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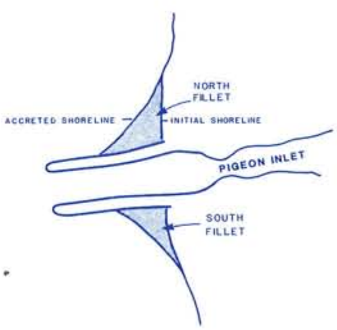


MISCELLANEOUS PAPER CERC-91-4

# COASTAL RESPONSE TO THE PORT SHELDON JETTIES AT PIGEON LAKE, MICHIGAN

by

Mark Hansen, Steven G. Underwood

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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Steven G. Underwood

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The purpose of this study was to determine the impact, if any, of the jetties at the entrance to Pigeon Lake, Michigan (Port Sheldon), on adjacent shorelines and nearshore zones. Analysis of historical shoreline position and bathymetry data in the vicinity of Port Sheldon indicates approximately 810,600 cu yd of material has been trapped by the jetties since construction in 1964. At present, it appears that the fillet areas adjacent to the jetties have volumetrically stabilized and that natural sand bypassing may be occurring around the lakeward tips of the jetties. Results of this study identified a zone of slightly higher erosion 3,000 to 9,000 ft south of the jetties that may be related to jetty construciton.

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Historical bathymetric analysis
Mitigation of shoreline loss
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## PREFACE

The US Army Engineer District, Detroit (CENCE), requested the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), to evaluate the impacts of the jetties at the entrance of Lake Pigeon, Michigan. This report addresses the evaluation of the impacts using mainly a historical shoreline and bathymetry analysis approach. Funding authorizations by CENCE were granted in accordance with Intra-Army Order No. NCE-IA-85-0053-EV.

This study was conducted at CERC under the general direction of Dr. James R. Houston, Chief, CERC; Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; Mr. Thomas W. Richardson, Chief, Engineering Development Division (EDD), and Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch (CSEB), EDD. This report was prepared by Messrs. Mark Hansen and Steven G. Underwood, CSEB, EDD, and edited by Ms. Lee T. Byrne, Information Technology Laboratory, WES.

This study was closely coordinated with Mr. Thomas Nuttle, CENCE Project Manager. Acknowledgment is made to all others involved at CENCE and at the area field office in Grand Haven, Michigan, for their assistance in the study.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

# CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet | 0.02831685 | cubic metres |
| cubic yards | 0.7645549 | cubic metres |
| feet | 0.3048 | metres |
| inches | 2.54 | centimetres |
| miles (US statute) | 1.609347 | kilometres |
| square feet | 0.09299304 | square metres |
| square miles | 2.589998 | square kilometres |

## COASTAL RESPONSE TO THE PORT SHELDON JETTIES AT PIGEON LAKE, MICHIGAN

### PART I: INTRODUCTION

1. The Consumers Power Corporation constructed two jetties at Port Sheldon, Michigan, for the purpose of maintaining an open waterway into Pigeon Lake. These jetties are located at the entrance of Pigeon Lake in Port Sheldon township, Ottawa County, on the eastern shore of Lake Michigan. The project site is approximately 9 miles* north of Holland, Michigan, and 11 miles south of Grand Haven, Michigan (Figure 1). Originally, water was drawn from Lake Michigan via Pigeon Lake Inlet for the purpose of cooling the J. H. Campbell fossil fuel power plant. The inlet into Pigeon Lake was deepened and widened throughout the early history of the power plant. Adjacent shorelines have been modified directly by Consumers Power Corporation and indirectly by the natural littoral response to the jetties.

2. In 1961, US Army Engineer District, Detroit (CENCE), issued a permit to Consumers Power Corporation for the construction of the two jetties at the entrance of Pigeon Lake. Since completion of this construction in 1962, littoral material has accreted in fillets both north and south of the jetties. Recently, local residents have filed suit against Consumers Power Company to mitigate for loss of shoreline in front of selected private properties on the south side of the jetties. The plaintiffs claim Port Sheldon jetties block littoral drift, thus depleting the source of littoral material available for deposition in front of their shore-front properties. One stipulation of the Federal permit regulation requires mitigation of damages, if any (i.e. shorefront erosion related to jetty construction), by the permittee. As a result, the US Army Engineer Waterways Experiment Station's Coastal Engineering

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

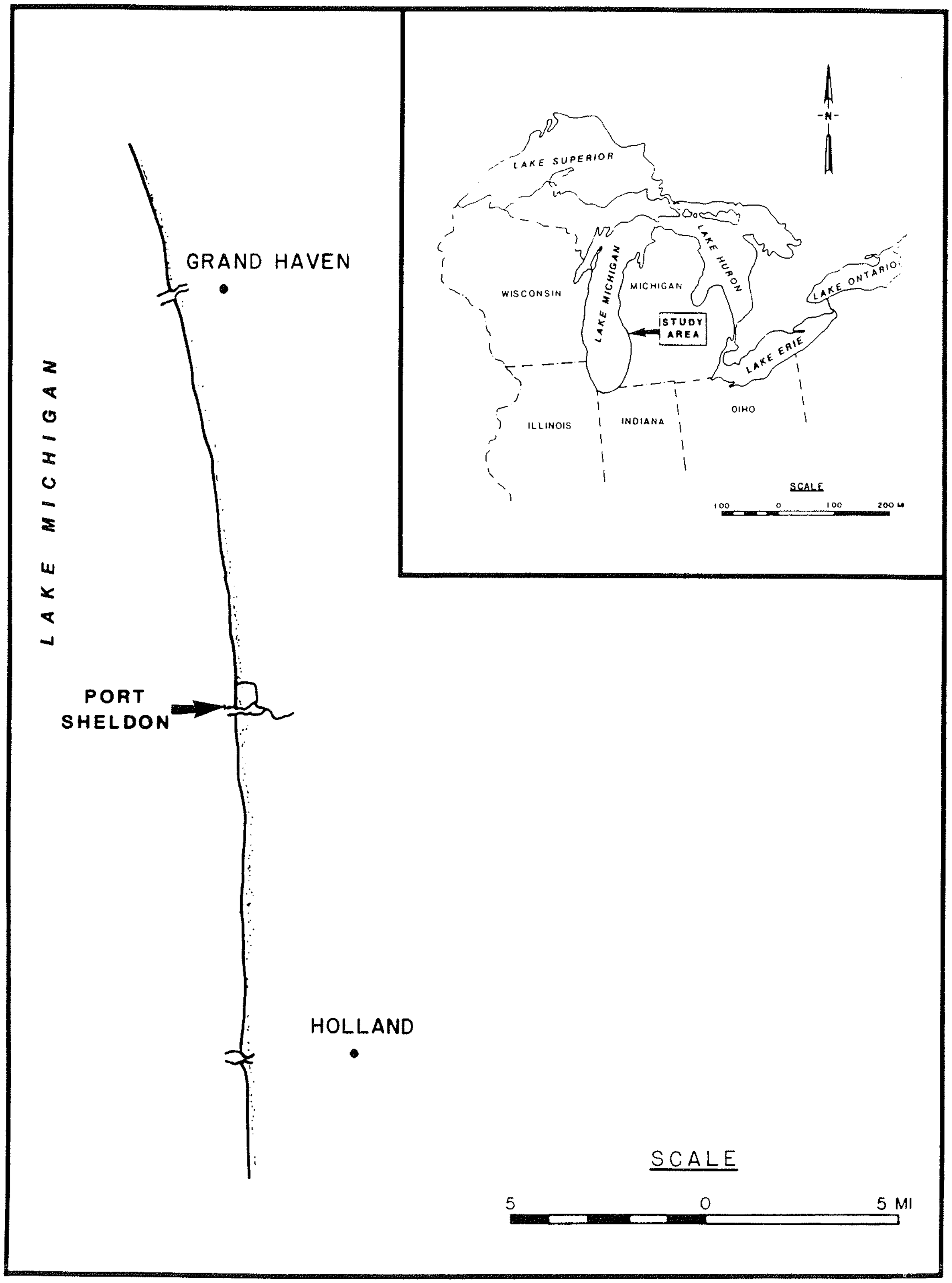



Figure 1. Location map

Research Center has been requested by CENCE to identify the effect of Port Sheldon jetties on adjacent shoreline erosion.

3. To determine the effects of the Port Sheldon jetties on adjacent shorelines, three phases of work have been developed and completed. The first phase was an historical aerial photographic analysis for the purpose of identifying shoreline movement trends in the Port Sheldon vicinity. One preproject and four postproject sets of aerial photographs were available for analysis. The second phase of work was to analyze historical bathymetric charts and compute volumetric sediment changes in the Port Sheldon vicinity. One preproject and two postproject time periods were available for analysis. Unfortunately, data overlap for the bathymetric surveys is available only in the immediate vicinity of Port Sheldon. The last phase of research was a historical information study focusing on other investigations in the region that can relate similar processes to the Port Sheldon area.

## PART II: BACKGROUND

4. Pigeon Lake is the natural outlet of Pigeon River into Lake Michigan. The drainage area into Pigeon Lake is approximately 60 square miles and represents an average runoff rate of about 40 to 45 $ft^3$/sec. The normal hydrological regime was modified with the installation of the J. H. Campbell Power Plant and its associated withdrawal of cooling water from Pigeon Lake. Lake Michigan water diluted with natural runoff passes through the plant cooling system, emptying directly into Lake Michigan via an offshore discharge diffuser located approximately 0.8 mile north of the inlet. Pigeon Lake Inlet was modified between 1962 and 1968 by the construction of sand-filled sheet-pile jetties, capped with concrete, projecting approximately 1,282 ft into Lake Michigan on both sides of the channel (Figure 2).

5. Construction of the Port Sheldon jetties began in 1962 and was completed in 1965. Initially, they extended 720 ft lakeward from the existing shoreline (Figure 2). The most landward 210 ft was a single row of steel sheetpiling. Lakeward of this segment was 510 ft of double-row steel sheetpilings 31 ft wide filled with sand and capped with concrete. Each winter since the plant had been operational, ice had formed inside the existing channel, blocking the plant's water supply. Without this cooling water, the plant could not operate at full capacity. In 1968, the icing problem was solved by adding an additional 562 ft of steel sheet-pile cellular structures lakeward of the existing structures. These cells are approximately 42.5 ft wide. The total length of the present structure is now 1,282 ft. The entrance is 300 ft wide and narrows to 100 ft at the connection between the older and newer structures.

6. Littoral drift in the Port Sheldon vicinity is predominately north to south at an estimated rate approximately between 17,000 to 61,000 cubic yards/year net to the south (US Army Engineer District (USAED), Detroit 1975). These rates were arrived at through a review of existing littoral drift studies completed at nearby harbors, Grand Haven to the north and Holland to the south. At Grand Haven, Michigan, the gross transport to the south and north was computed to be 300,000 and 264,000 cubic yards/year, respectively. These rates are probably comparable to those experienced at Port Sheldon. The large gross transport relative to the net transport suggests that sediment transport in the Port Sheldon vicinity is relatively balanced.

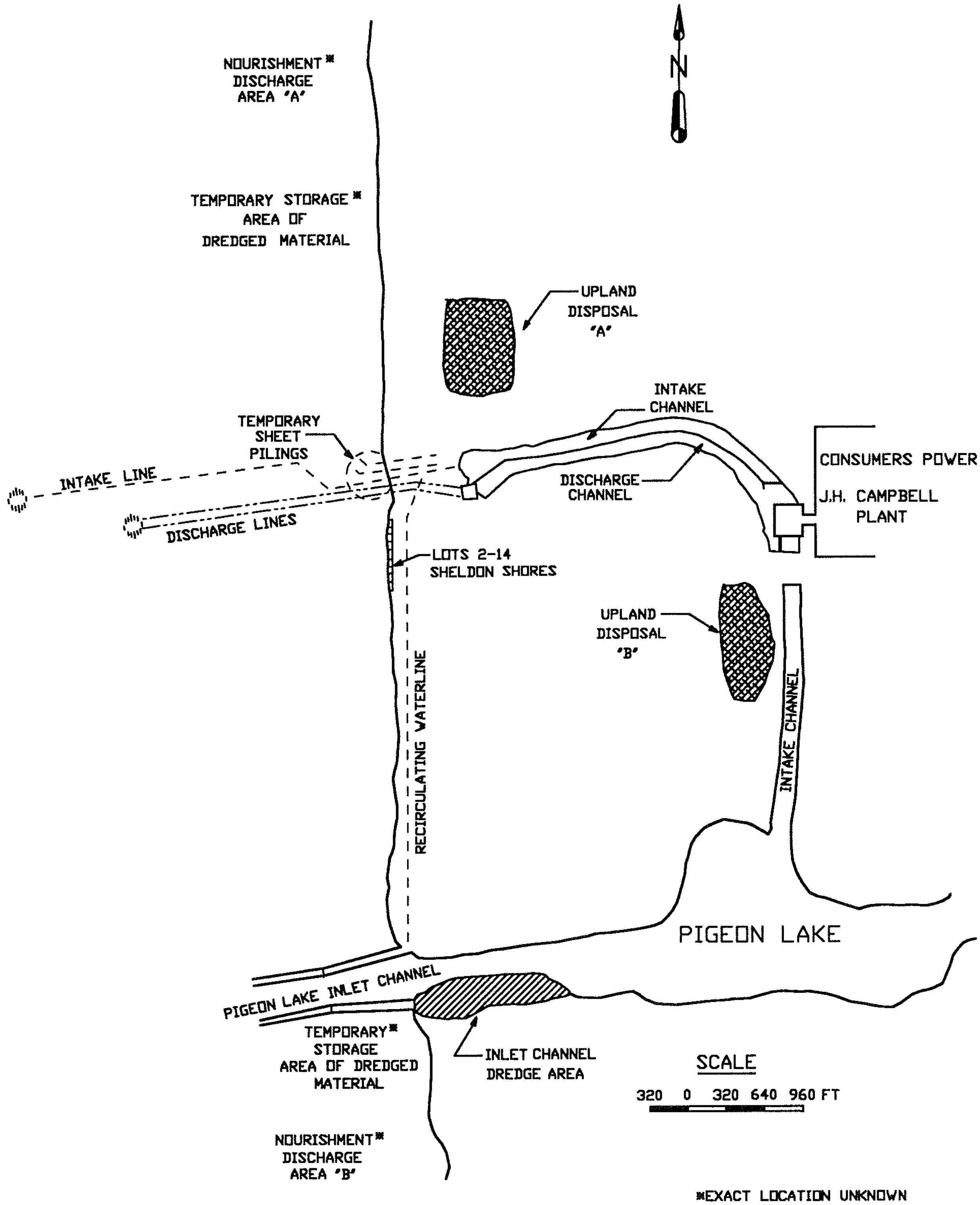



Figure 2. Schematic of the Port Sheldon area with dredge disposal sites

7. Reversals in littoral drift occur frequently in the Port Sheldon area during the summer months. These reversals are primarily attributable to changing current and wind patterns. In general, due to the restrictive fetch length on Lake Michigan, sea conditions (erosive) prevail over the swell conditions (constructive); therefore, beach erosion tends to prevail over beach accretion (Hands 1979).

8. Storms that affect the study area generally move through the Great Lakes region from west to east. The combination of this path and counterclockwise circulation produces strong winds from the north and northwest usually following storm passage.

9. The power plant property is located in the Warren Dunes Shoretype (Department of Resource Development 1958). This shoretype is characterized by a sandy beach 20 to 30 ft wide backed by a foredune 25 to 30 ft high. The foredune is in turn backed by a high sandy dune about 240 ft high. In some places, particularly during high lake levels, the foredune and beach have disappeared, and the high backdune is affected by direct wave attack, producing unstable slopes. The soil type along the shoreline is the Bridgeman Fine Sand, which is described as having a shallow humus layer underlain by fine sand that is incohesive and has tendencies to blow and shift.

10. Solid ice cover on the shore sections of Lake Michigan over the area usually persists from mid-January until the third week of April (USAED, Detroit 1975). Ice cover provides some shore protection from winter storms; however, ice can also aggravate shoreline erosion by pushing upon the beach and loosening consolidated beach and bluff material (Siebel 1972).

## PART III: DATA METHODOLOGY

### Shoreline Movement Analysis

11. Shoreline analysis studies of this type typically investigate long-term shoreline trends before and after project construction to determine local impacts from the structures. To accomplish this analysis, shoreline positions must be normalized to a common datum assuming known fixed foreshore slope(s). However, for this study, shoreline positions were not normalized because of unknown and varying foreshore slopes and eroding bluffs and numerous private shore-protection structures that could affect foreshore slopes. Instead, subreaches along the shoreline were defined to analyze spatial trends between zones adjacent to the structures and zones not influenced by the structures. The defined subreaches remained the same for all comparisons.

12. Shoreline position maps were obtained from Abram's Aerial Survey Corporation, Lansing, MI, for five time periods: 1938, 1962, 1967, 1980, and 1984. These time periods bracket the initial jetty construction period of 1961-1962. Each time period was composed of four individual blue-line sheets. The Abram's maps were derived from rectified aerial photographs drawn on Mylar at 1 in. = 200 ft (1:2,400) scale. Contour lines with a contour interval of 2 ft were drawn on the maps with the shoreline indicated by a dashed line. The shoreline was delineated by the foreshore wet/dry sand interface and referenced to International Great Lakes Datum (IGLD), 576.8 ft above mean water level at Father Point, Quebec (1955), at the time of the photograph. Coastal structures were identified on the maps as well as most shore-front dwellings and dominant topographic features. Shoreline orientation within the study area trends north-south and extends from 484,000 to 527,000 N (Michigan coordinate system), respectively. The data coverage represents approximately 6 miles of shoreline to the south and 2 miles to the north of Port Sheldon.

13. The maps were digitized using a Calcomp 9000 electromagnetic digitizer. Coordinate points along the shoreline were computed at approximately 50-ft intervals. Digitized data from each blue-line survey sheet were combined in the database to construct the entire shoreline for each individual time period.

14. Horizontal error in the digitized shoreline data is a function of (a) mapping error, (b) shoreline etching width, and (c) digitizer error. The

horizontal accuracy of Abram's Corporation maps is ±1/40 in., or 5 ft (Personal Communication, Abram's Corp., Lansing, MI). Line width on the maps is approximately 1/50 in., or 4 ft at map scale. The Calcomp 9000 digitizer has a resolution of ±0.001 in., or ±0.2 ft at map scale. Maximum possible horizontal error for locating one shoreline position is ±14.4 ft, or 14.4 t feet/year, where t is the time interval. All shoreline X-Y coordinates are referenced to the Michigan coordinate system, south zone (Lambert conformal conic), 1927 North American datum.

15. Transects were computed along the shoreline at 500-ft intervals extending from 484,000 to 527,500 N. Intersections between the transect and each shoreline were mathematically computed and recorded. The distance between shoreline intersections could then be computed to determine the shoreline movement between time periods.

## Historic Bathymetric Analysis

16. US Lake Survey and CENCE hydrographic survey sheets were digitized using an electromagnetic digitizer. Depending upon the data coverage, the data were digitized both north and south of the project site, extending from the shoreline to approximately 30 ft water depth (IGLD). The 1984 survey also includes subaerial beach and dune topographic elevations.

17. All survey sheets were recorded relative to IGLD; therefore, no postprocessing of vertical datum corrections was necessary. The 1944 and 1965 bathymetric surveys were recorded in latitude/longitude and converted to state plane coordinates. The 1984 survey taken by CENCE was recorded in Michigan coordinated system, east zone Universal Transverse Mercator (UTM) and converted to the south zone (Lambert conformal conic).

18. Three hydrographic surveys (1944, 1965, and 1984) were used to compute spatial and temporal volumetric changes. Temporal changes could be performed as all surveys were relative to IGLD. Of the three hydrographic surveys analyzed in the study, only the 1984 survey contained topographic (subaerial) data.

19. The digitized X, Y, and Z data points were input into the software contouring/volumetric package CPS-1 (Radian Corporation) to create contour maps and compute volumetric changes. CPS-1 uses the data points to create an interpolated rectilinear grid. Each grid node is assigned a value based on a

piecewise least-squared algorithm and computes contour positions based upon the grid values.

20. Volumetric calculations were based upon an integration algorithm of the grid nodes for each contour map. Polygons were digitized for the purpose of defining a closed boundary to compute volumetric changes between time periods.

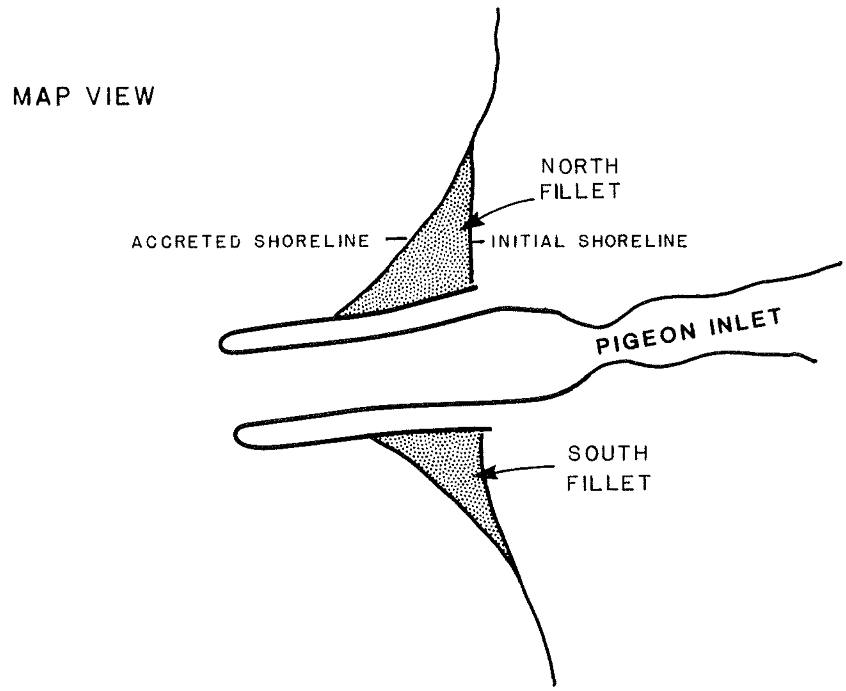
21. Bathymetric volume polygons for this study extend from 484,500 to 527,500 N. Each polygon is 500 ft in the Y-direction centered about the shoreline movement transects, e.g. from 499,750 to 500,250 centered about 500,000. The lakeward boundary for all polygons is at 1,494,000 E or at approximately the 18- to 20-ft contour below IGLD. The shoreward boundary consists of a segment of shoreline for that time period that is located between the upper and lower extremes of the polygon, i.e., 499,750 to 500,250. All volumetric calculations for this analysis were limited to data below 0 ft IGLD.

22. Computation of material accumulated in the fillet areas was a multistep process (Figure 3).

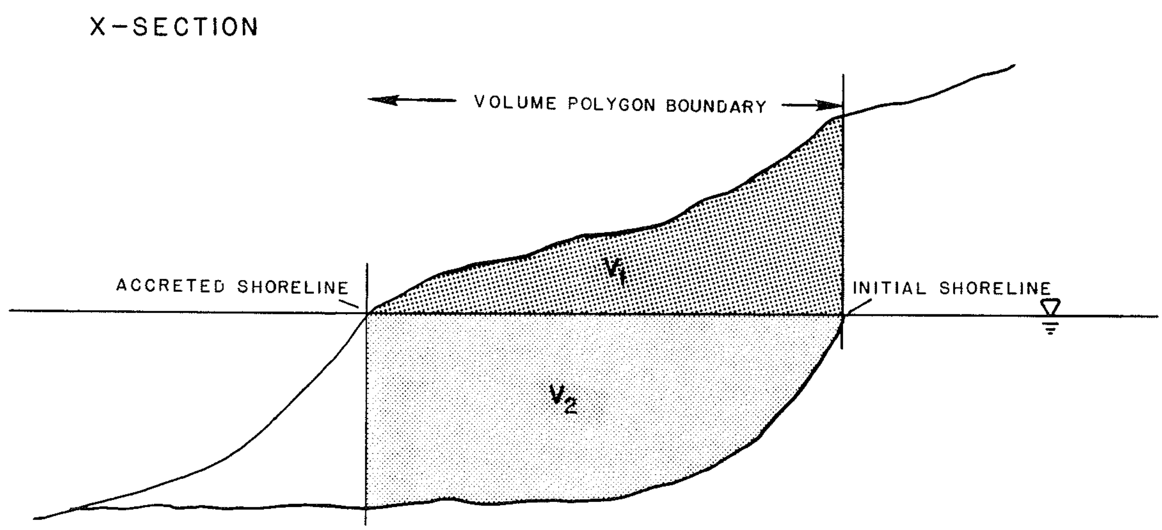
- a. Volume polygons were determined using the digitized 1944, 1965, and 1984 shoreline positions. Each volume polygon was closed at the point where the two shorelines intersected, e.g. 1944/1984 (Figure 3a). This was 514,500 N on the south fillet and 518,500 N on the north fillet.
- b. The quantity of material was computed for the submerged (below 0 IGLD) volume (V2) of the 1944 and 1965 surveys and the subaerial (above 0 IGLD) volume (V1) of the 1984 survey (Figure 3b). The respective shoreline positions were used in defining each polygon calculation.
- c. Total accumulation between the 1944-1984 and 1965-1984 periods was computed by summing the respective subaerial V2 (1984) and submerged V1 (1944/1965) volumes contained with the polygons. Due to the lack of topographic data in the 1944 and 1965 surveys, fillet accretion between 1944 and 1965 was determined by computing the volume difference between the 1944/1985 and 1965/1984 surveys.

## Collection of Sediment Samples

23. Surface sediment samples were collected in August 1986 in the vicinity of the Port Sheldon jetties using a ponar grab sampler. Samples were taken along transects located 400 ft north and south of the jetties. Samples were also collected along a transect 4,000 ft south of the south jetty.




a. Shaded region represents volume polygons for fillet areas




b. Subaerial ($V_1$) and submerged ($V_2$) portions of volume polygons

Figure 3. Accumulation of materials in the fillet areas

## PART IV: RESULTS

### Shoreline Movement Analysis

24. At each transect, the distance and rate of change between consecutive time periods, i.e. 1938-1962, as derived from the aerial photography, were computed in addition to the 1962-1984 and 1938-1984 comparisons (Appendix A). These data were plotted with the 1984 shoreline for each time interval.

25. Five subreaches were established based upon similar rates of change for that portion of shoreline. The reaches are A (484,000 to 506,500 N), B (507,000 to 513,000 N), C (513,500 to 515,300 N), D (516,600 to 521,000 N), and E (521,500 to 527,000 N). The Port Sheldon jetties are located between subreaches C and D (515,300 and 516,600 N). Table 1 and Figure 4 represent

Table 1

Average Rate of Change for Subreaches in Units of Feet per Year and Ranking (in Parentheses)

| Subreach | 1938-1962 | 1962-1967 | 1967-1980 | 1980-1984 | 1962-1984 |
|---|---|---|---|---|---|
| Lake Level ft (IGLD) | 579.4-578.9 | 578.9-578.5 | 578.5-580.8 | 580.8-581.1 | 578.9-581.1 |
| Maximum Error, ft | +0.6 | +2.8 | +1.1 | +3.6 | +0.7 |
| A 484,500 N-506,500 N | -2.0(5) | 6.0(2) | -6.5(4) | -2.2(1) | -2.9(3) |
| B 507,000 N-513,000 N | -0.9(4) | 4.6(3) | -10.7(5) | -3.1(2) | -5.8(5) |
| C 513,500 N-516,000 N | -0.3(2) | 0.4(4) | 2.6(2) | -3.7(3) | 1.2(2) |
| Port Sheldon Jetties | | | | | |
| D 516,650 N-521,000 N | -0.2(1) | 12.0(1) | 4.9(1) | -11.9(5) | 3.7(1) |
| E 521,500 N-527,000 N | -0.8(3) | -1.0(5) | -3.5(3) | -8.4(4) | -3.8(4) |

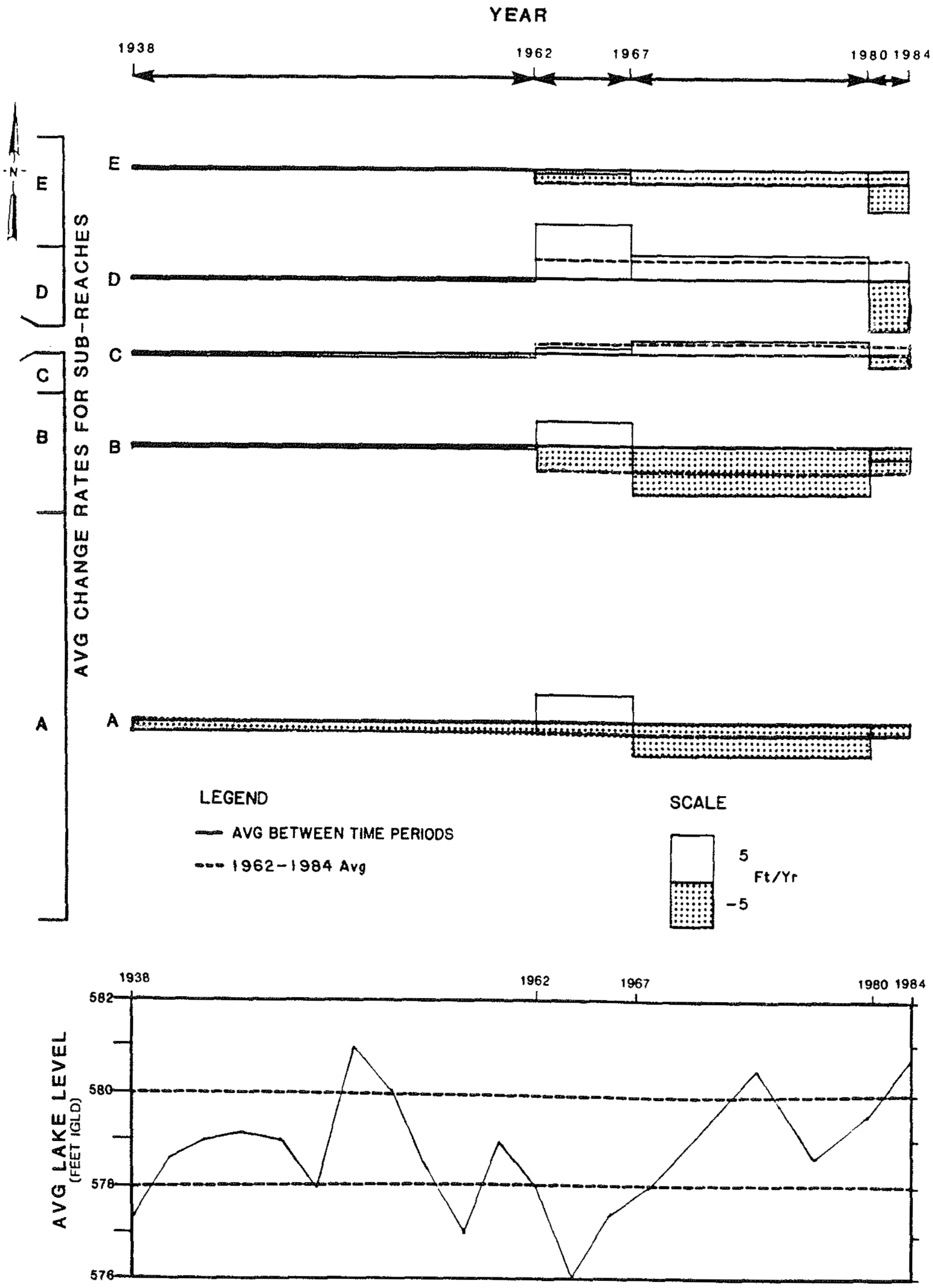



Figure 4. Average change rates for subreaches between time periods with corresponding Lake Michigan average lake levels

the average rate of change for each subreach for all time period comparisons. For each time period, each subreach has been ranked in order from positive (accretion) to negative (erosion) rates of change in order to help identify trends within each subreach.

1938-1962 prejetty time
period (Figures 5 and 6)

26. This prejetty time period indicates overall erosion of the study area with the highest erosion occurring in subreach A. Lower erosion rates in subreaches C and D suggest the initiation of fillet formation immediately after construction of the jetties, indicating entrapment of littoral material. Historic lake levels for this time span were approximately 578 ft (IGLD) in 1938 and 1962, peaking in 1952 at 581 ft IGLD. This time period is the only indicator of relatively natural (prejetty) shoreline rates for the Port Sheldon area.

1962-1967 (Figure 5)

27. Historic low lake levels occurred during this time span (approximately 576 ft IGLD in 1965) as reflected by accretion in subreaches A, B, C, and D. Erosion occurred in an area of B and C (i.e. 512,500 through 514,000 N) suggesting sediment depletion caused by the jetties. This erosion might be related to the high accretion in the north jetty fillet. A slight increase in the accretion rate in the northern section of the subreach D might be a result of upland disposal of dredged material in 1962 (USAED, Detroit 1983) (Table 1). Asymmetric accumulation of material in the fillet areas suggests a dominant southerly transport during this time span.

1967-1980 (Figure 5)

28. With the rise in lake levels, erosion occurred along subreaches A, B, and E. Erosion increased in subreach B between 507,000 and 511,500 N. Again, erosion might be due to blockage of littoral material by the jetties. Accretion occurred in both fillet areas (subreaches C and D); however, the north fillet accreted at a higher rate. This accretion further suggests that the dominant direction of sediment transport is from north to south. There is a noticeable accretionary zone in the northern section of subreach D, perhaps due to localized beach restoration as a result of modification of the power plant in 1979 (USAED, Detroit 1983) (Table 1).

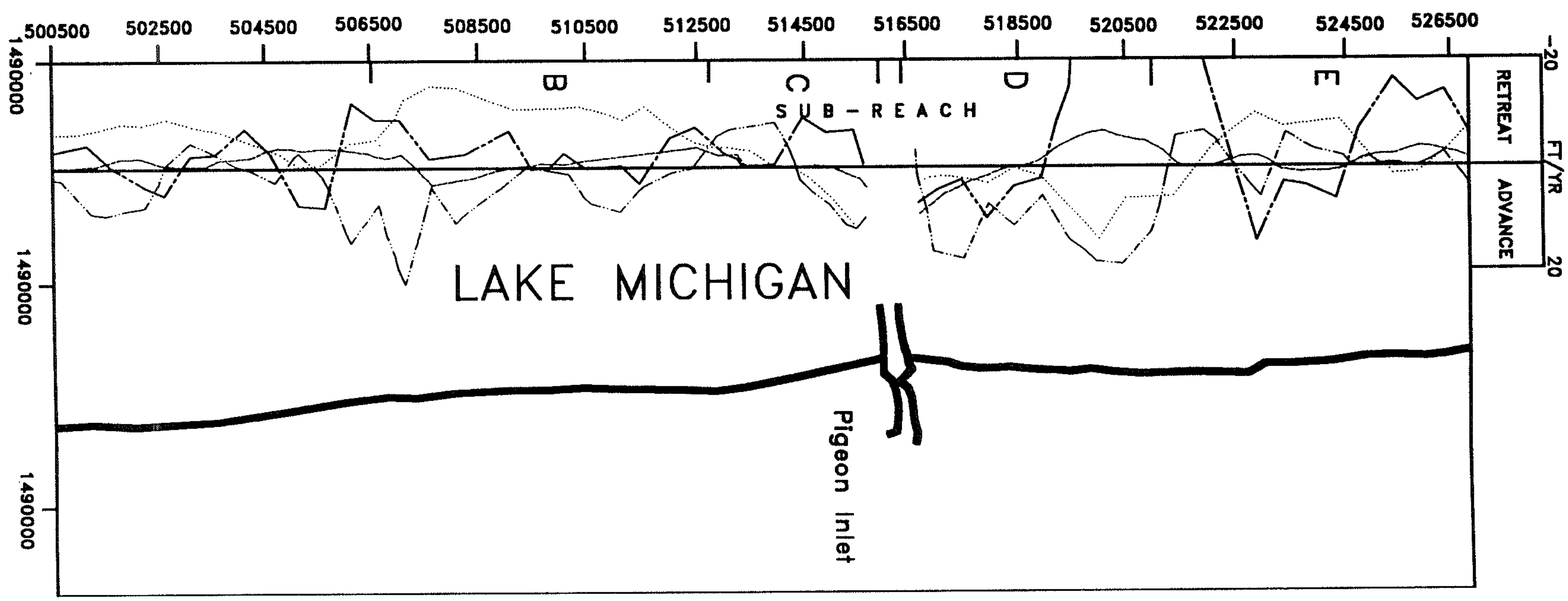



Figure 5. Rates of shoreline change (feet/year) plotted with 1984 shoreline

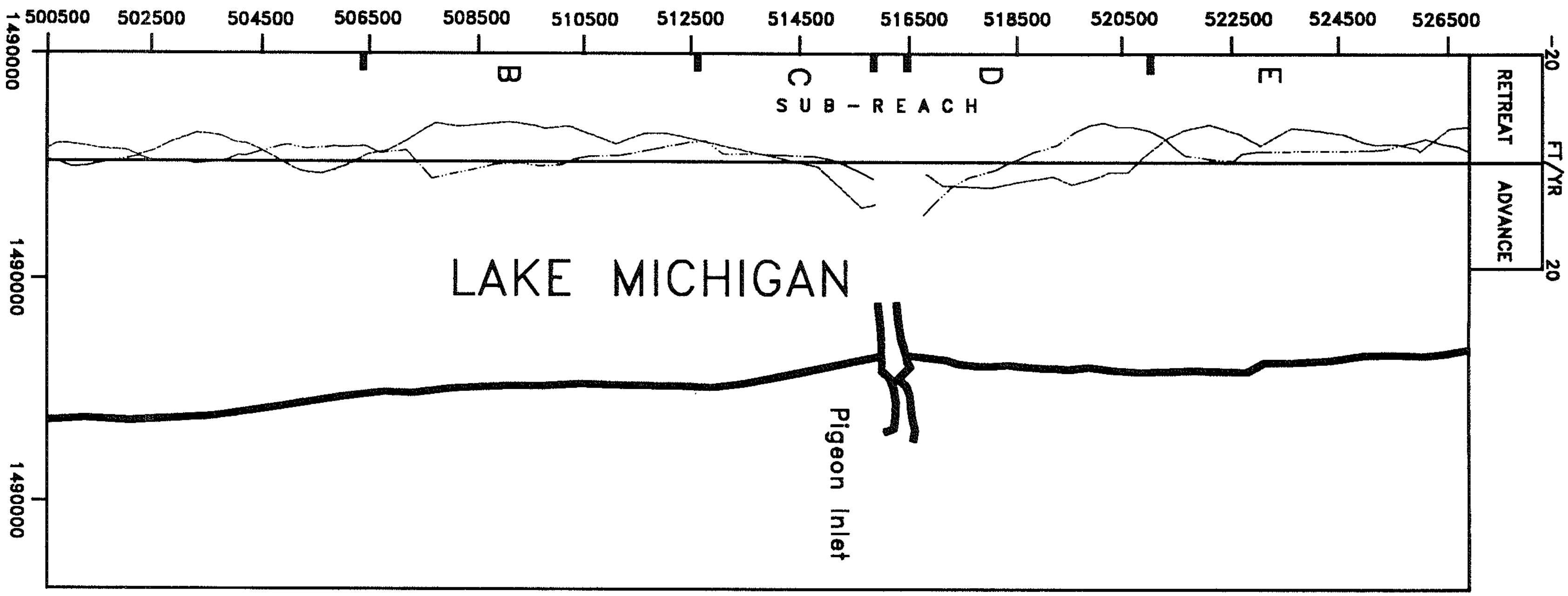



Figure 6. Rates of shoreline change (feet/year) plotted with 1984 shoreline

1980-1984 (Figure 5)

29. Record high lake levels occurred during this time span. In general, the entire shoreline was eroding at varying rates during this interval. Both fillet areas (subreaches C and D) experienced erosion; however, there was localized accretion immediately adjacent to the north jetty. An unusually high rate of erosion occurred in a 2,000-ft-long section that straddles subreach D and E. This erosion might be a result of man-made modifications to the adjacent shoreline (USAED, Detroit 1986).

1962-1984 Postjetty time period (Figure 6)

30. This time span encompasses the entire period since jetty construction. It includes a period of both record low and high lake levels. Much of the local variability in shoreline change computed for the shorter time periods (i.e. 1980-1984) have been averaged out because of the longer time interval. Subreaches A, B, and E indicate that the shoreline has eroded with the maximum erosion occurring in subreach B. The increased rate in this zone might be due to trapping of southerly transported littoral material by the jetties. Accretion has occurred in both fillets; however, higher accretion rates are evident in the north fillet.

## Hydrographic Analysis

31. Since an immediately prejetty construction hydrographic survey was not available, the 1944 survey was used to represent the preconstruction hydrographic condition. The investigators of this study have some doubt as to the accuracy of the 1944 survey. The reason for doubt is that it appears all contours, i.e. depth recordings, are displaced lakeward approximately 300 to 500 ft compared with the 1965 and 1984 surveys. However, the position of the shoreline appears to be in a reasonable location. Research with CENCE survey branch (Personal Communication, Carl Lamphere) and National Ocean Service (NOS) (Personal Communication, Bill Montieth) suggest that horizontal and vertical datum corrections were incorporated in the survey. It is uncertain what natural processes could have caused such a major shift of the offshore contours along the entire stretch of shoreline. Therefore, it is felt that hydrographic comparisons to the 1944 survey should be used with caution.

## Historic Contour Maps

32. The 1944 contour map of the Port Sheldon vicinity indicates fairly straight, parallel contours existed before jetty construction (Figure 7). There appears to be no lakeward "bulge" of contour lines near Pigeon Lake Inlet. In 1965, two distinct bar systems are present in approximately 12-ft water depth (Figure 8). The bar system between 508,500 and 516,500 N terminates on the north end at the south jetty. Lakeward of the 12-ft water depth, the contours are essentially straight and parallel. The 12-ft contour (1965) passes just lakeward of the jetty tips. Contour locations in the 1984 map are in close proximity to the 1965 map. The most dominant feature in the 1984 map is the trench indicated by the "U"-shaped contours near the J. H. Campbell offshore cooling discharge pipes located at approximately 520,000 N (Figure 9). The 12-ft contour near the jetties passes just inside the jetty tips. The positions of the 18, 24, and 36 contours near the project between the 1965 and 1984 surveys are almost identical, suggesting very little, if any, offshore jetting of nearshore sediments by the jetties.

## Fillet Volume Analysis

33. Inconsistencies in the 1944 survey precluded its use in the fillet volume calculations. However, since the shoreline appears to be in the correct location, it was used for defining volume polygons for the 1944-1965 and 1944-1984 comparison. To determine ongoing trends of fillet accretion, certain assumptions were made in order to approximate preconstruction conditions. The submerged volume for the 1944-1964 comparison was approximated applying the following two assumptions: (a) nearshore (submerged) slopes within the fillet areas to 12-ft water depth remained constant between 1944 and 1984, and (b) there is a direct proportion between the fillet polygon area and the submerged volume within the polygon. Accumulation of the subaerial portion for the 1944-1965 time period was derived by determining the difference between the 1944-1984 and 1965-1984 subaerial volumes.

34. Assuming the 1944 survey represents the preconstruction condition and the relationship between fillet area and submerged volume is proportional, the fillets have accumulated approximately 246,300 $yd^3$ of sediment (Table 2). The north fillet apparently accumulated littoral material quite rapidly within

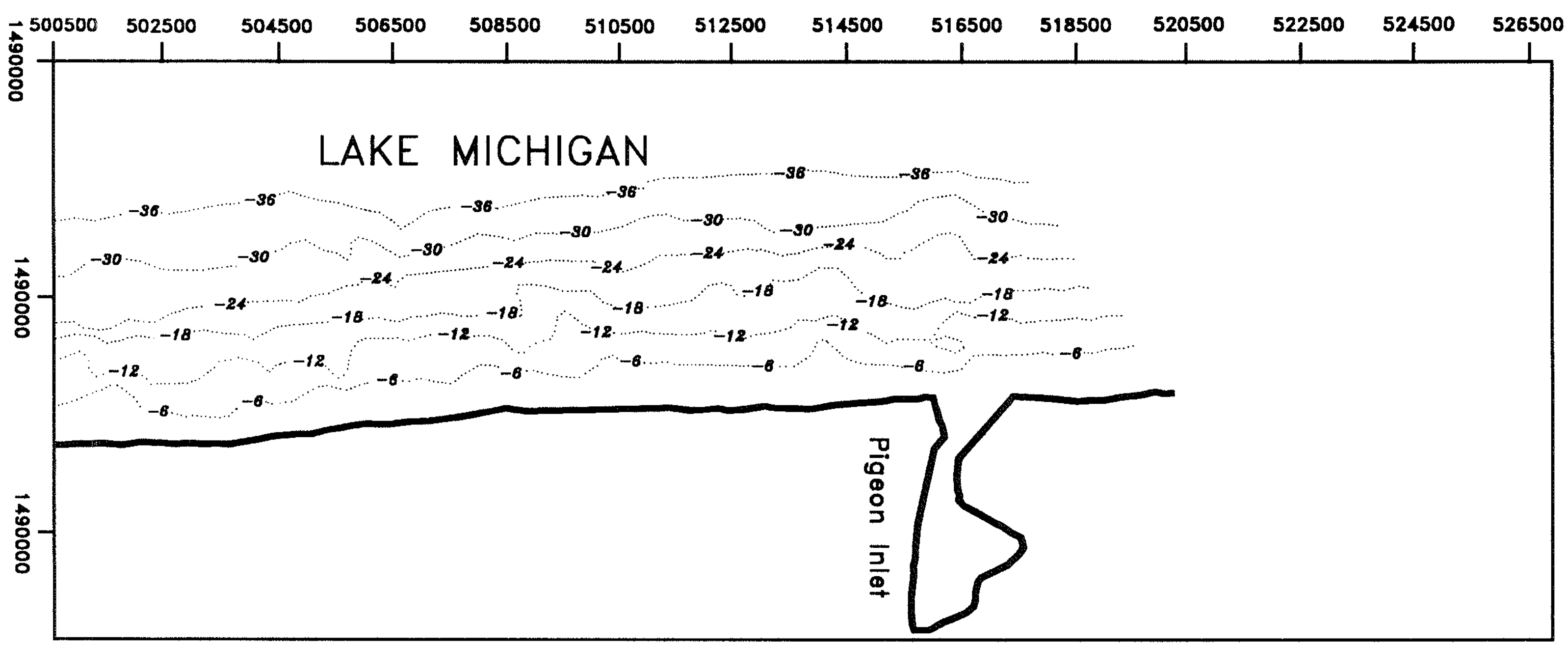



Figure 7. Hydrographic survey of Port Sheldon, Michigan, and vicinity, 1944

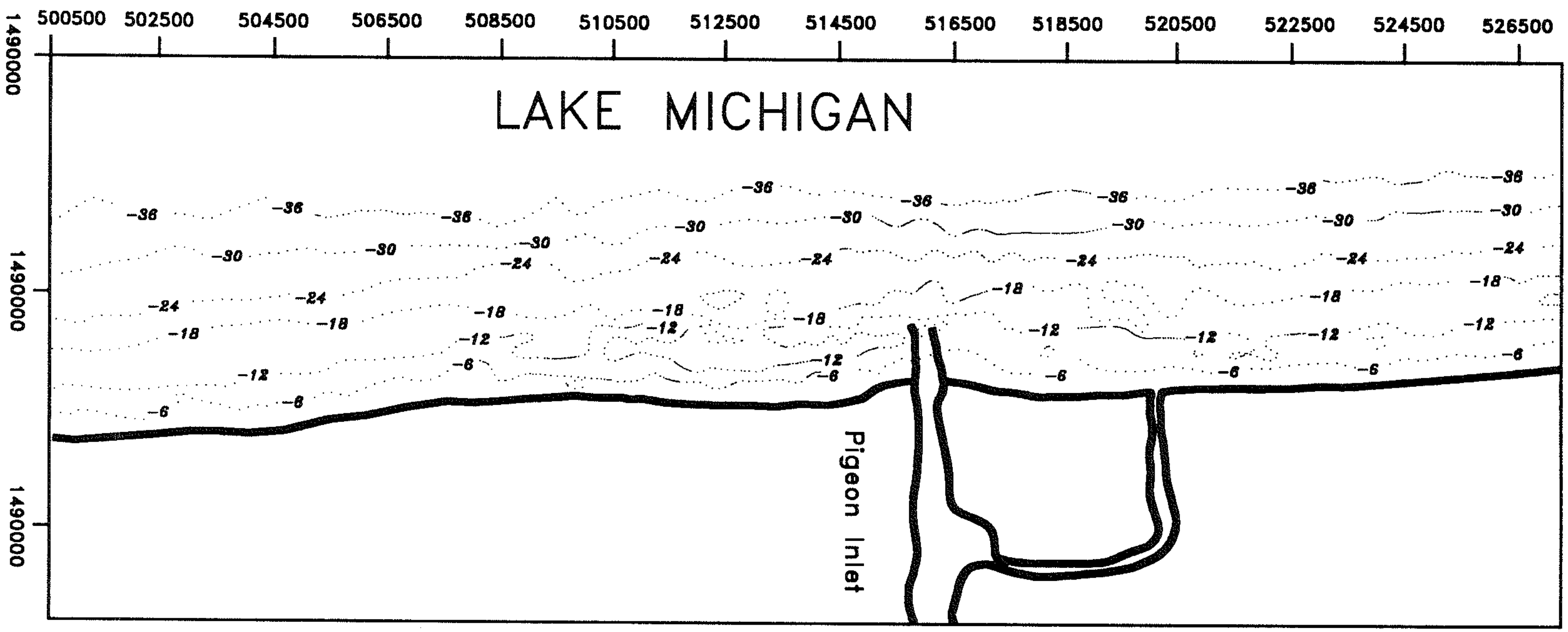



Figure 8. Hydrographic survey of Port Sheldon, Michigan, and vicinity, 1965

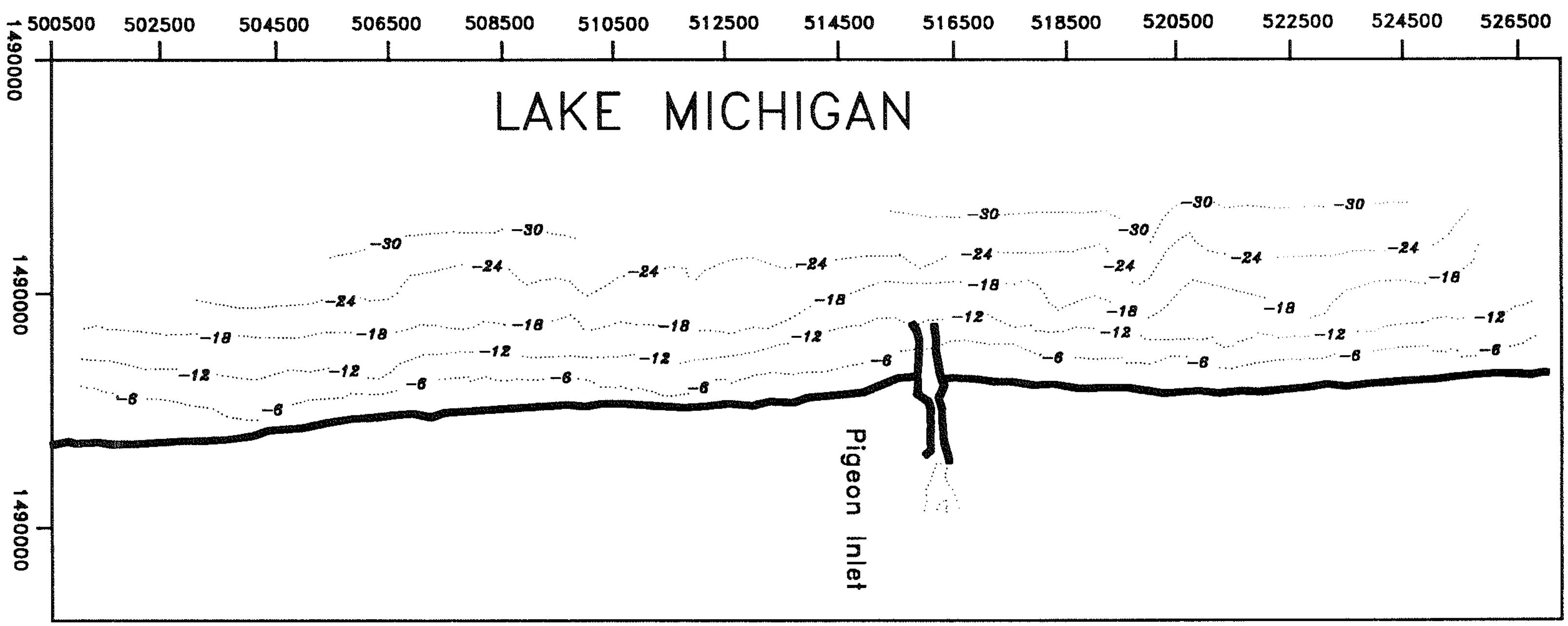



Figure 9. Hydrographic survey of Port Sheldon, Michigan, and vicinity, 1984

Table 2

Computed Volumes for the North and South Fillet Areas

| Location | Area $ft^2$ | Subaerial Volume $yd^3$ | Submerged Volume $yd^3$ | Total Volume $yd^3$ | Rate $yd^3/yr$ |
|---|---|---|---|---|---|
| | | 1944-1965* | | | |
| North fillet | 211,700 | 97,800 | 6,100 | 103,900 | 34,600 |
| South fillet | 60,700 | 24,000 | 1,700 | 25,700 | 8,600 |
| Total | | | | 129,600 | |
| | | 1965-1984 | | | |
| North fillet | 188,200 | 48,100 | 5,200 | 53,300 | 2,800 |
| South fillet | 170,500 | 58,600 | 4,800 | 63,400 | 3,300 |
| Total | | | | 116,700 | |
| | | 1944-1984 | | | |
| North fillet | 399,900 | 145,900 | 11,300 | 157,200 | |
| South fillet | 231,200 | 82,600 | 6,500 | 89,100 | |
| Total | | | | 246,300 | |

* These calculations assume the 1944 survey represent the 1962 condition, i.e. 1962-1965.

the first 3 years after construction (1962-1965). The rate of accumulation for this 3-year time span is approximately 34,600 cubic yards/year. Since 1965, the north fillet has accreted at a much lower rate of 2,800 cubic yards/year. For the first 3 years after construction, the south fillet accumulated material at a much lower rate (8,600 cubic yards/year) than the north fillet. Since 1965, the accretion rate for the south fillet has slightly exceeded the north with 3,300 cubic yards/year accumulation. Of the total volume (246,100 $yd^3$) trapped by the jetties, approximately 64 percent (157,200 $yd^3$) has accumulated in the north fillet area and 36 percent (89,100 $yd^3$) in the south fillet area.

Evaluation of nearshore volumetric data

35. Volume data are calculated for the same subreaches as the shoreline movement data in order to relate potential trends between the two data sets. Because of an incomplete data set, offshore volume changes were normalized to annual volume change per linear foot of shoreline (cubic yards/year/foot).

The entire nearshore zone between the 1944 and 1965 survey appears to be eroding (Appendix B). Data are not available for subreach E. Highest offshore erosion rates occur in subreaches A and B with an average volume loss of -11.0 and -10.2 cubic yards/year/foot (Table 3 and Figure 10). Subreaches C and D adjacent to the jetties had lower losses with -8.2 and -4.4 cubic yards/year/foot. A zone of high volume loss is located approximately 1,500 ft south of the south jetties between 512,000 and 514,000 N.

36. The data overlap between 1965 and 1984 is limited to all of subreaches B, C, and D and portions of A and E. This data set indicates offshore accretion in the immediate vicinity of the project. The highest accretion rate is located in subreach C followed by E and D, +5.4, +4.3, and +2.6 cubic yards/year/foot, respectively (Figure 10). Erosion occurred in both subreaches A and B, -7.4 and -4.4 cubic yards/year/foot, respectively.

Evaluation of sediment data

37. Surficial sediment samples in the vicinity of Port Sheldon exhibit similar grain size characteristics (Table 4). Samples taken along both transects near the jetties reveal almost identical means and standard

Table 3

Average Volumetric Rate of Change for Subreaches

| | 1944-1965 | | | 1965-1984 | | |
|---|---|---|---|---|---|---|
| Subreach | Data Coverage | Total $yd^3/yr$ | Rate $yd^3/yr/ft$ | Data Coverage | Total $yd^3/yr$ | Rate $yd^3/yr/ft$ |
| A 484,500 N-506,500 N | 484,500 N-506,500 N | -247,300 | -11.0 | 504,000 N-506,500 N | -22,000 | -7.4 |
| B 507,000 N-513,000 N | 507,000 N-513,000 N | -66,200 | -10.2 | 507,000 N-513,000 N | -28,400 | -4.4 |
| C 513,500 N-516,000 N | 513,500 N-516,000 N | -26,600 | -8.2 | 513,500 N-516,000 N | +17,700 | +5.4 |
| Port Sheldon Jetties | | | | | | |
| D 516,600 N-521,000 N | 516,650 N-519,000 N | -11,300 | -4.4 | 516,650 N-521,000 N | +12,000 | +2.6 |
| E 521,500 N-527,000 N | - | - | - | 521,500 N 525,000 N | +19,300 | +4.3 |

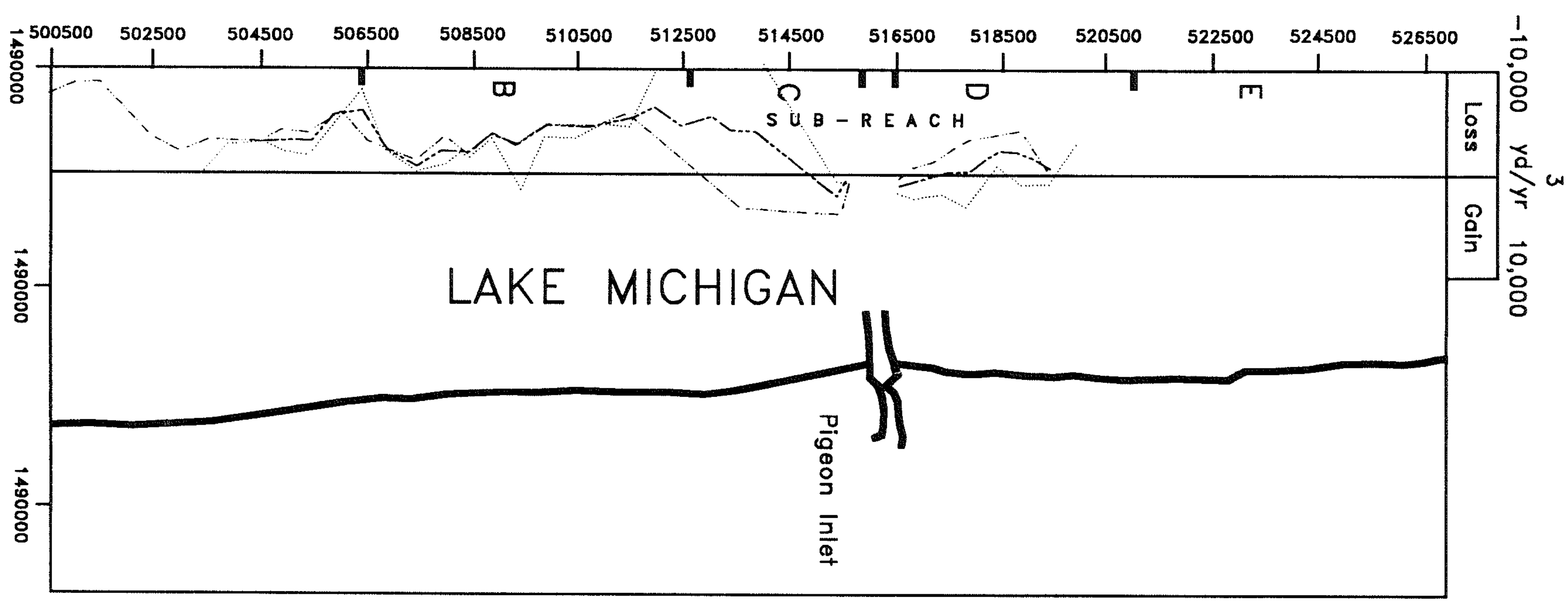



Figure 10. Rates of volumetric change (cubic yards/year) plotted with 1984 shoreline

Table 4

Summary of Sediment Analysis in the Vicinity of Port Sheldon

| Sample | Depth SWL,* ft | Distance from Shoreline, ft | Location | Mean Phi | Standard Deviation Phi |
|---|---|---|---|---|---|
| | | 400 ft North of North Jetty | | | |
| 4N1 | 4 | 50 | 1st trough | 2.0 | 1.9 |
| 4N2 | 5 | 100 | 1st crest | 2.0 | 2.0 |
| 4N3 | 12 | 200 | 2nd trough | 2.0 | 2.0 |
| 4N4 | 9 | 300 | 2nd crest | 2.0 | 2.0 |
| 4N5 | 13 | 500 | | 2.0 | 1.8 |
| 4N6 | 22 | 680 | 3rd trough | 2.7 | 2.6 |
| 4N7 | 29 | 1,290 | | 2.4 | 2.3 |
| 4N8 | 31 | 1,840 | | 2.0 | 2.0 |
| 4N9 | 17 | 2,000 | 3rd crest | 2.1 | 2.0 |
| | | 400 ft South of South Jetty | | | |
| 4S1 | 6 | 40 | 1st trough | 2.0 | 1.9 |
| 4S2 | 5 | 60 | 1st crest | 2.0 | 2.0 |
| 4S3 | 14 | 240 | 2nd trough | 2.0 | 2.0 |
| 4S4 | 10 | 490 | 2nd crest | 2.0 | 2.1 |
| 4S5 | 18 | 730 | | 1.6 | 1.6 |
| 4S6 | 17 | 1,280 | 3rd trough | 1.9 | 1.9 |
| 4S7 | 21 | 1,580 | 3rd crest | 1.9 | 1.9 |
| 4N8 | 31 | 1,840 | | 1.9 | 1.9 |
| | | 4,000 ft South of South Jetty | | | |
| 40S1 | 16 | 60 | 1st trough | 1.9 | 1.9 |
| 40S2 | 10 | 180 | 1st crest | 2.0 | 2.0 |
| 40S3 | 20 | 430 | 2nd trough | 1.6 | 1.5 |
| 40S4 | 33 | 1,680 | 3rd trough | -0.2 | -0.4 |
| 40S5 | 27 | 2,370 | 3rd crest | 2.6 | 2.4 |

* SWL = still-water level.

deviations. For this set of samples, there is no distinction between sediment collected from the troughs or crests of longshore bars. However, this uniformity may be due to the mild wave conditions present at the time of sediment collection. Samples collected from 4,000 ft south of the jetties exhibit some variability. Samples 40S3 and 40S4 are composed mostly of coarse sand and gravel, respectively. This area may represent bar migration over an exposed lag deposit, a process probably unrelated to the Port Sheldon jetties.

## PART V: HISTORICAL INFORMATION SUMMARY

38. Historical information summaries were derived from CENCE Section 111 reports at Grand Haven Harbor and Holland Harbor, Michigan (USAED, Detroit 1975, 1976). The intent of these summaries was to relate similar coastal responses at these sites to Port Sheldon as the result of jetty construction.

### Grand Haven Harbor Section 111 Study

39. Construction of jetties at Grand Haven Harbor entrance began around 1867 and was completed in 1894. Building of the south and north jetties began in 1867 and 1875, respectively. Present lengths of the jetties are 3,569 and 5,549 ft for the north and south sides, respectively. The jetty tips terminate in approximately 15- to 18-ft water depth. Analysis of historical charts and aerial photographs indicates rapid growth of both the north and south fillets. By 1894, the north fillet was more lakeward than the south fillet, despite the 8-year construction lag. Significant accumulation of material in the fillets was documented through 1947, with minor accumulation until 1973. Study results state the present shoreline is in "effective equilibrium" with accretion of the fillets occurring at a very low rate (USAED, Detroit 1976).

40. To assess the impacts of the jetties, the adjacent shoreline was divided into segments: immediately north and south of the jetty and both updrift and downdrift of the project site. Assessment of the difference in littoral processes adjacent to the project and those out of the influence of the project was determined to be the impact of the Federal project.

41. A sequence of five sets of aerial photographs of the Grand Haven Harbor vicinity was analyzed. The time interval 1950-1973 was assessed to determine long-term evolutionary development of the shoreline. A regression analysis was performed to correct the shoreline for lake level fluctuations/variations and determine long-term erosion/accretion rates along the coast. Shoreline positions were measured at 300 increments along the coast.

42. Littoral drift computed from wave statistics Summary of Synoptic Meteorological Observations (SSMO) indicates the gross sediment transport potential in the Grand Haven vicinity to be 564,000 cubic yards/year with a

net of 36,200 cubic yards/year to the south. Gross potential to the south and north was computed to be 300,000 and 264,000 cubic yards/year, respectively.

43. Results of this study indicate erosion exists both north and south of the Federal project interrupted by short reaches of accretion. Highest erosion rates occur 16,000 ft north and south varying from 1 to 5 feet/year. Presently, the north fillet appears to account for approximately 10 percent of the 40,000 cubic yards/year erosion on the 16,000 ft of shoreline north of the project, while the south fillet accounts for approximately 33 percent of the 47,000 cubic yards/year erosion on the south 16,000 ft of shoreline.

44. The report concludes that the Federal project interrupted the natural littoral sediment transport patterns. Initially, sediment was trapped in the fillet areas; however, recently it has been deflected lakeward or accumulated in the entrance channel. Prior to 1972, dredged material was placed in offshore waters greater than 18 ft.

45. The mitigation plan called for an initial beach nourishment of 50,000 $yd^3$ placed on seven different sites. Annual renourishment of 50,000 cubic yards/year or on an as-needed basis would prevent further damages because of the Federal project. Of the total average annual sediment loss in the vicinity, this mitigation would eliminate 60 percent caused by the Federal project. The remaining 40 percent of the total is due to natural processes.

## Holland Harbor Section 111 Study

46. In 1866, Federal construction was initiated, and by 1909 the present dimensions of the navigation project at Holland Harbor were established. The northern jetty extends 1,765 ft from the shoreline, and the southern pier extends 1,634 ft. Dredging of the entire channel to existing project depths (23 ft at entrance) was accomplished in 1938, and maintenance dredging has continued annually.

47. To assess the impact of Federation navigation structures at Holland Harbor, differences between the littoral processes in the immediate vicinity of the harbor (north and south) and those occurring farther away (not influenced by the breakwaters) were compared. A sequence of eight sets of aerial photographs of the Holland Harbor was analyzed. The time interval from 1950 to 1973 was assessed to determine long-term evolutionary development of the shoreline. A regression analysis was performed to correct the shoreline for

lake level fluctuations/variations and to determine long-term erosion/ accretion rates along the coast. Shoreline positions were measured at 290-ft increments along the coast.

48. Historic surveys indicate that shortly after construction began, the north and south fillet areas accreted; however, the shoreline 1,200 ft south of the breakwater began to erode. Since the 1933 survey, it appears the north fillet has been relatively stable with southerly moving material now accumulating in the channel or being diverted lakeward.

49. Quantitative results of the regression study indicate 4,060 ft of shoreline north of the project accreted at a rate of 1.7 feet/year; however, the subreach from 4,930 to 10,585 ft north of the project was eroding at a rate of 1.28 feet/year. The 2,000 ft of shoreline immediately south of the south jetty has accreted at a rate of 9.6 feet/year from 1871-1944. South of this zone erosion dominates with the highest erosion (3 feet/year) occurring 5,200 ft south of the project.

50. Net littoral drift potential in the vicinity of Holland Harbor as computed in the Section 111 report (CENCE) is approximately 60,000 to 70,000 cubic yards/year from north to south with a large variability in any individual year. The gross potential sediment transport rate was estimated to be between 300,000 and 500,000 cubic yards/year. These measurements were derived from (SSMO) wave statistics.

51. Results indicate that 61,000 cubic yards/year (net) of material from the north is transported towards the project. Of this quantity, 38,500 cubic yards/year arrives at the harbor entrance with the balance of material naturally deposited updrift of the structures or lost offshore. It is estimated that 13,500 cubic yards/year of material was permanently lost from the littoral zone due directly to the Federal project. Dredging records indicate that the annual shoaling rate in the channel is approximately 25,000 cubic yards/year. This material was disposed offshore in deeper water. Results of this study are that 22 percent of the total erosion in the vicinity of Holland Harbor is directly attributable to the Federal project.

52. In order to mitigate the damages, a feeder beach was located approximately 1,200 ft south of the harbor extending southward a distance of about 3,300 ft. An initial fill quantity of about 170,000 $yd^3$ was placed on the feeder beach. The study recommends the harbor entrance be overdredged (beyond the requirements for navigation) to improve its sediment trapping

capabilities. Annual nourishment of 61,000 $yd^3$ of dredged material from the harbor entrance and a lake borrow source is required to maintain the feeder beach.

## Summary of Dredging History

53. The following summary has been compiled from dredging permits applied for by Consumers Power Company, J. H. Campbell Plant at Port Sheldon, Michigan (Table 5). Department of the Army (DOA) Permit 61-56-2 (issued on 17 March 1961) was for construction of two jetties extending 700 ft lakeward from shore and for dredging of 8,000 $yd^3$ for an intake channel. Dredged material was placed on upland disposal "B" area (Figure 2). On 27 April 1961, a permit was issued to extend the jetties another 20 ft, for a total length of 720 ft. On 2 November 1964, the Grand Haven Project Office (GHPO) filed a completion report. On 6 January 1959, DOA Permit 58-56-6 was issued to dredge 23,000 $yd^3$ in order to construct a discharge channel and place the material on upland disposal "A" (Figure 2). On 2 November 1964, the GHPO filed a completion report. Each winter, ice forms in the inlet channel, preventing intake water from reaching the power plant. This icing condition prohibits operation at full capacity. To alleviate this problem, 562-ft extensions to the existing jetties (DOA Permit 65-56-2) and a warmwater recirculation line (DOA Permit 65-56-5) were completed to the Pigeon Lake Inlet entrance. Consumer Powers verified completion of the jetty extension on 6 July 1966. The GHPO inspected and verified completion of the recirculation pipe on 12 June 1969. An extension of the intake channel (DOA Permit 76-56-21) was issued on 2 August 1976 to excavate a total of 10,000 $yd^3$ in the dry and dispose of this material on upland disposal "B." Consumers Power confirmed that the work was completed on 21 October 1977. On 8 May 1978, repair work (DOA Permit 58-56-5.1) started on two combination steel sheet-pile and rubble-mound bulkheads located immediately adjacent to Pigeon Lake outlet. A recent storm had dislodged some rubble-mound riprap into the south side of the inlet. Also, 5,000 $yd^3$ of sand was removed and placed on the south shore of Consumers Power property.

54. DOA Permit 77-56-54 was submitted to perform the following work items: (a) dredge approximately 960,000 $yd^3$ of material to form trenches for intake and discharge systems, (b) install a 18-ft-diam corrugated pipe

Table 5

Summary of Dredge History at Port Sheldon as Derived from CENCE Permitting Records

| DOA Permit No. | Date Issued | $Yd^3$ | Source | Placement | Verification |
|---|---|---|---|---|---|
| 61-56-2 | 17 Mar 61 | 8,000 | Intake channel | Upland disposal site "B"* | 2 Nov 64 |
| 8-56-6 | 6 Jan 59 | 23,300 | Discharge channel | Upland disposal site "A"* | 2 Nov 64 |
| 76-56-21 | 2 Aug 76 | 10,000 | Intake channel | Upland disposal site "B"* | 21 Oct 77 |
| 58-56-5.1 | 28 Oct 63 | 5,000 | Pigeon Lake Inlet channel | South shore of Consumer Power Corporation | None |
| 77-56-54 | 24 Mar 78 | 960,000 | Intake/ disposal channels | Upland disposal site "A," nourishment site "A," offshore temp. storage,* and on beach north of Pigeon Inlet | 31 Oct 80 |
| 78-56-48 | 7 Aug 79 | 18,000<br>2,000/<br>10,000 | Pigeon Lake Inlet channel | Nourishment site "B"* | None<br><br>Annually |
| 83-56-15 | 12 Apr 83 | 333 | Lake Michigan shoreline | Lots 11-14 Sheldon Shores Plat | 24 Jun 83 |
| 83-56-75 | 7 Oct 83 | 350 | Lake Michigan shoreline | Lots 2-9 Sheldon Shores Plat | 1/2 Work Completed 16 Nov 83 |

* Probable sites.

(intake) extending lakeward from shore 3,500 ft to approximately 35 ft of water, (c) install two additional 18-ft-diam (intake) pipes terminating at the shoreline for future use, and (d) install two parallel 10-ft-diam concrete pressure pipes (discharge) extending 2,375 ft from shore terminating in approximately 20 ft of water. Approximately 35,000 $yd^3$ of deepwater intake and discharge pipeline trench material was used for beach nourishment in an area located along the shoreline approximately 5,500 to 7,200 ft north of the inlet channel, which is labeled nourishment discharge area "A."* Approximately 20,000 $yd^3$ of inlet channel dredgings currently stored in the inlet channel storage area was used as final pipe backfill over the deepwater intake and discharge pipelines. This material was loaded onto bottom dump barges and discharged as backfill. In order to raise the grade to match the surrounding bluff line, approximately 400,000 $yd^3$ of dune sand was needed for closure of the discharge channel. The source of this material is unknown. Upon the completion of the construction activity, all excess material stored in the areas designated as "temporary storage of excavated material" and construction material was distributed along the shoreline 3,000 to 7,200 ft north of the inlet channel, which is labeled nourishment discharge area "A." On 31 November 1980, a letter from Consumers Power to the Corps of Engineers indicated work was completed on DOA Permit 77-56-54 on 31 October 1980. DOA Permit 78-56-48 to initially dredge 18,000 $yd^3$ and provide annual maintenance dredging of 2,000 to 10,000 $yd^3$ thereafter from Pigeon Lake Inlet channel to a maximum depth of 12 ft below IGLD was issued on 7 August 1979. This material was to be placed in nourishment discharge area "B," which lies 2,300 to 6,300 ft south of the inlet. An additional 10,000 $yd^3$ of suitable material, obtained during previous dredging operations and stored in inlet channel storage area, was also permitted to be placed in nourishment site "B." Additionally, annual maintenance dredged material that cannot be economically transported to nourishment discharge area "B" will be stored in a 200- to 500-ft temporary uncontaminated dredged material storage area. When sufficient quantities of material are available, temporary pipeline will be reconstructed, and dredged material will be hydraulically removed and pumped to nourishment discharge area "B." Maintenance dredging was to begin on 1 September 1979; however, no indication in the records confirmed this action. On

* Probable disposal placement sites.

3 December 1985, a letter from Consumers Power to CENCE indicated that approximately 5,000 $yd^3$ was dredged between 6 and 31 December 1985. Again, no confirmed inspection was logged. DOA Permit 83-56-15 was issued on 12 April 1983 to dredge 333 $yd^3$ of crushed stone from a 9,000 $ft^2$ area (lots 11-14 of Sheldon Shores Plat) for the purpose of beach restoration. Finally, DOA Permit 83-56-75 was issued to dredge 350 $yd^3$ from an area along lots 2-9 of Sheldon Shores Plat for the purpose of separating stone and sand in the sediment. This material was redeposited within the same area. As of 16 November 1983, Consumers Power stated that less than half of the work was completed. Work was suspended on this project for the rest of 1983.

# PART VI: DISCUSSION

55. The shoreline and nearshore volume changes described in the Holland Harbor and Grand Haven Harbor Section 111 studies are the typically expected response of the beach to construction of jetties and maintenance of a navigation channel. Any coastal structure such as the Port Sheldon jetties affects the natural longshore sediment transport regime, altering the normal coastal processes in some manner. In the case of the Port Sheldon jetties, evidence of sediment disruption is most strongly supported in the fillet volume assessment. If the assumptions in the fillet volume analysis are correct, it is evident from the fillet volume calculations that the initial response to the jetties was quite rapid. Within the first 3 years, approximately 66 percent of the north fillet and 29 percent of the south fillet had filled to their present capacity. Results from the shoreline analysis concur with the volumetric data. Shoreline transects immediately adjacent to the north fillet (516,650 to 517,500 N) (Appendix A) demonstrate very rapid response in the first year of construction. These data correlate extremely well with the fillet response documented at the Grand Haven and Holland projects. Since the 1965 hydrographic survey, it appears the rate of filling in the north fillet has significantly decreased, whereas the reverse is true for the south fillet. Again, the shoreline movement data support this trend. Of the total volume trapped within the fillet areas, approximately 64 percent of the total volume is contained within the north fillet, and 36 percent in the south fillet. This correlates within reason of the split in gross longshore sediment transport computed in the Grand Haven Section 111 study.

56. Due to the history of construction activities along the shoreline north of the project, it is difficult to isolate the shoreline response due to the project. However, it appears north of 521,000 N (approximately 4,300 ft north of the project), the shoreline is eroding at a rate similar to the southern reaches. Nearshore volume changes in this subreach (E) do not support that this is a zone of erosion. Accretion has occurred in the two subreaches (C and D) immediately adjacent to the jetties. Accumulation of material on both sides of the structure is probably a result of the large gross transport potential in this vicinity. Subreach B (between 507,000 and 513,000 N), approximately 3,000 ft south of the south jetty, appears to be eroding at the highest rate of all reaches since jetty construction. This

distance correlates very closely with the zone of greatest erosion measured at the Holland Harbor project. Results of the nearshore volume analysis confirm erosion in this zone (subreach B). The rate of historic shoreline change in subreach A is rather uniform throughout the reach, which may suggest this area is not within the direct influence of the Port Sheldon jetties.

57. The 1965 and 1984 contour maps in the vicinity of the jetties suggest very little, if any, jetting of sediment to deeper water. The 18-, 24-, and 30-ft contours are in relatively the same location for both time periods. Detailed hydrographic surveys collected by Roberge (1977) suggest the inlet bottom is relatively stable over the long term. Offshore jetting would be difficult since a mean velocity of 1.0 fps is produced in the inlet throat (at mean low water) when the plant is operating at full capacity (Roberge 1976).

58. The dredging history of the J. H. Campbell Plant is somewhat obscure. It is evident from the permitting records that a large amount of construction altered the shoreline and nearshore zone in the immediate vicinity of the power plant, i.e. north of the jetties. In general, the majority of construction completed to date appears to have redistributed the material in the nearshore zone rather than remove it from the system. The overall impact of these actions is unknown. It appears from the permit records that shoaling in Pigeon Lake Inlet has not been a major problem; however, DOA Permit 78-56-48 (24 March 1978) suggests that 18,000 $yd^3$ had accumulated in the channel and that the annual shoaling rate in the channel is approximately 2,000 to 10,000 cubic yards/year. This material is dredged on an annual or as-needed basis and placed south of the south jetty either on the beach or in the nearshore zone. In summary, dredging practices related to the power plant appear to place the majority of disposal material back in the littoral zone.

## PART VII: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

59. The purpose of this study is to determine the impact, if any, of the jetties on the adjacent shorelines and nearshore zones. The jetties have definitely caused a blockage of sediment transported within the Port Sheldon vicinity and trapped sediment moving in both directions. Initially after construction, the jetties probably created a near impermeable barrier to littoral material. This is substantiated in the shoreline, nearshore, and fillet analysis. The total volume trapped in the fillets has certainly deprived neighboring areas of sediment that would have normally been transported around Pigeon Inlet. The volumetric analysis also indicates an accumulation of material in the nearshore zone on both sides of the jetties.

60. Even though there is the potential for large gross sediment transport in this area (large quantities of sediment moving in both directions), it is evident from the fillet volumes and history of sediment accumulation that the net transport is to the south. Other studies in the region agree with this conclusion. Therefore, it is most likely the majority of impact from the jetties would be located south of the project. Results of this study identified a zone of impact from the jetties in the area south of the project described as subreach B. The distance of impact from 3,000 to 9,000 ft south of the south jetty correlates very well with the impact area described in the Holland Harbor Section 111 study. Any adverse impacts from the project immediately north of the jetties are obscured by construction and cannot be verified with this data set.

61. The shoreline positions in the fillet areas remained constant or slightly retreated from 1980 to 1984. By itself, this constancy would suggest the fillets are beginning to stabilize in an equilibrium configuration. However, this was a period of high lake levels. It took approximately 30 years for the fillets at Holland Harbor to stabilize; however, these structures are larger than the Port Sheldon jetties.

62. Previous studies by Hands (1976) suggest that movement of littoral material past a structure may occur along outer bar formations. Analysis of aerial photographs and geophysical data indicates three or four bars are usually present in the Port Sheldon vicinity with the third and fourth bar

located in approximately 12- to 15-ft water depth, the same depth as the jetty tips. Analysis of sediment data suggests the sediment populations are similar on both sides of the jetties. These observations, in addition to the apparent decrease in rate of accretion in the fillets, suggest some sediment is currently being transported around the Port Sheldon jetties. However, without additional hydrographic and topographic surveys, it is difficult to determine if the fillets have stabilized volumetrically with normal sediment transport occurring around the structures.

63. The quantity of material deprived from adjacent shorelines can be documented in the fillet analysis and nearshore volume change. Up through 1984, it is estimated that a total of 246,300 $yd^3$ has been trapped in both fillet areas. Relying on the 1965 to 1984 hydrographic surveys, 336,300 $yd^3$ (17,700 cubic yards/year $\times$ 19 years) and 228,000 $yd^3$ (12,000 cubic yards/year $\times$ 19 years) have accumulated offshore in subreaches C and D, respectively. Accretion in subreach E may or may not be a function of the jetties because of the level of construction in the vicinity. Summing these quantities results in approximately 810,600 $yd^3$ trapped by the project. This is a conservative estimate as the nearshore volume accumulated within the first 3 years after construction is not included because of uncertainties in the 1944 (precondition) survey.

## Recommendations

64. The zone of most impact appears to be located in subreach B; however, with this data set, the impact in subreach B cannot be quantified. Many factors could have contributed this anomaly, i.e. private shore-front structures, geomorphology/soil type of the zone. To quantify the direct impact of the Port Sheldon jetties in subreach B, a detailed sediment budget based upon hydrodynamic and sediment transport studies should be performed.

65. To assess if the fillet areas have stabilized, it is suggested that future hydrographic and topographic surveys be scheduled. Detailed hydrodynamic and sediment transport studies near the jetties may also aid in verifying if sediment bypassing is presently occurring around the structure and to what degree. These suggested studies are outlined in the original scope of work for this project.

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## APPENDIX A: SHORELINE MOVEMENT DATA

This appendix represents shoreline movement data computed for each transect. Transects are located at 500 ft intervals starting from 484,500 N to 527,000 N, except in the inlet throat. Represented are the Y-coordinate of the transect, distance between shorelines for consecutive time periods, rate of change between consecutive time periods, rate of change between 1962-1984 and 1938-1984, and standard deviation for the data set.

| Year | Total Ft | Ft/Yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 484500.0 | | | |
| 1938-1962 | -80.1 | -3.3 | 1962-1984 | -18.9 | -0.9 |
| 1962-1967 | 47.4 | 9.5 | 1938-1984 | -99.0 | -2.2 |
| 1967-1980 | -85.8 | -6.6 | | | |
| 1980-1984 | 19.5 | 4.9 | | | |
| Std Dev 7.4 | | | | | |
| | | Y = 485000.0 | | | |
| 1938-1962 | -94.4 | -3.9 | 1962-1984 | -31.6 | -1.4 |
| 1962-1967 | 48.0 | 9.6 | 1938-1984 | -126.0 | -2.7 |
| 1967-1980 | -66.0 | -5.1 | | | |
| 1980-1984 | -13.6 | -3.4 | | | |
| Std Dev 6.9 | | | | | |
| | | Y = 485500.0 | | | |
| 1938-1962 | -92.5 | -3.9 | 1962-1984 | -38.3 | -1.7 |
| 1962-1967 | 90.5 | 18.1 | 1938-1984 | -130.8 | -2.8 |
| 1967-1980 | -70.1 | -5.4 | | | |
| 1980-1984 | -58.6 | -14.7 | | | |
| Std Dev 13.9 | | | | | |
| | | Y = 486000.0 | | | |
| 1938-1962 | -101.8 | -4.2 | 1962-1984 | -1.0 | 0.0 |
| 1962-1967 | 78.4 | 15.7 | 1938-1984 | -102.8 | -2.2 |
| 1967-1980 | -58.3 | -4.5 | | | |
| 1980-1984 | -21.1 | -5.3 | | | |
| Std Dev 10.2 | | | | | |

(Continued)

(Sheet 1 of 17)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 486500.0 | | | |
| 1938-1962 | -79.3 | -3.3 | 1962-1984 | 27.6 | 1.3 |
| 1962-1967 | 95.5 | 19.1 | 1938-1984 | -51.6 | -1.1 |
| 1967-1980 | -92.5 | -7.1 | | | |
| 1980-1984 | 24.6 | 6.2 | | | |
| Std Dev 11.7 | | | | | |
| | | Y = 487000.0 | | | |
| 1938-1962 | -55.6 | -2.3 | 1962-1984 | 3.9 | 0.2 |
| 1962-1967 | 47.8 | 9.6 | 1938-1984 | -51.8 | -1.1 |
| 1967-1980 | -98.0 | -7.5 | | | |
| 1980-1984 | 54.1 | 13.5 | | | |
| Std Dev 9.9 | | | | | |
| | | Y = 487500.0 | | | |
| 1938-1962 | -58.4 | -2.4 | 1962-1984 | -4.8 | -0.2 |
| 1962-1967 | 56.0 | 11.2 | 1938-1984 | -63.1 | -1.4 |
| 1967-1980 | -93.6 | -7.2 | | | |
| 1980-1984 | 32.9 | 8.2 | | | |
| Std Dev 8.7 | | | | | |
| | | Y = 488000.0 | | | |
| 1938-1962 | -70.5 | -2.9 | 1962-1984 | -18.6 | -0.8 |
| 1962-1967 | 67.4 | 13.5 | 1938-1984 | -89.1 | -1.9 |
| 1967-1980 | -63.3 | -4.9 | | | |
| 1980-1984 | -22.8 | -5.7 | | | |
| Std Dev 9.1 | | | | | |
| | | Y = 488500.0 | | | |
| 1938-1962 | -45.5 | -1.9 | 1962-1984 | -49.4 | -2.2 |
| 1962-1967 | 65.8 | 13.1 | 1938-1984 | -94.9 | -2.1 |
| 1967-1980 | -88.1 | -6.8 | | | |
| 1980-1984 | -27.0 | -6.8 | | | |
| Std Dev 9.4 | | | | | |

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 489000.0 | | | |
| 1938-1962 | -4.3 | -0.2 | 1962-1984 | -101.8 | -4.6 |
| 1962-1967 | 16.0 | 3.2 | 1938-1984 | -106.0 | -2.3 |
| 1967-1980 | -82.5 | -6.3 | | | |
| 1980-1984 | -35.3 | -8.8 | | | |
| Std Dev 5.5 | | | | | |
| | | Y = 489500.0 | | | |
| 1938-1962 | 28.4 | 1.2 | 1962-1984 | -135.9 | -6.2 |
| 1962-1967 | -26.5 | -5.3 | 1938-1984 | -107.5 | -2.3 |
| 1967-1980 | -100.1 | -7.7 | | | |
| 1980-1984 | -9.3 | -2.3 | | | |
| Std Dev 3.8 | | | | | |
| | | Y = 490000.0 | | | |
| 1938-1962 | 27.4 | 1.1 | 1962-1984 | -132.9 | -6.0 |
| 1962-1967 | -3.4 | -0.7 | 1938-1984 | -105.5 | -2.3 |
| 1967-1980 | -114.5 | -8.8 | | | |
| 1980-1984 | -15.0 | -3.8 | | | |
| Std Dev 4.4 | | | | | |
| | | Y = 490500.0 | | | |
| 1938-1962 | -9.1 | -0.4 | 1962-1984 | -69.9 | -3.2 |
| 1962-1967 | 15.3 | 3.0 | 1938-1984 | -79.0 | -1.7 |
| 1967-1980 | -101.6 | -7.8 | | | |
| 1980-1984 | 16.5 | 4.1 | | | |
| Std Dev 5.4 | | | | | |
| | | Y = 491000.0 | | | |
| 1938-1962 | -6.4 | -0.3 | 1962-1984 | -64.8 | -2.9 |
| 1962-1967 | 27.8 | 5.6 | 1938-1984 | -71.1 | -1.5 |
| 1967-1980 | -76.4 | -5.9 | | | |
| 1980-1984 | -16.1 | -4.0 | | | |
| Std Dev 5.0 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 491500.0 | | | |
| 1938-1962 | -7.0 | -0.3 | 1962-1984 | -77.3 | -3.5 |
| 1962-1967 | 34.4 | 6.9 | 1938-1984 | -84.3 | -1.8 |
| 1967-1980 | -108.0 | -8.3 | | | |
| 1980-1984 | -3.6 | -0.9 | | | |
| Std Dev 6.2 | | | | | |
| | | Y = 492000.0 | | | |
| 1938-1962 | -60.0 | -2.5 | 1962-1984 | -62.8 | -2.9 |
| 1962-1967 | 50.8 | 10.1 | 1938-1984 | -122.8 | -2.7 |
| 1967-1980 | -116.5 | -9.0 | | | |
| 1980-1984 | 3.0 | 0.8 | | | |
| Std Dev 8.0 | | | | | |
| | | Y = 492500.0 | | | |
| 1938-1962 | -22.3 | -0.9 | 1962-1984 | -107.9 | -4.9 |
| 1962-1967 | 36.6 | 7.3 | 1938-1984 | -130.1 | -2.8 |
| 1967-1980 | -158.4 | -12.2 | | | |
| 1980-1984 | 13.9 | 3.5 | | | |
| Std Dev 8.4 | | | | | |
| | | Y = 493000.0 | | | |
| 1938-1962 | -28.9 | -1.2 | 1962-1984 | -130.9 | -5.9 |
| 1962-1967 | 12.0 | 2.4 | 1938-1984 | -159.8 | -3.5 |
| 1967-1980 | -98.1 | -7.5 | | | |
| 1980-1984 | -44.8 | -11.2 | | | |
| Std Dev 6.1 | | | | | |
| | | Y = 493500.0 | | | |
| 1938-1962 | -84.9 | -3.5 | 1962-1984 | -108.8 | -4.9 |
| 1962-1967 | -0.8 | -0.2 | 1938-1984 | -193.6 | -4.2 |
| 1967-1980 | -86.1 | -6.6 | | | |
| 1980-1984 | -21.9 | -5.5 | | | |
| Std Dev 2.8 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 494000.0 | | | |
| 1938-1962 | -91.1 | -3.8 | 1962-1984 | -67.9 | -3.1 |
| 1962-1967 | -4.6 | -0.9 | 1938-1984 | -159.0 | -3.5 |
| 1967-1980 | -87.3 | -6.7 | | | |
| 1980-1984 | 24.0 | 6.0 | | | |
| Std Dev 5.4 | | | | | |
| | | Y = 494500.0 | | | |
| 1938-1962 | -82.0 | -3.4 | 1962-1984 | -63.0 | -2.9 |
| 1962-1967 | 14.6 | 2.9 | 1938-1984 | -145.0 | -3.2 |
| 1967-1980 | -80.0 | -6.2 | | | |
| 1980-1984 | 2.4 | 0.6 | | | |
| Std Dev 4.1 | | | | | |
| | | Y = 495000.0 | | | |
| 1938-1962 | -95.1 | -4.0 | 1962-1984 | -52.3 | -2.4 |
| 1962-1967 | 9.1 | 1.8 | 1938-1984 | -147.4 | -3.2 |
| 1967-1980 | -56.6 | -4.4 | | | |
| 1980-1984 | -4.8 | -1.2 | | | |
| Std Dev 2.9 | | | | | |
| | | Y = 495500.0 | | | |
| 1938-1962 | -116.9 | -4.9 | 1962-1984 | -32.1 | -1.5 |
| 1962-1967 | 52.4 | 10.5 | 1938-1984 | -149.0 | -3.2 |
| 1967-1980 | -62.9 | -4.8 | | | |
| 1980-1984 | -21.6 | -5.4 | | | |
| Std Dev 7.8 | | | | | |
| | | Y = 496000.0 | | | |
| 1938-1962 | -116.9 | -4.9 | 1962-1984 | -38.1 | -1.7 |
| 1962-1967 | 45.3 | 9.1 | 1938-1984 | -155.0 | -3.4 |
| 1967-1980 | -82.3 | -6.3 | | | |
| 1980-1984 | -1.1 | -0.3 | | | |
| Std Dev 6.9 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 496500.0 | | | |
| 1938-1962 | -87.1 | -3.6 | 1962-1984 | -76.3 | -3.5 |
| 1962-1967 | 7.6 | 1.5 | 1938-1984 | -163.4 | -3.6 |
| 1967-1980 | -46.4 | -3.6 | | | |
| 1980-1984 | -37.5 | -9.4 | | | |
| Std Dev 4.5 | | | | | |
| | | Y = 497000.0 | | | |
| 1938-1962 | -85.8 | -3.6 | 1962-1984 | -62.0 | -2.8 |
| 1962-1967 | 129.0 | 25.8 | 1938-1984 | -147.8 | -3.2 |
| 1967-1980 | -168.1 | -12.9 | | | |
| 1980-1984 | -22.9 | -5.7 | | | |
| Std Dev 17.1 | | | | | |
| | | Y = 497500.0 | | | |
| 1938-1962 | -30.8 | -1.3 | 1962-1984 | -136.6 | -6.2 |
| 1962-1967 | 48.9 | 9.8 | 1938-1984 | -167.4 | -3.6 |
| 1967-1980 | -136.8 | -10.5 | | | |
| 1980-1984 | -48.8 | -12.2 | | | |
| Std Dev 10.1 | | | | | |
| | | Y = 498000.0 | | | |
| 1938-1962 | -31.3 | -1.3 | 1962-1984 | -85.5 | -3.9 |
| 1962-1967 | 46.3 | 9.3 | 1938-1984 | -116.8 | -2.5 |
| 1967-1980 | -111.6 | -8.6 | | | |
| 1980-1984 | -20.1 | -5.0 | | | |
| Std Dev 7.7 | | | | | |
| | | Y = 498500.0 | | | |
| 1938-1962 | -35.9 | -1.5 | 1962-1984 | -58.0 | -2.6 |
| 1962-1967 | 35.3 | 7.1 | 1938-1984 | -93.9 | -2.0 |
| 1967-1980 | -75.9 | -5.8 | | | |
| 1980-1984 | -17.4 | -4.3 | | | |
| Std Dev 5.8 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 499000.0 | | | |
| 1938-1962 | -64.9 | -2.7 | 1962-1984 | -27.5 | -1.3 |
| 1962-1967 | 0.5 | 0.1 | 1938-1984 | -92.4 | -2.0 |
| 1967-1980 | -31.9 | -2.5 | | | |
| 1980-1984 | 3.9 | 1.0 | | | |
| Std Dev 1.8 | | | | | |
| | | Y = 499500.0 | | | |
| 1938-1962 | -14.6 | -0.6 | 1962-1984 | -117.3 | -5.3 |
| 1962-1967 | -24.5 | -4.9 | 1938-1984 | -131.9 | -2.9 |
| 1967-1980 | -64.8 | -5.0 | | | |
| 1980-1984 | -28.0 | -7.0 | | | |
| Std Dev 2.7 | | | | | |
| | | Y = 500000.0 | | | |
| 1938-1962 | -22.8 | -0.9 | 1962-1984 | -71.8 | -3.3 |
| 1962-1967 | 14.1 | 2.8 | 1938-1984 | -94.5 | -2.1 |
| 1967-1980 | -75.4 | -5.8 | | | |
| 1980-1984 | -10.5 | -2.6 | | | |
| Std Dev 3.6 | | | | | |
| | | Y = 500500.0 | | | |
| 1938-1962 | 2.6 | 0.1 | 1962-1984 | -86.6 | -3.9 |
| 1962-1967 | 8.9 | 1.8 | 1938-1984 | -84.0 | -1.8 |
| 1967-1980 | -82.4 | -6.3 | | | |
| 1980-1984 | -13.1 | -3.3 | | | |
| Std Dev 3.6 | | | | | |
| | | Y = 501000.0 | | | |
| 1938-1962 | -10.0 | -0.4 | 1962-1984 | -72.6 | -3.3 |
| 1962-1967 | 43.3 | 8.6 | 1938-1984 | -82.6 | -1.8 |
| 1967-1980 | -99.4 | -7.6 | | | |
| 1980-1984 | -16.5 | -4.1 | | | |
| Std Dev 7.0 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 501500.0 | | | |
| 1938-1962 | -26.3 | -1.1 | 1962-1984 | -70.5 | -3.2 |
| 1962-1967 | 44.9 | 9.0 | 1938-1984 | -96.8 | -2.1 |
| 1967-1980 | -115.4 | -8.9 | | | |
| 1980-1984 | 0.0 | 0.0 | | | |
| Std Dev 7.3 | | | | | |
| | | Y = 502000.0 | | | |
| 1938-1962 | -37.8 | -1.6 | 1962-1984 | -56.0 | -2.5 |
| 1962-1967 | 40.6 | 8.1 | 1938-1984 | -93.8 | -2.0 |
| 1967-1980 | -108.9 | -8.4 | | | |
| 1980-1984 | 12.3 | 3.1 | | | |
| Std Dev 7.0 | | | | | |
| | | Y = 502500.0 | | | |
| 1938-1962 | -2.3 | -0.1 | 1962-1984 | -96.4 | -4.4 |
| 1962-1967 | 2.1 | 0.4 | 1938-1984 | -98.6 | -2.1 |
| 1967-1980 | -119.8 | -9.2 | | | |
| 1980-1984 | 21.3 | 5.3 | | | |
| Std Dev 6.1 | | | | | |
| | | Y = 503000.0 | | | |
| 1938-1962 | 8.0 | 0.3 | 1962-1984 | -131.4 | -6.0 |
| 1962-1967 | -22.0 | -4.4 | 1938-1984 | -123.4 | -2.7 |
| 1967-1980 | -99.3 | -7.6 | | | |
| 1980-1984 | -10.1 | -2.5 | | | |
| Std Dev 3.3 | | | | | |
| | | Y = 503500.0 | | | |
| 1938-1962 | -30.1 | -1.3 | 1962-1984 | -112.6 | -5.1 |
| 1962-1967 | -8.6 | -1.7 | 1938-1984 | -142.8 | -3.1 |
| 1967-1980 | -92.3 | -7.1 | | | |
| 1980-1984 | -11.8 | -2.9 | | | |
| Std Dev 2.7 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 504000.0 | | | |
| 1938-1962 | -42.8 | -1.8 | 1962-1984 | -87.4 | -4.0 |
| 1962-1967 | 2.5 | 0.5 | 1938-1984 | -130.1 | -2.8 |
| 1967-1980 | -57.4 | -4.4 | | | |
| 1980-1984 | -32.5 | -8.1 | | | |
| Std Dev 3.7 | | | | | |
| | | Y = 504500.0 | | | |
| 1938-1962 | -83.3 | -3.5 | 1962-1984 | -26.5 | -1.2 |
| 1962-1967 | 14.4 | 2.9 | 1938-1984 | -109.8 | -2.4 |
| 1967-1980 | -33.0 | -2.5 | | | |
| 1980-1984 | -7.9 | -2.0 | | | |
| Std Dev 2.8 | | | | | |
| | | Y = 505000.0 | | | |
| 1938-1962 | -70.6 | -2.9 | 1962-1984 | 16.8 | 0.8 |
| 1962-1967 | -14.4 | -2.9 | 1938-1984 | -53.9 | -1.2 |
| 1967-1980 | 0.0 | 0.0 | | | |
| 1980-1984 | 31.1 | 7.8 | | | |
| Std Dev 5.1 | | | | | |
| | | Y = 505500.0 | | | |
| 1938-1962 | -75.0 | -3.1 | 1962-1984 | 21.5 | 1.0 |
| 1962-1967 | 9.3 | 1.9 | 1938-1984 | -53.5 | -1.2 |
| 1967-1980 | -20.8 | -1.6 | | | |
| 1980-1984 | 33.0 | 8.3 | | | |
| Std Dev 5.1 | | | | | |
| | | Y = 506000.0 | | | |
| 1938-1962 | -78.1 | -3.3 | 1962-1984 | -41.5 | -1.9 |
| 1962-1967 | 72.3 | 14.4 | 1938-1984 | -119.6 | -2.6 |
| 1967-1980 | -62.0 | -4.8 | | | |
| 1980-1984 | -51.8 | -12.9 | | | |
| Std Dev 11.5 | | | | | |

(Continued)

(Sheet 9 of 17)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 506500.0 | | | |
| 1938-1962 | -42.8 | -1.8 | 1962-1984 | -67.6 | -3.1 |
| 1962-1967 | 34.0 | 6.8 | 1938-1984 | -110.4 | -2. |
| 1967-1980 | -62.7 | -4.8 | | | |
| 1980-1984 | -38.9 | -9.7 | | | |
| Std Dev 6.9 | | | | | |
| | | Y = 507000.0 | | | |
| 1938-1962 | -62.9 | -2.6 | 1962-1984 | -104.8 | -4.8 |
| 1962-1967 | 109.9 | 22.0 | 1938-1984 | -167.6 | -3.6 |
| 1967-1980 | -175.8 | -13.5 | | | |
| 1980-1984 | -38.9 | -9.7 | | | |
| Std Dev 16.0 | | | | | |
| | | Y = 507500.0 | | | |
| 1938-1962 | 75.6 | 3.2 | 1962-1984 | -184.1 | -8.4 |
| 1962-1967 | 17.5 | 3.5 | 1938-1984 | -108.5 | -2.4 |
| 1967-1980 | -197.4 | -15.2 | | | |
| 1980-1984 | -4.3 | -1.1 | | | |
| Std Dev 8.8 | | | | | |
| | | Y = 508000.0 | | | |
| 1938-1962 | 45.6 | 1.9 | 1962-1984 | -145.0 | -6.6 |
| 1962-1967 | 53.9 | 10.8 | 1938-1984 | -99.4 | -2.2 |
| 1967-1980 | -191.0 | -14.7 | | | |
| 1980-1984 | -7.9 | -2.0 | | | |
| Std Dev 10.6 | | | | | |
| | | Y = 508500.0 | | | |
| 1938-1962 | 18.6 | 0.8 | 1962-1984 | -157.5 | -7.2 |
| 1962-1967 | 31.8 | 6.3 | 1938-1984 | -138.9 | -3.0 |
| 1967-1980 | -171.0 | -13.2 | | | |
| 1980-1984 | -18.3 | -4.6 | | | |
| Std Dev 8.3 | | | | | |

(Continued)

(Sheet 10 of 17)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 509000.0 | | | |
| 1938-1962 | 21.6 | 0.9 | 1962-1984 | -172.8 | -7.9 |
| 1962-1967 | 7.9 | 1.6 | 1938-1984 | -151.1 | -3.3 |
| 1967-1980 | -149.6 | -11.5 | | | |
| 1980-1984 | -31.0 | -7.8 | | | |
| Std Dev 6.5 | | | | | |
| | | Y = 509500.0 | | | |
| 1938-1962 | -7.3 | -0.3 | 1962-1984 | -145.5 | -6.6 |
| 1962-1967 | -2.3 | -0.4 | 1938-1984 | -152.8 | -3.3 |
| 1967-1980 | -148.4 | -11.4 | | | |
| 1980-1984 | 5.1 | 1.3 | | | |
| Std Dev 5.8 | | | | | |
| | | Y = 510000.0 | | | |
| 1938-1962 | -24.0 | -1.0 | 1962-1984 | -158.3 | -7.2 |
| 1962-1967 | 5.4 | 1.1 | 1938-1984 | -182.3 | -4.0 |
| 1967-1980 | -152.3 | -11.7 | | | |
| 1980-1984 | -11.4 | -2.8 | | | |
| Std Dev 5.6 | | | | | |
| | | Y = 510500.0 | | | |
| 1938-1962 | -40.4 | -1.7 | 1962-1984 | -118.6 | -5.4 |
| 1962-1967 | 34.6 | 6.9 | 1938-1984 | -159.0 | -3.5 |
| 1967-1980 | -151.6 | -11.7 | | | |
| 1980-1984 | -1.6 | -0.4 | | | |
| Std Dev 7.6 | | | | | |
| | | Y = 511000.0 | | | |
| 1938-1962 | -40.3 | -1.7 | 1962-1984 | -79.1 | -3.6 |
| 1962-1967 | 45.8 | 9.1 | 1938-1984 | -119.4 | -2.6 |
| 1967-1980 | -121.9 | -9.4 | | | |
| 1980-1984 | -3.0 | -0.8 | | | |
| Std Dev 7.6 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 511500.0 | | | |
| 1938-1962 | -59.4 | -2.5 | 1962-1984 | -118.4 | -5.4 |
| 1962-1967 | 18.9 | 3.8 | 1938-1984 | -177.8 | -3.9 |
| 1967-1980 | -149.5 | -11.5 | | | |
| 1980-1984 | 12.3 | 3.1 | | | |
| Std Dev 7.1 | | | | | |
| | | Y = 512000.0 | | | |
| 1938-1962 | -75.6 | -3.2 | 1962-1984 | -109.4 | -5.0 |
| 1962-1967 | 8.5 | 1.7 | 1938-1984 | -185.0 | -4.0 |
| 1967-1980 | -94.1 | -7.2 | | | |
| 1980-1984 | -23.8 | -5.9 | | | |
| Std Dev 4.0 | | | | | |
| | | Y = 512500.0 | | | |
| 1938-1962 | -97.6 | -4.1 | 1962-1984 | -89.0 | -4.0 |
| 1962-1967 | -2.5 | -0.5 | 1938-1984 | -186.6 | -4.1 |
| 1967-1980 | -55.6 | -4.3 | | | |
| 1980-1984 | -30.9 | -7.7 | | | |
| Std Dev 2.9 | | | | | |
| | | Y = 513000.0 | | | |
| 1938-1962 | -36.3 | -1.5 | 1962-1984 | -80.4 | -3.7 |
| 1962-1967 | -29.4 | -5.9 | 1938-1984 | -116.6 | -2.5 |
| 1967-1980 | -42.0 | -3.2 | | | |
| 1980-1984 | -9.0 | -2.3 | | | |
| Std Dev 1.9 | | | | | |
| | | Y = 513500.0 | | | |
| 1938-1962 | -36.4 | -1.5 | 1962-1984 | -70.9 | -3.2 |
| 1962-1967 | -36.0 | -7.2 | 1938-1984 | -107.3 | -2.3 |
| 1967-1980 | -34.6 | -2.7 | | | |
| 1980-1984 | -0.3 | -0.1 | | | |
| Std Dev 3.1 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 514000.0 | | | |
| 1938-1962 | -28.1 | -1.2 | 1962-1984 | -33.1 | -1.5 |
| 1962-1967 | -43.0 | -8.6 | 1938-1984 | -61.3 | -1.3 |
| 1967-1980 | 6.8 | 0.5 | | | |
| 1980-1984 | 3.1 | 0.8 | | | |
| Std Dev 4.4 | | | | | |
| | | Y = 514500.0 | | | |
| 1938-1962 | -10.4 | -0.4 | 1962-1984 | -9.4 | -0.4 |
| 1962-1967 | 12.6 | 2.5 | 1938-1984 | -19.8 | -0.4 |
| 1967-1980 | 17.0 | 1.3 | | | |
| 1980-1984 | -39.0 | -9.8 | | | |
| Std Dev 5.6 | | | | | |
| | | Y = 515000.0 | | | |
| 1938-1962 | -4.9 | -0.2 | 1962-1984 | 90.9 | 4.1 |
| 1962-1967 | 37.1 | 7.4 | 1938-1984 | 86.0 | 1.9 |
| 1967-1980 | 79.6 | 6.1 | | | |
| 1980-1984 | -25.9 | -6.5 | | | |
| Std Dev 6.4 | | | | | |
| | | Y = 515300.0 | | | |
| 1938-1962 | 47.4 | 2.0 | 1962-1984 | 129.8 | 5.9 |
| 1962-1967 | 38.5 | 7.7 | 1938-1984 | 177.1 | 3.9 |
| 1967-1980 | 102.8 | 7.9 | | | |
| 1980-1984 | -11.5 | -2.9 | | | |
| Std Dev 5.2 | | | | | |
| | | Y = 516650.0 | | | |
| 1938-1962 | 235.8 | 9.8 | 1962-1984 | 55.5 | 2.5 |
| 1962-1967 | -14.9 | -3.0 | 1938-1984 | 291.3 | 6.3 |
| 1967-1980 | 40.6 | 3.1 | | | |
| 1980-1984 | 29.8 | 7.4 | | | |
| Std Dev 5.6 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 517000.0 | | | |
| 1938-1962 | 160.8 | 6.7 | 1962-1984 | 124.4 | 5.7 |
| 1962-1967 | 80.5 | 16.1 | 1938-1984 | 285.1 | 6.2 |
| 1967-1980 | 24.3 | 1.9 | | | |
| 1980-1984 | 19.6 | 4.9 | | | |
| Std Dev 6.1 | | | | | |
| | | Y = 517500.0 | | | |
| 1938-1962 | 78.3 | 3.3 | 1962-1984 | 119.9 | 5.4 |
| 1962-1967 | 89.6 | 17.9 | 1938-1984 | 198.1 | 4.3 |
| 1967-1980 | 20.4 | 1.6 | | | |
| 1980-1984 | 9.9 | 2.5 | | | |
| Std Dev 7.8 | | | | | |
| | | Y = 518000.0 | | | |
| 1938-1962 | 38.5 | 1.6 | 1962-1984 | 120.1 | 5.5 |
| 1962-1967 | 36.5 | 7.3 | 1938-1984 | 158.6 | 3.4 |
| 1967-1980 | 43.1 | 3.3 | | | |
| 1980-1984 | 40.5 | 10.1 | | | |
| Std Dev 3.9 | | | | | |
| | | Y = 518500.0 | | | |
| 1938-1962 | -5.6 | -0.2 | 1962-1984 | 83.0 | 3.8 |
| 1962-1967 | 58.5 | 11.7 | 1938-1984 | 77.4 | 1.7 |
| 1967-1980 | 12.0 | 0.9 | | | |
| 1980-1984 | 12.5 | 3.1 | | | |
| Std Dev 5.4 | | | | | |
| | | Y = 519000.0 | | | |
| 1938-1962 | -40.0 | -1.7 | 1962-1984 | 73.0 | 3.3 |
| 1962-1967 | 28.1 | 5.6 | 1938-1984 | 33.0 | 0.7 |
| 1967-1980 | 35.8 | 2.8 | | | |
| 1980-1984 | 9.1 | 2.3 | | | |
| Std Dev 3.0 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 519500.0 | | | |
| 1938-1962 | -119.5 | -5.0 | 1962-1984 | 116.6 | 5.3 |
| 1962-1967 | 68.4 | 13.7 | 1938-1984 | -2.9 | -0.1 |
| 1967-1980 | 109.9 | 8.5 | | | |
| 1980-1984 | -61.6 | -15.4 | | | |
| Std Dev 13.2 | | | | | |
| | | Y = 520000.0 | | | |
| 1938-1962 | -160.3 | -6.7 | 1962-1984 | 58.3 | 2.6 |
| 1962-1967 | 92.1 | 18.4 | 1938-1984 | -102.0 | -2.2 |
| 1967-1980 | 185.5 | 14.3 | | | |
| 1980-1984 | -219.4 | -54.8 | | | |
| Std Dev 33.6 | | | | | |
| | | Y = 520500.0 | | | |
| 1938-1962 | -131.5 | -5.5 | 1962-1984 | 43.8 | 2.0 |
| 1962-1967 | 94.3 | 18.9 | 1938-1984 | -87.8 | -1.9 |
| 1967-1980 | 82.9 | 6.4 | | | |
| 1980-1984 | -133.4 | -33.3 | | | |
| Std Dev 22.3 | | | | | |
| | | Y = 521000.0 | | | |
| 1938-1962 | -114.3 | -4.8 | 1962-1984 | -38.6 | -1.8 |
| 1962-1967 | 65.0 | 13.0 | 1938-1984 | -152.9 | -3.3 |
| 1967-1980 | 81.0 | 6.2 | | | |
| 1980-1984 | -184.6 | -46.2 | | | |
| Std Dev 26.5 | | | | | |
| | | Y = 521500.0 | | | |
| 1938-1962 | -16.8 | -0.7 | 1962-1984 | -104.3 | -4.7 |
| 1962-1967 | -27.8 | -5.6 | 1938-1984 | -121.0 | -2.6 |
| 1967-1980 | 84.1 | 6.5 | | | |
| 1980-1984 | -160.6 | -40.2 | | | |
| Std Dev 20.7 | | | | | |

(Continued)

(Continued)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 522000.0 | | | |
| 1938-1962 | -12.6 | -0.5 | 1962-1984 | -142.8 | -6.5 |
| 1962-1967 | -34.0 | -6.8 | 1938-1984 | -155.4 | -3.4 |
| 1967-1980 | -30.6 | -2.4 | | | |
| 1980-1984 | -78.1 | -19.5 | | | |
| Std Dev 8.6 | | | | | |
| | | Y = 523000.0 | | | |
| 1938-1962 | -37.4 | -1.6 | 1962-1984 | -41.9 | -1.9 |
| 1962-1967 | 31.9 | 6.4 | 1938-1984 | -79.3 | -1.7 |
| 1967-1980 | -132.4 | -10.2 | | | |
| 1980-1984 | 58.6 | 14.7 | | | |
| Std Dev 10.6 | | | | | |
| | | Y = 523500.0 | | | |
| 1938-1962 | 32.4 | 1.3 | 1962-1984 | -116.0 | -5.3 |
| 1962-1967 | -30.0 | -6.0 | 1938-1984 | -83.6 | -1.8 |
| 1967-1980 | -96.4 | -7.4 | | | |
| 1980-1984 | 10.4 | 2.6 | | | |
| Std Dev 5.1 | | | | | |
| | | Y = 524000.0 | | | |
| 1938-1962 | 35.0 | 1.5 | 1962-1984 | -99.8 | -4.5 |
| 1962-1967 | -11.3 | -2.3 | 1938-1984 | -64.8 | -1.4 |
| 1967-1980 | -104.5 | -8.0 | | | |
| 1980-1984 | 16.0 | 4.0 | | | |
| Std Dev 5.2 | | | | | |
| | | Y = 524500.0 | | | |
| 1938-1962 | 21.5 | 0.9 | 1962-1984 | -91.6 | -4.2 |
| 1962-1967 | -7.9 | -1.6 | 1938-1984 | -70.1 | -1.5 |
| 1967-1980 | -108.5 | -8.3 | | | |
| 1980-1984 | 24.8 | 6.2 | | | |
| Std Dev 6.0 | | | | | |

(Continued)

(Sheet 16 of 17)

(Concluded)

| Year | Total Ft | Ft/yr | Year | Total Ft | Ft/Yr |
|---|---|---|---|---|---|
| | | Y = 525000.0 | | | |
| 1938-1962 | -31.1 | -1.3 | 1962-1984 | -45.1 | -2.1 |
| 1962-1967 | 5.1 | 1.0 | 1938-1984 | -76.3 | -1.7 |
| 1967-1980 | -17.6 | -1.4 | | | |
| 1980-1984 | -32.6 | -8.2 | | | |
| Std Dev 4.0 | | | | | |
| | | Y = 525500.0 | | | |
| 1938-1962 | -45.8 | -1.9 | 1962-1984 | -44.3 | -2.0 |
| 1962-1967 | -1.3 | -0.3 | 1938-1984 | -90.0 | -2.0 |
| 1967-1980 | 27.5 | 2.1 | | | |
| 1980-1984 | -70.5 | -17.6 | | | |
| Std Dev 9.0 | | | | | |
| | | Y = 526000.0 | | | |
| 1938-1962 | -75.6 | -3.2 | 1962-1984 | -22.3 | -1.0 |
| 1962-1967 | 6.0 | 1.2 | 1938-1984 | -97.9 | -2.1 |
| 1967-1980 | 19.3 | 1.5 | | | |
| 1980-1984 | -47.5 | -11.9 | | | |
| Std Dev 6.2 | | | | | |
| | | Y = 526500.0 | | | |
| 1938-1962 | -58.3 | -2.4 | 1962-1984 | -103.0 | -4.7 |
| 1962-1967 | -7.4 | -1.5 | 1938-1984 | -161.3 | -3.5 |
| 1967-1980 | -38.9 | -3.0 | | | |
| 1980-1984 | -56.8 | -14.2 | | | |
| Std Dev 6.0 | | | | | |
| | | Y = 527000.0 | | | |
| 1938-1962 | -12.4 | -0.5 | 1962-1984 | -97.8 | -4.4 |
| 1962-1967 | 21.8 | 4.3 | 1938-1984 | -110.1 | -2.4 |
| 1967-1980 | -102.3 | -7.9 | | | |
| 1980-1984 | -17.3 | -4.3 | | | |
| Std Dev 5.2 | | | | | |

(Sheet 17 of 17)

# APPENDIX B

This appendix represents the volume of change (cubic yards/year) between time periods in the nearshore zone for each polygon. Each polygon extends from the land/water interface to 1,494,000 E or approximately 18- to 20-ft water depth International Great Lakes Datum. The "Y" distance for each polygon is 500 ft, except immediately adjacent to the jetties, centered about the midline coordinate.

| Mid-line Y Coordinate | Change in Volume, $yd^3$/year | |
|---|---|---|
| | 1965-1944 | 1984-1965 |
| 485000.0 | -4251.7 | -* |
| 485500.0 | -6703.2 | - |
| 486000.0 | -8734.5 | - |
| 486500.0 | -6281.9 | - |
| 487000.0 | -4759.5 | - |
| 487500.0 | -7772.9 | - |
| 488000.0 | -9444.6 | - |
| 488500.0 | -8709.1 | - |
| 489000.0 | -7955.5 | - |
| 489500.0 | -6210.2 | - |
| 490000.0 | -4812.2 | - |
| 490500.0 | -2152.5 | - |
| 491000.0 | -3407.7 | - |
| 491500.0 | -2715.5 | - |
| 492000.0 | -2482.2 | - |
| 492500.0 | -3327.9 | - |
| 493000.0 | -5263.5 | - |
| 493500.0 | -7369.8 | - |
| 494000.0 | -8089.3 | - |
| 494500.0 | -6139.7 | - |
| 495000.0 | -5084.1 | - |
| 495500.0 | -5616.2 | - |

(Continued)

* Data were not available.

(Continued)

| Mid-line Y Coordinate | Change in Volume, $yd^3$/year 1965-1944 | 1984-1965 |
|---|---|---|
| 496000.0 | -6587.5 | - |
| 496500.0 | -6639.1 | - |
| 497000.0 | -5915.3 | - |
| 497500.0 | -6142.2 | - |
| 498000.0 | -5573.2 | - |
| 498500.0 | -5642.2 | - |
| 499000.0 | -7583.9 | - |
| 499500.0 | -6776.8 | - |
| 500000.0 | -6290.0 | - |
| 500500.0 | -7421.0 | - |
| 501000.0 | -8486.0 | - |
| 501500.0 | -8447.7 | - |
| 502000.0 | -6119.6 | - |
| 502500.0 | -3475.8 | - |
| 503000.0 | -2123.2 | - |
| 503500.0 | -3487.3 | - |
| 504000.0 | -3435.1 | -2853.5 |
| 504500.0 | -2813.7 | -2676.3 |
| 505000.0 | -4296.8 | -1865.9 |
| 505500.0 | -3729.8 | -2038.9 |
| 506000.0 | -5831.8 | -4830.4 |
| 506500.0 | -3239.9 | -7781.4 |
| 507000.0 | -2119.1 | -2037.6 |
| 507500.0 | -321.1 | -1069.8 |
| 508000.0 | -856.9 | -3728.4 |
| 508500.0 | -2440.1 | -1289.6 |
| 509000.0 | -4543.6 | -3446.8 |
| 509500.0 | -6354.7 | -1287.5 |
| 510000.0 | -5621.8 | -3519.9 |
| 510500.0 | -5240.6 | -3107.4 |

(Continued)

(Sheet 2 of 3)

(Concluded)

| Mid-line Y Coordinate | Change in Volume, yd$^3$/year 1965-1944 | 1984-1965 |
|---|---|---|
| 511000.0 | -4419.4 | -4565.7 |
| 511500.0 | -4226.0 | -5671.4 |
| 512000.0 | -9636.6 | -2756.6 |
| 512500.0 | -10265.2 | 2033.4 |
| 513000.0 | -10175.8 | 2019.1 |
| 513500.0 | -10569.6 | 3212.0 |
| 514000.0 | -10244.9 | 2920.6 |
| 514500.0 | -5885.8 | 3218.9 |
| 515000.0 | -2062.4 | 3535.4 |
| 515500.0 | 1131.5 | 3791.2 |
| 515700.0 | 1011.8 | 1058.4 |
| 516650.0 | 821.7 | 1961.3 |
| 517000.0 | -7.8 | 2386.5 |
| 517500.0 | -1270.9 | 1903.7 |
| 518000.0 | -3127.9 | 3302.1 |
| 518500.0 | -3736.8 | -575.6 |
| 519000.0 | -3944.7 | 1082.3 |
| 519500.0 | - | 1121.9 |
| 520000.0 | - | -2920.6 |
| 520500.0 | - | 2431.0 |
| 521000.0 | - | 1221.7 |
| 521500.0 | - | 1663.1 |
| 522000.0 | - | 137.1 |
| 522500.0 | - | -566.2 |
| 523000.0 | - | -4098.0 |
| 523500.0 | - | 641.1 |
| 524000.0 | - | 3963.2 |
| 524500.0 | - | 2467.2 |
| 525000.0 | - | 1498.6 |

(Sheet 3 of 3)