LAKE MICHIGAN STUDIES

Special Report Number LM 11

CURRENTS AT FIXED STATIONS NEAR CHICAGO

May 1963

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Great Lakes-Illinois River Basins Project

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INTRODUCTION

The first detailed studies of currents using current meters at fixed locations began in the fall of 1962. The techniques and methods of study were based on tests conducted in the lake during the previous six months. The study represents the first such data ever collected from Lake Michigan.

Period of Study

Stations 3 and 4 were set on December 18, 1962 northeast of the city of Chicago (see Figure 1). The meters at these stations were set to record information on speed and direction for 50 seconds at intervals of 30 minutes. Each meter recorded about 4,500 readings. The details on the make-up of each station are shown in Table 1. One station was set on March 22, 1963, at the approximate position of the diffuser outlet proposed by Mr. Hazen (Lakes States Exhibit 528) and recorded continuously for a six-day period. Approximately 7,200 readings were made when printing the data at a 1.25 minute interval.

Stations 3 and 4 were in operation for approximately 93 days and Station X for 6 days. The stations were set on a "U" shaped mooring as described in Figure 6 of Special Report No. LM 9. The instruments were the Woods Hole type current meters and temperature recorders.

Purpose of Study

Stations 3 and 4 are part of the network of stations proposed for a one-year study to provide knowledge of water motions (currents) in Lake Michigan. This report includes data on the ranges of current speed and direction with respect to time and depth, and relates these generally to wind movements recorded simultaneously at the U.S. Weather Bureau Station at Midway Airport, Chicago.

The current survey during the winter of 1962-63 provided periods of data before, during, and after the ice cover on the Lake.

RESULTS

At the present time, there is no backlog of studies or published reports on large quantities of current data. Thus, the effort here is to illustrate, by new techniques, the current data obtained from Lake Michigan and to show movement of water during the period of observation.

Ice of varying extent and thickness covered the southern part of Lake Michigan during the period when stations 3 and 4 were in operation. Details as to the dates of ice cover over the stations are unknown.

After the film records were removed from the meters and processed, they were scanned electronically by a Flying Spot-Scanner attached to a PDP-1 computer. This is part of a new technique developed recently. The current speed and direction were read from the fifty second recording made each half hour and were transferred to magnetic tape and processed at the Computer Center of New York University. The data are recorded each half hour for speed and direction and the six-hour vector averages are tabulated. The two hour "envelopes" of speed and direction are plotted on a separate tabulation. The data from each meter were grouped into frequencies by class intervals - using five-degree intervals of azimuth for direction, and speed increments of 0.03 ft./sec.

Daily Current Graphs

Figures 2, 3, 4, 5, and 6 show the envelopes of the maximum and minimum speeds and direction for each two-hour period. When any of the values in a two-hour period are missing, only the maximum value shown is plotted. These graphs illustrate the possible magnitude of variation that occurred during the time period shown. The graphs show the stable and changing current patterns from day to day and cover a six-day period.

Figures 2 and 3, Station 4 at 30-ft. depth, show two separate six-day periods, January 29 to February 3, 1963 and March 14 to March 20, 1963. These periods were selected to show variable (Figure 2) and stable (Figure 3) current direction and variations of speed. On January 30 (Figure 2) the current was from the SSW (180°-216°) with speeds about 0.80 ft./sec. which were maintained for about 36 hours. On January 31 the speeds decreased to 0.20 ft./sec. at noon and began to shift to the west at midnight and had shifted to the northwest by the end of the following day. The currents remained low for nearly

24 hours. On February 2 the current shifted again, coming from the SW; the speed increased to a maximum of 1.20 ft./sec. at 2:00 P.M. and remained high for 14 hours. The current speed decreased to 0.12 ft./sec. at midnight on February 3. As the current speed decreased, there was a slight shift in direction to a movement out of the SE.

Figure 3, March 14 to 20, 1963, is an example of a steady direction of flow for a continuous six-day period. The current, from the south, began on March 14 and remained fairly constant in direction until March 20. The speeds ranged from near zero to 0.77 ft./sec. The small amount of oscillation of the direction indicates very little fluctuation in movement or a stable current.

Figure 4 shows a six-day period for the 50-ft. depth at station 4. It is apparent that there is more shifting and slightly lower speeds than at the 30-ft. depth (Figure 2). The period covered by Figure 4 is from January 30 to February 5. At noon on January 31, the current was from the SE and shifting to the SW. By February 3, the current speed reached 0.90 ft./sec. at the 50-ft. level as compared to 1.20 ft./sec. at the 30 ft. level (Figure 2). The current was from the south, whereas it was from the southwest at the 30 ft. depth. The current velocity decreased on February 4 and remained at approximately 0.25 ft./sec. for the next two days. The direction during this period shifted from the SE to the west.

Figure 5, station 4 at 50 feet, February 19 to February 25, shows a complete shift of 360° in 34 hours during which time there was a 24-hour calm period. On February 19 the currents were from the SE and continued from that direction until the afternoon of the 22nd. The current pattern appeared to rotate clockwise 360° until the movement was again from the SE on the morning of the 24th. Although speeds decreased to zero, there is enough evidence to indicate a complete rotation. Current speeds during the period changed from 0.10 ft./sec. to 0.70 ft./sec. from February 19 to 21 and dropped to zero early on February 23. The water began to move again on the 24th and gradually increased in speed.

Figure 6, station 3 at 30 feet, covers the same time period as Figure 5. The station is 15 miles west of station 4. The current direction on February 19 was from the north along the shore through noon of the 20th. At station 4 the flow during the same period was from the southeast. The current at station 3 shifted abruptly about noon of the 20th, also to a movement from the southeast, remained in that quadrant until late on the 23rd, and began to rotate clockwise, completing a 360° rotation by the 25th. Direction at station 4

began to shift more than 24 hours earlier and made the complete swing only 12 hours before the shore station. This sequence of movement suggests that a large anticyclonic eddy current moved in from the southeast was first detected at station 4 and some time later showed up at station 3 as it moved toward the shore. The records suggest that the eddy had a clockwise rotation and moved around the basin in a clockwise path.

Speeds were higher at station 3 than at station 4 for the same period, which is to be expected because the water is shallower and wind stress can be imparted to the entire mass. Speeds ranged from near zero to 1.10 ft./sec.

Table 2 shows the number of hours of consecutive readings for which the current speed was less than 0.1 ft./sec. and the maximum number of hours of consecutive readings from one quadrant.

Prevalence of Movement

Figures 7, 8, and 9 show variations in speed and direction, on a percentage-of-time basis without regard to chronology, summarized for the period of record. On each figure, the polar diagram is shaded to show the percentage of time in which the direction of flow was from each sector. It will be seen from Figures 7 and 8 that the currents flowed from the southerly quadrant 70% or more of the time during the three-month period at station 4. The inshore station (No. 3) showed a bimodal effect, as shown on Figure 9. Nearly 60% of the movement was from the south and 40% from the north.

The histograms (bar graphs) on Figures 7, 8, and 9 show the percentage of time in which the speed was within a specified range, in class intervals of 0.1 ft./sec. Speed distribution was bimodal in all three records - exhibiting at station 4 a primary mode at about 0.2 ft./sec. and a secondary mode between 0.6 and 0.7 ft./sec. At station 3 the primary mode was a speed of about 0.3 ft./sec., with a secondary mode also between 0.6 and 0.7 ft./sec. Speeds exceeding one foot per second occurred about one per cent of the time. (Mode is a statistical term referring to the most frequently occurring set of values in a series.)

Of a ninety-day period during the winter, speeds less than 0.08 ft./sec. were recorded on 18 days (not consecutive). Undoubtedly, a portion of the time the stations were under an ice cover which could be at least partly responsible for nearly calm conditions occurring so much of the time.

Figure 10 (station X) shows a trimodal frequency distribution of water movement during the six-day record. Twenty-four percent of the time the water moved from the northwest, 44% from the southwest, and 23% from the northeast. The speeds were bimodal with the greatest percent between 0.1 ft./sec. and 0.2 ft./sec., and a secondary increase between 0.4 ft. and 0.5 ft./sec.

Figures 11 and 12 show the percent of the prevailing wind direction and mean speeds at Chicago and Milwaukee for the period January 1 to March 22, 1963. The records were obtained from the official U.S. Weather Bureau offices at these stations. The predominance of winds from the WSW to NW at Chicago and west at Milwaukee gives a fair estimation of the wind movement over the lake during this period of time. The wind speeds were primarily between eleven and fifteen miles per hour.

It is enlightening to calculate the hypothetical displacement of a water particle from station 4 during the period from January 21 to 24. Assuming that velocity readings at station 4 (at the 30 ft. depth) represent a mass water movement, and not local eddies, the displacement of a water particle, which started at the station on January 21, would be given by the vector sum of velocities on succeeding days. Such a displacement is depicted on Figure 13. Total displacement, as shown, would have been 18.7 miles in a northwesterly direction (315°).

ANALYSIS OF RESULTS

Daily Movements

Figures 2 to 6, and 13, graphically demonstrate that under varied conditions water will tend to move in a particular direction for prolonged periods of time. Present studies indicate that a particular direction of flow may be maintained for up to six days and perhaps longer. Table 1 of Special Report No. LM 9, Lake Currents at a Single Station, and Table 2 of this report, show that water can move from the northwest or southeast for 80 to 142 consecutive hours. Under such conditions, an introduced effluent could move en masse for a long period of time and be transported many miles. Calm periods, exceeding a day or more with little or no flow, could occur at any time of the year.

Long Term Movements

The winter study of 1962-63 shows for the first time a clockwise rotation in a portion of the southern basin. Results from a single station operated from May to July 1962 and previously reported (see Special Report No. LM 9), indicated a prevailing flow from the northwest at station 4, and seemingly confirmed other evidence of a counterclockwise rotation. There is apparently a seasonal shift in current patterns in the Lake.

Because of the orientation, symmetry, and latitude of the southern basin of the Lake, winds will tend to produce either a clockwise or counterclockwise movement of the currents, depending upon the direction of wind. In the northern hemisphere the resultant force exerted by wind on the water surface will be to the right of the wind direction. When the wind flows across the lake at an oblique angle to the shore it will tend to pile water against the downwind shore, and move the water laterally along that shore. Water piled up on the east shore of the lake and forced toward the south will produce a northward flow in the Chicago area. This sets up a clockwise rotation. Likewise, water piled against the west shore and forced northward will produce a southerly flow on the eastern side of the basin to compensate for the northerly flow and thus set up a clockwise rotation. Winds from 240°-350° and 110°-180° appeared to produce a clockwise rotation in the basin for the period of record studied in December 1962 to March 1963. The winds from 350°-110° and 180°-240° would tend to produce a counterclockwise rotation. Since, at Chicago, the greatest fetch (over-water distance over which the wind has blown)

is from the north and northeast quadrant it would indicate that the predominant movement (strongest flow) would be from the north near Chicago. However, the prevailing flow (greatest percentage of time) would be from the south over the winter period in the vicinity of Chicago.

Limits (degrees) of wind sectors favoring a particular circulation in the lake are only approximate and vary ten or more degrees one way or the other. Whether a shift in rotation will occur depends upon many factors, such as the number of days a current regime has been established, the number of hours the new stress has been applied and the thermal structure of the lake.

The prevailing clockwise rotation of the southern basin during the winter of 1962-63 and an apparent counterclockwise rotation earlier in the year suggest that there are at least two major water motion regimes near Chicago which respond to wind movements. A counterclockwise rotation apparently occurred during the spring and summer period but then reversed in the winter.

An effluent discharged into the lake at the proposed diffuser location or anywhere in the vicinity of Chicago may move in a northerly or southerly direction depending on the direction of the currents, which in turn depend upon the wind field over the lake and the thermal structure of the water. Calm periods in the water can be expected about ten to twenty percent of the time for as long as 24 hours. Data gathered for this study as well as data collected during late spring indicate that there is no single current regime in southern Lake Michigan.

TABLE 1

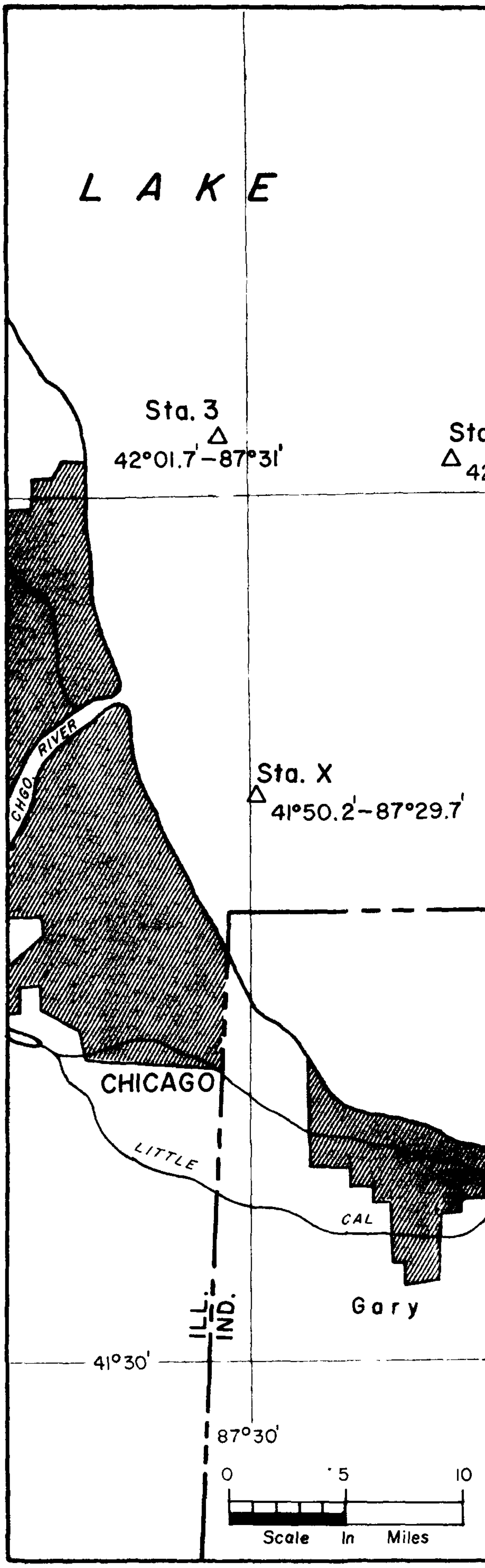
STATION DESCRIPTION

Station No.	Current Meter #	Temp. Recorder #	Recording Interval in Minutes	Depth in Feet	Date Set	Time	Date Removed	Time	Lat.	Long.
3	200	149	30	50	12/17/62	1530	3/22/63	1300	42°01.75'	87°31.75'
4	183	151	30	30	12/18/62	0815	3/22/63	1550	42°01'	87°20'
4	191	153	30	50	12/18/62	0815	3/22/63	1550	42°01'	87°20'
X	271	-	Continuous	30	3/22/63	1123	3/28/63	1340	41°50.25'	87°29.75'

TABLE 2

Maximum Hours of Consecutive Calms
and Movement From One Quadrant

Station Number	Depth Ft.	Hours of Calm	Hours from One Quadrant		Direction
4	30	34	142	-	200°
4	50	46	136	-	145°
3	30	20	130	-	145°

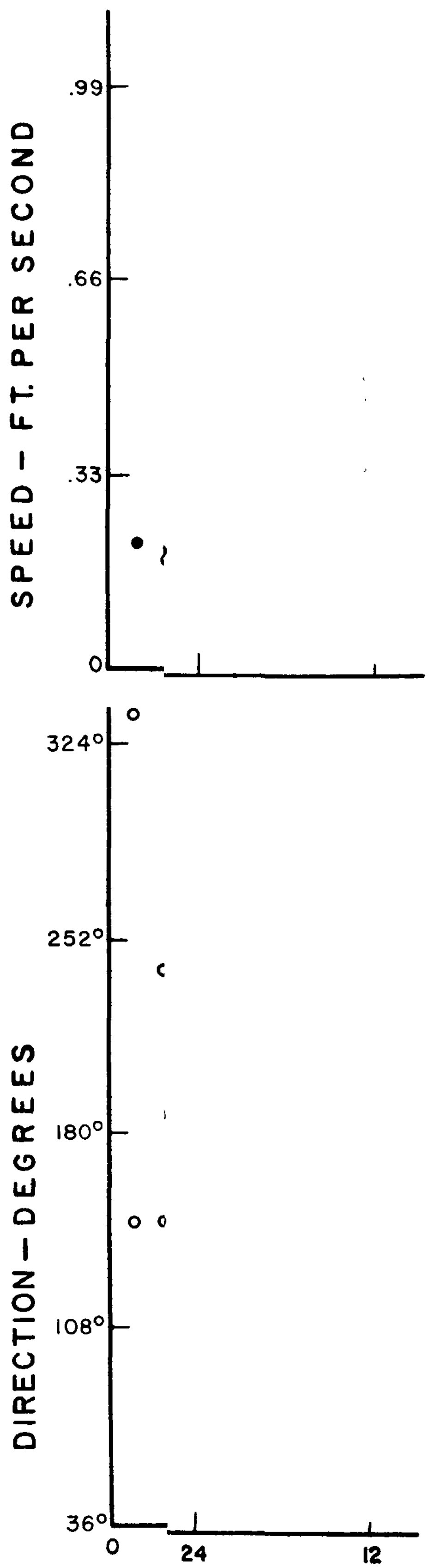


GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

LOCATION OF CURRENT METER STATIONS

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 1



January 29 to February 4, 1963

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

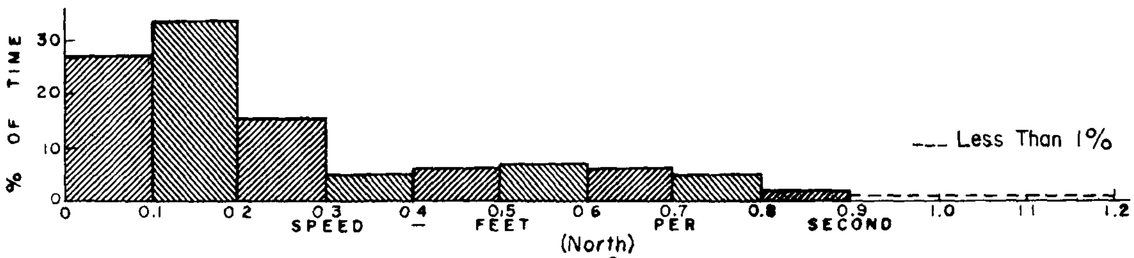
TWO-HOUR ENVELOPES OF SPEED & DIRECTION

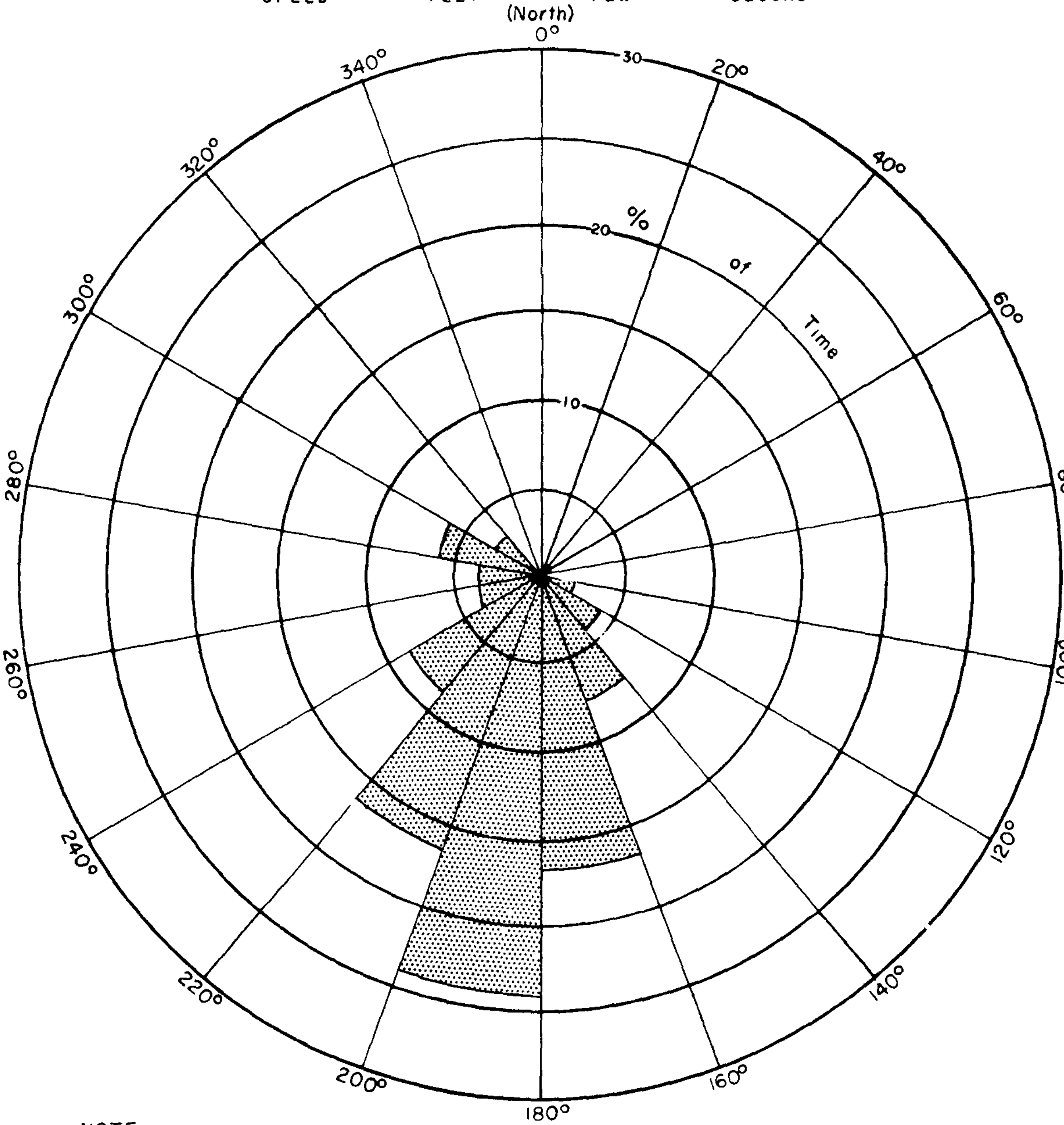
Station 4, Depth 30 Ft.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

REGION V CHICAGO, ILLINOIS

FIGURE 2





NOTE:
Direction is from the sector shaded, toward the center.

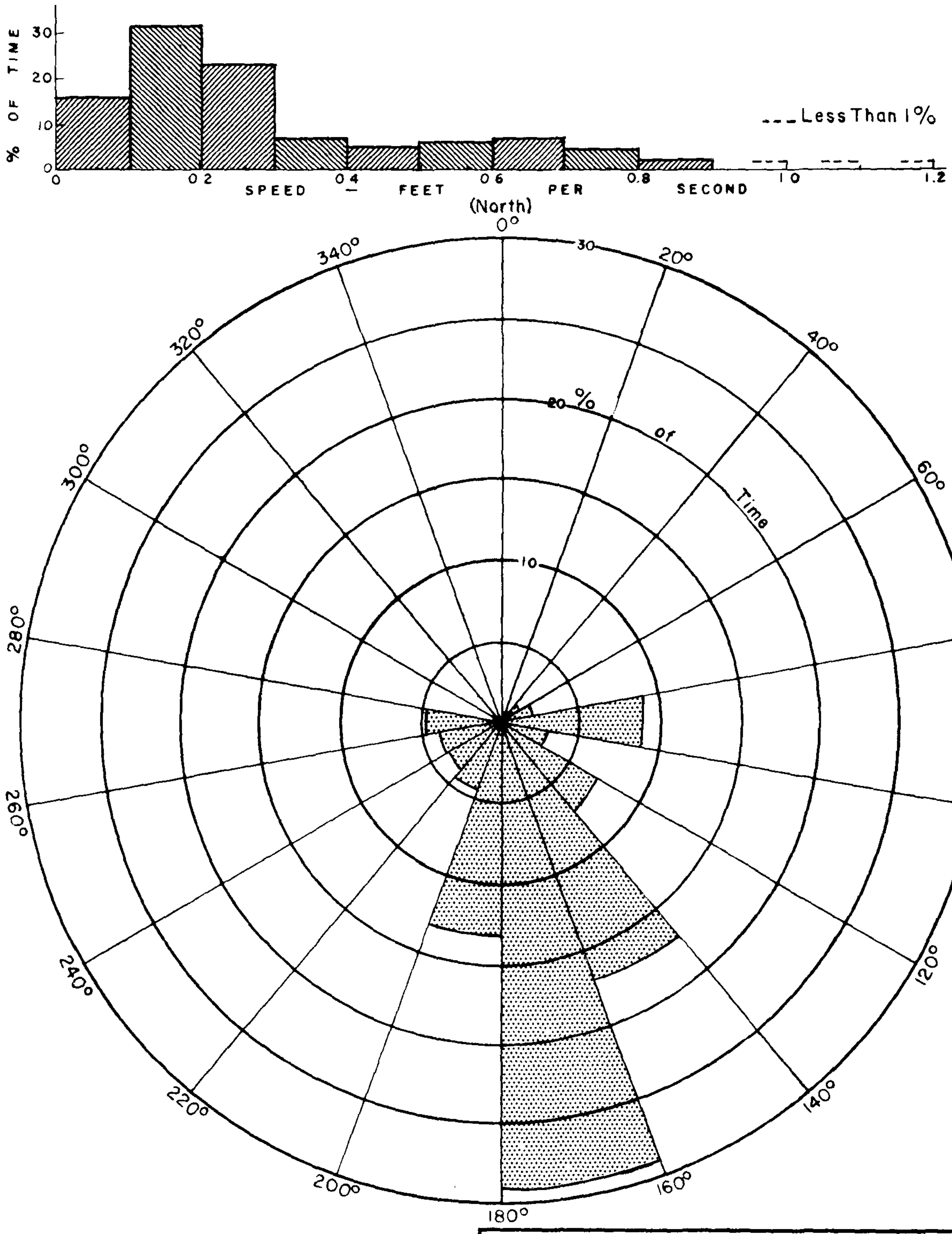
CURRENT
January 6, to March 22, 1963

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

PREVAILING SPEED & DIRECTION
STATION 4 — DEPTH 30 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 7



NOTE:
Direction is from the sector shaded, toward the center.

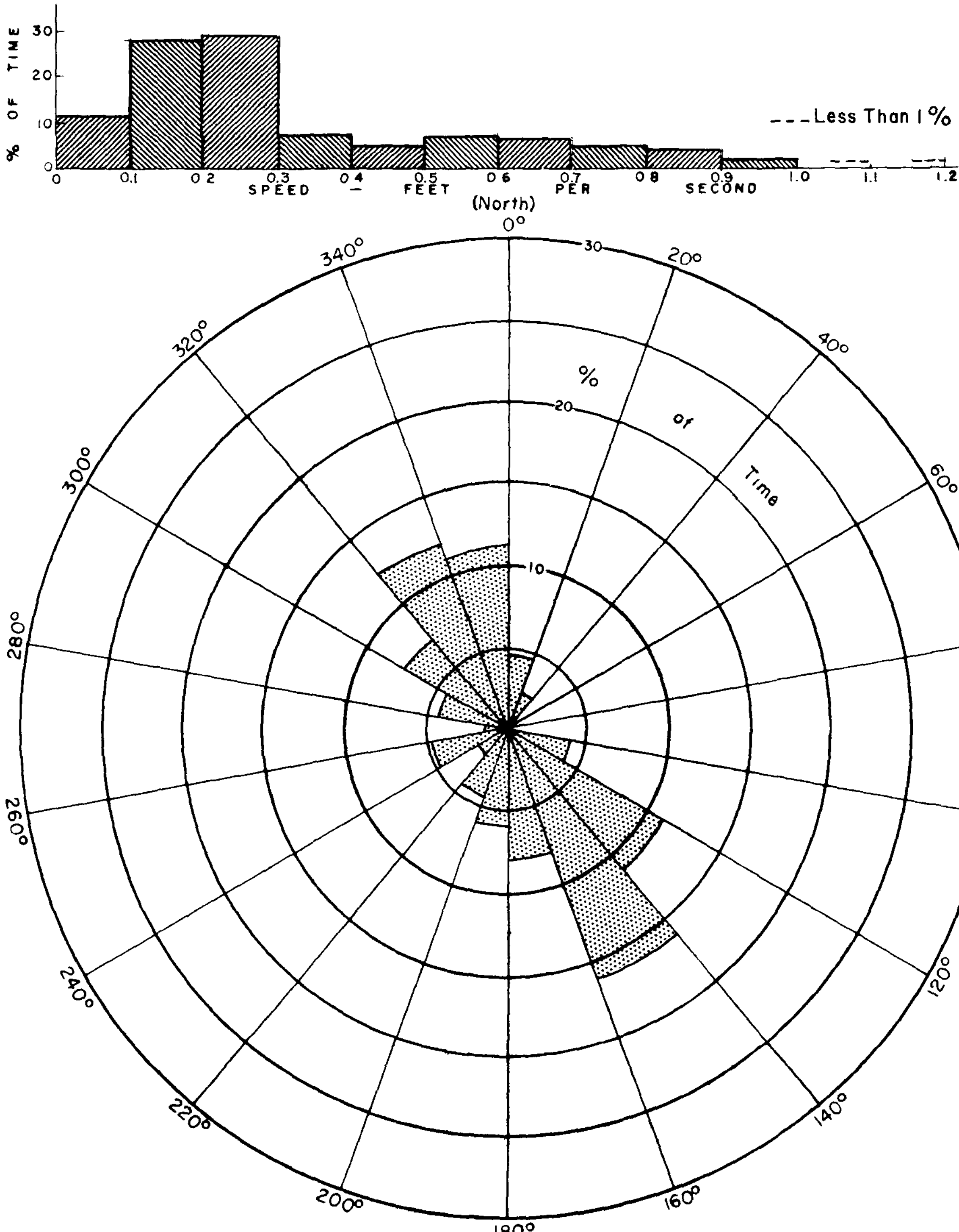
CURRENT
December 25, 1962 to March 22, 1963

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

PREVAILING OF SPEED & DIRECTION
STATION 4 — DEPTH 50 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 8



NOTE:
Direction is from the sector shaded, toward the center.

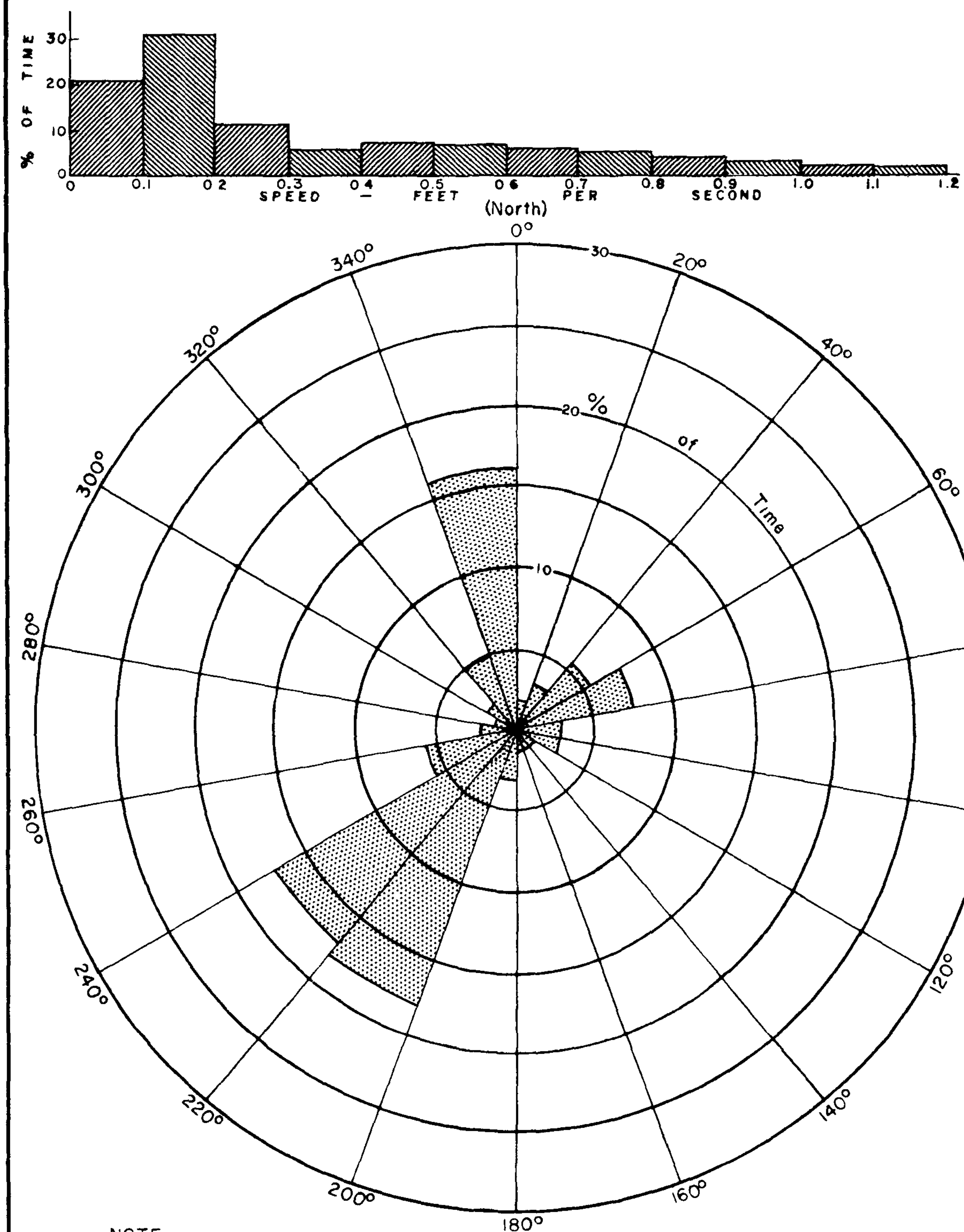
CURRENT
January 31 to March 22, 1963

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

PREVAILING SPEED & DIRECTION
STATION 3 — DEPTH 50 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 9



NOTE.
Direction is from the sector shaded, toward the center.

CURRENT

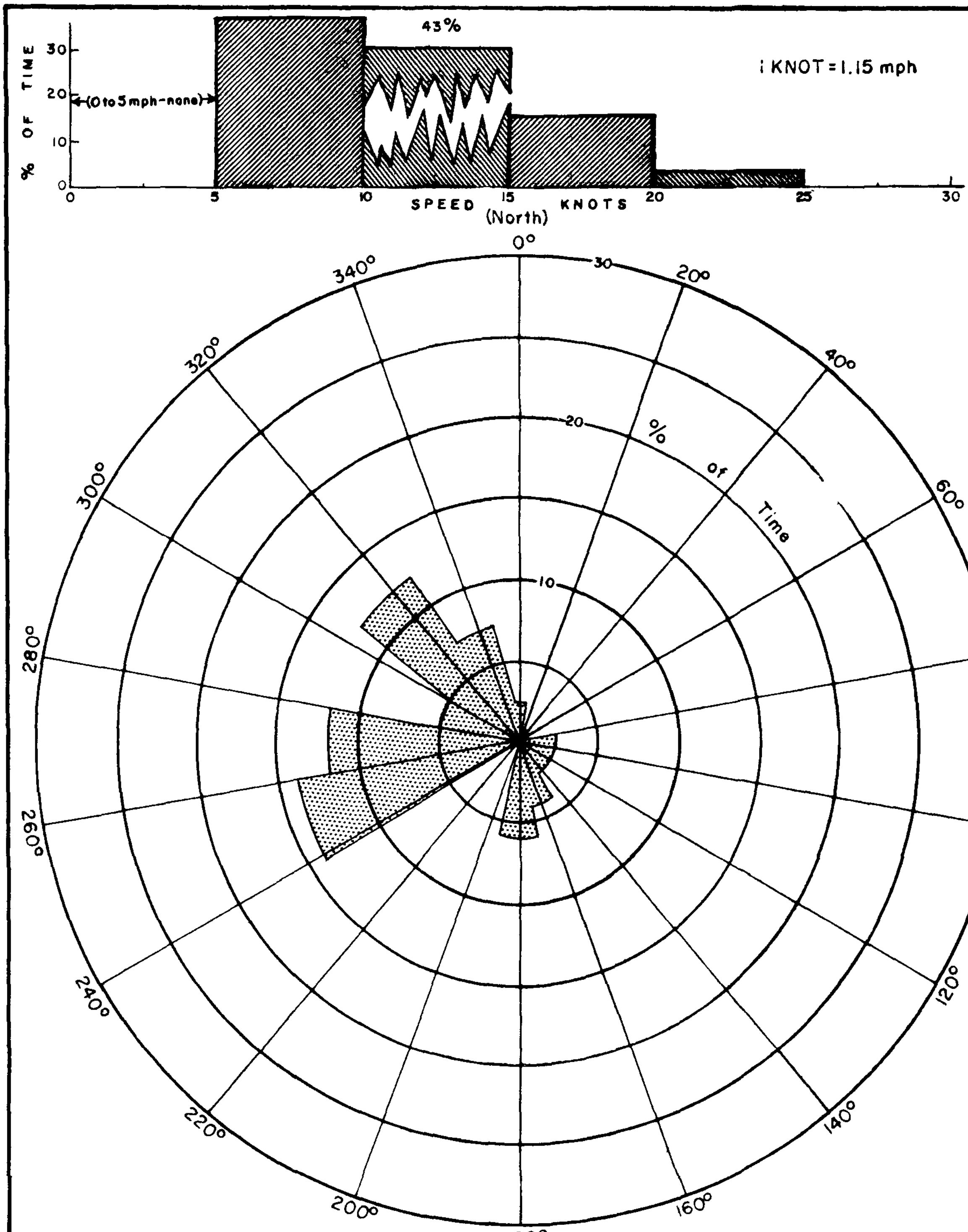
March 22 to 28, 1963

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

PREVAILING SPEED & DIRECTION
STATION X—DEPTH 30 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 10



NOTE:
Direction is from the sector shaded, toward the center.

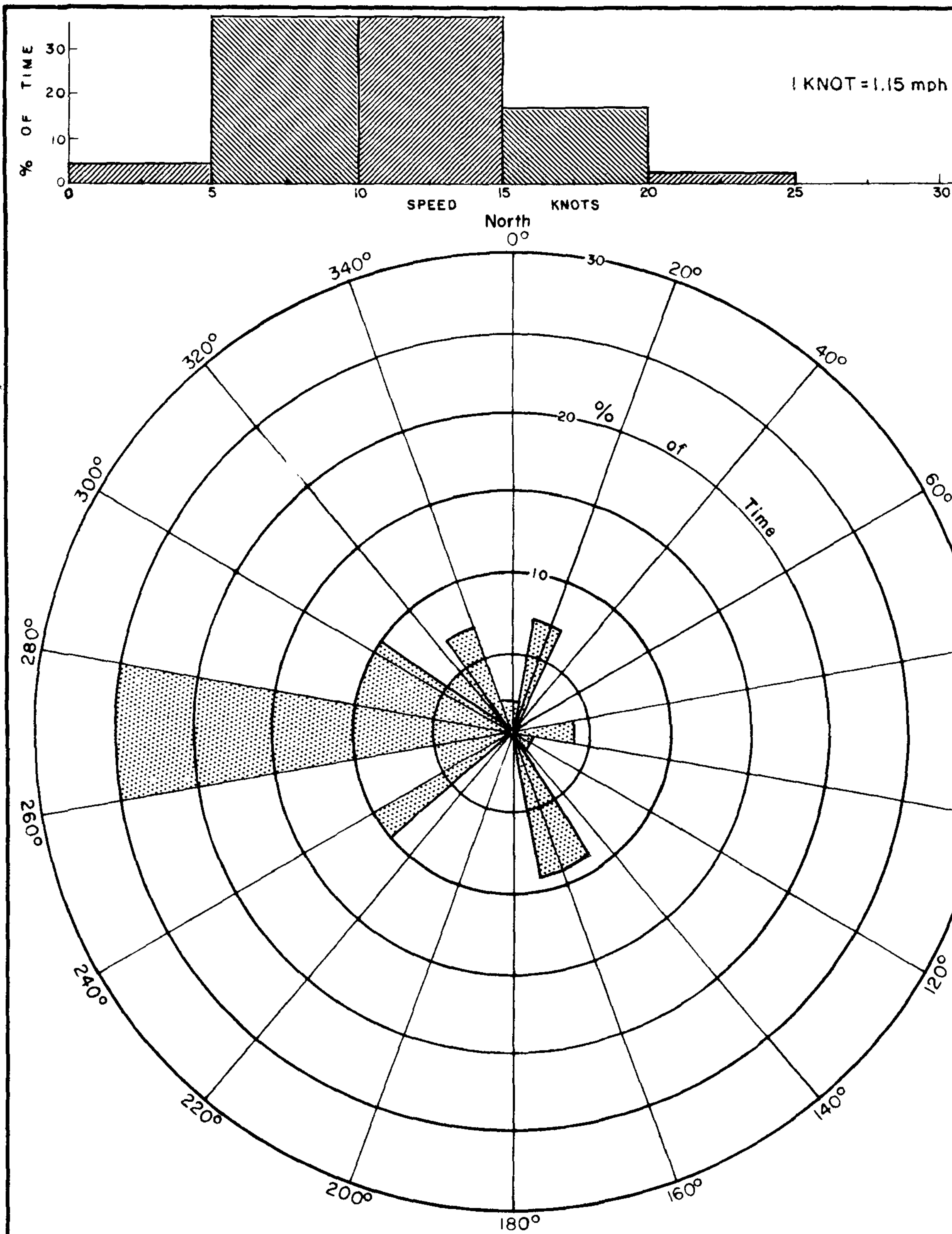
WIND
Jan. 1 to Mar. 22, 1963

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

PREVAILING SPEED & DIRECTION
CHICAGO, ILLINOIS (MIDWAY AIRPORT)

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 11



NOTE:
Direction is from the sector shaded, toward the center.

WIND

January 1, to March 22, 1963

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

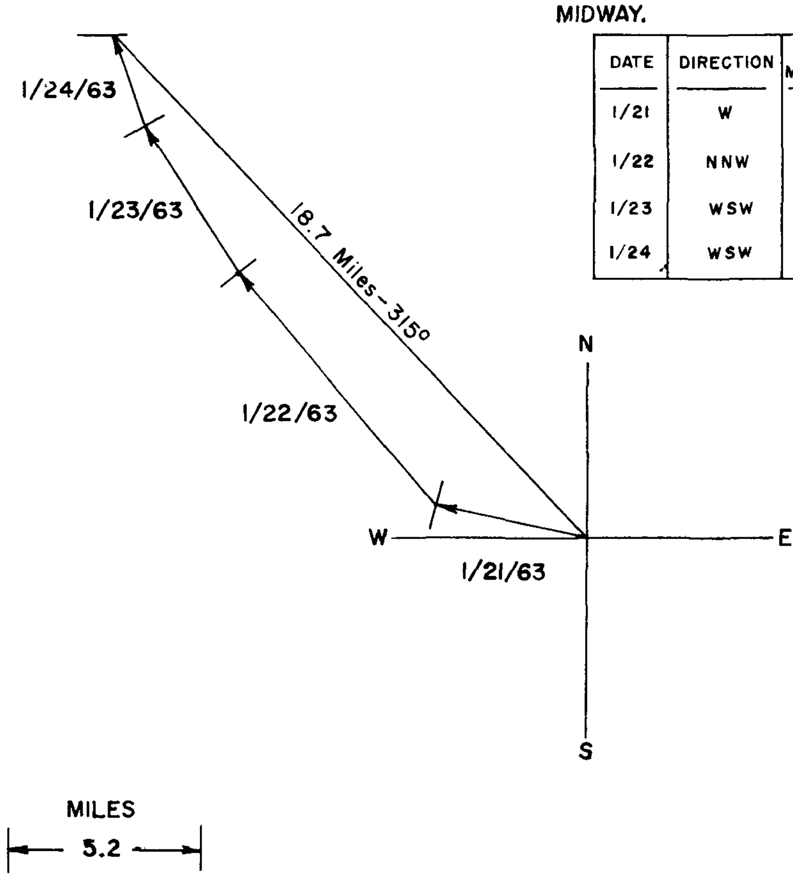
PREVAILING SPEED & DIRECTION
MILWAUKEE WISCONSIN
GENERAL MITCHELL FIELD

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 12

MEAN 24 HOUR WIND VELOCITIES FOR INDICATED DATES AT MIDWAY.

DATE	DIRECTION	SPEED MILES/HR.
1/21	W	12
1/22	NNW	17
1/23	WSW	18
1/24	WSW	19



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

CURRENT-VECTOR AVERAGES STATION 4-DEPTH 30 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 13