LAKE MICHIGAN STUDIES

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MICROBIOLOGICAL INVESTIGATIONS

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ENVIRONMENTAL

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INTRODUCTION

This report is based on (1) a preliminary study of the microbiology of Lake Michigan conducted by the Great Lakes-Illinois River Basins Project during the spring, summer, and autumn months of 1962 (April-December); (2) a review of raw water data of several water plant intakes withdrawing water from Lake Michigan; (3) data from samples of bathing beach waters in the Chicago area; and (4) laboratory studies of survival of coliform and fecal streptococci in Lake Michigan water.

The study of the microbiology of Lake Michigan conducted by the Great Lakes-Illinois River Basins Project was achieved through a series of eight cruises on vessels equipped with laboratories for performing microbiological procedures. It was thereby possible to process all samples immediately for analysis of bacterial content. The locations of sampling stations are shown in Figures 1, 2, and 3 of the present report.

The raw water data review consisted of an analysis of data obtained from records of certain water treatment plants in the Chicago area. The bathing beach data were obtained from the Chicago Park district, and the survival studies were carried out by the Great Lakes-Illinois River Basins Project laboratory.

The purpose of the present report is to present the findings on the present status of the microbiology of Lake Michigan and to discuss the possible effects of returning treated sewage effluent from the City of Chicago to Lake Michigan.

PROJECT INVESTIGATIONS

The objective of the microbiological program was to determine the present water quality of Lake Michigan in terms of bacterial parameters. Qualitative and quantitative aspects were incorporated so that the distribution of the pertinent bacterial varieties with respective densities throughout might be ascertained. The various determinations utilized were selected to indicate the sanitary quality of the water as well as general biological productivity.

Parameters

Analyses were made for coliform content, and for total plate counts at 20°C and 35°C. In certain of the harbor studies, some of the samples were analyzed for fecal streptococcus content. Approximately 1,400 samples comprised the coliform study. Total plate counts at 20°C and 35°C were made on approximately 1,400 samples.

Coliform bacteria are defined in Standard Methods for the Examination of Water and Wastewater (1)* as "including all of the aerobic and facultative anaerobic, Gram-negative, non-sporeforming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C.

Coliform organisms are significant to water quality since these bacteria occur in the fecal matter of all warm-blooded animals, including man. Consequently, the presence of coliform bacteria in a body of water is interpreted as indicative of contamination of the water by fecal matter. Since contamination of water by fecal matter is one avenue of transmission of certain water-borne diseases to humans, coliform bacteria are utilized as indicators of possible pathogenic contamination. Increasing densities of coliform bacteria found in water are, therefore, related to the increasing degree of pollution of enteric origin and to increasing health hazard to those exposed to the water.

Fecal streptococci, as used in the present study, includes any species of streptococci commonly present in significant numbers in the fecal excreta of humans or other warm-blooded animals (2). Streptococci are Gram-positive cocci occurring in chains composed of varying numbers of cells. These organisms may be parasitic or saprophytic. The fecal streptococci, like the coliform bacteria,

*See references listed at end of report.

are enteric organisms abounding in the fecal matter of all warm-blooded animals; they likewise indicate the presence of fecal matter in water. Fecal streptococcus results augment coliform findings in that the streptococci indicate recent fecal contamination of water, whereas the coliform bacteria may derive from more remote contamination.

Total plate counts, according to Standard Methods (1), are approximate enumerations of total bacteria multiplying at temperatures of 35°C and 20°C on any one of several nutrient agars; they yield useful information concerning the quality of the water tested and may provide supporting data regarding the significance of the results of the coliform test. (The medium of choice for the present investigations was tryptone glucose extract agar.)

Total bacterial densities in water correspond to the decomposition of organic matter. In this large group there are species which grow well at several incubation temperatures. These are present in most waters in small numbers and, in waters enriched with organic matter, they occur in great abundance. Several species of this group grow best at temperatures ranging from 5°C to 20°C. Other species have become semi-parasitic,being especially adapted to the decomposition of organic matter in the intestines of warm-blooded animals. These latter forms develop most actively at body temperatures (35°C to 37°C) (15).

Field Procedures

The samples were collected at each station at fixed depths:surface (designated "0" meters), 5, 10, 20, 30, 50, 75, 100, 150, and 250 meters. The number of samples at a given station was therefore determined by the depth of the lake at that point. The deepest samples collected at a station are referred to in this report as "lowermost." The samples were collected in three zones: deep water, inshore, and city harbors. The inshore investigations utilized samples collected at intervals of 1 mile, 4 miles, and 10 miles offshore. The inshore work was devoted largely to the southern half of Lake Michigan.

All bacterial samples were collected in Zobell J-Z water samplers, permitting individual sample collections from the various depths in sterile glass bottles which remained sealed until sampling depth was reached.

Laboratory Procedures

All bacterial determinations were made in accordance with the procedures set forth in *Standard Methods for the Examination of Water and Wastewater* (1), Eleventh Edition, 1960, pp 477-526, or in accordance with modifications of these procedure as established through research at the Robt.A.Taft Sanitary Engr.Center, Cincinnati, Ohio.

These latter modifications were related to the media constituents of the streptococcus medium (2). Coliform and fecal streptococcus determinations and total plate counts were made by the membrane filter technique. Results for coliform, fecal streptococci, and total plate counts are reported on the basis of number of organisms per 100 milliliters (ml).

Findings

Deepwater and Inshore Studies

Coliform Findings. Table 1 shows that, of 313 surface samples collected at the deepwater and inshore points, 134 (42.8%) contained a density of less than 1 coliform bacterium per 100 ml. A total of 233 (74.6%) samples contained 10 coliform bacteria or less per 100 ml and a total of 292 (93.4%) showed coliform densities of 100 or less. An additional 17 samples showed coliform densities in the range of 100-1,000 per 100 ml. Only 4 samples (1.3%) exceeded 1,000 per 100 ml and these were in the range 1,000-2,000 per 100 ml. These latter 4 samples were from sampling points located within one mile offshore and adjacent to Gary, Indiana, and Racine, Wisconsin. Also shown in Table 1 is a summary of results from the deepest samples collected. Examination of test results from all samples (approximately 1,400) showed that, in general, variations in coliform density did not reflect significant differences in water quality with respect to depth. Therefore, further details of this aspect are not included.

The geographical distribution of the coliform densities derived from the surface samples is shown in Figures 1, 2, and 3. An examination of these map graphs shows that in the southern basin the higher coliform densities are located adjacent to the shoreline and correlate with the centers of urbanization. The western shoreline from Milwaukee to Gary showed consistently higher coliform densities than did the eastern shore. Beyond this zone of contamination, the deep water in the majority of samples showed little or no coliform content (reported as less than 1 per 100 ml). These relationships are presented in Figures 4 and 5 showing coliform densities as they were measured at intervals of 1 mile, 4 miles, and 10 miles offshore. Diminishing coliform densities consistently occurred from one mile offshore to 10 miles offshore around the periphery of the southern half of Lake Michigan. All 10-mile samples from Gary, Indiana to Muskegon, Michigan, failed to give positive coliform findings in 100 ml samples.

These findings, in general, indicate that the bacteriological quality of Lake Michigan water is excellent where not locally contaminated through domestic sewage entering the lake.

Total Plate Count Findings. The bacterial densities of species growing at 20°C and 35°C parallel those of the coliform bacteria. The lowest densities (100 to 500 per 100 ml) were found in the central body of the lake (deep water). Highest densities were observed in the inshore areas in relation to the geographical location of cities and towns. (See Figures 6, 7, 8, 9, 10, 11, and 12). Approximately 25% of the samples contained densities (20°C and 35°C) greater than 10,000 per 100 ml.

Highest 20°C densities encountered were approximately 500,000 per 100 ml (near Racine, Wisconsin, at 1 mile offshore). Other areas showing densities in excess of 100,000 per 100 ml were offshore from Milwaukee, Racine, Kenosha, Chicago and Michigan City.

The highest densities observed with the 35°C test were in excess of 500,000 per 100 ml. These occurred at Milwaukee, Kenosha, and Gary. The highest 35°C density was approximately 1,300,000 per 100 ml approximately 7 miles off the Chicago waterfront.

Tables 2 and 3 show the per cent of samples which contained various total densities. The cumulative per cent distribution of the 20°C and 35°C total densities is also shown. Results in these two tables originate from surface samples. The wide range in the numbers present throughout the lake, and the considerable number of samples showing high densities, are indicative of organic enrichment of these waters.

Harbor Studies

Three city harbors were investigated: Chicago, Racine and Milwaukee. Samples were collected in the immediate harbor area and in the adjacent waters in a radial zone extending 3-5 miles around the chief river mouth emptying into the harbor.

The highest coliform densities encountered were associated with and located in the Milwaukee Harbor. The next highest densities were found in the Racine Harbor area. The Chicago Harbor area showed the least coliform occurrence of the three harbors studied. Highest total plate counts occurred at those stations showing highest coliform densities. Sampling stations are shown in Figures 13, 14, and 15.

Coliform Findings. Fifteen samples were collected from 15 sampling points in the Chicago Harbor study. All samples contained fewer than 1,000 coliform bacteria per 100 ml, while 6 (86.7%) contained fewer than 500 coliform per 100 ml. Seven of the samples (46.7%) were in the 1-50 per 100 ml range and 3 (20.0%) of the samples were in the 1-10 per 100 ml range. (See Figure 13 and Table 4).

The higher coliform levels (100-1,000 per 100 ml) were encountered in an area immediately adjacent to the mouth of the Chicago River (both inside and outside the breakwater harbor) and extending south of the harbor for approximately 2 miles in the waters about one-half mile or less offshore.

In the Racine Harbor higher coliform densities were encountered, with 38.2% of the 34 samples in the study containing coliform levels in the range of 1,000-10,000 per 100 ml. The highest coliform density (in the 5,000-10,000 per 100 ml range) was encountered at the mouth of the Root River which empties into the breakwater harbor. Coliform densities in the next lower range (1,000-5,000 per 100 ml) were encountered at the harbor mouth and in a zone extending south of the harbor mouth for approximately one mile in the waters which were sampled approximately 1,500 feet offshore. However, the remainder of the radial area surrounding the harbor for a distance of one to two miles uniformly contained coliform densities in 100-1,000 per 100 ml range. (See Figure 14).

The Milwaukee Harbor manifested the highest coliform densities, with 15.9% of a total of 76 samples tested containing coliform bacteria in the 10,000-40,000 range. The highest coliform densities (in the 10,000-40,000 per 100 ml range) were encountered at the mouth of the Milwaukee River and within the breakwater in the southern two-thirds of the harbor. The northern third of the harbor contained coliform densities in the 1,000-10,000 range. A breakwater leads south from the harbor for a distance of some two miles. The coliform densities in the waters between this breakwater and the shore progressively decreased from 5,000-10,000 per 100 ml at the harbor inlet to 100-1,000 per 100 ml where the open water is reached. In the open waters adjacent to the harbor breakwater, the northern area showed very little or no coliform content. Most samples originating in the open waters surrounding the southern half of the harbor breakwater contained coliform densities ranging from 10-100 per ml at the central harbor mouth to 100-1,000 per 100 ml in the southern most waters adjacent to the breakwater running south for approximately two miles. (See Figure 15).

The bacterial findings at each of the harbors indicated that the harbor waters mingle with the surrounding waters of Lake Michigan and that the direction of flow is to the south.

Fecal Streptococcus Findings. Fecal streptococcus determinations were included in the Milwaukee and Racine Harbor studies. The maximal density of fecal streptococci encountered in the Milwaukee Harbor samples, originating from surface waters, was 19,000 per 100 ml. This sample was collected in the Harbor, just north of mouth of the Milwaukee River. At the mouth of the Harbor (opposite the mouth of the Milwaukee River) a fecal streptococcus density of 40 per 100 ml was observed. A level of 300 per 100 ml was observed at one point just south of the southern inlet into the harbor. Samples in the open waters adjacent to the northern half of the Harbor were reported as less than 10 per 100 ml.

The streptococcal densities from the Racine Harbor were 200 per 100 ml at the mouth of the Root River, with a density of 400 per 100 ml at the main Harbor mouth;in the waters south of the harbor densities in the range of 10-610 per 100 ml were observed. Observations to the north of the Harbor were 10 and 20 per 100 ml.

Total Plate Count Findings. As previously stated, the results of the total plate counts agreed with the coliform findings, showing high counts at sampling stations where maximum coliform densities occurred and generally decreasing as coliform densities decreased.

In the Chicago Harbor study, 9 of the 17 samples showed total densities in the 50,000-500,000 range as estimated by the 20°C total plate count. The 35°C total plate count showed similar total densities, with 9 of the 14 samples tested falling into the 50,000-500,000 per 100 ml range. The highest densities (300,000-500,000 per 100 ml) occurred in the waters immediately outside the breakwater and in the area extending approximately two miles to the south and one-half mile or less offshore. (See Tables 5 and 6). The distribution of 20°C total bacterial densities in the Chicago Harbor are shown in Figure 16.

In the Racine Harbor the total plate counts at 20°C gave rise to estimations of higher densities than did the 35°C plate count. 93.7% of 32 samples contained total densities in the 100,000-1 million range as estimated by the 20°C total plate count, and 89.3% of the 28 samples tested at 35°C contained densities in the 10,000-500,000 range. Densities of approximately one million (20°C) were encountered at the Root River mouth and throughout the harbor. (Figure 17). The entire one-to-two-mile radial zone around this harbor contained total 20°C densities of approximately 200,000 per 100 ml.

The Milwaukee Harbor showed the highest total bacterial densities of the three harbors herein discussed. Of 75 samples, 32 (42.7%) contained densities in the 50,000 to less than 1 million range as estimated by the 20°C total plate count (Figure 18) and 30 (40.0%) of 75 samples were in the same range as estimated by the 35°C total plate count. Densities of 1,300,000 to 1,500,000 per 100 ml (20°C) were encountered at the mouth of the Milwaukee River and in the central one-third of the Harbor. The corresponding 35°C density at the river's mouth was 2,200,000 per 100 ml. At the extreme northern end of the harbor the total densities were 180,000 and 140,000 (20°and 35°C, respectively). At the southern extremity of the harbor the respective densities were 170,000 and 130,000. In the breakwater zone south of the harbor the 20°C densities progressively diminished from 260,000 per 100 ml to 48,000 (at open water). The 35°C densities diminished from 210,000 to 24,000 throughout the same area. In the open waters adjacent to the northern portion of the harbor much lower densities were often observed (from 10,000 to only a few hundred per 100 ml on both 20° and 35°C tests). The densities at the central harbor mouth were 13,000 and 7,200 (20° and 35°C, respectively). This latter situation may indicate prevailing inflow of Lake Michigan water at the harbor mouth. In the open waters along the breakwater extending south of the harbor, 20°C densities were fairly constant at approximately 30,000 per 100 ml. The 35°C densities in the same area were somewhat lower (28,000 to 9,700). (See Tables 5 and 6).

Discussion and Significance of Findings

From the above findings, it is apparent that the bacterial quality of Lake Michigan water is generally good in deep water and is more degraded in varying degrees along the shoreline and in city harbors. The coliform findings indicate the presence of pollution of fecal origin in these shoreline and harbor areas, showing increased densities with respect to sampling stations located in these areas.

At a distance of 1 mile offshore along the western shore from Milwaukee, Wisconsin, to Gary, Indiana, the coliform levels were frequently in the 100-1,000 per 100 ml range, representing substantial pollution in the 1 mile zone. The highest coliform densities were encountered in water contiguous to the towns of Milwaukee, and Racine, Wisconsin; Chicago, Illinois; and Hammond, and Gary, Indiana. The water quality was much less degraded in the northern half of Lake Michigan.

The coliform and fecal streptococcus findings in the Milwaukee Harbor indicate the presence of gross pollution. The same may be said of the Racine Harbor as well as of the waters adjacent to Whiting and Gary, and Hammond, Indiana, although the pollution encountered was not as intense as that of the Milwaukee Harbor.

OTHER MICROBIOLOGICAL DATA

Coliform Densities at Various Drinking Water Intakes and Bathing Beaches

In addition to the data collected by the Great Lakes-Illinois River Basins Project, daily water sampling results at the various city water intakes as well as routine sampling of bathing beaches, gives much additional information on prevailing quality as well as the occurrence of sudden and localized deteriorating influences. Tables 7 and 8 are included to show the presence of coliform densities occurring at substantially higher levels than encountered in the Great Lakes-Illinois River Basins Project cruises. Additional microbiological aspects pertinent to the evaluation of the present and future quality of the waters of Lake Michigan are to be found in the discussion below.

From the records of the water treatment plants at Chicago and Evanston, Illinois (3, 4), it is indicated that the water of Lake Michigan is of good bacterial quality as long as pollution from domestic sewage inflows is not present. Bacteriological samples collected at the water intakes at the Chicago and Evanston water treatment plants often have shown coliform density of less than 2.2 per 100 ml. At times, however, evidence of pollution of varying degrees is encountered at the water intakes (located one to four miles offshore), as judged by coliform content. (See Figure 19 for location of the Chicago water intakes). Such increase in pollution is reported to be encountered at the Dunne Crib when the prevailing winds are southerly. The pollution accruing from the cities located at the southern tip of the lake, as well as polluted water from the Calumeg-Sag Channel and other points flowing into Lake Michigan during heavy rainfalls, thus is introduced into the water intake of the City of Chicago's South District Filtration Plant (Dunne Crib). This polluted water often bears marked phenolic tastes and odors believed to originate in the industrial and other wastes introduced into the lake along with the domestic sewage cited above.

Table 9, comprised of data from the official records of the City of Chicago, summarizes variations in prevailing water quality in terms of the coliform content encountered at Dunne Crib for the years 1951, 1956, and 1961, as examples typifying conditions in past records. The total number of days when the coliform density (MPN per 100 ml) was 2.2 or less per 100 ml were: 1951, 186; 1956, 90; and 1961, 174. Days when the coliform density was 50 or greater were as follows: 1951, 11 days; 1956, 48 days; and 1961, 54 days. The maximum coliform densities encountered in 1951, 1956, and 1961 were 374, 1100, and 3000 per 100 ml, respectively.

The maximum coliform density reported at the Evanston water treatment plant for 1956 was 23,000. This density was encountered on the following dates: January 10, 12, 13, 17; September--1 day; November 24, 25, 29; and December 15, 21, and 25 (4).

Inspection of coliform levels at these two locations, separated by 20 miles, but both located on the west shore of Lake Michigan, near heavily populated metropolitan areas, reveals great variation and lack of homogeneity in the distribution of coliform bacteria present in Lake Michigan water, particularly when a density of 23,000 per 100 ml prevailed for more than one day consecutively at Evanston and nothing comparable was detected simultaneously at the Dunne Crib.

Earlier records show that heavily contaminated water would reach and travel past Dunne Crib as in the years 1940, 1941, 1942, when isolated coliform levels of 300,000 were detected. On October 19, 1940, a maximum of 300,000 coliform per 100 ml was detected in the Dunne Crib intake, while an adjacent water intake located only 300 feet closer to shore and sampled within 15 minutes, showed a level of 2400 coliform per 100 ml (3). Pollution in this order of magnitude was known to originate in cities located at the southern tip of Lake Michigan which contributed large amounts of domestic and industrial wastes to Lake Michigan. Improvements in these local conditions resulted in sharply reduced maximum coliform levels reaching the Dunne Crib in subsequent years. It was this degraded water quality in the southern end of Lake Michigan that determined the need for and location of the City of Chicago's first water filtration plant (the South District Filtration Plant, put into service in 1946) (6, p.15).

Table 7 presents data revealing the coliform densities that prevailed during the months of June-November, 1961, inclusive, at three locations adjacent to the north side of the City of Chicago's Central District Filtration Plant, currently under construction (3). It will be noted that the levels of coliform at all points exceeded the recommended maximum of 50 to 100 coliform bacteria per 100 ml for source water to be used for public water supplies where chlorination is the only treatment provided (7, p.11). The maximum MPN per 100 ml reported from these points was 24,000.

The range of commonly accepted standards established by States for water to be used for swimming and other recreational uses is 50 to 2400 coliform bacteria per 100 ml (14). Table 8 presents the coliform levels occurring at each of the beaches located on the Chicago lakefront during the summer of 1961 and is based on samples collected during the months of May through September at each sampling point (5). The southern-most beaches show days of gross pollution

with Most Probable Numbers (MPN) greater than 110,000. Three points on the Calumet Beach showed MPN's per 100 ml in excess of 1,000 in 70% of the samples collected. Beaches at Hammond and Whiting, Indiana showed 72% of samples in excess of 1,000. The range for the other 24 beaches was 19-60% wherein MPN's per 100 ml were detected in excess of 1,000. The highest MPN per 100 ml detected was 240,000 occurring at 12th Street Beach on September 15, 1961 in the wake of the polluted water backflowing through the locks into Lake Michigan (see discussion below).

Pollution Persistency

The material and data presented above demonstrate the lack of uniformity in the quality of Lake Michigan water, wherein local areas of the lake show excessive pollution, as measured by the coliform MPN, and other areas, either adjacent or more removed, may show quite low coliform content. Polluted slugs of water entering the lake are not immediately dispersed and tend to maintain their identity for days. The latter condition has been demonstrated when the locks on the Chicago River have been opened to alleviate flood conditions in the Upper Illinois Waterway.

The locks at the Chicago River were opened to release flood waters on September 14, 1961. At the same time flood water was released from the Upper Illinois Waterway through the locks at the upper end of the North Shore Channel at Wilmette, Illinois. At the southern end of Lake Michigan, massive amounts of flood water entered the lake from the Calumet River when the direction of flow in the river was reversed in response to the heavy rainfall. A survey to determine the location, migration, and persistency of the flood water introduced into Lake Michigan was undertaken by the Great Lakes-Illinois River Basins Project (8). The discharge from the Chicago River was more intensively studied than the other two massive discharges. Testing and identification of the polluted water was maintained in terms of coliform and fecal streptococcus levels (membrane filter determinations). Coliform densities per 100 ml in the magnitude of 180,000-150,000 were encountered 1 3/8 and 7/8 miles, respectively, offshore opposite the mouth of the Chicago River, the first day, with slight diminution on the second day, and a maximum of 11,000 appearing on the third day. On the third day a density of 320,000 was encountered to the north near Wilson Avenue Crib (water intake). This body of polluted water may have originated from the flood water released concurrently on September 14, 1961, from the North Shore Channel at Wilmette.

The bacteriological findings of this investigation indicated that the polluted flood water tended to maintain its identity for at least 3 days and was kept fairly close to its point of introduction (around the mouth of the Chicago River) by the prevailing winds. A tongue of polluted water appeared to extend some 4 miles in a southerly direction from the point of heaviest concentration of pollution.

The normal quality of Lake Michigan water in the Chicago area was apparently influenced by the heavy rainfalls and subsequent run-off which occurred during September, 1961. The total precipitation recorded at Midway Airport (14.17") was the heaviest for any month of record at this station (1928-1961). The Chicago Avenue and Wilson Avenue Control Stations of the Chicago water department as well as Dunne Crib, reported sustained periods of high chlorine demand occurring throughout the remainder of September, October, and November. Table 10 summarizes the change in coliform content of water taken in at Dunne Crib throughout the year of 1961, with the exception of December. It is apparent that higher levels of coliform bacteria were encountered in September, October, and November at greater frequency than at any other period of the year.

ULTIMATE SURVIVAL OF PATHOGENS IN LAKE MICHIGAN

The question of ultimate survival of bacteria, including pathogens, artificially introduced into Lake Michigan (through sewage effluents, flood water overflow from polluted sewers, etc.) is one of great importance and is of particular significance in relation to public health and safety. Pathogenic forms such as typhoid organisms have been known to survive winter conditions in northern locations, travel downstream following thaws and subsequently precipitate epidemics among water users (9). Pathogenic enteroviruses have been shown to be much more resistant to chlorination than are vegetative bacterial cells, and may be presumed to be persistent in nature until proven otherwise (10, 16, 17). Other enteric parasites (such as Endamoeba histolytica and nematode eggs) are known to survive outside the human intestinal tract and to be more resistant to chlorination than the sewage indicator organisms, the coliform group (10).

Little information is available on the survival of any of these forms, including the coliform bacteria in Lake Michigan. The very nature of the problem and the peculiarities of microbial survival and reproduction render field investigations extremely difficult since no known method is available on a practical basis to follow a given inoculum of bacteria through the many depths and currents of a body of water like Lake Michigan. Moreover, the introduction of pathogenic forms into a body of water used as a source for public drinking water for study purposes is not tenable. Laboratory studies cannot easily duplicate the conditions found in nature. Nonetheless, such studies do provide useful information in considerations related to survival of enteric microorganisms in nature. While many laboratory studies relating to the survival of pathogenic forms in either laboratory or natural conditions can be cited, one survival study on Shigella sonnei seems particularly noteworthy. In this study S. sonnei remained viable when stored in tap water for 211 days (11). In another investigation Salmonella typhosa was found to survive in impounded surface water up to 26 days (12).

A survival study using Lake Michigan water was conducted in the laboratories of the Great Lakes-Illinois River Basins Project wherein the survival of coliform and fecal streptococci was investigated. In this experiment, Lake Michigan water was collected 20 miles offshore. Initial coliform measurements on the water as collected were less than one coliform cell per 100 ml, with no fecal streptococci detected. This water was seeded with untreated sewage collected from the West-Southwest Treatment works and transferred to sterile gallon jugs. These containers were stored at the following temperatures and conditions:

(1) 25°C with room illumination during working hours
(2) 25°C in the dark, and
(3) 5°C in the dark.

Under each of these test conditions, the fecal streptococci showed less survival capacity than did the coliform bacteria. Initial streptococcus levels were in the ranges of 680,000 to 1,000,000 cells/100 ml. At 25°C with light, no streptococci were detected at the end of 5 days. In the dark at 25°C, 2 per 100 ml were measured at the end of 15 days, and at 5°C in the dark, 340 per 100 ml were viable at the end of 15 days. Determinations for both the streptococci and coliform were via direct colony count using membrane filter techniques.

Initial levels of coliform were approximately 500,000 in each of the test containers. At the end of 15 days the following levels were detected as still viable: (1) 25°C with light, 3400 per 100 ml; (2) 25°C dark, 7400 per 100 ml, and (3) 5°C dark, 11,000 per 100 ml. Under the conditions of (2) the coliform bacteria underwent an initial increase of 30% at the end of the first day and under the conditions of (3) a 50% increase by the end of the fifth day. Following these peaks, the numbers decreased without interruption through the 15-day test period. These results are set forth in Figures 20, 21, and 22. While this study was a small investigation, and exploratory in nature, its immediate significance lies in the fact that bacteria from Chicago sewage wastes were combined with Lake Michigan water on a test basis. The results wherein coliform survived at 5°C through 15 days (and would, no doubt, have been detected as viable for a more extended period had the test not been terminated at the end of 15 days) are of particular importance if the same or greater survival rate should prevail from sewage bacteria introduced into Lake Michigan. It has been observed in some areas (13) that residual bacteria remaining viable in partially chlorinated sewage treatment plant effluent may multiply in great numbers in the waters receiving the effluent. This rapid multiplication occurs since competitors for the food supply (other bacteria and other microbial forms) and predators are killed off, leaving the residual bacteria surviving uninhibited in an environment rich in the nutrients upon which they thrive. Currents and wave distribution could, under certain conditions, carry such contamination to the vicinity of water intakes and bathing beaches within a few days at most.

Possible Effect of Returning Treated Effluent to Lake Michigan

The possible effect of returning sewage effluent produced by the MSD plants to Lake Michigan is complex, with manifold ramifications. The factors relating to the fate or survival of pathogens introduced into the lake are largely unknown. Distribution and survival of living pathogens, both surface-wise and depth-wise, cannot, at the present time, be intelligently discussed since little information is available relating to both the functioning of the biological entities in question and the physical and limnological characteristics of Lake Michigan.

It can be proposed, however, on the basis of available information that the addition of sewage effluent from the MSD plants would contribute to the deterioration of the microbiological quality of Lake Michigan water. It has been observed that under certain conditions polluted water may maintain its identity and move in discrete masses within the lake. It is reasonable to assume that drinking water intakes and bathing beaches would, at times of varying frequency, be influenced by water of objectionable quality. On many days in the bathing season of 1961 the present water quality at several of the Chicago beaches had very high coliform levels. Any addition to the prevailing levels of pollution could be expected to seriously menace this use of Lake Michigan. The same observations would apply to the lake as a source of public water supplies.

CONCLUSIONS

1. The coliform concentrations in certain areas of Lake Michigan water at times exceed the level regarded as the safe limit for water used as a source of public water supply where chlorination is the only treatment provided.

2. The most recent records of the quality of Lake Michigan water at points up to two and one-half miles offshore in the vicinity of Chicago bathing beaches show that coliform concentrations are often in excess of acceptable limits for swimming and other recreational uses.

3. Coliform densities are so high in city harbors and adjacent areas studied, that a grave threat to health must be presumed to exist through contact with these waters.

4. The fecal streptococcus levels, as well as the coliform bacteria, indicate gross pollution in the harbors studied.

5. Lowest total bacterial densities were observed in the central body of lake water with increasing densities occurring in relation to the placement of cities and towns. Increasing total bacterial densities usually indicate deterioration in the sanitary quality of water through the presence of pollutants contributing to the enrichment of the water.

6. Masses of bacterially-polluted water introduced into Lake Michigan may maintain their identity for several days.

7. It is known that microbial forms pathogenic to man survive in natural bodies of water for varying periods; some forms may be able to survive longer than the indicator organisms commonly used, i.e., the coliform bacteria.

8. The return to Lake Michigan of sizable quantities of treated waste waters, now being discharged to the Illinois River, would increase the densities of coliform bacteria and other microbial forms in the vicinity of the outlet. This would increase the potential hazards to public health in the use of waters in the area, and heighten the need for protective measures - including, but not limited to: complete treatment of waste waters before discharge to the Lake and complete treatment of municipal supply taken from the Lake.

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TABLE 1

COLIFORM RESULTS FROM DEEPWATER AND INSHORE STUDIES

	Surface Samples				Lowermost Samples			
No. per 100 ml	No. of Samples	Per Cent	Cumulative Totals	Cumulative Per Cent	No. of Samples	Per Cent	Cumulative Totals	Cumulative Per Cent
< 1	134	42.8	134	42.8	156	56.3	156	56.3
1-10	99	31.8	233	74.6	75	27.1	231	83.4
11-50	47	15.0	280	89.6	28	10.1	259	93.5
51-100	12	3.8	292	93.4	4	1.4	263	94.9
110-200	8	2.5	300	95.9	7	2.5	270	97.4
210-300	4	1.3	304	97.2	2	0.7	272	98.1
310-400	1	0.3	305	97.5	0	0	-	-
410-500	1	0.3	306	97.8	1	0.4	273	98.5
510-600	2	0.6	308	98.4	3	1.1	276	99.6
610-700	0	0	-	-	0	0	-	-
710-800	1	0.3	309	98.7	0	0	-	-
810-900	0	0	-	-	0	0	-	-
910-1,000	0	0	-	-	0	0	-	-
1,100-2,000	4	1.3	313	100.0	0	0	-	-
2,000-2,500	0	0	-	-	1	0.4	277	100.0
Total	313	100.00			277	100.0		

TABLE 2

20°C TOTAL PLATE COUNT RESULTS FROM DEEPWATER AND INSHORE STUDIES

	Surface Samples				Lowermost Samples			
No. per 100 ml	No. of Samples	Per Cent	Cumulative Totals	Cumulative Per Cent	No. of Samples	Per Cent	Cumulative Totals	Cumulative Per Cent
100-490	17	6.3	17	6.3	13	5.5	13	5.5
500-990	18	6.6	35	12.9	17	7.2	30	12.7
1,000-4,900	109	40.2	144	53.1	85	35.9	115	48.6
5,000-9,900	48	17.7	192	70.8	59	24.9	174	73.5
10,000-49,000	46	16.9	238	87.7	25	10.5	199	84.0
50,000-99,000	12	4.5	250	92.2	15	6.3	214	90.3
100,000-490,000	21	7.8	271	100.0	21	8.9	235	99.2
500,000-990,000	0	0	-	100.0	2	0.8	237	100.0
Total	271	100.0			237	100.0		

TABLE 3

35°C TOTAL PLATE COUNT RESULTS FROM DEEPWATER AND INSHORE STUDIES

	Surface Samples				Lowermost Samples			
No. per 100 ml	No. of Samples	Per Cent	Cumulative Totals	Cumulative Per Cent	No. of Samples	Per Cent	Cumulative Totals	Cumulative Per Cent
10-90	8	2.6	8	2.6	0	0	0	0
100-490	37	11.9	45	14.5	26	12.3	26	12.3
500-990	34	10.9	79	25.4	19	8.9	45	21.2
1,000-4,900	99	31.8	178	57.2	82	38.7	127	59.9
5,000-9,000	53	17.0	231	74.2	32	15.1	159	75.0
10,000-49,000	37	11.9	268	86.1	21	9.9	180	84.9
50,000-99,000	19	6.1	287	92.2	13	6.2	193	91.1
100,000-490,000	21	6.9	308	99.1	16	7.5	209	98.6
500,000-990,000	1	0.3	309	99.4	2	0.9	211	99.5
1 M+	2	0.6	311	100.0	1	0.5	212	100.0
Total	311	100.0			212	100.0		

TABLE 4

COLIFORM RESULTS FROM HARBOR STUDIES (SURFACE SAMPLES ONLY)

No. per 100 ml		No. Stations Sampled	No. Samples	Per Cent	Cumulative Totals	Cumulative Per Cent
			Chicago Harbor			
1-10			3	20.0	3	20.0
11-50			4	26.7	7	46.7
100-490			6	40.0	13	86.7
500-990			2	13.3	15	100.0
	Total	15	15	100.0		
			Racine Harbor			
10-50			3	8.8	3	8.8
50-100			2	5.9	5	14.7
100-490			11	32.4	16	47.1
500-990			5	14.7	21	61.8
1000-5000			12	35.3	33	97.1
5000-10,000			1	2.9	34	100.0
	Total	34	34	100.0		
			Milwaukee Harbor			
1			9	11.8	9	11.8
1-10			5	6.5	14	18.3
10-50			8	10.5	22	28.8
50-100			4	5.3	26	34.1
100-490			18	23.7	44	57.8
500-990			3	3.9	47	61.7
1000-5000			10	13.2	57	74.9
5000-10,000			7	9.2	64	84.1
10,000-20,000			4	5.3	68	89.4
20,000-30,000			4	5.3	72	94.7
30,000-40,000			4	5.3	76	100.0
	Total	76	76	100.0		

TABLE 5

20°C TOTAL PLATE COUNT RESULTS FROM HARBOR STUDIES (SURFACE SAMPLES ONLY)

No. per 100 ml	No. Stations Sampled	No. Samples	Per Cent	Cumulative Totals	Cumulative Per Cent
		Chicago Harbor			
500-990		1	5.8	1	5.8
1000-4900		4	23.5	5	29.3
5000-9900		3	17.8	8	47.1
50,000-99,000		1	5.8	9	52.9
100,000-490,000		8	47.1	17	100.0
Total	17	17	100.0		
		Racine Harbor			
5000-9900		1	3.1	1	3.1
10,000-49,000		1	3.1	2	6.2
100,000-490,000		23	71.9	25	78.1
500,000-990,000		5	15.6	30	93.7
1 million +		2	6.3	32	100.0
Total	32	32	100.0		
		Milwaukee Harbor			
500-990		1	1.3	1	1.3
1000-4900		9	12.0	10	13.3
5000-9900		12	16.0	22	29.3
10,000-49,000		21	28.0	43	57.3
50,000-99,000		8	10.7	51	68.0
100,000-490,000		14	18.7	65	86.7
500,000-1 million		4	5.3	69	92.0
1 million +		6	8.0	75	100.0
Total	75	75	100.0		

TABLE 6

35°C TOTAL PLATE COUNT RESULTS FROM HARBOR STUDIES (SURFACE SAMPLES ONLY)

No. per 100 ml		No. Stations Sampled	No. Samples	Per Cent	Cumulative Totals	Cumulative Per Cent
			Chicago Harbor			
500-990			2	14.3	2	14.3
1,000-4,900			1	7.1	3	21.4
10,000-49,000			2	14.3	5	35.7
50,000-99,000			5	35.7	10	71.4
100,000-490,000			3	21.5	13	92.9
500,000			1	7.1	14	100.0
	Total	14	14	100.0		
			Racine Harbor			
1,000-4,900			2	7.1	2	7.1
5,000-9,900			1	3.6	3	10.7
10,000-49,000			9	32.1	12	42.8
50,000-99,000			4	14.3	16	57.1
100,000-490,000			12	42.9	28	100.0
	Total	28	28	100.0		
			Milwaukee Harbor			
100-490			4	5.3	4	5.3
500-990			3	4.0	7	9.3
1,000-4,900			15	20.0	22	29.3
5,000-9,900			8	10.7	30	40.0
10,000-49,000			15	20.0	45	60.0
50,000-99,000			5	6.6	50	66.6
100,000-490,000			17	22.7	67	89.3
1 million +			8	10.7	75	100.0
	Total	75	75	100.0		

TABLE 7

COLIFORM LEVELS AT THREE POINTS
ADJACENT TO CENTRAL DISTRICT FILTRATION PLANT, CHICAGO, ILLINOIS, 1961*
MPN per 100/ml

	Distance from Shore		June	July	August	September	October	November
East End	App. 1 mile	Max.	2,400	24,000	780	9,200**	790	1,300
		Av.	738	4,114	198	1,629	400	285
Center	App. ½ mile	Max.	5,400	13,000	780	490	1,300	16,000
		Av.	1,500	2,486	165	187	339	2,104
West End	Near Shore	Max.	3,300	4,900	790	220	1,100	2,400
		Av.	1,273	1,613	235	138	393	487

* Data Supplied by: Department of Water and Sewers, City of Chicago

** September 14, 1961

TABLE 8

COLIFORM INCIDENCE AT THE CHICAGO BEACHES, SUMMER, 1961*

BEACH		SAMPLING POINT	COLIFORM MPN/100 ml MAX	No. days at Max.	No. days > 1000
1.	Juneway Terrace	301	1,500	1	5
2.	Rogers Ave.	302	12,000	1	10
3.	Howard Street	303	11,000	1	9
4.	Sherwin Ave.	304	> 110,000	2	8
5.	Rogers Park	305	110,000	1	8
6.	Farwell Beach	306	46,000	1	9
7.	Pratt Blvd.	307	4,600	1	6
8.	Columbia Ave.	308	> 11,000	1	5
9.	North Shore Ave.	309	15,000	1	5
10.	Albion Ave.	310	11,000	1	6
11.	Granville Ave.	311	7,500	1	10
12.	Thorndale Ave.	312	21,000	1	7
13.	Hollywood Ave.	313	7,500	1	9
14.	Foster Ave.	314	24,000**	1	11
15.	Montrose Beach	315	24,000**	1	16
16.	North Ave. (North)	316	15,000	3	8
17.	North Ave. (South)	317	> 110,000	1	10
18.	Oak Street	318	15,000	1	12
19.	12th Street	319	240,000**	1	17
20.	31st Street	320	46,000	1	10
21.	49th Street	321	> 1,100	1	5
22.	57th Street	322	4,600	2	12
23.	Jackson Park	323	46,000	1	12
24.	67th Street	324	4,600	1	9
25.	Rainbow (North)	325	110,000	1	10
26.	Rainbow (South)	326	> 11,000	1	10
27.	Calumet (Outer)	327	46,000	1	15
28.	Calumet (North)	328	> 110,000	1	18
29.	Calumet (South)	329	> 110,000	1	22
30.	Hammond	330	> 110,000	2	20
31.	Whiting	331	> 110,000	2	19

**9-15-61

*Data supplied by the Park District, City of Chicago

TABLE 9

COLIFORM BACTERIA Per 100 ml at DUNNE CRIB in 1951, 1956, and 1961 (Standard MPN)*

	1951		1956		1961	
	< 2.2	> 50	< 2.2	> 50	< 2.2	> 50
No. of days	186	11	90	48	174	54
Highest Daily maximum		374		1100		3000

* Data supplied by: Dept. of Water and Sewers, City of Chicago

TABLE 10 Summary of Coliform Levels at Dunne Crib for 1961 (MPN/100 ml)

	Number of Samples Having an MPN of $\leq$ 2.2	Number of Samples Having an MPN of $\geq$ 50	Maximum MPN During Month
JANUARY	24	0	10.0
FEBRUARY	23	0	6.9
MARCH	10	3	120.0
APRIL	19	3	88.0
MAY	16	8	510.0
JUNE	18	0	33.0
JULY	5	1	120.0
AUGUST	13	0	44.0
SEPTEMBER	2	9	450.0
OCTOBER	1	18	1800.0
NOVEMBER	0	14	3000.0
DECEMBER			

Data Supplied by: Department of Water and Sewers, City of Chicago

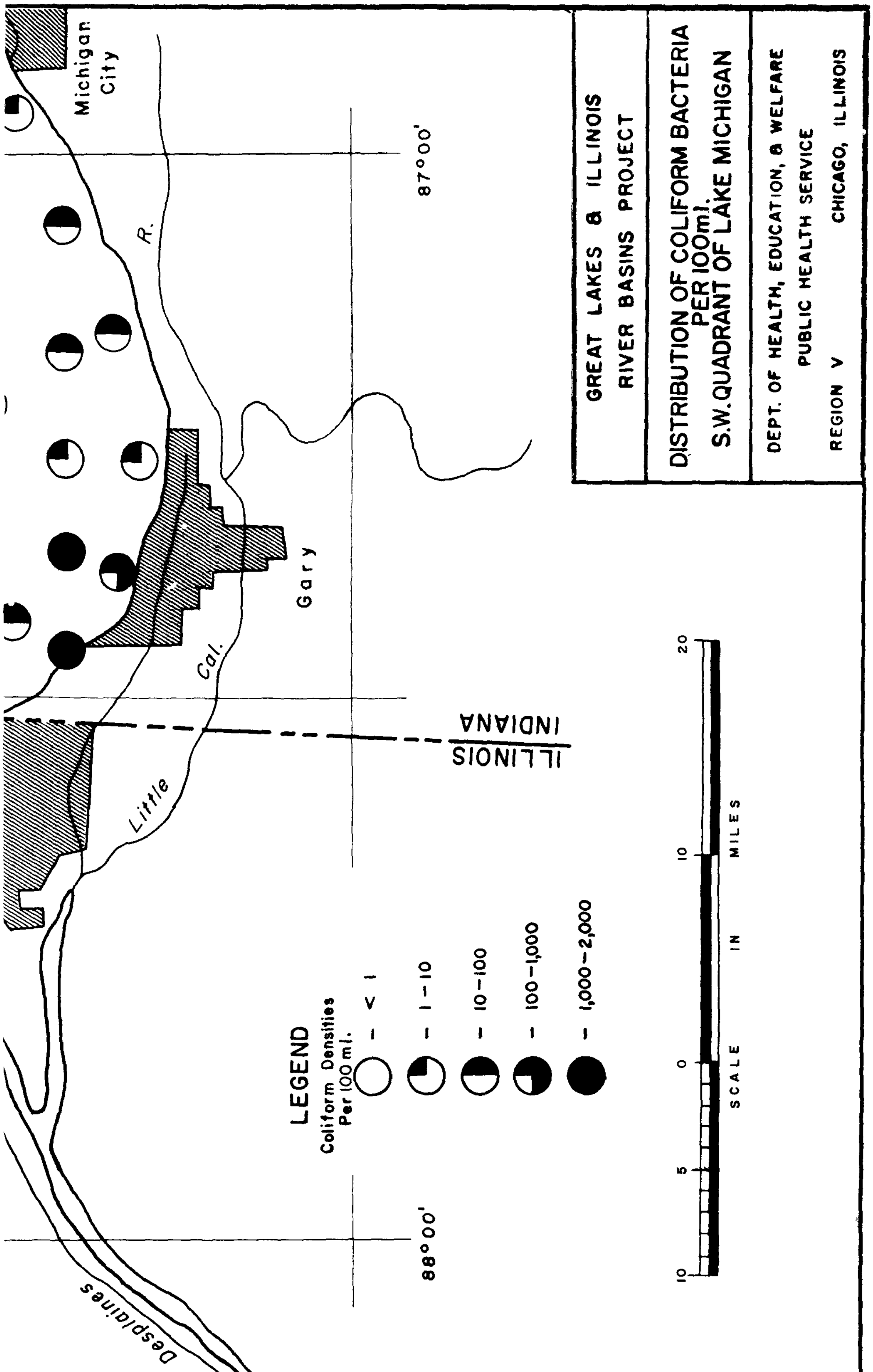
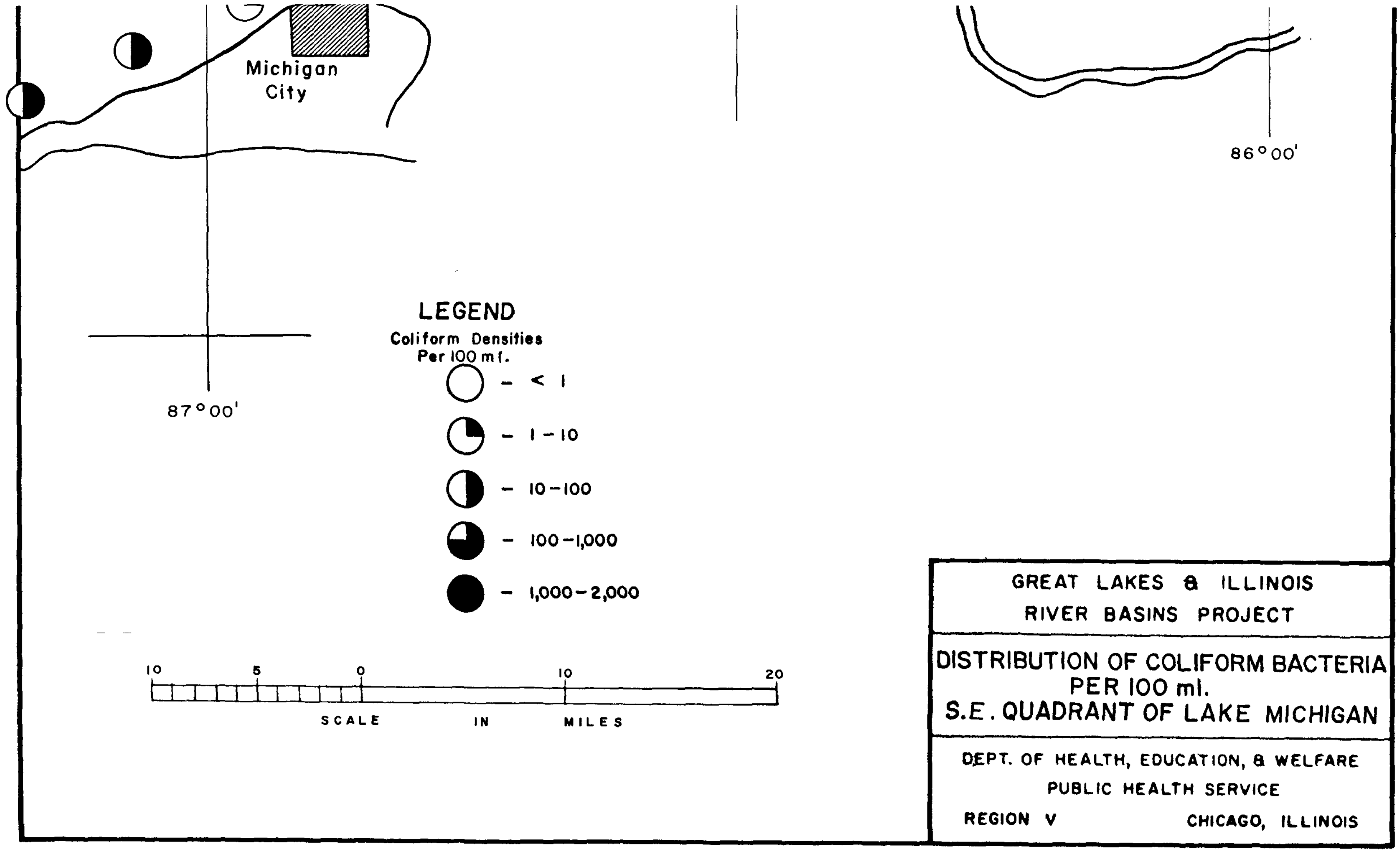

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF COLIFORM BACTERIA
PER 100ml.
S.W. QUADRANT OF LAKE MICHIGAN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS
Michigan City
87°00'
R.
Gary
Cal.
Little
ILLINOIS
INDIANA
Desplaines
88°00'
LEGEND
Coliform Densities
Per 100 ml.
– < 1
– 1 - 10
– 10 - 100
– 100 - 1,000
– 1,000 - 2,000
10
5
0
10
20
SCALE IN MILES

FIGURE 1



Michigan City
87°00'
86°00'
LEGEND
Coliform Densities Per 100 ml.
– < 1
– 1 – 10
– 10 – 100
– 100 – 1,000
– 1,000 – 2,000
10
5
0
10
20
SCALE IN MILES
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF COLIFORM BACTERIA
PER 100 ml.
S.E. QUADRANT OF LAKE MICHIGAN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 2

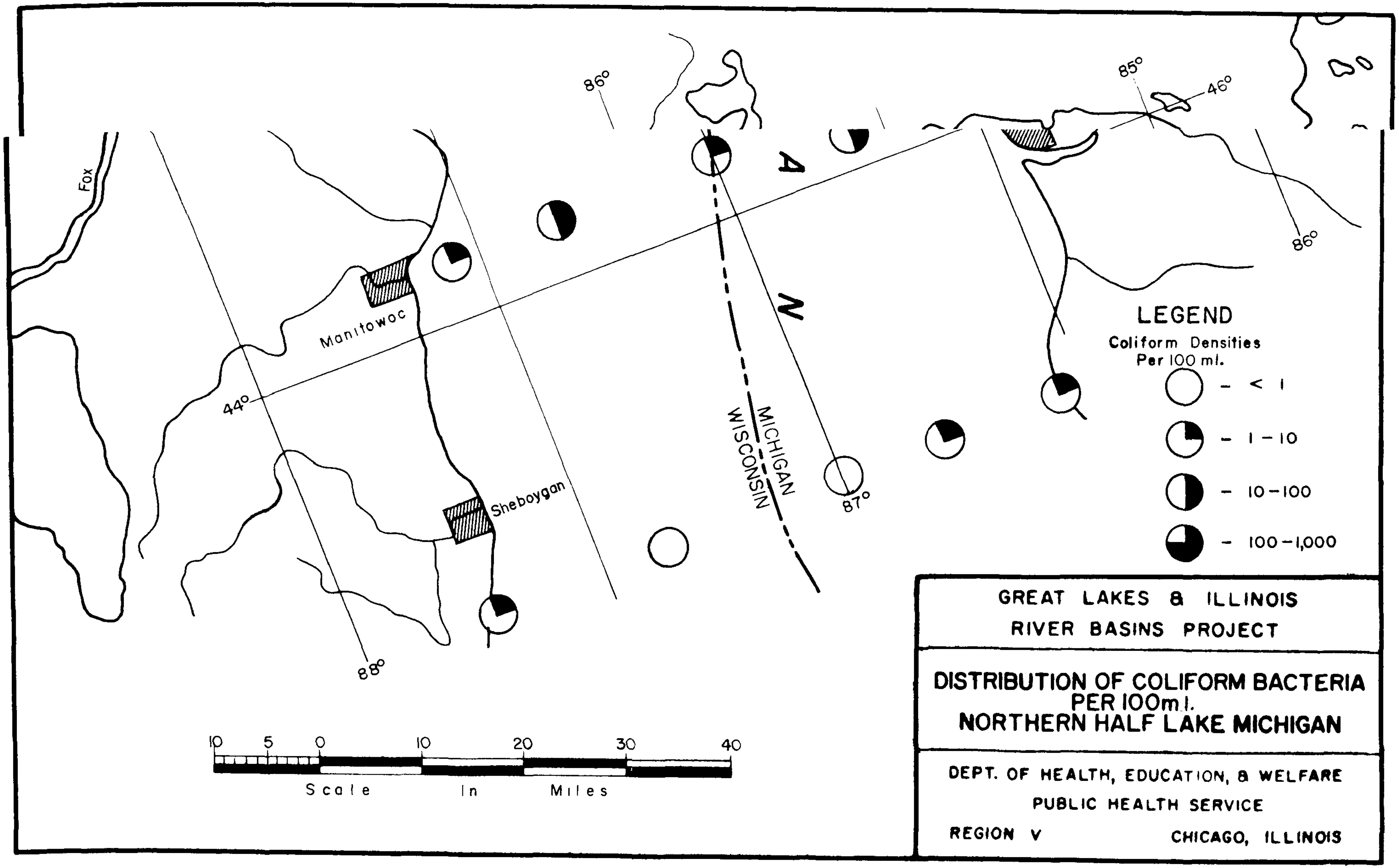

Fox
86°
85°
46°
86°
Manitowoc
44°
Sheboygan
88°
87°
A
N
MICHIGAN
WISCONSIN
LEGEND
Coliform Densities
Per 100 ml.
– < 1
– 1 – 10
– 10 – 100
– 100 – 1,000
10 5 0 10 20 30 40
Scale In Miles
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF COLIFORM BACTERIA
PER 100ml.
NORTHERN HALF LAKE MICHIGAN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

Figure 3

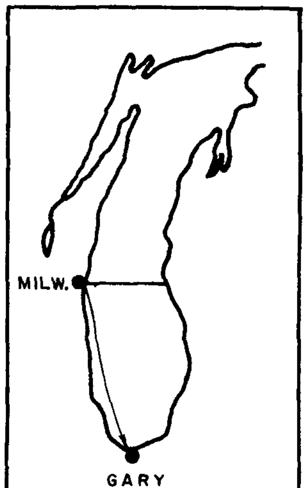
NUMBER OF COLIFORMS PER 100 ml.

LEGEND

1 Mile Stations

4 Mile Stations

10 Mile Stations



AREA REPRESENTED

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

COLIFORM DENSITIES
IN 10 MILE ZONE ALONG WEST
SHORE OF LAKE MICHIGAN

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

FIGURE 4

10.

1

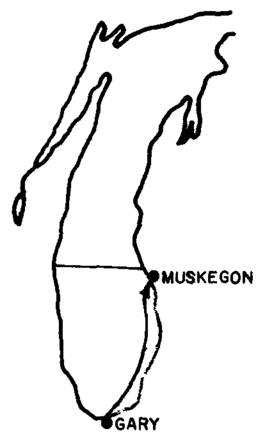
NUMBER OF COLIFORMS PER 100ml.

LEGEND

●———● 1 Mile Stations

○— — —○ 4 Mile Stations

NOTE—
All samples from 10 mile contour contained coliform densities of less than 1 per 100ml. Therefore no 10 mile contours are shown on this graph.



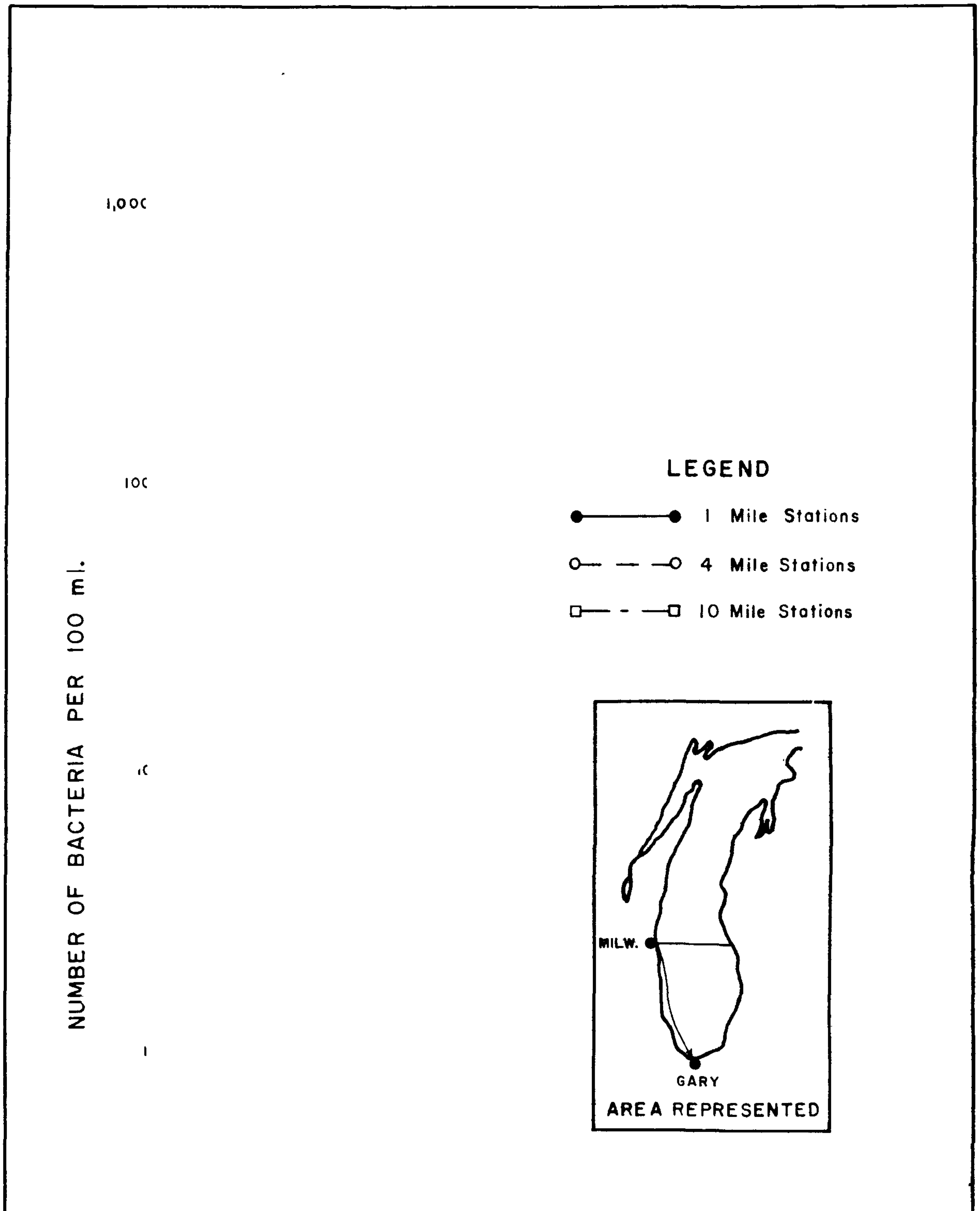
AREA REPRESENTED

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

COLIFORM DENSITIES
IN 10 MILE ZONE ALONG EAST
SHORE OF LAKE MICHIGAN

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

FIGURE 5



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

20° C TOTAL BACTERIAL DENSITIES IN 10 MILE ZONE ALONG WEST SHORE OF LAKE MICHIGAN

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

FIGURE 6

1,000

100

10

1

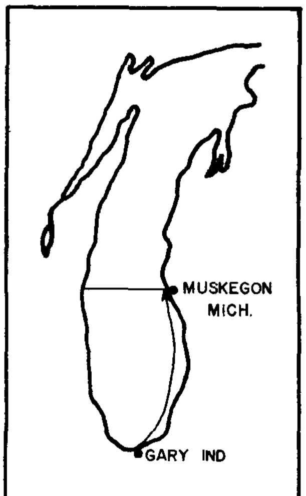
NUMBER OF BACTERIA PER 100 ml.

LEGEND

● — ● 1 Mile Stations

○ — — ○ 4 Mile Stations

□ — - — □ 10 Mile Stations



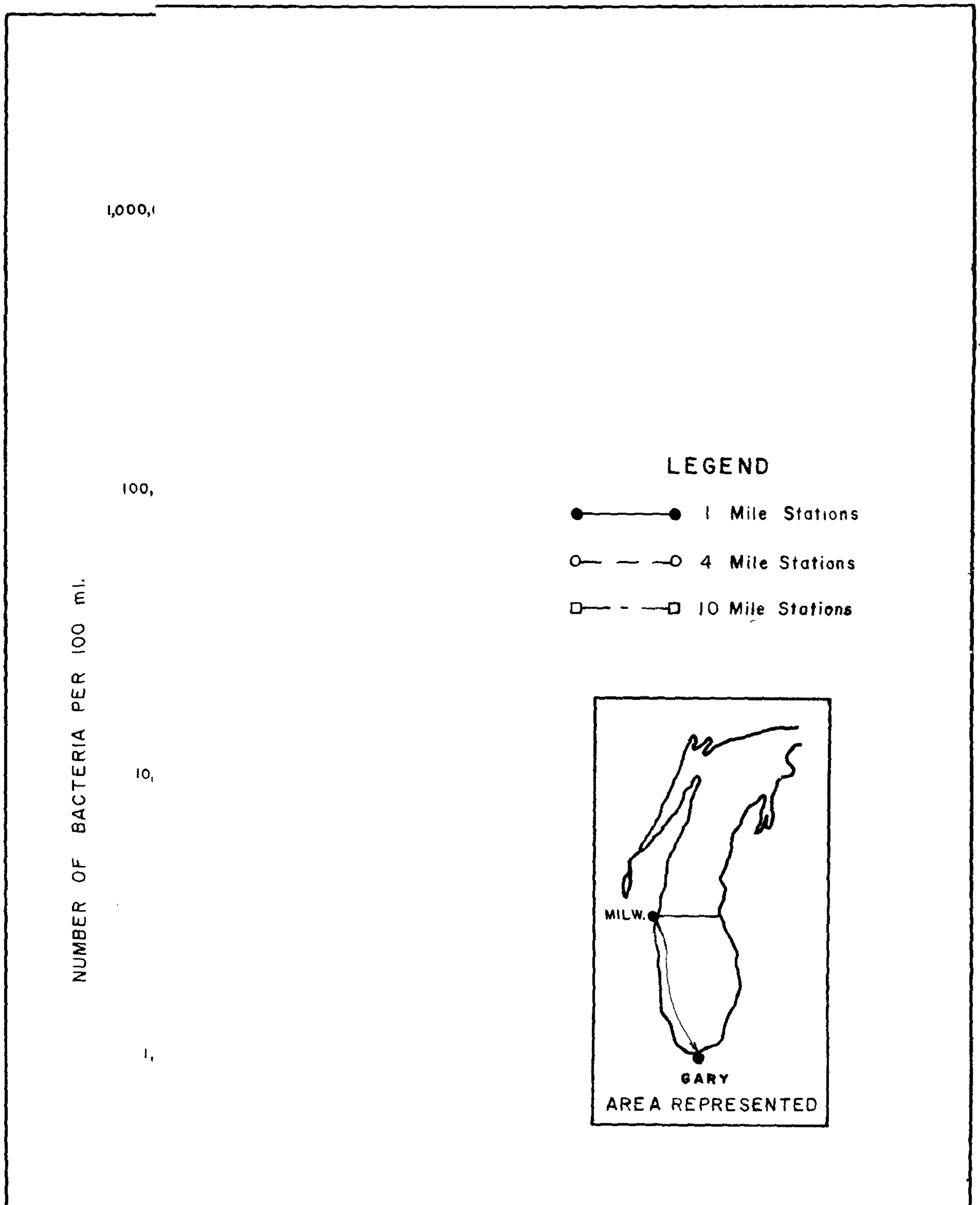
AREA REPRESENTED

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

20°C TOTAL BACTERIAL DENSITIES
IN 10 MILE ZONE ALONG EAST
SHORE OF LAKE MICHIGAN

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

FIGURE 7



GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

35°C TOTAL BACTERIAL DENSITIES IN 10 MILE ZONE ALONG WEST SHORE OF LAKE MICHIGAN

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

FIGURE 8

1,000

10

1

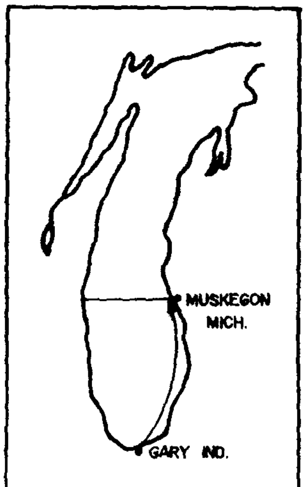
NUMBER OF BACTERIA PER 100 ml

LEGEND

●———● 1 Mile Stations

○— — —○ 4 Mile Stations

□— - —□ 10 Mile Stations



AREA REPRESENTED

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

35°C TOTAL BACTERIAL DENSITIES IN 10 MILE ZONE ALONG EAST SHORE OF LAKE MICHIGAN

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

FIGURE 9

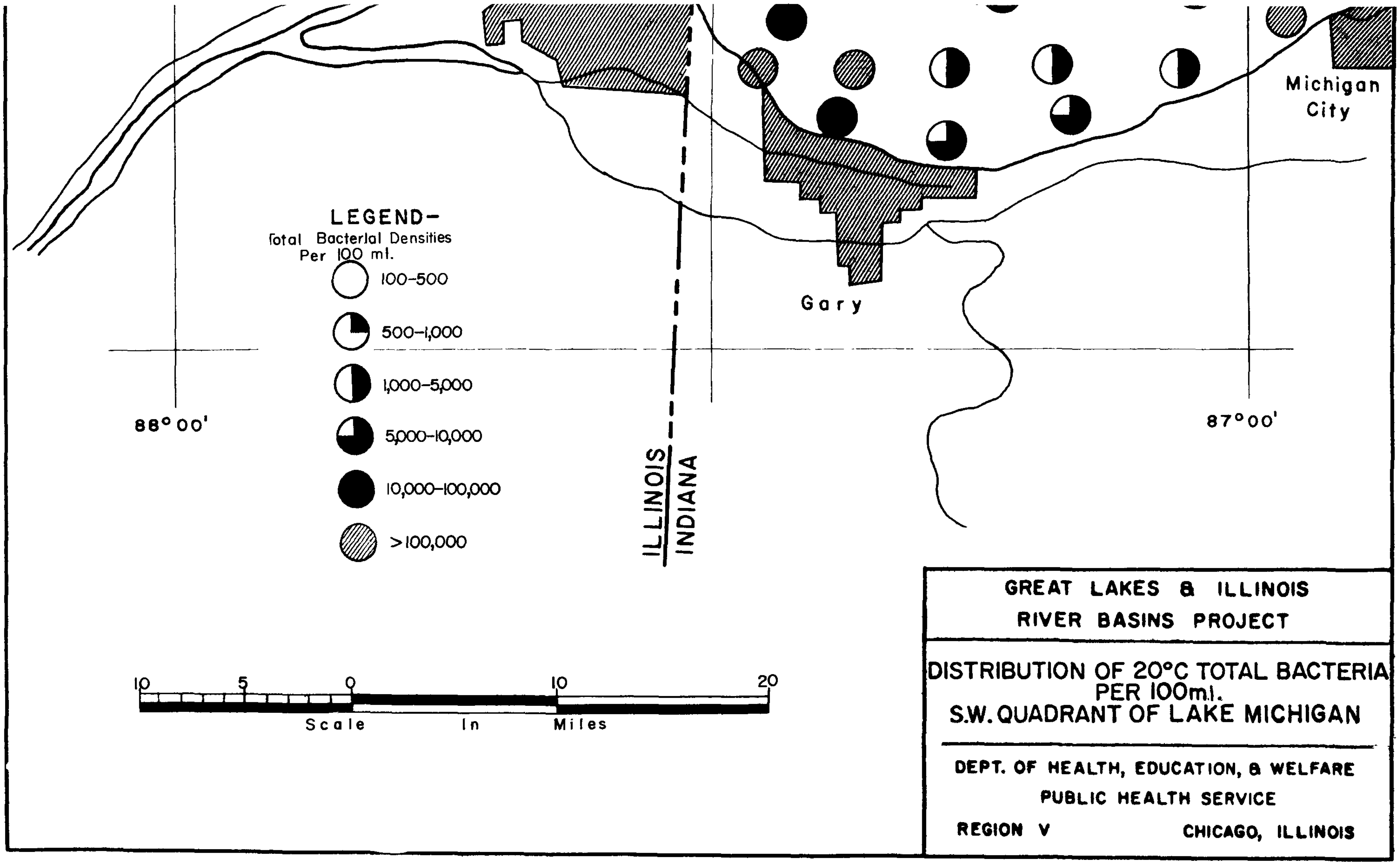

Michigan City
Gary
88°00'
87°00'
ILLINOIS
INDIANA
LEGEND-
Total Bacterial Densities Per 100 ml.
100-500
500-1,000
1,000-5,000
5,000-10,000
10,000-100,000
>100,000
10 5 0 10 20
Scale In Miles
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF 20°C TOTAL BACTERIA PER 100ml.
S.W. QUADRANT OF LAKE MICHIGAN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

Figure 10

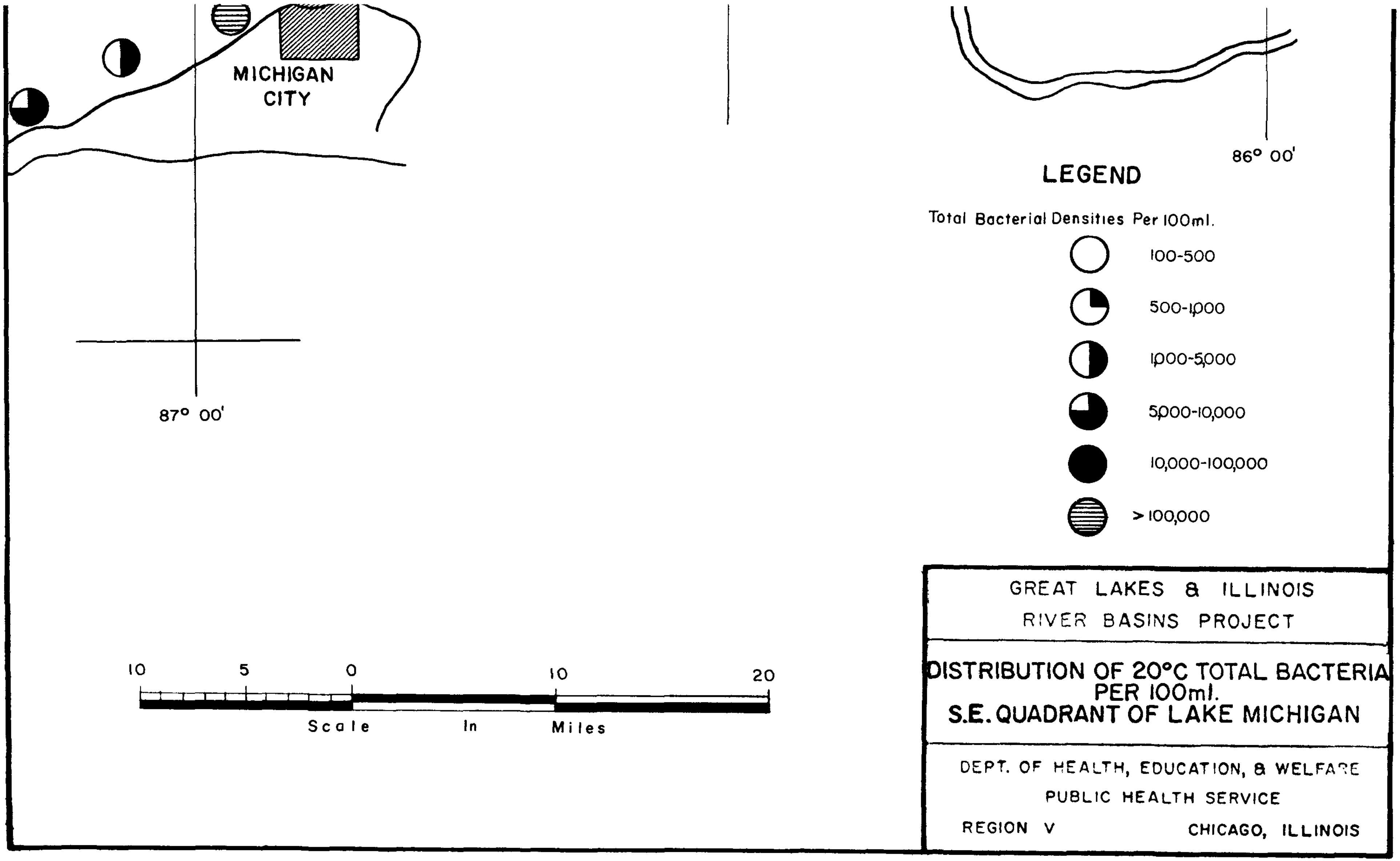

MICHIGAN CITY
87° 00'
86° 00'
LEGEND
Total Bacterial Densities Per 100ml.
100-500
500-1,000
1,000-5,000
5,000-10,000
10,000-100,000
> 100,000
10
5
0
10
20
Scale In Miles
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF 20°C TOTAL BACTERIA PER 100ml.
S.E. QUADRANT OF LAKE MICHIGAN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 11

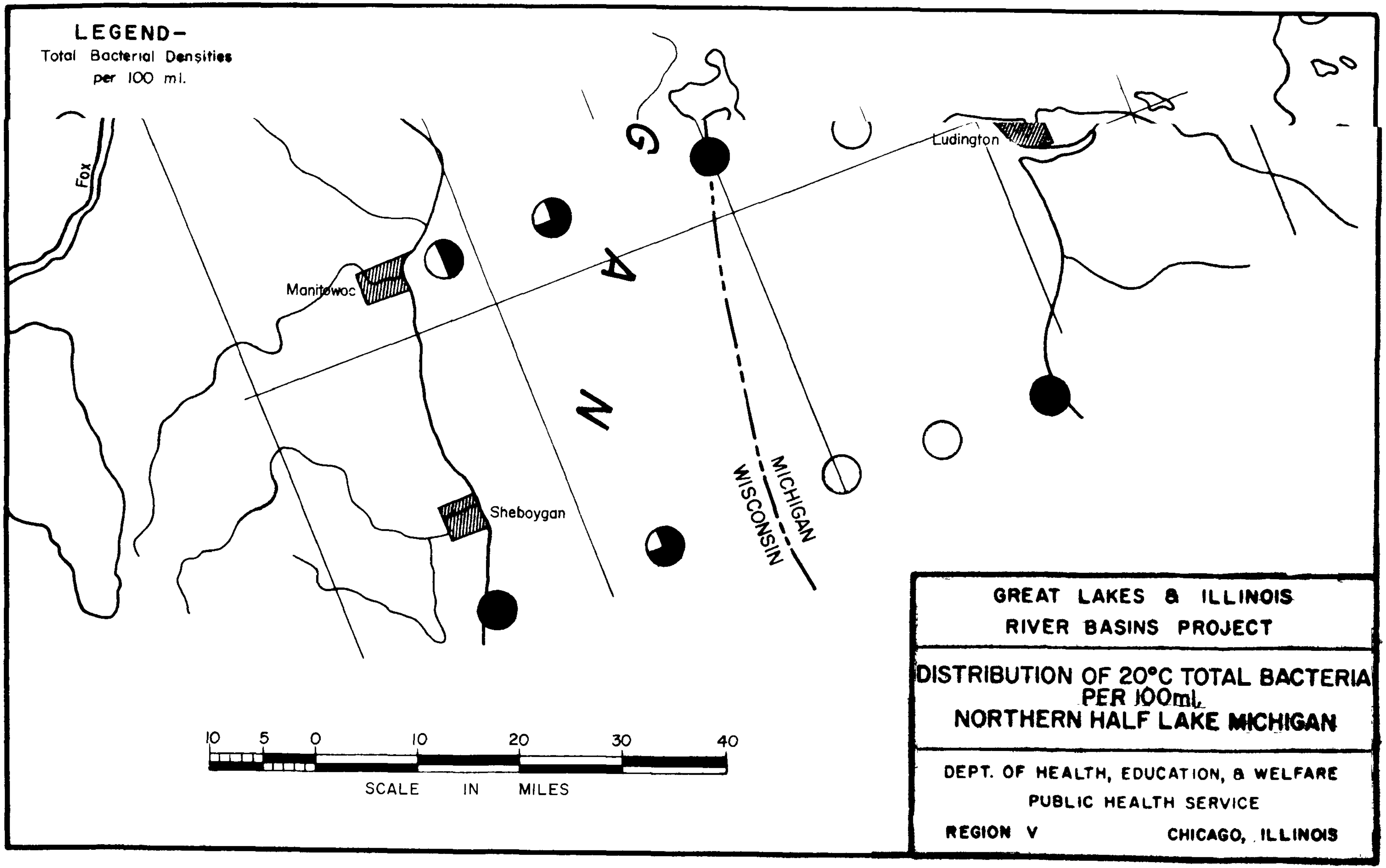
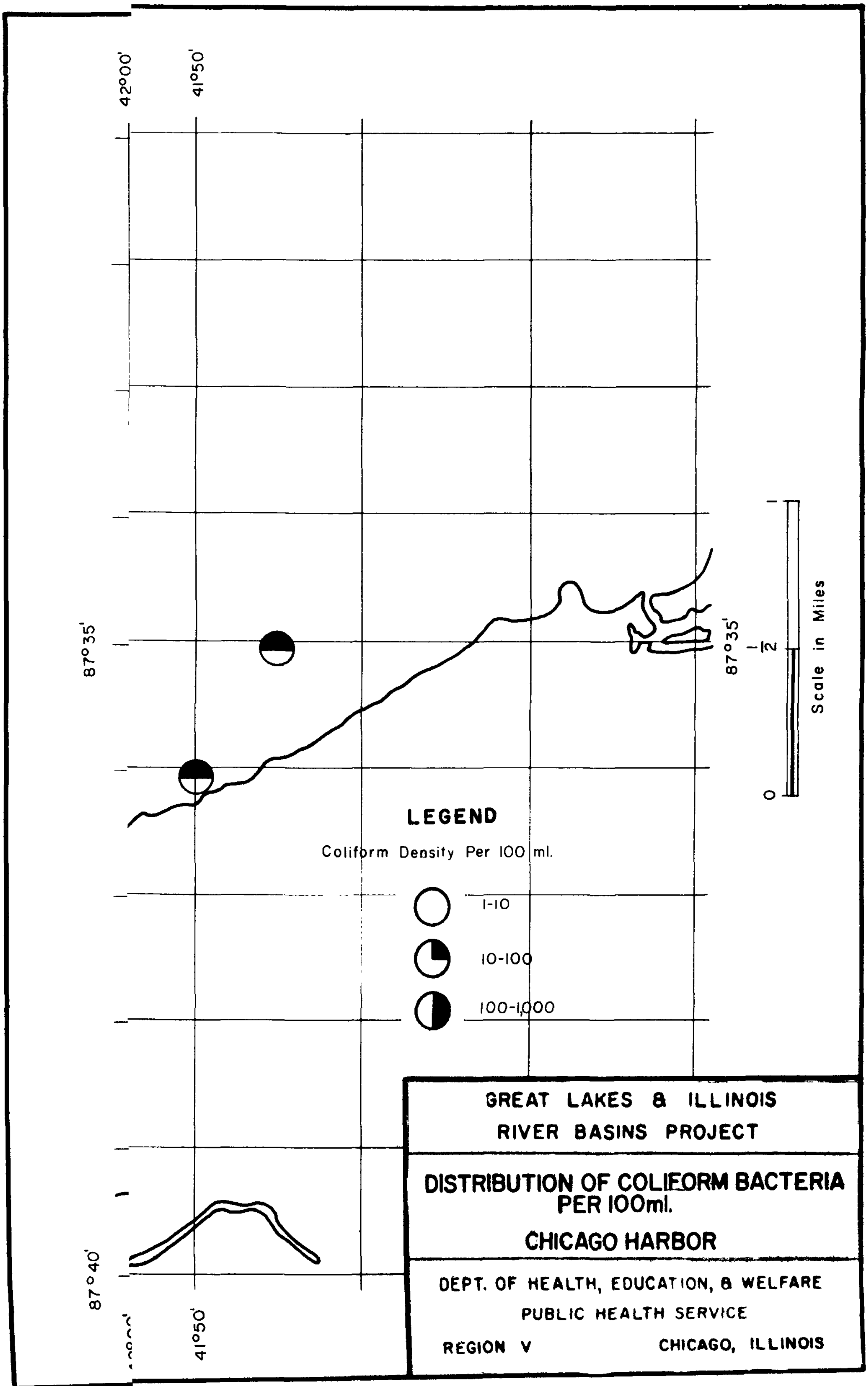

LEGEND-
Total Bacterial Densities
per 100 ml.
Fox
Manitowoc
Sheboygan
Ludington
MICHIGAN
WISCONSIN
10 5 0 10 20 30 40
SCALE IN MILES
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF 20°C TOTAL BACTERIA
PER 100ml.
NORTHERN HALF LAKE MICHIGAN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 12



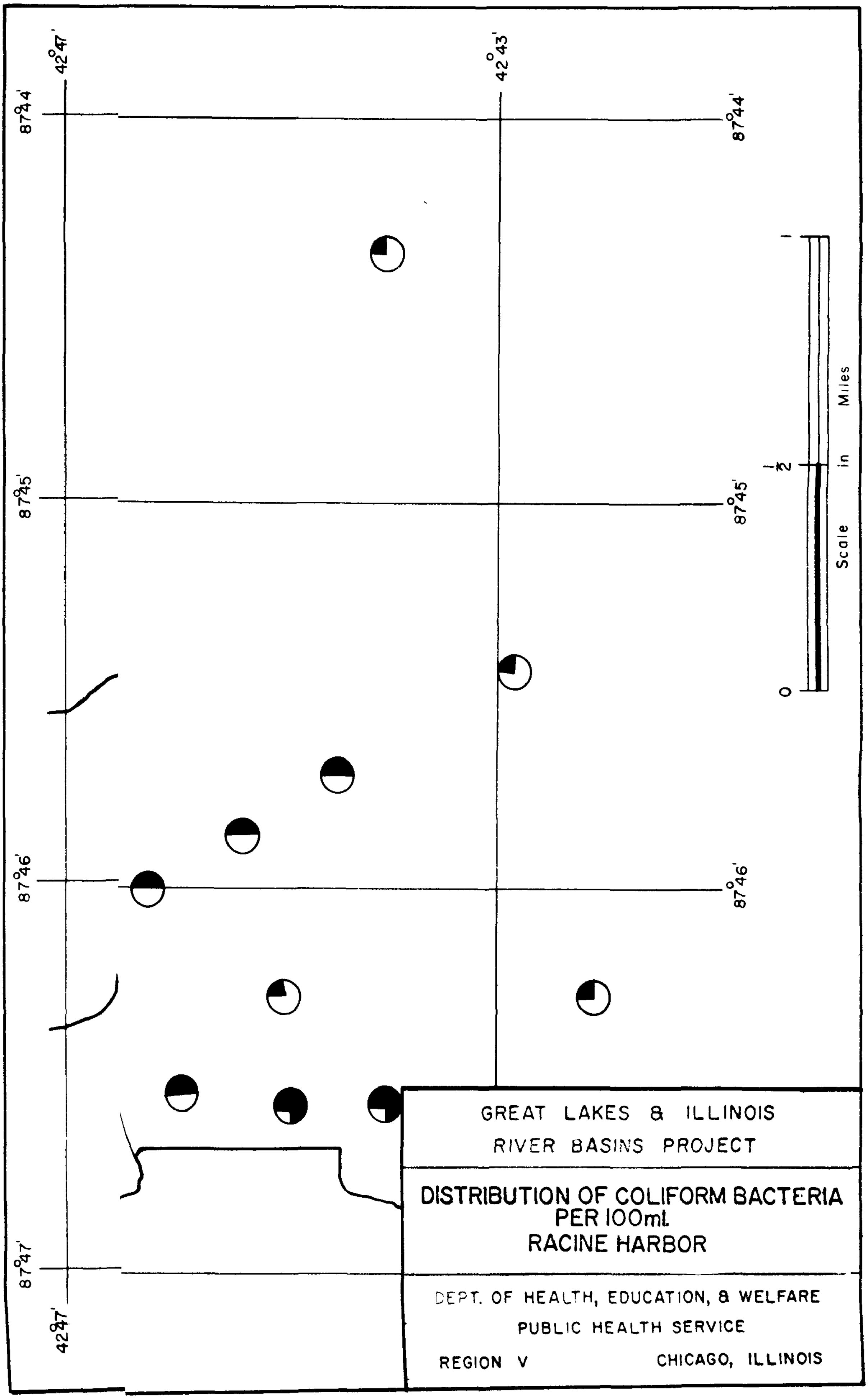
GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

DISTRIBUTION OF COLIFORM BACTERIA PER 100ml.

CHICAGO HARBOR

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

FIGURE 13



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

DISTRIBUTION OF COLIFORM BACTERIA PER 100ml. RACINE HARBOR

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

FIGURE 14

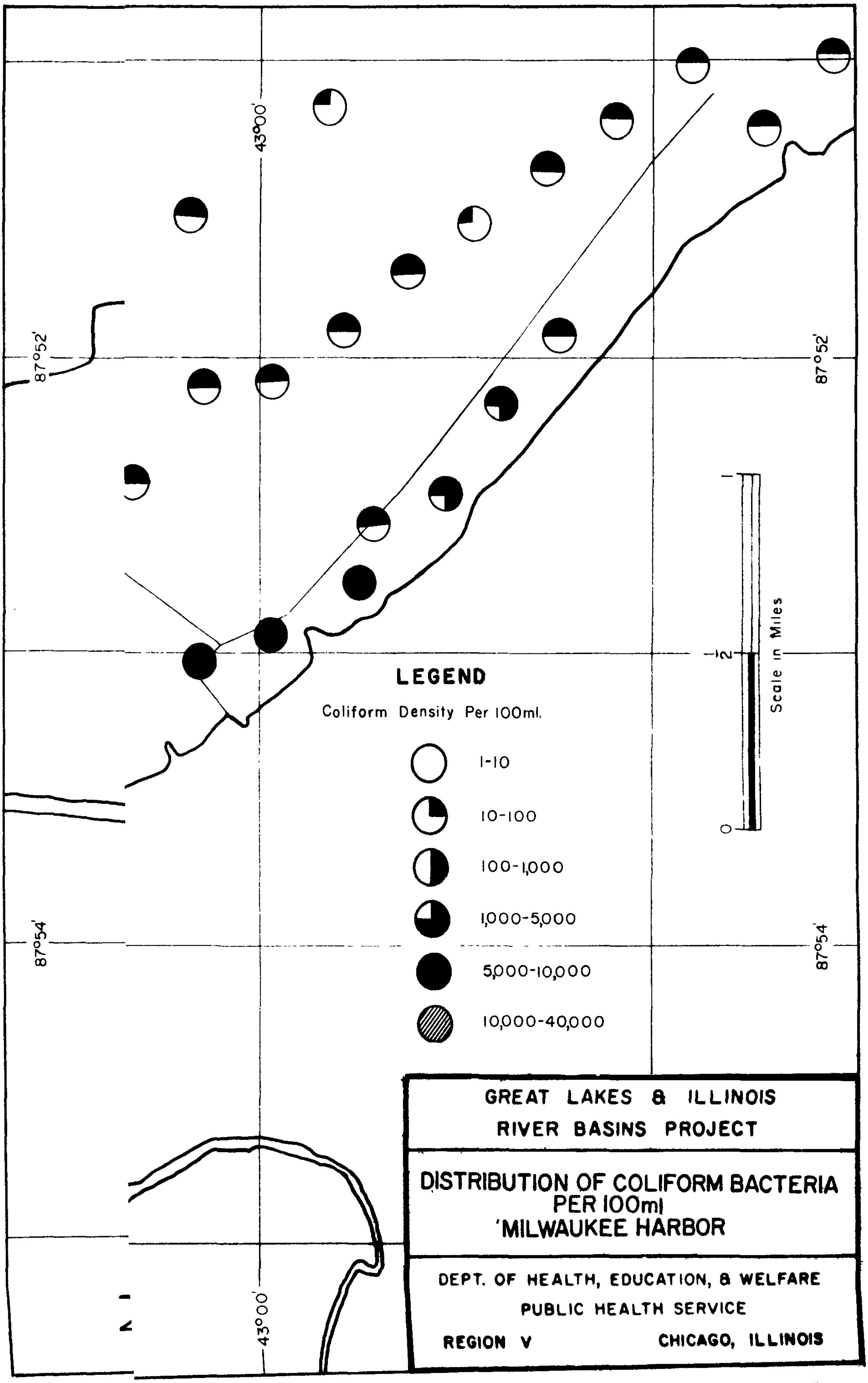
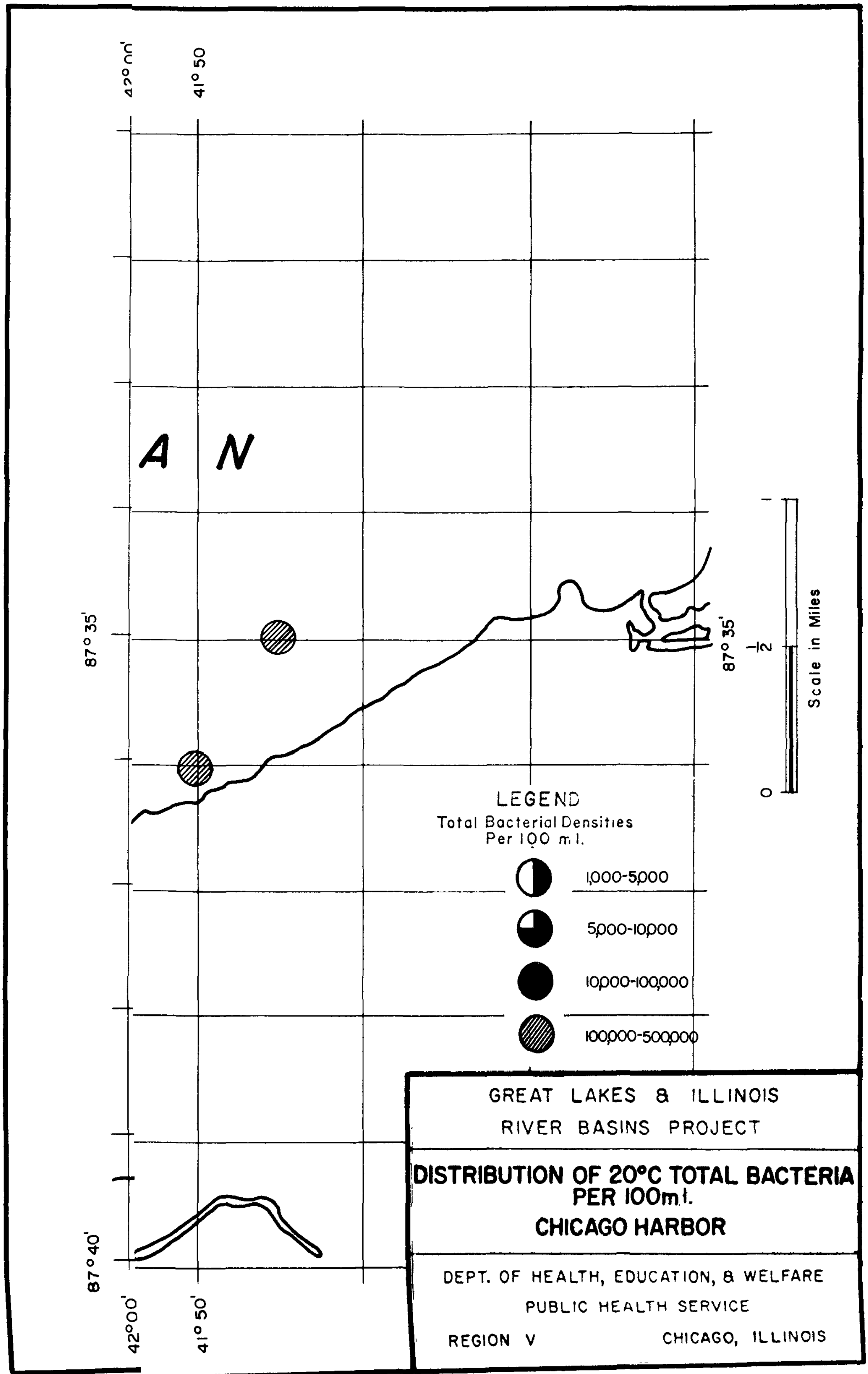

43°00'
87°52'
87°52'
87°54'
87°54'
43°00'
LEGEND
Coliform Density Per 100ml.
1-10
10-100
100-1,000
1,000-5,000
5,000-10,000
10,000-40,000
Scale in Miles
0
1/2
1
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF COLIFORM BACTERIA
PER 100ml
MILWAUKEE HARBOR
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 15

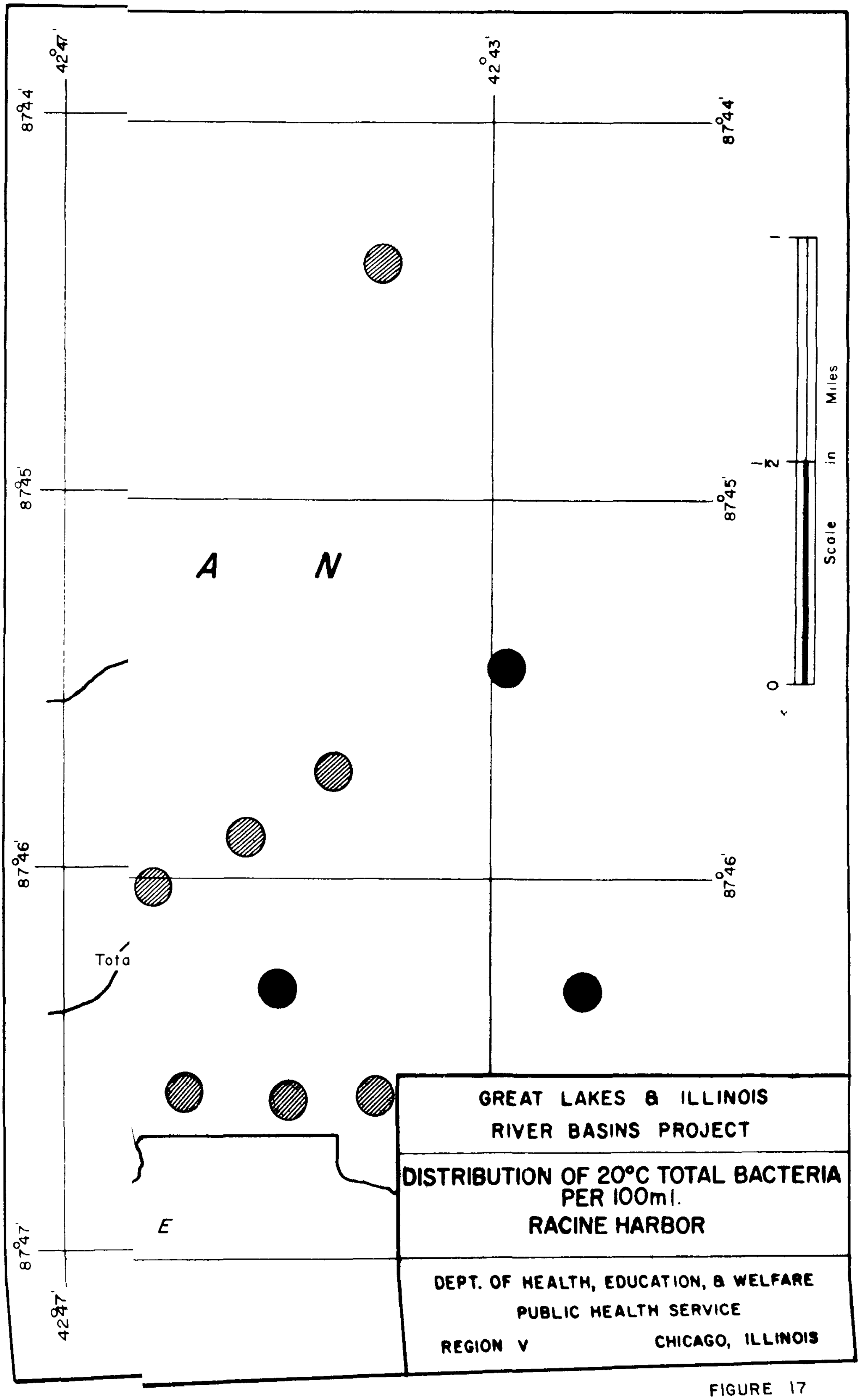


GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

DISTRIBUTION OF 20°C TOTAL BACTERIA PER 100ml.
CHICAGO HARBOR

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

FIGURE 16



GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

DISTRIBUTION OF 20°C TOTAL BACTERIA PER 100ml.

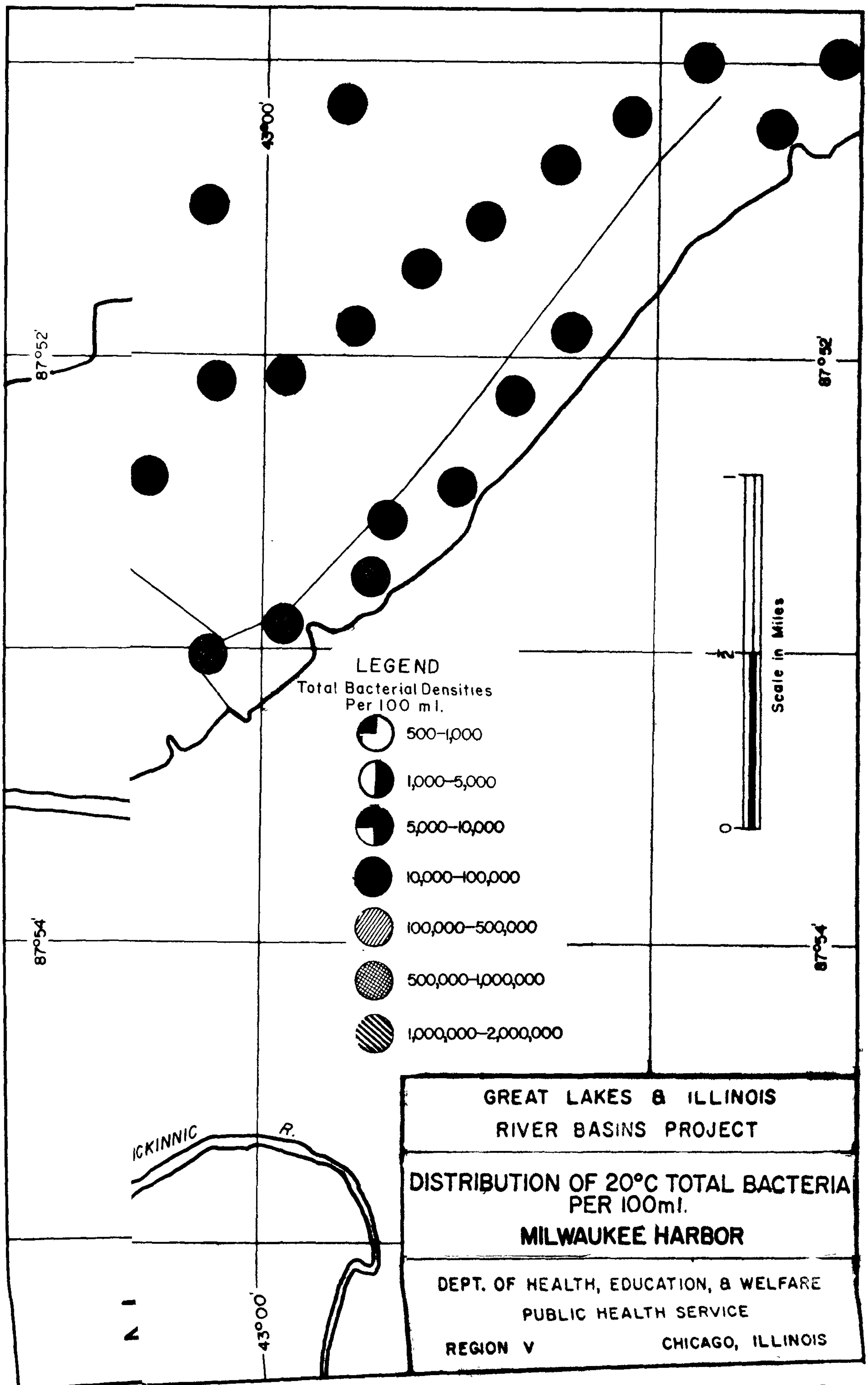
RACINE HARBOR

DEPT. OF HEALTH, EDUCATION, & WELFARE

PUBLIC HEALTH SERVICE

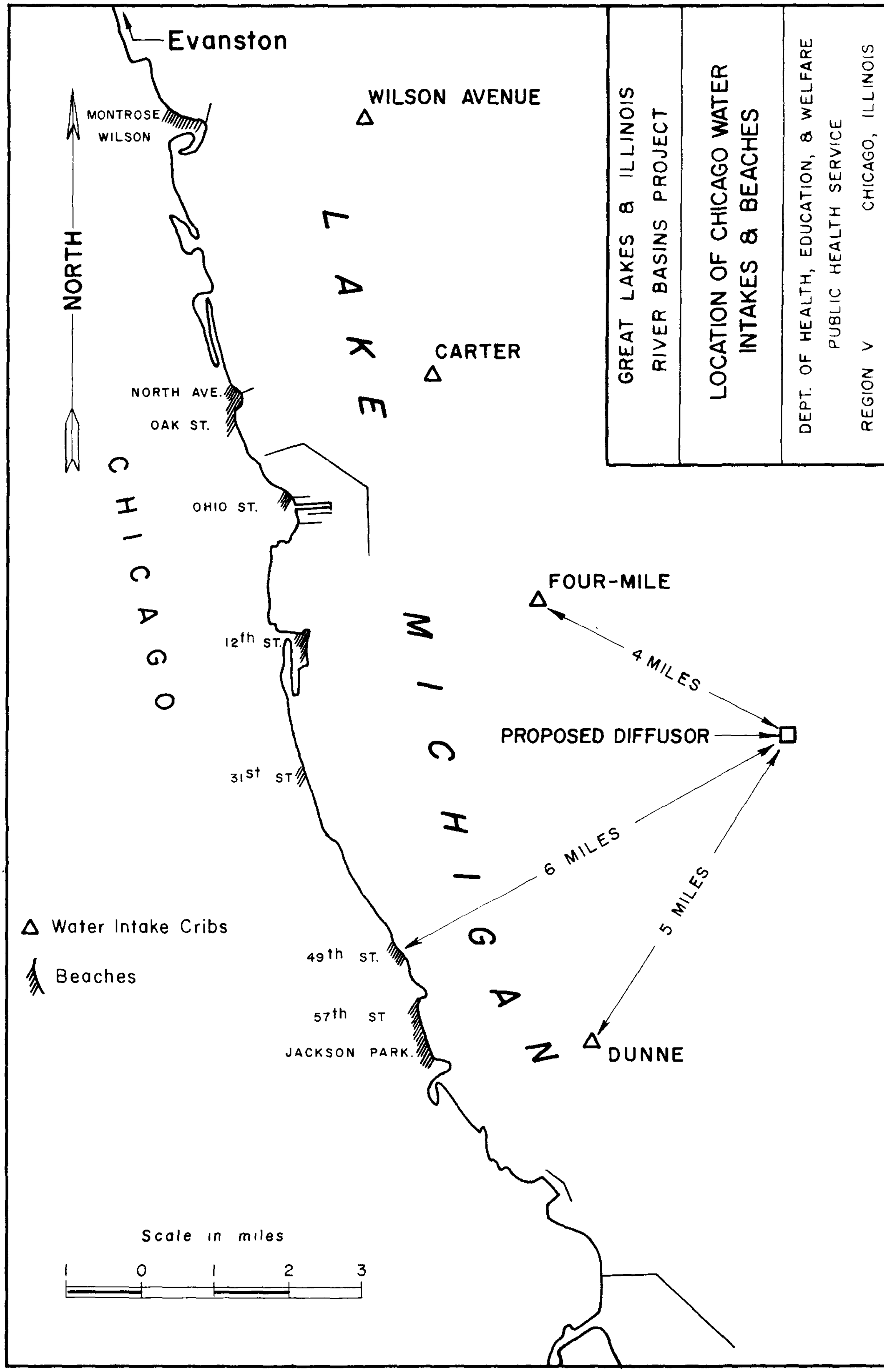
REGION V CHICAGO, ILLINOIS

FIGURE 17



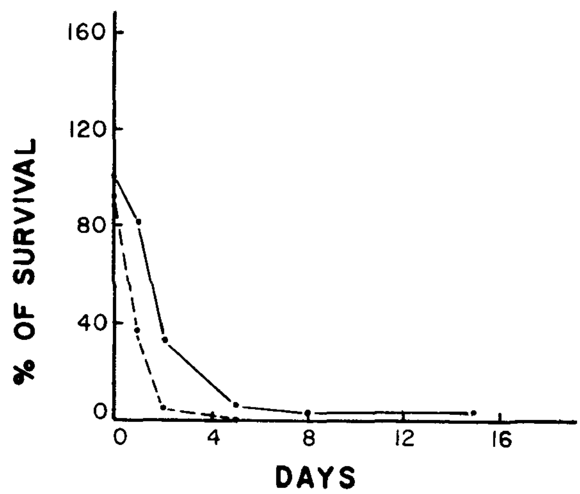
43°00'
87°52'
87°52'
87°54'
87°54'
Scale in Miles
0
½
LEGEND
Total Bacterial Densities
Per 100 ml.
500-1,000
1,000-5,000
5,000-10,000
10,000-100,000
100,000-500,000
500,000-1,000,000
1,000,000-2,000,000
ICKINNIC R.
43°00'
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF 20°C TOTAL BACTERIA
PER 100ml.
MILWAUKEE HARBOR
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 18



GREAT LAKES & ILLINOIS RIVER BASINS PROJECT
LOCATION OF CHICAGO WATER INTAKES & BEACHES
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS
Evanston
NORTH
WILSON AVENUE
MONTROSE
WILSON
LAKE
CARTER
NORTH AVE.
OAK ST.
CHICAGO
OHIO ST.
FOUR-MILE
4 MILES
12th ST.
MICHIGAN
PROPOSED DIFFUSOR
31st ST
6 MILES
5 MILES
Water Intake Cribs
Beaches
49th ST.
57th ST
JACKSON PARK.
DUNNE
Scale in miles
1
0
1
2
3

FIGURE 19



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

SURVIVAL OF COLIFORM BACTERIA & FECAL STREPTOCOCCI IN LAKE MICHIGAN WATER AT 25°C WITH ILLUMINATION

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

FIGURE 20