HYDROLOGIC AND GEOLOGIC STUDIES OF A POTENTIAL POWER PLANT SITE ON SANDUSKY BAY

I. PROGRESS REPORT ON HYDROLOGIC AND GEOLOGIC STUDIES

by
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The Ohio State University

September 1973

II. GEOLOGY OF A PROPOSED POWER PLANT SITE ON SANDUSKY BAY

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April 1973

Prepared for
American Electric Power Service Corporation
Ohio Power Company

Submitted by
Center for Lake Erie Area Research
The Ohio State University
Columbus, Ohio

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I. PROGRESS REPORT ON HYDROLOGIC AND GEOLOGIC STUDIES

September 11, 1973

TO: Charles E. Herdendorf, Director
Center for Lake Erie Research

FROM: Vincent T. Ricca, Principal Investigator
Professor, Department of Civil Engineering

SUBJECT: 6 month Progress Report
Environmental Investigation of Potential Power Plant Site on Sandusky Bay - Phase II, Sub-Account RF 3584-C1, Hydrologic Studies.

In response to your recent request for a 6 month progress report on the above project I am submitting the attached materials. Although, the Phase II project has been underway for 6 months, if you recall, our involvement had officially begun with your letter of June 20, 1973 to Lester Stout of the Research Foundation.

Our work to date has mainly been with assessment of the situation, assignment of personnel to execute the various tasks involved and preliminary studies of the more salient and time consuming topics.

In view of this late start and summer absence of key personnel I feel that we have just begun to get the project under control.

I am pleased to say that we have progressed well on the more difficult aspects of the evaluation and the topics remaining are the more routine types which should be handled quickly when our faculty and students return later this month.

For matter of my convenience I will discuss progress on the key aspects of our role in the projects by using the material as we have assembled it in its preliminary state. Please bear in mind that this material is in its raw form and after further work and review only the pertinent aspects of it will be used in the environmental impact assessment.

The following are the major factors that are intended for evaluation in The Geology and Hydrologic Studies. As we have discussed, there will be an overlap or joint effort between us on our two portions of the work. Items not specifically handled by my group will be done by yours.

1. Review of other Power Plant Impact Statements on file
   a) Ascertain what subject matter and to what degree it was covered.
   b) See what pertinent questions were asked by reviewers and make certain there are investigated herein.

2. Analysis of flows in the Sandusky River for:
   a) Flood frequency
   b) Drought periods
   c) Flow duration studies and water yields

3. Sandusky Bay Stage Behavior
   a) Response to Sandusky River flows
   b) Effect of Lake Erie Seiches
   c) Removal of Cooling Tower Water

4. Pickerel Creek Watershed Study (major stream on proposed site)
   a) Site description, Land forms, Soils, Land use, etc.
   b) Surface and bedrock geology
   c) Climate
   d) ERTS Imagery
   e) Extrapolation to Sandusky Basin

5. Geology and Groundwater at the site
   a) Bedrock contours
   b) Surface geology
   c) Water table behavior
   d) Groundwater supply at the site, Aquifer characteristics yields, etc.

6. Evaluation of Special Features in the area
   a) Miller's Spring hole discharge
   b) Cavities and other subsurface anomolies

Work accomplished to date is along these lines:

1. Several field trips to the site to evaluate the situation and ascertain data collection locations and equipment needed.
   a) Particular efforts on:
      i. locating wells, springs, and other sources of data for piezometric monitoring of the water table
      ii. streamflow monitoring stations on site creeks and drainageways
      iii. Miller's Spring weir site
      iv. shoreline erosion and wave observation sites
      v. choosing a site for the Sandusky Bay surface level fluctuation gage

2. Visitation with the Ohio E.P.A. Power Plant Siting Commission
   a) Borrowed 5 previously filed impact statements for review and analysis of type of information generated.
   b) General discussion with personnel as to what information they seek in impact statements.

3. Collection of several Impact Statements from the A.E.C.
   a) Reviewed and categorized as to type of information sought.

4. Review and Analysis of literature on Seiches and Lake Erie Seiches.
   a) Background material and governing equation
   b) Lake Erie behavior
   c) Sandusky Bay behavior

Preliminary work on Seiches is included in the appendix A.

5. Pickerel Creek Watershed
   a) Geological and Hydrological description
   b) Extrapolation to Sandusky River watershed

Preliminary work on this study is included in theappendix B.

6. Geology and Groundwater at the site and surroundings
   a) Bedrock contours mapped
   b) Overlying surface deposits described
   c) Hydraulic properties and coefficient of the aquifer evaluated.

Preliminary work on this aspect is included in the appendix C.

7. Field data collection established
   a) Some of the required field data collection on the site has begun.

See data collection sheet in appendix D.

   b) Field installed equipment
      1. Sandusky Bay Stage recorder has been borrowed from the Ohio Geological Survey. A stilling well for the unit has been ordered. A site for the installation has been chosen.
      2. A temporary plywood weir for monitoring flows from the Miller's spring has been designed and is being fabricated. Permission for installation has been requested fron the Ohio Dept. of Natural Resources.
      3. Piezometric surface position gage for monitoring artesian well pressures on existing selected wells in the site area has been designed and is being assembled.

8. Thermal Imagery Mapping has been laid out and bids have been received from two firms. No decision will be made as to using this until some additional work is completed in the geology study portion.

Now that the new academic year will be underway shortly, our efforts on the project will increase. Professor Whitlatch will assist in analysing the Seiche behavior and the hydrology of the Sandusky River. Professor Mintzer will become involved with interpretation of the geologic findings. I will continue to coordinate the hydrologic aspect of the project and pay particular attention to the behavior of Sandusky Bay as to site flooding and water supply for the plant. Mr. Palombo will continue as a Graduate Student Research Associate working on the geological aspects and Mr. Lloyd will come on board as a Graduate Research Associate working on the hydrologic aspects.

PROJECT PERSONNEL AND AREA OF RESPONSIBILITY

Principal Investigator

Dr. Vincent T. Ricca
Professor, Department of Civil Engineering

Seiche Behavior

Dr. Earl Whitlatch
Asst. Professor, Department of Civil Engineering

Kenneth L. Smarkel
Graduate Student, Department of Civil Engineering

Thermal Imagery

Dr. Olin W. Mintzer
Assoc. Professor, Department of Civil Engineering

Geology and Groundwater

Dr. Wayne A. Pettyjohn
Professor, Department of Geology

Dennis Palumbo
Graduate Student, Department of Geology

Watershed Studies

Roy Koch
James Beasley
Graduate Students, Department of Civil Engineering

Hydrologic Field Monitoring

James E. Voegle
Research Technician, Center for Lake Erie Area Research

APPENDIX A

SEICHES AND THEIR AFFECT ON LAKE ERIE AND SANDUSKY BAY

SEICHES AND THEIR AFFECT ON LAKE ERIE AND SANDUSKY BAY

Objective

This paper will try to accomplish several goals. After defining a seiche it will explain several of the various causes of seiches. First it will take a theoretical approach then a more practical viewpoint will be taken. Finally some of the principles will be used to give an overview of what actually happens in Lake Erie and Sandusky Bay.

Definition

During the middle of the nineteenth century almost all prominent specialists in the field of lake mechanics turned their attention to seiches in lakes with much work being done on Lake Erie. The first person to actually express seiche in a formulation was Merian. His basic assumption was that seiches were formed by two waves of equal length passing through each other with equal but opposite velocities. For a uninodal seiche it was assumed that the waves were, from trough to trough, twice as long as the lake bed in which they were acting. As the waves passed through each other they created a standing wave.

Unlike surface waves, seiches are translatory in nature. From a great distance the surface of the lake would appear to slowly rise at one end while simultaneously lowering at the other end. An imaginary line can be drawn approximately in the middle of the lake bed at which there would be practically no vertical movement. All the movement at this line would be horizontal, hence the translatory nature.

Origin

Like all natural phenomena seiches must have some initiating force. Over the years many different natural forces have had seiches attributed to them. Today there are five accepted causes of seiches. In order of acceptance they are: wind set up; rapid air pressure change; barometric fluctuations; heavy precipitation; and seismic disturbances.

Wind movement has always been recognized as exerting a strong external force on the surface of water due to friction between the rapidly moving air particles and the water particles. As the water is horizontally moved across the surface of a lake it tends to pile up at one end of the lake. On a long shallow lake the effect is most pronounced. If the wind suddenly ceases or shifts direction the pent up potential energy is released and a seiche results (Figure 1).

A similar cause is heavy precipitation. If heavy rains or melt water suddenly is added to one end of the lake the level of the lake increases at that end due to storage capacity, much like a reservoir. As the lake re-establishes equilibrium, a seiche results.

A rapid change in barometric pressure at one end of the lake is very similar to increasing (or decreasing) the effective depth of the lake at that end. If the pressure change is continued for at least one half the period of oscillation and then suddenly subsides, a seiche is again created by the potential energy differential. A special case of this is barometric fluctuations. In this case as the water is pushed to one end the high or low moves to the opposite end of the lake and again reinforces the seiche that it started.

Seismic disturbances, like barometric pressure, can cause a seiche in two ways. In the first case one end of the lake is lifted causing the water to rush to the opposite end. In the second case the fluctuations of the lake bed have a horizontal velocity approximately equal to the velocity of the seiche wave, reinforcing the primary seiche.

Formulation

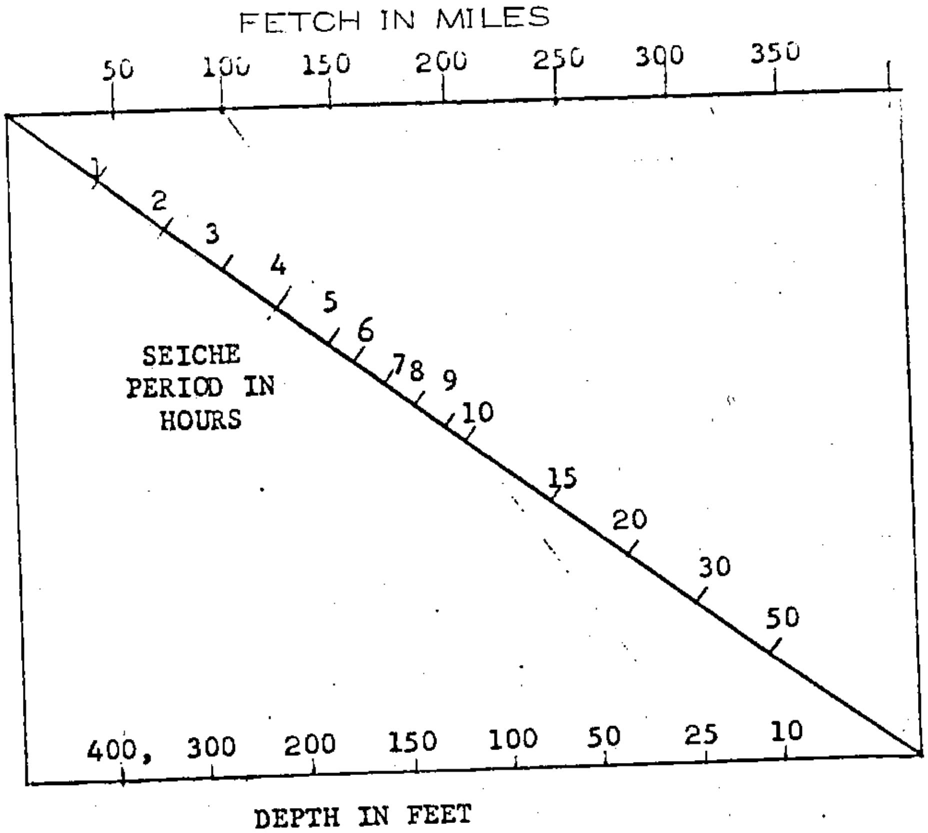
As was previously stated Merian was the first person to express seiches as a mathmatical formulation. He believed that the period of oscillation could be expressed as the time necessary for one of the two identical waves to travel twice the distance between the effective ends of the lake bed.

His formulation took this form:

$$T = \frac{2L}{(gh)^{1/2}}$$

T = period
L = effective length of the lake bed
h = depth of lake
g = acceleration due to gravity

This derivation assumes a lake of uniform cross section with a rectangular shape.



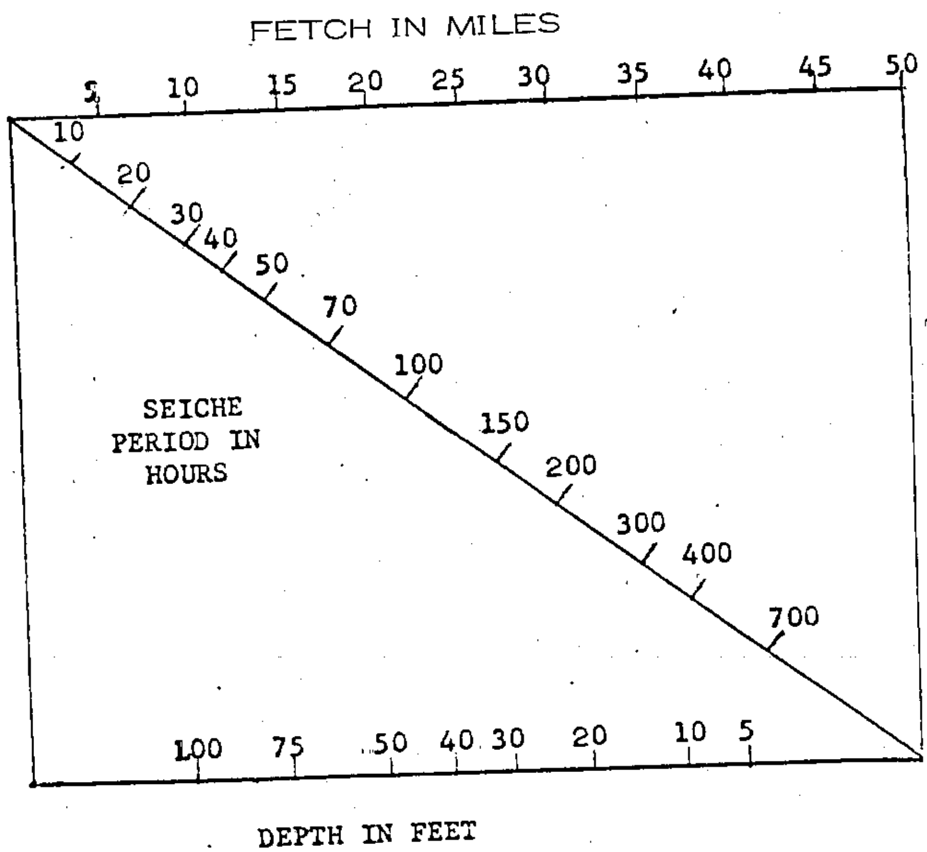


FIGURE 1. RELATIONSHIP OF FETCH, WATER DEPTH AND SEICHE PERIOD

The imaginary line that can be drawn across the lake at the point of no vertical movement is a node. The free oscillation of the lake is in some respects like all other forms of free oscillation and as such has harmonics coexistant with the primary mode. The primary mode has only a single node but there are also binodal, trinodal, quadrinodal,... forms of seiche. Merian's formula can easily compensate for the introduction of higher harmonics by the addition of a single term. Merian's formulation then becomes:

$$T = \frac{1}{n}\frac{2L}{(gh)^{1/2}}$$

n = number of nodes

Until this time the only seiche that has been discussed is the longitudinal seiche. It must be kept in mind that either independently of simultaneously a transverse seiche may be initiated and reinforced.

When the transverse seiche occurs independently the period may be calculated in the same manner as the longitudinal seiche with the substitution of the width "B" for the length "L." However, when there is a longitudinal and transverse seiche occurring simultaneously the result is quite different.

The seiche created, rather than longitudinal or transverse, is oblique in direction. The original Merian formula is altered to compensate for the two perpendicular components of the oblique seiche.

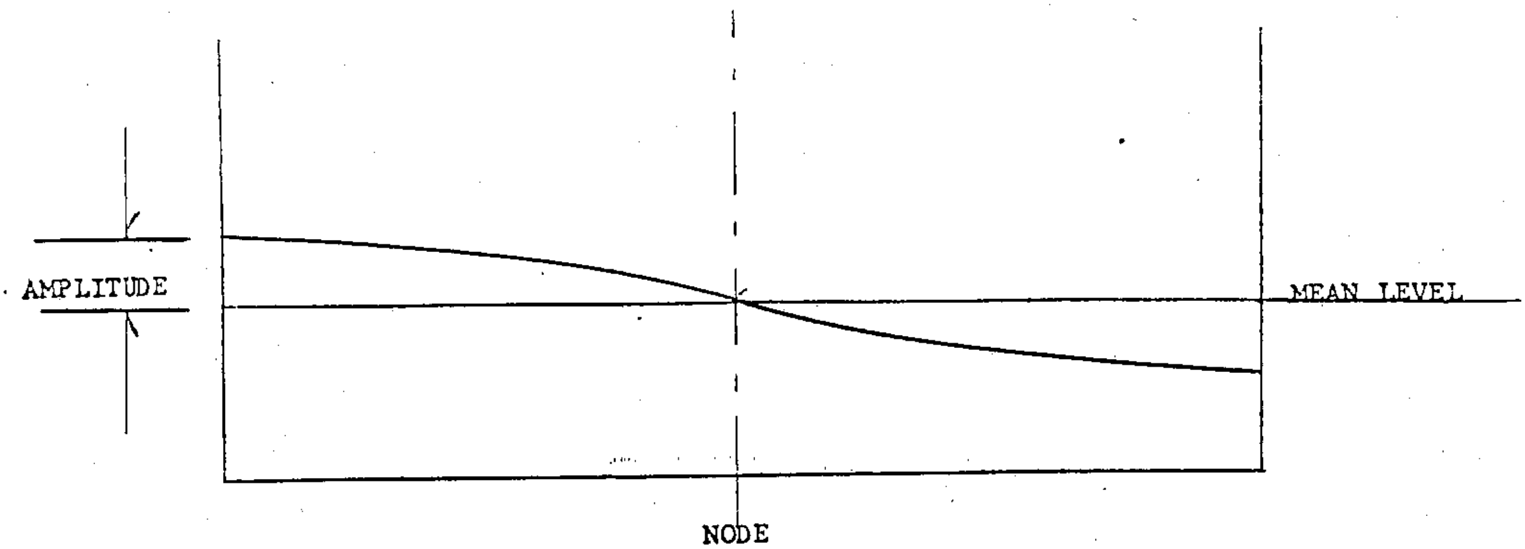
$$T = \frac{2L}{(gh)^{1/2}} \times [(\frac{B}{L})^2 m^2 + n^2]^{-1/2}$$

m = number of transverse nodes

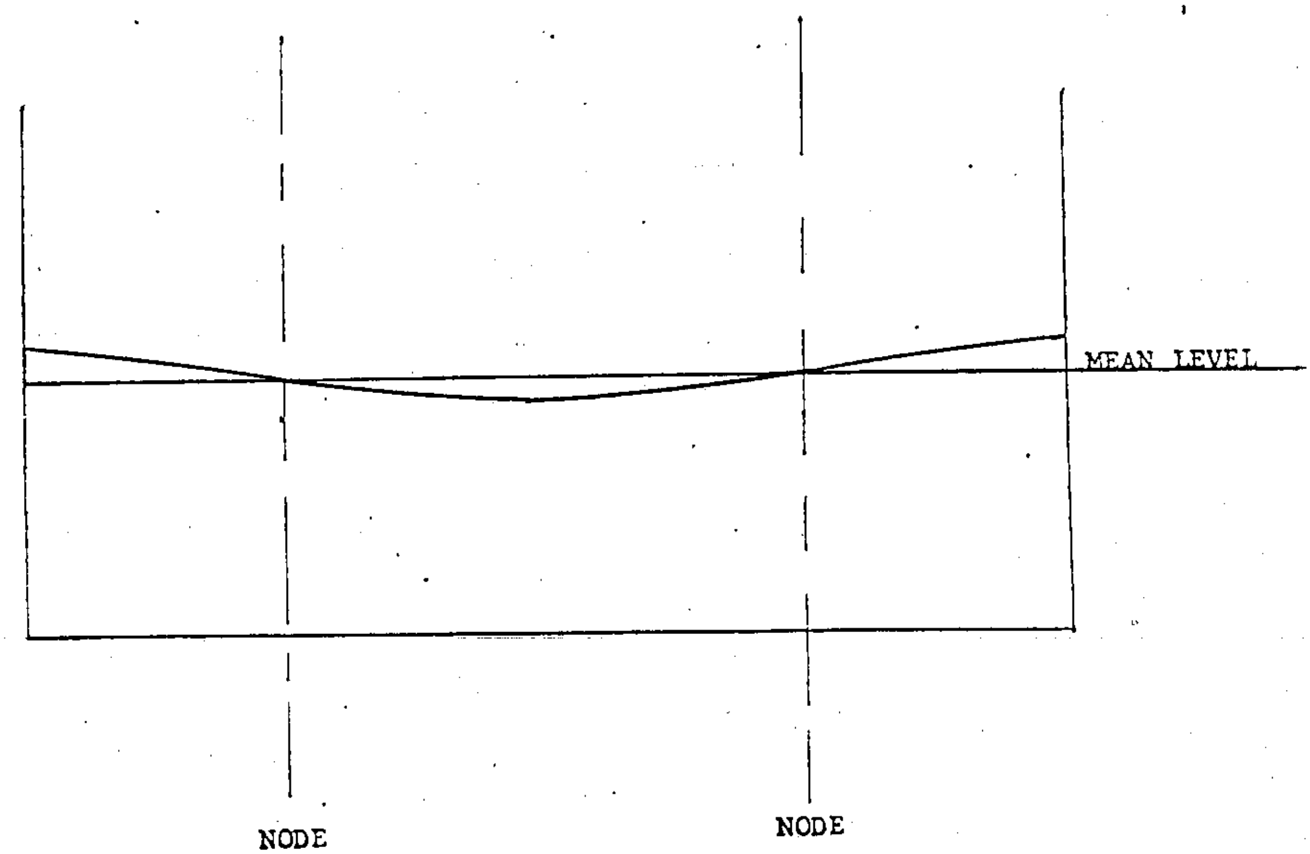
Application

Even though the Merian formula was originally derived for a rectangular basin of constant depth, it can be applied to an irregular basin with surprising accuracy. The only compensation necessary for the uninodal case is that since most lakes are not of uniform cross-section the average depth must be used.

A difficulty arises when the original formula is applied to the higher harmonics of an actual lake. The increased damping friction of the irregular shape becomes very prominent as the number of nodes increase (Figure 2).



UNINODAL SEICHE



BINODAL SEICHE

FIGURE 2. ILLUSTRATIONS OF A UNINODAL AND BINODAL SEICHE

Chrystal empirically determined a method of proportioning the multinodal seiches to the primary seiche periods. His formulation includes a dimensionless term "E" which is empirically obtained for an individual lake basin.

$$\frac{Tn}{T1} = [(1+E)/(n^2+E)]^{1/2}$$

Due to the irregularity of most lake basins there is no clear nodal line but rather a nodal zone. The nodal zone is the area over which the nodal line shifts.

Resonance

It has been found that is a semi-enclosed body of water is open on one side to a larger body of water that a resonance phenomena can occur. If the period of oscillation of the larger body of water is

$$T = \frac{4L}{s(gh)^{1/2}}$$

where s = 1, 3, 5,... the bay can resonate with the nodal line at the mouth of the bay. The number of nodes is

$$n = (s + 1)/2$$

with one node always at the mouth of the bay.

Lake Erie

Verber conducted several experiments to determine empirically the accuracy of the Merian Formula (Figure 3). For his first experiment he used a rectangular tank or uniform depth. After initiating a seiche with a glass plate he timed the period and found it to be in agreement with the period calculated by the Merian equation. He then modified the end and side slopes and again found the Merian formula to yield the same quantity as the observed results. In his last experiment he modified the shape of the tank to simulate the Lake Erie basin. He found from visual observations that the western basin of the simulated lake did not actually participate in the seiche. The Merian formula did verify his assumption, The only length that yielded the proper period of oscillation was the length excluding the western basin.

The reason that the western basin does not participate in the longitudinal seiche is the constrictions in line with Point Pelee and the shallowness of the basin. The western basin actually acts as

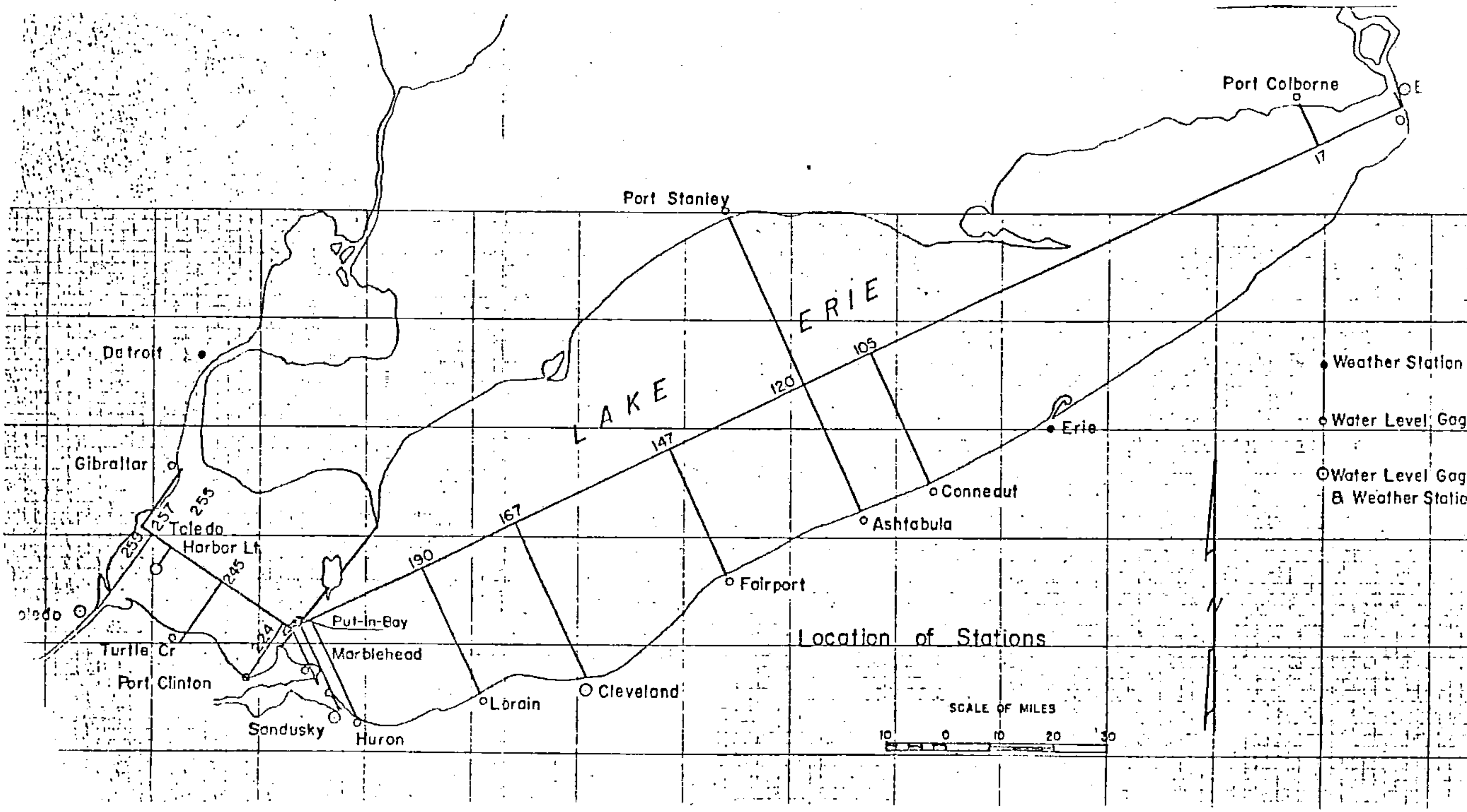


FIGURE 3. AXIS OF A LONGITUDINAL SEICHE ON LAKE ERIE

a runoff for the rising water during a seiche. As the water rises on the western end it surges through the southern channel then the water receeds and pours out of the western basin through the northern channel. This creates a circular motion in the western basin and deposits sediment on the east side of Point Pelee.

Sandusky Bay

The major rise and fall of Sandusky Bay is due to the primary seiche on the longitudinal axis of the lake. There is a secondary rise and fall within the individual basins which can be attributed only to the seiches within the respective basins.

Verber also made a model of the Sandusky Bay to determine whether or not a seiche could act over the entire basin. He found that at no time could a seiche started on one side propagate to the opposite side. This is due to the constriction at the middle. However, the water did tend to pile up at the constriction causing currents that in actuality sometimes attain a velocity of five miles per hour through the constriction (Figure 4).

Consequently even if the resonant period of the outer basin did occur it would not in all likelyhood affect the inner basin.

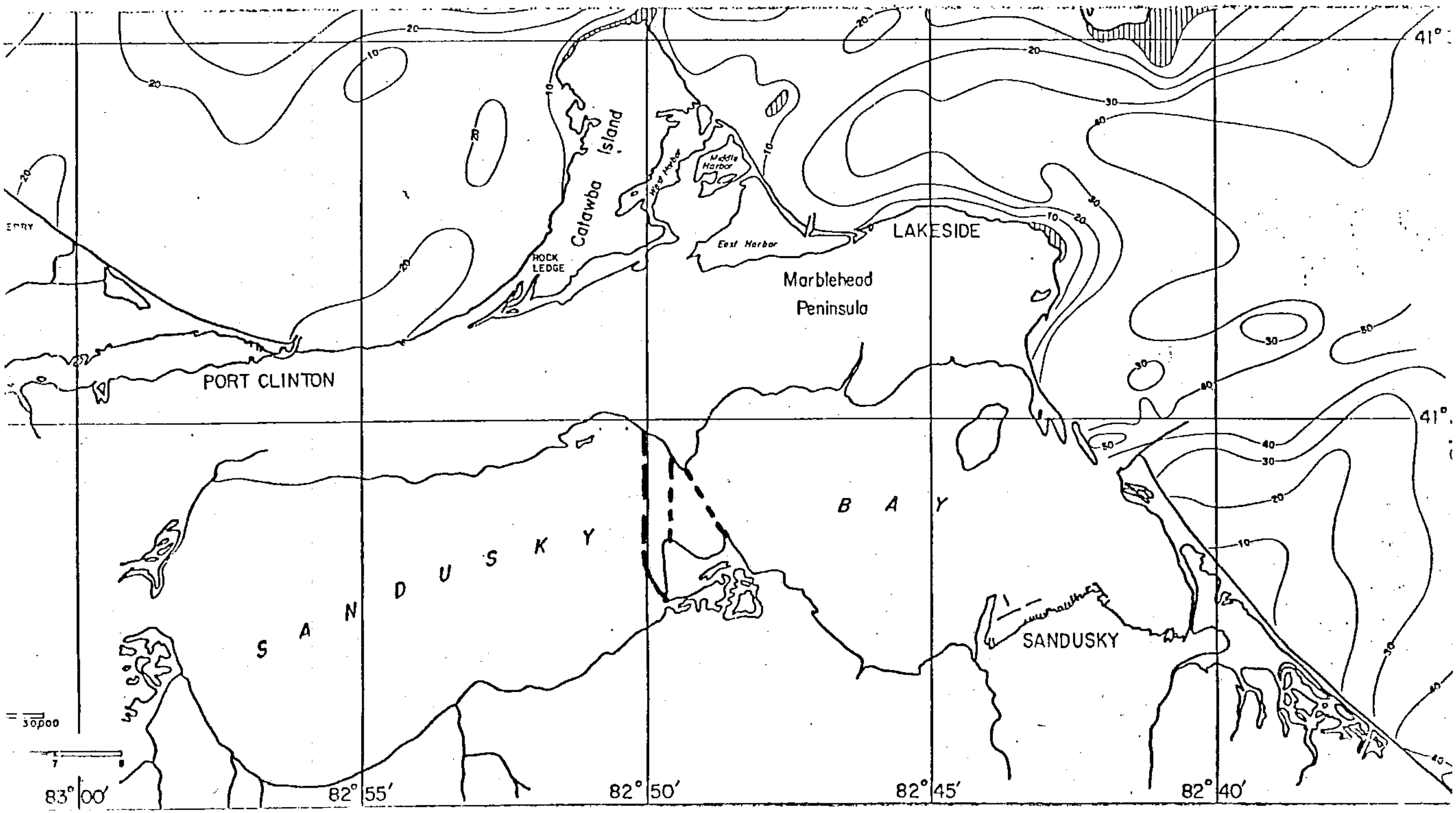


FIGURE 4. MAP OF SANDUSKY BAY SHOWING CONSTRICTIONS

References

Chapman, C. R. 1955. Sandusky Bay report. Ohio Division of Wildlife.

Hayford, J. F. 1922. Effects of winds and of barometric pressures on the Great Lakes. Carnegie Institution of Washington.

Hutchinson, G. E. 1957. A treatise on limnology. John Wiley & Sons.

Platzman, G. W. and D. B. Rao. 1963. The free oscillations of Lake Erie. Studies on Oceanography, Koji Hidaka, 1965. University of Washington Press.

Verber, J. L. 1959. Long and short period oscillations in Lake Erie. State of Ohio, Department of Natural Resources.

APPENDIX B

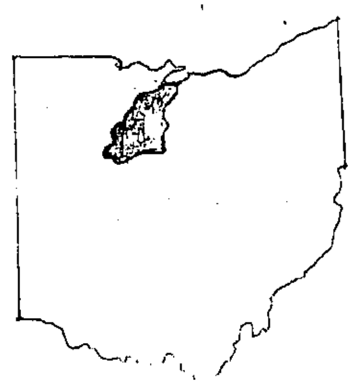
PICKEREL CREEK WATERSHED STUDY WITH IMPLICATIONS OF POSSIBILITY OF HYDROLOGIC EXTRAPOLATION TO SANDUSKY BAY

PICKEREL CREEK WATERSHED STUDY WITH IMPLICATIONS OF POSSIBILITY OF HYDROLOGIC EXTRAPOLATION TO SANDUSKY WATERSHED

DESCRIPTION OF THE AREA

Location

The Sandusky and Pickerel Creek watersheds are situated in the north-central part of Ohio (see location sketch). They border on Sandusky Bay to the north, which forms part of Lake Erie. The Sandusky watershed is far larger than the Pickerel Creek watershed. The drainage area of Pickerel Creek is approximately 3.26% of the drainage area of the Sandusky River. The Pickerel Creek Basin lies almost entirely in Sandusky County while the Sandusky Basin extends through Sandusky, Seneca, Wyandot, and Crawford Counties.



Location Sketch

Surface Geology

A large portion of these watersheds lies within the lake plain (see Figure 1, appendix A) of Lake Maumee. This plain is crossed to the southeast by three narrow, nearly parallel ridges, representing shore deposits laid down at successive stages of the receding glacial lakes known as Lakes Maumee, Whittlesey, and Warren (in chronological and volumetric order).

While the general slopes of the two watersheds are directionally similar, generally to the north and northeast, there is a dichotomy in rates of slope between the basins. In the Sandusky Basin the gradient along the Sandusky River, from head to mouth, is about 3.9 feet per mile. In contrast, the average slope of Pickerel Creek is 10 feet per mile.

While the area included within the old lake plain is in general level and often almost floorlike, there are some undulations and ridges rising 10 to 20 feet above the surrounding plain. Some dissection of the plain has taken place along the drainage ways, but for the most part erosion has been slight. Owing to the meandering sluggish nature of the major streams throughout most of their courses (see figure 2 and 3, appendix A), the streams flow only 10 to 30 feet below the general level of the plain. The short slopes bordering them, however, are quite steep. Narrow strips of bottomland occur along the larger streams and a few small terraces are found along the Sandusky River.

The gravel and sand beach ridges dissecting the watersheds are 150 to 200 yards wide and rise 20 to 30 feet above the adjacent lake plain. Associated with them are rounded sand dunes, frequently rising 30 or more feet above the general level. These dunes are most extensive along the outermost Maumee Beach, which is the oldest and contains a larger accumulation of sand and gravel (see figure 1, appendix A).

To the southeast the topography consists of level to gently rolling upland containing numerous small depressions or sinks. Part of this region is morainic and hummocky. Moving farther south in the Sandusky watershed, outside the southern boundary of the Pickerel Creek watershed, a curious shift in the direction of flow of the major streams occurs. These streams apparently defy the general northeasterly slope of the basin and flow in a direction slightly south of west (see figure 3, appendix A). This apparent anomaly is easily understood when one considers the subsoil of the area. These westerly flowing streams in Seneca, Wyandot, and Crawford Counties are underlain by a layer of corniferous (Columbus and Delaware) limestone (gray limestone layer in figure 4, appendix A), a particularly hard variety of limestone, which resisted the wearing effect of the glaciers. This limestone layer retarded the retreat of the glaciers and precipitated the deposition of morainic material. Since morainic deposition parallels the leading edge of a glacier, this material is stratified horizontally in an east-west direction. The divides between creeks in the area consist of these moraine accumulations, which, further west and at lower levels, are not sufficient to divert the drainage from the general course of the main valley. The westerly flowing streams experience an abrupt almost right angle change in direction within about 5 miles of the Sandusky. This unexpected occurrence is the result of the insufficient moraine accumulation mentioned above and is easily explained in terms of the underlying bedrock and its effect on the surface geology. There is a transition from the hard corniferous limestone to a somewhat softer waterlime or Monroe limestone which can be traced by the change in direction of the drainage. In general, this morainic belt and accompanying east-west drainage pattern extends south to the Continental Divide, the southern limit of the Sandusky watershed.

Bedrock Geology

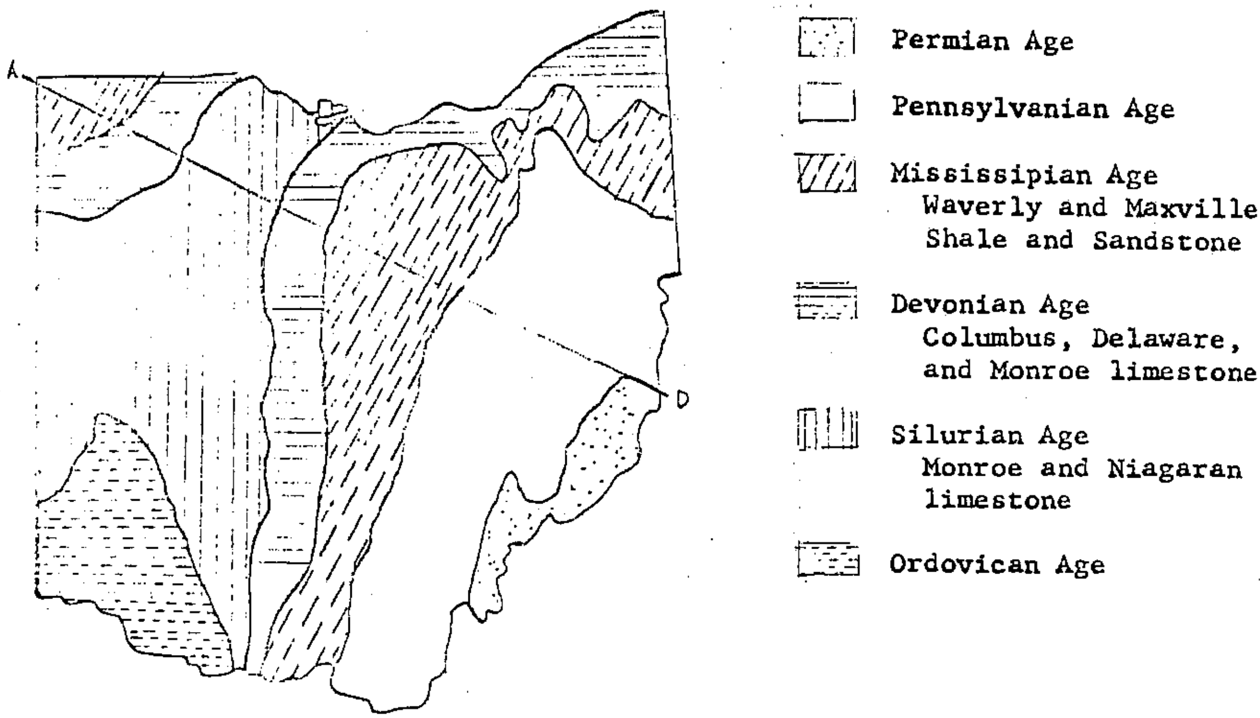
The importance of the bedrock geology within the Sandusky Basin is apparent in its effect on the drainage of the area. In addition, bedrock controls to varying degrees (1) the amount of rainwater that runs off on the surface, (2) the amount that infiltrates as groundwater, (3) the nature and type of material transported by streams, and (4) the foundation requirements for large structures. Furthermore, the bedrock itself may be of industrial value as in the case of the study watersheds. Items (2) and (4) are particularly applicable to the study basins also.

The bedrock underlying the basins is consolidated sedimentary rock deposited during the Paleozoic period when the entire area was inundated. These sedimentary rocks have been folded into a broad anticlinal structure called the Cincinnati Arch. The axis of the arch passes along the western boundary of the Sandusky watershed. The arch is composed primarily of limestones of the Mississipian, Devonian and Silurian ages (in order of decreasing elevation and hence increasing age). The bedrock involved in this fold dips east and west away from the axis.

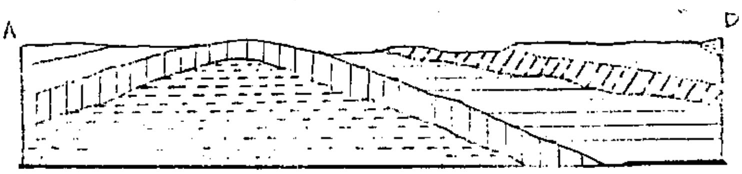
Outcrops of these various limestones are distributed from Mississipian in the southeastern parts of the watersheds to Silurian along the western boundary of the Sandusky Basin as shown in the sketch on the following page.

The Niagaran formations of Silurian age are predominantly dolostones and limestones with interbedded shales. The blue-gray crystalline dolomite and limestones are quite dense and fine-grained.

The deposition of the Monroe Group began during Silurian and continued into Devonian time. Typically dense dolomite and limestone are the predominant rock type, but thin-bedded anhydrite and shale are also present. The upper part of the Monroe Group, the Cayugan Series, contains gypsum and salt.



Bedrock Geology



Cincinnati Arch

The Devonian rocks may be divided into two groups. The Columbus and Delaware Formations are composed of limestone with chert and small amounts of fine sand and clay-sized material. The upper Devonian material of the Ohio and Olentangy Groups consists of gray to black carbonaceous and argillaceous shale with minor zones of siltstone.

The Mississipian rocks consist of shales and sandstones with minor amounts of conglomerate. The sandstones and conglomerates have a high porosity and usually make excellent farm and domestic aquifers if not contaminated.

Climate

The climate of the study area is the product of two physiographic features. The more significant of these is the large mass of relatively flat land west of the area. Less significant is the proximity of Lake Erie.

Weather moving across the relatively flat plain reaches and passes over these basins comparatively undisturbed by topographic irregularities. This airstream has the effect of a barrier which deflects the paths of high and low pressure centers on the principal storm tracks. Low pressure centers associated with maritime tropical air masses from the Gulf of Mexico region generally pass to the south and east. Continental polar air masses and the accompanying high pressure centers from Canada tend to be deflected to the northeast. This means that the subject basins are in the fringe areas of storms produced by both of these weather patterns. In large measure, this accounts for the fact that this is the area of least precipitation in the state.

The influence of Lake Erie is limited to a very narrow band along the lake shore. In this band the lake effect is limited to delaying the dates of maximum and minimum temperatures to a few days later than is usual in the remainder of the state, and to retarding warm weather in the spring until there is little danger of frost while extending the frost-free period in the fall. The frost-free period is 10 to 20 days longer particularly in the insular and peninsular parts of the area. By contrast, the effects of the lake farther east account for the fact that the annual average snowfall is double that of the study basins. This is a result of the movement of prevailing winds from land to lake along the western end of the lake, but from lake to land along the eastern lake shore.

The mean annual temperature in the subject area is 51.1° F with observed extremes in daily temperature of 110° F and -28° F. The number of frost-free days occurring annually ranges from 160 to 193.

The mean annual precipitation ranges from 32 inches along the lake shore to 37 inches near the southern edge of the Sandusky watershed.

ANALYSIS OF ERTS IMAGERY

Two images recorded by the Earth Resources Technology Satellite (ERTS) were studied in order to determine the gross regional features of the area. These images were both in the infrared range, one on band 7, the other on band 6. The water features in these images are shown as dark areas and accented from the surrounding lighter land. The moisture content of the soils is also evident from their tone.

The overall topography of the study area appears extremely flat with little or no relief evident.

There are two distinct linear features apparent on the images which appear lighter than the surrounding areas, indicating a low moisture content. The features are oriented in a northwest-southeast direction and extend into the study area. The hypothesis can be formed that these are beach ridges remnant from the ancient lakes, Warren and Whittlesey.

The area to the north of these ridges is clearly darker in tone than that to the south leading to the conclusion that the former is more poorly drained than the latter.

There are definite indications of a parallel to subparallel drainage pattern throughout the area. One feature of note with respect to the drainage is a sharp directional shift in the channel at about the 41st parallel. Above this line the direction is north while below the streams flow west.

Finally, there are indications that the land use is primarily agriculture owing to the tone pattern throughout the area and apparent absence of large cities

SANDUSKY BASIN ANALYSIS

In order to analyze the hydrologic performance of the Sandusky River Basin, it is necessary to derive an outflow hydrograph for the watershed. One method that has been applied, and is used in the Ohio State University version of the Stanford Watershed Model (OSU-SWM) is the Instantaneous Unit Hydrograph Method. This procedure synthesizes a unit hydrograph of an instantaneous rainfall by routing a time-area histogram through the basin.

Development of the Isochrone Map

To derive the required time-area histogram, the basin must first be divided into areas of equal flow time by equal time contours known as isochrones. This is accomplished by computing the flow time from various points along the main stream and its tributaries to the basin outlet. A formula, proposed by Kirpich for watersheds with an area greater than fifteen square miles can be used for computing the time of concentration at various points. This formula is:

$$T_c = 0.0078 \left[\frac{L}{\sqrt{S}} \right]^{0.77}$$

where T_c is the flow time in minutes

L is the flow length in feet, and

S is the channel slope in feet per foot

Taking the length from topographic maps, figure 5, appendix A was constructed and slopes were taken from it. The isochrone map, figure 2, appendix A, was constructed when equal flow times were plotted on the streams and lines were drawn connecting these points. The total time of concentration for the basin was found to be 120 hours, and since a six element isochrone was desired, the time interval was chosen as 20 hours.

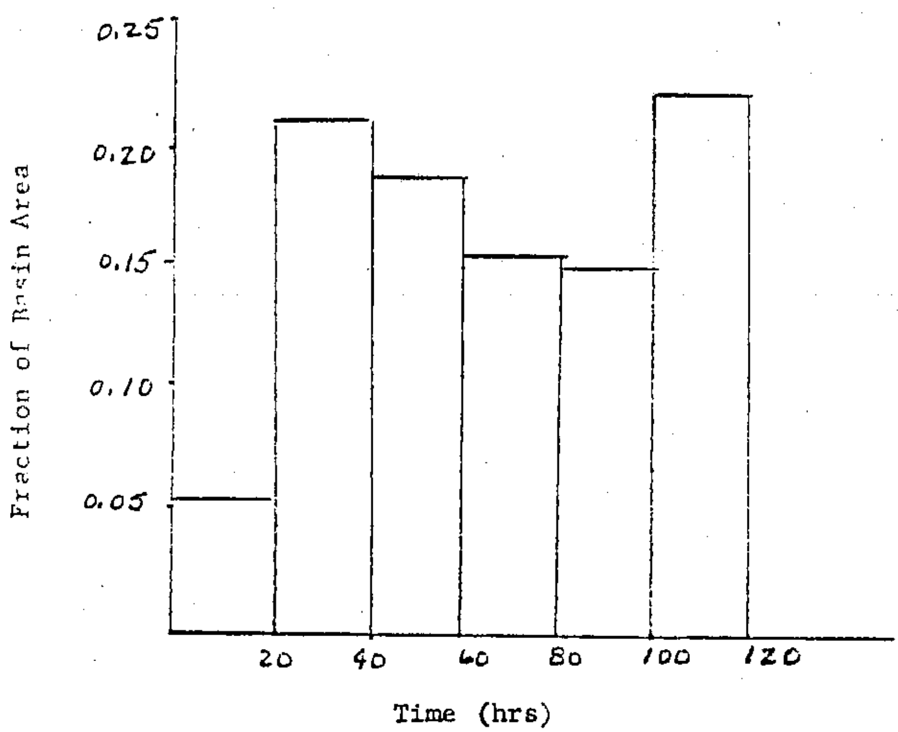
Development of the Time-Area Histogram

After completion of the isochrone plot, the area between each contour is planimetered to determine its area. These are then expressed as a fraction of the total basin area (Table 1) and plotted as a histogram

Time (hrs)	Area (sq mi)	Fraction of the Total Area
0 - 20	81	.057
20 - 40	304	.214
40 - 60	271	.191
60 - 80	225	.158
80 - 100	221	.156
100 - 120	317	.224

Table 1

with the ordinate as the fraction of the total basin area and the abscissa as time. This plot is shown below.



Time - Area Histogram for the Sandusky River Watershed

Development of the Instantaneous Unit Hydrograph

In order to determine the shape of the unit hydrograph associated with the time-area histogram, it is necessary to route this input through the basin to the outlet. Since the system is linear, this routing can be accomplished by piecewise routing and superposition of the separate results on the appropriate time scale. This will not be done due to time limitations, but some speculation can be made with regard to the possible outcome.

Since the input (the time-area histogram) has two distinct peaks, it is likely that the associated hydrograph will have two peaks. Their occurrence, however, will probably be lagged due to the attenuation of the flood wave in the channel storage. This resulting hydrograph would, however, represent an instantaneous input over the entire basin. Since the basin is so large (1420 square miles) and the time of concentration so great (120 hours or 5 days), it is unlikely that there will ever be a storm over the entire basin at the same time such that each area could contribute to form the derived hydrograph shape.

It can be seen, then, that one hydrograph could not be representative of all climatological situations over the basin. Storm characteristics such as duration, time-intensity pattern, and areal distribution will effect the shape.

PICKEREL CREEK BASIN ANALYSIS

Landforms

The Pickerel Creek watershed, like much of Ohio, has witnessed the advance and retreat of several glaciers during the Cenozoic Period. Therefore, it is not suprising that many of the present day landforms in the area are glacial or originally of glacial origin. Referring to Figure 1, appendix A, the location and extent of the various landforms have been noted for the area with aerial photograph coverage.

The large expanse of lacustrine plain (LB) in the upper half of the diagram is the remains of the glacial lakes, Maumee, Whittlesey, and Warren, which formerly covered the area. The beach ridges (BR) which dissect the basin are alluvial deposits of glacial till left along the shores of lakes Warren and Whittlesey during their reign over the area. The outermost beach ridge is that of lake Whittlesey and the remaining ridge nearest Sandusky Bay is the shoreline of former lake Warren. Sandy deposits from these beach ridges have been reworked by wind and now form stationary sand dunes (SD) near the beach ridges. So while this sand is of glacial origin it is now aeolian in nature. Similarly, the flood plain (FP) of Pickerel Creek while composed of glacial drift is now classified as fluvial material due to its most recent mode of deposition.

Between the beach ridges and extending south from the lake Whittlesey beach ridge a till plain (TP) or ground moraine landform exists. Because the till plain is underlain by a layer of limestone which has a noticeable effect on the drainage in some areas, these areas are noted by the symbol TP/LS.

Soils Map and Cross-Section

A general classification of the various soils throughout the basin can be inferred from the landform map. Associated with the lake bed one will find the usual assortment of sand and clay stratified horizontally and vertically. The coarser sand and gravel particles will settle out of the quiescent water first. This results in a convex layer of sand forming the base of the lacustrine deposit. The coarser sand and gravel particles will precipitate out of the water on first encountering the glacial lake, when the velocity of the stream carrying the particles is initially reduced. As a further reduction in velocity and turbulence of the water takes place on proceeding toward the center of the lake, progressively finer particles of material will be deposited. Eventually the fine clay particles will be precipitated. This entire general structure might be slightly modified later by wave and tidal action if the lake is large enough to be influenced by the moon, and has a fetch sufficient to generate appreciable waves. Furthermore, with the recession of the glacial lake, the erosive forces of nature take command and begin to modify the surface soils or A horizon. All of these processes have left their indelible fingerprints on the soil in the lake bed area. The soil profile (Figure 4, appendix A) stands witness, both literally and figuratively, to their relentless onslaught.

Moving out of the lake bed region to the south the evidence of tidal and/or wave action is indicated by the alluvial beach ridges. Characteristically beach ridges are composed largely of sand with some gravel and these beach ridges are no exception. Like the lake bed region farther north, these ridges were subsequently subjected to the erosive forces of nature after the recession of the lake. Numerous small stationary sand dunes bordering the beach ridges remain as monuments to the erosive power of the wind.

The portion of the basin covered by till plain has a very shallow soil mantle consisting of silts and clays with a predominance of clay. This till has followed the usual mode of morainic deposition with little or no stratification. Hence these soils are highly unstratified clays with an intermixing of minor amounts of silt, all of glacial origin.

In the extreme northwest corner of the watershed there is a flood plain of limited extent where soils of glacial origin have been sorted and laid to rest along Pickerel Creek. Due to the sluggish meandering nature of Pickerel Creek in the lower reaches of its journey through the basin, the materials deposited in its flood plain are necessarily of a very fine nature. Furthermore, due to the proximity and near equality in elevation of Sandusky Bay to the flood plain these soils are fairly moist. Hence the soil of the flood plain may be classified as a fine organic muck.

Overlying much of the basin is a thin layer of loam from 1 to 3 feet thick. This loam layer is a mixture of organic material mixed with the soil prevalent in the particular areas. Figure 6, appendix A and Figure 4, appendix A clearly show the loam surface layer and confirm most of the conjectures concerning the soil throughout the basin.

Land Use

The area within the boundary of the Pickerel Creek watershed has come under intense cultivation since ditches were constructed by the early settlers to drain the lands that were once swamp. This was only needed, however, in the lake bed region of the area where internal drainage of the soil is extremely poor.

In the beach ridge area of the watershed land uses are typical of the well drained soils present. Cherry and apple orchards are scattered throughout these regions, some being very sizable. Due to the well drained conditions, roads are built on the beach ridges. They provide excellent foundation materials and little fill or cut is required in the construction.

In the upper portions of the basin where the predominant soils are those associated with glacial till, agriculture is also the main land use. Although not on the photographs, several inactive limestone quarries are evident in the area on the topographic map. Only small communities have developed, the largest being Clyde immediately southeast of the area with a population of only several thousand.

Hydrology

From an inspection of the basin drainage map (Figure 3, appendix A) a difference in drainage characteristics is noted between the upper and lower Pickerel Creek watershed. The lower portion of the basin exhibits some parallelism in its natural drainage and man-made ditches are prevalent. In the upper basin there is a noticeable lack of drainage with the exception of a few man-made ditches.

This change in drainage pattern seems to be coincident with the land form change noted in Figure 1, appendix A. The lower portion of the basin lies in the lake plain area and is a remnant of the ancient glacial lakes that once covered the area. Since the soils associated with such an occurrence are fine grained, i.e. clays and fine silts, it can be expected that the soil will have a very poor infiltration capacity and that most of the incoming precipitation will either run off or be ponded in low lying areas to slowly evaporate and infiltrate. What moisture does infiltrate and percolate through the soil could form a perched water table on the sand and gravel lenses that are present throughout the area. These are seen in the soil cross section, Figure 4, appendix A.

The upper basin, with its definite lack of any developed surface drainage, must exhibit better subsurface drainage than the lower portion. This section of the basin is underlain by limestone and dolomite covered by only a few feet of glacial till. The many depressions in this area of the watershed seem to indicate that most of the incoming precipitation is delivered directly to the ground water. The limestone and dolomite can transfer this water through fractures, solution channels, and along bedding planes providing adequate, although chemically hard, water to areas in the lower basin.

The subsurface hydrology is by far the most important in this basin and produces several very interesting effects. From the soil profile, Figure 4, appendix A, it can be seen that where the greatest amount of water enters the bedrock aquifer, in the upper basin, the elevation is much higher than the lower basin areas. This leads to artesian conditions in many wells penetrating this aquifer in the lower portion of the watershed. Miller's Blue Hole, (see Figure 1, appendix A) is a natural spring which lies on the boundary of the Pickerel Creek watershed. It is fed from the above mentioned aquifer, but the water is then diverted out of the basin through an apparent man-made channel. The fact that Pickerel Creek is a perennial stream is also due to the underlying artesian conditions of the ground water in the upper basin.

Effects of Development

Development of the Pickerel Creek watershed could have some significant effects on the hydrology of the area, particularly in the upper portion of the basin. Since development, in particular urbanization, is usually accompanied by paving and storm sewer systems, there would most probably be a marked decrease in the amount of water allowed to infiltrate and recharge the underlying limestone aquifers. It is not known exactly ~~the~~ which area ~~that~~ is responsible for the recharge and, therefore, impossible to say how significant an effect urbanization would have on the ground water recharge. If, however, the lower portion of the basin is fed by subsurface water from the upper portion, the water supplies in the lower portion could be cut substantially as would the streamflow since it is sustained for the dry portions of the year by baseflow from the ground water.

Another effect would be increased run off at a higher rate than presently noted, this water being conducted directly to streams and ditches would increasing flood peaks in the lower basin area.

As well as effecting the hydrology, development in this basin, particularly the upper reaches might be discouraged due to the underlying limestone which is prone to forming solution cavities and eventually sink holes. This situation is not notably present in the lower reaches and, since those areas near the bay will not affect the hydrology significantly, it would be advisable to select a development site in that area if such plans are proposed. One feature that must be considered, however, in lakeside development is the possible flood hazard noted in the last few years in that area.

The above comments are admittedly qualitative and further study would be required in order to make any firm statements, especially about the hydrology. One method that might be used in such an in-depth study is the Ohio State University version of the Stanford Watershed Model (OSU-SWM).

Possible Problems in Basin Modeling

If an attempt were made to model this basin using the OSU-SWM, some difficulty might be encountered in estimating two of the ground water parameters. LZSN, defined as the soil moisture storage index and approximately equals the volume of water that may be stored in the soil between the ground surface and the water table, might be extremely difficult to estimate since the ground water conditions become artesian in the lower portion of the basin overlain by a nearly impervious clay layer.

One other ground water parameter, K24L, indicates the fraction of moisture lost or diverted from active ground water storage through subsurface flow across basin boundaries. Since Miller's Blue Hole is known to discharge anywhere from 1000 to 3000 cubic feet per second, it would have to be determined what portion of this flow was being contributed from the upper Pickerel Creek basin. Another approach to the problem would be to adjust K24L until simulation was accomplished by trial and error. This would most probably give a fairly accurate indication as to how much water was being lost through the spring.

One further parameter which may need adjustment is SDIV, defined as the average streamflow diverted into or out of the basin. Since much of the drainage in the lower portion of the basin is artificial, there are ditches either entering or leaving the basin as can be seen in Figure 3, appendix A. The flow carried in these ditches as well as the direction, i.e. in or out of the basin, would have to be determined. This may, however, prove to be an insignificant amount.

CONCLUSIONS

Extrapolation of Data to the Sandusky Watershed

From the information collected in this study it seems unlikely that hydrologic data gathered from the Pickerel Creek Watershed could successfully be extrapolated to the Sandusky River Basin. There is first of all an extreme size discrepancy, Pickerel Creek being only 46 square miles while the Sandusky Watershed is over 1400 square miles. Further, there are land forms present in the Sandusky Watershed that are not evident in the Pickerel Creek area. The moranic terrain of the upper Sandusky basin has relief much in excess of any found in the vicinity of Pickerel Creek.

Although it is not certain~~ly known~~, it can be surmised from the geological data on the area that the southeastern portion of the Sandusky Watershed is underlain by materials of the Mississippian age, principally shales and sandstones, subject to much different subsurface hydrology than the Pickerel Creek area. Further, a greater portion of the Sandusky basin lies within bedrock of the Silurian age, a much harder rock than the Monroe which covers much of the Pickerel Creek basin.

In general, the only portions of the Sandusky Watershed that might be thought analogous to Pickerel Creek are the lower reaches of the Sandusky and Green Creek. If more time were available for analysis, however, more similarities between the two basins might be discovered.

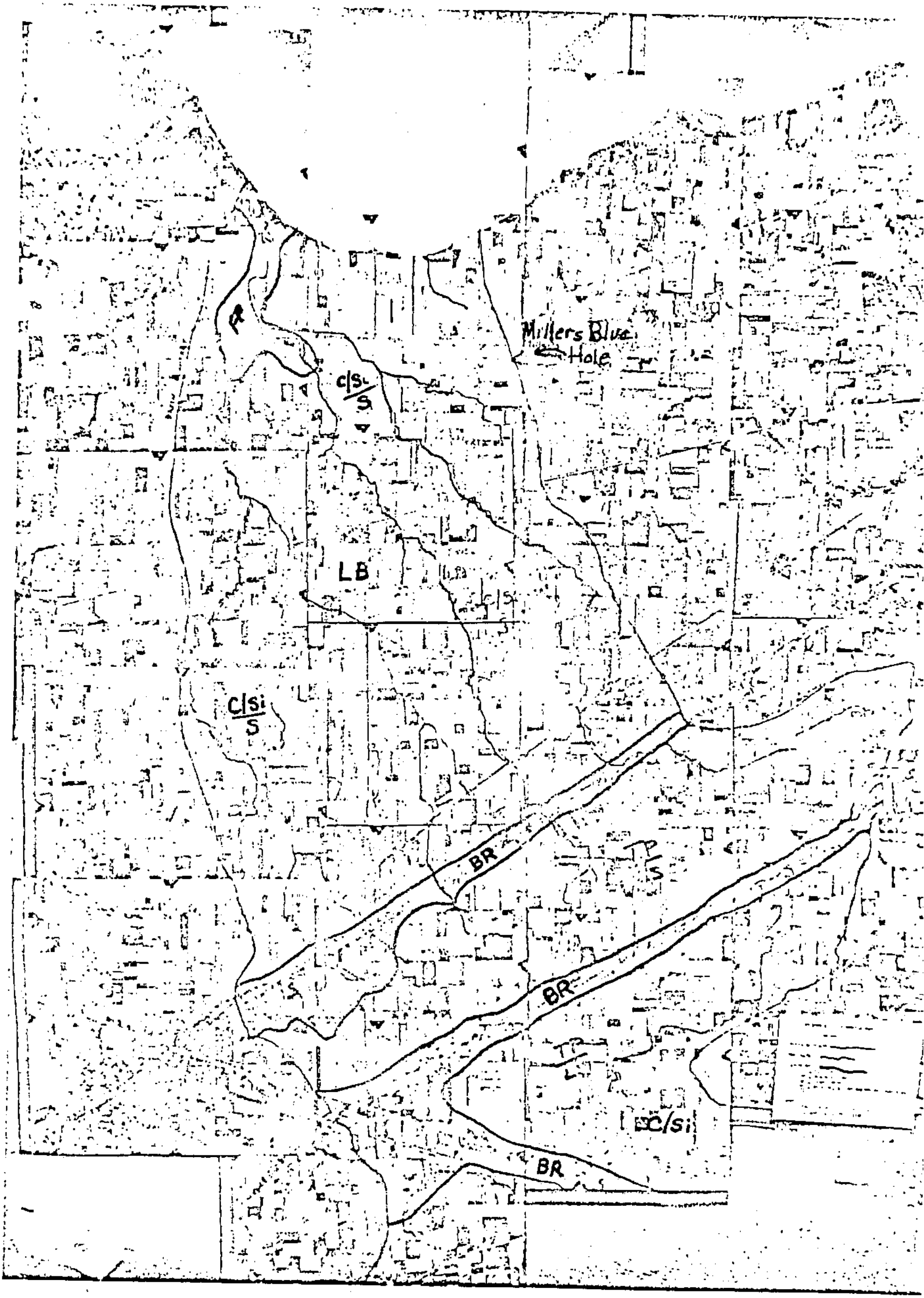
Effectiveness of ERTS

In this study ERTS did not prove to be a very effective tool. Except for the limited data presented in a previous section, nothing was determined from the images. When viewed at a scale of 1:1,000,000 it was impossible to even determine the course of Pickerel Creek and the upper reaches of the Sandusky River were only barely discernible.

It is possible that with a blowup of the imagery, more information such as those areas influenced by bedrock and the nature of the influence might be obtained. If such analysis were possible, the conclusions on extrapolation could well be reversed, but with the limited equipment available for viewing the images, no such conclusions were drawn.

A P P E N D I X

FIGURE 1. ERTS IMAGERY



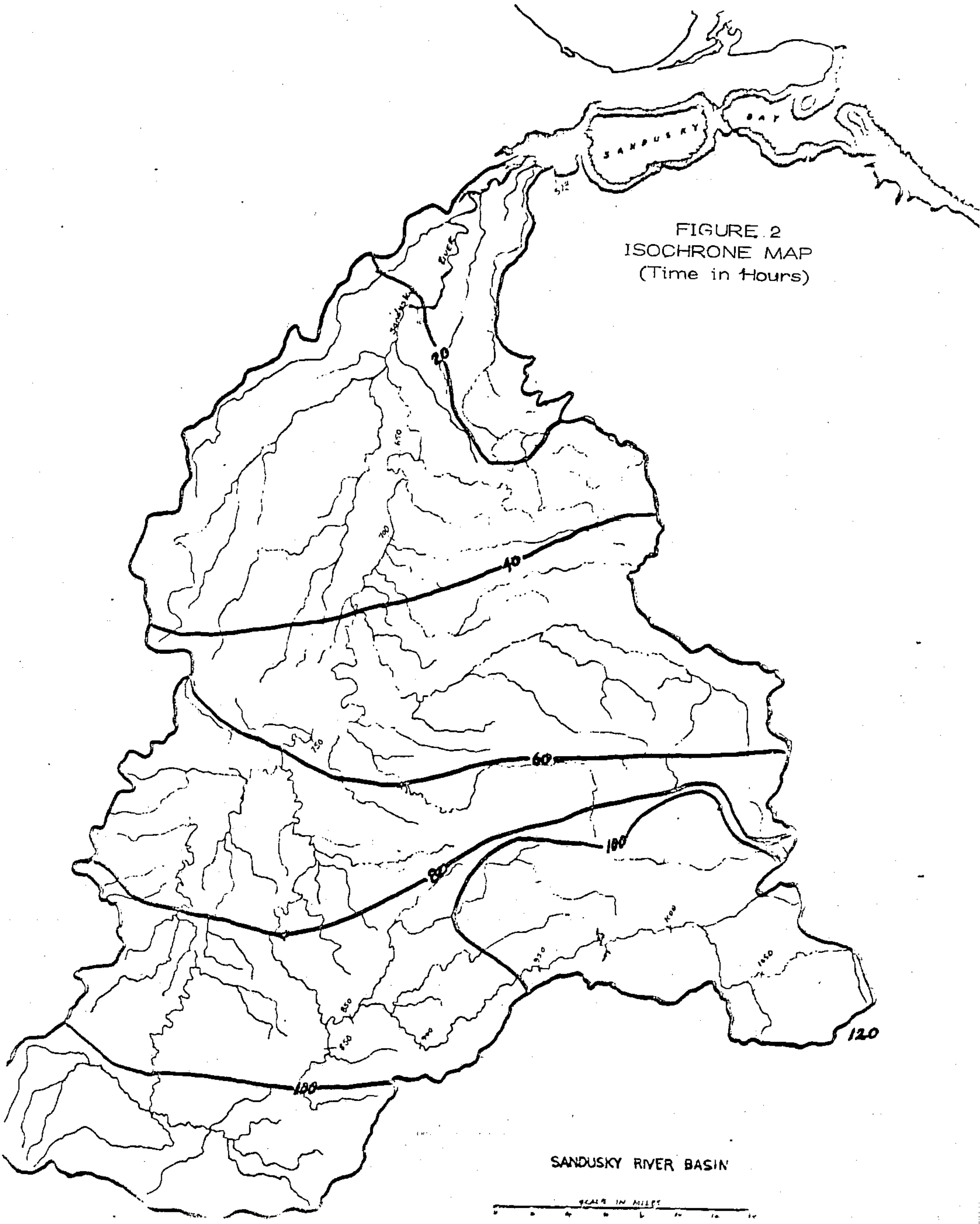


FIGURE 2
ISOCHRONE MAP
(Time in Hours)

FIGURE 3
DRAINAGE DIAGRAM FOR
THE
PICKEREL CREEK WATERSHED

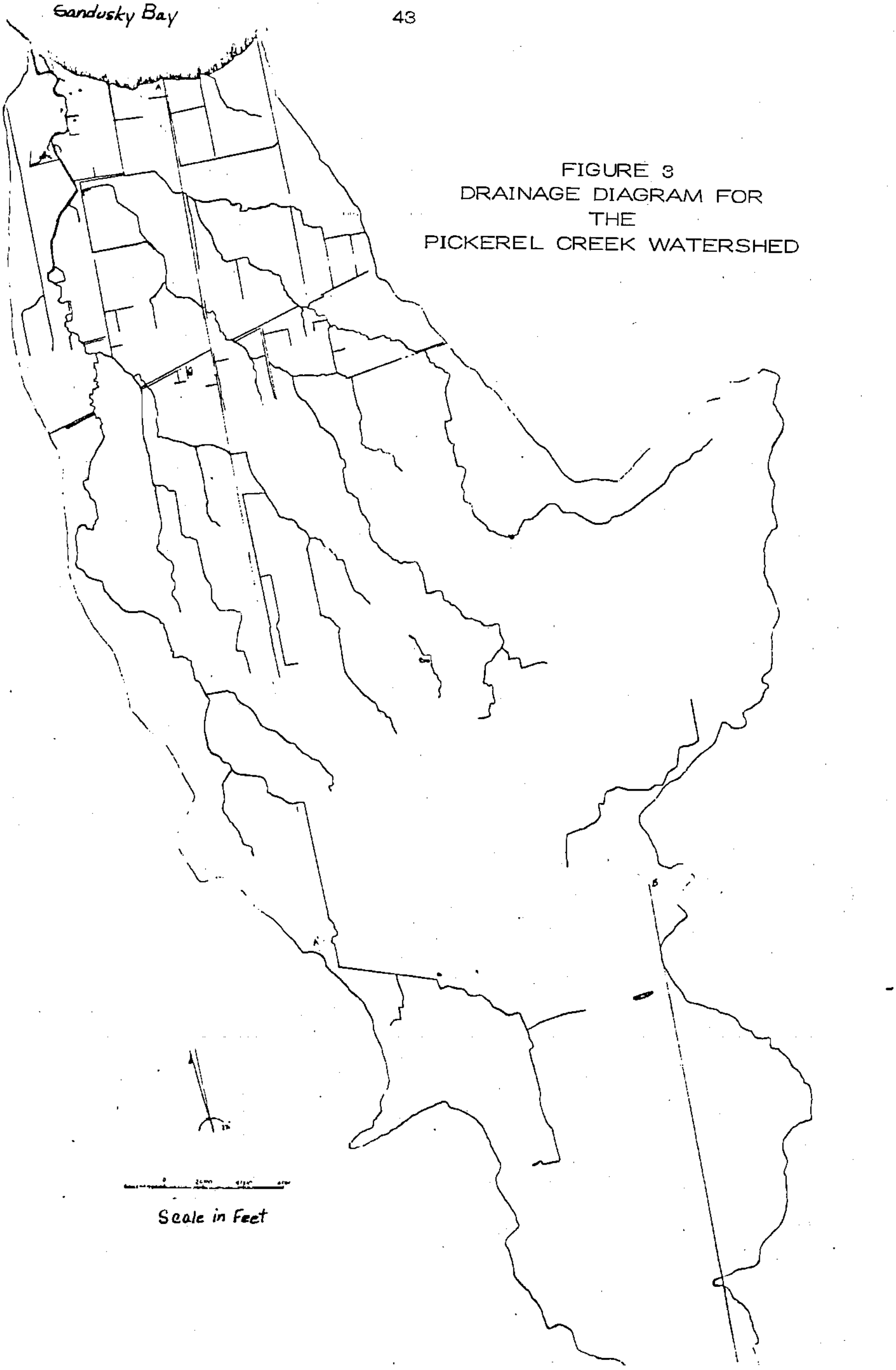
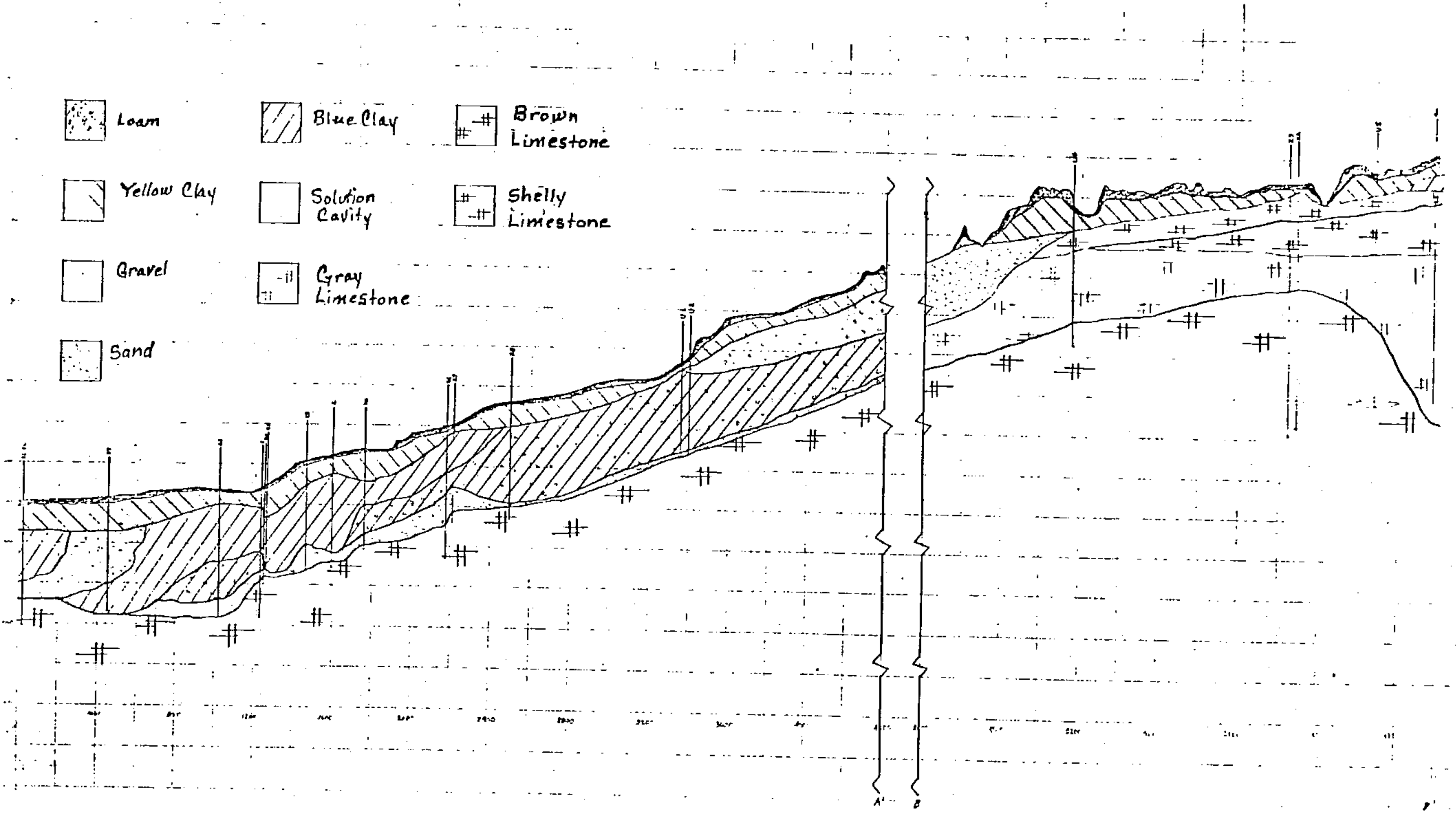


FIGURE 4. SOIL PROFILE



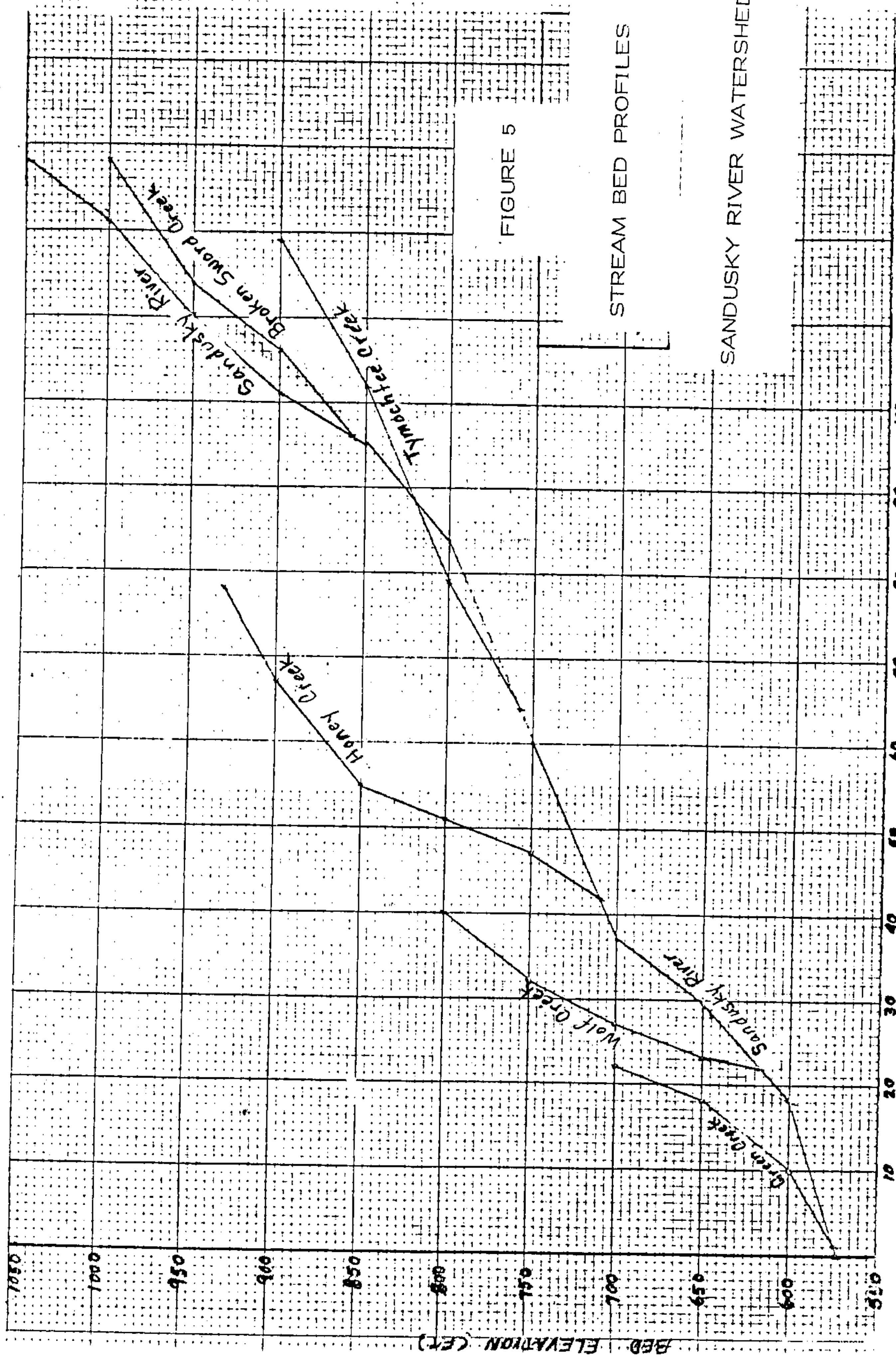
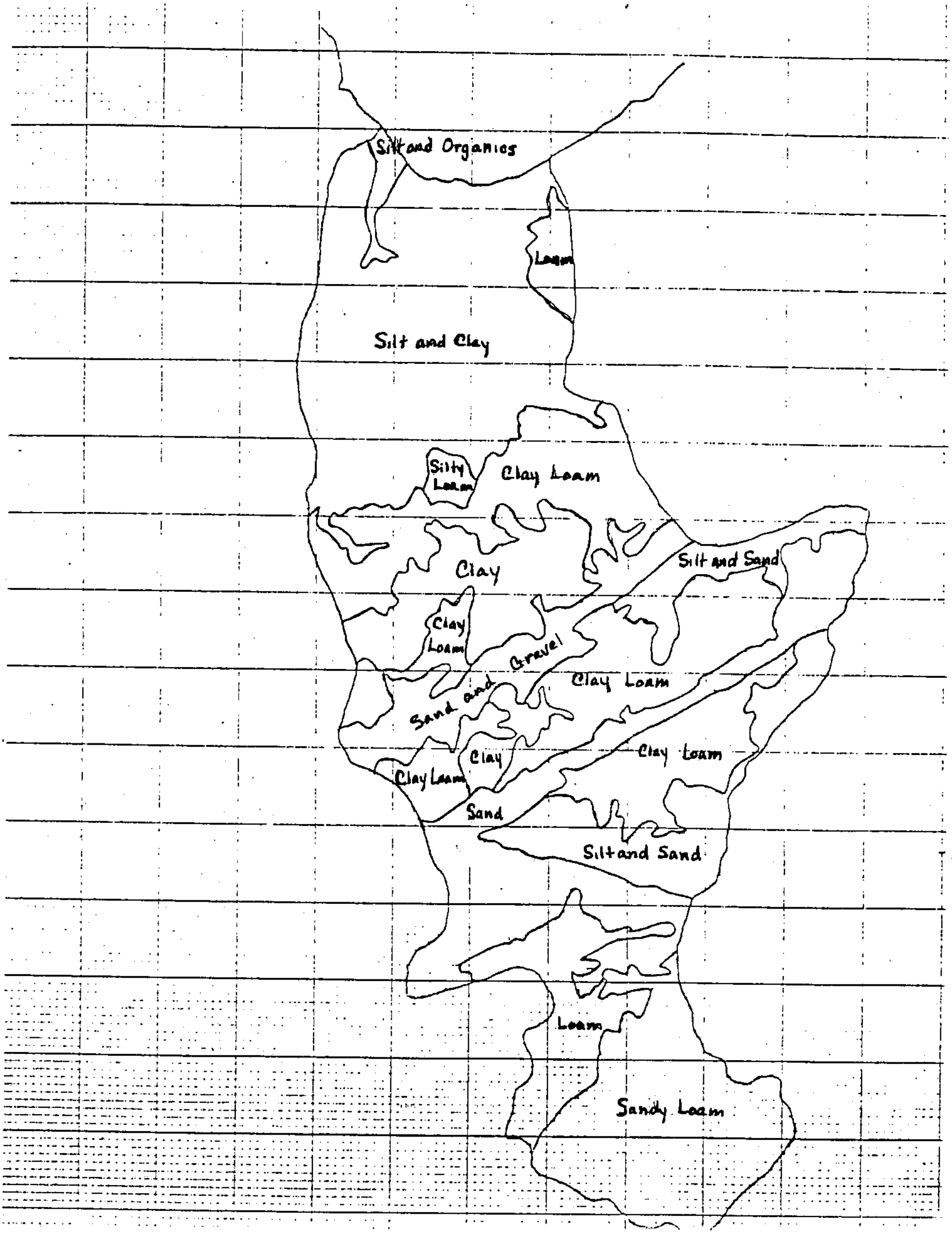


FIGURE 5

STREAM BED PROFILES

SANDUSKY RIVER WATERSHED

FIGURE 6. SOIL MAP FROM LITERATURE REVIEW
(after Allen, E. K. et al)



APPENDIX C

PROGRESS REPORT ON INVESTIGATIONS OF GEOLOGY AND GROUNDWATER FOR THE SANDUSKY BAY PROJECT

PROGRESS REPORT ON INVESTIGATIONS OF GEOLOGY AND GROUNDWATER FOR THE SANDUSKY BAY PROJECT

Activities

During the first months of study of the proposed nuclear power plant site on Sandusky Bay, attention was given to a literature review on available geologic and hydrologic information of the area. It was also necessary to begin to familiarize ourselves with literature concerning the construction and operation of a nuclear plant, so we can predict its impact on the geology and water resources of the surrounding region. Several environmental statements of other nuclear power plants have been reviewed as a guide for determining the basic geologic and hydrologic parameters needed for an impact study of a proposed site.

Although there has been no extensive groundwater study done on the site itself, many regional studies have discussed portions of the area which may give a helpful insight to the area's general groundwater picture. An important consideration when undertaking any groundwater study, is the surface water characteristics, such as drainage patterns, stream hydrographs, and seepage runs. These studies can be instrumental in determining permeability rates and recharge areas. It was for this reason that reference was made to published works on the Sandusky River, the Portage River, Pickerel Creek, and other tributaries of Sandusky Bay. This information coupled with our own findings should be sufficient to make some conclusions concerning the plant's impact on groundwater resources.

Most of the general geologic facts of the area have been discussed in several published reports. These include information on historical geology, structural geology, stratigraphy, geomorphology and other geologic aspects. As in the case of the groundwater studies, the geology reports are written on a regional basis and do not concern themselves explicitly with the proposed site. At the present time geologic data is being collected from test borings on the site area.

Other pertinent facts on geology and hydrology that are needed but have not yet been reviewed are data pertaining to well logs, water levels, auger probes, seismic refraction surveys, chemical analyses of rock, sediment, and groundwater, and piezometer measurements.

Findings

While studying the geology of the site area during the first few months of the project, some interesting facts were found. After plotting the well logs that were obtained and drawing a bedrock contour map, I have noticed a pronounced buried valley which runs through the site and out into the bay. There is also another buried valley that shows up just east of the site. These valleys, depending on the character of their fill, can be potential areas of high groundwater yield. In this case, previous studies have indicated only variable amounts of sand and gravel in these valleys, most of the fill being composed of lacustrine clay. Therefore we can only expect locally high yields in the fill.

Other features noted in the general area by the use of bedrock contour maps are former beach ridges locatednortheast of the city of Clyde, Ohio. They run northeast-southwest through the city. In the area of these beach ridges are located sand and gravel deposits. These permeable deposits, which underlie a thin layer of lake clay, are rather loose in texture and therefore transmit water readily to the underlying rocks. Recharge for the dolomite bedrock is derived then from precipitation falling directly on this sandy area. Because of the flow of underground water toward the bay, the recharge water from the Clyde-Bellevue area flows northward into the site area (the general assumption that the water flows north shall be substantiated when additional data becomes available). So recharge for the dolomite on the site comes from northward flowing water from the beach ridge recharge area, and also from areas on the site where the bedrock is covered by only a thin veneer of glacial drift.

The beach deposits noted in the above discussion is probably the reason accounting for the fact that the Clyde-Bellevue area has no surface drainage. The deposits, which are very permeable and thus allow water to infiltrate easily, are formed by the beach ridges of three former glacial lakes. These lakes are known as Warren, Whittlesey, and Maumee. In this partiuclar area, the proximity of the three beaches and their permeable deposits accounts for the absence of surface drainage.

A considerable amount of time has been spent on the hydraulic properties of the site with particular attention given to an extimation of the transmissibility of the dolomite aquifer. The transmissibility or T of an aquifer is a measure of the movement of water through the entire thickness of the aquifer. The importance of T in our study is that it serves as a basic tool in determining the maximum yield of an aquifer, in case the power plant needs groundwater to supplement its supply from the shallow Sandusky Bay. Also T is needed to predict the effect of the plant's pumpage on other wells and springs in the vicinity.

The best way to determine T is by a pumping test. This is a test of the response of an aquifer when pumping water out at a partiuclar rate. Unfortunately there are no pumping tests on file with the Ohio Division of Water for any wells on the site area. The only information available to estimate the transmissibility for the site area are some specific capacity data from some wells just outside the area. The method used for the T approximation from the specific capacity was taken partly from Ogden, 1965. It involves a rearrangement of Theis' non-equilibrium equations for a non-leaky artesian aquifer. Theis' equations

$$s = \frac{114.6Q\ W(u)}{T} \qquad \text{where} \qquad u = \frac{1.87r^2S}{Tt}$$

are rewritten as:

$$T = \frac{114.6Q\ W(u)}{s} \qquad \text{and} \qquad T = \frac{1.87r^2S}{ut}$$

Then the two above expressions for T are equated and solved for uW(u).

$$uW(u) = \frac{1.87r^2Ss}{114.6Qt}$$

Where Q = discharge, in g.p.m.

s = drawndown, in feet

T = coefficient of transmissibility, in g.p.d. per foot

S = coefficient of storage, fraction

r = distance from the pumped well, in feet

t = time after pumping started, in days

W(u) = well function

All variables on the right hand side of the equation can be determined except S, which we will assume. After we have determined uW(u), we must construct a table and or graph of uW(u) versus u from previous tables of u versus W(u) and then find a corresponding u. We substitute u into the following equation and solve for T.

$$T = \frac{1.87r^2S}{ut}$$

The value that we have calculated for T may or may not be a good estimate. In our particular case, after comparison with known T's in the area (values obtained from the Ohio Division of Water), it was found that by use of this method, T is consistently about 65% too large. This value of 65% was determined by finding the T of wells in the general vicinity of the site from information at the Division of Water. Then this T was compared with the T found from our above method. It was noted that the T value calculated from our method was about 65% larger than the value from the Division of Water. Therefore since the closest well to the site (about 10,000 feet southeast of the site) is located in the same area as those above, the T should then be multiplied by 0.65 to obtain a value corresponding to the work of the Division of Water. This fraction is a correction factor for the area's hydraulic characteristics is reference to our particular method. The following calculation is my calculation for T from specific capacity data on a well 10,000 feet southeast of the site:

Q = 60 g.p.m.

s = 17 ft.

t = 2880 min. or 2 days

r = 0.33 ft.

S = 0.0002 (assumed value for artesian conditions)

$$uW(u) = \frac{1.87(.33)^2(.0002)17}{114.6(60)2} = 4.7 \times 10^{-8}$$

by the graph $u = 2 \times 10^{-9}$

T then is equal to $\frac{1.87(.33)^2(.0002)}{(2 \times 10^{-9})2}$ = 10,000 g.p.d. per ft.

Actual T, 10,000 (.65) g.p.d. per ft.

Walton, 1970 gives a formula which relates T to the specific capacity, so this will give us a means to check our value for T. The equation is as follows:

$$\frac{Q}{s} \quad \frac{T}{264 \log \frac{Tt}{2693r\ S} - 65.5}$$

$\frac{Q}{s}$ specific capacity, in g.p.m. per ft.

Q discharge, in g.p.m.

s drawdown, in ft.

T coeffieient of transmissibility

S coefficient of storage, fraction

r radius of well

t time after pumping began, in min.

After plugging in all values, we find that the specific capacity $(\frac{60 \text{ g.p.m.}}{17 \text{ ft.}})$ ends up being equal to 3.3 which is pretty close. Out T of 6500 is given additional confidence by observing the transmissibility of a well in Port Clinton, Ohio. It was found to be 6400 by the Division of Water.

Because all of the aforementioned wells were drilled in the Tymochtee dolomite, further complication will result due to the relatively high solubility of the carbonate rock. In the ground, water usually moves through openings between grains and so results in fairly uniform flow, and (if the aquifer's thickness remains constant and there is no loss or gain of water) a fairly uniform T. However in limestone and dolomite, the space between the grains is very small, and the water moves along joints and fractures which slowly enlarge due to solution. As a result, the flow of water through these carbonates is erratic, depending on susceptibility to solution, occurrence of joints or fractures and the length of time of exposure to groundwater movement. Therefore it is because of the nature of limestone and dolomite that T can vary greatly over very short distances. Great care must be given when estimating T in carbonate aquifers of any size.

Much information is still needed in order to interpret the geology and groundwater conditions of the area. Such data as piezometric elevations, thin sections, chemical analyses, stream hydrographs to determine basin permeability, and if available, seismic refraction surveys. The literature has been of extreme benefit, but it is generally too broad, and we therefore must have this specific data.

A proposed outline for the study of the geology and groundwater conditions of the Sandusky Bay Site is presented in Table 1.

TABLE 1

PROPOSED STUDY OUTLINE
GEOLOGY AND GROUNDWATER CONDITIONS OF A PROPOSED NUCLEAR POWER PLANT SITE ON SANDUSKY BAY

I. Introduction
   A. Purpose and scope of the study
   B. Location
   C. Geologic and groundwater considerations

II. Geology
   A. Geologic history of the area
      1. Formation of Sandusky Bay
      2. Evolution of the site area
   B. Gedrock geology
      1. Stratigraphic column
      2. Structural relations
      3. Geologic cross-section through the site
      4. Bedrock contour map
      5. Petrographic analysis of selected formations (susceptibility to solution)
      6. Possible permeability and porosity measurements
   C. Surface geology
      1. Topography and landforms
      2. Unconsolidated materials at the site and in the bay
         a. Isopach map
         b. Chemical analysis
   D. Seismologic information
      1. Earthquakes in the area
         a. Causes
         b. Intensities
      2. Tilting and earth movements (subsidence)
   E. Erosion of the shoreline
      1. Rate of erosion
      2. Physical weathering (waves)
      3. Chemical weathering
   F. Significance of geology on the plant
      1. Foundation
      2. Earth movements
      3. Floods

4. Erosion
5. Characteristics of the bay
6. Sedimentation

III. Groundwater

A. Properties
   1. Potentiometric surface (map)
      a. Maxima, minima, average
   2. Bedrock contour map and isopach map
      a. Determination of buried valleys and character and thickness of fill
   3. Determination of velocity and direction of flow in rock and unconsolidated deposits
   4. Permeability of area
      a. Hydrographs of streams
      b. Areas where streams gaining or losing
         1. Seepage runs
   5. Hydraulic properties of rock and unconsolidated deposits
      a. Transmissibility
      b. Storage coefficient (determined from aquifer tests)
   6. Areas of recharge and discharge
      a. Areas of high infiltration (recharge areas)
      b. Amount of recharge or discharge
   7. Head Differences
   8. Water yielding capacity
   9. Temperature

B. Groundwater quality
   1. Gas and chemical constituents
   2. Quality explanations
   3. Contamination from Bellevue
      a. Possible effects on the plant operations

C. Groundwater significance on plant operations
   1. Use of groundwater by the plant
   2 a. Effects on other wells in the vicinity
   2. Groundwater contamination by waste disposal
   3. Possible groundwater problems during construction

IV. Conclusions

A. Do geologic and groundwater conditions make the operation of a nuclear plant feasible on Sandusky Bay?

B. Possible problems that might be encountered

APPENDIX D

FIELD DATA COLLECTION SHEETS

SANDUSKY BAY PROJECT
HYDROLOGIC MEASUREMENTS

Date ____________
Time ____________

Water Wells

1. Flowing - rate (gpm):
   a) Well #1 ________ gpm   Temp. ________ °F
   b) Well #2 ________ gpm   Temp. ________ °F

2. Static - level (ft. below ground):
   a) Well #3 ________ ft.   Temp. ________ °F
   b) Well #4 ________ ft.   Temp. ________ °F

Streams

3. Pickerel Creek - flow & direction
   a) Rt. 6 ________ ft/sec ________, Temp. ________ °F
   b) Co. Rd. ________ ft/sec ________, Temp. ________ °F

4. Miller Blue Hole Stream - flow & direction
   a) Head ________ ft/sec ________, Temp. ________ °F
   b) Rt. 6 ________ ft/sec ________, Temp. ________ °F

5. Scherz Ditch - flow & direction
   a) Rt. 6 ________ ft/sec ________, Temp. ________ °F
   b) Co. Rd. ________ ft/sec ________, Temp. ________ °F

Sandusky Bay

6. Wind:
   a) Velocity ________ mph
   b) Direction ________ (from)

7. Waves:
   a) Height ________ ft.
   b) Length ________ ft.
   c) Period ________ sec.
   d) Direction ________ (toward)

8. Shore current:
   a) Velocity ________ ft/sec
   b) Direction ________ (toward)
   c) Temp. ________ °F

9. Weather conditions:
   a) Cloud cover ________ %, Haze ________ Fog ________
   b) Rain ________ inches Snow ________ inches Air Temp. ________ °F

10. Ice conditions:
   a) Bay coverage ________ %, Type ________
   b) Thickness ________ inches
   c) Wind rows height ________ ft. Location ________
   d) Remarks ____
   ____
   ____

II. GEOLOGY OF A PROPOSED POWER PLANT SITE ON SANDUSKY BAY

by
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Department of Geology
Bowling Green State University

April 1973

INTRODUCTION

Knowledge of the geology of a site is essential before any major structure, such as a power plant, can safely be built there. In this report, both the geology of the proposed power plant site along the south shore of Sandusky Bay and its practical significance are considered.

The first section deals just with the geologic setting. All the aspects of the geology and the related landscape are considered - the bedrock, surficial materials (clay, glacial till, and "broken-rock" zone), surface topography, climate, lake bottom surface and deposits, shore erosion, water resources, and seismicity, in that order. The second section attempts to evaluate the significance of the geologic data in terms of the construction and subsequent operation of the proposed power plant. A final section presents what is essentially an abstract, or summary, of all the geologic and applied data presented in more detail previously.

THE GEOLOGIC SETTING

Sources of information, beyond that of my own background, are given at the end of each section; full references are listed at the end of the report.

Bedrock

Bedrock underlying the site of the proposed power plant is Silurian (400 million years old) Tymochtee Dolomite (magnesium limestone). This rock, though composed of solid carbonate material, is characterized by small, abundant irregular-shaped openings, which is probably why this rock provides such a dependable source of ground water in western Ohio. These openings were probably made either by irregular solution of the rock, recrystallization of the sediment after its initial deposition, or a combination of these processes.

In two places (Crystal Rock, five miles east of the site and Put-in-Bay on South Bass Island), collapse-type caves apparently made by settlement caused by solution of underlying gypsum are known, but these appear to be localized; the chances of encountering such a feature at the proposed power plant site exist, but seem very small. Analyses of the bedrock (Stout, 1941) from near Gypsum on the north shore of Sandusky Bay are given in Tables 1 and 2.

TABLE 1

CHEMICAL ANALYSIS OF BEDROCK

Silica, SiO_2	6.50
Alumina, Al_2O_3	1.65
Ferric oxide, Fe_2O_3	0.12
Ferrous oxide, FeO	0.28
Pyrite, FeS_2	< 0.01
Magnesium oxide, MgO	18.42
Calcium oxide, CaO	25.72
Strontium oxide, SrO	3.43
Barium oxide, BaO	< 0.01
Sodium oxide, Na_2O	0.04
Potassium oxide, K_2O	0.10
Water, hydroscopic, H_2O-	0.19
Water, combined, H_2O+	0.40
Carbon dioxide, CO_2	40.35
Titanic oxide, TiO_2	0.07
Phosphorus pentoxide, P_2O_5	0.07
Sulphur trioxide, SO_3	2.70
Manganous oxide, MnO	0.035
Carbon, organic, C	0.08
TOTAL	100.155 %

TABLE 2

MINERAL COMPONENTS OF BEDROCK

Sericite, $(K,Na)_2O.3Al_2O_3.6SiO_2.2H_2O$				1.33
Kaolinite, $Al_2O_3.2SiO_2.2H_2O$				2.86
Celadonite, $(Fe, Mg, K_2, Na_2)O.2SiO_2H_20$: $Fe_2O_3.6SiO_2.3H_2O$				0.26
Quartz or free silica, SiO_2				4.40
Limonite, $2Fe_2O_3.3H_2O$				0.12
Pyrite, FeS_2				0.00
Rutile, TiO_2				0.07
Apatite, $3CaO.P_2O_5$				0.15
Anhydrite, $CaO.SO_3$				0.09
Celestite, $SrO.SO_3$				6.08
Dolomite	Main Components	$MgO.CO_2$	38.52	84.21
		$CaO.CO_2$	45.69	
	Parts in solid solution	$FeO.CO_2$	0.37	
		$MnO.CO_2$	0.055	
Water, hydroscopic, H_2O-				0.425

Hydrocarbons, C_nH_{2n+2}	0.08
Unbalanced parts (excess CO_2, H_2O)	-0.11
TOTAL	100.155 %

Topography on the buried bedrock surface (Figure 1) reveals buried valleys to the east and west, but only somewhat irregular buried upland at elevations of 520-530 feet under the site of the proposed power plant. (Carman, 1927, 1957; Stout, 1941; Shaffer, 1951, Forsyth, 1971).

Surficial Materials

Lying above the bedrock is a layer of glacial till about 40 feet thick, overlain along the Sandusky Bay shore by about 20 feet of lacustrine (lake) clay. Thickness of the entire section of surficial materials is thus about 60 feet, as shown in Figure 2.

The till, like all other northwest Ohio tills, is compact and calcareous, and is composed dominantly of clay and silt, with a small amount of sand and pebble-sized material, and rare boulders scattered throughout it. The till is saturated with as much water as its compact clayey nature will permit, though this water is held too tightly to allow its being successfully tapped by a well or being drained in order to create a more solid structural foundation.

Between the till and the bedrock in places is a thin zone, generally about 5 feet thick (though locally increasing to as much as 10 or 12 feet), which is called variously by drillers "sand and gravel" or "broken rock". This zone is apparently a combination of broken fragments of bedrock, meltwater-washed sediments, and/or other periglacial-type materials, which is quite permeable in some places and almost completely impermeable in others. Where it is thick enough and permeable enough, this zone carries water which can be tapped by wells. In such places near the power plant site, the water in this zone is under considerable pressure, perhaps being related to the water in the series of springs called the Blue Holes, one of which (Miller Blue Hole) lies less than a mile southeast of the power plant site.

Above the till is about 20 feet of lacustrine clay, which is the material present at the surface throughout the power plant site area. The entire five foot exposure along the low wave-cut cliff west of Bayshore is composed of this material, material which is extremely vulnerable to wave erosion. The material is composed dominantly of silt and clay, with the later predominating, and

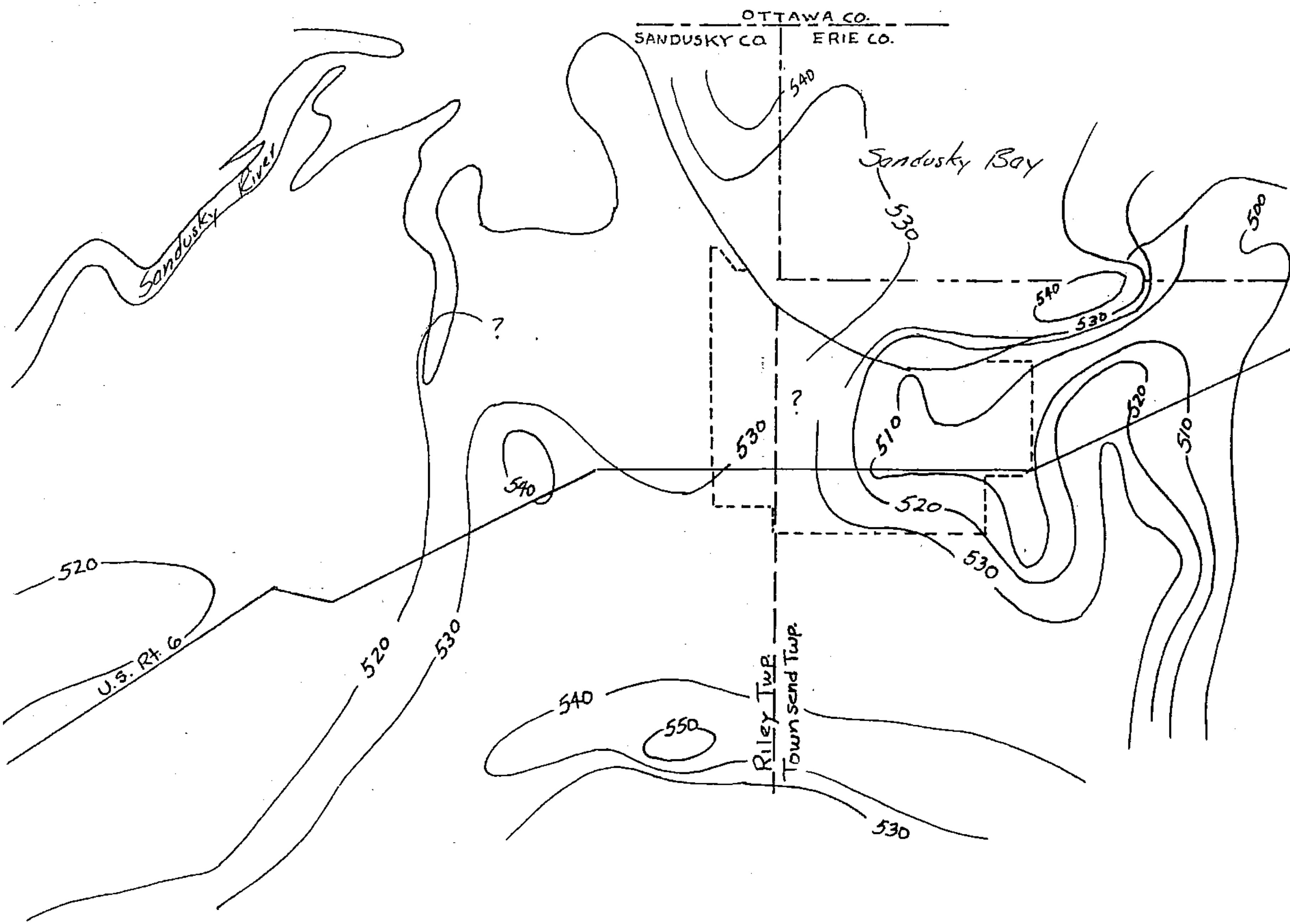


Figure 1. Topography on buried bedrock surface.

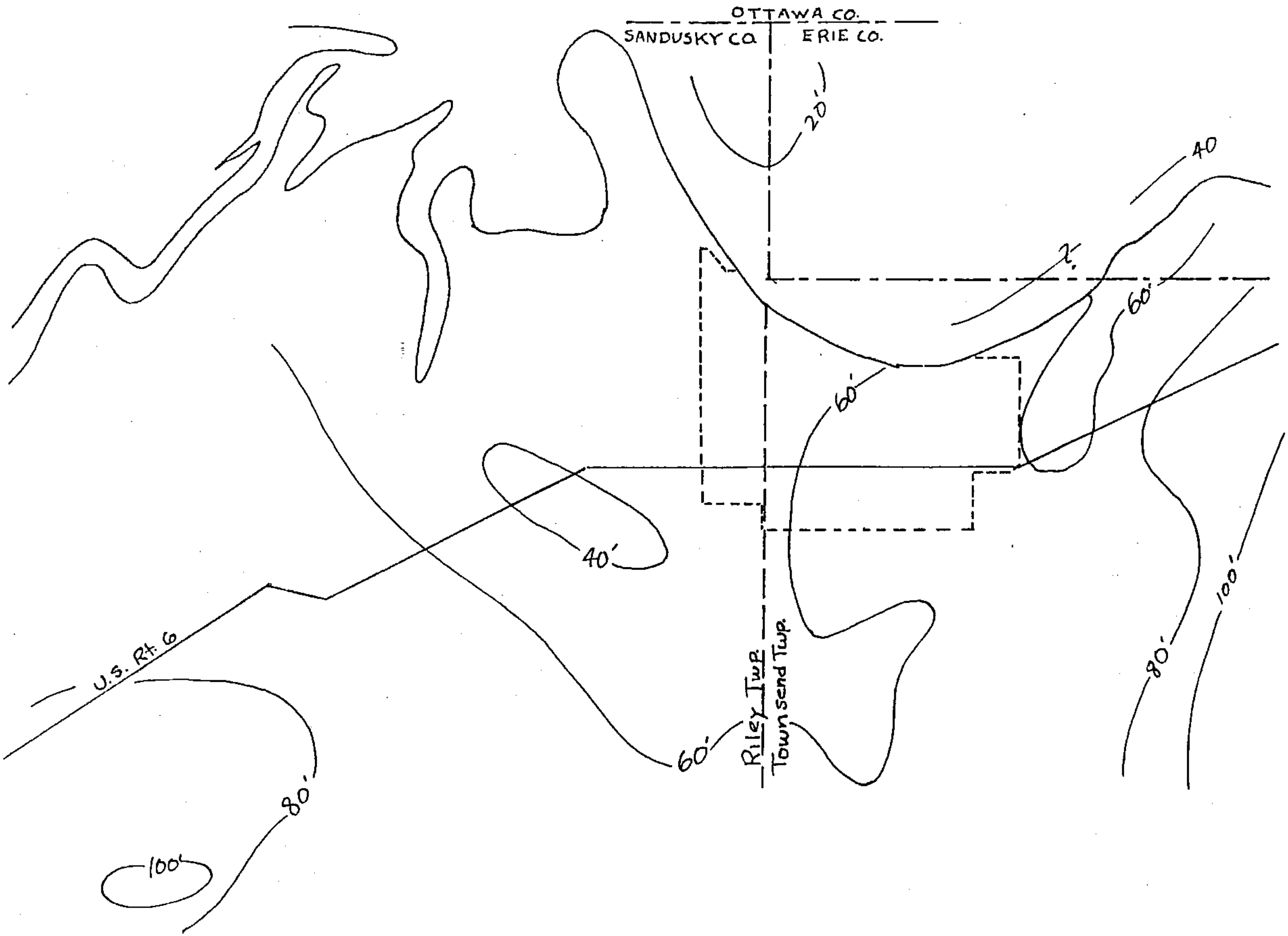


Figure 2. Depth to rock (thickness of surficial material).

reveals very faint laminations. It is weak and, at the surface where it is exposed to the air, it granulates, or tends to crack and break into small pieces. In addition, larger cracks form which may extend as deep as two feet down into the clay. This combination of granulation and cracking makes the clay readily susceptible both to erosion by waves and to attack by frost action and rain wash. In addition, the clay is reported to slake, that is, after having been thoroughly dried in the sun, the clay, if it becomes completely soaked with water again, will break down into a mass of poorly cohesive material (Shaffer, 1951).

The soil at the surface of this deposit is the Toledo silty clay (Redmond, et al., 1971), originally called the Newton silty clay. This soil, which appears dark colored at the surface and mottled brownish to dark gray in the subsoil, is characterized mainly by its poor drainage. Water completely saturates the clayey material composing this soil, but, because of its tight nature, does not readily drain out. For this reason, and also because of the extreme flatness of the ground and the low height of the area above Sandusky Bay, the soil is very poorly drained, often having small ponds of water standing at the surface for extended periods of time. The organic material content is high and the tilth is generally good, so that, where the land has been satisfactorily drained, the soil is very productive. For engineering uses, the soil is less good, because of its clayey plastic nature, its unstable character, its poor drainage, its high shrink-swell potential, and its high corrosion potential for steel (Redmond, et al., 1971). (Moseley, 1905, 1906; Shaffer, 1951; Corps of Engineers, 1953; Erie Regional Planning Commission, 1967; Redmond, et al., 1971).

Surface Topography

The land surface south of Sandusky Bay is very flat, rising very gradually to the south, away from the Bay. Along the shore, the land surface is almost at the level of the water, so that, at times of especially high water (such as now in 1972-73), flooding and erosion are extensive. A 5 foot bluff (called 8 feet by the Corps of Engineers in 1953, when the lake was about 2 feet lower) is present along the shore. Back from this bluff, the slope of the land up to the south is only about 8 to 10 feet per mile. Because of the flatness of the land, drainage by field tile and open ditches has been used almost everywhere, though the land at the power plant site is so extremely low and swampy that drainage has never been successful. (Moseley, 1905, 1906; Shaffer, 1951; Corps of Engineers, 1953).

Climate

The climatic pattern is important both in its effect on the erosion of the lacustrine clay and on the future landscaping of the power plant grounds. Tables 3 and 4 give data on temperature, precipitation, and the probability of freezing temperatures, based on records made at Sandusky during the period of 1936 - 1965 (Redmond, et al., 1971).

Lake Bottom

The bottom of Sandusky Bay is very flat, and water depths are shallow. The bottom slopes out away from the shore at a rate of 4 to 8 on 100 for the first 100 feet and then, farther offshore, becomes more gentle, with a slope of only 0.5 to 1.0 on 100 (Corps of Engineers, 1951). Water depths both in this offshore area and all across the Bay are generally 5 to 6 feet deep (values which, right now, during the 1972-73 period of exceptionally high water, should be increased by 3 to 4 feet).

The material on the bottom of the Bay is soft lake mud, material that was originally sediment suspended in the water, and, since settling, is easily stirred up again. This sediment is generally 4 to 6 feet thick, being almost as thick as the depth of lake water standing above it. Farther out in the Bay, some of the sediment is part of the estimated 30,000 tons of material brought into the Bay and Lake each month by the Sandusky River, but in the area immediately offshore from the site of the proposed power plant, all of the sediment is extremely fine semi-suspended lake mud, which riles up with the least wave or current action.

Beneath the mud is very compact clay, so compact that bottom-sampling devices which penetrate the mud with ease can be forced into it only with the greatest difficulty. This clay, which is lake clay, underlain at some depth by clay-rich glacial till (both of which have about the same engineering characteristics), 41 feet being the value at the station closest to the proposed power plant site. (Moseley, 1905, 1906; Corps of Engineers, 1951; LakeErie navigational chart 39, published by the Lake Survey Center; 1972 Ohio Geological Survey unpublished sampling data).

Shore Erosion

Shore erosion anywhere along Lake Erie is most effective when the lake level is highest, and when the storm winds blow unhindered across the greatest extent of water. Lake level (and therefore the level in Sandusky Bay) varies through the years, depending on the overall amounts of precipitation and rates of evaporation throughout the Great Lakes watershed; at the present time (1972-73), Lake Erie is at an all-time high. Judging from past records, published by the Corps of Engineers' Lake Survey Center in Detroit, the level of the lake should begin to lower in a few years, reaching a low level in the cycle about 1985 or so, and then it should rise again, reaching a maximum height about 1994. Whether that height will be as high as the present level cannot be predicted, but the possibility must be considered. Superimposed on the overall pattern of lake-level cycles are smaller variations, related to season, rainy spells, etc.

There is also a very slow rise of water levels in the Lake and Bay as a result of very gentle tilting of the region, produced by removal of the heavy weight of the Ice Age (Pleistocene) glaciers. The heavy ice weighed the land down, especially to the north and northeast in Canada, where it was thicker; melting of the ice has permitted the land to rise. These responses go on very slowly, however, with considerable lag after the act which triggered them. Most of the postglacial rise appears to have taken place already, but it is still going on very slowly. The present rate of uplift at the east end of the Lake Erie basin, the position of the outlet which of course also controlls the level of the lake, is extremely slow, having been estimated at rates of from 0.5 to as much as 2 feet per century (Moseley, 1905, 1906; Corps of Engineers, 1953; Lewis, 1969). Clearly, therefore, though this uplift of both the outlet and the Lake and Bay is indeed going on, its rate is not enough to produce any serious flooding problems in the next 50 to 100 years.

There are no strong currents in Sandusky Bay. Gentle inflow of water from the Sandusky River produces a very slow movement of water toward Lake Erie, but drifting of marked bottles, even submerged ones (released by Moseley), appeared to respond only to the effects of the wind. Littoral drift along the shore adjacent to the proposed power plant site is very weak, but is toward the west, apparently as an eddy off the main Sandusky River water flow to the east. None of the current action is strong enough to create any shoreline erosion problems, or even to stir, to any observable extent, the soft mud on the bottom of the Bay. The same cannot be said for the effects of strong northeast winds, which commonly stir up this soft mud and greatly increase the turbidity of the Bay water.

Erosion is most evident along the south shore of Sandusky Bay,

TABLE 3

AIR TEMPERATURE AND PRECIPITATION DATA FOR SANDUSKY, OHIO, 1936–1965

Month	Temperature				Precipitation				
	Average daily maximum	Average daily minimum	Two years in 10 will have at least 4 days with—		Average total	One year in 10 will have—		Average snowfall	Average number of days with 1 inch or more of snow
			Maximum temperature equal to or higher than—	Minimum temperature equal to or lower than—		Less than—	More than—		
	° F.	° F.	° F.	° F.	In.	In.	In.	In.	
January	34	21	54	4	2.40	0.73	4.51	7.2	3
February	36	22	55	7	2.19	.95	3.65	6.3	2
March	45	30	69	14	2.88	1.31	4.74	5.8	2
April	57	40	78	28	3.23	1.56	5.15	1.1	(1)
May	70	51	87	39	3.41	1.50	5.68	0	0
June	79	61	92	51	4.11	1.59	7.15	0	0
July	83	65	96	56	3.62	1.56	6.05	0	0
August	82	64	95	55	3.23	1.58	5.14	0	0
September	75	57	90	45	2.80	1.14	4.79	0	0
October	65	47	82	35	2.02	.56	3.87	0	0
November	50	35	68	21	2.22	1.01	3.65	2.5	1
December	38	25	57	9	2.04	.96	3.28	6.1	2
Year	59	43	[2] 98	[3] 0	34.15	26.49	42.37	29.0	10

[1] Less than 0.5 day. [2] Average annual maximum. [3] Average annual minimum.

TABLE 4

PROBABILITY OF FREEZING AIR TEMPERATURES IN SPRING AND FALL FOR SANDUSKY, OHIO, 1936–1965

Probability	Dates for given probability and temperature				
	20° F. or lower	24° F. or lower	28° F. or lower	32° F. or lower	36° F. or lower
Spring:					
1 year in 10 later than	March 28	April 9	April 12	April 24	May 7
3 years in 10 later than	March 19	March 30	April 4	April 18	April 30
5 years in 10 later than	March 13	March 23	March 30	April 14	April 25
Fall:					
1 year in 10 earlier than	November 16	November 11	October 23	October 18	October 3
3 years in 10 earlier than	November 24	November 18	November 1	October 25	October 12
5 years in 10 earlier than	November 30	November 23	November 8	October 29	October 18

(Redmond, et al., 1971)

where measurements show that the shoreline had retreated as much as 1150 feet between 1820 and 1951, an average rate of retreat of more than 9 feet per year. This very fast rate of erosion is a product of two factors: the very soft, easily eroded lacustrine clay forming the south shore of the Bay, and the fact that the greatest storms come mainly from the northeast, so that the winds which have gained strength by blowing straight across the whole of central and eastern Lake Erie blow directly into the mouth of Sandusky Bay, resulting in tremendous erosion. Because of the orientation of the Bay's shores, in comparison with the long axis of Lake Erie, it is especially the shore by the power plant site where erosion has been greatest. Locally, where rocks, trees, fallen tree trunks, or human construction of some kind provide a little strenthening of the shoreline, the shore has not been eroded so fast, resulting in small promontories at each of the protected sites, suggesting that adequate protection from shore erosion would not be difficult to accomplish here. The rise in water level in the Bay during northeast storms (seiche) can be as much as 5 feet, but waves rarely get bigger than 2 or 3 feet, because of the restricted size of the mouth of the Bay and its shallow waters, so that shore erosion design need not be higher than 7 or 8 feet.

The combination of rising water levels in Sandusky Bay and northeast storm winds, winds that are especially effective when water levels are higher, has almost destroyed many islands and much Bay-shore mainland in the western end of the Bay. Islands such as Eagle Island and Squaw Island have been completely or almost completely destroyed, and many marginal mainland areas that were once farmed are now marshes or flooded land (effects recorded by Moseley and shown by photographs of old maps and of the modern shoreline by Lowden).

Flooding will not get significantly worse in the next 50 to 100 years at the proposed power plant site; the land is already very low and swampy, and will simply remain that way. Wave erosion, however, unless checked, will cause considerable loss of land; the unusually big storm of November, 1972, produced an estimated retreat of the shoreline in this area of about 20 to 30 feet. If erosion-control structures are built only in the area adjacent to the power plant, though, destruction of the vulnerable clay to either side of the site will result in the power plant area becoming a peninsula or even an island in the Bay, which will increase the strength of wave erosion here, and may require additional erosion-control measures. (Mosely, 1905, 1906; Moore, 1948; Corps of Engineers, 1953; Lewis, 1969; Lowden, 1969).

<u>Water Resources</u>

Water occurs in the ground in both the dolomite bedrock and the clay-rich surficial materials (lacustrine clay and glacial till), but it cannot readily be removed from the latter.

In terms of obtaining a water supply from wells, water is available from the bedrock; present wells close to the proposed power plant site provide approximately 15 gallons per minute from depths of 60 to 75 feet (Figure 3). Some of this water comes from shallow aquifers in the rock, but much derives from the "broken-rock" zone. Greater amounts of water, reportedly (Walker, 1962) up to 300 gallons per minute, are available from depths of several hundred feet in the rock, though this water in some places may contain considerable amounts of sulphur.

All water here is artesian and in almost all wells is flowing at the surface. It is possible that the extra pressure which produces such a high percentage of flowing wells may be a result of water coming from springs like the Blue Holes and welling up through the bedrock and into the "broken-rock" zone, from which many of the local wells derive their water. In only a few places is this zone so thin and/or so impermeable that it does not contain much water. With water pressures that are this strong, any engineering design for the construction of the power plant should allow for possible water problems at this level during excavation for the piling.

Water quality reported from wells in the immediate area of the site is good, though the water is hard (as is the water of the Bay, also). Sulphur water, a problem elsewhere in northwest Ohio, has not been reported for this part of Sandusky County, though it is possible that deep drilling here (to depths of several hundred feet) might encounter it, as happens elsewhere in northwest Ohio.

More critical, in terms of water quality, is the belt of contaminated water flowing northward through the bedrock from the sewage-disposal wells of Bellevue to the south. Only recently has this town built a sewage treatment plant. Before that, sewage of both individual homes and the entire municipality was disposed of in wells leading down into the cavernous limestone below the town, the same area that, in part, serves as a watershed feeding the Blue Holes. The distribution of the ground-water contamination produced by this disposal has been mapped (Figure 4); it lies entirely east of the site of the proposed power plant, its western margin extending just into the eastern edge of Townsend Township. Now that Bellevue has a sewage treatment plant, it is highly unlikely

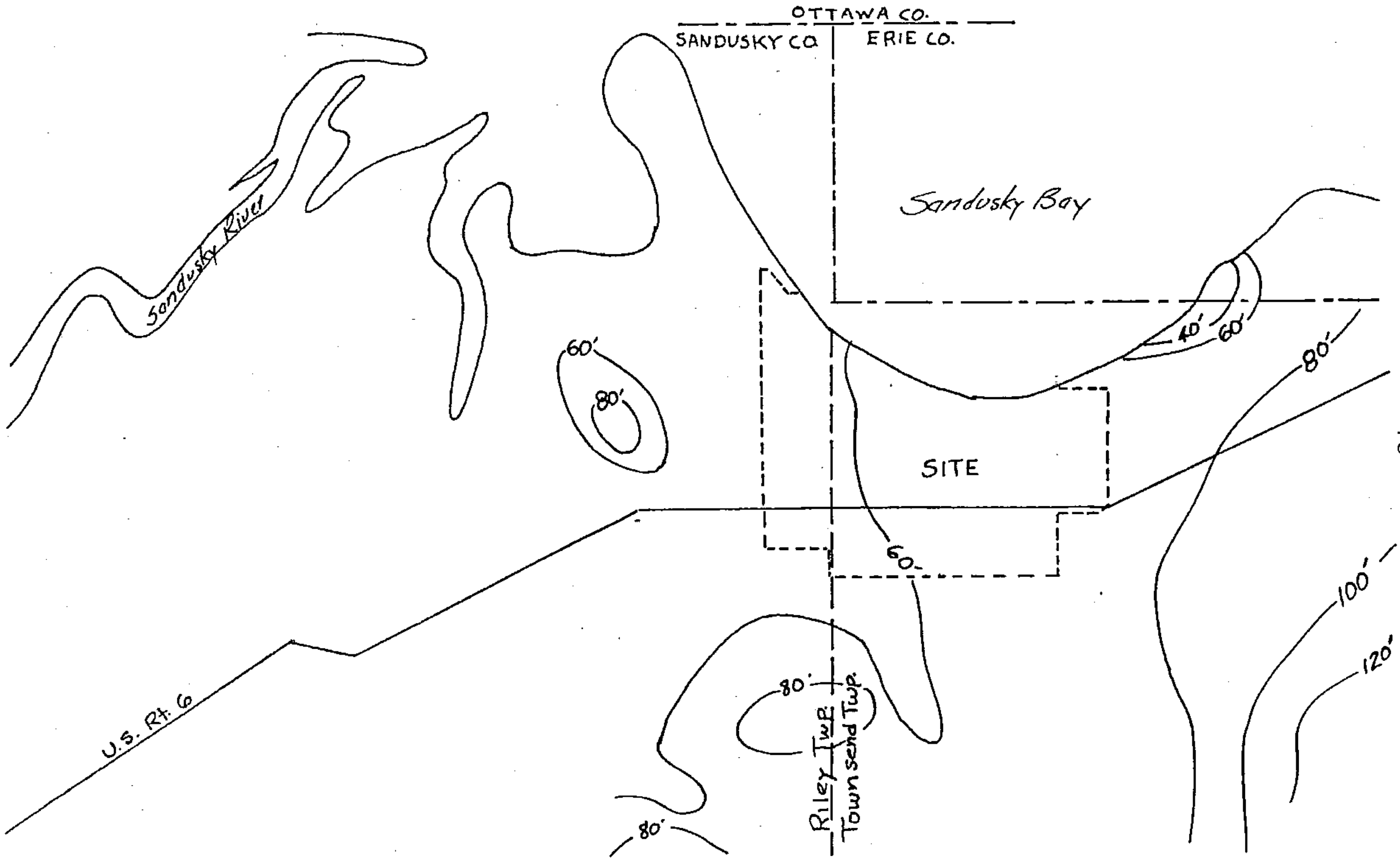
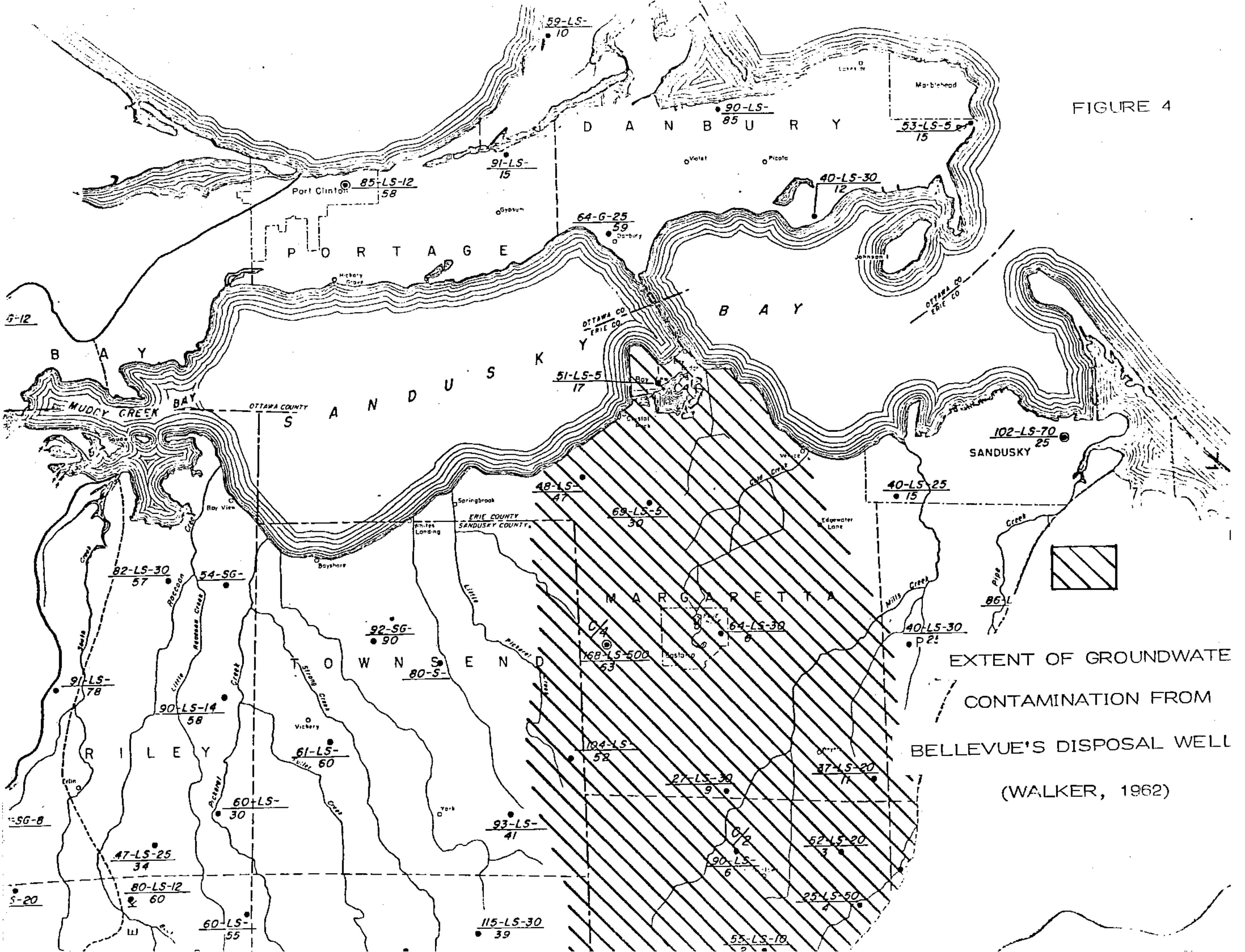


Figure 3. Contour map showing depth to water (from water-well data).

FIGURE 4



EXTENT OF GROUNDWATE[R]
CONTAMINATION FROM
BELLEVUE'S DISPOSAL WELL
(WALKER, 1962)

that such contamination will ever spread as far west as the power plant site.

Sandusky Bay is of course a large and convenient source of water. However, taking in and discharging large quantities of water from this source will quickly stir up the soft mud on the bottom, producing very meddy, very turbid water in the Bay and in the intake system. Technology can solve the problem of the large proportion of suspended particulate matter (both mineral matter and some organic material) taken in through the intake system, but turbidity in the Bay will create severe environmental problems that are less easily solved.

The water is normally only 5 to 6 feet deeo there, an amount about equal to the thickness of easily riled-up mud on the bottom. High turbidity would greatly reduce light penetration, cutting off the source of essential sunlight to shallow-water submerged plants there, plants which are an important source of oxygen, thus drastically reducing oxygen levels in the water. Low oxygen has been one of the main problems creating "Dead" Lake Erie, both in terms of reducing available oxygen for oxygen-demanding animals and in terms of increasing the amount of dead organic material that needs oxygen in order to decay; in such a much more shallow, more potentially turbid, restricted area as Sandusky Bay, the effects would be very much greater, and there would be no deeper water to flow in and ameliorate the effects.

In addition, natural heating of the water during the critical summer growing season would greatly increase. Such a shallow bay would naturally heat up more than deeper waters, due to greater penetration of the sun's rays, but, with increased turbidity, this natural heating, as the sun's rays strike the suspended particles closer to the water surface, would be greater. Thus, with continual riling up of the mud on the bottom of Sandusky Bay, conditions of low oxygen and high temperatures would have very serious effects on aquatic organisms. If, in addition, Sandusky Bay water were also used for cooling in the power plant, a less satisfactory arrangement than for sites on Lake Erie because heated water in this shallow, muddy, current-less bay would not readily cool off or be diluted, this influence of heating could well increase to lethal proportions, because of the restricted area and depth of the Bay. (Walker, 1962).

Seismicity

The locations of earthquakes and other seismic events for the State of Ohio from 1776 to the present are shown in Figure 5 and are summarized in Table 5 . If seismic events other than earthquakes,

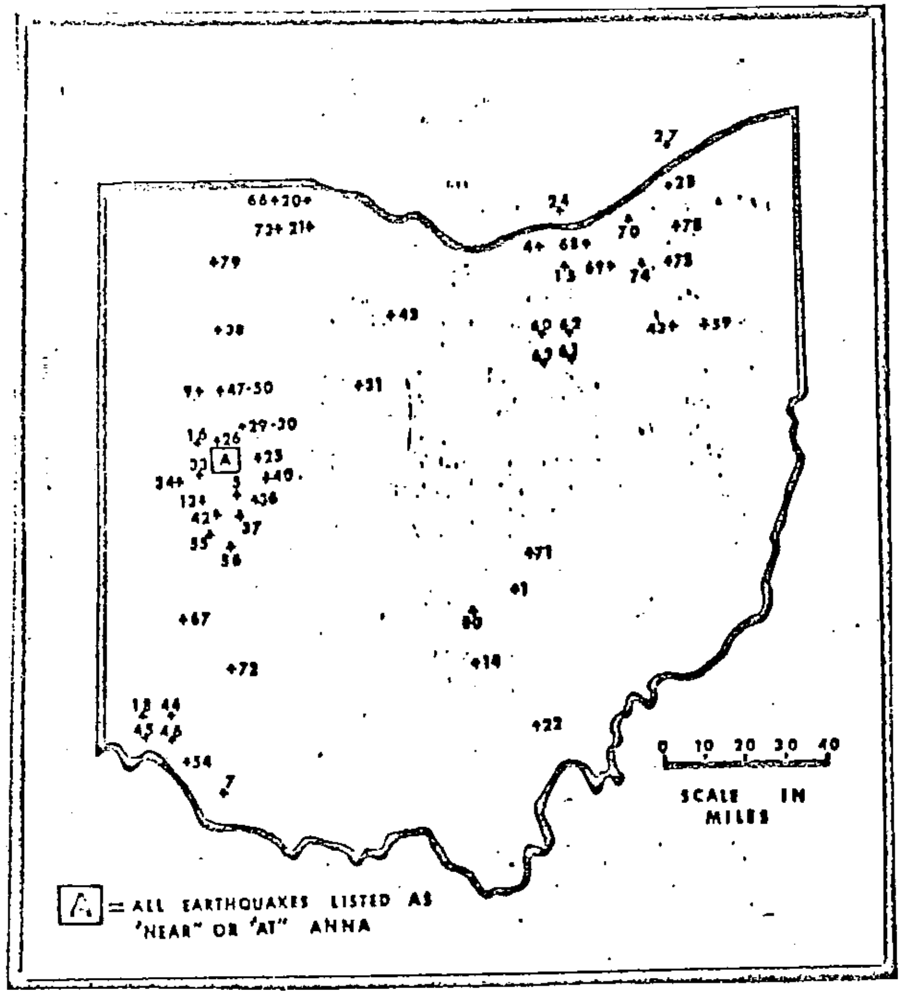


Figure 5. Earthquakes in Ohio (1776 - 1972)

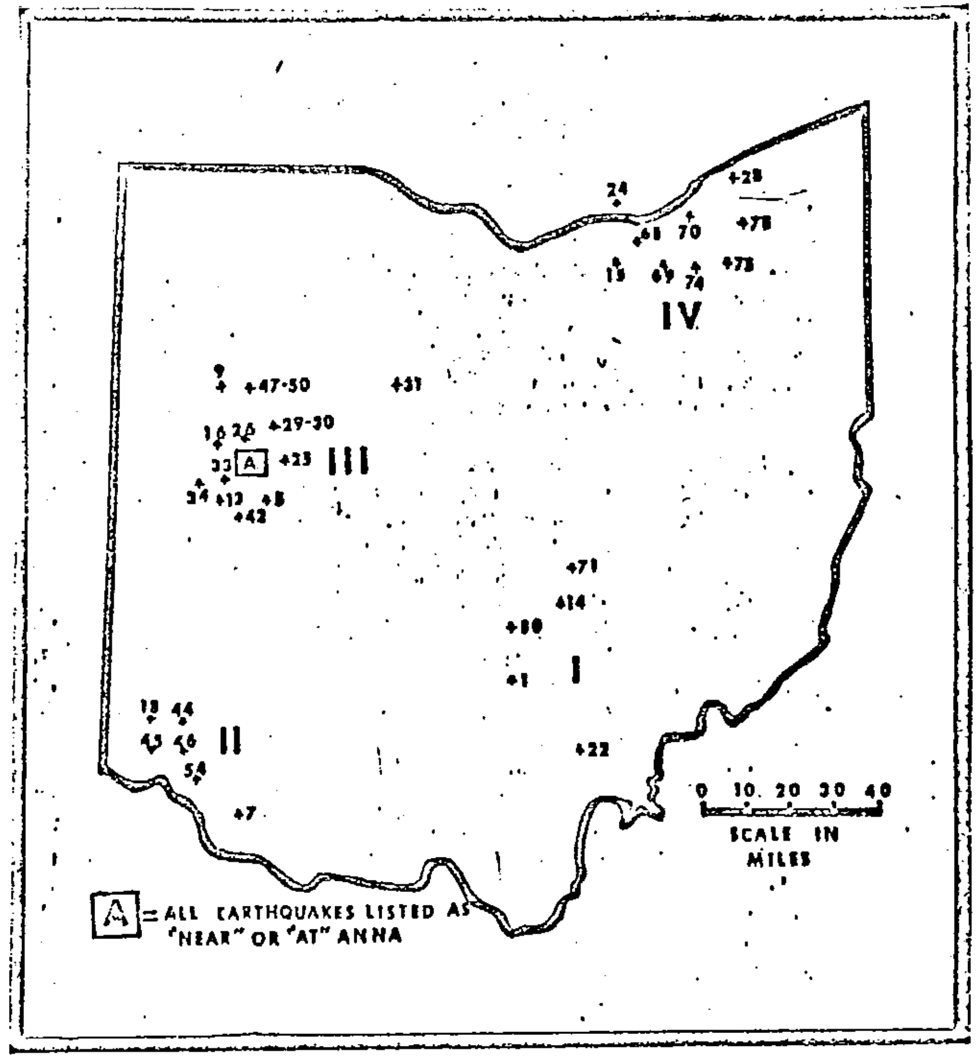


Figure 6. Epicenters and Zones of Ohio Earthquakes

TABLE 5

OCCURRENCE OF EARTHQUAKES IN OHIO FROM 1776 TO THE PRESENT
DATA SOURCE: U.S. DEPARTMENT OF COMMERCE

Map no.	Date	Location	Intensity	Map no.	Date	Location	Intensity
1*	1776-Summer	Muskingum River	VI	41	1932-Jan. 21	Summit Lake; Akron (felt)	IV
2	1810-Night(?)	New Madrid (felt)	III	42*	1933-Feb. 23	Sidney	III
3	1845-(?)	Putnam County	(Earth Slump)	43	1936-Jan. 31	Tiffin (felt)	III
4	1872-July 3	Elyria; Lorraine	(Rockslide)	44*	1936-Oct. 8	Cincinnati	III
5*	1875-June 18	40.2N, 84.0W	VII	45*	1936-Dec. 26	Cincinnati	III
6*	1876-June	Near Anna	VI	46*	1936-Dec. 26	Cincinnati	III
7*	1877-Jan. 23	Brown and Adams County	III	47*	1937-Mar. 2	40.7N, 84.0W	VI
8*	1882-Feb. 9	Near Anna	V	48*	1937-Mar. 3	40.7N, 84.0W	V
9*	1884-Sept. 19	40.7N, 84.1W	VI	49*	1937-Mar. 3	40.7N, 84.0W	III
10*	1884-Dec. 23	At Anna	III	50*	1937-Mar. 9	40.7N, 84.0W	VIII
11*	1889-Sept.	Near Anna	III	51*	1937-April 23	Near Anna	III
12*	1892-Summer	Near Anna	VI	52*	1937-April 27	Near Anna	III
13*	1896-Mar. 15	Near Sidney	IV	53*	1937-May 2	Near Anna	III
14*	1901-May 17	39.3N, 82.5W	VI	54*	1937-Oct. 17	Cincinnati	III
15*	1906-June 27	41.4N, 81.6W	V	55	1939-Mar. 18	At Sidney (felt)	II
16*	1914-(?)	Near Anna	III	56	1939-Mar. 18	Near Anna (blast)	III
17	1925-Mar. 27	Southern Ohio (felt)	V	57*	1939-June 18	At Anna	IV
18*	1925-April 4	Near Cincinnati	III	58*	1939-July 9	At Anna	II
19*	1925-October	Near Anna	III	59	1940-May 31	Akron (blast)	II
20	1926-Oct. 28	East Toledo (blast)	III	60	1940-June 16	North of Nankin (blast)	III
21	1926-Oct. 28	Toledo Suburbs (blast)	IV	61	1940-July 28	North of Nankin (blast)	II
22*	1926-Nov. 5	39.1N, 82.1S	VI	62	1940-Aug. 15	North of Nankin (blast)	II
23*	1927-Feb. 17	Near Mansfield	IV	63	1940-Aug. 19	North of Nankin (blast)	II
24*	1928-Sept. 9	41.5N, 82.0W	V	64*	1943-Mar. 9	42.2N, 80.9W	IV
25*	1928-Oct. 27	Jackson Center	III	65*	1944-Nov. 13	Near Anna	III
26*	1929-Mar. 8	40.4N, 84.2W	V	66	1948-Jan. 18	Toledo (blast)	III
27	1929-June 10	Cleveland (blast)	III	67	1950-April 20	Dayton (aircraft)	III
28*	1929-Sept. 17	Cleveland	II	68	1951-Dec. 3	Cleveland	IV
29*	1930-June 26	40.5N, 84.0W	IV	69*	1951-Dec. 7	Cleveland	II
30*	1930-June 27	40.5N, 84.0W	IV	70*	1951-Dec. 21	Cleveland	II
31*	1930-July 11	40.7N, 83.2W	IV	71*	1952-June 20	39.8N, 82.2W	VI
32*	1930-Sept. 20	Near Anna	VI	72*	1953-May 5	Near Crooksville	IV
33*	1930-Sept. 29	40.3N, 84.2W	III	73	1953-June 12	Toledo (felt)	IV
34*	1930-Sept. 30	40.3N, 84.3W	VII	74*	1955-May 26	Cleveland, SE.	V
35*	1930-October	At Anna	IV	75*	1955-June 29	Cleveland, SE.	V
36	1931-Mar. 21	Sidney; Jackson Center (felt)	III	76*	1956-Jan. 27	Near Anna	V
37	1931-April 1	Jackson Center (felt)	III	77*	1957-July 23	At Ripley	III
38	1931-June 10	Malinta (meteor impact)	V	78*	1958-May 1	Cleveland	V
39*	1931-Sept. 20	At Anna	VII	79*	1961-Feb. 22	Findlay	III
40	1931-Oct. 8	At Anna (felt)	III	80	1967-April 8	39.6N, 82.5W	V

such as quarry blasts and sonic booms, are removed from the data, the result is that given in Figure 6. From this figure, it is evident that all known earthquakes in Ohio occur in either the southeast (Zone I), the southwest (Zone II), the west (Zone III), or the northeast (Zone IV). Absolutely no earthquakes have been recorded in northwestern Ohio in the area of the proposed power plant. Clearly this site, with no record of any seismic activity whatsoever, presents no such hazard.

Of all the areas of earthquake activity in Ohio, that closest to the power plant site is Zone IV, in northeastern Ohio. Even here, about 70 miles away, only 9 earthquakes have ever been experienced over the past 57 years, all with epicenters concentrated in the Cleveland region (Figure 7 and Table 6). The intensities of these earthquakes ranged only from 2 to a maximum of about 4 on the Richter scale. Cause of this minor seismic activity in northern Ohio is not known; some have suggested that it may be due to movement along a westward projection of a fault occurring along the St. Lawrence River valley, and others have attributed it to the release of crustal stresses in response to underground mining of salt in the Cleveland area. Thus, even here, though some earthquakes have taken place, such occurrences are rare and their intensities are weak, in comparison with the destructive earthquakes of other parts of the country. (Office report dated January 30, 1973, by Dr. Edmund F. Pawlowicz, Director, Seismological Observatory, Bowling Green State University, and Registered Professional Engineer, Ohio).

APPLICATION OF GEOLOGIC DATA TO CONSTRUCTION AND OPERATION OF PROPOSED POWER PLANT

The geologic data described earlier affects both the construction and later phases of the proposed power plant. During construction, potential foundation and ground-water problems are identified by the geology. Following completion of the structure, there are potential problems of flooding and erosion by lake water, and of water supply, especially for cooling, in light of the shallowness of Sandusky Bay and the thick accumulation of easily riled-up mud on the bottom of the Bay.

Foundation

Foundation materials at the land surface are wet, unstable clays. Location of heavy structures on such weak materials is possible only if the construction plans make adequate allowance

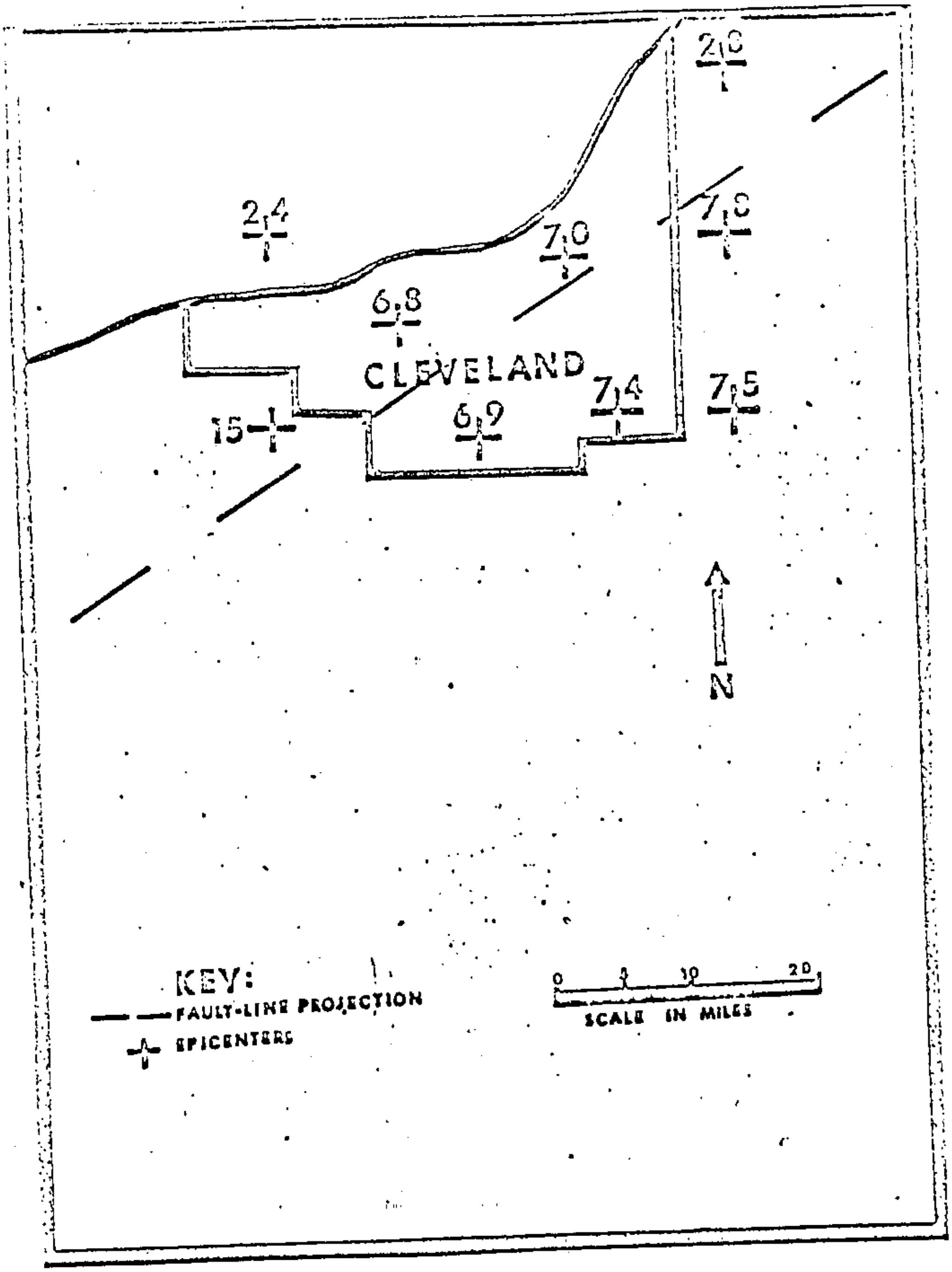


Figure 7. Earthquake Structures of Zone IV

TABLE 6
CHARACTERISTICS OF EARTHQUAKES FOR ZONE IV

Map no.	Date	Shock waves felt at:	Intensity
15	1906	Fairport, Put-in-Bay	V
24	1928	Along southern shore of Lake Erie	V
28	1929	Euclid	II
68	1951	Cleveland	IV
69	1951	same	II
70	1951	same	II
74	1955	same	V
75	1955	same	V
78	1958	same	V

for this tremendous lack of bearing strength. The clay-rich glacial till that underlies the surface clays at a depth of about 20 feet is also saturated, but is not as weak as the clays at the surface.

If construction requires deep excavation it is important to note that the bedrock surface in this area is between 60 and 80 feet deep. One of the most serious problems that will probably be encountered during construction is the artesian water in the "broken-rock" zone, and possibly also within the dolomite bedrock itself. Water wells on all sides of the proposed power plant site are fed by artesian water under enough pressure to form flowing wells. Major excavation to these levels could well release a flood of artesian water, submerging the construction site and at the same time possibly causing neighborhood wells to go dry. In addition, this may seriously lower the water level in the noted state-owned Blue Hole just across U.S. 6 from the power plant property, the Miller Blue Hole, an ecologically exciting site, much studied by professional biologists and ecologists of Ohio.

Flooding

Flooding by Sandusky Bay water of the proposed power plant site, which already is part of the swampland marginal to Sandusky Bay, is a problem that probably has an easy solution. However, careful soils analysis is essential to determine whether the addition of a layer of fill material on top of the weak lacustrine clay will cause any critical flowage of the clay or other problem.

Erosion

Erosion problems, which are presently serious because of the excessive nonresistance of the lacustrine clay that forms the shore along Sandusky Bay, also have easy solutions. A simple and relatively cheap solution proposed by the Corps of Engineers in 1953, which was designed then to protect small shore cottages and cropped fields, involved the construction of a revetment.

The revetment had to be as high as the highest water that would occur, which would be the total of the highest estimated seiche level, 5 feet, plus the highest estimated wave height, 2 to 3 feet. The height of the wave-cut cliff then was about 7 feet, close to the desired height of protection, so the Corps of Engineers recommended simply grading the cliff to a more gentle slope, laying a 5 foot wide filter blanket of unscreened crushed stone on it, and then adding quarry-run stone to a height of 4 feet and graded to a slope of 1 on 1.5.

Judging by the effectiveness of a single rock or tree in preventing erosion of the bank in this area today, such a simple structure should provide ample protection, and might well form the basis of an erosion-control design for the proposed power plant site. Whatever method is used to prevent erosion here, the construction involved should extend considerable distances either side of the plant, or else erosion will cause such extensive loss of land on each side that the site of the power plant may end up as a promontory or even an island, thus receiving stronger, more concentrated wave attack than when the shoreline was straighter.

Water Supply

The biggest problem created by the location of a power plant on this site relates to its use of water from Sandusky Bay, because the Bay is so shallow (5 to 6 feet deep during most years) and, more importantly, because of the thick (4 to 6 feet) accumulation of soft, semi-suspended mud on the bottom.

In terms simply of the operations of the proposed power plant. the Bay is not too shallow to provide enough water, but, once pumping of this water is begun, the soft mud on the bottom will be so stirred up that high concentrations of suspended materials (mostly mineral; some organic) will be moved through the intake system. Heated water returned to the Bay will not cool readily because of the shallowness of the water there, and the motion of the outflowing water will increase the amount of bottom sediments stirred up and put back into suspension. Even with cooling towers, a small discharge of heated water must go out, and in this restricted Bay, much less dilution of the hot water is possible, as compared with sites located along the Lake Erie shore. In addition, hot water released into Lake Erie can move downward into the deeper, lake water, where maximum cooling and mixing can go on; Sandusky Bay, on the other hand, is too shallow for such processes, with the result that cooling of the released heated water would be very slow.

Environmental and ecological problems resulting from the use of Sandusky Bay water are more critical than are those related simply to the power plant's processes. Increased muddiness, or turbidity, resulting from the action of intake pumps or discharged water, reduces light penetration,thus preventing photosynthesis by oxygen-producing aquatic plants and killing them. Reduced dissolved oxygen is deadly to most aquatic animals, and increased suspended sediment can destroy forms that either live on the bottom or lay their eggs there. Loss of these organisms from the Bay ecosystem means less consumption of organic wastes coming into the Bay from the Sandusky River and other tributaries, thus increasing the pollutant level in the Bay and lowering the water quality there. Such pollutants also use up available dissolved oxygen as they decay, reducing the amount of this essential material even more. Elimination of organisms in Sandusky Bay that are dependent on the environmental conditions of such a large, shallow, relatively quiet body of water might mean their extinction, for such environmental conditions occur in only very limited, widely scattered locations around Lake Erie, and not all contain these particular organisms.

Heating of the water in the Bay can also contribute to the loss or extinction of many of these organisms. Some cannot tolerate excess heat, especially in the juvenile state. Others can live in somewhat warmer waters, but their rates of metabolism and their tendencies to reproduce are increased to the point that the organisms simply "wear themselves out".

Thus the excessive shallowness of Sandusky Bay and the great thickness of soft, semi-suspended mud on the Bay's bottom create the most serious of all the geologic hazards for the proposed power plant, creating problems both for the operation of the plant itself and for the aquatic environment on which it depends, problems that need realistic solutions before expensive construction is begun.

SUMMARY

The site of the proposed power plant is on the south shore of Sandusky Bay, where very flat land, sloping extremely gently down to the north, ends in a low 5 foot high wave-cut cliff. Geologic material present at the surface here is weak, easily eroded lacustrine clay, which is generally saturated and constitutes a very unstable foundation material. This clay extends to a depth of 20 feet, where it lies on more solid, clay-rich glacial till, which is about 40 feet thick, and in turn lies on dolomite bedrock. Between the glacial till and bedrock in most places is a "broken-rock" zone, which commonly carries artesian water under such pressure that water in nearby wells tapping this zone flows at the surface, pressure which may produce serious flooding problems when, during construction, excavation is carried deep enough to penetrate this zone. Bedrock is solid, with many very small water-filled openings; the likelihood of encountering large caves in this rock exists, but is very small.

Shore erosion here goes on faster than in many other areas because of the readily eroded nature of the lacustrine clay and because of the orientation of Sandusky Bay, opening out toward the northeast, the direction from which the strongest storm winds usually come. Average rates of retreat of the shoreline here, for the period between 1820 and 1951, were calculated from a total amount of 1150 feet (a quarter of a mile) to average 9 feet per year; an estimated 20 to 30 feet of shoreline were washed away during the one big storm of November, 1972. Because the land is so very low and flat, it is also very wet and swampy, a problem that, because of the soft, weak clay at the surface, needs careful consideration in the design of this facility.

Most critical of all the problems presented by this site is Sandusky Bay itself, which is shallow (normally 5 to 6 feet deep) and has a layer of soft semi-suspended mud 4 to 6 feet thick on the bottom. This mud is readily stirred up by storm winds, but pumping of water to an intake and discharge of water would greatly increase this muddying, causing excessive intake of suspended matter, which might produce more problems in the power plant system, and serious turbidity in the Bay, turbidity which would certainly destroy many of the Bay's aquatic organisms. This destruction might come as a result of the direct effects of the suspended particles as a result of loss of oxygen because light could not reach oxygen-producing aquatic plants, as a result of sediment settling on eggs, or as a result of water overheating, either natural (due to the sun's heat being absorbed on the suspended particles) or from power plant discharge. Even discharge of minimal amounts of hot water (where a cooling tower is present) creates problems, for the Bay is too shallow to provide good dilution or to permit hot water to be able to sink under and mix, and even a small discharge will stir up this very soft mud, smoothering and suffocating aquatic organisms in the Bay.

REFERENCES

Carman, J. E. 1927. The Monroe Division of Rocks in Ohio. J. Geol. 35, p. 481-506.

Carman, J. E. 1957. In Coash, John R., Bernhagen, Ralph J., and Forsyth, Jane L. Geology of the Central Lake Plain. Ohio Acad. of Sci. Guide to the 32nd annual field conference of Section of Geology, April 20, 1957 (Bowling Green meeting).

Corps of Engineers. 1953. Ohio Shoreline of Lake Erie, Sandusky Bay, Ohio. Beach Erosion Control Study. U.S. House Document no. 126. p. 15.

Erie Regional Planning Commission. 1967. Land Capability Report for Erie County and Townsend Township, Sandusky County, Ohio. Erie Regional Planning Commission, 1200 Sycamore Line, Sandusky, Ohio. p. 158.

Forsyth, Jane L. 1971. Geology of the Lake Erie Islands and adjacent shores. Guidebook for Mich. Basin Geol. Soc. Ann. Field Excur. p. 63.

Lewis, C. F. M. 1969. Late Quaternary history of lake levels in the Huron and Erie Basins. Proc. of 12th Conf. on Great Lakes Res., Internat. Assoc. for Great Lakes Res. p. 250-270.

Lowden, Richard M. 1969. A vascular flora of Winous Point, Ottawa and Sandusky Counties, Ohio. Ohio J. Sci. v. 69, p. 257-284.

Moore, Sherman. 1948. Crustal movement in the Great Lakes area. Geol. Soc. Amer. Bull. v. 59, no. 7, p. 699-709.

Moseley, E. L. 1905. Formation of Sandusky Bay and Cedar Point. 13th Ann. report, Ohio Acad. Sci. 1904, p. 179-238.

Moseley, E. L. 1906. Sandusky Bay and Cedar Point, their formation, the changes wrought by the hand of time, what the waters have covered in ages past, nature's silent forces. Sandusky Daily Register, Sat., Jan. 20, 1906, p. 9-10, vol. 84, no. 262, p. 9-10.

Redmond, C. E., Hole, T. J. F., Innis, C. H., and Wachtman, M. 1971. Soil Survey of Erie County, Ohio. U.S.D.A. Soil Cons. Serv. p. 166.

Shaffer, Paul R. 1951. Shore erosion on Sandusky Bay. Ohio J. Sci. v. 51, no. 1, p. 1-5 (also Ohio Geol. Survey Report of Invest. 7. p. 5).

Stout, W. 1941. Dolomites and limestones of western Ohio. Ohio Geol. Survey Bull. 42. p. 468.