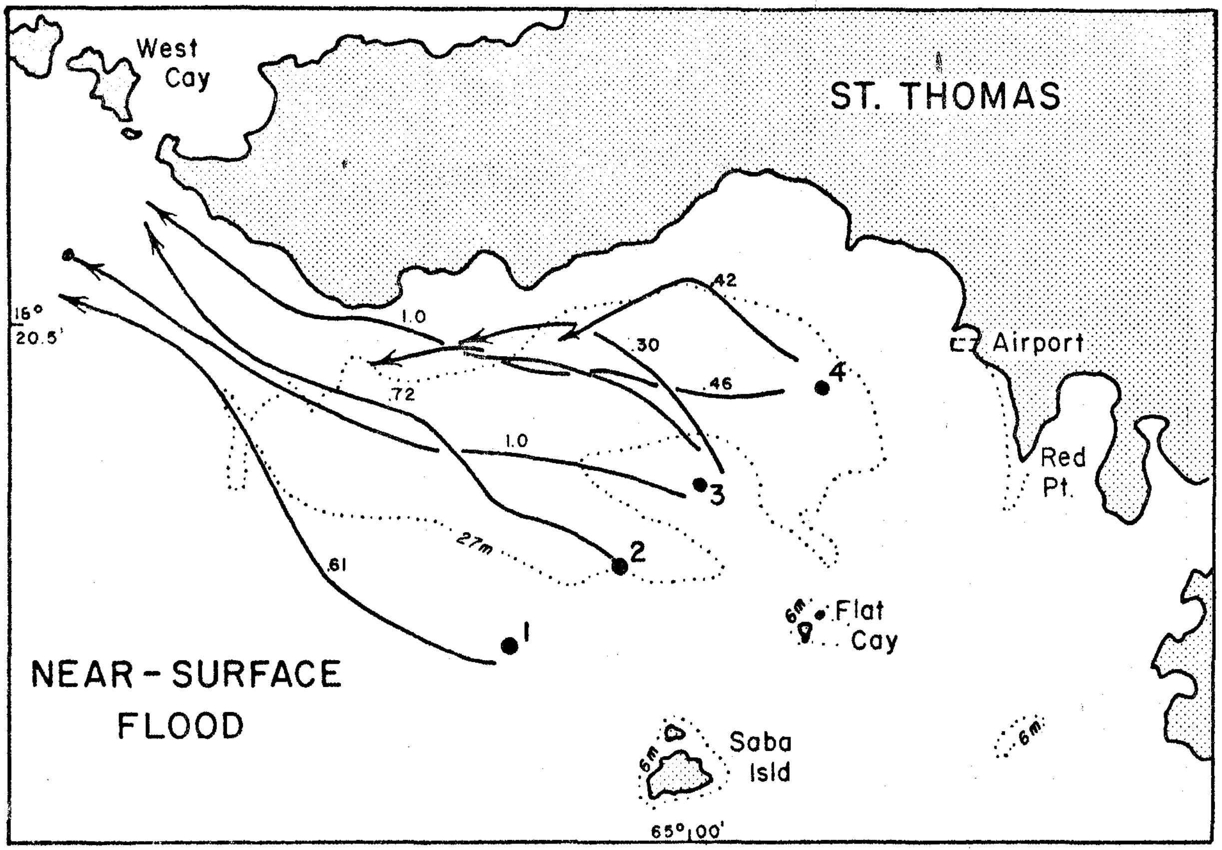
TABLE 2 (Continued). Index and Summary to Drogue Experiments, 29 December 1979 to 10 October 1980.

		PREDICTED TIDE		OBSERVED WIND			OBSERVED CURRENT	
DATE/TIME	RELEASE STATION	RANGE, CM	DOMINANT DIRECTION*	DOMINANT DIRECTION	SPEED, KNTS.**	DOMINANT CONDITION & TIDE	DOMINANT DIRECTION*	AVERAGE SPEED, KNTS.***
3-4 Sept 80 1815-0757	1,2,3,4	27	Ebb-Flood	SSE to S	6-8	"Low" Wind, Spring	Ebb Flood	0.26 0.61
24 Sept 80 0915-1420	3,4	21	Ebb	SEXE to SE by S	<5	"Low" Wind, Mean	Flood	0.22
24 Sept 80 1436-2016	3,4	21	Flood	NEXN to E	<5-7	"Low" Wind, Mean	Flood	1.00
10 Oct 80 0917-1430	1,2	9	Ebb	SSE to S	<5-6	"Low" Wind, Neap	-	0.40

* Ebb is easterly during falling water.
Flood is westerly during rising water.

** Range of modal wind speeds.

*** Average surface speed observed over drogue excursion from station 2 or 3.



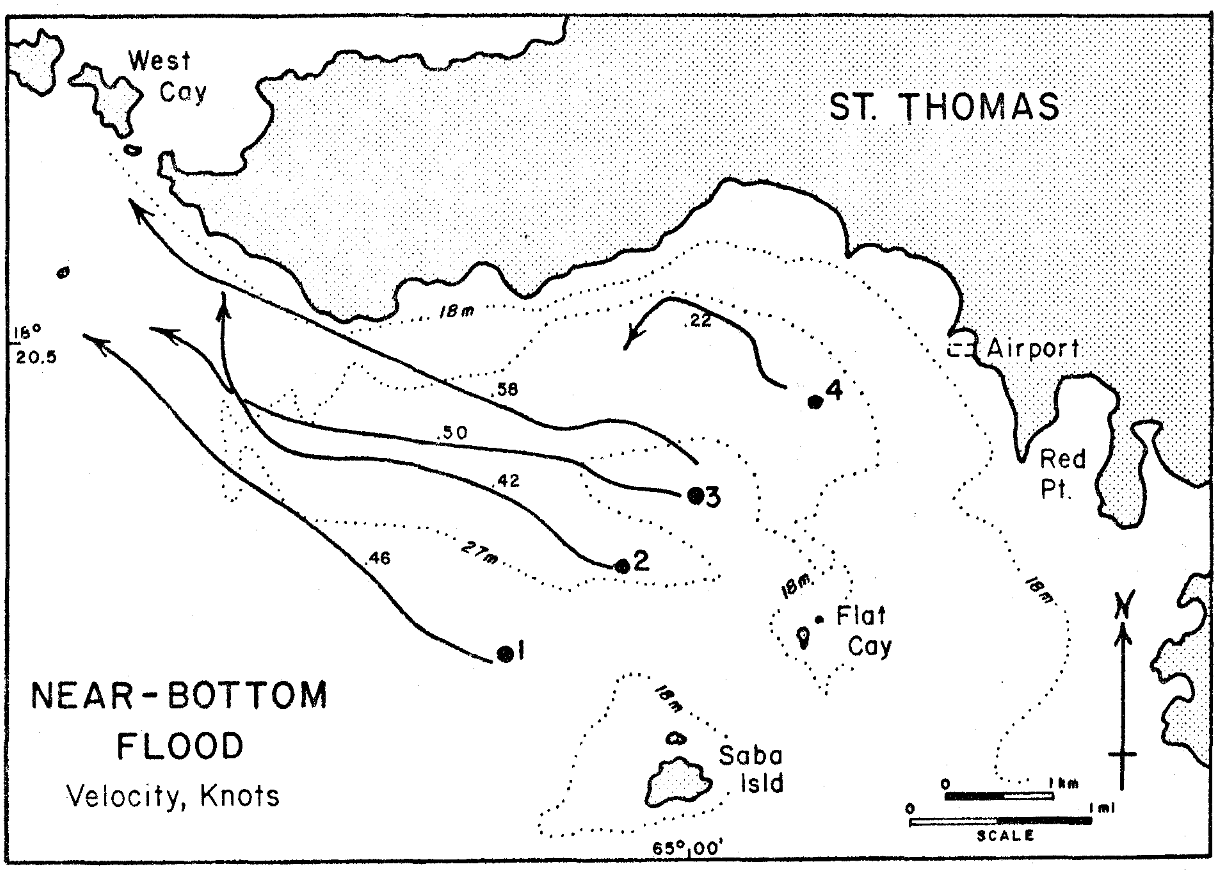


Figure 3. Composite system of drogue tracks for flood tide, Jan. 13, April 4-5, Sept. 24, 1980; near surface, upper; near-bottom, lower.

The surface current is faster in central reaches, station 2, than inshore or offshore (Figure 4A).

During ebb tide and light wind, drogue paths display slightly sinuous or curved paths (Figure 5). They tend to diverge from the release stations and then converge eastward in passages between islands and reefs. The divergence is produced by geometry of the Road whereby drogues go around islands and reefs whereas the convergence is produced by geometry whereby water funnels through narrowed reaches. A few drogues ground on the reefs but most go around the reefs and cays (Figure 5). Near-surface ebb currents are about 50 precent slower than near-surface flood currents, i.e. up to 0.49 knots (24 cm per sec) however, near-bottom speeds are about the same, i.e. up to 0.52 knots (26 cm per sec), as near-surface speeds. Current speeds in both near-surface and near-bottom water are faster by a factor of two or more in central reaches, i.e. in vicinity of passages, than nearshore (Fig.5B). Interestingly, differences between surface and bottom speeds are much greater on the flood than during ebb.

When the current speeds for all excursions are averaged and the directional frequency calculated on a percentage basis, it is evident that a flood or westward movement predominates both in the surface and in the bottom at all stations (Figure 6). Flood currents are generally stronger and last longer than ebb currents. The velocity-frequency diagrams suggest the greatest flood predominance is nearshore at station 4, whereas flood and ebb differences are much less near the bottom at station 2. The diagrams also reveal that current directions are more reversing at station 2 than elsewhere, especially near the bottom. By contrast, at station 1 directions are more variable

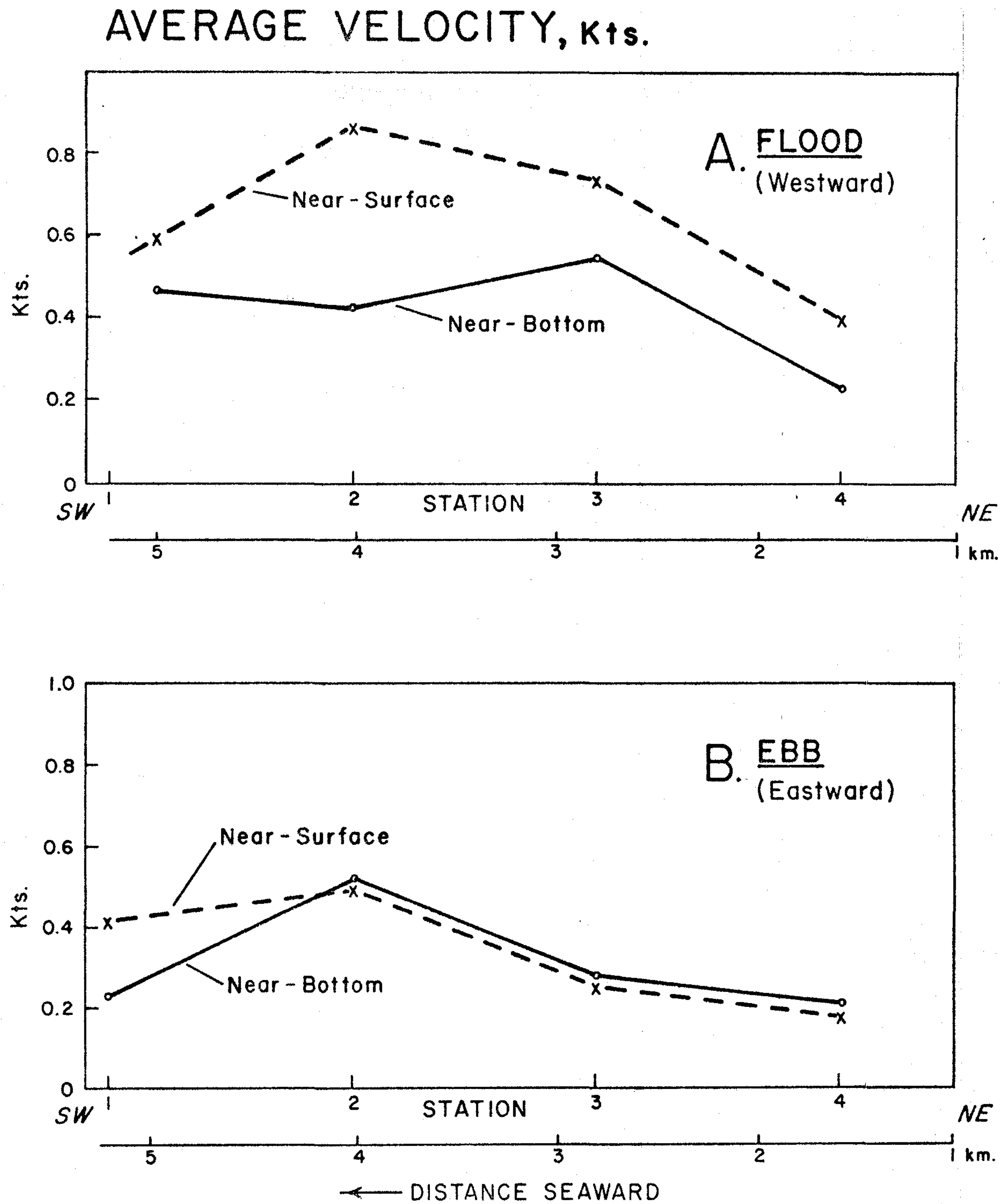


Figure 4. Seaward change in average current speed over a drogue excursion across Southwest Road; A. flood, upper; B. ebb, lower. Averages based on data for excursions in Figures 3 and 5.

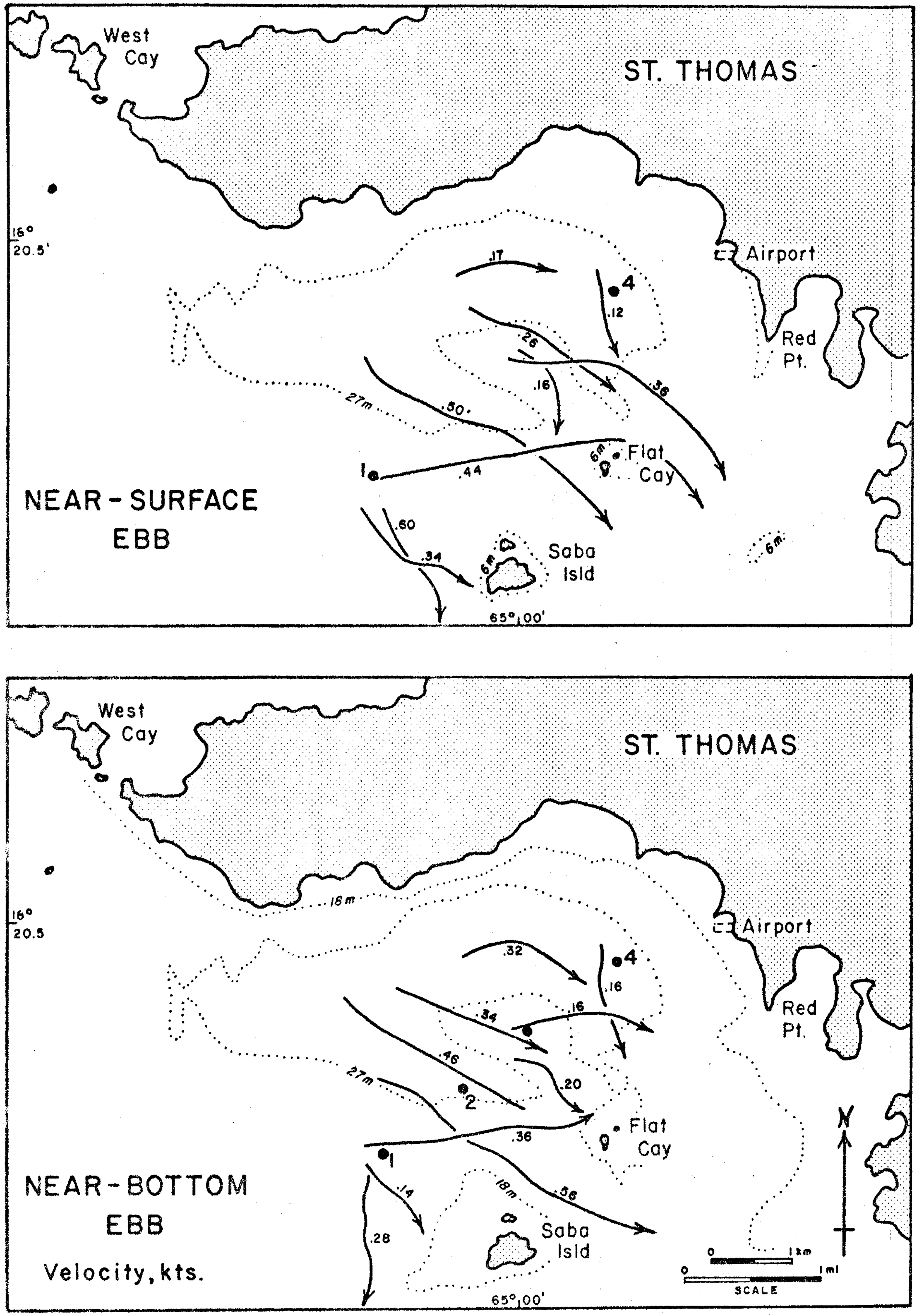


Figure 5. Composite system of drogue tracks for ebb tide, December 29, 1979-January 1, 1980. January 3-4, February 22, August 15, September 3-4, October 10, 1980; near-surface, upper; near-bottom, lower.

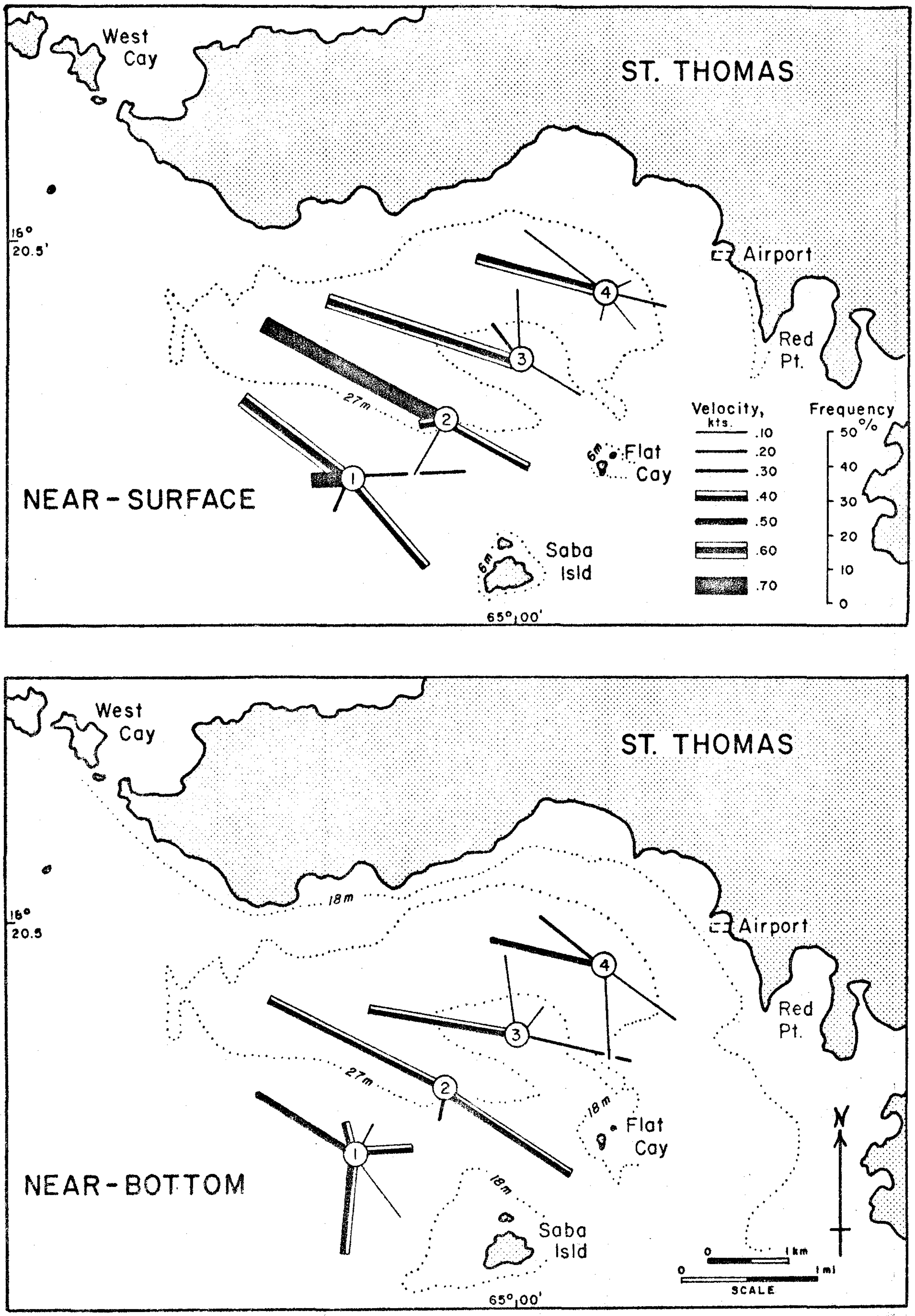


Figure 6. Directional frequency-velocity plots for all available drogue data; near-surface, upper; near-bottom, lower.

than elsewhere at station 1. This trend reflects the topography whereby tidal flow at station 1 is affected by divergence (ebb) and convergence (flood) around Saba Island while currents at station 2 flow freely through the passage between Saba Island and Flat Cay. Directional characteristics are not only displayed in the velocity-frequency diagrams based on averaged data, but also in individual drogue paths.

As the tide turns from ebb to flood, drogues traversing central reaches, vicinity of stations 2 and 3, reverse direction. They turn sharply, 180 degrees, during a short period of less than one hour near slack current, e.g. ebb, December 29-January 1, Appendix B. Of note however, are a few near-bottom drogues that occasionally turn counterclockwise as the current changes from flood to ebb, e.g. flood, June 19-20, Appendix B. This contrasts with the change from ebb to flood which is distinctly reversing.

Rotary motions are more common than reversing motion around slack water in near-shore reaches, vicinity of station 4, and also offshore, vicinity of station 1, near Saba Island. The nearshore spin is mainly counterclockwise as the tide changes from flood to ebb. This motion conforms to the bed geometry defined by the 18 and 27 m depth curve, and to the shoreline configuration which is directed southwestward between Perseverance Bay and Fortuna Bay. Drogue paths recorded during a diurnal tide September 3-4 demonstrate the counterclockwise motion or gyral, in both near-surface and near-bottom water. The feature is not well-organized or persistent because an opposite spin, clockwise, was observed on the same tide January 3-4, and June 26-29, a time of moderate southeast wind (Appendix B).

Offshore, northwest of Saba Island, a transient rotary motion was observed; (1) clockwise as the tide turned from flood to ebb, e.g. February 22; (2) counterclockwise as the tide turned from ebb to flood, e.g. September 3 and June 19-20, Appendix B. Although the rotary motions occur mainly around slack water when current is weak, over many tidal cycles they can produce a small but significant net onshore or offshore movement of water. This is exemplified by the 13-hour excursions of near-bottom drogues around stations 3 and 4, September 3-4, Appendix B.

The tide does not change throughout the entire area at the same time. Instead there are significant inequalities across the area. At conditions of ambient or light wind and semi-diurnal tide, both the slack before flood and the slack before ebb are about two hours earlier offshore, vicinity of station 1, than nearshore, near station 4. Intermediate stations 2 and 3 lag station 1 by 0.7 and 1.5 hours respectively. As a result the current can be flooding for several hours nearshore while offshore it is ebbing, e.g. June 19-20, near-bottom, Appendix B. When the tide is diurnal, phasing can reverse so that the slack before ebb offshore (station 1) lags the same slack nearshore (station 4) by about 2.7 hours. For synoptic observations such differences create an apparent horizontal shear between nearshore and offshore waters.

Generally near-bottom drogues turn around slack water at the same time as their companion near-surface drogues. Differences can take place however, during ebb tide when near-bottom drogues move eastward whereas near-surface drogues move westward for two to three hours or more. The opposed directions are produced partly by differences in the time of slack water between the surface and bottom, e.g. September 24, Appendix B. For another part they are created by easterly winds that drive a drift current westward near the surface. This flow component exceeds the weak easterly ebb component as is the case at stations 3, 4, June 5, 8, 19-20, 26-29, Appendix B. In brief, the main effect of southeasterly winds (> 8 knots) is to attenuate ebb flow and to drive near-surface water, in vicinity of stations 3 and 4, onshore between Perseverance and Fortuna Bays.

Comparison of drogue excursions at contrasting neap and spring tide range shows that ebb currents are about 50 percent faster at spring range. Therefore, neap excursions are shorter and more variable than at spring. Differences in flood excursions are less evident because many "flood" drogues departed the tracking area to the west before completing one-half a tidal excursion.

When the new results of this study are compared with prior observations in adjacent areas, they exhibit many common features. The trend for low speeds near shore particularly near the bottom, is consistent with observations of Nichols and Towle (1977). Additionally, the trend for flood predominance at station 4 is consistant with a residual flood along the coast between Perseverance Bay and Fortuna Bay recorded by Nichols and Towle. As noted by Tetra-Tech (1977) moderate southeast winds produce an onshore flow in this area. Whereas Nichols and Towle observed a net easterly inshore flow off Brewers Bay (station Dee) the present drogue observations indicate a flood predominance in an area farther offshore (station 4). This anomaly may represent flow in different parts of a transient flood gyral. The present observations generally verify near-bottom current measurements of U.S.G.S. (Miller et al 1980). From one week of continuous in situ measurements U.S.G.S. detected a flood predominance at three stations, close to stations 1, 2 and 3 of this study. However, the flood at U.S.G.S. station 2 was directed northward whereas the drogue observations record a northwestward flow near this station.

In summary, drogue observations of this study reveal a primary tidal circulation with a predominate westward movement through Southwest Road. The predominance probably reflects the superposition of a semi-permanent flow on the tidal current. As shown in Figure 7 the irregular geometry of the Road modifies the primary flow in such a way that the flood converges westward while the ebb diverges eastward around island and reefs. This pattern results in an intensification of current speed through passages and central reaches whereas currents are reduced and less organized in near-shore and near-island reaches. These areas have a transient secondary circulation governed by phasing of tidal currents, local geometry and the wind. Both primary and secondary circulations are stronger and better organized during spring range and diurnal tide than during neap range and semi-diurnal tide.

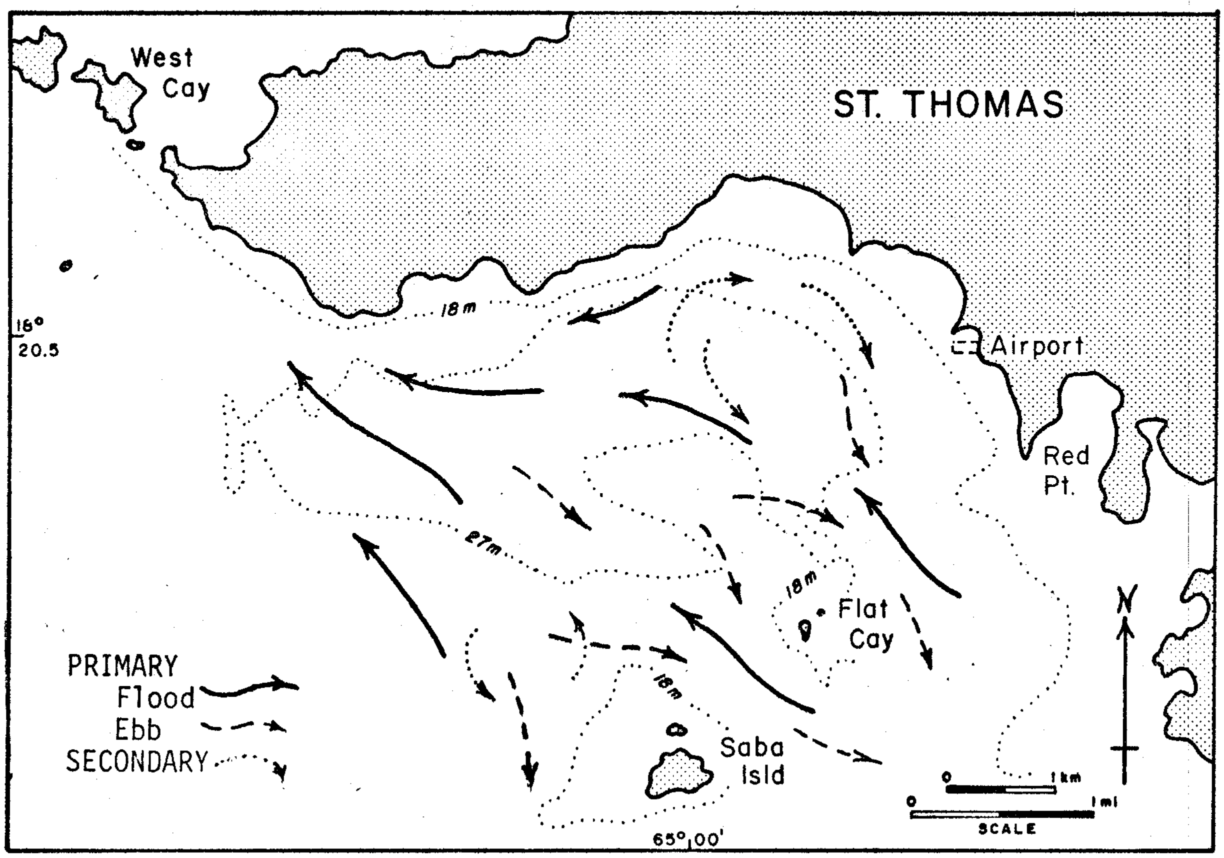


Figure 7. Simplified pattern of circulation in Southwest Road.

Suspended Solids

The data for total concentration of suspended material collected over the 11-month period, December 5, 1979 to October 30, 1980, are presented in Appendix C and Figures 8 and 9. The temporal distribution is relatively uniform throughout the period. Concentrations at all stations (4) and all sampling points (8) varied within narrow limits, from a minimum of 0.03 mg/l to a maximum of 2.85 mg/l. The mean of all values was 0.75 mg/l. The annual variation of weekly mean values for all stations and all depths varied 0.28 to 1.20 mg/l. Table 3 gives the mean values station by station and depth by depth. In general, nearshore concentrations (station 4) are slightly higher than offshore concentrations (station 1). This gradient suggests that the supply, or source of suspended material, is nearshore. It indicates the nearshore water mass, in vicinity of station 4, differs from the offshore water mass over the year.

Table 3. Mean dry weight of suspended solids from Southwest Road sampled weekly between December 5, 1979 and October 30, 1980.

Station/Depth		Mean Dry Weight mg/l
1	surface (offshore)	0.46
	bottom	0.59
2	surface	0.65
	bottom	0.77
3	surface	0.65
	bottom	0.73
4	surface (nearshore)	0.89
	bottom	1.26
	Mean	0.75

Preliminary microscopic examination of filtered suspended material shows components consist of phytoplankton including diatoms and peridisians, organic detritus, fine calcareous particles and reef mucus.

When temporal changes are examined from week to week and monthly (Figure 10), concentrations are generally (> 1 mg/l) higher at station 4 between February and June and at station 2 in April and May, than at other times of the year except for early August. The increased load during February and April at station 4 occurred at a time of airport construction activity when a trench was dug into the nearshore bed by dragline dredging. The elevated values during May and early June at stations 2 and 4 occurred at a time of heavy rainfall and rougher than normal seas which may have stirred recently exposed or recently deposited dredged material. This is supported by monitoring observations of the V. I. Division of Natural Resources Management (Rogers, 1980) that indicated relatively high values at near-shore stations, particularly in surface water, near the airport. Although station 2 lies 3.5 km offshore and station 4 lies 1.3 km offshore, water from these locations is susceptible to increased loading associated with either airport construction or runnoff from the island. But the levels of suspended material are low, less than 2.5 mg/l.

The short-term increase of near-bottom concentrations at station 4, August 6 is associated with passage of Hurricane Allen which reached its greatest intensity at St. Thomas, August 5, 1980. No significant increases were observed at other stations or sampling points. However, high concentrations, up to 144 mg/l, were observed in nearshore zones (Rogers, 1980). In brief, the effects of hurricane wave stirring of reefs and nearshore zones including recently exposed or deposited fill or dredged material, is largely limited to nearshore and near-reef reaches of Southwest Road.

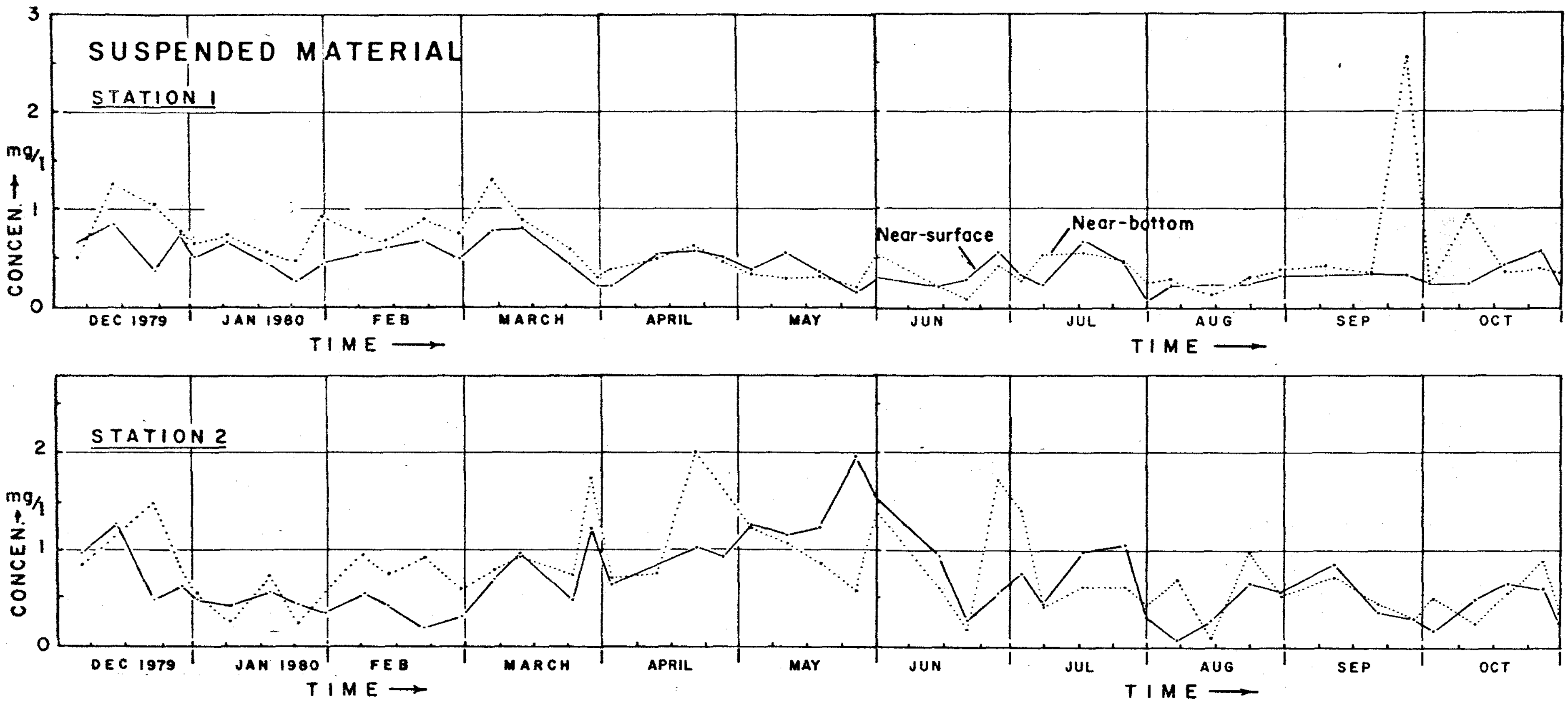


Figure 8. Temporal distribution of total suspended material, mg/l from December 1979 to October 1980, stations 1 and 2; near-surface and near-bottom.

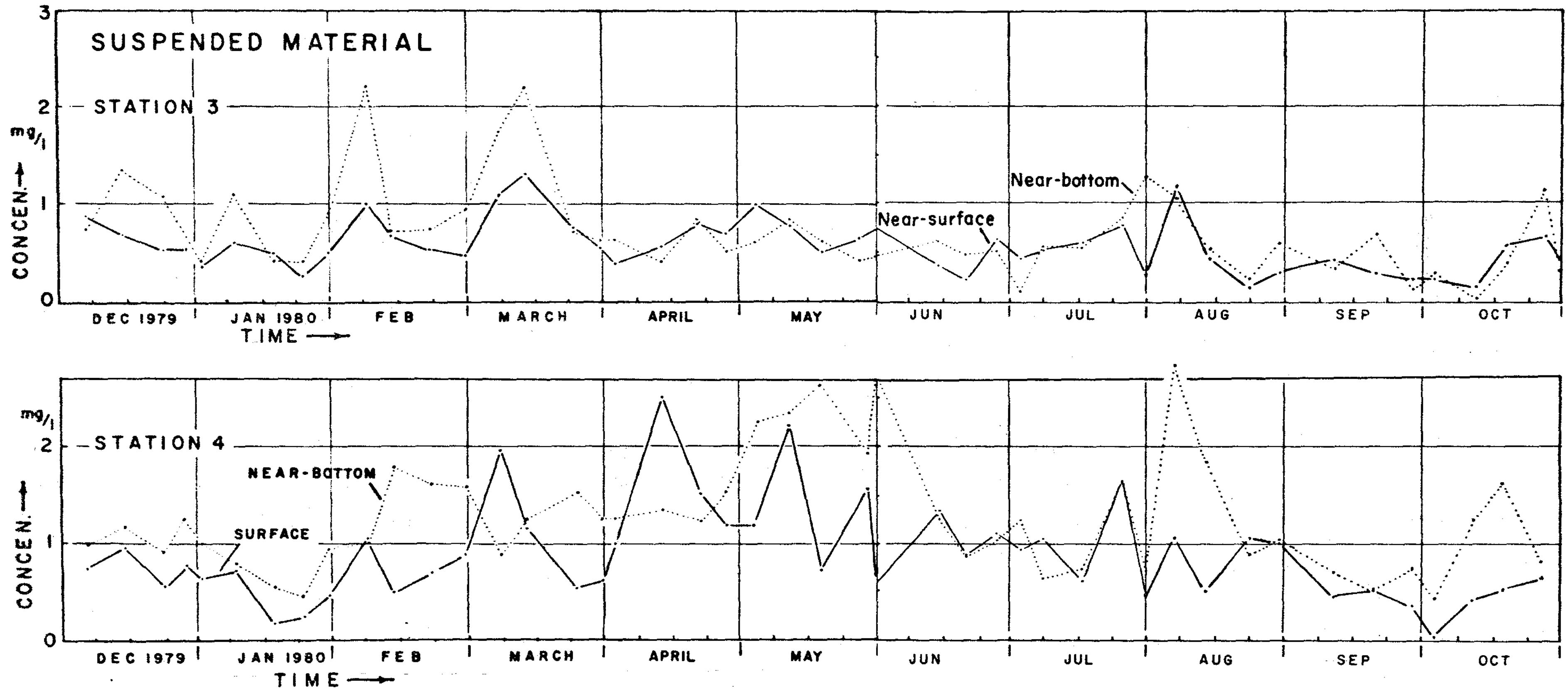


Figure 9. Temporal distribution of total suspended material, from December 1979 to October 1980, stations 3 and 4; near-surface and near-bottom.

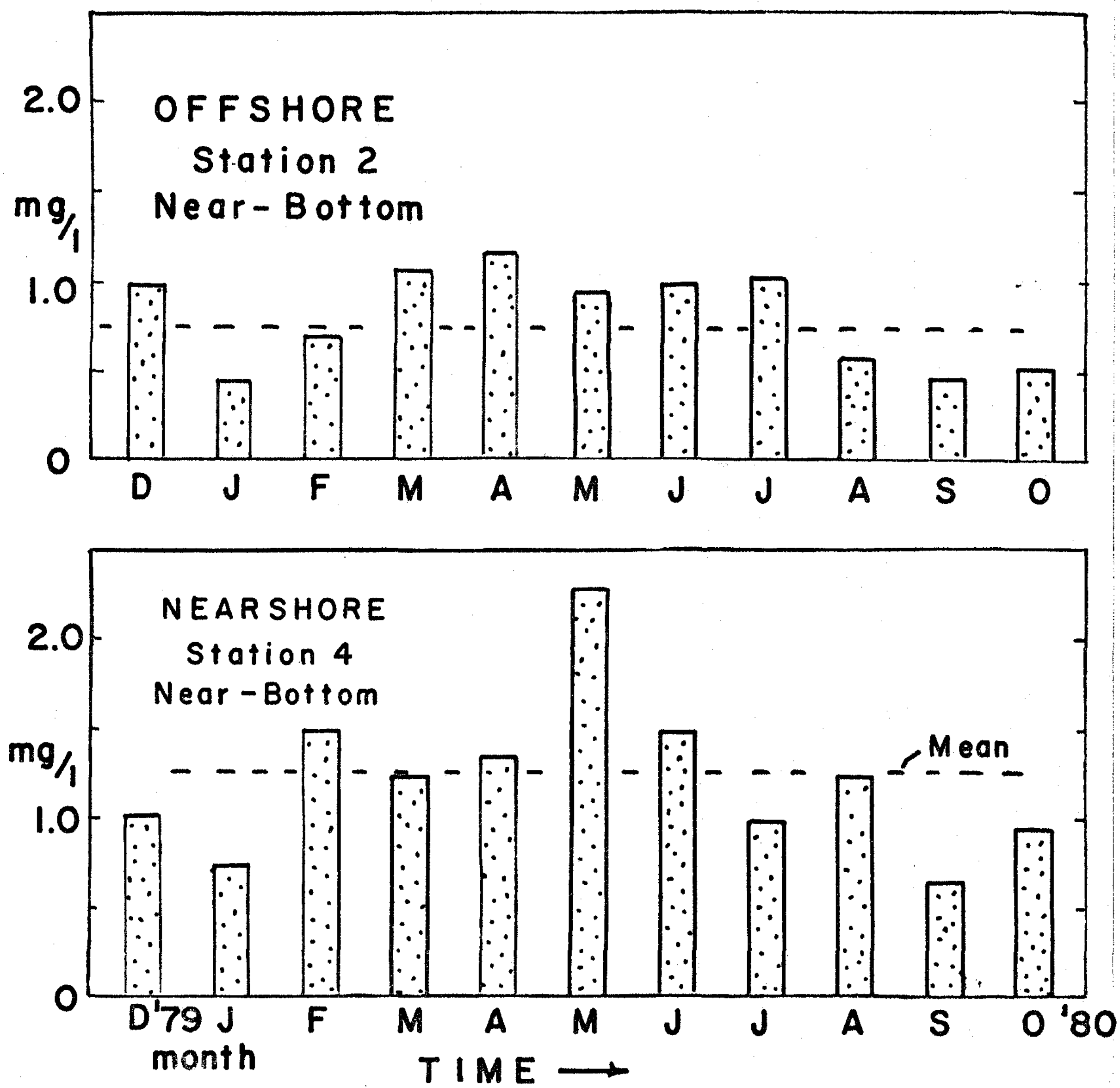


Figure 10. Temporal distribution of monthly mean total suspended material, mg/l at stations 2 and 4, near the bottom.

4. IMPLICATIONS

The drogue observations show that circulatory conditions for dispersion of mining discharge are highly variable. A turbid plume can be expected to vary hourly, tidally, daily, fortnightly and seasonally in extent and direction. The plume would most likely trail narrowly northwest-southeast in the predominate tidal current. It would extend farther to the northwest than to the southeast, thus lessening impact on reefs around Saba Island and Flat Cay. Whenever, the wind blows more than 10 knots from the southeast, or possibly from the south or southwest, near-surface plumes of flotables may be expected to extend shoreward to beaches between Fortuna and Brewers Bay. This threat however is partly offset by the fact that most suspended material settles. Additionally, its concentration is reduced by natural mixing and dilution. To confine dredged material to the mining site, dredging should be scheduled to take advantage of low energy conditions: e.g. periods of slack tide and neap tide range when ebb current is weak; and periods of low wind when near-surface drift is minimal.

5. REFERENCES

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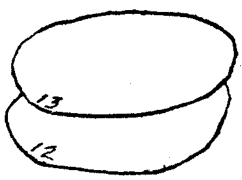
6. ACKNOWLEDGEMENTS

The work for this study was accomplished as follows: Mr. Random Dubois, research scientist of the Island Resources Foundation, accomplished the drogue experiments, collected water samples and analysed the suspended material in the lab. He was assisted by Robert Franks, Kathy Hall, Pam Peebles, Westerfield, Canright, Hulse and Spang. Bruce Potter of IRF acted as general operations manager. We thank Judith Towle of IRF for an accurate and timely accounting of fiscal matters. Peggy Peoples drafted the figures and Teresa Haynes typed the final report.

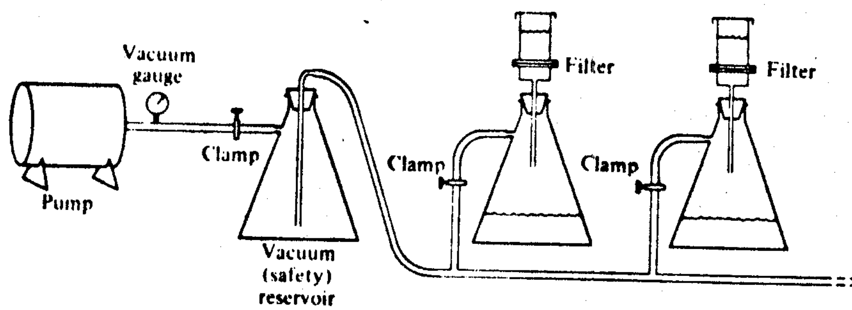
PROCEDURES FOR GRAVIMETRIC DETERMINATION OF TOTAL SUSPENDED MATERIAL (SOLIDS) IN SEA WATER

Following Procedures of Strickland and Parsons (1972)

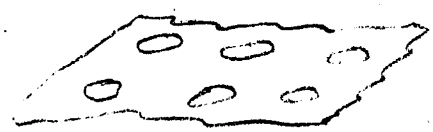
Outline of Method: Flow Chart of Processing



1. Filter preparation; and pre-weighing



2. Filtration set-up and filtering



$$\Sigma \frac{W_2 - W_1 + X}{V}$$

3. Filter drying ⟶ 4. Post-weighing ⟶ 5. Calculations

General Notes:

- Process samples and filter samples within 12 hours after collection.
- Keep instrument room and filtering spaces free of contaminating dust, hair and cigarette ashes.
- Clean lab table and floor prior to processing with wet sponge and mop.
- Handle filters only with forceps throughout processing.
- Always use recently pre-weighed filters. Do not store pre-weighed filters more than one month.

1. Filter Preparation (pre-filtration preparation)

   a. Take the required number of filters, one working filter for each sample and one control for every other working filter, and number the filter edge. Use consecutive numbers and place number on outer edge (bottom side facing observer). Use a permanent, non-water soluble ball point pen.

Precautions:

- Avoid touching filters with fingers; handle only with clean forceps throughout processing.
- Avoid dust contamination throughout processing; eliminate air drafts; cover filters during temporary storage.
- Ensure that filters are not frayed, broken or fibers removed.

b. Soak the filters for 5 minutes in dishes of filtered (0.45 μ) freshwater. This is to remove soluble extracts.

c. Transfer filters one at a time onto shiny surface of clean aluminum foil. Remove excess water by shaking during transfer. Spread out filters to dry without overlap; cover filters with another sheet of foil. To deter sticking of filters to foil, wrinkle the foil.

d. Air dry filters for at least one hour in dehumidified room. Let edges curl up to prevent sticking to foil.

e. Store filters in a storage box or in petri dishes, covered.

f. Weigh filter in dehumidified room at about 45-55 percent constant humid. Remove 16 filters at a time and wait until they come into atmospheric equilibrium of the weighing room (at least six hours).

g. Weigh filter on balance. Use forceps to handle filters, check zero and center balance on every weighing.

h. Record filter number, weight to nearest .05 mg and the humidity at time of weighing.

i. Reweigh filter a second time and transfer filter to petri dish for storage.

Note: Filters cannot be stored for more than one month. Reweigh stored filters as necessary.

2. Filtration Assembly

a. Assemble vacuum pump and filter chain.

b. Pre-clean funnels and bases with filtered freshwater.

c. Place white porous pad on top of filter holder and wet under vacuum; center over holder. Use a new pad for every third filter. (Handle with forceps only.)

d. Place a control filter on top of pad; center over holder and wet with wash water with vacuum on. Record filter number.

e. Place a working filter (solids collecting filter) on top of control filter (this makes a sandwich of pad, control and working filter); center over holder. Turn vacuum on and wet with wash water. Record filter number on data sheet.

   Note: Get rid of air trapped under control and working filters by remounting and wetting down.

f. Assemble filter funnel in center of holder and clamp firm.

Filtering:

a. Shake water sample vigorously in sample bottle or jar. Remove lid immediately and dump sample into pre-clean graduate cylinder. Fill to 1 liter (1000 cc) or an appropriate portion thereof. Read cylinder to nearest 1 ml. Use care not to overflow the funnel.

   Note: How much? For clear water sample 2 to 5 liters of water may be required. Amount of sample water depends on capacity of filter to pass the water. Therefore, add a little sample water at a time until an idea of a suitable volume of water is attained. A maximum amount of water yields better precision. Maintain vacuum suction to less than 15 inches of mercury.

   Shake well each time an aliquot of sample water is delivered to the funnel. Deliver entire contents of cylinder to funnel if possible.

b. Record total volume of sample water delivered to the funnel that corresponds to the filter used.

c. Rinse graduate with filtered freshwater and pour contents into funnel.

d. When funnel is empty rinse funnel 3 times with filtered freshwater. Work down from top and around lower rim. This is to wash down particulate matter and to remove sea salts.

   Flood filters with 2-5 ml of rinse water. This can be accomplished by disconnecting vacuum between each rinse and then rapidly apply suction to remove the water.

   Rerinse according to preceding step; cover filter with rinse water each time.

   Caution: If the rinse water does not cover the filter before suction is applied, parts of the membrane may go unwashed and retain salts that add to weight.

e. With vacuum applied remove funnel when funnel is empty and wash the filters with 1 to 2 ml of rinse water carefully from the side. Repeat rinsing twice.

   Note: This washing step is important as salts are retained along the sides even when sucked dry and may cause substantial errors.

f. Turn off vacuum valve and remove working filter from holder; place on clean and wrinkled aluminum foil to dry. Handle with flat forceps only. Do not stack or overlap filters; spread out.

Rerinse control filter around edges and remove.

Rerinse funnels, holders and cylinders for next samples.

3. Let filters air dry or place foil in oven at 75°C for 1 hour. (If filters curl in oven, let them air dry in future.) Transfer and store in petri dishes individually.

4. Place filters in dehumidified room for 6 hours at the same constant humidity as when they were pre-weighed. Reweigh to determine dry weight. After weighing store filters in freezer.

Note: If the control filters do not return to their original pre-weight ($\pm$ 0.5 mg) processing is suspect.

5. Calculate weight difference between control filters before and after processing. Determine mean difference of all control filters in the batch, either positive or negative. This is a correction value (X).

Calculate the dry weight of total suspended matter by determining the difference in filter weights before and after filtration. Then, add the correction value and divide by the total volume of water filtered.

$$\text{Total dry weight mg/l} = \frac{W_2 - W_1 + X}{v}$$

W_2 is the post-weight (filter plus suspended matter).

W_i is the pre-weight of filter.

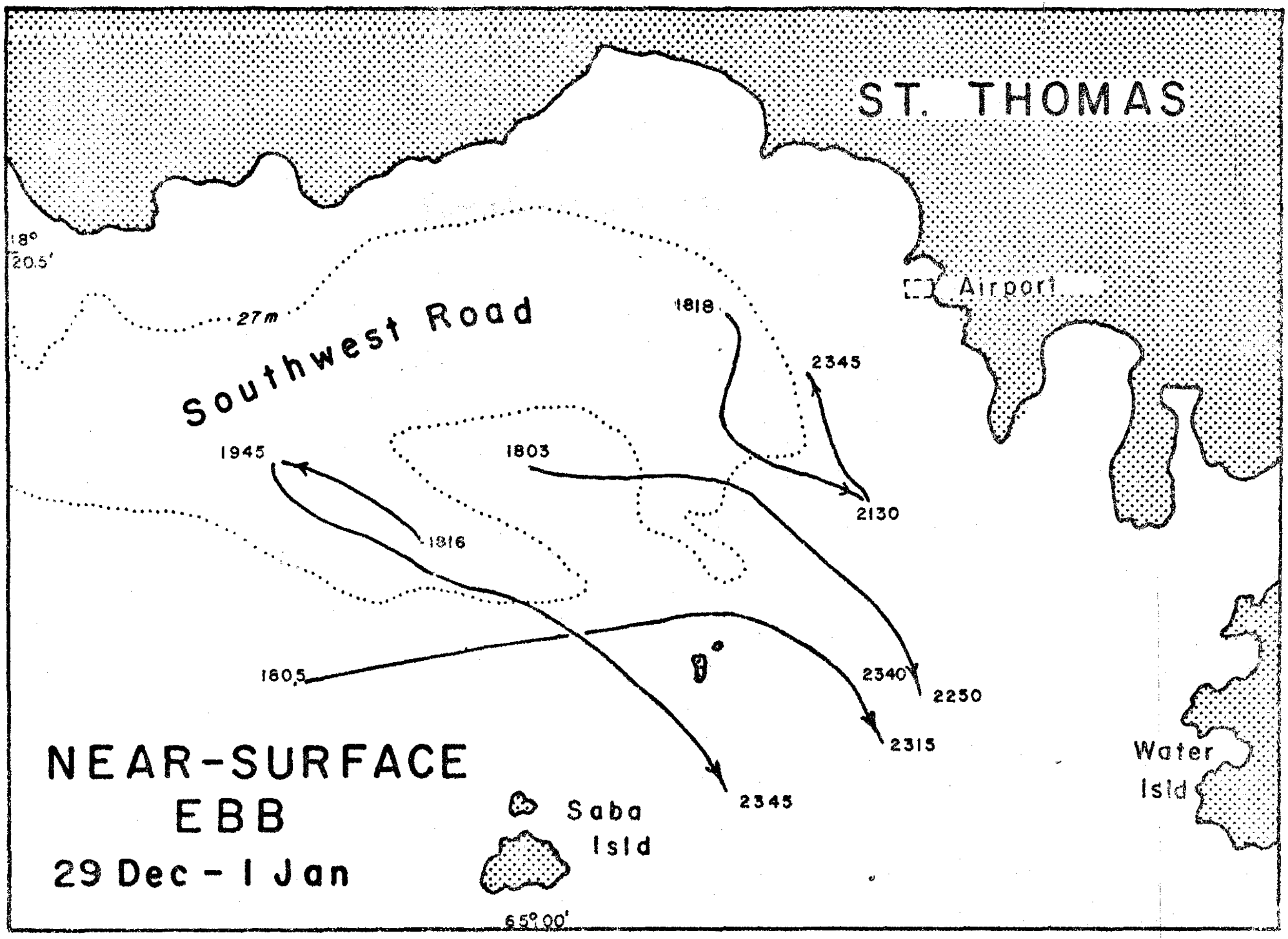
v is the volume filtered in liters (ml X 1000).

Lab Equipment and Apparatus

Millipore pads, 47 mm
Millipore filters, 47 mm diameter, 0.45 µ pore size
Flat-bladed forceps
Millipore filter train (2); clamps funnels (2); flasks (2 liter); vacuum pump
Overflow flask (2 liter capacity)
Ball point pen, fineline, permanent, non-water soluble
Dishes, 1-2 liter capacities
Aluminum foil
Petri dishes
Data sheets

APPENDIX B

Drogue tracks for experiments at different conditions of tide and wind.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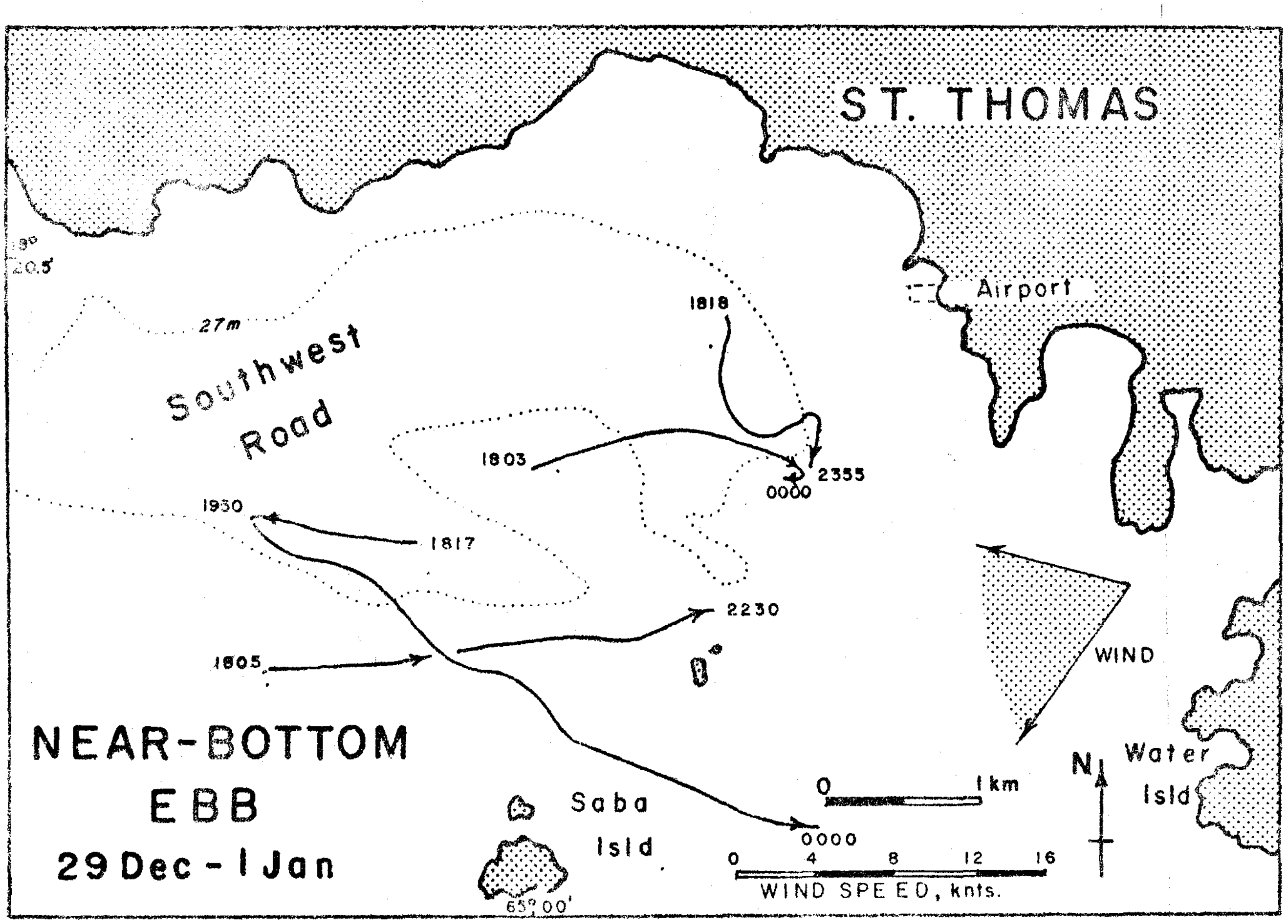
18°
20.5'
Airport
27m
Southwest Road
1818
2345
1945
1803
2130
1816
2340
2250
1805
2315
2345
Water
Isld
NEAR-SURFACE
EBB
29 Dec - I Jan
Saba
Isld
65°00'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18°
20.5'
Airport
1818
27m
Southwest
Road
1803
2355
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1930
1817
2230
1805
WIND
NEAR-BOTTOM
EBB
29 Dec - I Jan
0
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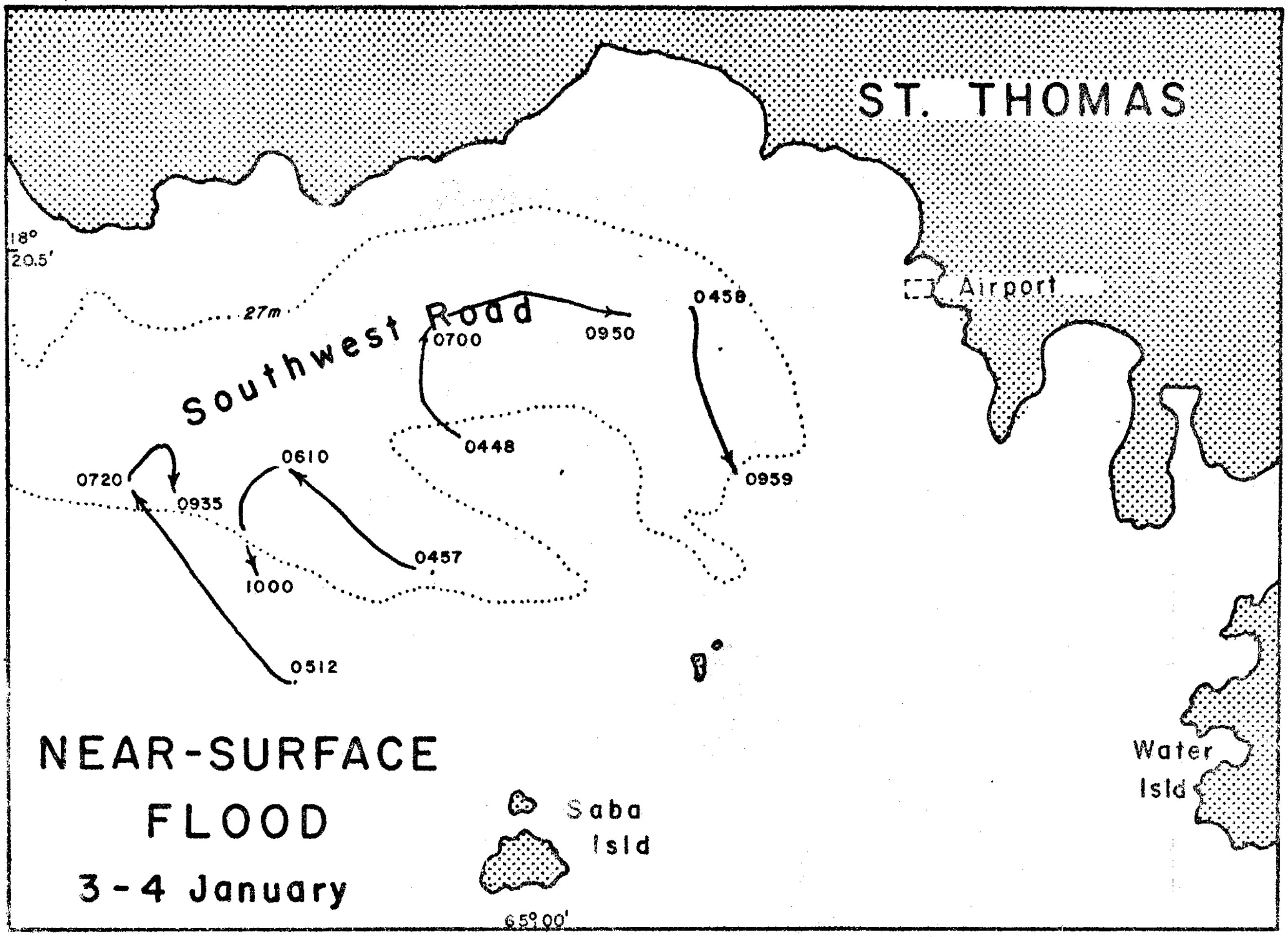
0000
0 4 8 12 16
WIND SPEED, knts.
65°00'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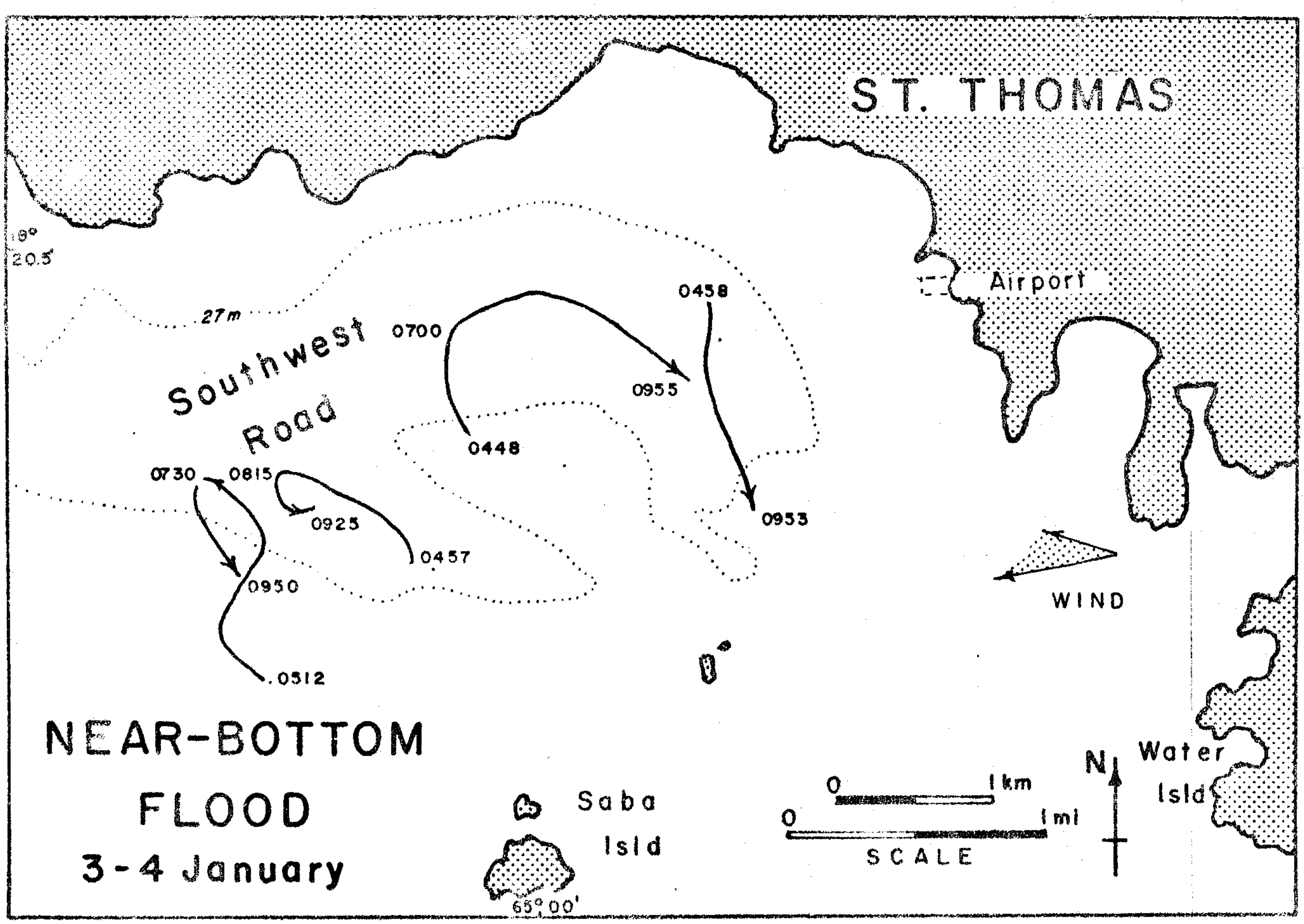
20.5'
27m
Southwest Road
0700
0950
0458
0448
0959
0720
0935
0610
0457
1000
0512
NEAR-SURFACE
FLOOD
3-4 January
Saba
Isld
Water
Isld
65°00'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27m
Southwest
Road
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0458
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0457
0930
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WIND
NEAR-BOTTOM
FLOOD
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Saba
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1 km
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SCALE
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Water
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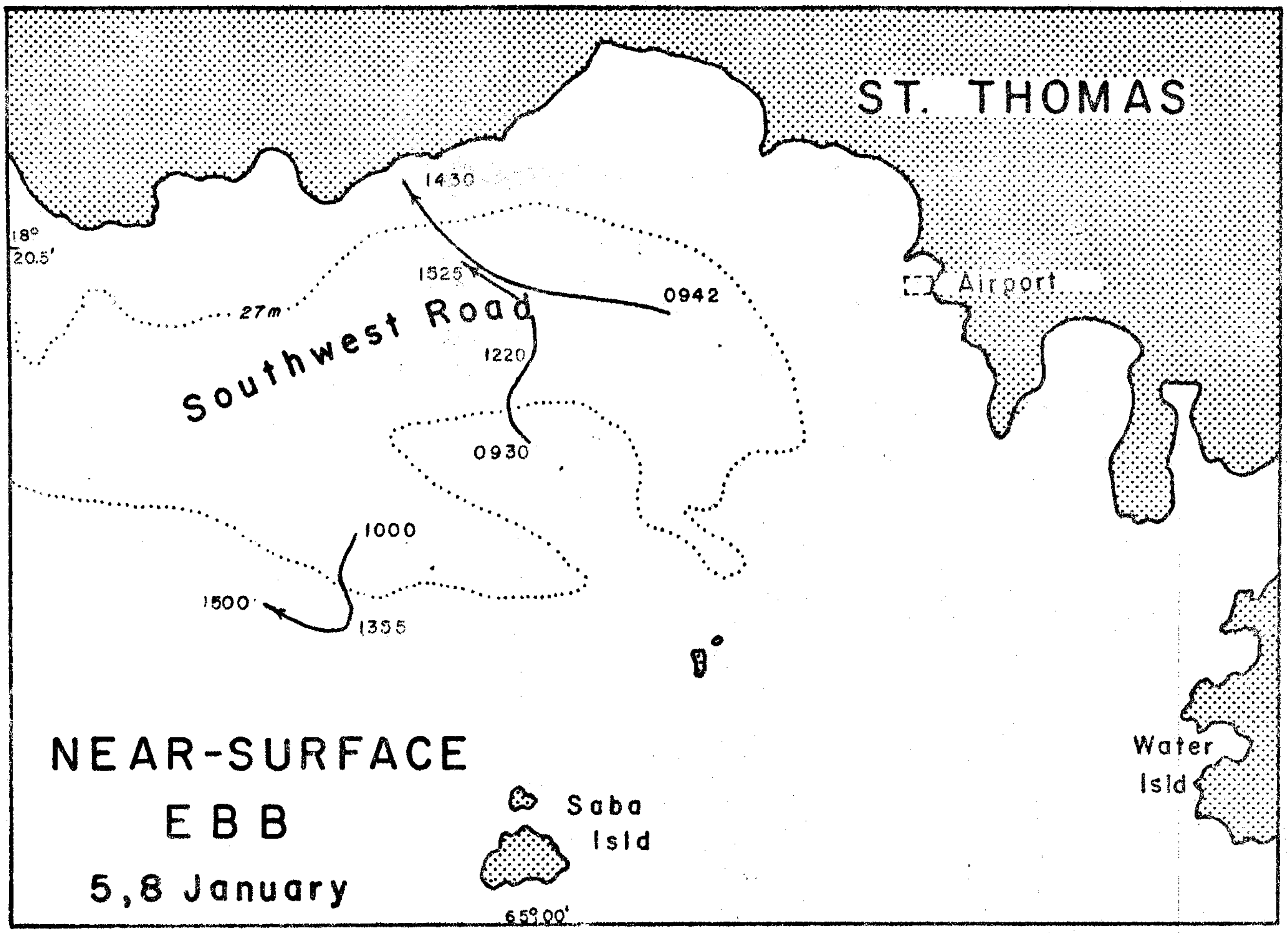
65°00'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Southwest Road
27m
18°
20.5'
1430
1525
0942
1220
0930
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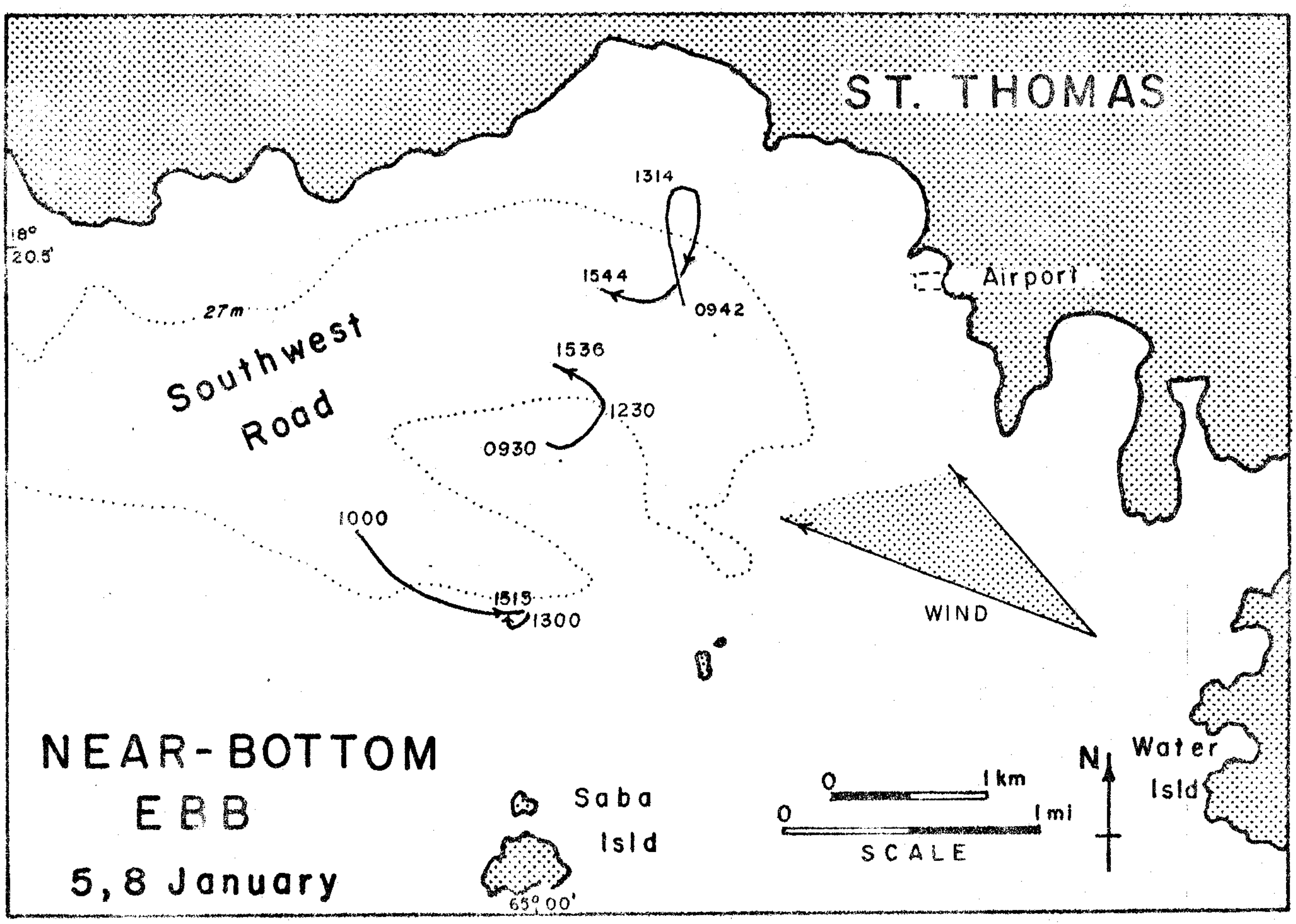
1355
Water
Isld
Saba
Isld
65°00'
NEAR-SURFACE
EBB
5,8 January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Southwest
Road
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1314
1544
0942
1536
1230
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WIND
Water
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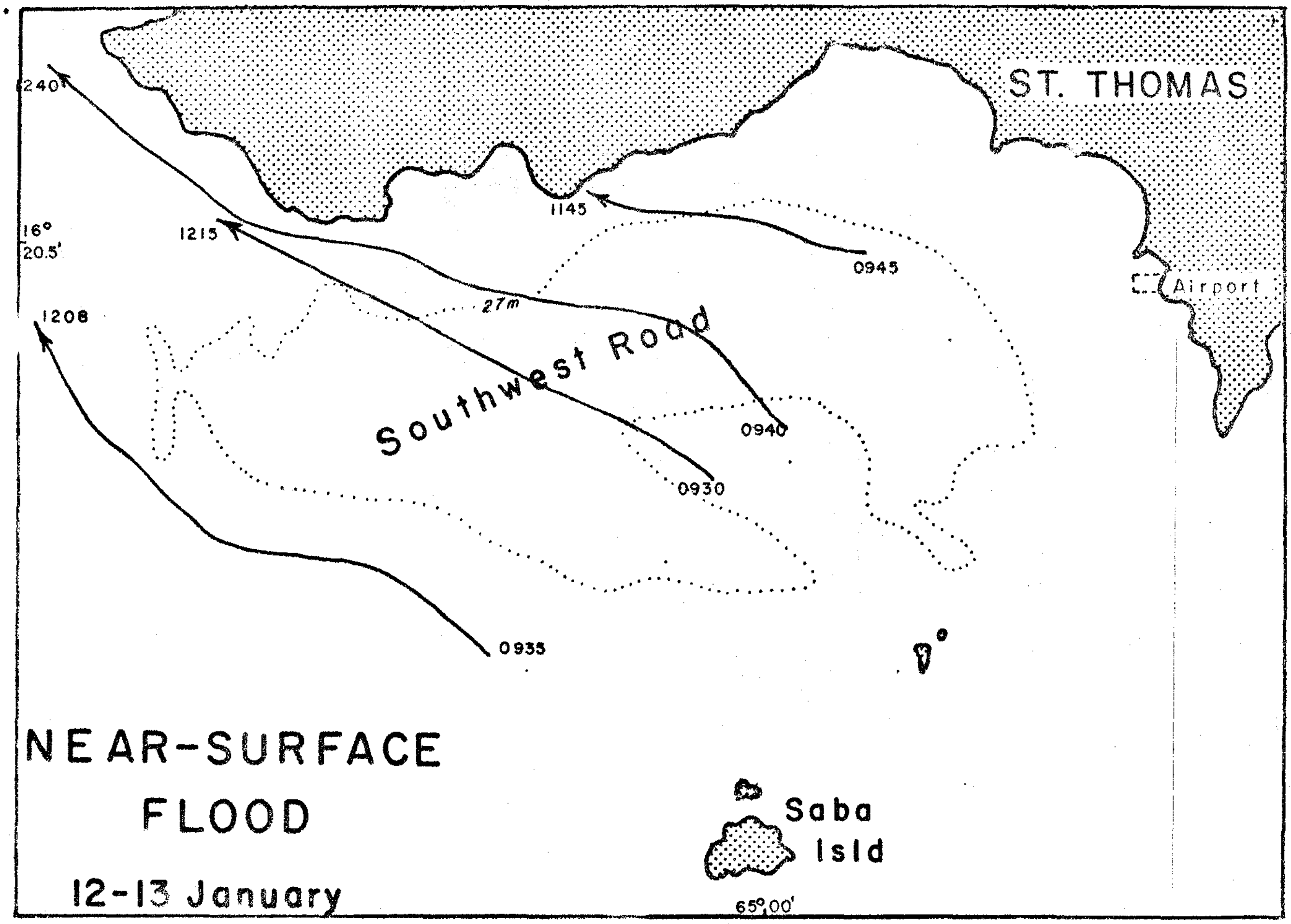
NEAR-BOTTOM
EBB
5,8 January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1145
16°
20.5'
1215
0945
Airport
27m
1208
Southwest Road
0940
0930
0935
NEAR-SURFACE
FLOOD
12-13 January
Saba
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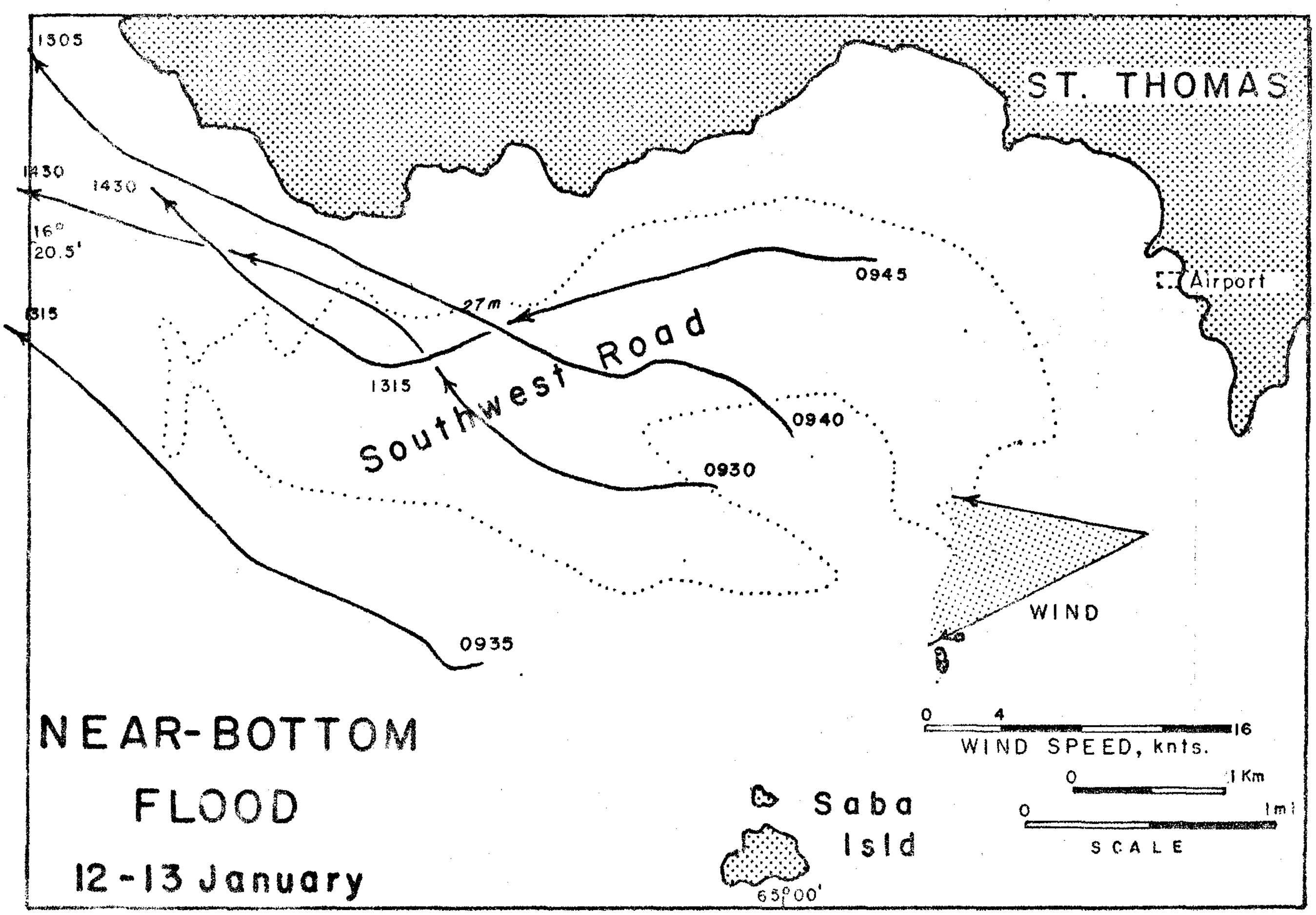
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1305
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1430
16°
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0945
Airport
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Road
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Southwest
0940
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WIND
0935
NEAR-BOTTOM
FLOOD
12-13 January
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WIND SPEED, knts.
0
1 Km
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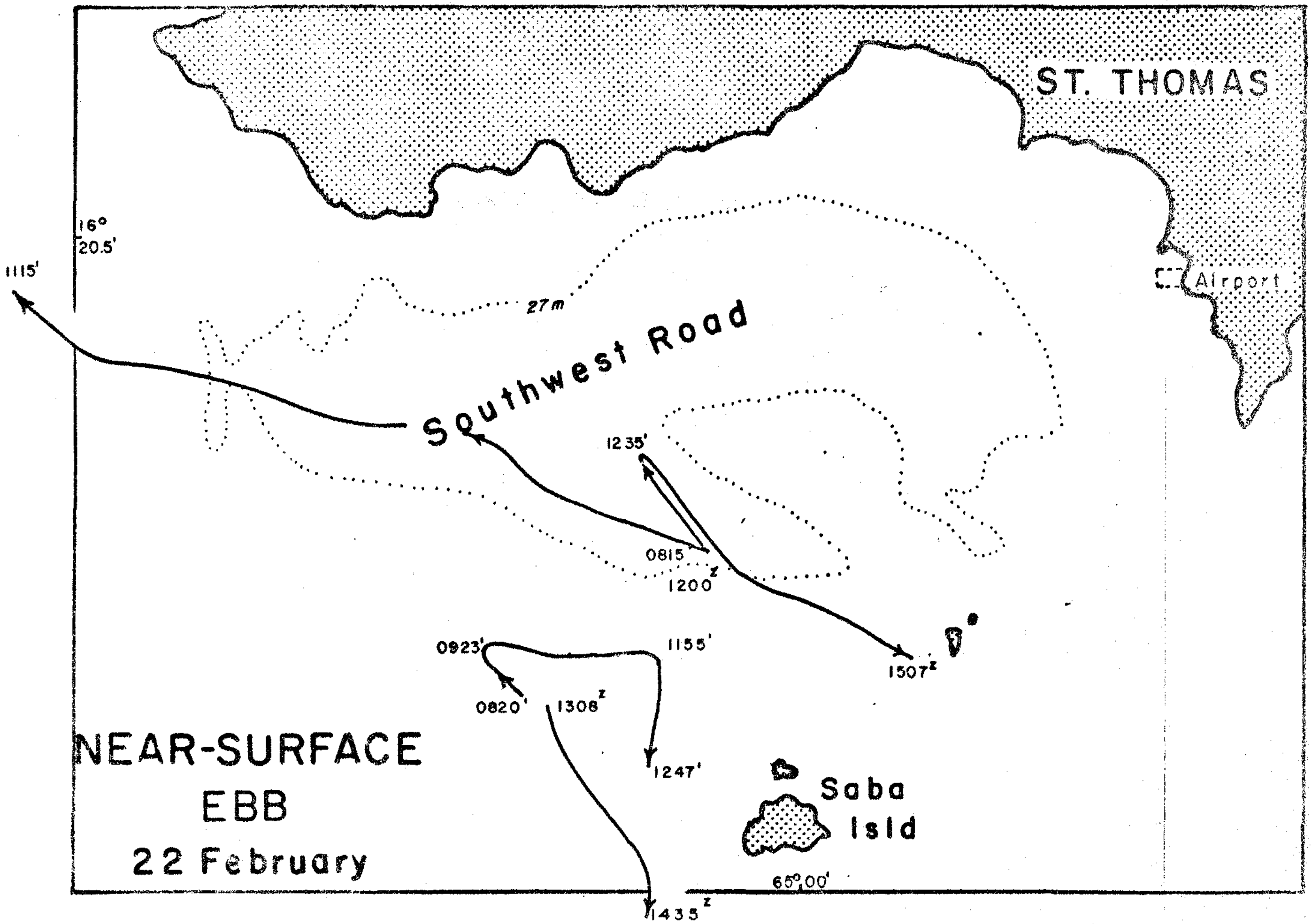
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Southwest Road
1235'
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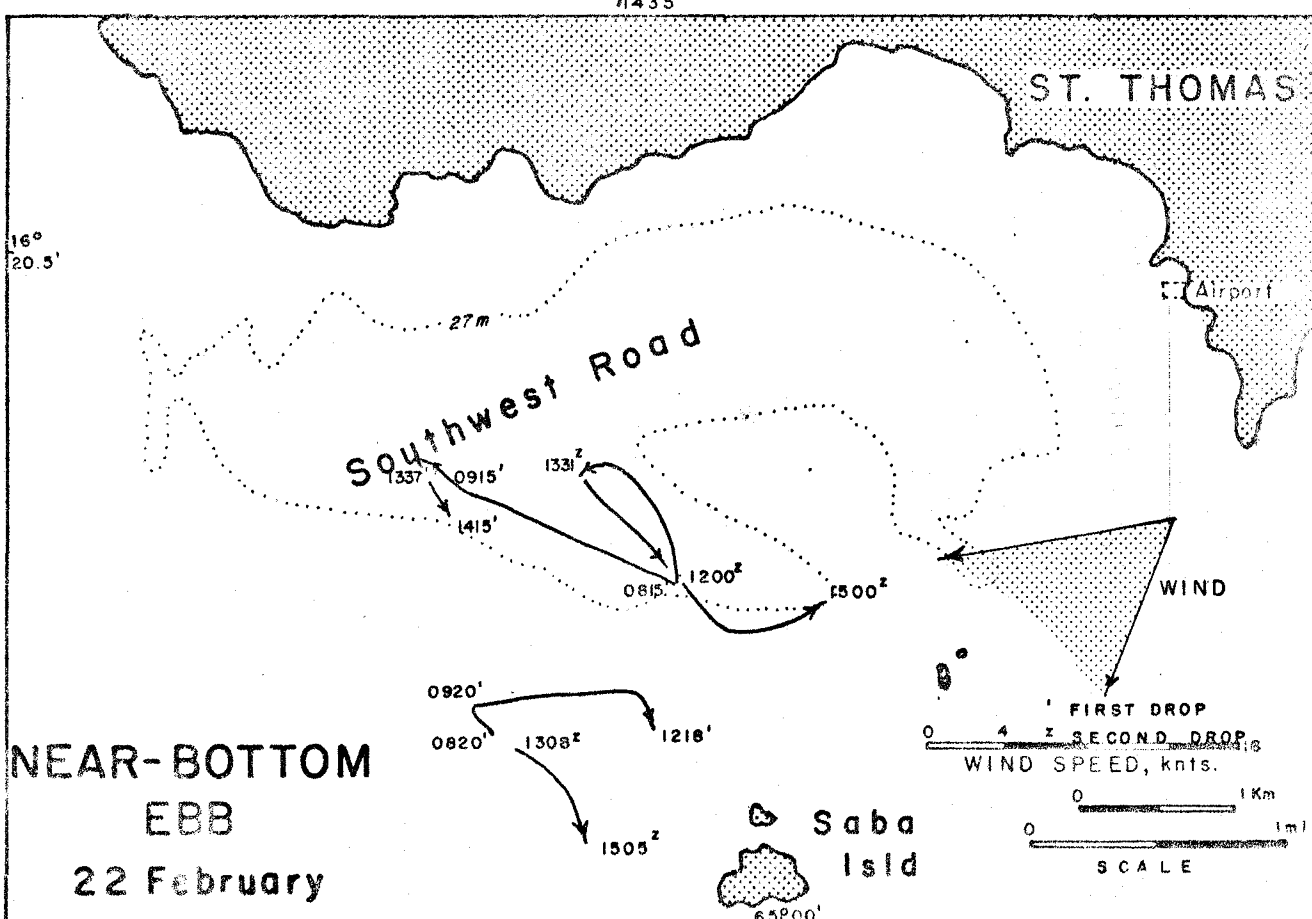
1200z
1507z
0923'
1155'
0820'
1308z
1247'
1435z
NEAR-SURFACE
EBB
22 February
Saba
Isld
65°00'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Southwest Road
1337'
0915'
1331z
1415'
0815
1200z
1500z
WIND
0920'
1218'
0820'
1308z
1505z
FIRST DROP
SECOND DROP
WIND SPEED, knts.
1 Km
1 mi
SCALE
NEAR-BOTTOM
EBB
22 February
Saba
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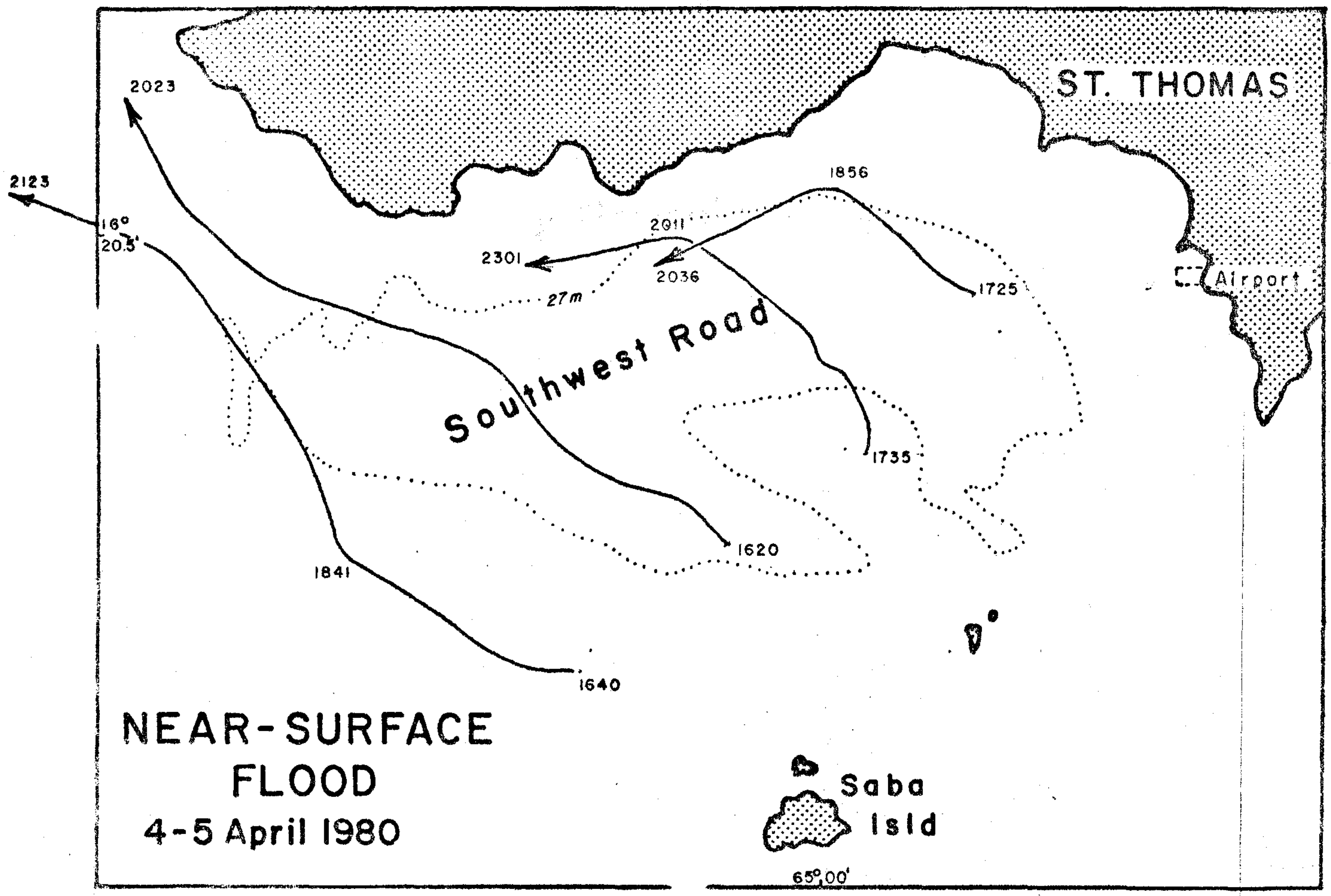
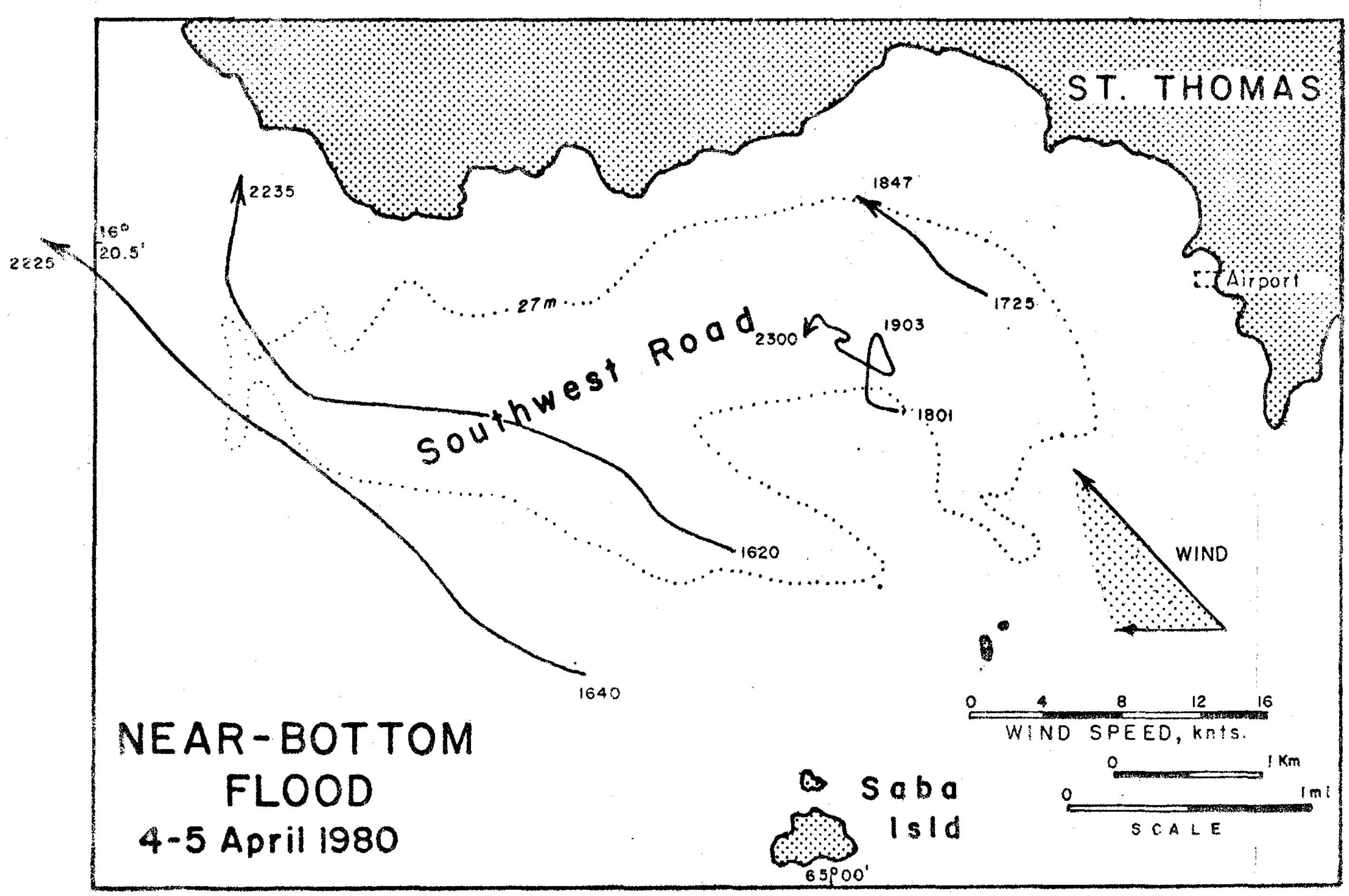
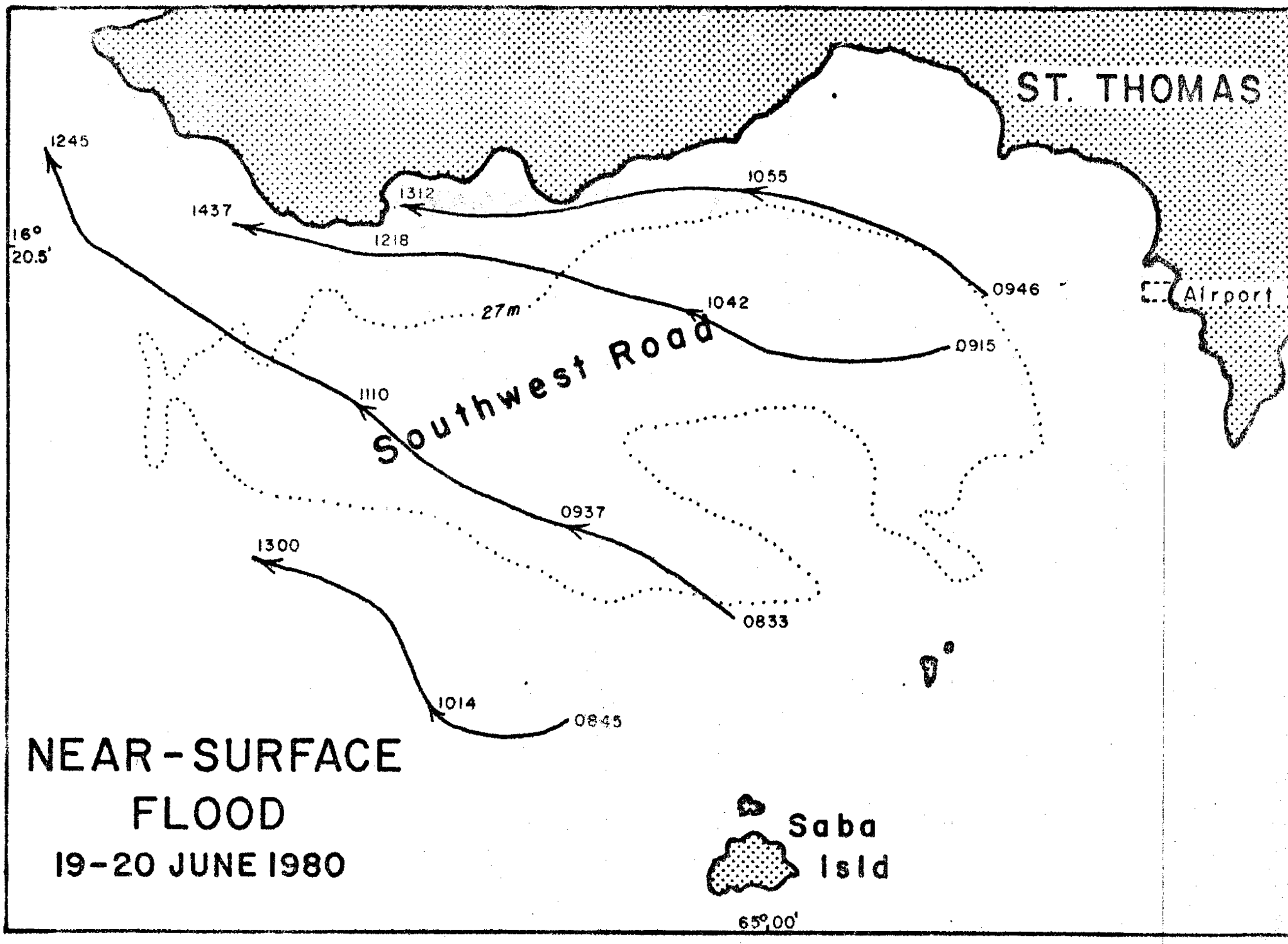
65°00'



NEAR-SURFACE FLOOD
4-5 April 1980



NEAR-BOTTOM FLOOD
4-5 April 1980


ST. THOMAS
Airport
Southwest Road
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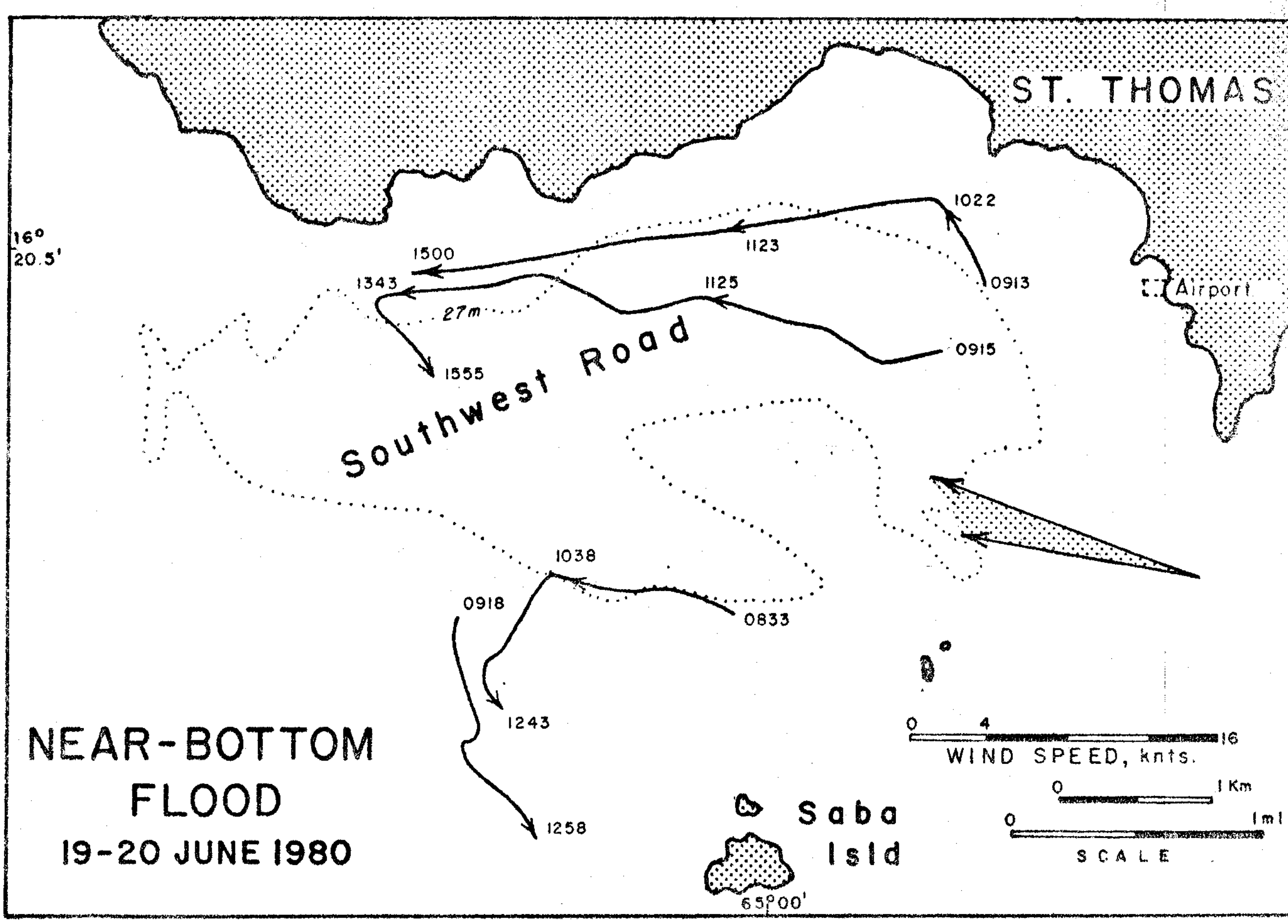
1300
0833
1014
0845
NEAR-SURFACE
FLOOD
19-20 JUNE 1980
Saba
Isld
65°00'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Airport
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27m
16°
20.5'
1022
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1123
0913
1343
1125
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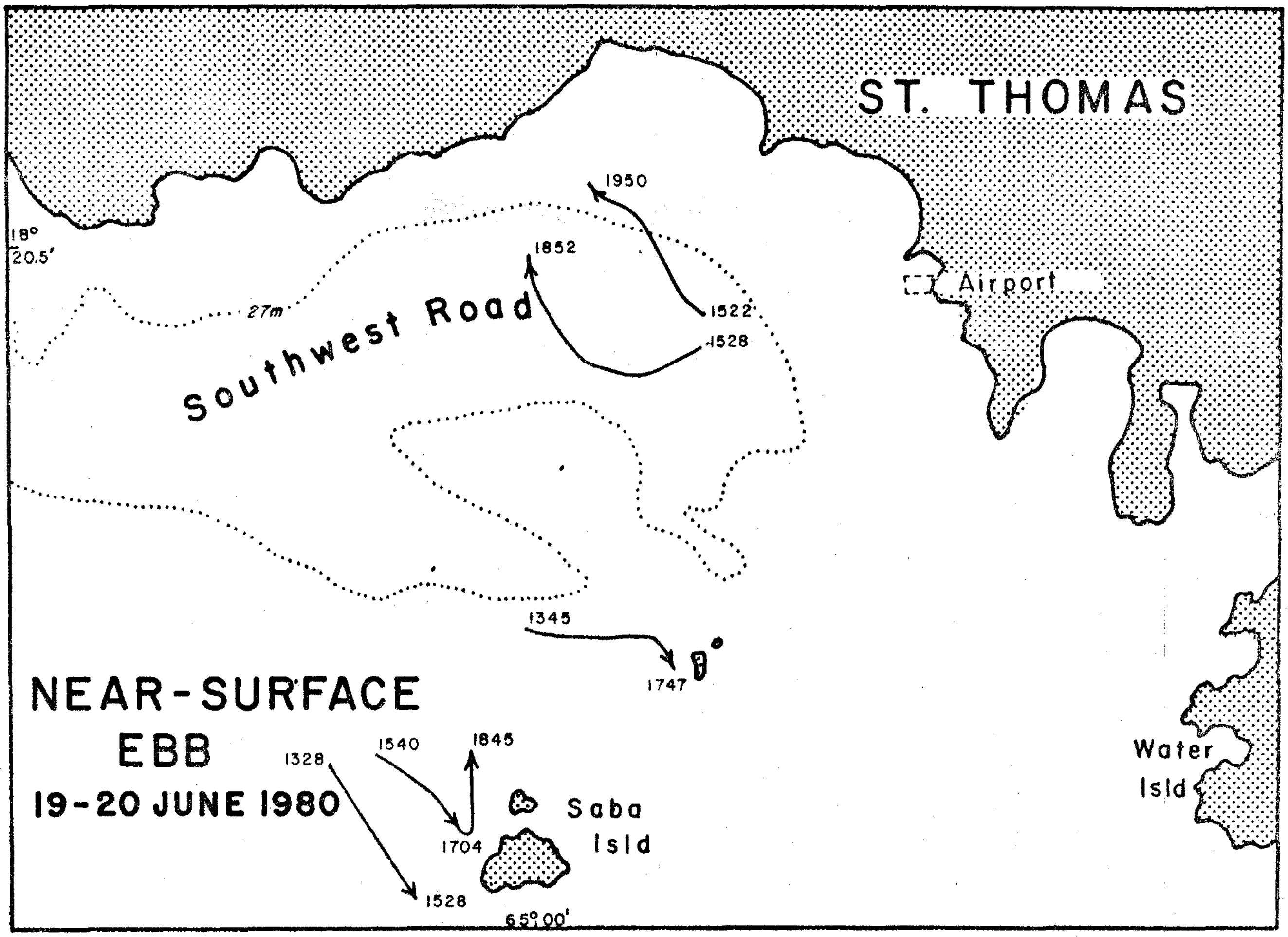
1038
0918
0833
1243
1258
NEAR-BOTTOM
FLOOD
19-20 JUNE 1980
0
4
16
WIND SPEED, knts.
0
1 Km
0
1 mi
SCALE
Saba
Isld
65°00'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Airport
Southwest Road
27m
18°
20.5'
1950
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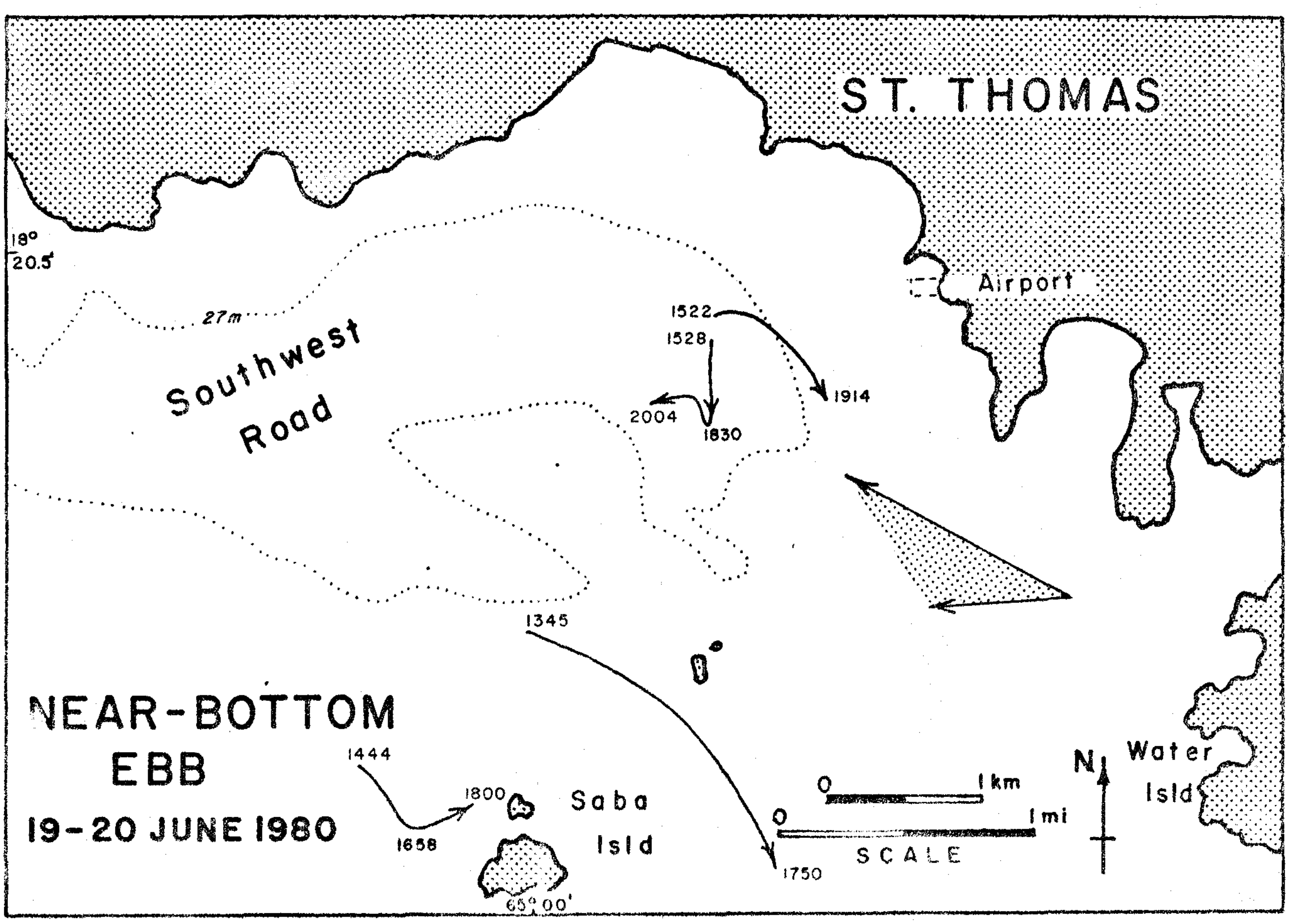
1522
1528
1345
1747
NEAR-SURFACE
EBB
19-20 JUNE 1980
1328
1540
1845
1704
1528
Saba
Isld
65°00'
Water
Isld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Airport
Southwest
Road
27m
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NEAR-BOTTOM
EBB
19-20 JUNE 1980
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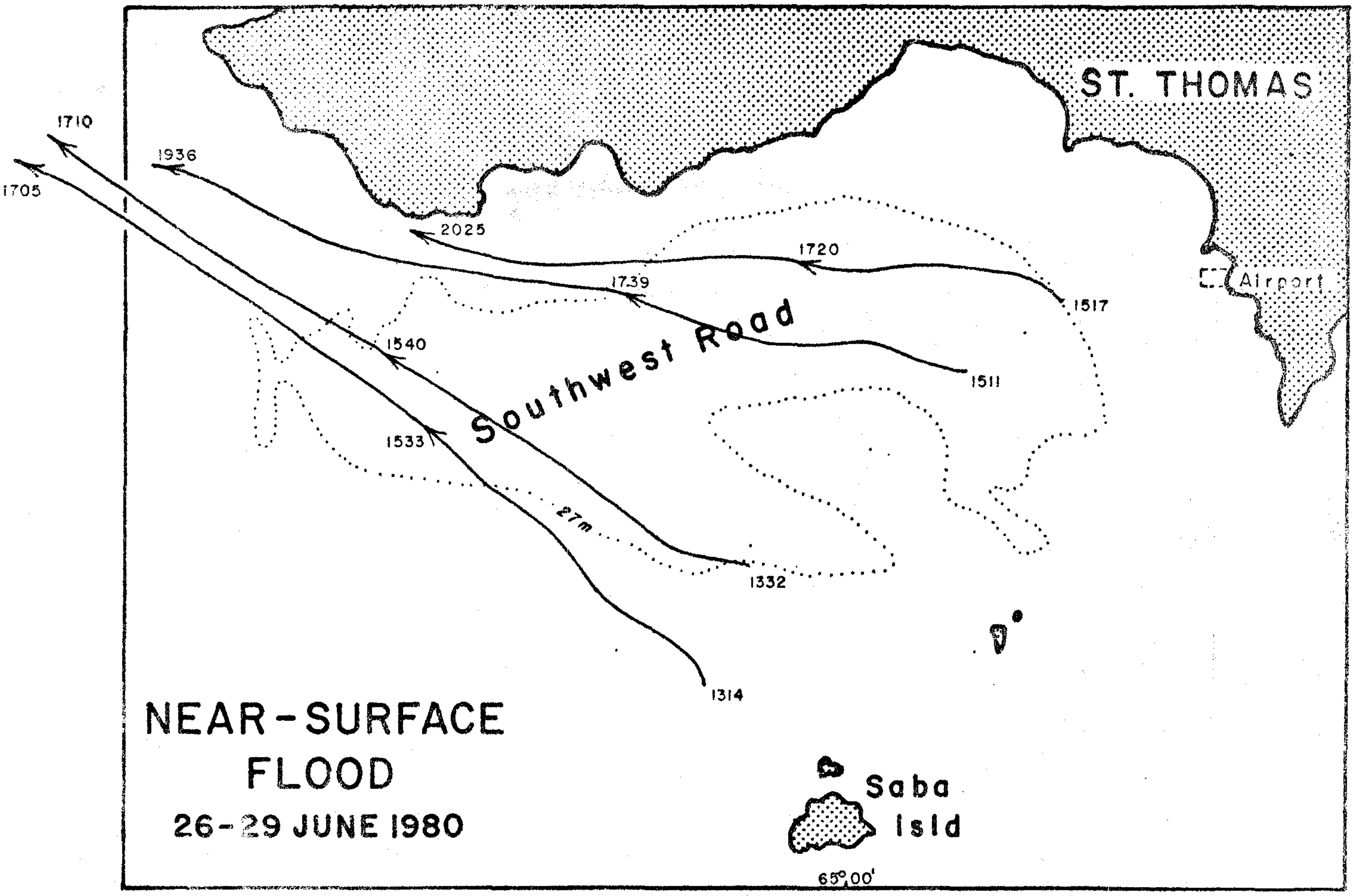
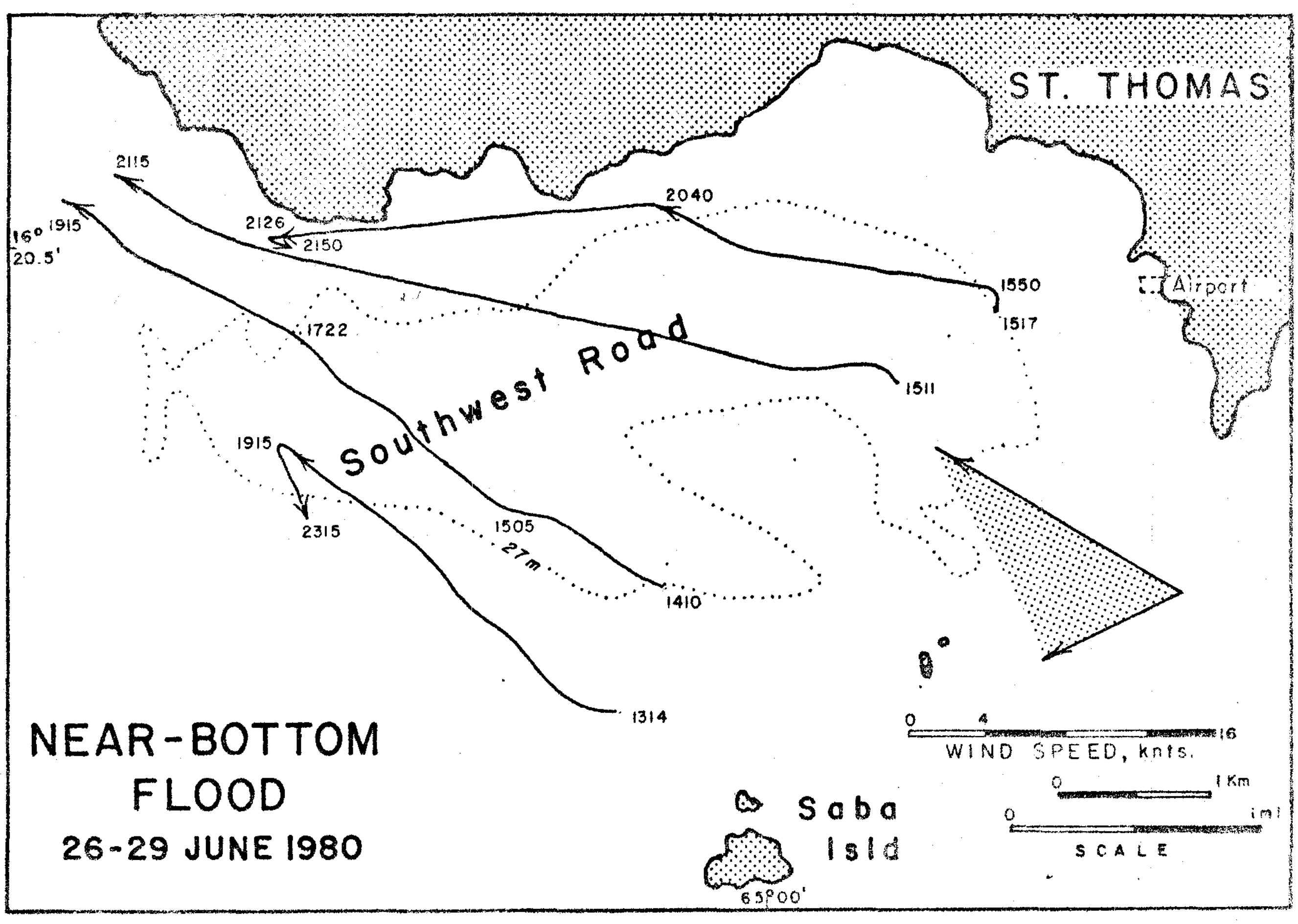
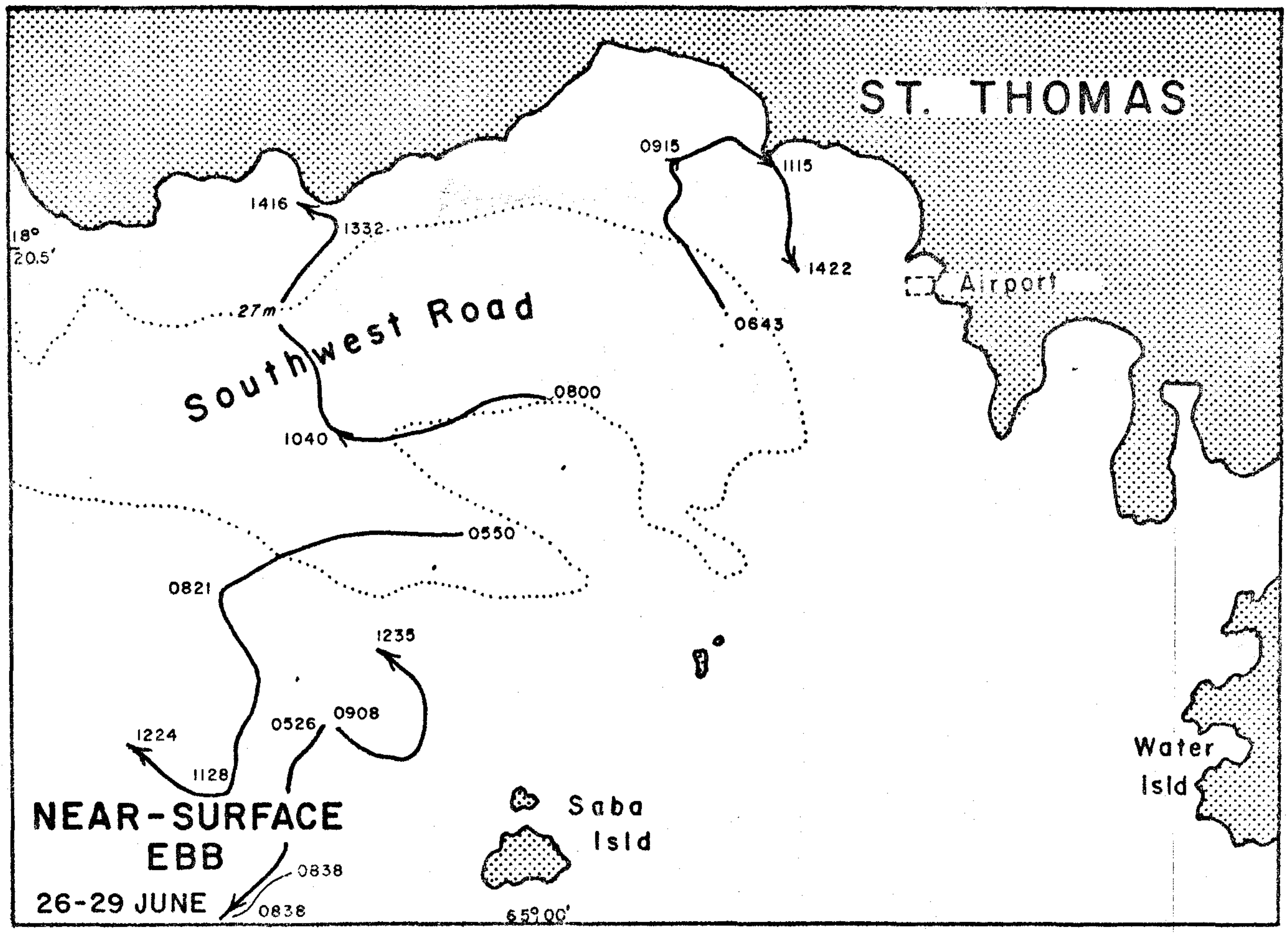
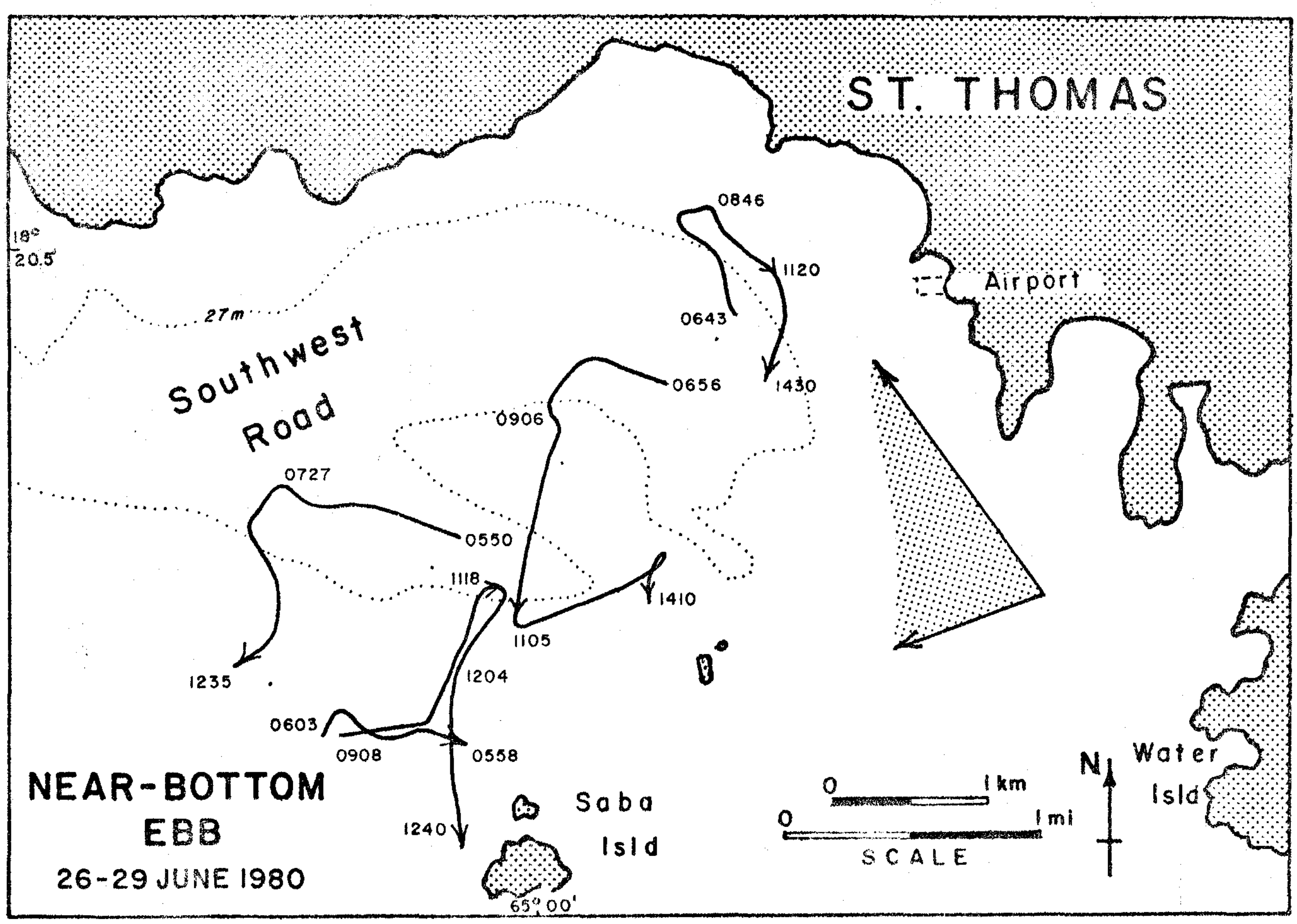
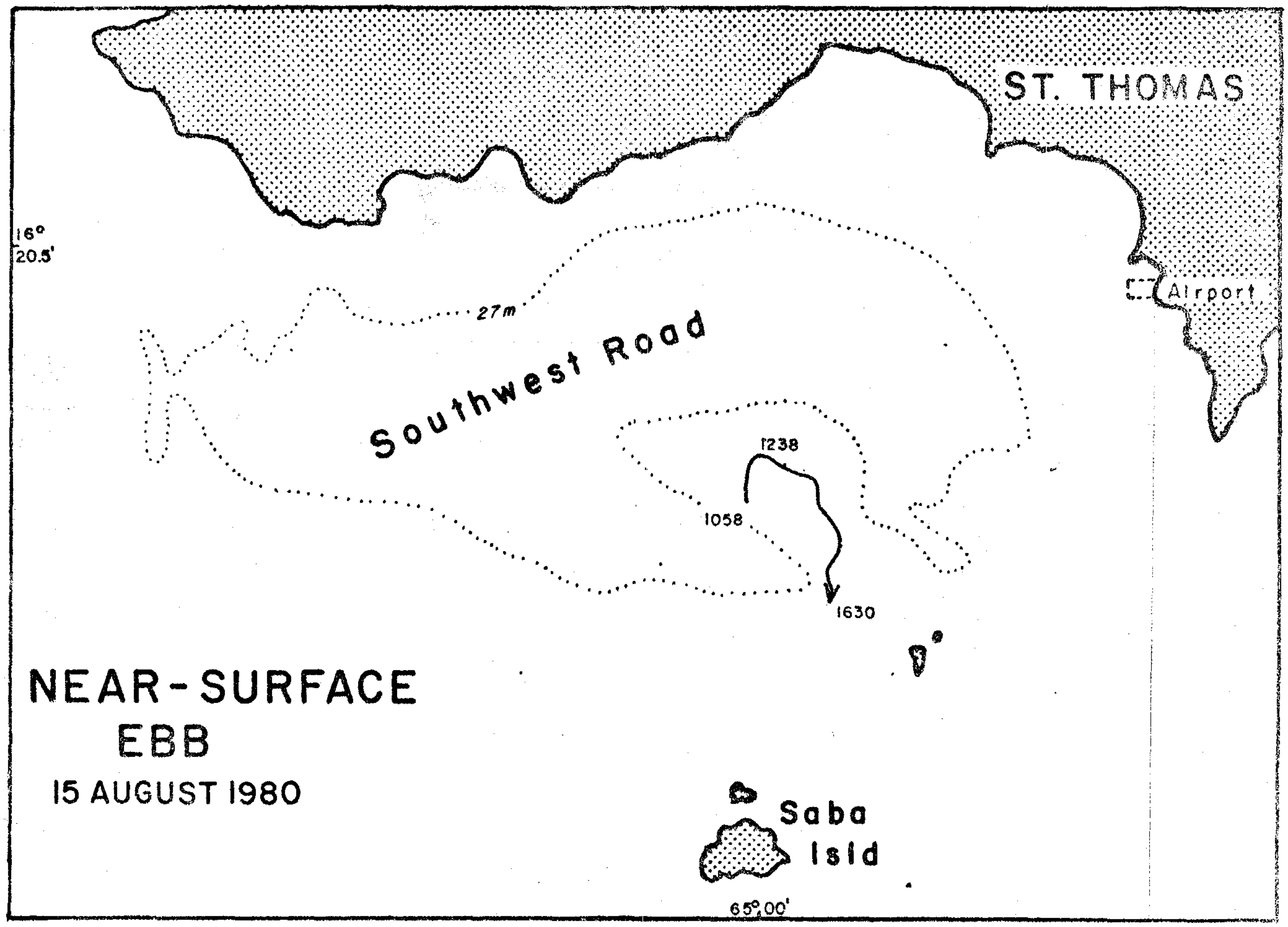
0
1 mi
SCALE
1750
N
Water
Isld

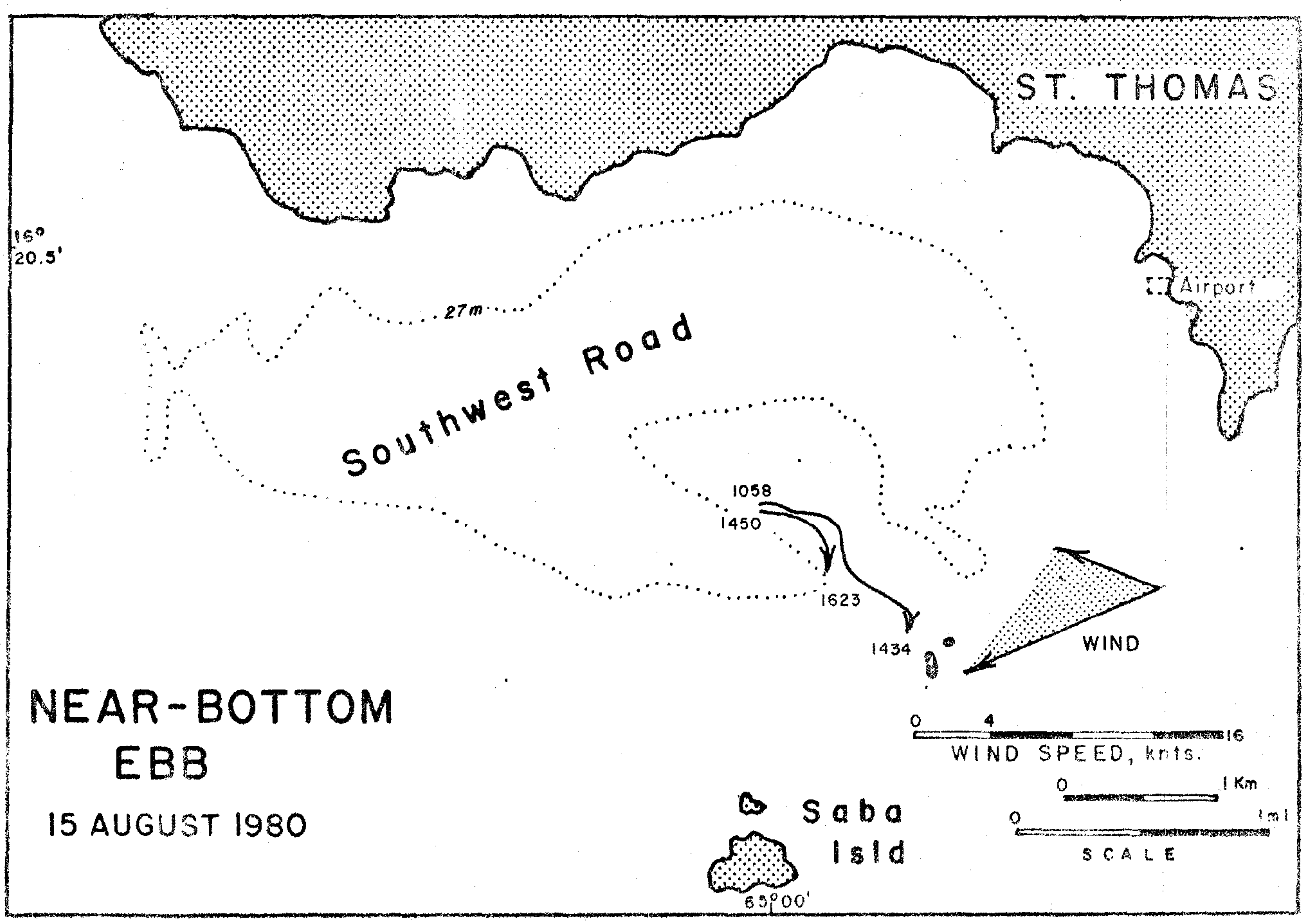

ST. THOMAS
Airport
Southwest Road
1710
1705
1936
2025
1720
1739
1517
1511
1540
1533
1332
1314
27m
NEAR-SURFACE FLOOD
26-29 JUNE 1980
Saba Isld
65°00'

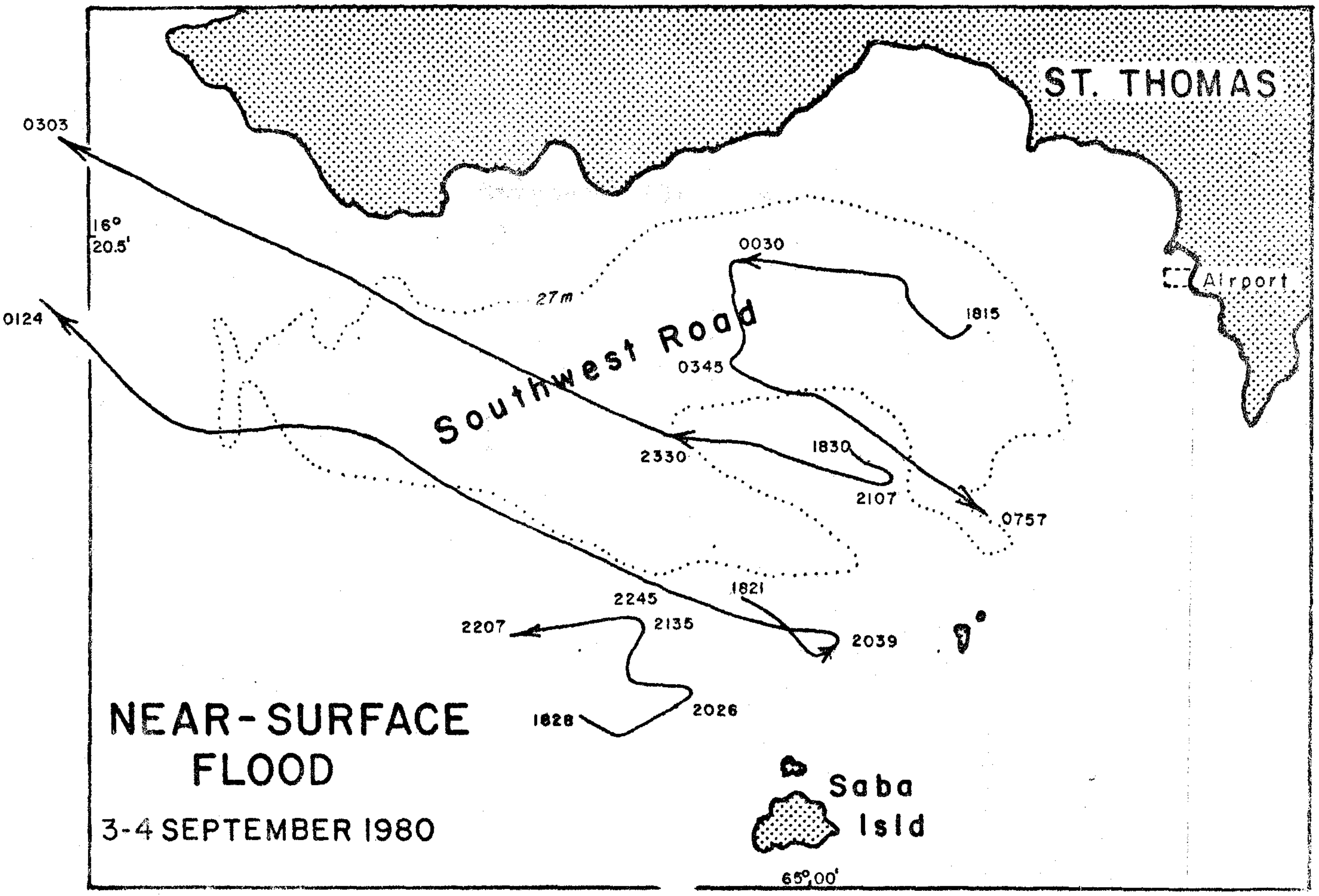

ST. THOMAS
Airport
Southwest Road
2115
16° 20.5'
1915
2126
2150
2040
1550
1517
1511
1722
1915
2315
1505
27m
1410
1314
NEAR-BOTTOM FLOOD
26-29 JUNE 1980
0 4 16
WIND SPEED, knts.
0 1 Km
0 1 mi
SCALE
Saba Isld
65°00'

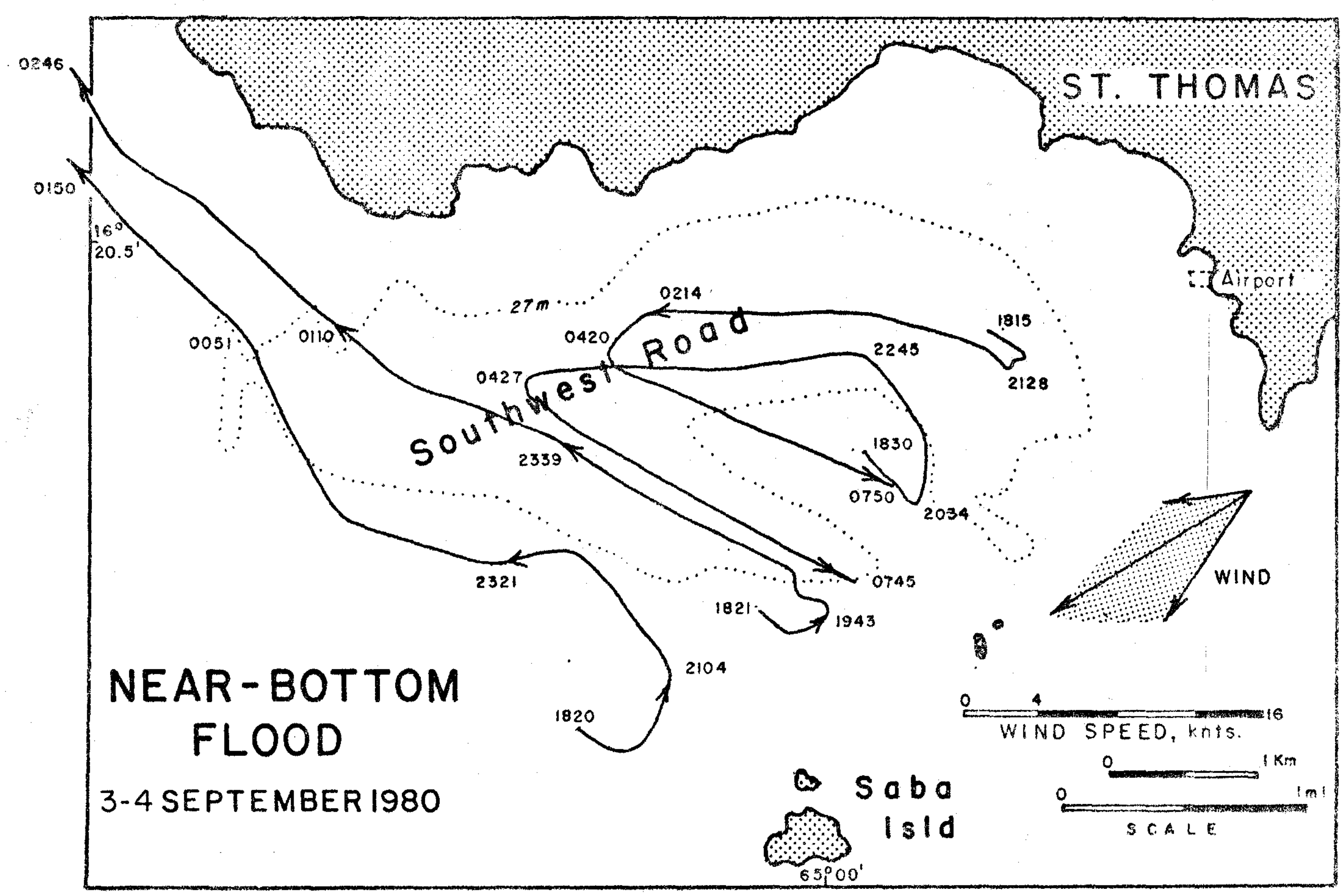

ST. THOMAS
0915
1115
1416
1332
1422
18°
20.5'
Airport
27m
Southwest Road
0643
0800
1040
0550
0821
1235
0526
0908
1224
1128
Water
Isld
NEAR-SURFACE
EBB
26-29 JUNE
0838
0838
Saba
Isld
65° 00'

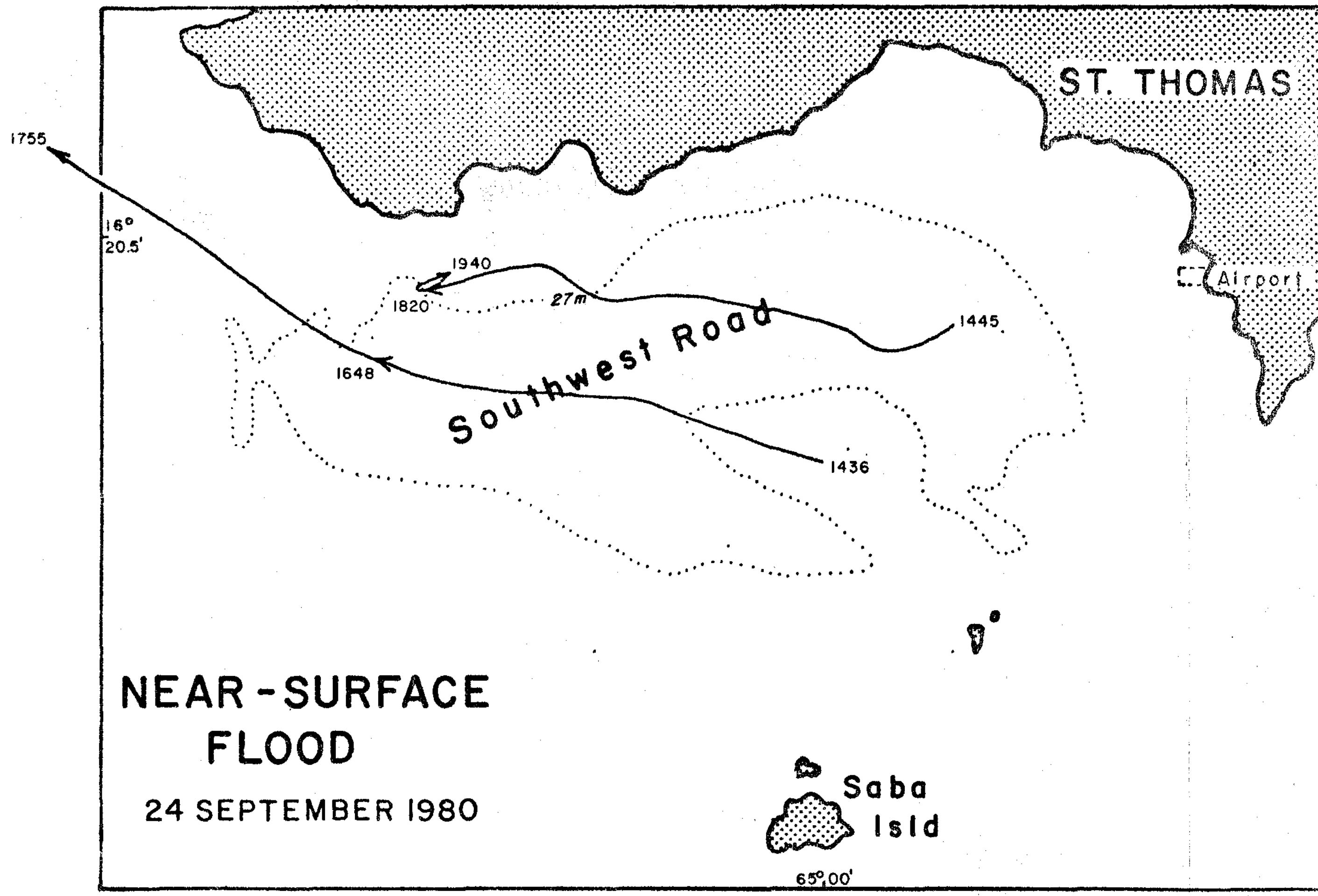

ST. THOMAS
0846
18°
20.5'
1120
Airport
27m
0643
Southwest
Road
0656
1430
0906
0727
0550
1118
1410
1105
1235
1204
0603
0908
0558
NEAR-BOTTOM
EBB
26-29 JUNE 1980
1240
Saba
Isld
0
1 km
0
1 mi
SCALE
N
Water
Isld
65° 00'

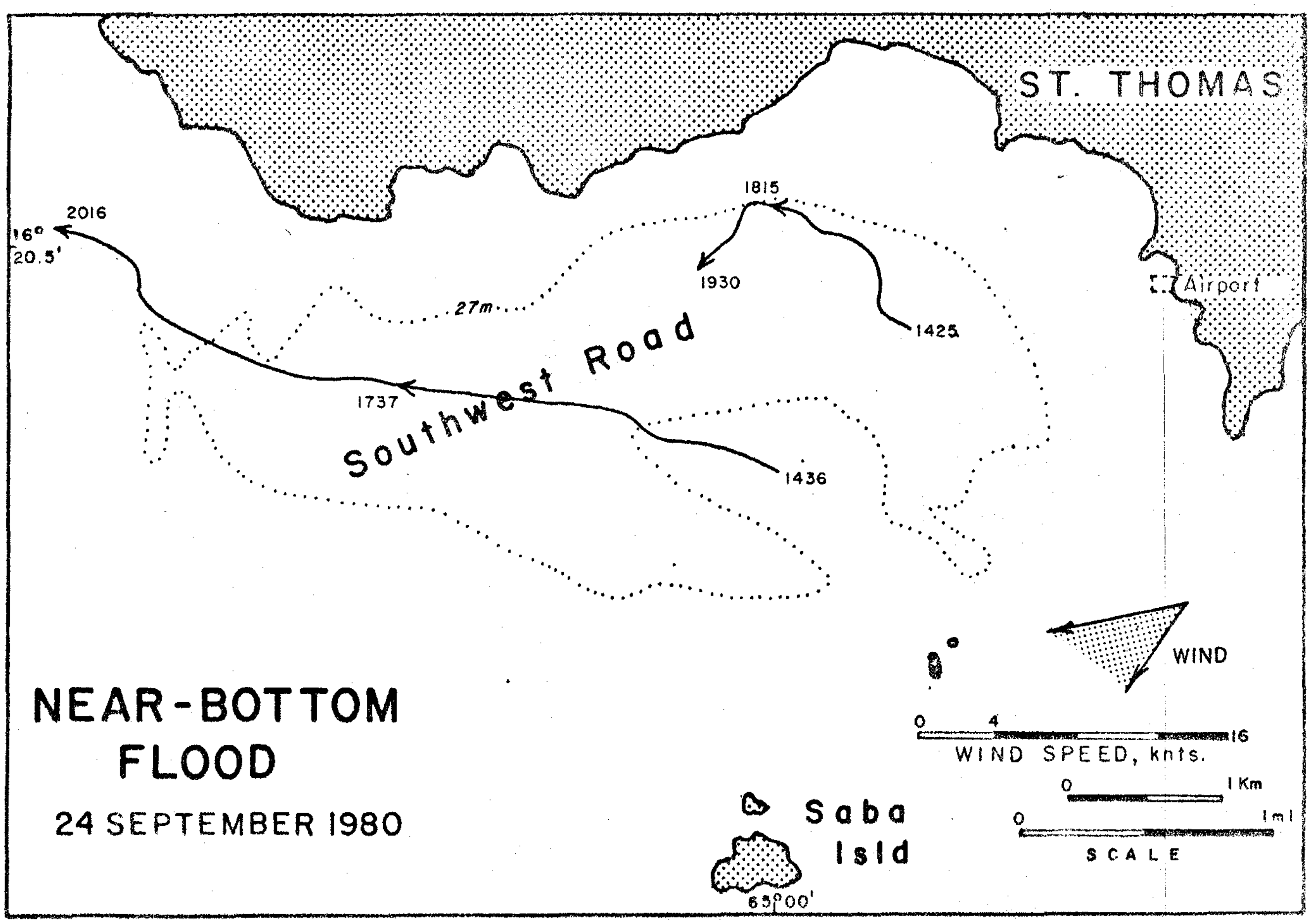

ST. THOMAS
16°
20.5'
Airport
27m
Southwest Road
1238
1058
1630
NEAR-SURFACE
EBB
15 AUGUST 1980
Saba
Isld
65°00'

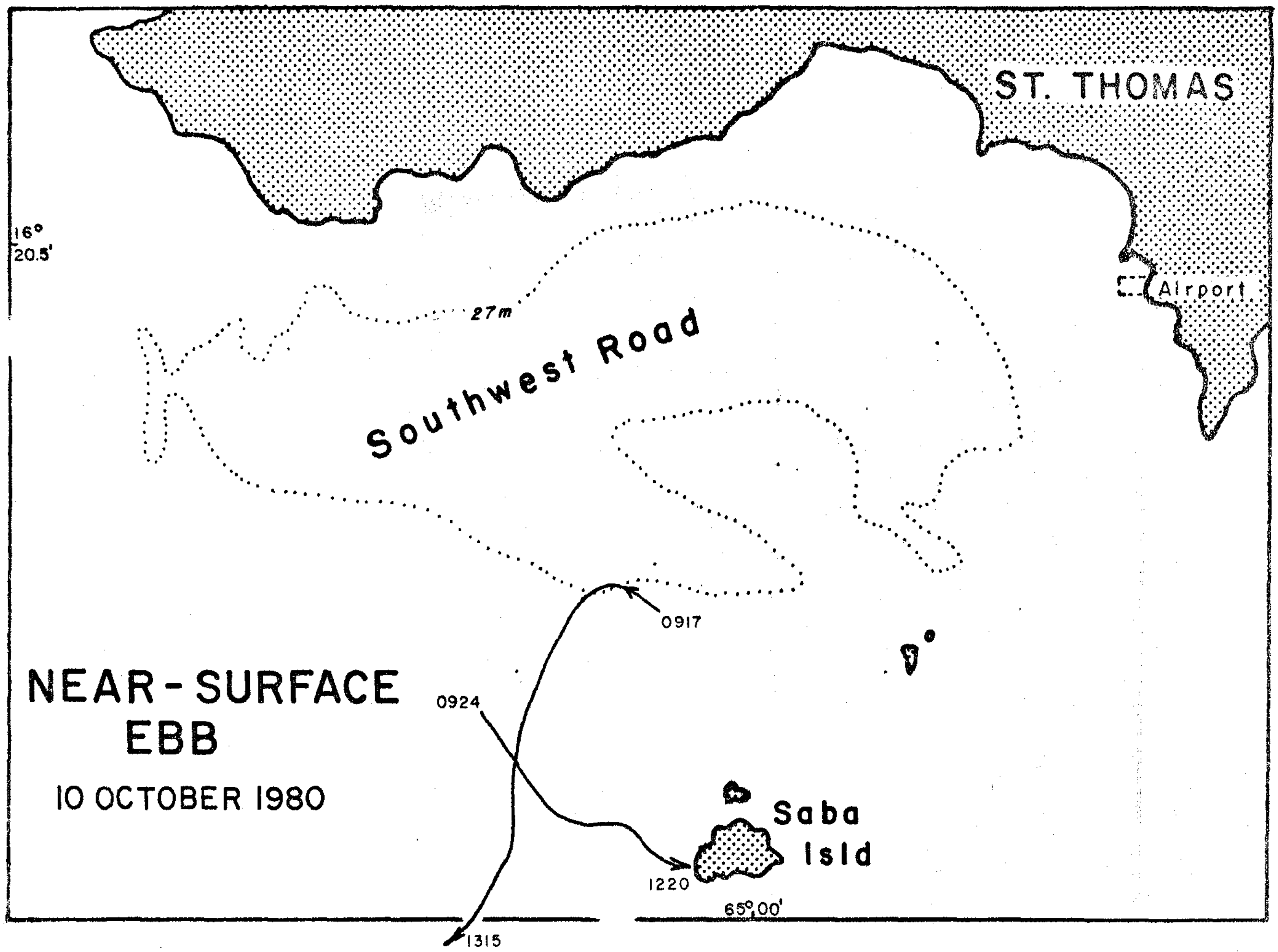

ST. THOMAS
16°
20.5'
Airport
27m
Southwest Road
1058
1450
1623
1434
WIND
NEAR-BOTTOM
EBB
15 AUGUST 1980
0
4
16
WIND SPEED, knts.
0
1 Km
0
1 mi
SCALE
Saba
Isld
65°00'

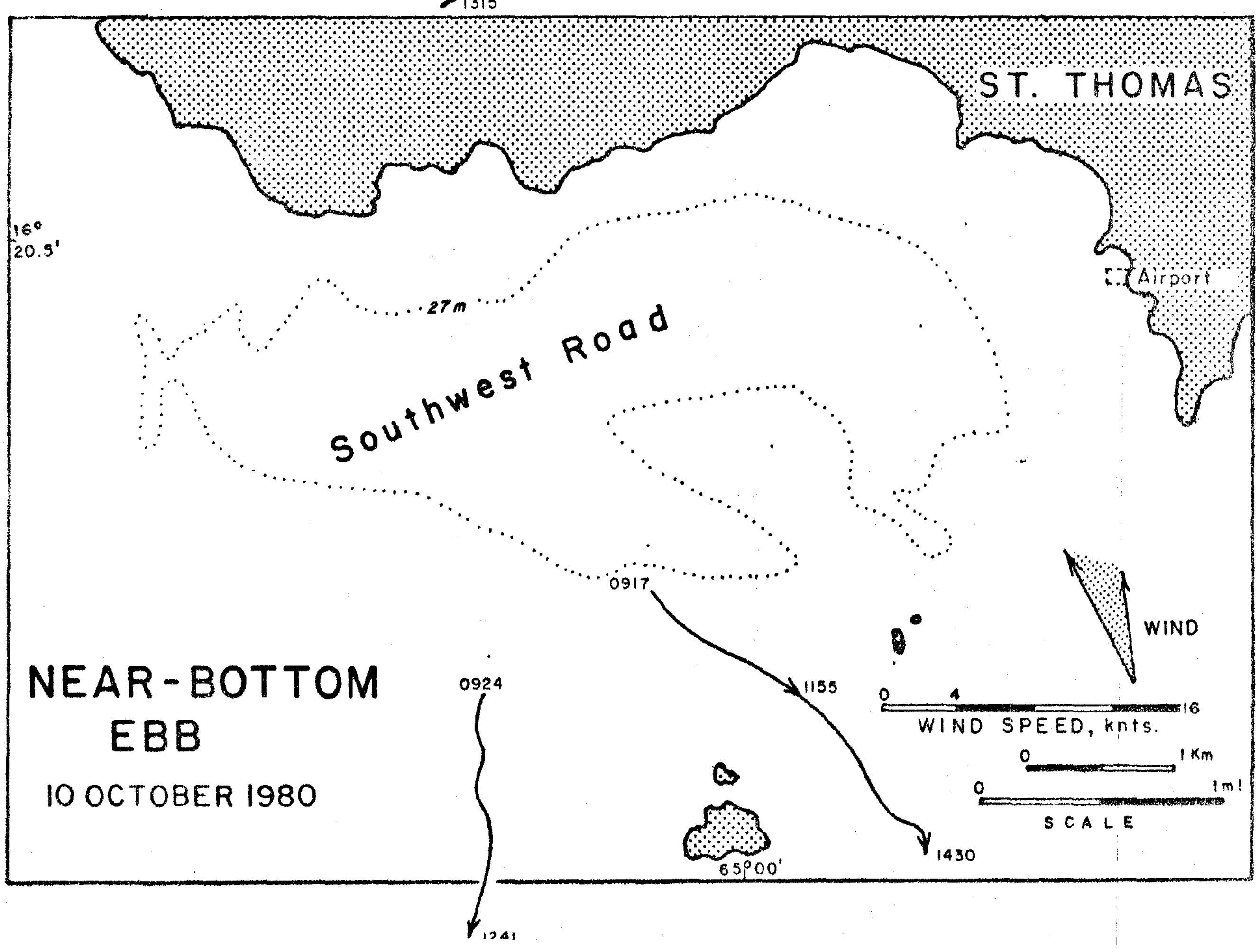

ST. THOMAS
Airport
Southwest Road
27m
16°
20.5'
0303
0124
0030
1815
0345
2330
1830
2107
0757
1821
2245
2135
2207
2039
2026
1828
Saba
Isld
65°00'
NEAR-SURFACE
FLOOD
3-4 SEPTEMBER 1980

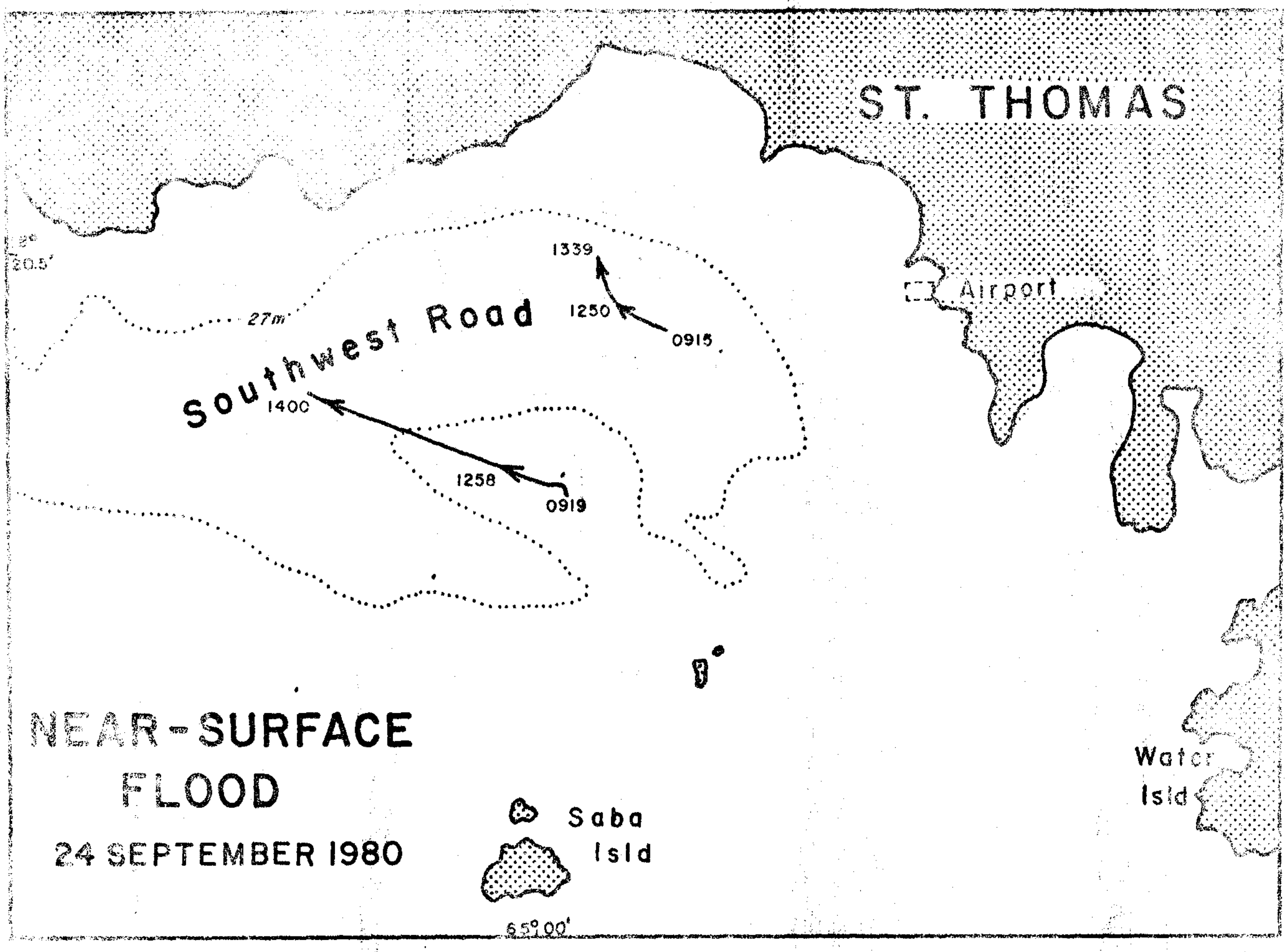

ST. THOMAS
Airport
Southwest Road
27m
16°
20.5'
0246
0150
0051
0110
0214
1815
0420
2245
2128
0427
2339
1830
0750
2034
0745
2321
1821
1943
2104
1820
WIND
0
4
16
WIND SPEED, knts.
0
1 Km
0
1 mi
SCALE
Saba
Isld
65°00'
NEAR-BOTTOM
FLOOD
3-4 SEPTEMBER 1980

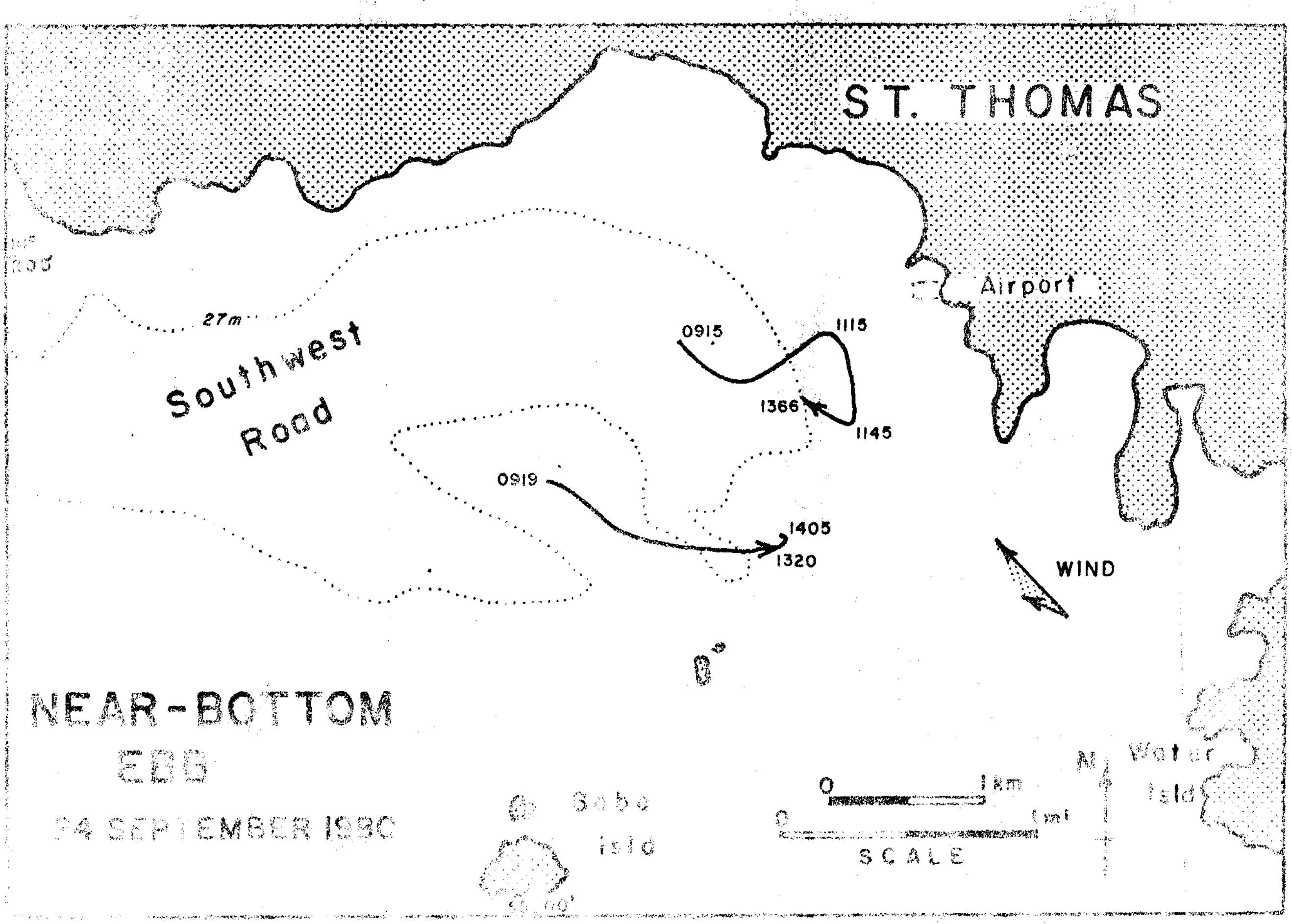

ST. THOMAS
1755
16°
20.5'
1940
1820
27m
1445
Airport
Southwest Road
1648
1436
NEAR-SURFACE
FLOOD
24 SEPTEMBER 1980
Saba
Isld
65°00'


ST. THOMAS
2016
16°
20.5'
1815
1930
27m
1425
Airport
Southwest Road
1737
1436
WIND
0
4
16
WIND SPEED, knts.
0
1 Km
0
1 mi
SCALE
NEAR-BOTTOM
FLOOD
24 SEPTEMBER 1980
Saba
Isld
65°00'


ST. THOMAS
16°
20.5'
27m
Southwest Road
Airport
0917
NEAR-SURFACE
EBB
10 OCTOBER 1980
0924
Saba
Isld
1220
65°00'
1315


ST. THOMAS
16°
20.5'
27m
Southwest Road
Airport
0917
WIND
1155
0 4 16
WIND SPEED, knts.
0 1 Km
0 1 mi
SCALE
NEAR-BOTTOM
EBB
10 OCTOBER 1980
0924
1430
65°00'
1241


ST. THOMAS
Airport
27m
Southwest Road
1339
1250
0915
1400
1258
0919
Water Isld
Saba Isld
NEAR-SURFACE
FLOOD
24 SEPTEMBER 1980
65° 00'


ST. THOMAS
Airport
27m
Southwest Road
0915
1115
1366
1145
0919
1405
1320
WIND
NEAR-BOTTOM
EBB
24 SEPTEMBER 1980
Saba Isld
Water Isld
0
1 km
0
1 mi
SCALE
N

APPENDIX C

Total Dry Weight ($^{mg}/l$) of Suspended Solids from Southwest Roads for the Period 1 November 1979 to 28 Feb. 1980.

	SAMPLE DATE														
Station	12/5	12/12	12/20	12/27	1/2	1/8	1/17	1/22	1/30	2/8	2/12	2/20	2/27	Max/Min	Mean Dry Weight
1.															
Surface	0.67	0.85	0.37	0.79	0.50	0.65	0.46	0.48	0.43	0.77	0.59	0.69	0.48	0.85/0.37	0.62
Bottom	0.50	1.25	1.05	0.78	0.66	0.72	0.56	0.26	0.92	0.54	0.66	0.90	0.75	1.36/0.26	0.78
2.															
Surface	0.80	1.27	0.48	0.61	0.49	0.42	0.56	0.43	0.33	0.53	0.41	0.20	0.30	1.27/0.20	0.56
Bottom	0.82	-	1.48	0.81	0.53	0.26	0.71	0.23	0.57	0.86	0.74	0.90	0.59	1.48/0.23	0.72
3.															
Surface	0.88	1.35	0.53	0.66	0.35	1.10	0.49	0.36	0.50	1.00	0.69	0.63	0.57	1.74/0.35	0.80
Bottom	0.72	0.67	1.07	0.62	0.41	0.61	0.43	0.51	0.91	2.20	0.75	0.75	0.96	2.20/0.41	0.92
4.															
Surface	0.73	0.95	0.53	0.77	0.61	0.73	0.18	0.26	0.47	1.06	0.50	0.70	0.90	1.06/0.18	0.69
Bottom	0.98	1.17	0.90	1.28	1.00	0.79	0.56	0.45	0.90	1.00	1.80	1.62	1.60	1.97/0.45	1.15
Mean mg/l	0.77	1.07	0.80	0.79	0.57	0.66	0.49	0.37	0.63	1.00	0.76	0.79	0.74		

APPENDIX C, Continued

Total Dry Weight (mg/l) of Suspended Solids from Southwest Roads for the Period 1 August 1980 to 31 October 1980

	SAMPLE DATE													
Station	8/6*	8/13	8/21	8/28	9/10	9/19	9/27	10/2	10/10	10/16	10/25	10/30	Max/Min	Mean Dry Weight
1.														
Surface	0.22	0.24	0.26	0.31	0.31	0.36	0.34	0.27	0.26	0.46	0.66	0.24	0.66/0.22	0.33
Bottom	0.31	0.14	0.31	0.39	0.43	0.36	2.57	0.27	0.96	0.38	0.40	0.38	2.57/0.14	0.58
2.														
Surface	0.09	0.29	0.68	0.57	0.86	0.36	0.29	0.18	0.50	0.66	0.60	0.26	0.86/0.09	0.45
Bottom	0.70	0.10	1.00	0.55	0.71	0.45	0.30	0.51	0.25	0.54	0.90	0.34	1.00/0.10	0.53
3.														
Surface	1.19	0.44	0.13	0.30	0.43	0.30	0.22	0.26	0.17	0.57	0.68	0.42	1.19/0.13	0.43
Bottom	1.02	0.51	0.22	0.61	0.39	0.70	0.11	0.30	0.03	0.39	1.12	0.31	1.12/0.03	0.48
4.														
Surface	2.85	0.50	1.08	1.01	0.45	0.50	0.37	0.05	0.41	0.52	0.69	0.71	2.85/0.05	0.76
Bottom	1.07	1.86	0.90	1.05	0.71	0.51	0.75	0.43	1.25	1.61	0.81	0.68	1.86/0.43	0.97
Mean Dry Weight	0.93	0.51	0.57	0.60	0.54	0.44	0.62	0.28	0.48	0.64	0.73	0.42		

*Post Hurricane Allen