THE LAKE HURON SHORELINE, GRAND BEND TO PORT FRANKS

THE SHORELINE OF LAKE HURON
FROM GRAND BEND TO PORT FRANKS,
AND THE PROBLEMS AT THE MOUTH OF THE AUSABLE RIVER

by

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ABSTRACT

The Ontario shoreline of Lake Huron is one of the most populated areas, with reference to recreational purposes, in Ontario. However, with the rising water levels of the Great Lakes during 1972 and again in 1973, serious problems of beach erosion have resulted, particularly in the area of Grand Bend and Port Franks. This loss of sand has threatened cottages built on the dunes in addition to destroying breakwalls, steps, and boat launching ramps along the beach. It was with the idea of learning more about the beach, and possibly suggesting some methods of beach protection, that the research for this thesis was initiated. During the course of study, the author also became interested in the Ausable River and the associated flooding and erosion problems, with reference to past, present, and future attempts to solve or at least alleviate these difficulties. Thus, one section of the thesis is concerned with the Ausable River alone.

The beach studied is actually the culmination of a series of raised beaches, formed during higher post-glacial lake stages. These raised beaches formed a bar separating the now non-existent Ausable Bay from Lake Huron, forming a lagoon eastward of the beach. This bar extends from Grand Bend, in a southwest direction, and culminates at Kettle Point. However, for the purposes of this thesis, that section between Grand Bend and Port Franks received the greatest amount of concentrated study. Over the years, the lagoon, formed by the growth of the bar has silted up, and is now drained for agricultural purposes.

The modern beach was observed during the summer of 1972. This involved, profiling of a portion of the shore and offshore topography, procuring beach samples for later analysis, the use of sequential air photographs for observing changes over time, and the analysis of wind and wave data, along with many conversations with local residents and personal observations.

The subsequent study of the above factors revealed several major conclusions regarding the beach. First, that it has good natural protection against erosion due to the abundance of sand stored by the dunes. Second, the beach appears to be in an equilibrium state, however as lake levels fluctuate, so must the beach level, thus destroying the equilibrium for a period of time. With the lowering of the water level, the beach will become wider, exposing sand to the onshore winds, which will in turn rebuild the dunes with the blowing sand. Finally, because of the prximity of man-made structures to the beach, on the unstable dunes, some method of stabilizing the beach is necessary. That suggested is a groin system, designed and constructed by the local authorities. This would help prevent erosion and would eliminate the often vain and possibly dangerous, (to the natural environment), attempts by individuals to halt erosion.

This is by no means a complete study of the area and its problems. Further consideration should be given to proposals which have been presented to the local conservation authority, and which were designed to alleviate some of these problems, particularly at Port Franks. The suggestions made here should also be given further thought. In addition to these practical problems, the actual growth of the original bar would provide an interesting subject for study.

ACKNOWLEDGEMENTS

The author would like to use this space to thank the many who have assisted in the research and the writing of this thesis. First, I would like to thank Dr. S. B. McCann for first introducing me to the study of beaches, and for his patience and encouraging words and smile, paricularly toward the end of the project. I also wish to thank Dr. P. Howarth for purchasing the rquired air photographs for this study. The assistance of both the Ministry of Natural Resources, and the Ausable-Bayfield Conservation Authority, in particular that of Mr. Roger Martin of the Conservation Authority were invaluable to the succesful completion of this thesis. Also I would like to thank those cottage owners in the Port Franks area whose cooperation and assistance was absolutely essential for the succesful completion of the field work. To all those who helped in any way, thankyou, and in paricular I wish to express my deepest thanks to Ms. Mary Hall, who helped me with much of the field work, typed most of the thesis, and generally put up with me, the numerous days after a late night of sieving, drawing profiles, or just plain working. Thank you all so very much.

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Preface

It has become apparent that the real purpose of retaining walls on the seashore is often not fully understood. Quite often, proposals are put forward to use them to protect beaches. These proposals are quite wrong in principle, since experience has shown that these walls will eventually lead to the destruction of the beach proper.

Where a natural beach exists, the sea will remove large quantities of sand from the dune system during periods of heavy wave attack. This sand is deposited offshore in a bar. During calm weather, it is returned to the beach and the dune by the actions of the sea and wind.

Natural beach restoration can occur only when the incoming waves are allowed to dissipate their energy on a gently sloping shore. If a rock wall exists, the waves are reflected off its steep face and carry the sand back out to sea, thus preventing beach restoration.

Where a rock wall has been built on a beach, restoration work can be carried out only by pumping sand and building a dune to cover it.

Sometimes it is suggested that a rock wall can protect dressing sheds and toilet blocks situated in the buffer zone between the developed area and the sea. As the whole purpose of the buffer zone is to allow periodic natural beach erosion, nothing needing such protection should be located in this area.

By observing this principle of beach conservation, the need for rock walls can be largely eliminated. After all, they do nothing for our beautiful beaches either technically or aesthetically.

The construction of rock walls along a beach, as considered above by A. J. Peel, Chairman of the Beach Protection Authority of Queensland, Australia, (from the newsletter for the American Shore and Beach Preservation Association, September, 1972,) is not only a problem in Australia, but has been a policy followed in Europe for many years. In some areas, such defences may be necessary, while in others, a better method of beach protection may be indicated.

With the erosion problems on the Canadian shorelines of the Great Lakes, the existence of breakwalls or seawalls is becoming more obvious. Certainly they are not as prominent as those in Lincolnshire, England, for example, but they are common. Their structures may range from cemented walls, to purely timber walls, to rubble walls. All of these indicate a lack of understanding, as stated by Peel, of the beach processes involved. Therefore, this thesis is not designed to do a purely academic study of a beach, but to consider the past and present beaches with references to the problems which are found. These problems are simply the conflict of natural forces with the human element. All of these problems could have been eliminated if those who built the cottages and houses had used some foresight in choosing their building location, specifically, above the river flood plain, and a sufficient distance inland from the shore to dispel the fear of sand dune erosion.

Chapter One : Introduction

The area to be investigated in this paper is a post-glacial beach on the Southeast shore of Lake Huron. Emphasis will be placed on the section of the beach, from Grand Bend, south through the Pinery Provincial Park,to Port Franks. Nevertheless, an overview of the surrounding area will be considered in order to present a complete picture.

Grand Bend is a resort town on the shore of Lake Huron, approximately 30 miles south of Goderich, 22 miles northwest of London, and 25 miles northeast of Sarnia. The village of Port Franks, approximately 6 miles south of Grand Bend, also consists largely of cottages, though its tourism is not as highly developed as that of Grand Bend. Figure 1.1 indicates the relative position of the research area.

The outlined section of Figure 1.1 approximates the study area which is shown in further detail by Figure 1.2. On this map, it is possible to note some of the general features and places which will be referred to throughout the paper, such as the curving beach between Grand Bend and Kettle Point, the major highways, towns and villages, and the drainage system, in particular, the Ausable River, The Cut, and the Parkhill Creek System.

Briefly, north of Grand Bend,there are boulder-clay cliffs, being actively eroded. Between Grand Bend and Kettle Point lies a major beach system consisting of sand,and a lesser amount of cobbles over its entire length. Behind this beach system lies a succession of

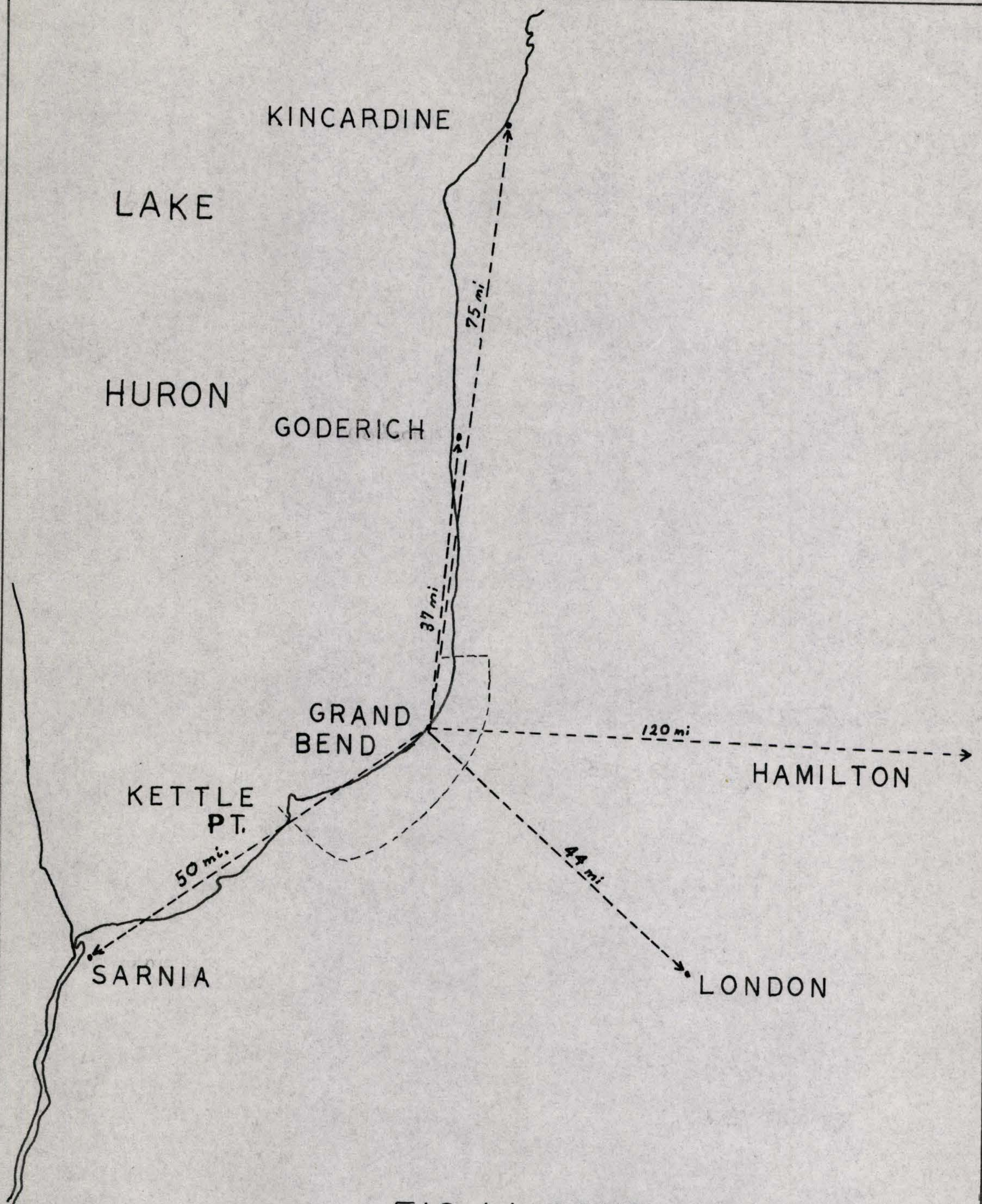
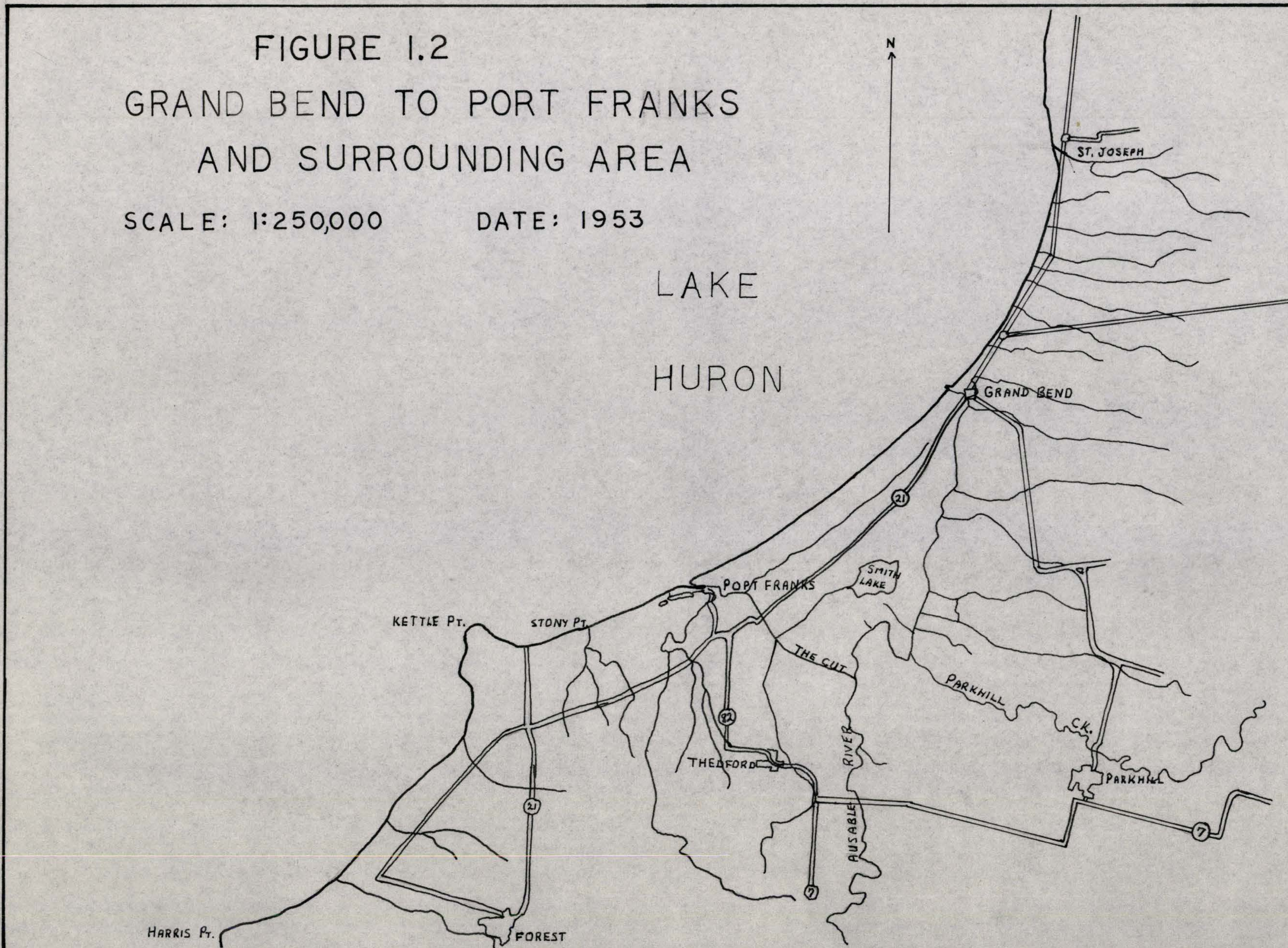


FIG. I.I SOUTHWESTERN ONTARIO

SCALE: I" ≡ 2 mi.

FIGURE 1.2
GRAND BEND TO PORT FRANKS AND SURROUNDING AREA
SCALE: 1:250,000 DATE: 1953



sand dunes, which have been built on what will be referred to as a bar. This bar separated the Ausable Bay from the present, and formed a lagoon, which has largely been infilled and drained, except for the area known as Smith Lake. From Port Franks to Kettle Point, the beach continues, interrupted only by the bedrock outcrop at Stoney Point. The objective of this paper is to study the processes and responses inherent in this area, and to relate them to the interaction of the various distinct parts within the area. This will involve such factors as flooding and erosion, human interference, and conservation.

This study has been divided into seven chapters, each accompanied by appendices, where appropriate. Chapter two will take into consideration work done previously on the whole area or any specific section. In addition, the setting of the site will be described under such headings as climate, topography, geology, winds and drainage. This will be followed by a detailed description of the site, according to the subdivisions most valuable to this study. The major human influences will also be integrated here, though briefly, as they will be considered in greater detail later.

The third chapter will be concerned wholly with evidence of changes in the beach zone. For the purpose of this chapter, the beach zone will be considered as the bar, or that area which at any time since the last glaciation has been the beach, and what at present is encompassed by the bar. First, the most obvious and simple field observations will be used, information that would be obvious to any interested person walking along or boating near the beach. Second, historical maps and air photographs, of which excellent stereo coverage has been obtained, will be used to denote the large scale changes which occur or have occurred over a considerably longer period of time. Lastly, a series of beach profiles, which were obtained for a section of the beach, will be observed and commented on.

The analysis of the beach sediments, both on the present shoreline, and from some older ones which are accessible, will be considered and will comprise chapter four. The study will involve general observations made in the field, and also the grain size analysis done in the laboratory. The major minerals comprising the sand will also be considered in this section.

A summary of the winds and their effects on this area will be considered in chapter five. This will also involve the use of Bretschneider diagrams to hindcast for the resultant waves of various storms. From this information, it will be possible to see the energy of the wave regime as it interacts with the shore and beach zones.

Chapter six will incorporate a detailed study done by the author, on the Ausable River and its drainage basin. Some comments will be made on the area behind the bar, which is essentially a vegetated and nearly dry lagoon. The emphasis will be placed on the river channel, The Cut, and the interference by man, as he attempts, or has attempted, to control flooding and erosion problems associated with the river and the beach.

The seventh chapter is designed to look at the whole thesis area, to observe the problems which arise as man encroaches on nature's realm, in this case a very delicately balance one. These problems will be outlined and discussed, considering the information contained in the previous chapters. The various attempts at controlling, or at least subduing, these problems will be surveyed with the intention of critically evaluating them. Existing proposals for future implementation will be included, and then the authors personal suggestions will be brought forth. These suggestions will be based on the ideas of protection and development, as an integrable part of the preservation of the natural state, to as high a degree as possible.

The final chapter will synthesize all of the information discussed earlier, along with the suggestions alluded to in chapter seven. Reccommendations for further study in this area, which might prove helpful in understanding and maintaining this natural balance, will also be suggested. Finally, the thesis as a whole will be critically evaluated, with a subjective assessment as to its worth, both academically and socio-economically.

Chapter Two : Description of the Site

Setting

Several authors have considered the Grand Bend/Port Franks area in works of varying depth, and stressing a considerable range of topics. The earliest reports on the area were concerned with the bedrock geology, both for academic and economic reasons. About the turn of the century, considerable exploration was being done in search of the oil and gas, which had been discovered at shallow depths within the bedrock. In addition, the growing salt industry farther south, towards Windsor and Sarnia, provided the stimulus for more study. Early geologists, namely Chalmers, 1902, Williams, 1912, and Coleman, 1909, have gone into depth on this topic, along with some more recent authors like Caley, 1943, and Antevs, 1934. Thus the discussion of the geology will be limited to a few brief comments, largely absracted from the Ausable Valley Conservation Report,(1949), and a masters thesis presented by N.L. Nicholson, (1949).

The surface geology is important in that it largely determines the surface relief, due to the fact that the movement of glacial ice is largely governed by the bedrock. Consequently, the deposition of the unconsolidated glacial material, which is largely responsible for the relief, was controlled by the more permanent rock. The Palezoic, sedimentary strata of this area dip gradually to the south-west from the higher Niagara Escarpment, at a rate of 20 feet per mile.

The surface of the bedrock is exposed in several locations, although it is the Hamilton Formation, a soft blue and grey shale, and grey limestone, which appears at the surface at Kettle Point and Stoney Point. At Rock Glen, near Arkona, the Ausable River has cut a gorge through the highly calcareous bedrock of this area.

Of more importance to this particular study is the local physiography. As previously mentioned, this is the direct result of the recent glaciation, in addition to the gradual lowering of the lake level, relative to the land. The preservation, in this area, of beaches associated with the post-glacial lakes, such as Lakes Warren and Algonquin, have led to considerable research, for the purpose of tracing the glacial and post Wisconsin glacial history. Early investigations were conducted by Jefferson, (1903), Goldthwaite, (1910), Taylor, (1895,1913) and Spencer,(1891), all of whom generally considered the raised beaches and the moraine systems east and south-east of Lake Huron. Coleman,(1901), proposed that all of these beaches were formed at or near sea level. This would account for the large numbers of shells or shell fragments in the beach ridges. The lowering of the land was due to the weight of the ice. He con-clude that the beaches were entirely post-glacial and that the decreas-ing water levels are associated with the rebounding land, rather than being so dependent on the elevation of the outlet. More recently, additional study has been done in this field, particularly by Hough,(1963) and Chapman and Dell,(1963). These studies are refinements of the earlier papers, and are summarized by Chapman and Putnam, (1966),

FIG. 2.1 PHYSIOGRAPHIC AREAS

- Till Plain
- Moraine
- Spillway
- Beach
- Sand Dunes
- Lake Plain
- Peat Bogs & Muck

from CONSERV. AUTH. REPORT, 1949

and also in the Ausable River Conservation Report of 1949.

Figure 2.1 outlines the major physiographic areas associated with the Ausable River Watershed. Although this thesis is concerned only with the more westerly fraction of this map, it is important to see the whole area. Basically, the surface relief can be divided into two main features- (i) the flat expanse near Lake Huron, with elevations from 600 to 800 feet, and (ii) an upland region from 800 to 1100 feet above sea level. This flat country consists of post-glacial deposits of silt, sand, and clay, or of glacial deposits smoothed and veneered by the action of water. This area, outlined in Figure 2.1, is comprised of (i) a large expanse of till plain, (ii) beach ridges, distinctive by their shape, which outline the former bay, (iii) peat bogs and much of the former lagoon area, and (iv)sand dunes, which overlay the bay-mouth bar. The upland region as indicated on Figure 2.1, is dominated by north-south trending ridges of moraine type material, with the elevation increasing from the west to the east.

The Grand Bend-Kettle Point area may be considered to have a contininental temperate climate, which is moderated slightly with the presence of the lake. The winter temperatures fall below 32 degrees F., while temperatures in the 50-70 degree F. range occur during the summer. The precipitaion is evenly distributed throughout the year. Also, the prevailing westerly winds blowing across the lake, pick up moisture, which falls as precipitation over the land. This tends to increase the amount of snow during the winter months, for a considerable distance east of Lake Huron. During the summer, besides the precipitation from the passing low pressure areas, heavy downpours often occur in the late afternoon. These are convectional storms, of high intensity, but of limited duration.

The major winds are the prevailing westerlies. In addition to their role in increasing precipitation, they are also primarily responsible for the waves that are produced. The longest fetches (i.e. distance over water which wind can blow to produce waves) are the northwest and the west. Therefore, these winds are the dominant sources of large waves, while southwest winds are of a lesser importance.

Since this area experiences several winter months of below freezing temperatures, ice plays a role in the process- response system. The rivers and streams in the area are completely frozen early in the season, while the lake freezes later in the season but only along the shore. This depends on the severity of the winter, for example, the mean winter temperature of 1973 was generally above average, and thus, the extent of lake ice was less than normal. Another factor worth mentioning for this study is that as in all of the Great Lakes, no tides exist. This tends to simplify the problem, as the lake level can be assumed to be constant in the short run. Obviously though, on a yearly basis, considerable fluctuations in the lake level will occur.

The major drainage system for this portion of the Lake Huron shore line is the Ausable River. Other smaller streams and tributaries exist, of which the major one is the Parkhill Creek System. Many short, often intermittent streams, drain directly into the lake.

Site Description

In order to simplify the study area, it has been subdivided into six major areas. These are outlined on the map and will be described in detail. This is the area the thesis was proposed to study, and it is largely indicated on Figure 2.2, (in map pocket), with some consideration of the north and south extremes of the map. The subdivisions are- (i) the present beach between Grand Bend and Port Franks, (ii) the sand dunes area which overlie the older beach sediments, which together form the bar, (iii) the Ausable River and its associated flood plains, including both its present and former courses, (iv) the swamp and lagoon area immediately to the east of the bar, and including in part the Ausable River and Parkhill drainage systems, (v) the beach and boulder-clay cliffs north from Grand Bend to St. Josephs, and finally, (vi) the beach area south of Port Franks to Kettle Point.

(i) The Beach : Grand Bend to Port Franks

The beach is composed of a large amount of medium to coarse grained sand, with cobbles being abundant but to a lesser extent. The sand is predominantly silica and calcite grains, thus accounting for the light beach texture. The cobbles are variable with regards to rock type, however they tend to be well rounded, often with one or two flat surfaces. This is probably a result of friction on one surface, as it is moved along the beach without being overturned. The trend of the beach north of Grand Bend is north-south, however at Grand Bend it curves in a southwest direction towards Sarnia. Between Grand Bend and Kettle Point, the beach is crescentic, although in an extremely gradual way.

The actual beach begins south of the pier at Grand Bend, and for purposes here, is taken to end at the mouth of the Ausable River. From initial observations, it would appear that this is an active beach, with material being moved from north to south. This is directly related to the prevailing wind direction and the longest fetches. South of Grand Bend, the beach appears to be actively eroding, while towards Port Franks, the deposition of some of this sediment load is obvious. An oblique ridge and runnel system is developed in the near shore zone, which culminates in a spit, encroaching on the mouth of the Ausable River.

At the present time, the beach is narrow ranging from 0 feet south of Grand Bend, to roughly 100 feet at Port Franks. This is largely a function of the lake levels, though. The high level at present will result in a narrower beach, while any lowering of the water level will most certainly increase its width. This narrow beach allows the waves to contact the sand dunes, behind the beach. These dunes, composed of well sorted, fine to medium grained sand, and having only a sparse vegetation cover, are thus easily eroded. Once this sand is removed from the dunes, it is easily transported downdrift by the longshore currents and littoral drift. Carlson (1972) would classify this shoreline as L.D.- that is a low sand dune, less than 30 feet high.

The beach itself provides excellent opportunity for lakeside recreation. Approximately,31,000 feet of beach is controlled by the Ministry of Natural Resources, while the remainder is backed mostly by privately owned property, and to some extent by lots leased from the Ausable River Conservation Authority. This recreational use not only indicates the necessity of preserving this beach, in a clean natural state, but also adds certain stresses to the delicate balance which occurs at the water-dune confluence.

(ii) The Sand Dunes

The sand dunes cover an extensive area,from Grand Bend, through the Pinery, to Port Franks, and to the area between Stoney Point and Kettle Point. The highest dunes occur in the area of Port Franks. To the south and to the north, the height of the dunes diminishes, although this is very gradual, in the direction of Grand Bend.

The dunes are actively formed in parallel bands along the shore. The oldest dunes, and consequently the most heavily vegetated ones, are farthest from the shore and are easily visible from highway #21. The age of the dunes toward the shore decreases, along with their stage of vegetation cover and their stability. The dunes right on the shore are sparsely vegetated, and thus, are easily eroded. This results in numerous blowouts in the dune ridges, along with the active erosion which occurs at the sand water interface, as mentioned previously. Sparling (1965) studied these dunes, which have been forming during the past 8,000 years, since the existence of Lake Algonquin. He described a series of three dunes, each separated by a'low'. The first dune ridge may be twenty to thirty feet in height, and represents the most recent accumulation of sand. The second dune ridge, which is the highest according to Figure 2.3, is reasonably stable due to its vegetation cover. The lower, third dune ridge is even more stable, as the vegetation has had a longer period in which to develop. Sparling stresses the warranted concern, however, that although these dunes may be largely stable at the present, they could be easily destroyed by such disasters as fires. The removal of the protective vegetation would result in the dunes becoming unstable, like the smaller dunes near the shore.

An investigation of the dunes on the north bank of the Cut, at highway #21, revealed that these dunes also appeared to have grown in several stages. Plate 2.A and 2.B show several darker soil horizons within the dune, which would indicate a period of stability during which plants were able to populate the dune. The reasons why this stability was lost and the drifting reestablished is beyond the scope and purpose of this paper.

Before leaving the dune area though, it is necessary to mention that they have been built entirely on the beaches of the post-glacial lakes. These raised beaches are the remains of Lake Algonquin in its latter stages, and of Lake Nippissing, as well as the present Lake Huron. (Nicholson, 1949)

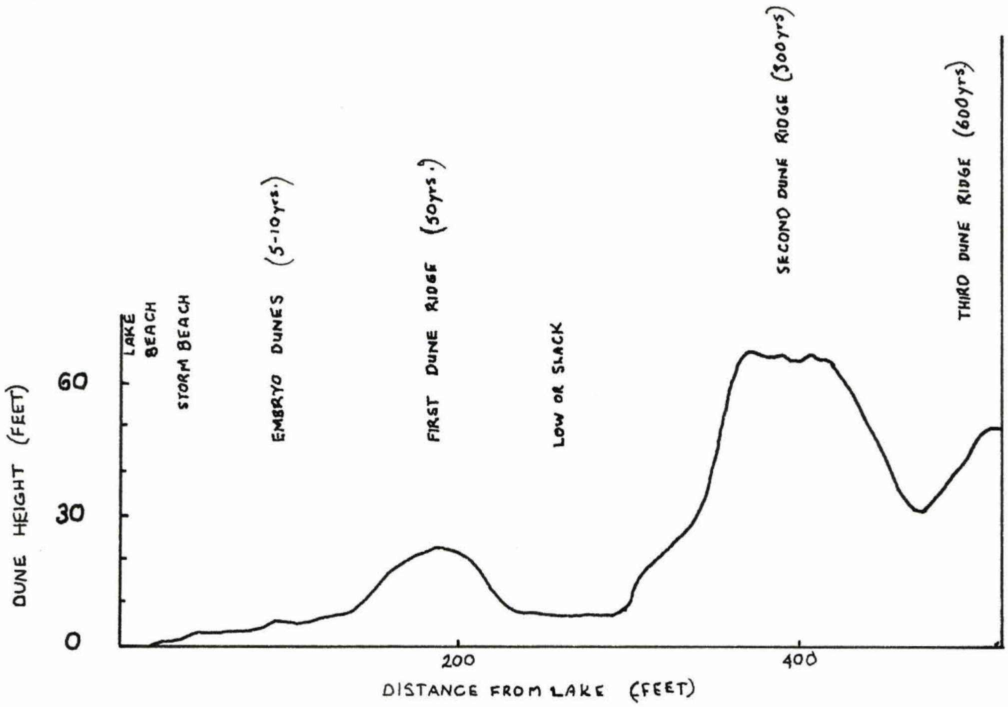


FIG. 2.3 PROFILE OF SAND DUNES

SPARLING, 1965.

Plate 2.A : The raised shoreline, overlain by wind blown sand on the north bank of The Cut, just downstream from the highway 21 bridge.

Plate 2.B : The same location as above, showing darker soil horizons inthe sand near the top of the dune.

(iii) The Ausable River

The river to be considered is made up of the Ausable River proper, The Cut, and the Parkhill Creek system. The river has had an extremely interesting and complicated history. Before the arrival of man, its channel and mouth wandered gradually southward, forced by the building of the bay-mouth bar. In more recent times, the mouth of the river has been centred around Port Franks. This is obvious by the large number of oxbows and meander scars in the area. The arrival of man has had an important effect on the river also. Not only have dams been built on the river, but also major realignments, such as The Cut, have been carried out.

The two main problems associated with the Ausable River are the flooding of the low-lying lagoon and flood plain area, and the erosion of the channel and subsequent wandering of the river. With several attempts to alleviate these problems, of which there has been little success, it is necessary to study the river in reference to the problems mentioned above. This is the subject matter of chapter six. In addition to this material, the almost complete closing of the river mouth, by the sediment carried by longshore currents, will also be considered.

(iv) The Swamp and Lagoon Area

This area, once a lagoon, has been infilled largely due probably to the suspended sediments which were carried into the lagoon by the Ausable River. As the lagoon was filled and the lake level was lowered relative to the land, the river was forced to seek a channel through the lagoon and flow directly into the lake. It is impossible to explain why this channel is along the north side of the lagoon, although it may be associated to a slightly more rapid rate of isostatic rebound in the south. Nevertheless, the river reached the lake and maintained a channel through the bar. The rate of infilling of the lagoon would consequently be slower now, as it would only have its own organic debris, plus a small amount of organic material which would be deposited in the lagoon, outside of the channel during the floods.

This is essentially the present situation of the lagoon. However, when The Cut was excavated in the late 19th century, it served to drain much of this area, so much so that only Lake Smith remains. The rest of the land provides excellent acreage for market gardening. Flooding does still occur in the lagoonal area, although this is generally during the spring runoff. The sudden flash floods, due to the torrential summer storms, cause the main problem in this area though, as the flooding will destroy delicate crops.

(v) Grand Bend, north to St. Josephs

Although beaches exist north of Grand Bend, they are generally less extensive than those to the south. They are smaller and are separated one from the other by minor outcrops of less erodible cliff material. The sand dunes and older beach deposits no longer lie behind the present beaches. The beaches are backed by boulder-clay forming erodible cliffs, which are increasing in height, to the north of Grand Bend. Carlson (1972) would classify them as H.B.E., high bluffs, 30 feet or higher and consisting of erodible material. Just south of St, Josephs, the beaches have generally disappeared, and the waves are actively undercutting the base of these cliffs, which have a maximum height above the lake of 50-75 feet. The cliffs extend almost as far as Clark Point.

In addition to the active erosion occuring at the land-water interface, this area of reworked boulder-clay, with few boulders remaining, has been dissected by a series of small, but deeply entrenched streams. The area, in its natural state, is poorly drained due to its flatness and clay matrix. Any disturbance of the natural vegetation cover, or natural drainage, such as tile drains, will cause the bluffs to actively erode at their face. Headward cutting occurs very quickly after this point, and it is only a short time before the deep gullies have been cut into plain. These gullies occur with an average frequency of 3 per mile, or approximately 28 in 10 miles, varying in length from fifty feet to almost 4 miles. Many of these gullies are recent features, resulting from such things as (i) removal of forest cover, (ii) increased and accelerated drainage, (iii) installation of drain tiles, (iv) no provision of a conduit to carry water down the cliff face, (v) straightening of drainage channels, and (vi) the cultivation of fields right to the edge of the cliff or gully. (Conservation Report, 1949) Combining these factors with erosive mechanisms results in a considerable amount of transportable material being introduced into the longshore currents. The effects of this situation will be discussed more fully at a later time.

(vi) Port Franks to Kettle Point

A brief study of air photographs of this area show that this is possibly one of the most interesting and yet probably one of the least studied sections, of the whole thesis area. Other than the few brief comments included here, this thesis will largely avoid this area. The two predominant and controlling features are the outcrops of bedrock at Kettle Point and Stoney Point. Both are covered by some unconsolidated material, however they do project into the lake. Thus they tend to act as a barrier to longshore transport, and effect the resultant beach pattern.

A series of raised beaches are very obvious in this area. They are outlined by vegetation and tend not to be overlain by blown sand as in the area between Port Franks and Grand Bend. Within these raised beaches exist areas of water, which were once channels belonging to the Ausable River, and obviously reached at least as far as Stoney Point at some time in the past. Figure 2.4, a map reproduced from air photographs during the years of 1963, 1966 and 1968, shows these features.

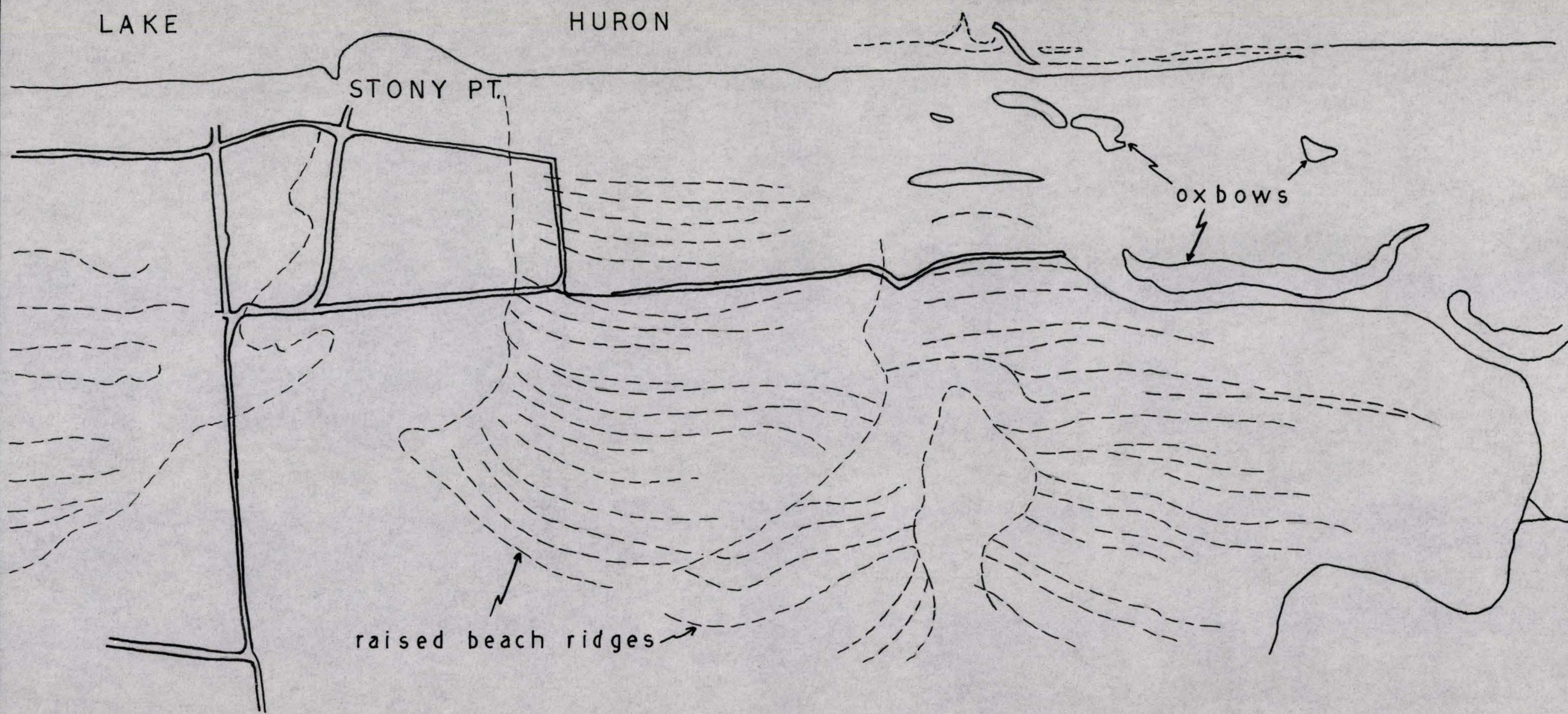


FIG 2.4: EVIDENCE OF RAISED BEACH RIDGES IN THE STONY PT. AREA

SCALE = 1:14,000

Chapter Three : Evidence of Changes in the Beach Zone

The evidence for erosion and/or deposition along the whole beach, from St. Josephs to Kettle Point, can be considered in several ways. First, there are the long term changes which were observed using old maps and sequential air photographs, for the period that this material is available. The second possibility is simple qualitative description , outlining obvious changes which occured in the beach zone during the period that the site was studied. Finally, a detailed and accurate study was done on the changing form of the beach and the near shore zone, during the period of August 20th to September 17th, 1972. This latter investigation, when related to the energy systems involved over the same period of time, will add quantitative description to the changing beach form. The first two descriptive methods will cover the whole thesis area, while the third will be concerned only with the portion of the beach extending from within the Pinery Provincial Park to the mouth of the Ausable River.

The growth of this bar, both with respect to length and breadth, shows that a considerable amount of energy has already been expended. Observation of maps indicate that the bar has, since the arrival of the earliest white settlers, maintained its present shape. The whole bar extends from Grand Bend, as far south as Kettle Point. Thus the dimensions of this bar, which is roughly triangular in shape, are at least 15 miles in length by approximately

2 miles in width at Port Franks. The width was determined at Port Franks, as it was easy to identify the extent of the beach deposits along the Cut. The bar decreases in width from Port Franks to Stoney Point, until it reaches Kettle Point where it curves to the lake, following the rock outcrop there.

Figure 2.4 indicates the raised beach ridges present in the Stoney Point and Kettle Point area. They were mapped frome the 1963, 1966 and 1968 air photographs, and indicate at least 20 recently formed beach ridges. Landward from the oldest ridge, there may be others, however, they are concealed by low sand dunes and a heavy vegetal cover. Between the youngest beach ridge mapped and the present shoreline, it would appear that the beach deposits have been reworked by the meandering Ausable River, which must have, at some time in the past, had its mouth in the area of Kettle Point. This conclusion is substantiated by the water filled depressions, which are actually remnants of the former channel. The existence of several of these depressions indicate that the channel probably wandered considerably during the time it was in this area. It would appear that it was forced further and further toward Stoney Point by the longshore drift, resulting from the major northwest storms. Thus, the width of the beach, reworked by the Ausable River, decreases towards Stoney Point, while the number of visible raised beach ridges increases. For some reason, unknown to the author, the mouth returned to the Port Franks area, at some time prior to the arrival of the early settlers, and has remained there till the present time. The main point being made here, however, is the present existence of some beach ridges, while others have probably been buried by sand dunes or reworked by the river.

Since air photograph coverage was available for the Port Franks area, from 1949 to 1968, it was felt that detailed maps, at the scale of 1: 14,000 would be valuable in delineating any significant changes which have occurred on the beach during this period. These maps have been reproduced from aerial photographs, however they were not corrected for distortion of any kind. Nevertheless, they are quite sufficient to indicate the changes which have occurred. In addition, the Grand Bend area was mapped at the same scale, from air photographs ranging from 1955 to 1966. These maps should also indicate changes which have occurred. Since the lake level plays an important role in determining whether the beach will be eroded or built up, the results from the maps will have to be related to the lake level at the time. These maps have been included as appendix I, and will be referred to throughout the following comments. However, only changes on the beach will be considered in this chapter. The discussion of the changes of the course of the Ausable River will be reserved for chapter six.

Although the earliest coverage is limited to the Port Franks-Ausable River area, the photographs are very interesting. Not only do they show the shape of the beach, and the mouth of the river, but also three offshore bars, outlined quite distinctively. From general observation, these bars seem to be quite similar to those found along the beach during 1972. For ease of reference, the lake levels have been included in Figure 3.1, for the years 1945 to 1971.

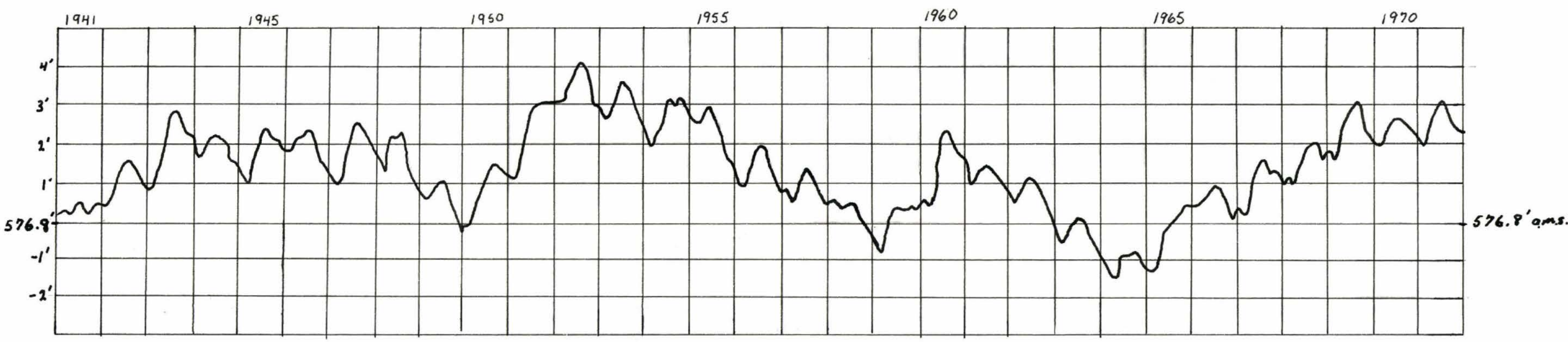


FIG. 3.1 LAKE HURON LEVELS, 1941 TO 1971.

At the approximate time of these photographs, Lake Huron would have had a lake level of roughly 578 feet above sea level. This level is on the declining limb of the lake levels, however, it is at least 2 feet below the expected lake level for 1972. Thus, the beach might be expected to be narrower, but not to have cut as far into the dunes as in 1972.

Air photograph coverage for the year 1955 was very good, and at a scale readily applicable to this study. One obvious change in the beach is the new channel which was dug in the hope of solving flooding and erosion problems on the Ausable River. The effect of the longshore currents on both of the exits is striking in this map, as both have been narrowed considerably. Once again, the bars close to the shore are well outlined on this map, except for the area at the mouth of the new channel. The bars appear to be fairly regualar, until the river 'mouths', where there is a tendency for them to widen and thus extend further into the lake. This situation of a very narrow beach, yet one which is in about the same position relative to the dunes, occurs again as the lake levels decline. Lake Huron reached a very high level of over 580 feet above mean sea level in 1952, and then declined somewhat to a level of approximately 578.5 feet by 1955. This high level of 1952 was probably comparable to that of 1972, and had the air coverage been available at the time of writing this thesis, some interesting comparisons could undoubtedly have been made.

The map for 1963 was also rather extensive and further indicated the effects of the longshore movement of sand, as evidenced

by the almost complete closing of the new mouth of the Ausable River. The small amount of water escaping through this extremely narrowed mouth was barely maintaining a route through the beach sand. In fact, this route was open only occassionally and soon to be closed completely. Lake Huron's water level dropped to 576.8 feet in 1963, approximately two feet lower than that in 1955. Incidentally, since beach gradient in the Port Franks-GrandBend area is low, a drop of two feet in the water level will have a highly significant effect on the beach.
In this case, the foreshore, or upbeach zone is wide, much wider than that of 1955, and even wider than that of 1949. Also, the dunes behind the beach have moved a considerable distance in the direction of the lake, relative to their positions in both 1955 and 1949. (Actual measurements of these changes are not included, basically since the upper limit of the beach zone was determined purely subjectively and thisalone could account for some of the changes.
In most cases however, it was chosen as the position of the bluff behind the beach or at the first evidence of vegetation.)

By 1966, the lake level had risen to approximately 577.5 feet, 1 foot above the 1963 level, and three feet above the minimum lake level of 574.5 feet recorded in 1964, and again in 1965.
The map indicates the complete closing of the man-made river mouth, while the original channel has been narrowed by the build up of sand on its northern most bank. Except for some small changes, the 1966 map is very similar to that of 1963.

The air photography for 1968, although of excellent quality, and quite extensive, was flown at an altitude of 15,500 feet using a camera with a focal length of 3.48 inches. Because of these two factors, the photographs were at a scale of approximately 1:52,250. This small scale made reduction to 1:14,000 difficult and inaccurate. Therefore, this map is not to be considered as being even as accurate as the four previous maps. For the reason given above, a map of the Grand Bend area was not produced , as it was felt that the inherent inaccuracies would far surpass any benefit that it might have provided. Generally though, this map shows continued longshore transport of sand, with a possible narrowing of the foreshore zone, all occurring with the water at an elevation of roughly 578.5 feet above mean sea level.

The maps of the Grand Bend area for the three years, 1955, 1963, and 1966, show two trends. The first is a general buildup of beach sediments on the north side of the pier, while the south side fluctuates. The foreshore zone, south of the pier is narrowest in 1955, following the high water levels of 1952 and 1953. This situation is similar to that observed in 1972, with the beach south of the pier being both narrow and actively eroded. This apparent starving of the beachsouth of the pier appears most obvious then during periods of high lake levels. Again, the possibility of a cycle of high and low lake levels seems apparent, resulting in a gradual widening and narrowing of the beach and migrating of the shoreward extent of the beach into and away from the dunes.

Qualitative Description

The observation that sand is being moved along the beach could be made by any person walking along the beach, or swimming in the water, when there are breakers at least 2 or 3 feet high. The littoral drift of pebbles and the suspended beach material is obvious, and is directly related to the height of the waves. The changes in the beach become even more obvious if the observer becomes familiar with the beach during the summer, and then continues to return and inspect it frequently during the fall. This is possible not only as the result of a longer period of observation, but also because the frequency and intensity of the storms increase in the fall. This same routine of observation was used by the author in this research.

The beach from Pinery Provincial Park to Port Franks, which is of major concern here, was first observed on June 4th, 1972. It was at this time that the beach was first discerned to be actively eroding its shores, even though the waves on this day were quite small. It was also on this date, that further study was decided upon, in order to determine the process-response system of this beach.

The beach could not be revisited until August 22nd, of the same year. This stay was planned to last only a month, at the most, during which the field work and general observations were to be completed. In this period, the profiles were surveyed and the waves and changes on the beach were monitored. However, before the discussion of the profiling, it is felt that a qualitative description of the beach would be beneficial.

Throughout the length of the Pinery Provincial Park, (hereafter referred to as the Pinery), the beach is generally narrow, roughly 20 to 30 feet behind which is a low dune bluff. This bluff may range from several feet to 10 feet at the most. Southwest of the park boundary, the height of this bluff steadily rises, culminating at its highest point of about 20 feet, on the north bank of the Ausable River. The existence of this almost vertical bluff adequately indicated the erosion. However, near Port Franks, where the bluff is highest, and the poplar trees are of substantial size, the erosion was made even more obvious as several of these trees had fallen to the beach at the base of the dune. During the fall, this bluff was eroded even more, and several more trees fell. This situation is illustrated in the photographs, Plate 3.A and 3.B, which were taken at the site of profile 180. Plate A was taken during August, while B was taken in October, and therefore shows how much more of the bank has fallen during September and October.

These two photographs also introduce another point of interest, specifically the protection systems. During the summer, two methods of shoreline protection were in existence, or in the process of being built, by cottage owners, on this section of the beach. At profiles 070 and 190, timber breakwalls were constructed several feet in front of the bluff. The one at 070 consisted of cement supports, while the other was built completely out of wood. Both were designed to protect the bluff from erosion, but only in front of the cottage of the respective owner. The breakwall at 190 was reasonably effective

Plate 3.A : The sand dune cliff just north of the mouth of the Ausable River, August, 1972.

Plate 3.B : The same as above, October, 1972.

at least until December 14th, after which time no more visits were made to the area, in the expectation of a general freeze up. It is doubtful though, that this wall remained all winter, as high waves had overtopped it and removed much of the supporting sand behind it. King (1972) has determined that breakwalls tend to cause the beach to be eroded in front of them, thus allowing an ever higher, and thus stronger wave to attack the wall. It appeared that at least one other breakwall on the same site had been destroyed by the attacking waves. The breakwall at profile 070 was much less successful than the former, as by early October, it had largely been destroyed.

Plate 3.A indicates the other type of shore protection attempted on the beach. In discussing the problem with the owner, the author was informed that the purpose of the tires and sand bags was to build up the beach in front of the bluff, and thus provide the best known natural protection against erosion. The owner recognized the problems of breakwalls; that due to the abrupt manner in which they halt the swash, breakwalls increase the backwash and cause the beach to aggrade. He also understood the problem of extreme energy expended on such walls, thus requiring considerable time and labour in their construction. Nevertheless, he too resorted to the timber breakwall, Plate 3.B, during the fall, due to certain inherent weaknesses in his first plan, to save his cottage and its sewage system, which were very close to the edge of the bluff. As a point of interest, he had lost his well sometime prior to August 20th, 1972. All of this information will be considered in reference to the profiles and in later discussion.

Additional evidence of sand transport is indicated in Plate 3.C. Although in a minor way, with the altimeter indicating scale, this photograph provides an indication of what is occurring at the mouth of the Ausable River. This recurved spit has been built by low waves from the northwest. This small spit is joined to a much larger one, which is attempting to close off the mouth of the Ausable River, or force it to migrate south, if the latter was possible. This is an interesting photograph as it indicates on a small scale what happens on a much larger one, with stronger winds producing much larger waves.

One other major source of evidence that this beach is undergoing important changes, is the general lowering of the beach. This was obvious all along the beach during the summer, as almost every set of steps from cottages down to the beach had, at one time, had one or more steps added at the bottom, in order to reach the level of the beach. This lowering was associated with erosion at the bluff face, although it was not always too obvious as the beach remained generally one width, and only over an extended period of time could significant erosion be noticed. This is adequately indicated by Plate 3.D, showing a set of steps, used during the summer, but going nowhere by October 30th, 1972. Actually, the beach had been cut back by several feet. This rate of sand removal was constant for nearly the whole length of the beach.

Personal communications with some of the cottage owners indicated that the erosion problem was severe. Some estimated a loss

Plate 3.C : A small recurved spit built on the much larger on at the mouth of the Ausable River.

Plate 3.D : Erosion along the beach, to the north of Port Franks, October 30, 1972.

of approximately 25 feet of property, (sand dunes), from the front of their cottage in a one year period. A loss of approximately 40 feet was estimated for the two year period prior to the summer of 1972. Most of the cottages were not in danger however, as they still had a considerable distance of sand dunes in front of them by the end of the fall. Also, the owners felt that, as in the past, the water level would subside and the dunes would be rebuilt, before any real danger was faced. One cottage, see Plate 3.E, that was previously mentioned at profile 180, was possibly in danger of being undermined, particularly with the mild winter just experienced in Southern Ontario.

It is difficult to estimate the energy involved in the erosional process, however, the extent to which erosion has occurred, and some of the resultant damages are illustrated in Plate 3.F. This is the most southernly of the three boat launching ramps in the Pinery. This particular ramp had been broken and shifted by earlier summer waves, and by October 30th, it was left in the state that the photograph illustrates. Approximately three feet of beach sand and cobbles had been removed in order to allow this ramp to fall to this position. Clearly, this is an active beach, posing numerous problems that must be considered even though they may soon remedy themselves with the continuation of the cycle.

Profiles

During the latter part of August and the first part of September of 1972, twenty-three beach profiles were constructed

Plate 3.E : Continued erosion at the same site as Plates 3.A and 3.B, prior to the construction of the breakwall.

Plate 3.F : Some other effects of the waves attacking the shoreline, in this case the destruction of the boat launching ramp at Burley Camp, in the Pinery.

along an 8,000 foot section of the beach. This section begins at the southern boundary of the Pinery, and extends to the mouth of the Ausable River. The purpose of these profiles was to study the changes which occur in the near shore zone, in effect to study the movement of the three sand bars extending along this whole length of beach. Actually the bars extend considerably farther north than the southern boundary of the park. It was found that the third, deepest bar reached the shore approximately 9,500 feet to the north of the park boundary. Thus the bars extend for a total length of 17,500 feet, from where they first appear north of the boundary, to the mouth of the Ausable River. Thus, the bars are very slightly oblique to the shoreline, however for the purpose of this study, they will be considered to be parallel. Their obliquenes is most noticeable where they contact the shore, and where they become very wide at the mouth of the river. The total bar system was not studied for two reasons-(i) to avoid the large number of people using the beach within the Pinery, and (ii) it was felt that concentrated study over a smaller area would be beneficial. It seems reasonable to note that at this point, that had the study been extended to include the whole bar system, it is most likely that more definite information about the shape and the formation of the bars could have been gained.

The method used to obtain the profiles was relatively simple. On August 23rd, the location of the profiles was surveyed, at a distance of 200 to 500 feet apart along the beach. The profiles can be located on map 2.2. Each stake was levelled with respect to a 4inch by 4inch post on the park boundary. This post was given the elevation of 100 feet for convenience, and thus all of the surveys are relative measurements. Once each stake was located, all that remained was to level at the major break of slope points across the backshore, and over the bar system. Occassionally stakes were lost and had to be resurveyed, introducing a new level. A 12 foot staff was used, being hand held for that profile by a person wading in the water. Errors due to subjectivity were introduced as it was the rod-man's decision to determine the highest point of a bar or the lowest point of a trough. Nevertheless, with familiarity this task became easier.

The beach was profiled as soon after a major onshore storm as possible. Generally, the storms arose and subsided during the evenings, and thus profiling could be started and completed within 10 hours of the storm, usually before any major change in the storm profile occurred. This method allowed for profiling on August 26th, August 30th, September 5th, and September 17th, in addition to the initial survey on August 23rd. It was necessary to leave the site from September 8th to the 17th, however weather reports were observed, and only one major storm passed through the area in this period.
It had been hoped that the surveying could be continued into the fall, however, this was impossible, not only due to the cold water, but also because it was not always possible to visit the beach on a calm day after a major disturbance. Thus these five profile times have to be sufficient at this time.

Before commenting on the actual profiles, a few brief comments will be made. First, the wind data for the period of profiling, and the wave heights recorded prior to each profile are summarized in Figure 3.2. The wave measurements were recorded usually at 6 A.M., 12 noon, 6 P.M., and 12 midnight, but only when the waves were of sufficient size to warrant continuous monitoring. The first major waves occurred on the 27th, 28th, and 29th of August, which by the morning of the 30th, had decreased to a swell from the northwest. This permitted the surveying of the beach on this day. By September 2nd and 3rd, another low pressure area had passed through, causing the waves measured on these dates. During visits later in the fall, particularly on October 9th, 10th and 11th, it was observed that the waves can reach considerable heights, approximately 7 to 10 feet in height at the pier in Grand Bend on these dates. Further consideration will be given to the wind and the waves in chapter five.

During the periods of highest waves in August and September, several observations were made. First, it was observed that the strongest waves approached from the northwest. A second observation was that the cobbles were completely removed from the beach, to be returned as a berm or beach ridge as the winds decreased. Thirdly, the bars could still be differentiated, but they became very uneven and could be described as pot-holy. Finally, it was observed that with these waves breaking on each bar, a considerable amount of sand was thrown into suspension or was carried along the bottom by the currents established by the obliquely approaching waves.

Figure 3.2 : Wind and Wave Data Prior to Profiling

Date	Wind: Av'ge Vel.	Wind: Dir'n.	Waves: Height	Waves: Length	Waves: Period
August 23,	calm		gentle swell all day		
August 24,	calm		gentle swell from northwest		
August 25	calm		1'	15'	3.4 secs.
August 26,	calm		gentle swell		
August 27,	12.6 mph.	WNW	1-2'	17-26'	2.7-2.2 secs.
August 28,	12.6 mph.	WNW	2'	52'	5.7 secs.
August 29,	calm		2'	56'	5.3 secs.
August 30,	calm		gentle swell		
September 1,	calm		gentle swell		
September 2,	14-18 mph.	N	2.5-3.0'	46-48'	5.5-5.0 secs.
September 3,	14.8 mph.	N	2.5'	52'	5.1 secs

Very little can be determined from the profiles, as they cover a very short period of time, and therefore, no general trends can be established. From these profiles, it appears that the bars tend to migrate shoreward with time, as long as a major storm does not arise. Once this storm passes, the bars are possibly rebuilt to their former level. Obviously, this is a summer profile, and the effect of winter could change it considerably. The backshore is also altered, however, this does not seem to follow any set pattern, and often seemed to be more closely related to debris of some sort on the beach, rather than to the actual storm conditions. Due to the depth of the water, only the first two bars could be surveyed, until close to the mouth of the river. Actually, the third bar was not reached until profile 200. From this point on, the bars became shallower and wider, until right at the mouth of the river, where the water was still only 4 to 5 feet deep at 700 feet from the shore. This does seem to locate the area where most of the sand being transported alongshore, is being deposited. The sand that is not deposited here is carried on toward Stoney and Kettle Points.

It was expected that this bar system, if it can be called that, would compare favourably with recent studies done on Lake Michigan in a similar geographical situation. However, terminology must first be considered. King and Williams, (1949), described two sets of 'bars', one for inland seas or lakes, and one for tidal oceans. For tideless seas, they propose barred beaches, consisting of parallel bars, rarely more than four in number, or a number of crescents of sand. Possibly the original bar might be considered as a crescentic bay-head bar. Nevertheless, the present bar system does not seem to really fit into this classification scheme.

Evans, (1940), working on Lake Michigan, does describe features similar to those referred to here, however he uses lows and balls. This refers respectively to a series of troughs and ridges along the shore, where the bottom slopes gently outward, and where there exists an abundant supply of sediment. They are roughly parallel to the shoreline, and may extend for many miles. The beach studied by Evans is very similar to this area on Lake Huron. Both are oriented north-south, and the majority of the beach material is sand, removed from the glacial drift. Sand dunes have been formed behind the beach in both cases.

The average number of balls is three, however, others may be present at greater depths, but could not be surveyed using the wading method. Generally, the distance between the second and third bar is greater than the distance between the first and second. The balls do not connect with each other, indicating that the material is not brought directly from the shore by littoral currents. In addition, the more regular the beach and currents, the more regular are the balls. Another point observed by Evans was that as the shallowness of the water increased, and the slope decreased, the lows and balls tend to have less relief, and are nearer to the surface. He concludes that the source of material for the building of these bars is from the lake bottom, which is transported by breaking waves toward the shore. This reasoning does not seem to adequately explain the bar system here. If the sand is derived wholly from the lake bed, it would be reasonable to expect bars along the whole length of the beach. However, as previously noted, this is not so. This author feels that the longshore transports must definitely play a role in the formation of these features. This appears reasonable as the bars do not begin immediately to the south of Grand Bend, where the pier retains sediments, thus interrupting the longshore drift, but begin several miles south, where the currents have had a chance to reform and to regain a load of sand which can be transported. possibly the presence of the bars indicates the incompetency of the longshore currents in transporting all of the sand being thrown into suspension by breaking waves.

Returning to the nomenclature problem, Evans' lows and balls seem most directly applicable. However this is a term which has not caught on in the literature. Instead, King's ridge and runnel system seems to have been applied to both ocean and lake bars. Therefore, this system could be described as a shallow water bar system or a weak ridge and runnel system.

Since Evans' early study of Lake Michigan, Davis and Fox (1972) have also studied the eastern shore of Lake Michigan. However, the bars which they describe, although parallel, are discontinuous, with rip channels located at spacings of a few hundred feet. This is a major contrast to Lake Huron, as at no time were major rip channels observed along the beach. The cusps associated with such channels were non existent. Instead, the beach was very regular and flat, with cusps being developed only at the end of a storm.

Fox and Evans concluded that the bars are not migrating, but are oscillating back and forth, depending on the existence of a high or low energy system. With the high energy system, only sand is transported, but over the whole ridge and runnel system, and the bars change their form yet remain in essentially the same position. During periods of low energy, a small amount of sand is transported, usually only on the inner bar. Again this only changes the shape of the bar, and does not alter its basic position.

Although considerably more time and effort would be valuable on the problem of the ridge and runnel system between Grand Bend and Port Franks, it was not possible for this study. A study of the present offshore bar system, as related to the building of the bay-head bar, would be of significance. Such a study should indicate the actual mechanism(s) by which this ridge and runnel system was formed and why it exists only along the particular portion previously described.

Chaper Four : Sediment Analysis With Reference to the Formation of the Bay-Mouth Bar

Sediment Analysis

An understanding of the beach is by no means complete without a detailed study of the sand, and in this case gravels and cobbles associated with the beach. Therefore, in the course of the field work for this thesis, considerable time was allotted to the gathering of samples. Most of the samples were taken at the sites of the profiles, between the Pinery and Port Franks, however, some additional samples were taken elsewhere. These include two sites within the Pinery, (near the boat launching ramps of Burley Camp, south end, and of Group Camp, at the north end of the park). Other samples were taken approximately 2,000 feet south of the pier at Grand Bend, 1,000 feet north of the same pier, and again on a beach roughly 2 miles to the north. A sample was also taken from the boulder-clay cliffs, 6 miles north of Grand Bend. Not only was the present beach of concern here though, but also earlier stages of it, and so several samples were taken purely for the purpose of comparing older sediments to the present ones. The two sites were at The Cut, 2,000 feet west of the highway #21 bridge, and at a gravel pit, 1 mile north of the previously mentioned site.

It was hoped that five main results would be achieved by this study. They are (i) to recognize any trends in sorting and grain size along the beach, (ii) to recognize trends in sorting and grain size normal to the beach, (iii) to determine the major minerals comprising the beach sand, both modern and early beaches, (iv) to determine the possibility that the cliffs north of Grand Bend were the source of beach material, and (v) to assist the determination of the manner of origin of the bay-mouth bar.

The method of differentiating the samples is basically simple. The sample number consists of three digits, with the numbers 010 to 220, at 10 digit intervals, referring to the profile location, (please refer to figure 2.2for these locations), and the numbers 1 to 5 along with the profile number, indicating the source of the sample. For example, 010 refers to the northernmost profile, while 011 refers to the berm sample at profile 010, 012 the swash limit, 013 the top of the step, 014 the first trough (which incidentally was usually closely associated with the bottom of the step), and sample 015 referring to the first bar. Any samples taken from locations other than the profiles were labelled from 501 to 526. Most of the samples were considered in this chapter, however, those numbered 501 to 507 are of greater significance to chapter six, a study of the river.

After the samples were collected, they were taken to the laboratory, where they were (i) dried for a period of 24 hours at a temperature of 250 degrees F. and (ii) after cooling, sieved for fifteen minutes at half phi intervals, using the Canadian Standard Sieve Series. Once a sample was sieved, the material contained by each sieve was weighed accurately to one decimal place. This data of phi size and weight for each sample was then punched on computer cards. Analysis of the data was accomplished by means of D.R. Ingram's and T.A. Bryant's modification to the Wood's Hole Ocean Program for Grain Size Analysis. The program produced a histogram of weights and a cumulative probabiltiy plot, in addition to determining the modes of the sample, its mean and median, the standard deviation, skewness, kurtosis, and sorting coefficient. Although only some of this information has been used in the analysis, the majority of it has been included in Appendix IV. Additional information regarding methodology and terminology has been included in Appendix III. Further laboratory techiniques used on the sediments for the purpose of analysis will be included in the relevant section.

The values of mean, median, standard deviation, and sorting coefficient were plotted according to relative distances from the possible source, namely the cliffs north of Grand Bend. These figures are contained in Appendix IV. The few samples taken between St. Josephs and profile 010 are scaled at approximated distances apart, while the samples from the profiles have been spaced regularly for simplification. Figgures IV.1 and IV.2 show the changes occurring in the samples taken at the berm and swash limit respectively, between St. Josephs and the first profile. Although a trend is not clearly indicated on either the berm or swash limit samples, there does seem to be an overall tendency toward a coarser and more poorly sorted material, particularly south of Grand Bend. This is reasonable, as the pier at Grand Bend tends to hold back sand being transported along shore, thus allowing the waves, of a high lake level, to erode former beach sediments, which from observation, appear to be a mixture of sand and gravels. However, with this explanation, one would expect the samples from Burley Camp to really be finer and better sorted, as the offshore ridge and runnel system is well established here, and the waves are cutting into sand dunes rather than an older beach. This anomalous situation may be due either to a poor choice of sampling site, or simply to local variations. Only more samples over an extended period of time, under various conditions, could help solve this problem. The consideration, that the samples are from one time only, must be remembered in the discussions to follow. Certainly this additional information could have added considerably to the understanding of the process-response system of the beach.

The seven profiles at which samples were taken and analysed show somewhat more encouraging trends, however they also are lacking in the information deduced from them, due to the limitations mentioned above. Some very irregular patterns are produced on these graphs. With regard to grain size, the median and the mean usually show the same trend. However, with respect to the sorting of the sample, the standard deviation is often more indicative of a basic trend than the sorting coefficient, or vice versa. Therefore, these latter two measures will be considered separately, while the mean and median measurements will be combined.

Samples from the swash limit and the first trough indicate a tendency of decreasing particle size toward the south, while samples from the first bar appear generally stable, except for the abnormal values found at sample 155. Possibly this is simply a local anomaly, and again extended sampling would have aided in the solving of this problem. In reference to sorting, however, the samples from the berm, swash limit, and first trough designate increased sorting to the south. The samples from the top of the step are very irregular, with regard to both size and sorting, most likely a function of the low swell waves, which form the step, at the time of sampling. These swells tend to rework a large range of material sizes into this area. Both the standard deviation and the sorting coefficient curves for the berm and first trough samples are similar. However, the swash limit samples show best the expected improvement in sorting, using the standard deviation curve. In conclusion then, it can be stated that particle size generally decreases, while the degree of sorting increases from north to south. This is the expected result if the major direction of longshore drift is also north to south.

The sorting normal to the beach is similar to that expected on sand-cobble beaches. Since the majority of the beach material is sand, the histograms of the samples show a fine tail. Cobbles are found on the berms or ridges built above the still water line. Within the swash limit, particularly between the top of the step and the first trough, a wide range of material exists from fine sand to pebbles. This is indicated by the low values for the sorting of the samples taken at the swash limit, and in particular, at the step. However, once beyond the step (ie within the ridges and runnels) the sand is usually well sorted with only the occassional sample showing a large amount of pebbles and coarse sand.

Plate 4.A : This cobble swash bar or berm ridge was observed to have been built by the waves in the photo, the main ridge was approximately 2000 feet long and covered the boat launching ramp at the Dunes Campground in The Pinery.

(November 14, 1972.)

Plate 4.B : Sample 514, from the crest of the ridge of Plate 4.A,

too coarse to sieve.

Plate 4.C : Sample 513, from behind the ridge of Plate 4.A.

Following the sediment size analysis, the samples were observed under a binocular microscope. From this, it was determined that 80-90% of the beach sand consisted of silica and calcite grains. The quartz grains were clear, while the calcite grains were often milky or stained red. In addition to the large number of indigenous calcite grains, many of the other minerals had calcite coatings.

The remaining 10-20% of the samples was comprised of several darker minerals. In order to prepare these for further study, the calcite was dissolved in concentrated hydrochloric acid and rinsed away. Then the quartz grains were separated from the darker crystals, using a Carpco Magnetic Separator, and the Frantz Isodynamic Separator. This allowed the separation of the sample into quartz grains, and heavy minerals, which were black, green, and amber in colour. With this separation, it was then possible to x-ray the samples in order to identify these major minerals. Thus in addition to quartz and calcite grains, the sand contains magnetite, tremolite, hematite, and spessartite. These comprise at least 95% of all the sand samples. Magnetite was found in the finer sieve fractions of nearly all the samples. The other three minerals, tremolite being the green crystals, hematite the black ones, and spessartite the amber ones, were constituents of all the other samples. The actual percentage contribution of these four minor minerals was highly variable, but the important point is, that they were present in every sample observed.

In addition to the studying of the modern beach sands, the sand fractions were observed for both the raised beaches and the boulder-clay cliffs in the St. Josephs area. In both cases, the major constituents were found to be identical to the crystals mentioned above, with the exception of magnetite.

The Formation of the Bay-Mouth Bar

In addition to seeking an understanding of the beach regime by means of sediment analysis, it was hoped that this information would be valuable indetermining the growth of the bay-mouth bar. Until this point, the existence of the bay-mouth bar has been implied, with no mention of its form or origin. On Figure 2.2, the bar has been roughly outlined, while Figure 4.1 shows the Pleistocene beaches of the Ausable River Watershed. Unfortunately the origin of this map was not determined, and thus the position of the raised beaches from Port Franks to Kettle Point is not shown. It appears reasonable to assume that they continue to the south, in the general trend shown here, drawing closer to the present shoreline towards Kettle Point. A cross section through the bar, showing heights and positions of the raised beaches relative to Lake Huron, is contained in Figure 4.2. The diagram in Figure 4.2 does not agree too well with the map of the raised beach ridges and with the cross-section observed by the author along The Cut. Figure 4.2 shows the Nippissing and Algonquin ridges located well behind the dune ridges, while it was apparent that the dunes extended to within 2,000 to 3,000 feet of the eastward extremity of the bay-mouth bar. Nevertheless, these observations were limited to the exposed section along The Cut, while it is quite possible that Figure 4.2 represents some other section of

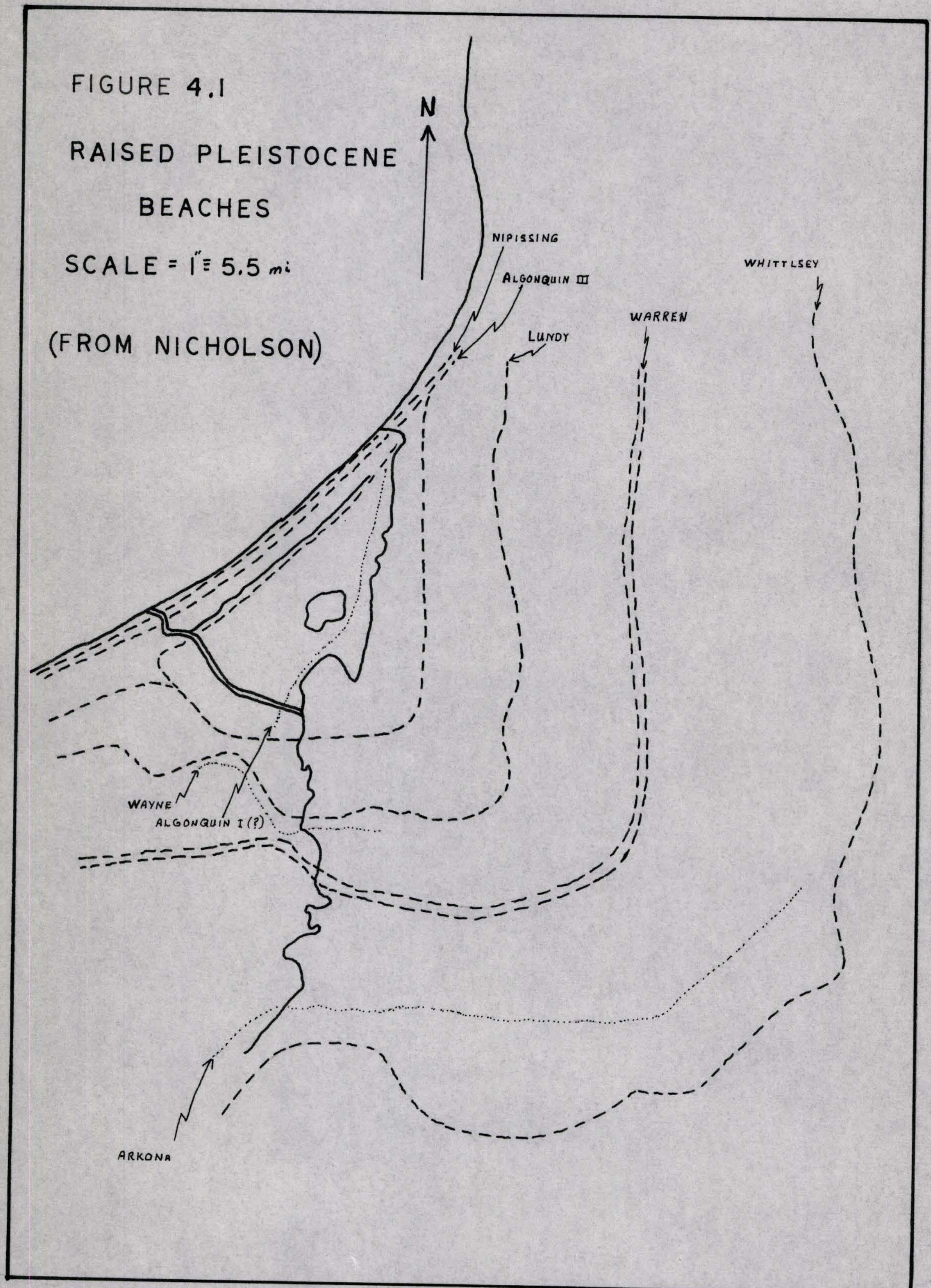


FIGURE 4.1
RAISED PLEISTOCENE BEACHES
SCALE = 1" = 5.5 mi
(FROM NICHOLSON)

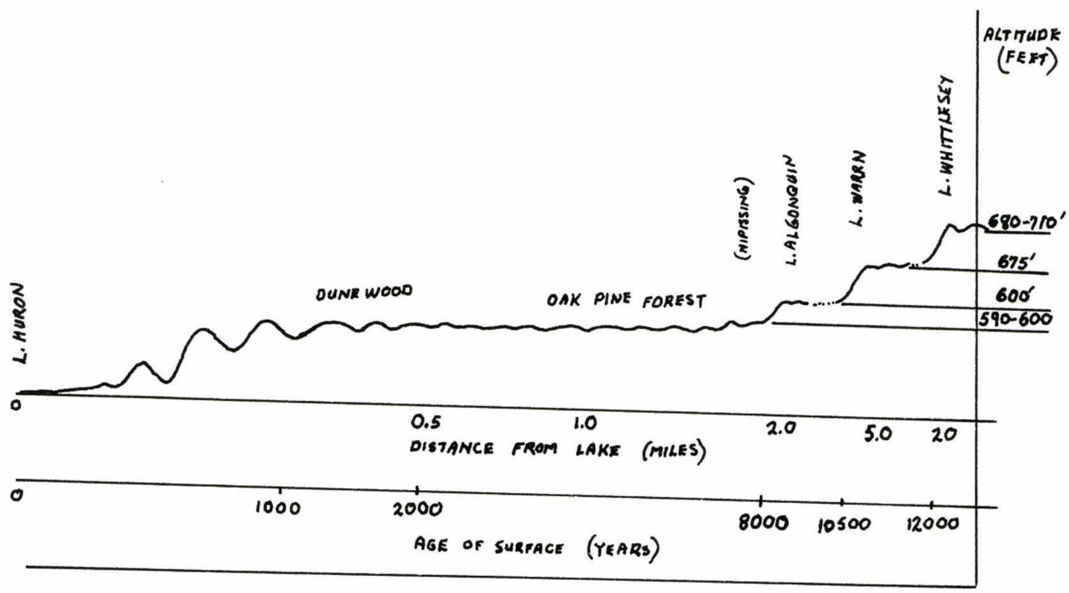


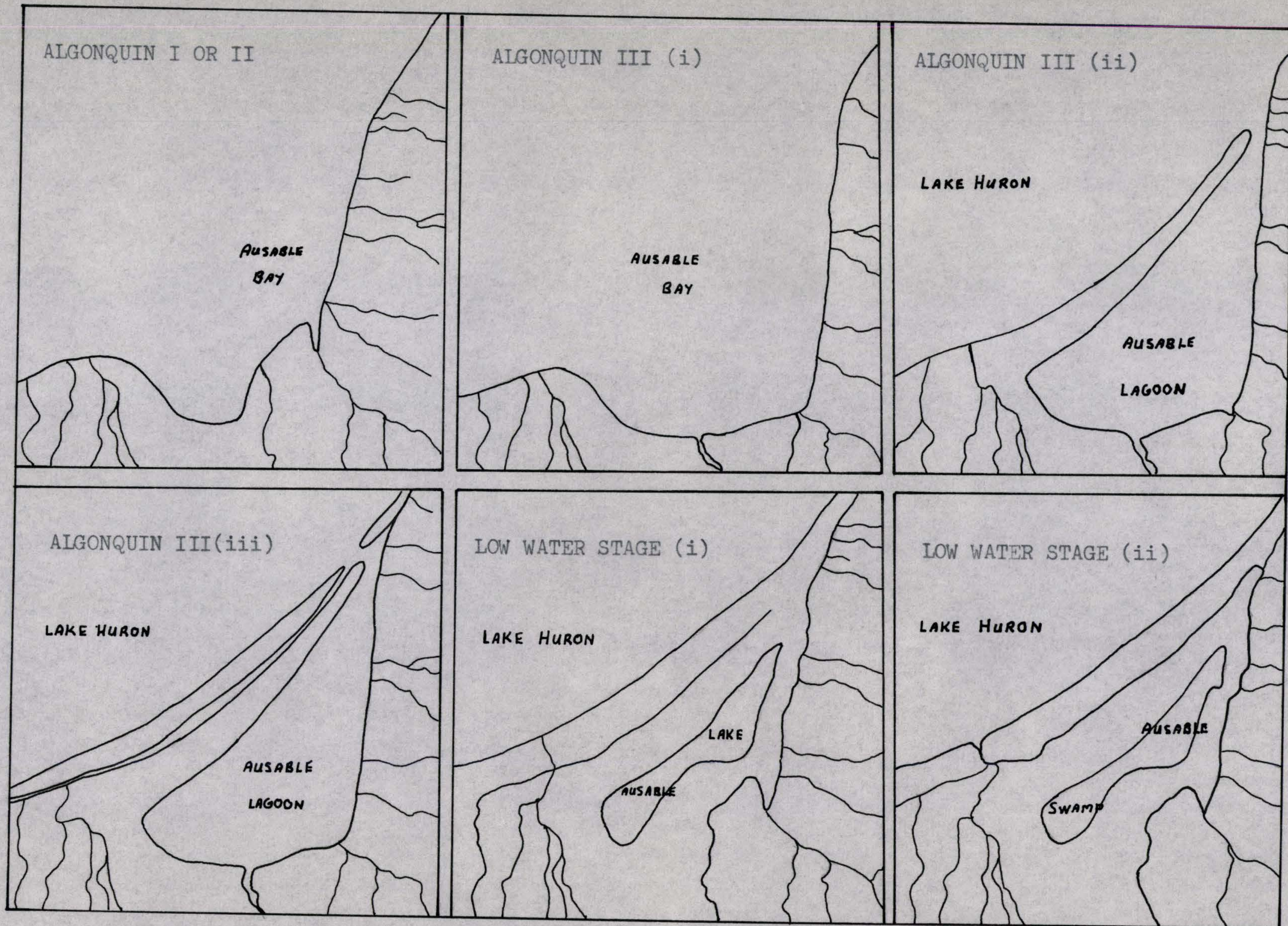
FIGURE 4.2 A DIAGRAMMATIC SECTION THROUGH THE GRAND BEND DUNES, SHOWING RAISED BEACHES.

FROM SPARLING,
1965.

the beach, most likely to the north of The Cut.

Concerning the actual origin and growth of the bar, which is essentially built from a series of beach ridges, N.L. Nicholson accepted the theory proposed at the turn of the century. The proposal, as indicated by Figure 4.3, was that, during the second stage of Lake Algonquin, the bar began to grow from the south, in the Kettle Point vicinity, and thus partially closed off Ausable Bay. In stage three, it appears that the bar grew in two directions, but still mainly from the south. This stage also left a low area between the two bar stages, which later was used by the Ausable River which entered the lake in the Grand Bend area during stage two and three. As the water level fell to the Lake Huron level, the bar completely closed off the bay forming the lagoon, which in Figure 4.3 is referred to as Lake Ausable. It was proposed that the water entered the lake at two locations, Grand Bend and close to Port Franks. The final stage shows the Ausable River being forced south, and having its mouth somewhere south of Port Franks. The lake has been infilled, so that it is now nothing but a swamp. With continued input of sediments into the swamp-lowland area, largely due to the silt deposits of the river during flood stage, the lagoon has built up. Prior to the excavation of The Cut about 1875, three shallow lakes existed, Lake Burwell, Lake George, and Smith Lake. As a result of The Cut, the former two were drained leaving only Smith Lake, a shallow reed-filled lake, existing at the present.

The evidence suggesting that the growth of the bar was from south to north during the Lake Algonquin stage, was minimal and



Hypothesized Growth of the Bay Mouth Bar from Nicholson, 1949.

Figure 4.3

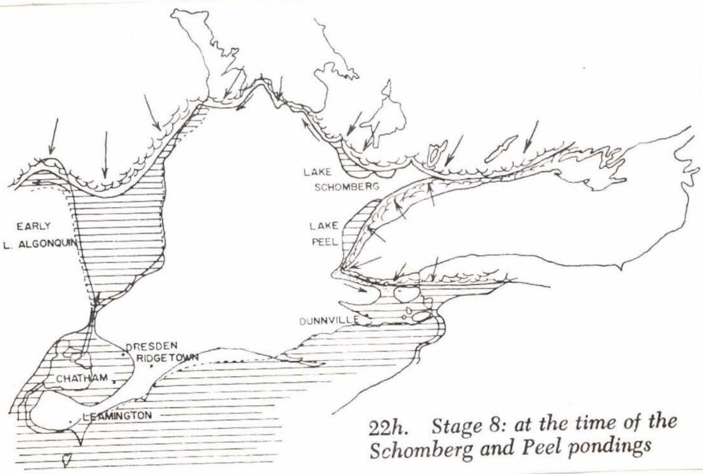
Plat 4.D : Showing some of the bedding features of the raised beaches comprising the bay-mouth bar, at the gravel pit on highway 21 north of the Ausable River.

indirect. It consisted only of the fact that the sand dunes were higher at the south than at the north of the bar. There are several objections to this proposal, some intuitive, others based on observations of the beach. The first objection is that the evidence cited (ie. the higher sand dunes of the south) is not necessarily the result of a bar which grew from south to north. The highest dunes occur in the Port Franks-Stoney Point area. From the map, this is the widest section of the bar, and in addition, it is in a favourable location to have sand blown from the beach onto the dunes by the prevailing westerlies and the strong northwesterly winds. Thus, the dunes are the highest here only because of their advantageous position and the accessibility of sand, and therefore, are not diagnostic of the direction of growth of the bar.

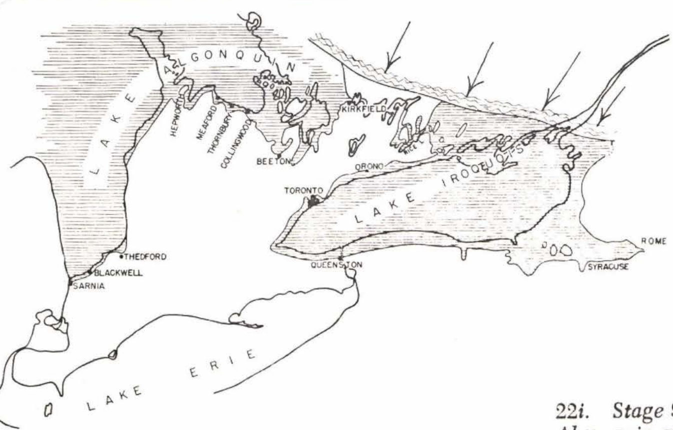
The second objection is based on the Wisconsin glacier recession as presented by Chapman and Putnam (1966), and indicated in Figure 4.4. Again the possibility of growth from the south appears limited. The study area was open to water during the Lake Warren stage, and from this map, there does not seem to be sufficient fetch to build a bar. The time necessary to build such a bar does not seem sufficient either. Stage 8, of Chapman and Putnam (ie. the Schomberg and Peel Pondings) lack the fetch to the south, while the Lake Algonquin stages largely follow the shoreline of the present Lake Huron, and thus also lack sufficient fetch. These latter two stages would be more likely to produce a southward growing bar.

A third factor to be considered in the growth of the bar, is

22g. *Stage 7: at the Gibraltar and Niagara Falls moraines, or during the lif of Lake Warren*



22h. *Stage 8: at the time of the Schomberg and Peel pondings*



22i. *Stage 9: at the times of lakes Algonquin and Iroquois*

Fig. 4.4, The Retreat Of The Wisconsin Glacier And Resultant Lake Stages, from Chapman and Putnam, (1966).

the source. Already the possibility of a source north of Grand Bend has been considered. In addition, ther are bluffs along the shore for a considerable distance, between Kettle Point and Sarnia, but the constituents of these were not determined. Nevertheless, a source area seems to exist, and so this is not really in opposition to the proposal.

A fourth objection to this proposal is the position of Kettle Point, which would tend to disrupt the waves and currents carrying the material toward the north. The sand would be deposited in the lee of the headland, thus filling up the area directly north of the outcrop. This should produce recurved beach ridges to the north of Kettle Point. The air photographs and Figure 2.2 show raised beach ridges, but not in the form expected to be produced by northward moving currents. Such a pattern may exist however, but has been covered over by the drifting sand. Due to the recurving effect, a very wide bar might be expected in the south which grows narrower towards Grand Bend.

The possibility that the bar has grown from Grand Bend to Kettle Point does not seem to have been considered in any literature. Therefore, the following reasons are suggested as a basis for the north to south development hypothesis.-

(i) The raised beach ridges between Stoney Point and Kettle Point as mapped in Figure 2.2 clearly indicate curved beaches produced by a north-south current.

(ii) The structural control of the rock outlier at Kettle Point has apparently resulted in the bar being narrow at its southern extremity. The fact that the bar is widest in the centre and decreases in width toward either end seems more indicative of a beach that grew from the north.

(iii) At present, the boulder-clay cliffs north of Grand Bend appear to be the source area for the modern beach. Not only is the predominant direction of longshore transport in this direction, but the cliffs, although containing a large percentage of clay, do have a considerable percentage by weight, of sand, pebbles, and angular stones. There is sufficient material here to form the beach. It is significant also that the major minerals found in the cliff sample are also those found in the beach samples. This is again true for the raised beach samples taken from The Cut, and the gravel pit on highway #21. The latter point is not too important however, as all glacial tills in this area having a high percentage of clay, possibly contain these same minerals.

(iv) As previously pointed out, the available fetch and wind direction suggest a north to south growth, while the location of the highest dunes fails to provide any evidence supporting either hypothesis.

The final answer concerning the direction of the growth of this bar remains unsolved. Detailed research on the bar itself will be required to reach a substantiated conclusion. Some of the problems with the north-south hypothesis are -

(i) Whether it is possible for the river to have maintained a

Plate 4.E : The slumps of the boulder clay cliffs to the north of Grand Bend at St. Joseph. These cliffs are probably the source of sediment for the modern beach.

Plate 4.F : The base of the cliffs shown in 4.E.

channel, nearly the whole length of the bar, unless some localized depression existed. This is accounted for by the south to north growth theory but not in the other.

(ii) In order to discuss the growth of the bar intelligently, it would be necessary to consider the wave refraction patterns occurring at the time of the bars origin. In addition to problem (i) above, it would be necessary to consider the effect of wave refraction on the river outlet, following the studies of authors such as Bascom (1954).

(iii) Fox, (1946), mentioned that a deep harbour once existed in the Port Franks area, landward to the then existing sand bar. With the completion of the Cut, this harbour has been continually silted up, so that today, only a few channels witha maximum depth of approximately 15 feet exist. How this deep harbour could have been formed in either hypothesis is an interesting problem.

It is impossible to say which proposal is true, although this writer prefers the north to south idea for the growth of the bar. A lot more study could be invested into this problem. It is felt that a study of sediment structures, both in the old and new beach ridges, in addition to a complete survey of the bar, including cores, to provide the third dimension, would do much to answer this question.

Chapter Five: The Winds and the Resultant Waves

Throughout this study, the responses to the winds and the waves have been considered. No real mention of these two active processes has been made, with the exception of a brief comment in Chapter 3, in regard to the study of the profiles. Therefore, this chapter will not only take a general look at the actual wind data, but also will use this data to derive values of wave parameters.

Hourly wind data for the two stations, Goderich Airport and Sarnia Polymer, were obtained from Environment Canada. This data covered the years 1971 and 1972. Formerly the airports at Grand Bend and at Centralia, would have provided the most relevant data, however both of these stations had been discontinued sometime prior to 1971. Therefore, the two stations closest to the Grand Bend - Port Franks area, yet still on the shore of Lake Huron, were chosen. Thus, it was necessary to determine which of these stations would be most representative of the study area, or whether both stations were consistently comparable. The relative location of the two stations is indicated in Figure 5.1.

Observation of the crude wind data showed considerable variation, with respect to both velocity and direction, between the two sations. Concisely, Sarnia usually had winds of a lesser velocity than Goderich. In addition, Sarnia seemed to have a larger percentage of the winds from the south and southwest, while northwest winds were more predominant at Goderich. A linear regression analysis was run on several random samples

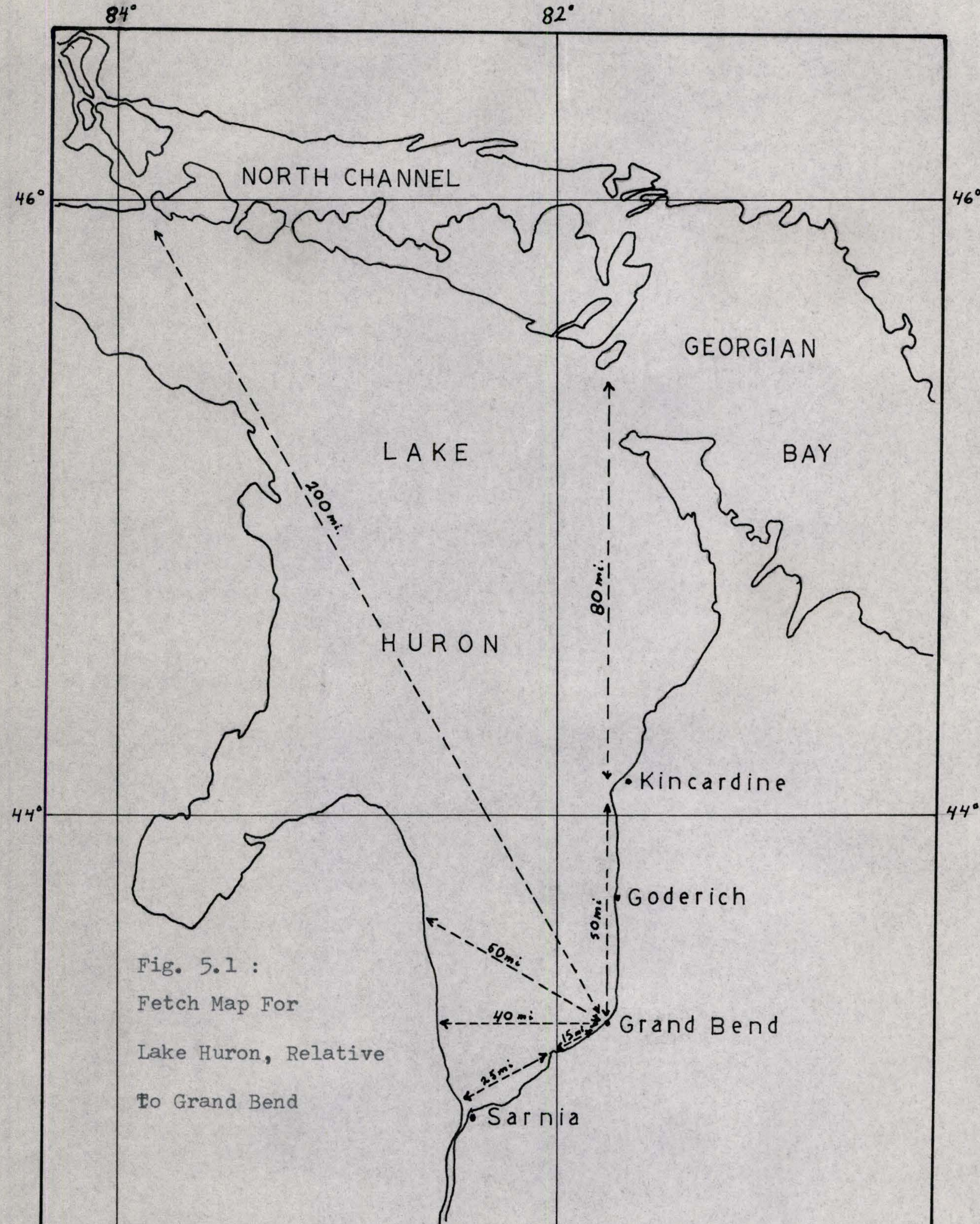


Fig. 5.1 : Fetch Map For Lake Huron, Relative To Grand Bend

of wind data. These included storm preiods, during spring, fall, and summer, and daily periods for the same seasons. The hourly velocities alone were compared, (i.e. no consideration of the wind direction), and the sample correlation coefficient for the regression lines varied from 0.35 to 0.85, for the wind data at Goderich plotted against that from Sarnia. Likewise, the main daily wind velocities were compared, again without considering the direction, and the best sample correlation coefficient obtained was 0.74. (In regard to these correlation coefficients, and all those mentioned later, the best possible value is 1.0.) Therefore, it was impossible to equate the two sations, and since Goderich was the closest, and its setting was more like that of the Grand Bend area, than Sarnia, it was decided that most of the work should be done using the Goderich data. It was also felt that since the author is most familiar with the 1972 season, that wind data of this period would be of more value.

The purpose of this study is not simply to analyse the winds of the area, but to confine the problem to only winds of those directions which will produce waves on the beach between Grand Bend and Port Franks. From this data it was possible to determine the wave dimensions produced by a particular period of wind, and then to evaluate the winds for their effective energy on reaching the shoreline.

The wind data, condensed somewhat by assuming that the lake was frozen during the months of December, January, and February, was studied from the first of March to the end of November. This period allowed certain generalizations to be made. The first was that the major storms of long duration, high velocity and suitable direction occurred predominantly in the spring and fall, particularly March and April, and October and November. Secondly, during the remaining months, the storms were usually less frequent and not as intense. Often the major storms which could have produced waves, were offshore winds and therefore of no importance to this study. The wind periods which do occur in this interval from May to September though, are typical onshore breezes, occurring in the afternoon, with low velocity, and lasting six to nine hours. These winds have been considered, though they may not be too effectual.

The Bretshneider Diagram in Appendix VI, was used to determine the wave heights and wave periods for each series of winds analysed. This diagram considers fetch distance, wind velocity and wind duration. In determining these values, certain assumptions were made. With regard to the distance of fetch in miles, two directions, north and west southwest, were given two values each. This was due to the unknown effects of headlands, one north of St. Josephs, and the other being Kettle Point. Thus the lower fetch value is that between Grand Bend and the respective headland, assuming that all waves in these two directions would only have this distance in which to form. The higher values are based on the assumption that waves could form beyond these headlands, and although affected, would not be destroyed by the two points. These two values will be referred to as the 'lower' and 'higher', throughout the thesis.

Periods of winds, which may consist of only a few hours or of several days, were considered. A period then is one in which the winds blow in one general direction, with an average velocity greater than twelve miles per hour. If within a period, the wind direction was inconsistent, but with only slight variations, the predominant direction was chosen.

Generally, records of winds with velocities much less than 12 mph., were not considered, unless they were a part of a period in which wind direction was essentially constant, and had higher wind velocities on either side. The average velocity for the winds of this period would again have to be equal to or greater than the 12 mph. lower limit of the Bretshneider Diagram.

Winds from directions other than north, north northwest, west northwest, west, and west southwest, (or within the compass bearings covered by these directions), will be assumed to have no effect on the beach. These few assumptions have introduced a certain amount of subjectivity into the study, however they were rigorously followed in an attempt to minimize any inconsistencies.

On the basis of the above discussion, the values of wave height and wave period were determined for the prescribed period. The data for both Goderich and Sarnia were used, again for the purpose of comparison. Appendix VII has this information summarized in tables. The problems of correlation between Sarnia and Goderich are again blatantly obvious from the tables, as evidenced by the lower values at Sarnia for average wind velocity, wave height and period, and the fewer usable wind periods. Thus, all further evaluations will be made using only the Goderich data.

Again, regression analysis was applied to the data to determine the correlation between the various inputs and outputs. For the Goderich statistics only, the following comparisons were made, with the resultant sample correlation coefficients. A sample size of 31 was chosen, (i.e. the values for the north northwest direction), to limit the sample size. This particular direction was used as it was the largest and most varied. Thus, the sample correlation coefficient is :

(i) 0. 672 for duration vs. wave height,

(ii) 0.862 for duration vs. wave period,

(iii) 0.921 for average velocity vs. wave height,

and (iv) 0.706 for average velocity vs. wave period.

In addition, an excellent correlation coefficient value of 0.941 was obtained for wave height versus wave period. This good correlation is expected in using the Bretshneider method. As a point of interest, no correlation was possible between average velocity and duration. Thus, all three factors, average velocity, duration, and fetch, can act independently in limiting the size of the wave produced by any given wind.

Using the derived values for wave height and period, the information contained in Appendix VIII was derived. This includes not only wave dimensions, but also expressions for wave energy and wave pressure. C. A. M. King (1972), suggests the following equations for evaluating waves.

(i) Wavelength = $L = 1.56\ T^2$, where T is the wave period and L is in feet,

(ii) Velocity = $C = \sqrt{\frac{g\ L}{2}}$, where g is the force of gravity (32 ft./sec.^{2}), and C is in feet per second,

(iii) Wave Steepness = $St = \frac{H_f}{L}$, where H_f is the wave height, and a value greater than 0.14 shows that the wave is unstable, (i.e. breaking),

(iv) finally a value for the wave energy, (total kinetic and potential energy per wavelength), is evaluated using the equation:

$$\text{Energy} = E = \frac{w\,L\,H^2}{8}\left(1 - 4.93\,\frac{H^2}{L^2}\right)$$, where w is the weight of one cubic foot of fresh water, equal to 62.4 pounds,

E is in pounds per square foot.

In addition to the above values, R. R. Minnikin, (1963), suggested the following equation for approximating the pressure of a wave on a vertical wall :

$$\text{Pressure} = \frac{H}{23} \times 3$$, in tons per square foot.

Several comments must be made in reference to this data. First, these values apply only to deep water waves, (i.e. waves in water greater than ½ their wavelength). In shallower water, the values for energy and pressure will decrease. Also, the values derived are only average values, and are really only useful in determining relative values, as no field checks were done to determine their absolute values. The effect of lake bottom topography, which will determine wave refraction, has not been considered here either, although this will have a significant effect only on the longer waves. A complete study of offshore topography would be necessary in order to fully appreciate the effect of wave refraction. Thus, this further complexity will not be considered here, but should be remembered as a contributing factor.

Using this information, it is first possible to compare the few measured values of wave height, period, and length, to those evaluated for the respective days, as seen in Figure 5.2.

Figure 5.2

DATE	MEASURED			CALCULATED		
	height	period	length	height	period	length
August 27,28	2'	5.0 secs.	50'	3'	4.2 secs.	27.5'
September 2	3'	5.5 secs.	47'			
September 3	2.5'	5.0 secs.	50'	2.8'	4.6 secs.	33.0'

Furthermore, the energy contributed by each of the directions considered could be evaluated as a percentage of the total energy input of the winds between March 1 and November 30, 1972. These values were determined for both the short fetches and the long fetches previously mentioned for the north and the west southwest directions, as indicated in Figure 5.3.

Figure 5.2 reveals a major discrepancy between the evaluated wavelength and those corresponding measured values. The easiest values to measure, (all measurements were recorded between the first and the second bars at the south end of the Pinery Provincial Park), were wavelength, and wave period, and yet it is the wavelength values that vary the most. Possibly the problem with the equation used to determine wavelength, is that it may not be directly applicable to small bodies of water. Further detailed measurements of all three wave factors, preferably

Fig 5.3 : Summary of Energy Values, March 1 to November 30, 1972.

Shortest Fetches

Direction	Percentage of total energy
North	14.71 %
North Northwest	68.23 %
West Northwest	7.53 %
West	9.36 %
West Southwest	1.88 %

Longest Fetches

Direction	Percentage of total energy
North	24.47 %
North Northwest	56.97 %
West Northwest	6.48 %
West	7.81 %
West Southwest	5.88 %

in deep water, would provide valuable information, which could be used in more extensive studies in wave hindecasting and/or forecasting. Figure 5.3, shows that for this short term, the north northwest direction, which has the greatest fetch, contributed over 50 % of the total energy exerted on the beach by the waves evaluated.

In order to determine the relative influence of the various wave parameters on the energy values, several regression analyses were performed. These showed that during the period from September 1 to November 30, (a sample size of 36), the wave height was most closely related to the resultant energy, as demonstrated by the 0.917 value for the sample correlation coefficient. Nevertheless, the other correlations were also quite good, as demonstrated by the 0.900 value for wavelength versus energy, the 0.836 value for wave period plotted against wave energy, and the 0.838 value for wave velocity versus energy. The high correlation coefficients in all cases indicate that the resultant wave energy is essentially equally dependent on all four of these variables, at least as they have been evaluated here.

The correlation of the values for energy using King's expression and the values determined for pressure on a vertical wall, by means of Millikin's simple equation, indicated a good comparison, with a sample correlation coefficient of 0.914. It would appear that reasonable values of relative energy or pressures can be determined using these methods. The accuracy of the absolute values is of less concern at this point, and again, would require exhaustive experimentation to evaluate.

This analysis has only scratched the surface of the information which could be derived from a wind-wave and resultant work done study.

These results will be considered further in chapter seven, nevertheless, the author does feel that a more detailed study, following this line of reasoning in particular, would be valuable and necessary when considering the possibility of controlling erosion, and littoral and longshore transport on the beach.

Chapter Six : The Ausable River, With Reference to the Problems of Flooding and Erosion

Introduction

The Ausable River drains the southeastern portion of the Lake Huron shoreline. French explorers originally referred to it as "La Rivierre Aux Sables", which most probably means "the river with the sands or at the sands". The present name is a derivative of the original spelling and the result of a compromise of the various forms which stemmed from the French "Aux Sables". The river rises just a few miles east of the village of Staffa, Ontario, and empties into Lake Huron at Port Franks. Its mouth is located approximately 45 miles northeast of Sarnia, and about 36 miles south of Goderich.

The watershed of the Ausable River has a particularly interesting post-glacial history, along with significant developments since the arrival of the early settlers. The attempts to control river flooding and erosion, which together have produced many channels near the mouth, are most interesting. With each human attempt to control the river, time is essentially set back to zero, making possible the study of river evolution. This has been extended to such a degree that in a small area near the mouth, changes can be observed using sequential air photographs. This allows a valuable study of the dynamics of a river system.

Thus, the major goals in this study will be - (i) to outline briefly, yet thoroughly, the history of the river up to 1947, (ii) to take a more detailed look at the section near the mouth between the years 1947 and the present, with emphasis on its dynamics, and (iii) to consider this information in reference to the problems of erosion and flooding, and to provide positive suggestions as to how these problems could be alleviated while still conserving the natural character of the river.

History up to 1947

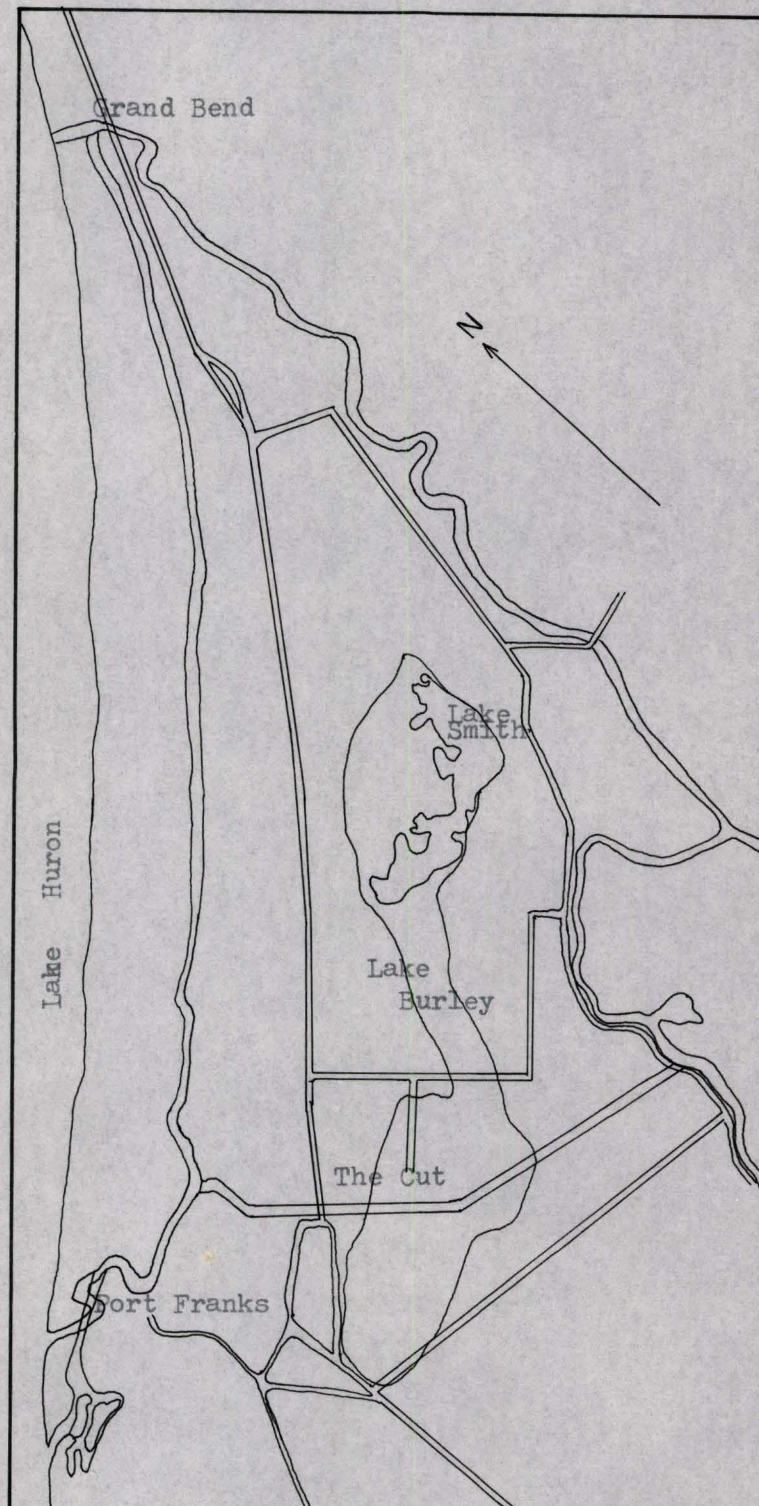
The major period covered in this section will be from the latter quarter of the 19th century up to the mid 20th century. However, the history of the river from the beginning of the recession of the Wisconsin Glacier, is not only academically interesting, but also important to this study of the present river pattern. The physiography of the watershed, which is largely determined by the glacial material present, has had an important effect upon the river, along with the underlying bedrock, although to a lesser extent. These factors have been considered in previous chapters. Thus, only a brief recap will be made.

Generally, the watershed of the Ausable River has an area of 411,750 acres or 640 square miles. It is bounded in the north by latitude 43° 28.5", 42° 58.5" in the south, longitude 81° 17.5" in the east, and 81° 57" on the west. The source near Staffa is approximately 1075 feet above sea level, while the river drops approximately 500 feet to Lake Huron. Its total length, from its source to Port

Franks, is roughly 95 miles.

Chapman and Putnam (1966) have outlined the recession of the Wisconsin Glacier. Since Lake Huron was a major contributor of glacial ice, the area of interest was covered by ice until late in the recession, until their stage 5. This was the period of late Lake Maumee and the Seaforth and Saint Thomas moraines. With further recession during the life of Lake Whittlesey, more of the basin was cleared of ice. The long period of ice cover accounts for the glaciers important role in the physiography. Another important factor was that much of the present watershed was once part of Ausable Bay. At the time of Lake Warren, the bay covered an area extending close to the present site of Arkona. Thus, much of the lower portion of the present watershed was inundated. Due to isostatic rebound and the relative lowering of the water level, this bay became very shallow, extending east to the present site of Thedford. This situation existed during the Schomberg and Peel Pondings, and finally to the glacial lake stages of Algonquin and Iroquois. Between the decreasing water level and the rising land, this area saw the building of a series of beach ridges, which culminated in a bar, on which the modern beach now exists. The growth of this bar separated the shallow lake area from Lake Huron, thus creating a lagoon behind or to the east of the bar. Over many years, the lagoon was gradually filled, until only the shallow and reedy Lakes Burwell, Smith and George remained, surrounded by a large swampy area. An idea of the situation can be seen in Figure 6.1, which shows the lagoon behind the very large bar.

Figure 6.1 : Grand Bend - Port Franks Area, About 1840



The growth of this bar also had a distinct effect on the course of the river. As discussed in chapter four, the river originally entered the lake at Grand Bend, but due to the growth of the bar, its course was altered considerably. Whatever the process, the river has entered Lake Huron in the Port Franks-Stoney Point area. This information has been considered in chapter two, with the maps of Appendix I indicating some of the most predominant meander scars south of Port Franks. These maps also indicate how the beach ridges have been reworked, and consequently obliterated by the wandering river channels. However, it would appear that the mouth has been centered in the Port Franks area now for many years. Figure 6.1 shows the position of the mouth about 1840, before the time of any major human interferences, which began in the late nineteenth century.

W.S. Fox (1946, 1958) has covered much of the early settlement history in his two books on the Ausable River. The Ausable River Conservation Authority also considered this topic quite well in their 1949 report. The following information has been obtained from these two sources, both of which are based largely on original documents.

The drainage basin of the river is subject to rapid runoff. This applies not only for the devastating spring floods, but also for the torrential downpours common during the summer months. The high rate of snow accumulation and the heavy rains are a result of the prevailing westerlies blowing inland from Lake Huron. Thus, the segment of the river below Arkona, where the gradient is at the most, only slightly more than 3 feet per mile,is prone to annual spring floods, and to periodic summer floods. Much of the watershed in this area comprises the post-glacial bay and lagoon, explaining the small gradient and the fact that flood waters cover a very large area.

The beginning of settlement in the Grand Bend-Port Franks area, and also the Thedford area, was the direct result of the acquisition of this large tract of land by the Canada Company. As population density grew, the settlers were forced to take up residence in the low lying areas along the river. The flooding, although providing some nutrients to the soil, caused difficulties for the farmers due to the unpredictable nature of the floods. Thus, the Canada Company proposed the building of The Cut, which extends approximately from Thedford to Port Franks, as seen in Figure 6.1. It was hoped that this would alleviate the flooding problem in the lower reaches of the river and also drain the large marsh area of Lakes Burwell and George. The drained swamp would then provide additional agricultural land. Several other conditions were causing problems in the low lying areas and which The Cut would hopefully eliminate. During the nineteenth century, the lumber industry had grown significantly, such that the spring log drives down the Ausable River, were so large that the logs, in addition to the ice, would essentially dam the river. This damming tended to increase the intensity and duration of the flooding. The growth of sawmills and gristmills in the area, saw the construction of many small dams for the purpose of power. This too, added to the flooding problem.

For the above reasons, The Cut was constructed during the years 1872 to 1875. It was to go due west across the base of the 'great loop' of the Ausable River, almost staight to Port Franks, and skirting Lakes Burwell and George so closely that their waters would be filtered off. (Fox, 1946) The old river channel was beheaded by means of an earthen dam below the new cut, which resulted in great flooding upstream from The Cut. The Cut rejoined the old river just upstream from the mouth. The Cut was dug so that the water in it would be at the level of Lake Huron, 10 to 12 feet below the river bed from which it was projected. (Fox, 1946)

The Parkhill Creek system, which comprises the section of the river basin between The Cut and Grand Bend, was sorrily depleted in its water supply. Nevertheless, flooding remained a serious problem due to the ineffectiveness of the now misfit stream against ice and log jams. A second lesser cut was made at Grand Bend in 1893 to alleviate this problem. It was not until the early 1900's though, when this cut was cleaned out and enlarged with a pier built at its mouth, that the problem was more or less eliminated. The purpose of the pier was to interrupt the longshore drift. This second cut did, however, kill a section of the river, that sectionwhich flows parallel to the Lake Huron shoreline between Grand Bend and Port Franks. (Conservation Authority Report, 1949)

With all of these projects completed by the first two or three decades of the twentieth century, the river was left largely untouched for the next twenty years. However in 1946 the Ausable River

Conservation Authority came into being. Its first major project was to protect Port Franks from the threat of floods by means of a new channel. This leads to the study of the river as it has existed from about 1947 to the present.

An Investigation of the Ausable River from 1947 to the Present

It is necessary to remember that the river now being considered, unless otherwise stated, is the original course to The Cut, and following The Cut to Port Franks. For ease of differentiation, the section entering the lake at Grand Bend will be called the Parkhill System.

The investigation of the Ausable River, particularly the section directly upstream from its mouth, was accomplished by several methods. First, familiarity with the navigable downstream section of the river was obtained by several days of boating and traversing its floodplains. In addition to this general observation, several samples were taken to be analysed for grain size in the laboratory. Some surveying had been intended on the meander scars, however the general absence of relief indicated that this task was not necessary. It was also hoped that the river could have been gauged, at several places between highway #21 and Port Franks in an attempt to determine velocity changes with river cross-section. The presence of ice on the river early in December forced the cancellation of this exercise, although some readings were attempted.

Returning to the laboratory, the river was observed using 1;50,000 topographic maps, and from these the longitudinal profile was constructed. Soils maps were also consulted so that the types through which the river flows could be determined. Lake levels and discahrge data were studied. Air photographs covering the lower section of the river from ca. 1947 to 1968 were contrasted for changes. Finally, the samples were sieved and analysed, as described in chapter four, while the channel plan of the lower section of the river was studied on a large scale map. The theory on which this has been based is taken largely from the writings of Morisawa, (1968); Leopold, Wolman, and Miller, (1964); and Leopold and Langbein, (1966).

Observation of Figure 6.2 shows the longitudinal surface expression of the river, which is the typical concave upward curve. An equation for a curve of best fit was not determined, as it is only the general form which is of importance here. The upstream segment of the river should be noted, with particular attention to the initial steepness, which decreases as it approaches Exeter. A small dam has been constructed upstream from Exeter and this would provide a local base level for the river in this area, but since the dam does not alter the 25 foot contour interval very much, the effect of the dam is indistinguishable at this scale. The maximum slope, as indicated on Figure 6.2 is reached a very short distance downstream from Exeter. Shortly after this local steepening, the general slope of the land levels off to a very gradual decline, thus fitting well with the concave upward curve. This gradual curve is only interrupted near Arkona, where it increases to 9.73 feet per mile. Actually, it is here that the river has cut through highly fossiliferous bedrock. Through the gorge, located near Arkona, the river falls in a series of rapids, about 30 feet in three miles. A dam once controlled water in this gorge, however it was destroyed early in the twentieth century.

Once past Arkona the gradient becomes low and regular until Lake Huron is reached. Again this conforms to the expected river profile. Of supreme interest are the differences of the length and slope of the old river channel, through Grand Bend and the Pinery, as compared to the present channel, direct to Port Franks. The Cut is less than half the length and over three times as steep as the original channel. In essence, this realignment had a catastrophic effect. As mentioned previously, The Cut was constructed so that it would be at the lake level existing in 1895. This meant a 10-12 foot drop in the river bed at the point of meeting of The Cut with the original channel, completely destroying any equilibrium which the river had no doubt achieved. The river had no choice but to rework this new channel into one which more closely represented its equilibrium situation. Undoubtedly, considerable erosion resulted, not only at the beginning of the Cut, but also all the way through to the bar, where fine beach sands and gravels, and even dune sands formed the river banks. The increased slope meant a greater river velocity which allowed the river to carry large quantities of material, in the form of suspended and bed load to Port Franks. The 50-60 foot deep harbour at Port Franks, (Fox, 1946), provided the calm water necessary to dump this load. This is easily seen from any recent air photgraph, as the natural harbour has been completely filled, so that now only a few channels exist, having a maximum depth of 12-15 feet. It was not enough, however, to adjust the bed of The Cut, but the water proceeded in its attempt to reach equilibrium by eroding the channel walls. During the 74 years, from 1875 to 1949, the river produced three large meanders indicated on the maps. This lengthened the river channel, thus increasing the slope somewhat. The presence of the village of Port Franks meant that the river could no longer migrate southwesterly, as it had previously done when its mouth was at Grand Bend. Thus, this man-imposed slope has been present until this day. This has meant that the erosion, particularly of the channel walls, has continued, resulting in changing channels and costly damage to sections of the village.

The river gradient is also related to the lake levels, which fluctuate considerably with time. In 1875, the time of completion of The Cut, the level of Lake Huron was high, at over 583 feet above sea level. In the nearly 100 years to 1972, the water level of the lake has ranged from the 583 foot level in 1875, to a minimum of approximately 574 feet in 1964, rising again to a peak of 580 feet in 1971. The highest level of the water during this period was 581 feet above sea level during the summer of 1952. This implies a maximum range of 7-11 feet for the lake level. Obviously such a change wouldhave considerable effect on the Ausable River. Assuming that the lake level is 580 feet above sea level on the profile, a drop to the minimum lake level of 574 feet in 1964 would increase the slope to 2.61 feet per mile. At maximum lake level, 581 feet, the slope would be decreased to 1.93 feet per mile. During the summer of 1972, when the lake level was quite high, probably greater that the 580 feet of 1971, it was observed that the river was approximately a foot from flood stage. This meant that even in the early fall, when river level is generally lowest, a strong northwest wind could pond a sufficient amount of water on the Ontario shore so that the river exceeded its bankfull state. This resulted in the flooding of the Port Franks area, particularly on the weekend of October 7th, 8th, and 9th of 1972.

This fluctuation in lake levels, as previously mentioned, plays an important role in determining the ability of the river to carry the load. Of particular importance here is the river's suspended load, which it has carried for many miles downstream. Its presence is indicated by turbidity in the Ausable River. With the rise of the base level, the river will essentially be ponded before it reaches Lake Huron. The extremely low velocity reached at this point means that a considerable amount of the suspended load and all of the bed load will be lost. This explains the rapid filling of the deep harbour at Port Franks. It would be interesting to take cores in this area to see what exactly the sediments are, how deep they are, and thus confirm this belief.

This ponding is indicated also by the narrownes of the actual mouth of the river. The river mouth is being narrowed by the buildup of the bar, due to longshore transport of sand from the north. This is particularly important at the present when the high water level causes waves to cut into the unstable dunes. Normally this process would force the river south, but the presence of man-made constructions in the form of breakwalls and rip-rap prevent this. Thus the channel becomes narrowere and deeper at the mouth. This increases the ponding effect behind the mouth, resulting in loss of suspended material, as apparent from the much decreased turbidity of the water entering the lake. Evidence supporting this conclusion could be made possible througha series of current meter readings at several places along the river. Since this was impossible, the following estimates were made. The velocity at the centre of the river beneath the bridge at highway #21 was estimated, by means of timing floating objects over a known distance, to be 1 foot per second. This is probably low for the mean velocity at this point, but was observed to be considerably less than the velocity at the mouth. A velocity of 1 foot per second, or approximately 30 cms. per second, was observed to be caple of eroding material of 0.1 to 1.0 millimeters in size. (Morisawa, 1968) This encompasses the sand sizes, and a slight increase in velocity would provide the energy necessary to carry granules and small pebbles downstream. The velocity at the mouth was not ascertained, nevertheless, the whole channel was frozen over by December 14th except for the mouth, which was completely free of ice, and which would probably remain so until the lake froze over. This indicates a considerable increase in velocity at the mouth of the river.

It was suggested above that the Ausable River carries a considerable amount of suspended load. In order to determine the reason for this, the Soil Surveys for Lambton County and Middlesex County were studied to determine the types of soils through which the river flows. Although the river actually rises outside of Middlesex County, it did not seem necessary to consider this upstream extremity. The original channel and The Cut were compared to determine any significant differences. (For a detailed description of the major soil types, see Appendix IX). The most striking feature about the material through which the river flows is the predominance of silt and clay. Within Middlesex County, every major soil group is either a silt-clay loam or else is underlain by a clay at very shallow depths. The few areas where gravels are found are associated with moraines and beach ridges. As the river enters Lambton County, there is a progression from sand or clay to lacustrine clay and finally to the sands and gravel of the bar. The Cut is much shorter and so the water spends less time passing through each soil type. The old channel, now the Parkhill System, flows through nearly identical soil types. Thus, there is no significant difference between the old and new channels, at least with regard to soil type.

The 1949 map of Appendix II, which will be referred to throughout this section, shows The Cut after 75 years of trying to achieve equilibrium. It is important to mention at this point, that the original cut, as shown in Figure 6.1, extended only to the old river channel rather than the lake. In order to join The Cut to the channel, the new river was curved sharply to the north. During the 75 years, this curve has been reworked so that it appears as a meander, similar to the older meanders downstream. Some of the former channels have beenoutlined with finely dashed lines to show the modification of the channel during the 75 years. The material comprising the river bed and banks is easily eroded. Consequently the migration of the meanders is indicated by the formation of point bars. This is particularly noticeable at Port Franks, where there is a great deal of variable sand on the inside of the large loop. Although only The Cut can be studied for actual change in the 75 year period, it alone in this small section shows how variable the channel may be. Thus it is easy to see how much the mouth and the near-mouth section of the river could have wandered over thousands of years. The meander study to follow will be based on the 1949 channel shape. A brief history of the mouth of the Ausable River, as presented by Mr. Roger Martin of the Ausable-Bayfield Conservation Authority, is contained in Appendix X.

Map 2. of Appendix I shows the channel realignment and the new mouth, which were completed in 1951. The new channel was straight, cut off all three meanders, and exited directly into the lake. The two meanders farthest upstream were not filled in at their heads until after 1955, and so water was able to flow through them. Continued growth of the point bar at Port Franks is indicated, along with a partial closing of the new mouth. This filling of the mouth may be due partly to the longshore drift, and partly to the dumping of the river's load at this point. Since the discharge was then split between two possible exits, decreasing the flushing effectiveness of the river, the original channel was also narrowed. All of this was occurring at a 1955 lake level of 580 feet, just slightly lower than the present level.

Map 4. based on 1966 photographs shows the mouth as it exists today. There are some important changes between this map and that of 1955, with the transition period indicated by Map 3. These include the complete closure of the new mouth, the widening of the original mouth, continued filling of the harbour, and the closure of the heads or the upstream entrance to the meanders. These meanders have since been reopened to prevent them from filling with debris and to maintain a boat channel. The lake level at this time was considerably lower, 577-578 feet, thus more of the beach was exposed.

Two engineers reports, Chisholm and Kilborn, have been presented since 1957, suggesting further improvement of this section of the channel. The Chisholm report was presented with no further action being taken, while the Kilborn report was presented in March 1972 and is still being considered. The latter suggests a major flood and erosion control scheme for the river. The problem, however, is deciding which channel to follow, the present channel or the one completed in 1951. Further comments on this proposal will be reserved for a later section of the paper.

Hydrographs

Runoff data for the Ausable River was provided courtesy of the Inland Division of Water Survey of Canada. The information is complete for the period from March 1946 to December 1971. The recording station is located on the Ausable River near Springbank. Hydrographs were prepared for the total period and should indicate sufficiently the yearly trends with respect to discharge. In each case the mean monthly runoff value used was calculated by the Inland Waters Division, using daily information. The hydrographs may be studied in Appendix XI.

The most striking factor presented on these hydrographs is the extreme fluctuations in the amount of discharge. These years have a maximum mean monthly discharge of over 1,400 cubic feet per second, and reach a minimum often less than 20 cubic feet per second. The hydrographs are highly indicative of the rapid runoff characteristic of the river basin. Not only is this true for the melt waters of the spring, but also for summer storms. This is obvious from the daily measurements, which in numerous situations show a jump from about 20 cubic feet per second to over 100 and even 200 cubic feet per second. This increased runoff will rise to a maximum and then decline to normal flow in a period usually less than a week. The greatest discharge occurs during the spring, generally in late February, March, and early April. By June however, the volume of water has decreased considerably, so that for most of the summer the velocity is generally low with a monthly mean runoff value in the neighbourhood of 20 cubic feet per second. The discharge usually begins to rise again in the fall, probably as a result of increased precipitation. These values do not represent too well the great range in runoff that does exist. The rapid runoff yields extremely high daily discharges. A consequence of this rapid runoff is the very low values found in the summer months. As an example, the minimum daily discharge for this sample period was 6.4 cubic feet per second on September 11th, 1963, while the maximum value for the same period was 10,800 cubic feet per second on February 2nd, 1968. Thus the maximum runoff is over 1687 times greater than the minimum runoff. The minimum value is not a good value for comparison, though. The mean discharge for the river for the eleven years would prove mor representative. It was found to be approximately 304 cubic feet per second. The maximum daily discharge is still 36 times greater than the mean value. Since the river designs its channel to accommodate the most frequent volume of water, anything above the 300-400 cubic feet per second level will cause strain on the channel. This strain leads to channel erosion and eventually to flooding, if the volume is sufficient.

One other factor to consider in this rapid runoff is the ice, debris, and silt jam which will occur at the already constricted mouth. Not only will there be the problem of river ice, but also shore ice. The end product of these factors will be the virtual damming of the river resulting in disasterous flooding upstream.

Analysis of Sediment Samples

A total number of seven samples were taken along the course of the river between highway #21 and Port Franks. The places where the samples were taken are marked on the meander analysis map (in pocket at end). They are generally related to : (a) upstream beach deposits, (b) fine material along the channel, which was possibly dredged from the channel bottom during realignment in 1950 and 1951, and (c) reworked beach material now found in the meander scars. The following is the locational description of each of the samples :

(i) 501 - centre of the new mouth at approximately four feet below the surface.

(ii) 502 - on west side of river across from #3 meander - beach sediments.

(iii)503 - same position as 502

(iv) 504 - reworked meander material on extension of meander #3 now on west side of river - right along present channel.

(v) 505 - west side of river, #3 meander in small gravel pit.

(vi) 506 - same as 505.

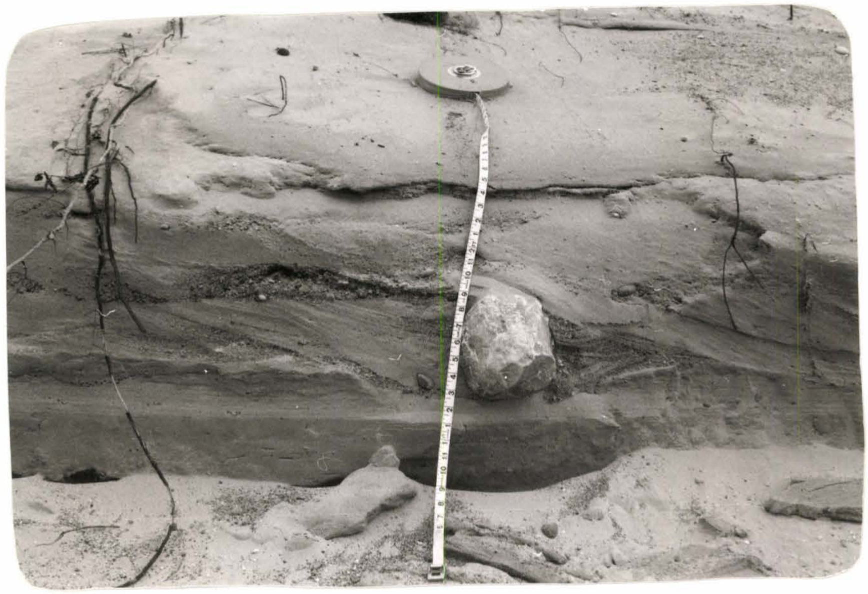
(vii)507 - beach deposits, 150 feet north of bridge on east bank of river.

Sample 501 was chosen to compare the material filling the channel mouth with sediments from the beach and river. Actually, the sample compared quite favourably with a sample from the dunes, although it was slightly coarser and less well sorted. The median and the mean are quite similar for both samples; however, as would be expected, sample 501 has a larger standard deviation and a slightly smaller coefficient of sorting. This analysis would clearly indicate that the material filling the channel, at least at the lake end of it, has been implaced by longshore currents which eroded the material largely from the dunes. In addition, this sample is quite similar to samples from the first trough of the bar system. This further substantiates the previous statement regarding origin. However, if samples had been cored from depth at the river end of the channel, it might have been possible to definitely determine the source of these sediments as being upstream.

Plate 6.A shows the general location, and gives an idea of the bedding and the material present at the sites of samples 502 and 503. The two samples were taken to provide a better concept of the beach deposits at this location. Both samples show a definite concentration in the sand fraction, while the former also contains a large percentage of gravels and pebbles. Neither of the samples are extremely well sorted, as indicated by the deviation from the normal distribution curve, and the low values for the sorting coefficient.

One of the major purposes of this study was to compare the material found in the meanders with the material through which the river flows, essentially the dune sand and the beach material upstream from the meanders. The river's suspended load did not seem to be associated with any of these samples, due to the definite lack of the clay fraction. In a few of the samples, the pan of the sieve nest did contain some material which would be of the clay fraction; however, it was always less than 1% of the total specimen. For this reason, the beach material, samples 505, 506, and 507, will be considered prior to sample 504. Generally these beach deposits had a wide size range, from coarse gravels to sands, and it was

Plate 6.A : Indicates the material comprising the southwest bank of the Ausable River, at samples 502 and 503.



hoped that the three samples would provide a good representation. Sample 505 shows a definite concentration of material in the coarser size fraction, with greater than 75%of the material being of granule size or larger. Poor sorting is exemplified by the value for standard deviation, which is larger than 1.5, and by the extremely low value of approximately 7 for the sorting coefficient. (A well sorted sample will have a sorting coefficient approaching 100.) Both samples 506 and 507, when compared to the previous sample, contained more sand size material, with the maximum grain size decreasing to the finer gravels. The means for samples 505, 506, and 507 are - 1.583, 0.769, and 2.163 respectively. This indicates an unequivocal contrast in size fractions, and the wide range of material sizes of which the river channel is comprised. The sorting improves somewhat with the finer samples, although at best these are only moderately sorted. (The terms used in describing the degree of sorting are taken from the "Origins of Sedimentary Rocks", by Middleton, Blatt, and Murray, 1969.)

The one sample, 504, taken from the reworked meander deposits shows a Gaussian or normal distribution, on the cumulative percentage probability plot. The mean in this case is -1.286 with the sorting statistics indicating very poor sorting, as in the beach deposits. It is important to remember that very good local sorting may exist, but the term poor sorting applies to a sample over a fairly large area, at least in comparison to the current bedding present. A weak tail in the fines is also indicated.

These statistics support the hypothesis that the river, with its present slope, is able to actively rework the beach deposits, which make up its channel boundaries. This material is carried largely as bed load and deposited as point bars. This erosional-depositional process allows channel migration, and the subsequent meander patterns. These factors will be most important during periods of peak flows, the flood periods. The high flow increases not only the volume of water, but also its velocity, and so the river has the energy potential to actively remove the beach deposits , even of the gravel size. All of this is a result of the excess energy of the river due to its imposed slope. Morisawa maintains that the depth of a river is inversely proportional to the amount of sediment being transported. An increase in velocity, and consequent sediment transport, requires a corresponding decrease in depth. If this is true for the Ausable River, then it is necessary that the river erode its channel walls and consequently alter its course.

Meander Analysis

Morisawa suggests two possible explanations for the river meanders. The first is helical flow, and the second is the hypothesis of Schulits and Sternberg, that the slope is a function of the size of the material that the water must carry. If the slope exceeds that which is required to transport the grains on the bed, the stream will meander to lengthen its course, and thus decrease the gradient. It has been found that meandering streams have banks with a high silt-clay content and deep, narrow channels. It was also suggested that meandering may result when a large portion of load is carried as suspended load. Friedkin found in laboratory experiments that a coarse material usually yields wide, shallow channels, with a steep gradient, and tends to develop a braided rather than a meandering channel pattern. Based on this information, the Ausable River must have two distinct hydrodynamic regimes. The first would occur at high flows, (the datum is impossible to determine without a concentrated study of the river), which would mean that the river, on entering the bar area, between highway #21 and Port Franks, would be carrying a suspended load but in addition, would have sufficient energy left to erode its banks. This would lead to a widening and shallowing of the channel, with a tendency towards braiding. During low flows, the river still carries its suspended load, and according to the above theory would tend to initiate a deeper meandering channel. Both extremes are possible, and it would seem that for some mean discharge value, the pattern of migrating channels, with erosion and deposition, has resulted.

Helical flow is believed to be the dominant factor according to Leopold, Wolman,and Miller. Once again, the idea of a river seeking an equilibrium state is proposed. However, these authors feel that with other conditions being equal, a meandering stream is steeper than a non-meandering one, because of the necessity of overcoming the additional friction loss due to channel curvature. A channel tends to adjust to a condition in which the rate of work expended in the system is a minimum. Therefore, the most likely channel pattern is sinuous, with all bends tending to have the same ratio of radius of curvature to channel width. Studies of pipe bends have

Plate 6.B : The Cut, looking southeast, i.e. upstream, with the highway 21 bridge in the background, and the former Lake Burwell in the distance.

Plate 6.C : The Cut looking southwest and downstream, and showing a portion of meander number 3.

shown that when the ratio of the radius of curvature to the channel width has a value of approximately 2, a minimum resistence due to curvature exists. This is related to the fact that the main flow tends to move from the inside region of great curvature toward the outer concave boundary, (Leopöld, Wolman, and Miller, 1964). These meanders however, showed a very wide range for these values, generally greater than 2, and thus the river must be a long ways from equilibrium. Meanders 5,6, and 7, of the old river channel do seem to conform to the expected value. Having assumed that the Ausable River, (The Cut), has not as yet attained an equilibrium profile, this study will be based on its desire to do so, as presented by Morisawa.

Regarding the geometry of meanders, the relationship between meander length, (wavelength), amplitude, radius of curvature, and channel width, may be considered linear. Wavelength should range from 7 to 10 times the channel width. The amplitude, however, may be determined more by the erosion characteristics of the river banks, and by other local factors, than by any hydrodynamic principle. Increased sinuosity is associated with small width relative to depth, while heterogeneous sediments may reduce the sinuosity. (Leopold, Wolman, and Miller, 1964)

The meanders studied are indicated on the large scale map of the river mouth in the map pocket. This map was produced somewhat after the realignment completed in 1951, and the large scale allows fairly accurate determination of the extent of the meanders. Using the air photographs taken prior to 1949, it was possible to check the accuracy of the map, and delineate its flood plain, the blue pencil line. The meanders have been numbered 1 to 11, with each half wavelength considered separately. This was done because not all of the meanders had a complete wavelength. The meanders numbered 1,2, and 3, belong to the present channel, while those numbered 4 to 11 are in the old channel, and thus can be assumed to be static. It is difficult to decide whether the channel at number 4 is truly representative of the former channel, because obviously the width is anomalous to the discharge which once occupied this channel. Nevertheless, it has been included as part of the study.

Generally, the meanders were sketched where necessary, from the air photographs. In the present channel the extent of the meander was determined as the line between obviously reworked river deposits and the natural sand dunes. In some cases this was also the present extent of the water. However for meander number 3, the extent of the channel along with the channel width had to be estimated. The old river was more strictly confined in its flood plain, and the meanders were taken as the present postion of the water. On this basis, the green partial circumference lines are approximate curves of best fit for the meanders. Largely based on the above, the other values of the radius of curvature, wavelength, and half-wavelength, (which is assumed to equal the channel length), were obtained. The actual measurements of these values, along with the river width, and a statement as to the presence of point bars, which was determined from the air photgraphs, are all included on this map.

Regarding the statistical evaluation of the meander data, it would seem necessary to separate the data for numbers 1,2, and 3, from the others. Although this was done, in most cases the results compared quite favourably in all of the meanders. Therefore, they will be differentiated, but the old channel will not be treated as a separate system from the present channel. The data was first considered for a relationship between channel length and meander length. It was found that a straight line relationship represented the points fairly well. This line had a positive slope of approximately 0.6. Leopold and Langbein,(1966), suggest other statistical relationships to analyse meanders. They state that a series of meanders should have -

(i) $\frac{\text{meander length}}{\text{channel width}} = K_1$

(ii) $\frac{\text{channel length}}{\text{radius of curvature}} = K_2$

(iii) $\frac{\text{radius of curvature}}{\text{channel width}} = K_3$

(iv) sinuosity : $\frac{\text{meander length}}{\text{channel length}} = K_4$

The actual statistics for the relationship above are contained in Appendix XII, however, the general comments below will provide the basic information. First the ratio of meander lenth to channel width failed to yield a constant of any type. The ratio value ranged from 6.0 to 72.0. A wider scatter of values was also found for the ratio of curvature to channel width, and thus it would seem that the width of the Ausable River has minimal effect on the meanders. However, the channel length-radius of curvature ratio yielded reasonable values witha mean of 1.87. This is considerably less than the 4.7 which Leopold and Langbein suggested for this ratio. The meanders can also be compared on the basis of their calculated sinuosity, which has a mean value of 1.67. These correlations would apparently indicate that all the meanders have been produced by a similar energy system. Therefore, it would seem that the actual amount of discharge plays a more important role in producing the meanders, than the velocity. The channel material is also important probably, and this would account for the similarity in the meander patterns, even though the sizes are differnt, as both the amount of water and the material have remained essentially unchanged. In the older channel, the meanders are tighter and more confined within a definite flood plain. This is probably due to the fact that this water was flowing much more slowly, with a greater distance of travel, and decreased slope. Therefore, the channel was deeper and narrower, and the banks were not eroded. Thus, any meander changes before The Cut would have occurred within the confines of the flood plain.

The information contained in this chapter is directly related to the beach study. Thus, further comment will be made with regard to the Ausable River in chapter seven, when the problems of flooding and erosion, and their possible solutions are discussed.

Chapter Seven : A Synthesis of the Problems of Flooding and Erosion in the Grand Bend and Port Franks Area

The basic approach of this thesis has been to divide the whole area, from St. Joseph to Kettle Point, including the lowlands east of the beach, into small sections in order to simplify the discussion. Based on this subdivision, it was possible to discuss a few areas in detail, and other areas briefly. This chapter, which considers the problems of the whole area, must necessarily begin by fitting the pieces back together again.

Along the present day beach, there exist several types of lakeshore interfaces, from the high eroding cliff at St. Joseph, to low stable cliffs north of Grand Bend, from aggrading and prograding beachessouth-west of Grand Bend, to the bedrock outcrops near Kettle Point. Thus, an essentially complete beach system exists here, with both its natural beauty and its problems. In addition to the beach, there are the sand dunes, exciting in their reforested state; the lowlands farther east, of value for their agricultural prodution; and finally, dissecting the whole area, the beautiful, unpredictable, Ausable River. Recognition of the innate beauty of the area is exemplified by the large tracts of public land, which are certainly popular recreation spots for people, not only from Ontario, but also from some American states, particularly Michigan. Nevertheless, this area, once wilderness, continues to evolve in a natural pattern, which before settlement would not have caused any problems. These natural changes however, interfere with man as he tries to control all things. Thus, the natural evolution of the river, the dunes and the beach, become 'problems'. These problems have been dealt with in the past, are being studied at the present, and will be planned for in the future. Two possiblesolutions exist, representing the extreme poles of thought. The first is to contrsl nature, at least locally, to the best advantage of man, that is to treat natural phenomena as nothing but a nuisance. The second alternative, at the other extreme, is to live with the earth, giving and taking for mutual benefit. Hopefully the latter approach is, and will remain dominant in the planning of man. Thus, in this chapter, the discussion centers around the principles of conserving natural phenomena while providing for mans comfort during his comparatively brief existence on earth.

The Beach - Problems and Possible Solutions

The basic problems in this area are flooding, erosion, and natural evolution as they conflict with man. Certainly there is the obvious erosion of the cliffs comprising the shore line north of Grand Bend. This is a study in itself however, and so can not be adequately dealt with here, except to recognize that the problem exists. Thus, there remains the erosion and deposition of sediment in the beach zone. This has resulted in the removal of a considerable amount of dune sand, which often threatens the existence of cottages and houses situated on the dunes. Associated with this erosion is the littoraland longshore transport of material, which for many years has caused problems at the river mouths in the area. The mouth of the Parkhill Crek System at Grand Bend, was stabilized early in the twentieth century, by means of the construction of piers on either side of the river mouth. The purpose of these piers was to interrupt the littoral drift of material and thus stabilize the river mouth. Associated with the construction of these piers however, is the removal of beach material on their leeward side. At the mouth of the Ausable River, the deposition of sand is presently causing similar problems of mouth instability. The use of piers in the Port Franks area for the purpose of control, has also been considered. Again, this will cause erosion on the downdrift side of the pier, in an area which already is severely eroded.

Generally, this beach is an example of a beach which has built its own natural defenses against erosion. This is evidenced by the abundant supply of sand cotained by the dunes. It does not appear that this beach is receeding, in fact it may even be growing, but it is obvious that the beach is simply responding to the cyclical fluctation of the lake level. At high water levels, the dunes and cliffs are eroded, and the material is transported alongshore. With receding water levels, the beach becomes wider, allowing the sand to be exposed, which is in turn transported by wind to reform the former dunes. Thus, it would appear that tha beach is able to maintain an equilibrium with the lake at all times. The problem arises when the erosion threatens the existence of the cottages and the deposition interferes with the river mouth and boat traffic. Therefore, with regard to the beach, the problem can be considered to be one of protecting existing structures and waterways from the dynamic beach environment.

In addition to the piers to protect the river mouth at Grand Bend, several small scale efforts to protect the beach have also been

Plate 7.A and 7.B : The south bank of the Ausable River at its mouth at Port Franks, showing the erosion of the bank and shore by the waves.

Plates 7.C, 7.D, and 7.E : The Problems associated wiyh the leeward side of the pier at Grand Bend. The coarser material of 7.E indicate that the beach is steeper and apparently being starved for material, to be carried along the beach.

Plate 7. E :

attempted. These attempts include as mentioned in aprevious section, the construction of timber breakwalls, the positioning of sand bags and such foreign objects as tires to trap the sand, and the placement of rubble piles in front of the dunes. These methods have resulted in varying effectiveness in controlling further erosion, with the piers, breakwalls and rubble apparently most successful.

The problems of coastal erosion and protection have been considered by many writers. C. A. M. King, (1967), has provided a sufficient summary for the purposes of this study. First, destructive wave action on a sand beach is highly successful in moving sand alongshore and offshore into deeper water. The best natural defence is an adequate beach which will tend to absorb the energy. The presence of sand dunes are valuable for their reserve supply of sand. However, when the situation warrants it, arificial methods of protection can be used. Such artificial methods have been investigated and tested for many years. Two major types have resulted, seawalls and groins. The former are walls which run along the beach, while the latter are defined as, a shore protection structure, designed to build or maintain a protective beach by trapping littoral drift, or to retard erosion on an existing beach, (U. S. Army Coastal Eng. Centre, 1966,). Seawalls have been used extensively in England and other parts of Europe for many years. The main problems with such structures is that they prevent or hinder the movement of sand from the beaches to the dunes, in addition to concentrating the backwash, (due largely to decreased percolation). Consequently the beach will be lowered and narrowed, and the replenishment of the dunes will be hindered. Any energy not expended on the seawall will be transmitted in a down beach direction, resulting in concentrated erosion at the end of the wall, (King, 1967). Minnikin, (1963), who was mentioned previously in chapter five, provided an equation derived by Luiggi, for the pressure exerted by waves on a vertical wall. These values have been given in Appendix VIII, which indicates a pressure in access of 1 ton per square foot for an average wave generated in Lake Huron. The accuracy of these two values is doubtful, although they do show that considerable energy is expended on such features. These high pressures are only developed when a wave is breaking as it approaches the wall, and thus traps a pocket of air between the water and the wall. The air is compressed, an explosion which releases considerable pressure on the wall, inthe area of the air cushion follows. Thus seawalls are generally unfavourable for controlling this beach because, (i) they require considerable strength for durability, (ii) they may retard the replenishment of sand dunes during lower lake levels, and (iii) they will detract from the natural beauty of the beach. Thus further consideration of this problem is necessary.

The use of groins appears to be the most favourable system to retard littoral transport and to build up a wide beach. For the beach from Grand Bend to Port Franks, the major purpose will be to stabilize a beach which is subject to advance and recession, as oppossed to the actual building of a beach. This would allow regrowth of the dunes when the water recedes and the beach advances, and would retard the erosion of the dunes with the rising water level.

Exhaustive studies have been carried out on the design and effectiveness of groins, by Per Bruun, (1953, 1954); Minnikin, (1963);

the U. S. Army Coastal Engineering Research Centre, (1966); and others summarized by King, (1967). These studies have yielded a considerable range of opinions on groin designs and effectiveness. It is generally agreed that long high groins are most effective in interrupting the littoral drift, however there is concern about the effect of such groins on the whole beach, and in particular the leeward side. Considerable disagreement arises however, when considering the most suitable groin height for the beach, the orientation of the groin with respect to the beach, the length, and the distance between each of the groins.

Since this thesis is not designed to specifically outline a design for a groin system on the beach, the following comments will be general. The suggestions are simply suggestions and would require more study prior to any consideration of implementation. Information regarding the design of groins, their usefulness and shortcomings, has been taken largely from the U. S. Army Coastal Engineering Research Centre, Technical Report no. 4, (1966).

Basically there are two types of groins, permeable and impermeable. The latter type allows some of the littoral material to pass through, while the former does not. The extent to which the littoral transport is modified depends on the height, length and permeability of the groin, in addition to the local wave and shore characteristics. This results in an accumulation of material on the updrift side, while supply is reduced on the leeward side resulting in erosion. This situation is analogous to the consequences of the pier built at Grand Bend. Before the use of groins can be considered however, it is necessary to consider several factors --

(i) the extent to which the downdrift beach will be damaged if groins are used;

(ii) the adequacy of natural sand supply to insure that the groins will function as desired;

(iii) the economic justification of groins in comparison to stabilization alone;

(iv) the adequacy of shore anchorage of groins to prevent flanking by downdrift erosion;

(v) minor fluctations of shorelines as a result of the groins must be allowable;

(vi) the adequacy of sufficient littoral material to fill the groins and to permit natural littoral supply to pass without interruption.

In determining the length of the groins, their spacing, and their orientation, the beach profile must be considered in detail, as outlined in the Technical Report no. 4. Figure 7.1 indicates the expected effect of a groin system on a beach.

If such a plan was ever to be pursued to determine the feasibility of groins to stabilize the beach, some further considerations could be made. The constructions of groins could be done by students during the summer, using local rock-fill, if it is felt that this material is suitable. Of course the design for such structures would have to be prepared prior to the initiation of such a project. With relatively inexpensive labour costs and adequate sources of bedrock, this project could be very economical, particularly with financial assistance

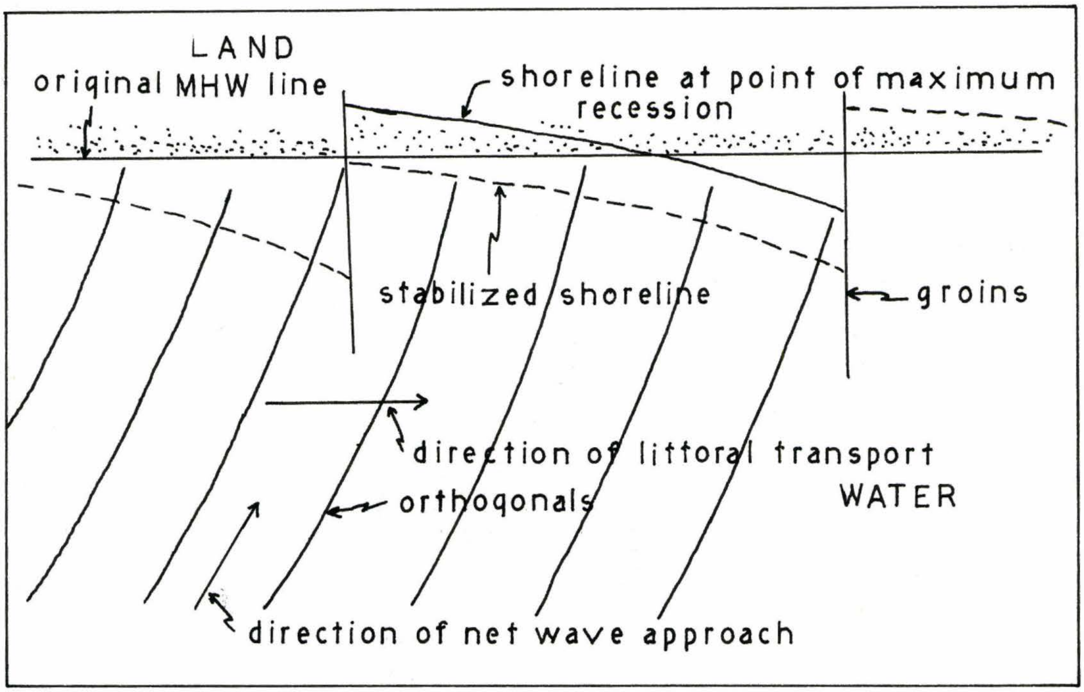


FIG. 7.1 GROIN SYSTEM OPERATION

FROM: U.S.A.C.E.R., TECH. REPORT no. 4

from the various levels of government.

In addition to the groins, which have been considered largely for the beach south of Grand Bend to Port Franks, one other method of beach stabilization appears warranted. This is artificial beach nourishment. The necessity of such a project to the south of Grand Bend has been considered in a previous chapter, where it was stated that the beach appears to be starving for material. This apparent starving is a direct result of the interruption of the littoral transport of material by the jetty at Grand Bend. Plate 7.A, B, and C indicate the situation here. The strongest breakwalls in the area exist at this point, and they are obviously being attacked furiously by the waves. This indicates the lack of a protective beach and thus, the necessity for artificial nourishment. Plates 7.D and 7.E, showing the south bank of the Ausable River, suggest another area where nourishment would be advisable. Major north northwest storms hit here with considerable force. This area has minimal beach protection in front of these cottages, due to the deposition of a large portion of the sand being transported in the vicinity of the river mouth to the north. With the construction of groins updrift from this site, or a jetty to protect the river mouth, the necessity of artificial nourishment would be even greater. This area of Port Franks should also be considered for possible protection by groins.

In summary, it is thought that the beach south of Grand Bend to the Port Franks area requires some sort of stabilization. As suggested, this would be best achieved by a combination of groins and artificial nourishment. Such a program would require further study of the beach area to determine the groin dimensions and the size of the material best suited for the artificial nourishment. This project should be completely organized under the auspices of the local government, conservation authority, and the two villages concerned, in cooperation with the provincial and federal governments. This would end the haphazard attempts at shore protection of the past, and would yield a more stable and yet beautiful recreational beach area.

The Ausable River - Problems and Possible Solutions

The critical problems, flooding and erosion, have prevailed over man's attempts to control the river for nearly one hundred years. This record suggests that all future plans should be rigourously considered, to eliminate useless cash output and to conserve the river in its natural, or as close to its natural state as possible. There is no question of the necessity to protect Port Franks from erosion along the river channel, but there is great doubt that the flooding can ever be completely controlled. The flood problem is directly related to both the river and the lake, and although the river might be controlled, it is not as easy to regulate the lake levels. The danger of floods is linked directly to the fact that Port Franks is built on a river flood plain, which is only a few feet above Lake Hurons water level. The suggestions presented, however, are designed to decrease the intensity of the spring flooding, and hopefully will eliminate the danger of summer flash floods.

In March of 1972, Kilborn Engineering Limited presented a report on possible means of controlling flooding and erosion problems in the Port Franks area. Two possibilities were suggested - (i) a control dam near Arkona, to regulate the river flow, (rejected due to the cost involved), and (ii) revetment of the channel of the Ausable River near Port Franks. The latter proposal has two possible channels, and both include the constuction of jetties to control the mouth of the river. The channel, as indicated by Figure 7.2, would be widened to 250 feet and deepened. This would supposedly allow most of the flood flows to escape to Lake Huron. The channel would be stabilized by means of rip-rap on its banks, extending as far as the downstream section of meander number 2. These suggestions it is thought, would largely control the flooding and erosion in Port Franks, although admittedly, the flooding problem is only diminished and can not be solved.

Several objections can be brought against this report. These objections may include problems which were possibly beyond the scope of the Kilborn Report, but should be considered by the Ausable River Conservation Authority. First, the net alongshore drift in the Port Franks area is most decidedly north to south. The energy values calculated in chapter five indicate this fact, although more detailed consideration is necessary to determine actual values of the alongshore components. Such work could involve expressions like Caldwell's for the alongshore component of wave energy, (King, 1972). Thus it does not seem necessary to construct a 300 foot jetty on the south side of the Ausable River. A much smaller structure could be used for the purpose of protecting the cottages nearby. The necessity of a

750 foot pier on the north side of the river is also questionable, if this structure became part of a groin system, extending north to Grand Bend.

The other objections refer directly to the river and the maintenance of its natural state. These objections are followed by possible alternatives to alleviating the flooding and erosion problems. Thus, the second objection is that these corrections will be temporary with the problems continuing due to the dynamics of the river system, working to seek an equilibrium state. Thirdly, the Ausable River will essentially be destroyed near its mouth. On the surface, it will become little more than a demonstration of engineering skills. This factor is too important to be overlooked, particularly since much of the adjacent property is owned by the local conservation authority, which is no doubt conscious of the importance of natural conservation. Thus, the ideas presented below will be considered before any major work is done on this section of the river.

The present condition has stemmed directly from the digging of The Cut in 1875. This destroyed the equilibrium, introducing a much steeper gradient for which the river has as yet been unable to compensate. Only a much greater reach, or a higher base level, will achieve any significant decrease in this slope. As described previously, the induced slope means a greater velocity, thus more erosion, and an increased probability of flooding. The one good possibility of this situation is, that when the Port Franks harbour is completely silted, as is happening rapidly, the ponding effect of the river would no longer be present. Thus, the river would enter the lake at an increased velocity. The material carried by the river will then be suspended until it settles in the lake, hopefully allowing the scouring effect of the river to be great enough to preserve the mouth.

The suggestion of controlling the channel by rip-rapping the banks would only be a temporary deterrent to erosion. With the rip-rapping only extending past the first meander, there remains a considerable distance upstream in which the river has wandered in the past. Unless the rip-rap was continued as far as highway #21, the channel would likely change sufficiently to require constant maintenance along its banks. Even with extensive rip-rapping, the high discharge rates which were previously determined to be responsible for most of the erosion, may erode the unprotected river bed. This is a result of excess energy in the water since no work can be done on the channel walls. The only loss of energy is due to friction. This again would indicate the necessity of constant maintenance of the channel, particularly after spring runoff. This combined with the deepening and meandering characteristics of the lesser flows would mean that rip-rapping only part of the channel would not solve the problem.

From all of this, it would seem that a major part of the problem is the rapid rate of runoff, a result of an extremely low storage capacity and a low infiltration rate. This has been discussed in the section on hydrographs. The best apparent solution to this problem is construction of dams upstream, such as that proposed for a site near Arkona. The storage capacity for this reservoir is variable, however, a dam 50 to 60 feet high should provide sufficient storage for the spring runoff. The permanence of a dam increases its feasibility compared to channel improvement. Although initial cost will be greater, estimated at 1.2 million dollars in the Kilborn Report for the dam, (not including land costs, legal costs and associated expenses), it will not require the continuous maintenance input suggested for the channel improvements. The same report estimated the cost of the channel improvements at roughly 895,000 dollars, again only considering construction costs. The effect of this dam, and any others which may be feasible will increase the storage capacity of the basin, and thus, the hydrographs will become more regular. The larger the storage capacity, the less the variation between maximum and minimum flows. The dams themselves will introduce local base levels to the river, allowing the suspended load of the river to settle out, resulting in possible silting problems in the reservoirs. The reservoirs in turn will provide additional recreational areas, thus further offsetting the cost disparity with the channel improvements due to revenue from the recreational areas. However, the losss of the river's suspended load will mean an increase in turbulence of the channelized water, which will increase erosion problems downstream. The two possibilities must be weighed against each other, and it would seem, providing that sufficient storage was available, that the discharge could be levelled to a factor which would mean less net erosion, due to the much decreased maximum volume of water. Then the runoff could be increased much above the present minimums of 6 to 10 cubic feet per second during the summer. It would be hoped that the normal summer flow of the river could be increased to the value calculated previously for the mean annual discharge. Spring flow, although still considerably higher some years, would nevertheless be substantially closer to this mean annual value also. Thus, the river would be more capable of designing a channel which could accomodate the most frequent volume. Theoretically, this channel will be considerably more stable than the present one.

With this control on the rate of discharge, which would hopefully involve several small dams in addition to the major one at Arkona, the problem of exiting flood waters into the lake as quickly as possible would no longer be so great. In addition, the problem of ice jams would be decreased, as it would only be the section downstream from the dam that would contribute the ice. Thus, the straight channel dug in the 1950's would no longer be so necessary, making possible the return of the river to its former meandering pattern. This would help to increase the slope of the river, and to retard even more the erosional processes. The slower flowing waters, would tend to deepen the river channel rather than widening it, and this would make the banks much more stable, confining channel wandering to the present flood plain. Comparing the old channel through the Pinery, to The Cut and resultant channel, demonstrates this possibility.

On this basis then, it would no longer appear necessary to rip-rap the entire river channel from Port Franks to the bridge at highway #21. Putting this money toward the dam at Arkona, and taking into consideration the expected maintenance costs, would certainly help offset the dollar disparity between the two projects. It might remain necessary to protect Port Franks from flooding by means of some relatively small, inexpensive earthen dikes. There is very little that can be done however, for those who have already built homes and/or cottages very close to the river banks, and at the same level as the river flood plain. These problems should have been considered at the municipal level before building permits for thses lots were granted. This conclusion was also reached in the Kilborn Report, and so there is no benefit, in regard to this matter, with either proposal.

These suggestions are not highly substantiated with figures and detailed investigations. They are based on accepted theories of river dynamics and the data acquired for the Ausable River. The author suggests that a more detailed consideration of these proposals be completed before any further major expenditures are initiated on this river. In addition, these suggestions would conserve some of the naturalness of the Ausable River in the wake of 100 years of interference by man. The latter has provided the motive for the river section of this thesis, and it is hoped that this report will stimulate reconsideration, as to the future plans for the control of the Ausable River.

Chapter Eight : Conclusions

This study has served to summarize much of the work that has been done on the bay mouth bar system from Grand Bend to Kettle Point, and its interaction with the surface drainage, in particular the Ausable River. The results of this paper have been summarized below for ease of reference. Some of these are conclusive, while others indicate the necessity of further study to reach substantiated conclusions. On the basis of these conclusions, the recommendations which have resulted are also briefly considered.

These are the major results of this study.

(i) The beach from St. Joseph to Kettle Point is very active, however it appears to be in equilibrium, aggrading and prograding only as the lake level fluctuates.

(ii) The series of profiles made were of too short duration and covered too small an area to provide much information concerning the offshore bars.

(iii) The beach sand consists of 80 to 90% silica and calcite, with the other 10 to 20% largely composed of tremolite, hematite, spessartite, and in some cases, magnetite. This was true for all samples taken along the beach, and those from the raised beaches also.

(iv) The cliffs north of Grand Bend also contained a considerable amount of calcite, silica, and the other four minerals were also indentified in this sample.

(v) The direction of growth of the original bar is still unknown and would require more study. The modern beach is definitely transporting material from north to south along the beach.

(vi) Major wave energy produced by the winds is from the north northwest, however insufficient data is available to check imperical values and so the energy values can not really be used until further study is done in this field.

(vii) Problems of erosion threatening cottages along the beach should be considered as a regional problem rather than a property owner's problem. The Ministry of Natural Resources and the Ausable River Conservation Authority should be at the forefront of whatever planning is done.

(viii) The flooding and erosion problems on the Ausable River should be further considered, in regard to possible alternatives to the suggestions of the Kilborn Report.

This paper has provided a better understanding of the beach and the Ausable River area. Although as mentioned at appropriate locations within the thesis, more detailed study is necessary in order to fully understand the process response system. Nevertheless, the paper has considered some of the important topics and will hopefully stimulate further study.

The suggestions made require careful consideration and study prior to any implementation, either in part or in whole. The basis for the suggestions has been natural preservation. It is up to the authorities now, whether or not to control nature, with no thought for conservation and possible innefficiencies in the present proposals, on the basis of saving money in the short run. The alternative is to preserve the natural beauty for those who follow, even though the present cost may be greater. Thus it is necessary in all plans to consider the social benefit of a natural preserve, not only for the present but also for the future. This may lead to different conclusions than those based simply on economics, and thus the respective values of each alternative will have to be determined. Adifficult task indeed, but one worth the effort to at least consider further.

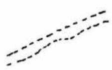
Appendix I : Maps of the Port Franks and the Grand Bend Area, (1:14000)

Appendix I : Legend to Accompany the Maps of Appendix I

Permanent Forest Boundary

Previous River Channels (Meander Patterns)

Point Bars and Variable Sand



Offshore Bars

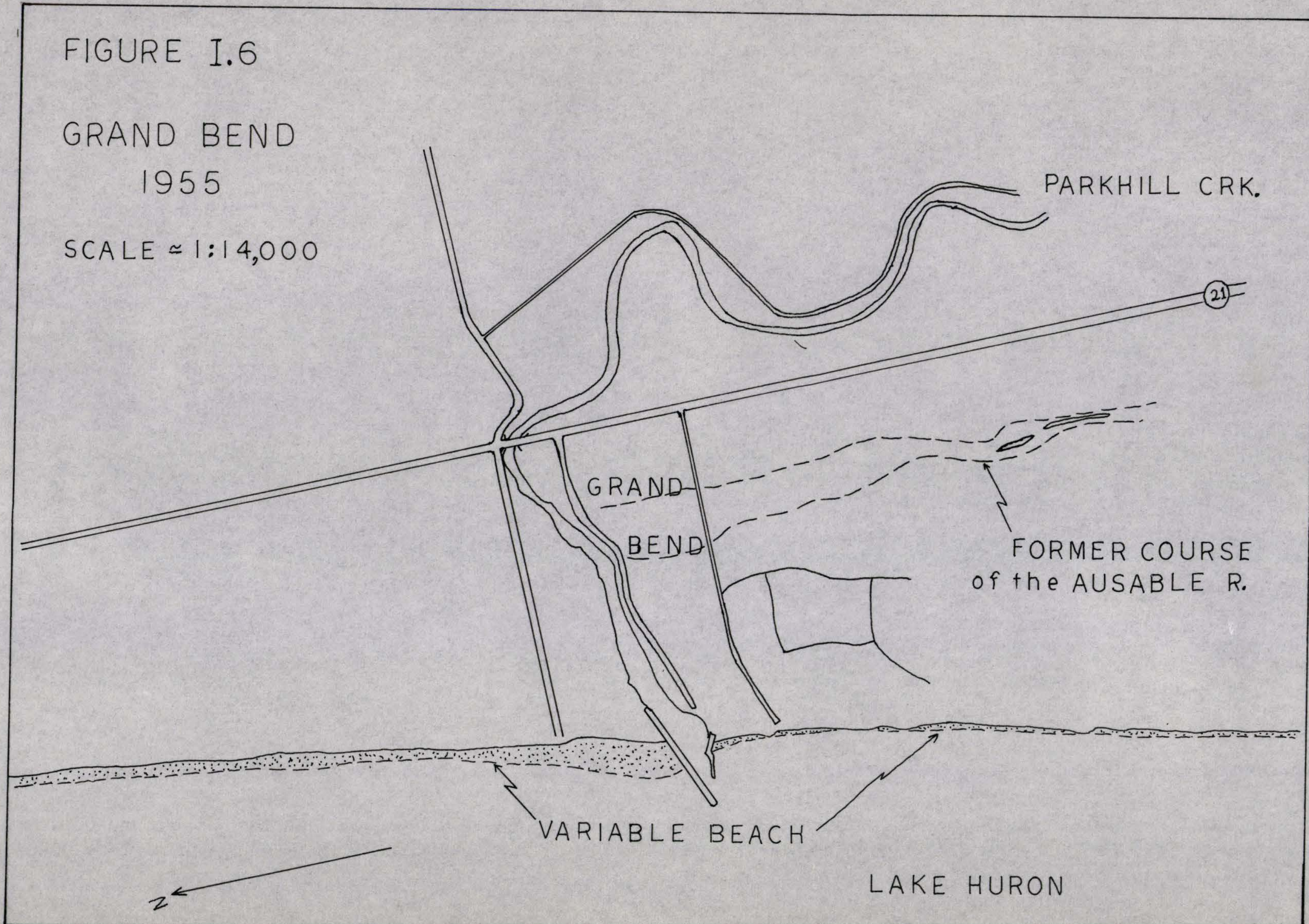


FIGURE I.6

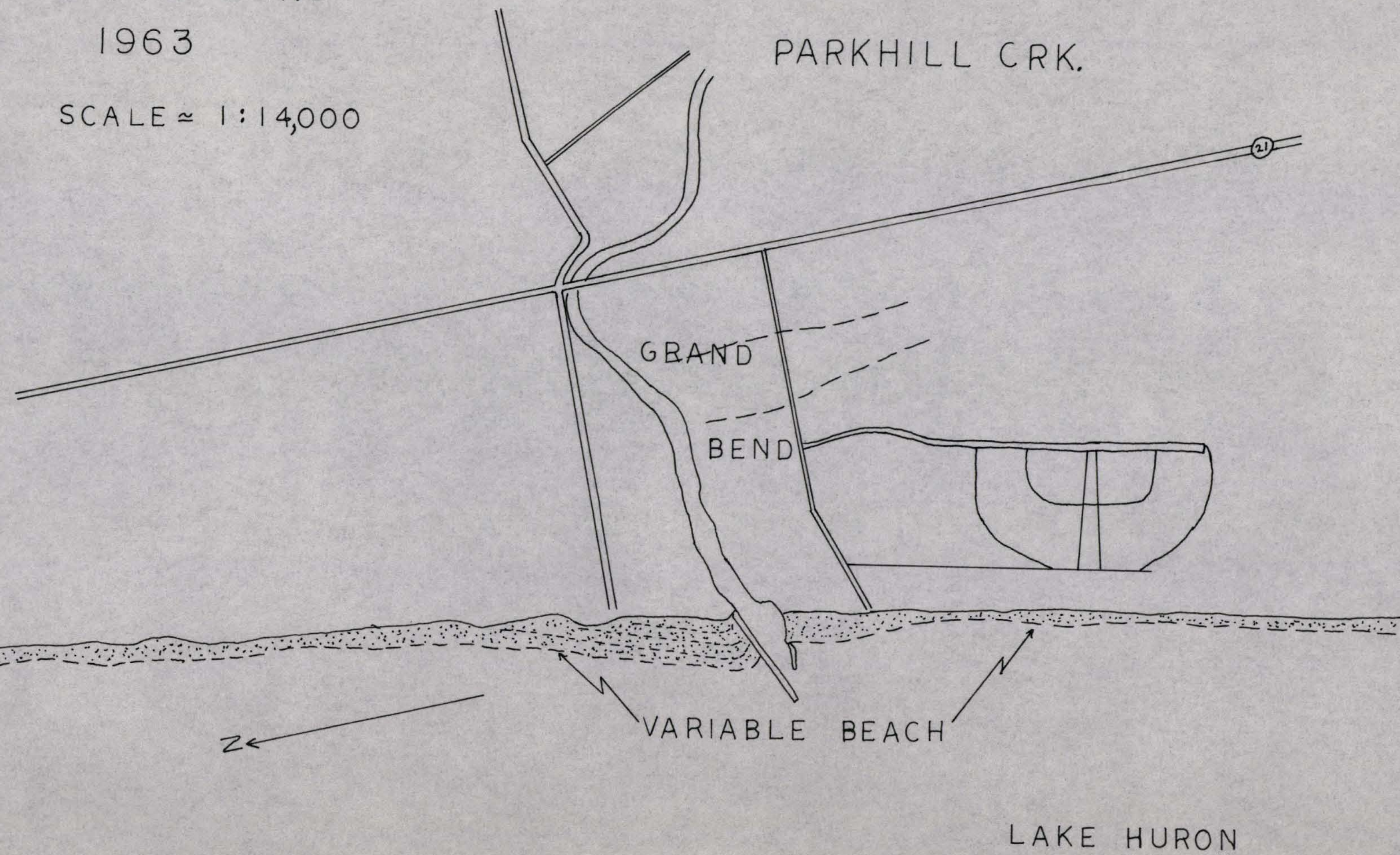
GRAND BEND
1955

SCALE ≈ 1:14,000

FIG. I.7

GRAND BEND
1963

SCALE ≈ 1:14,000



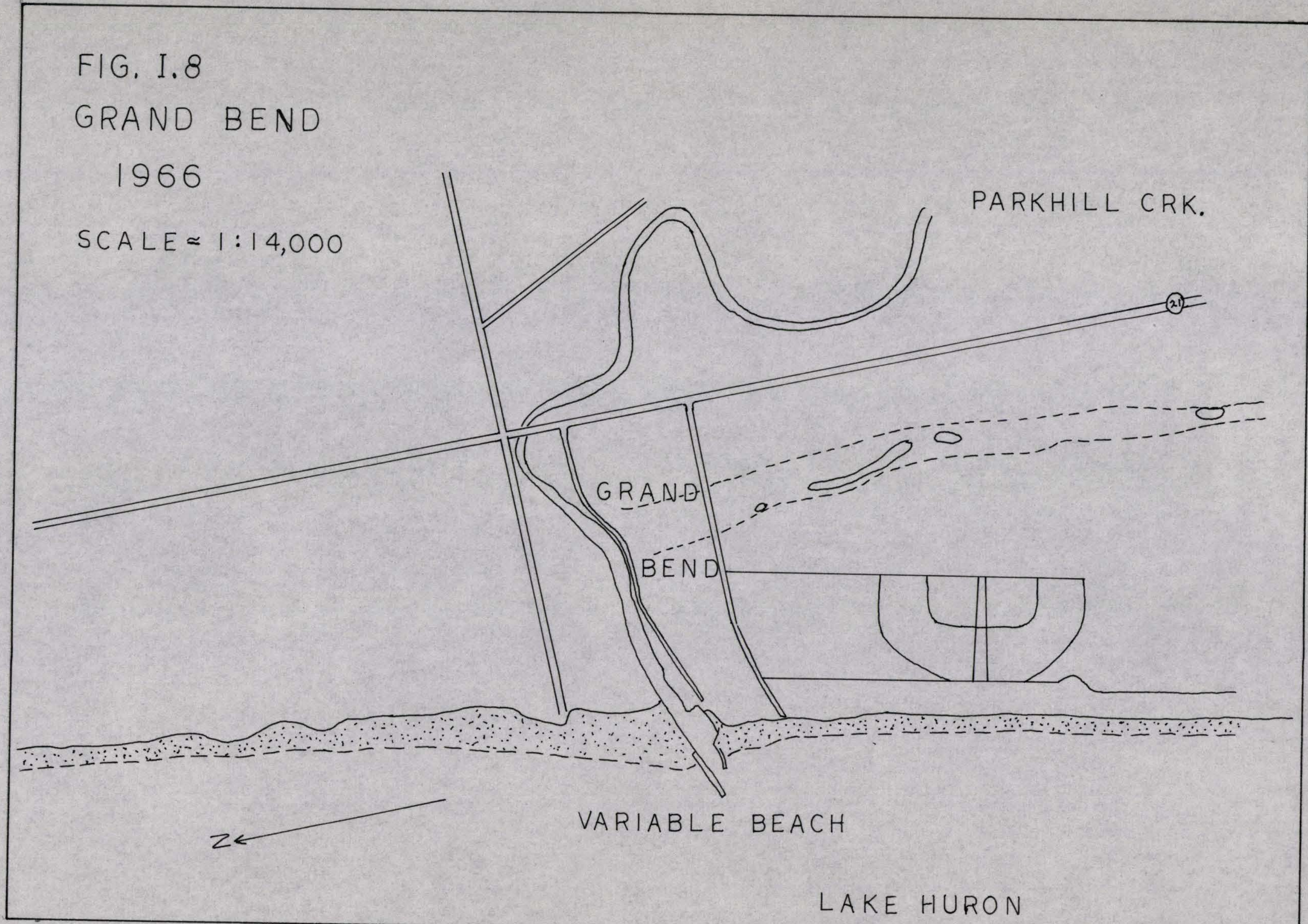
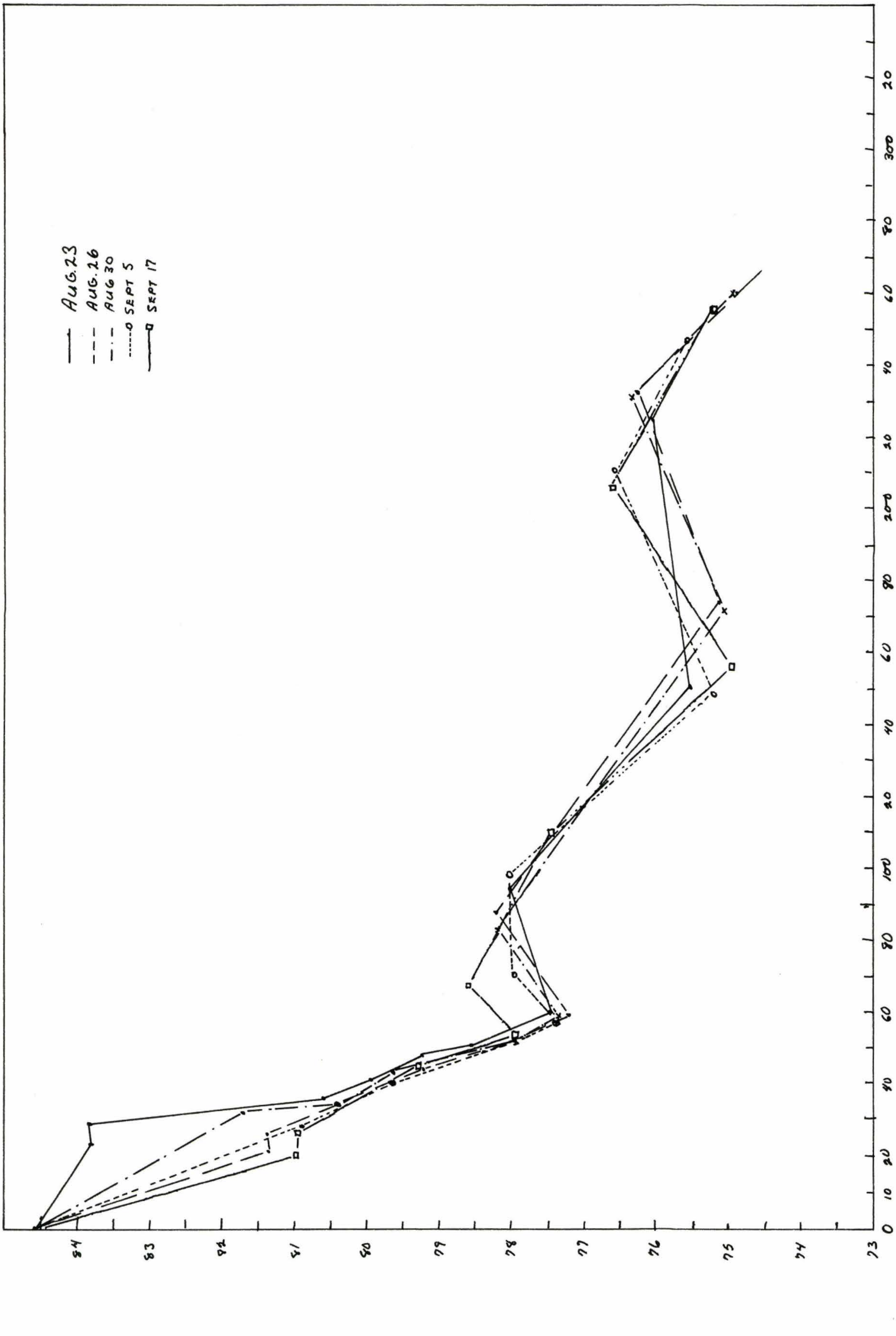


FIG. I.8
GRAND BEND
1966
SCALE ≈ 1:14,000

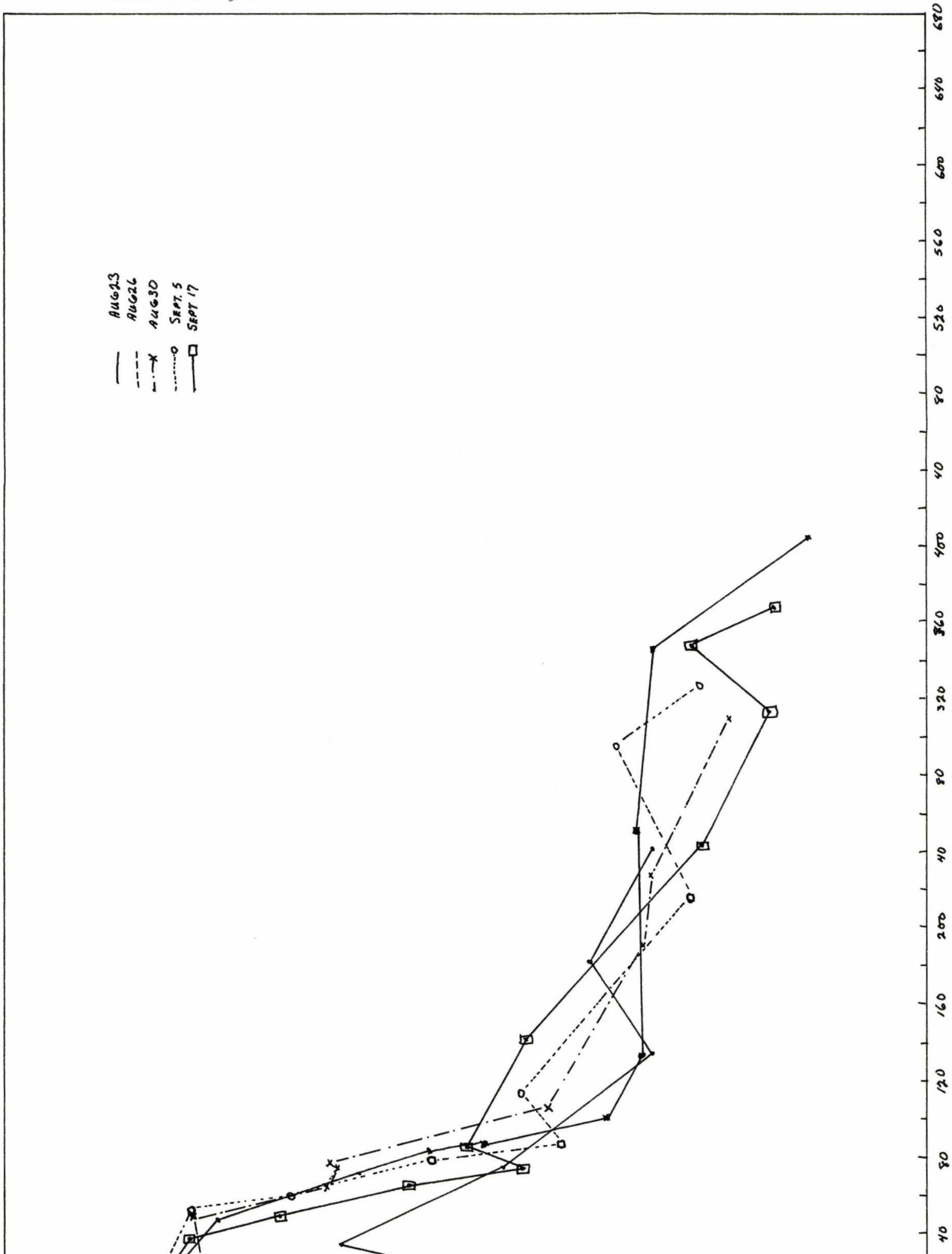
Appendix II : Profiles of the Beach

Note: only three profiles have been included due to the necessity of reducing them to page size, in doing so, the small changes which did occur on the beach became difficult to distinquish, therefore to avoid 23 profiles which were very jumbled and confusing, only these three were plotted, they do however show the changes in plan of the bars as they proceed from south to north.

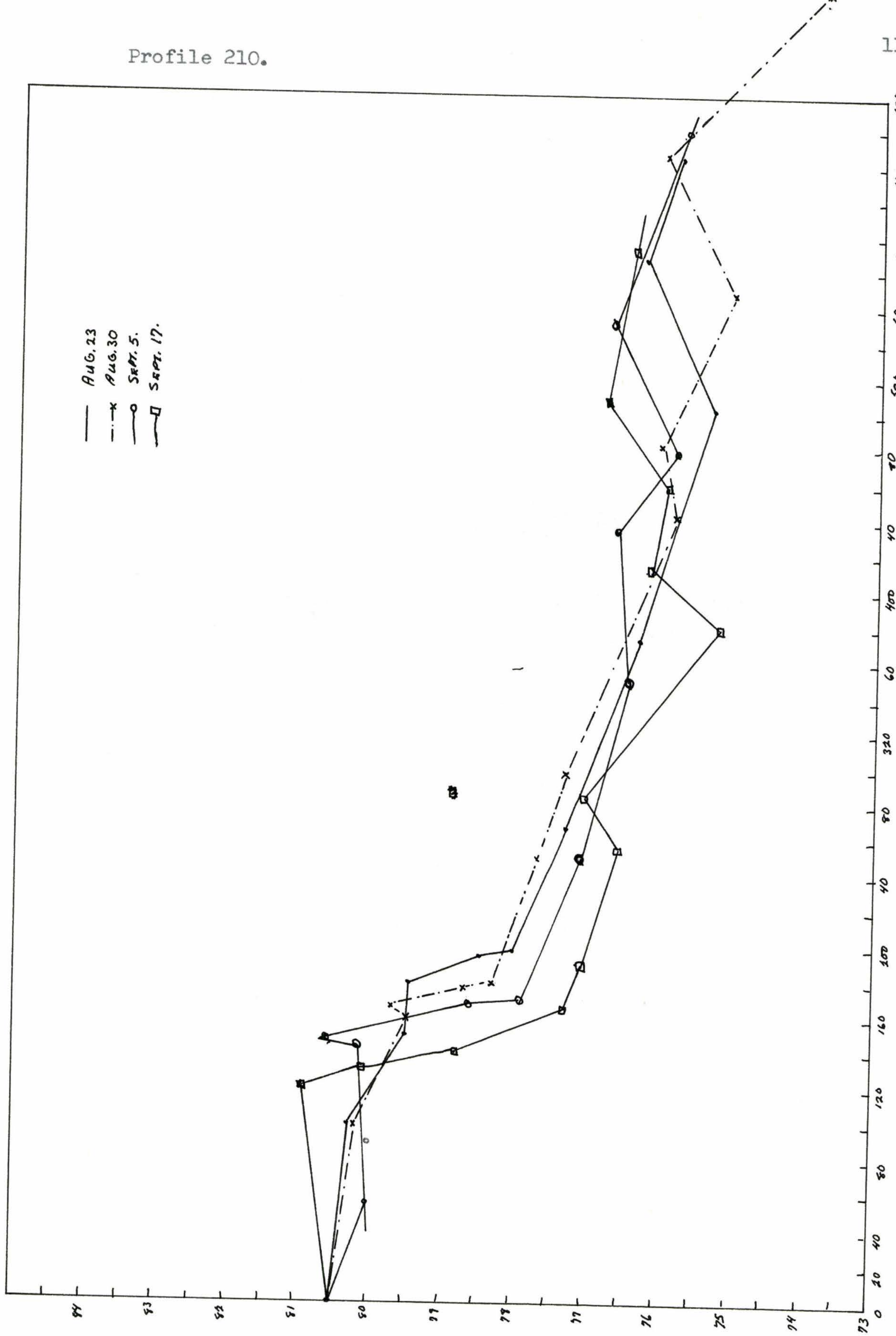
Profile 010.



Profile 150.



Profile 210.



Appendix III : Notes on Measurement of Central Tendency

(from King, 1967, and Blatt, Middleton and Murray, 1972).

(i) Mode: generally ignored in this discussion, refers to the ½ phi class(es) in which the weight of the sediment is greatest.

(ii) Median: the 50% value of the cumulative frequency graph, defines the phi size which separates the sample into two equal halves by weight.

(iii) Mean: if the sample has a symmetrical distribution, the mean will have the same value as the median, if assymmetrical, the mean will differ from the median

(iv) Standard Deviation:
1. less than 0.35, very well sorted.
2. 0.35-0.50, well sorted,
3. 0.51-0.70, moderately well,
4. 0.71-1.0, moderately,
5. 1.1-2.0, poorly,
6. 2.1-4.0, very poorly,
7. greater than 4.1, extremely poorly sorted.

(v) Skewness: indicates the dparture of the mean from the median, (-ve = coarse tail, +ve = fine tail)

(vi) Kurtosis: a measure of peakedness, indicates the ratio of the average spread of the tails of the distribution to the standard deviation, (ignored here),

(vii) Sorting Coefficient: measure of the degree of sorting, ranging from 0 to 100, with 0 being poorly sorted and 100 being the maximum value for sorting, 100 is not usually approached in nature.

Appendix IV : Sediment Analysis - Sediment Size Parameters

Appendix IV : Values of Sediment Size Parameters

Miscellaneous Samples, 501 to 526

Sample no.	Median	Mean	Standard Deviation	Skewness	Kurtosis	Sorting Coefficient
501	---	---	---	---	---	---
502	2.557	1.862	1.506	-1.226	0.186	24.893
503	2.720	2.370	1.168	-2.154	4.320	33.014
504	-1.292	-1.286	1.673	0.178	-1.149	2.781
505	-1.584	-1.583	1.582	0.522	-0.558	6.920
506	2.417	2.163	1.021	-1.640	2.929	25.606
507	0.899	0.769	0.949	-0.496	0.145	21.058
508	1.440	0.571	1.840	-0.488	-1.322	9.814
509	-2.1o2	-2.237	0.886	-0.068	1.165	31.704
510	-3.313	-2.977	1.862	1.824	2.478	28.939
511	-2.421	-2.554	1.078	1.284	3.998	28.290
512	0.460	0.049	1.642	-0.200	-1.393	7.293
513	-1.687	-1.807	0.677	-0.270	-0.210	31.652
514	---	---	---	----	---	---
515	-4.126	-4.137	0.753	0.390	-0.666	15.515
516	1.348	1.298	0.595	-0.522	0.949	34.427
517	1.948	1.912	0.489	-1.338	5.624	43.556
518	1.810	1.782	0.506	-0.424	0.343	35.591
519	0.076	0.234	1.438	0.156	-1.253	8.839
520	1.078	0.231	1.914	-1.500	0.638	34.143
521	1.715	1.714	0.408	0.048	0.140	44.890
522	1.564	1.579	0.576	0.036	-0.451	25.361
523	1.852	1.845	0.475	-0.122	-0.187	38.015
524	0.734	0.445	1.258	-0.862	0.171	17.080
525	0.850	0.228	1.995	0.330	1.047	14.346
526	2.435	2.450	0.379	0.062	-0.231	56.373

Appendix IV : cont'd.

Sample no.	Median	Mean	Standard Deviation	Skewness	Kurtosis	Sorting Coefficient
	Berm Samples,					
011	-2.603	-1.717	2.243	0.862	-0.828	20.996
031	-2.234	-1.759	1.750	1.206	0.439	17.549
051	-2.727	-2.403	1.895	1.018	0.227	13.194
091	1.912	o.742	2.234	-1.064	-0.486	26.589
151	2.284	2.229	0.569	-2.274	10.551	45.787
191	----	----	----	----	----	----
221	2.485	2.403	0.773	-3.626	19.231	45.679
	Swash Limit Samples					
012	-0.051	-0.793	2.187	0.280	-1.542	2o.555
032	-1.167	0.258	1.975	-0.464	-1.241	9.693
052	-1.572	-1.007	1.993	0.570	-0.924	10.158
092	-0.382	-0.037	1.822	0.162	-1.439	9.735
152	-0.982	-0.665	1.549	0.892	-0.012	13.663
192	2.324	2.124	0.981	-2.888	8.752	42.682
222	2.512	2.490	0.413	-3.370	28.053	60.323
	Top of Step Samples					
013	2.296	1.326	2.317	-1.678	1.004	46.633
033	-2.622	-2.431	2.094	0.862	0.198	18.921
053	-1.371	-1.449	0.903	0.120	-0.136	22.773
093	-2.072	-2.o63	0.782	1.162	5.787	34.615
153	-1.969	-2.030	0.603	-0.048	-0.317	25.997
193	-1.727	-0.926	2.209	0.710	-1.030	15.944
223	-1.248	-0.710	1.814	0.780	-0.675	12.125

Appendix IV : cont'd.

First Trough Samples

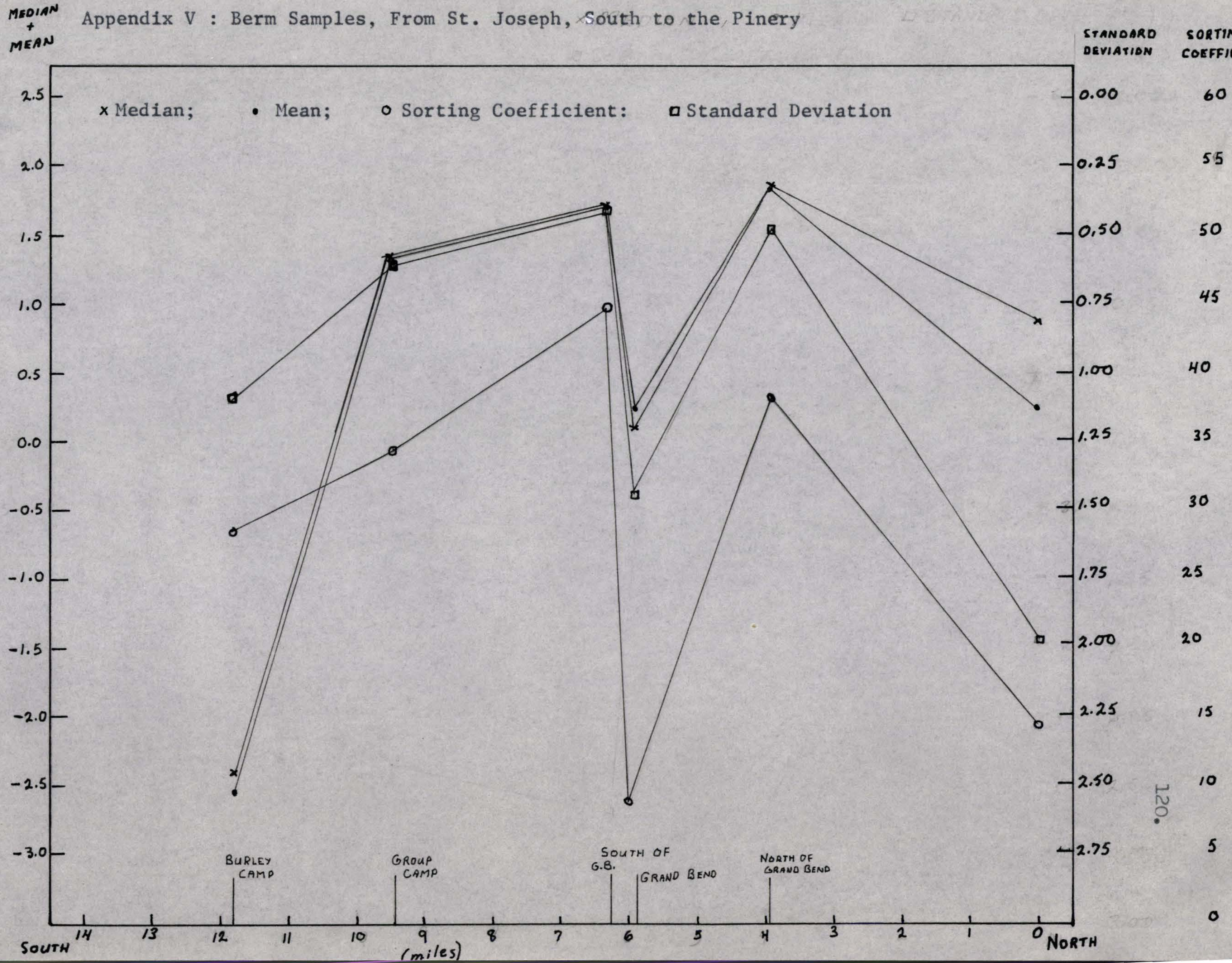
Sample no.	Median	Mean	Standard Deviation	Skewness	Kurtosis	Sorting Coefficient
014	-2.217	-1.993	2.136	0.734	-0.402	10.694
034	-1.824	-1.261	2.161	0.442	-1.014	8.564
054	-1.529	-1.125	2.716	0.344	-1.573	23.508
094	2.313	2.167	0.885	-2.098	5.991	33.818
154	2.546	2.295	1.009	-2.702	8.093	37.097
194	2.567	2.509	0.530	-2.410	12.517	46.806
224	2.489	2.481	0.399	-0.712	4.403	51.817

First Bar Samples

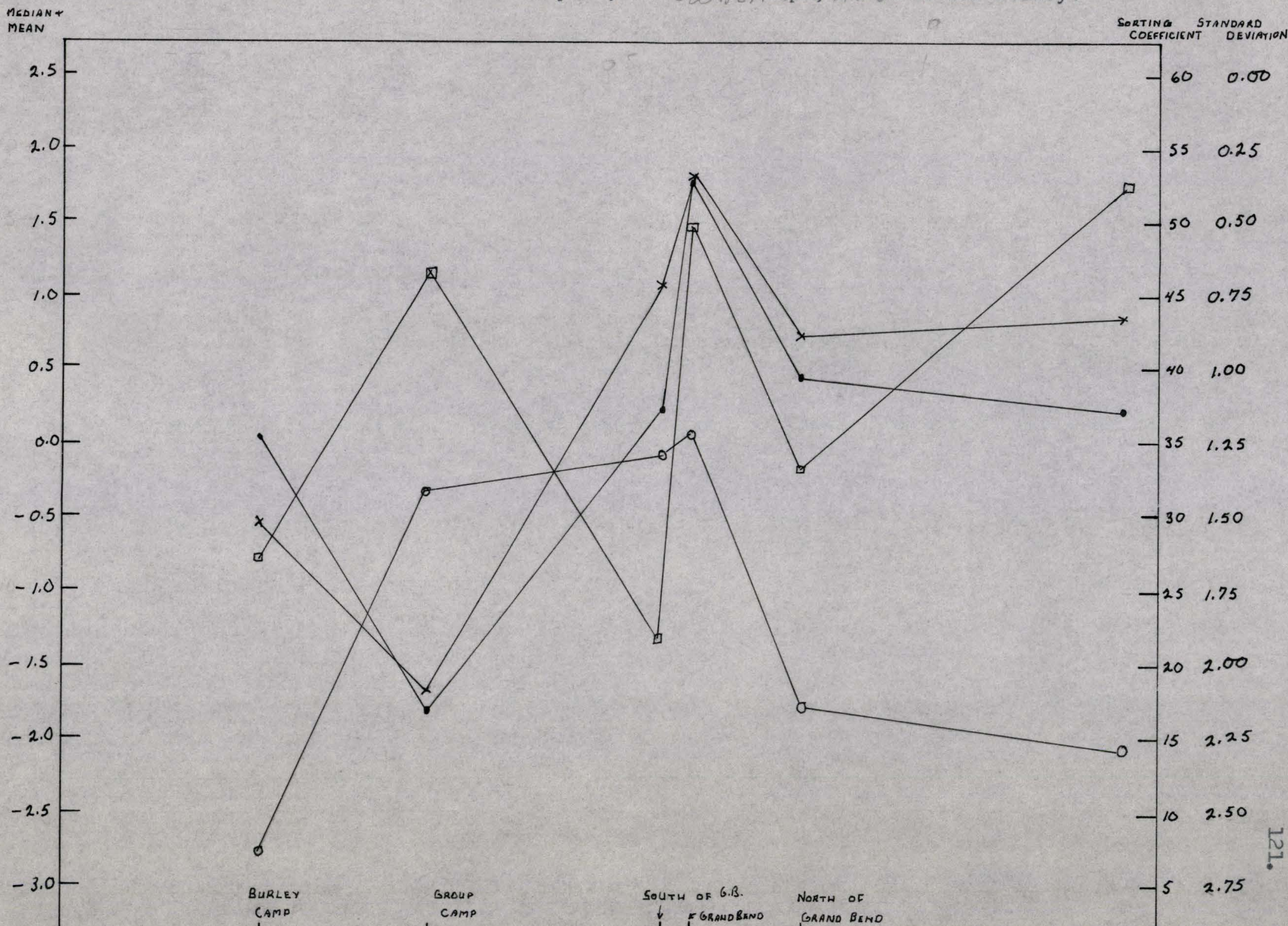
Sample no.	Median	Mean	Standard Deviation	Skewness	Kurtosis	Sorting Coefficient
015	2.418	2.370	0.513	-1.344	5.220	47.307
035	2.463	2.454	0.423	-1.438	10.891	54.505
055	2.433	2.414	0.479	-2.264	15.613	52.365
095	2.340	2.323	0.584	-0.782	3.245	41.310
155	-2.450	-1.863	1.939	1.448	0.838	22.620
195	2.393	2.398	0.398	-0.912	6.152	52.570
225	2.324	2.152	0.932	-3.160	11.872	41.612

Appendix V : Plot of Sediment Size Parameters Along the Beach

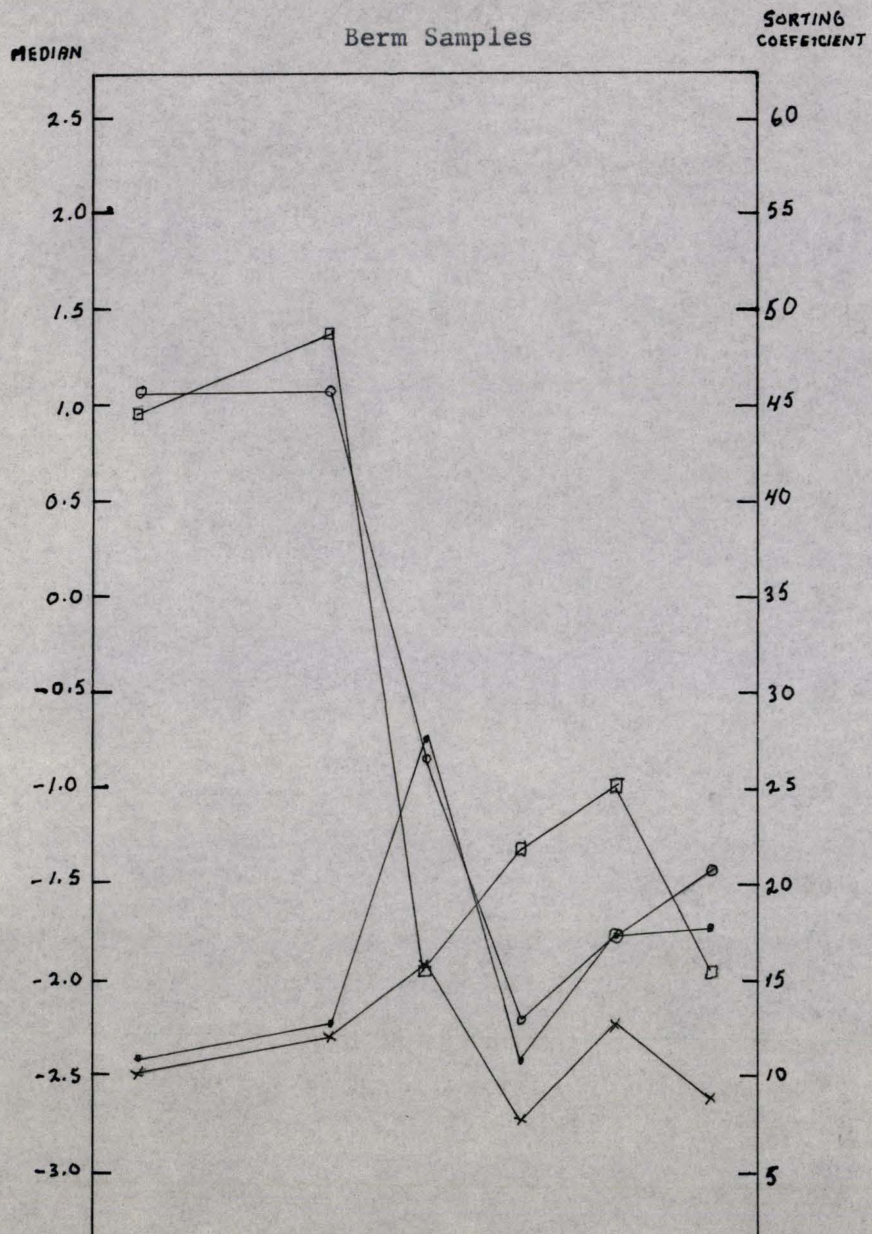
Appendix V : Berm Samples, From St. Joseph, South to the Pinery

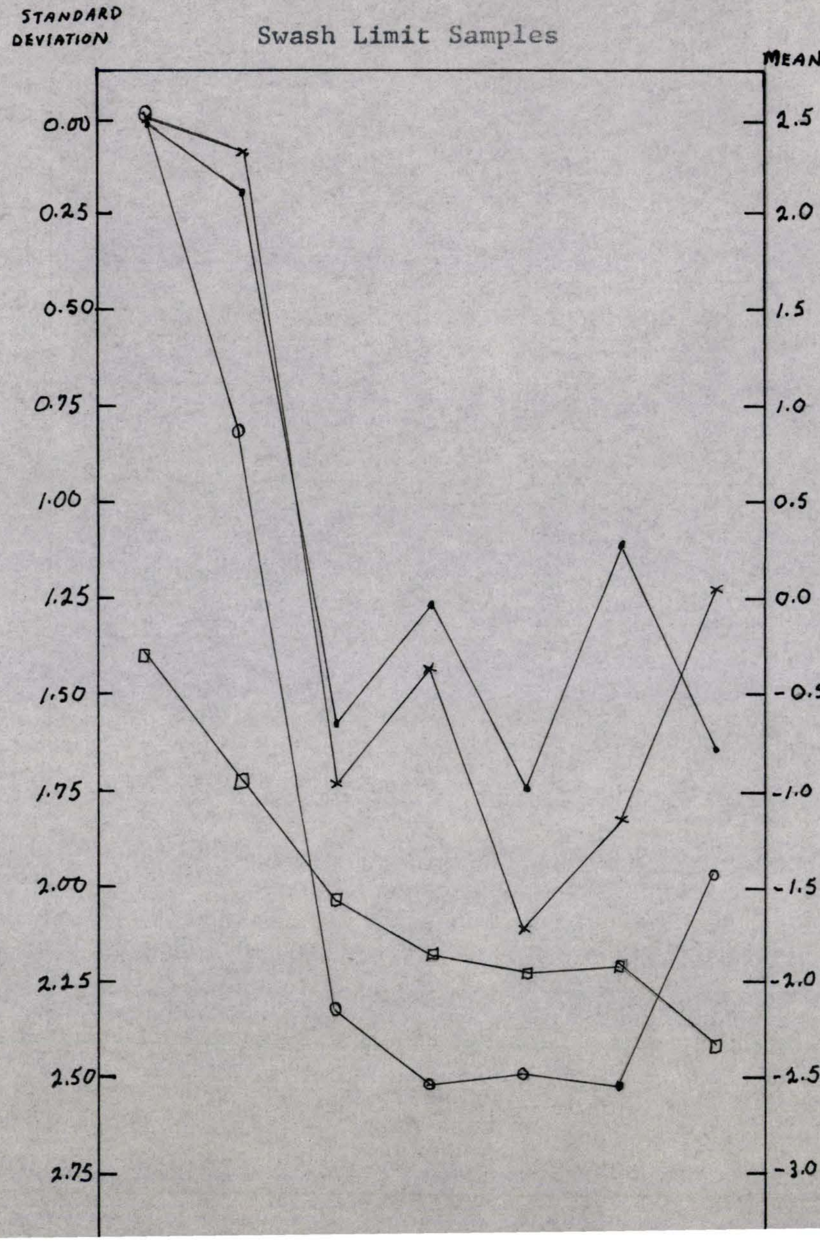


Appendix V : cont'd. Swash Limit Samples, From St. Joseph, South to the Pinery.



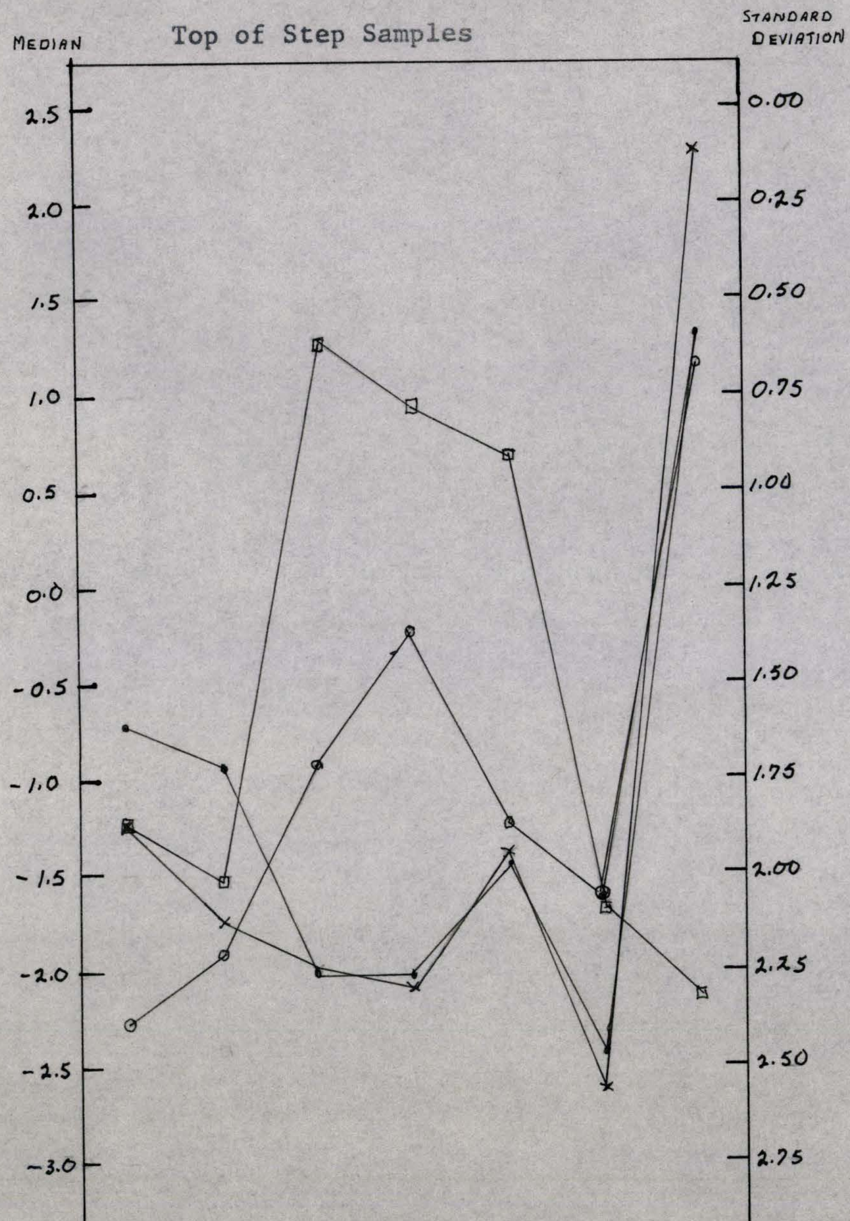
Appendix V : cont'd., The Pinery, South to Port Franks.



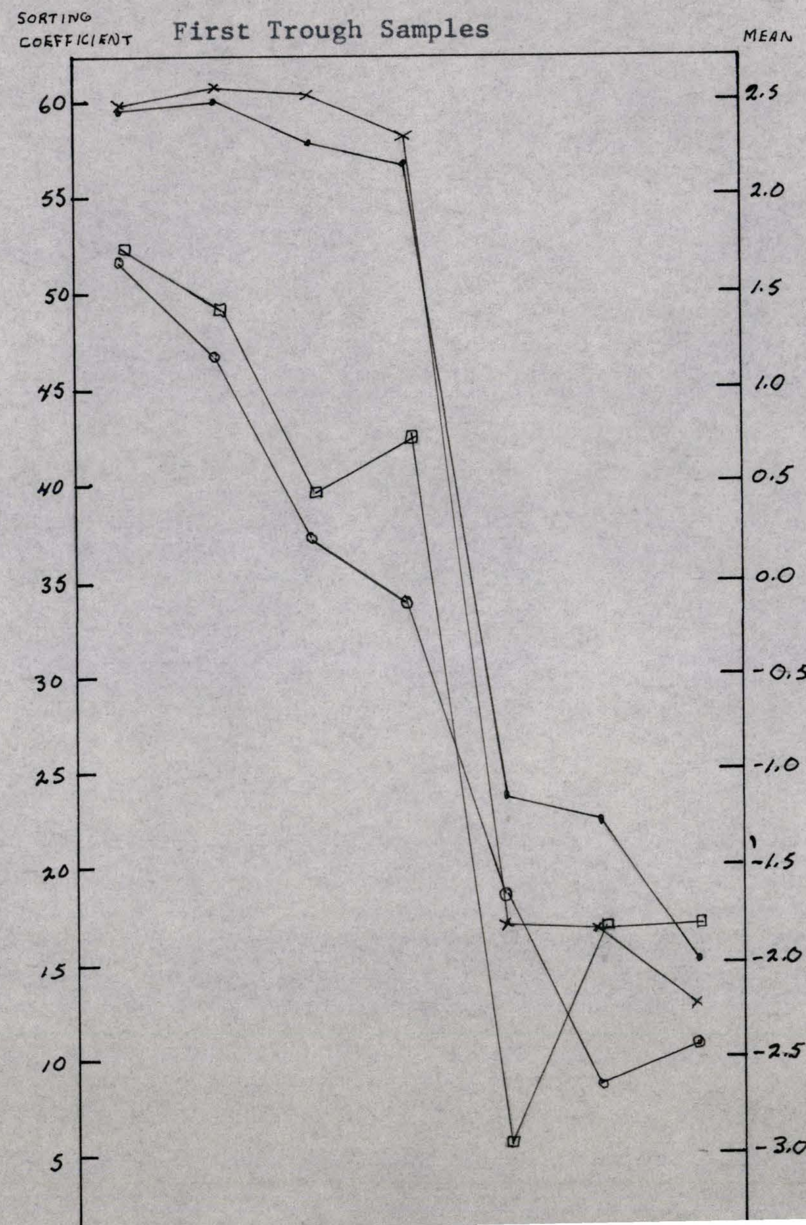


Appendix V : cont'd., The Pinery, South to Port Franks.

Top of Step Samples



First Trough Samples



Appendix V : cont'd., The Pinery, South to Port Franks.
First Bar Samples

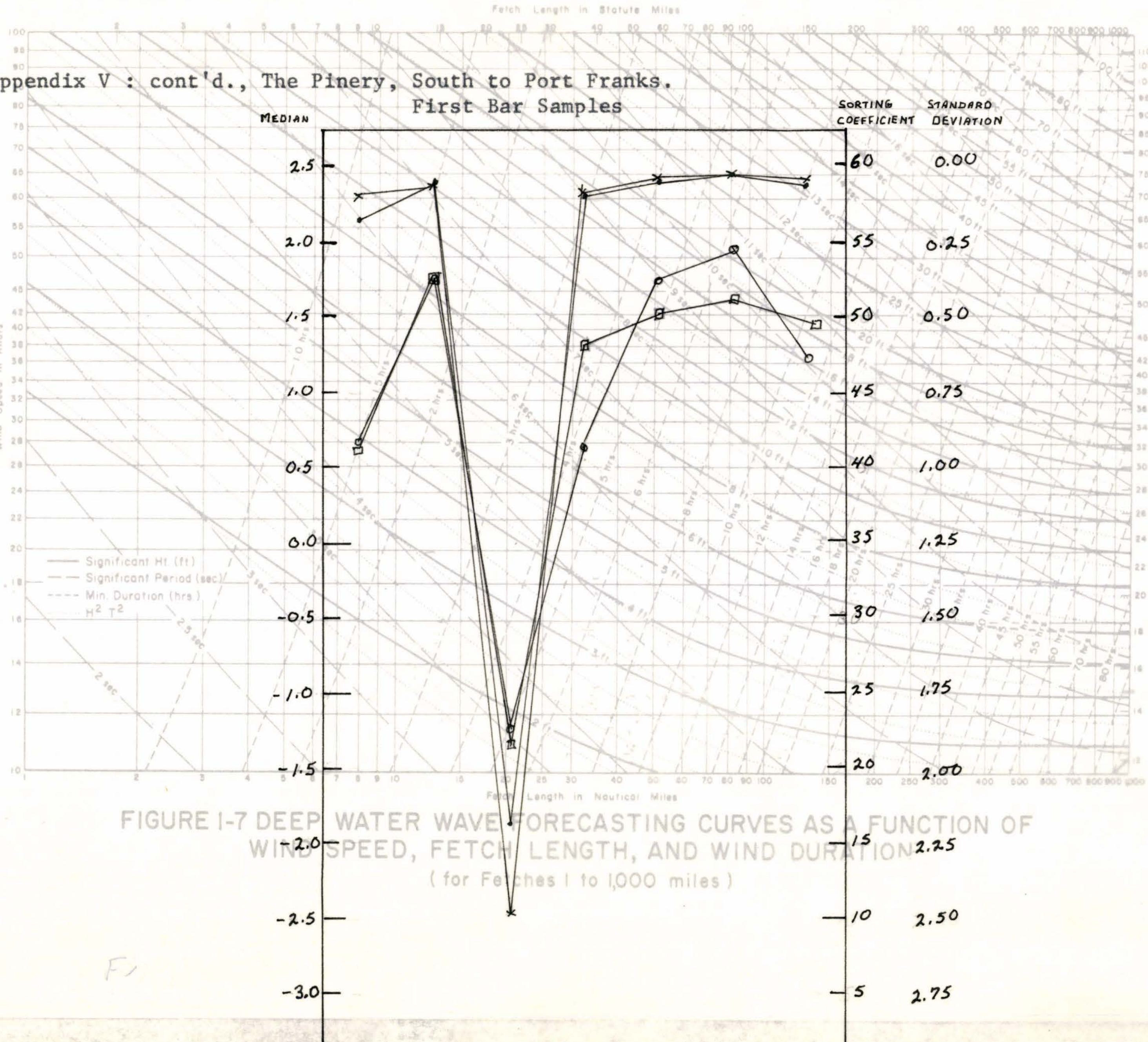


FIGURE I-7 DEEP WATER WAVE FORECASTING CURVES AS A FUNCTION OF WIND SPEED, FETCH LENGTH, AND WIND DURATION
(for Fetches I to 1,000 miles)

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Appendix VI : Bretschneider Diagram, used to Evaluate Wave Period and Wave Height.

Part I Chapter I

Appendix VI : Bretschneider Diagram, used to Evaluate Wave Period and Wave Height.

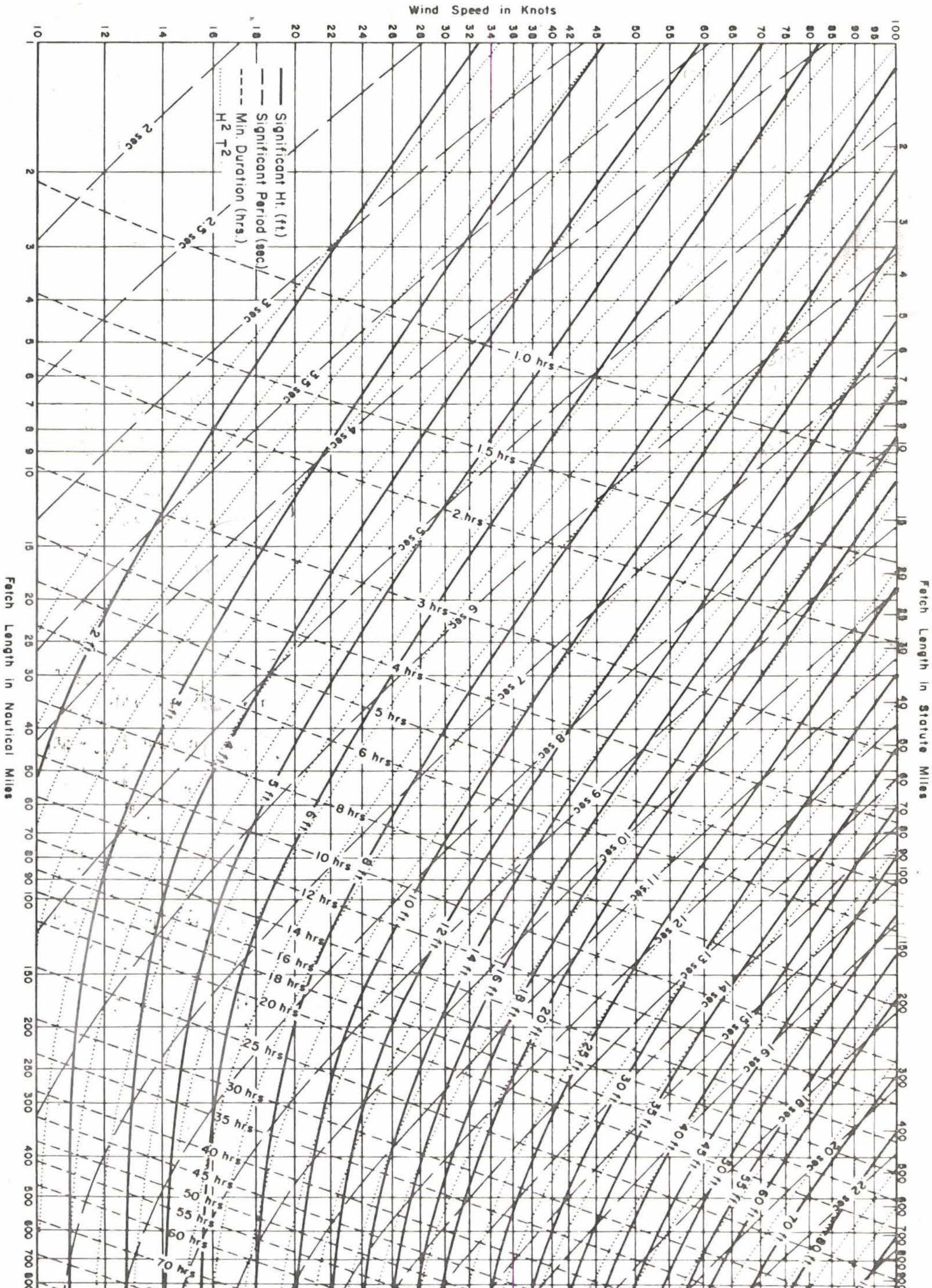


FIGURE 1-7 DEEP WATER WAVE FORECASTING CURVES AS A FUNCTION OF WIND SPEED, FETCH LENGTH, AND WIND DURATION
(for Fetches 1 to 1,000 miles)

Appendix VII : Wind, Wave Height, and Wave Period.

Appendix VII : Wind and Wave Data, Using Bretschneider's Diagram to Determine Wave Height and Wave Period

Goderich, March 1 to November 30, 1972,

Date		Prevailing Direction	Duration (hours)	Fetch (miles)	Average Velocity (mph)	Wave Height (feet)	Wave Period (secOnds
March	2	N	10	50/130	14.4	2.8/2.9	4.5/4.8
	2	NNW	11	200	14.9	3.1	5.0
	3	N	10	50/130	11.6	2.0/2.0	4.0/4.0
	5	WSW	6	15/40	22.5	3.0/4.5	4.0/5.5
	5	W	13	40	20.5	4.0	5.0
	5&6	WNW	12	50	15.8	3.8	5.0
	7	WSW	5	15/40	13.6	---/2.0	3.3/3.6
	7&8	W	13	40	18.5	3.4	4.8
	8&9	NNW	17	200	18.0	5.0	6.5
	17&18	NNW	27	200	13.9	3.5	6.2
	22	W	12	40	15.7	2.9	4.5
	22	NNW	7	200	21.6	4.9	5.7
	23	N	24	50/130	18.8	4.0/5.3	5.2/6.5
	25	NNW	8	200	13.3	2.3	4.2
	26	WNW	7	50	13.9	2.4	4.2
	27	N	13	50/130	13.7	2.7/3.0	4.5/5.0
	30	WSW	18	15/40	14.8	1.9/2.7	3.4/4.4
April	1	WSW	10	15/40	14.4	---/2.5	3.7/4.3
	4	NNW	9	200	16.9	3.8	5.3
	4	W	4	40	12.5	---	3.3
	5	W	5	40	12.8	---	3.5
	13&14	NNW	8	200	13.6	2.4	4.2
	17	NNW	6	200	12.2	---	3.6
	24	NNW	12	200	14.9	3.3	5.1
	27	NNW	9	200	14.4	2.8	4.7
May	6&7	NNW	11	200	15.5	3.4	5.2
	7	NNW	7	200	12.0	---	3.7
	9	N	10	50/130	15.9	3.1/3.5	4.8/5.1
	11	NNW	12	200	14.4	3.0	5.0
	19	NNW	5	200	12.0	---	3.6

Appendix VII : cont'd.

Goderich, March 1 to November 30, 1972.

Date	Prevailing Direction	Duration (hours)	Fetch (miles)	Average Velocity (mph)	Wave Height (feet)	Wave Period (seconds)
May 20	NNW	9	200	12.0	2.0	4.1
21	NNW	7	200	12.7	2.0	3.9
30&31	NNW	24	200	12.5	3.0	5.6
June						
4	NNW	12	200	15.4	3.5	5.2
6	NNW	7	200	14.1	2.5	4.2
9&10	N	35	50/130	15.7	3.0/4.0	4.7/5.9
16	NNW	14	200	12.6	2.6	4.8
17	NNW	8	200	14.3	2.7	4.4
18	NNW	7	200	12.0	---	3.7
21&22	N	48	50/130	17.3	3.5/4.7	5.0/6.3
23&24	NNW	31	200	16.0	4.4	6.6
July						
3	NNW	6	200	14.0	2.3	4.0
25	NNW	18	200	15.7	4.0	6.0
27	NNW	8	200	12.3	2.0	4.0
28	NNW	5	200	12.0	---	3.3
August						
3	N	10	50/130	14.5	2.8/2.9	4.6/4.8
4	NNW	9	200	13.8	2.6	4.5
9	NNW	9	200	17.2	3.7	5.2
27&28	WNW	16	50	12.6	2.3	4.2
September						
3	N	11	50/130	14.8	2.8/2.8	4.6/4.6
8&9	N	20	50/130	14.0	3.0	4.8
9	NNW	9	200	14.6	2.8	4.7
14	N	14	50/130	15.7	3.0/3.8	4.7/5.6
21&22	NNW	22	200	14.7	3.7	5.9

AppendixVII : cont'd.

Goderich, March 1 to November 30, 1972.

Date	Prevailing Direction	Duration (hours)	Fetch (miles)	Average Velocity (mph)	Wave Height (feet)	Wave Period (seconds)
September						
26&27	N	20	50/130	12.3	2.2/2.7	4.2/5.2
29	N	8	50/130	12.8	2.3/2.3	4.2/4.2
30	NNW	15	200	17.0	4.5	6.1
October						
6&7	N	24	50/130	12.0	2.0/2.6	4.2/5.0
7	MNW	3	200	13.0	---	3.1
8	WSW	9	15/40	17.4	2.3/3.2	3.7/4.7
8&9	NNW	34	200	22.9	8.0	8.0
12	N	22	50/130	15.4	3.0/3.9	4.7/5.8
14	WNW	8	50	15.8	3.0	4.7
14&15	NNW	24	200	19.1	6.1	7.4
16&17	WNW	20	50	19.5	4.3	5.4
17	N	5	50/130	15.2	2.4/2.4	3.9/3.9
23&24	N	16	50/130	12.0	2.1/2.7	4.2/4.9
29	N	9	50/130	12.0	2.1/2.1	4.1/4.1
November						
2&3	W	12	40	20.8	4.1	5.1
8&9	N	25	50/130	17.2	3.5/4.7	4.9/6.2
11	NNW	6	200	13.0	2.0	3.7
14&15	N	12	50/130	15.4	2.9/3.5	4.6/5.3
20	NNW	9	200	12.4	2.2	4.2
23	W	13	40	16.4	3.0	4.6
23&24	WSW	26	15/40	18.4	2.5/3.5	3.7/4.9
26,27,28, &29	WSW	84	15/40	18.1	2.5/3.5	3.6/4.8

Appendix VII : cont'd.

Sarnia, March 1 to November 30, 1972.

Date		Prevailing Direction	Duration (hours)	Fetch (miles)	Average Velocity (mph)	Wave Height (feet)	Wave Period (seconds)
March	2	NNW	12	200	12.9	2.5	4.5
	5	WSW	16	40	17.9	3.4	4.8
	7&8	WSW	35	40	16.3	3.0	4.5
	22	WSW	20	40	17.4	3.2	4.7
	23	NNW	25	200	15.2	4.0	6.4
	24	NNW	18	200	12.2	2.7	5.0
April	4	WNW	10	50	12.8	2.4	4.3
	4	WSW	7	15/40	15.1	---/2.6	3.4/4.4
	5	WSW	9	15/40	14.6	---/2.6	3.3/4.3
	6	NNW	11	200	15.5	3.4	5.2
	7	N	17	50/130	17.3	3.4/4.6	4.9/6.2
	8	NNW	16	200	13.9	3.2	5.3
	13&14	WNW	18	50	15.9	3.1	4.7
	20	NNW	8	200	12.1	2.0	4.0
	23	WSW	11	15/40	13.9	---/2.4	3.4/4.3
	24	NNW	10	200	13.5	2.6	4.5
May	6	WSW	5	15/40	17.4	2.2/2.8	3.6/4.4
	6&7	NNW	9	200	13.6	2.5	4.4
	9	NNW	12	200	15.8	3.6	5.3
	21	NNW	7	200	13.1	2.1	4.0
	30&31	NNW	19	200	12.7	2.8	5.2
June	21,22,23, &24	NNW	80	200	16.4	4.7	6.7
July	3	NNW	9	200	13.7	2.6	4.5
	25	WNW	7	50	12.9	2.0	3.9
August							
	3&4	NNW	15	200	12.8	2.7	4.9
	4	NNW	8	200	12.5	2.1	4.0
September							

Appendix VII : cont'd.

Sarnia, March 1 to November 30, 1972.

Date	Prevailing Direction	Duration (hours)	Fetch (miles)	Average Velocity (mph)	Wave Height (feet)	Wave Period (seconds)
September						
2	NNW	10	200	14.1	2.8	4.6
3	NNW	14	200	12.9	2.7	4.8
8&9	NNW	18	200	12.5	2.8	5.1
9	NNW	10	200	12.9	2.4	4.4
14	NNW	11	200	14.6	3.0	4.9
18	WNW	6	50	13.7	2.2	3.9
19	NNW	6	200	12.7	---	3.7
26&27	NNW	9	200	13.7	2.6	4.5
30	WNW	11	50	12.4	2.2	4.2
October						
6&7	NNW	14	200	13.1	2.8	4.9
8	WNW	14	50	16.4	3.2	4.8
16&17	WNW	21	50	13.0	2.4	4.3
November						
8&9	NNW	20	200	16.6	4.7	6.5
14&15	NNW	18	200	18.6	5.4	6.7
20	NNW	6	200	13.5	2.0	3.8

Note : any valuesfor wave height data which have been omitted were less than 2.0 feet.

Appendix VIII : Energy and Pressure Values for the Waves

Appendix VIII : Evaluated Wave Parameters for Goderich Data, March 1 to November 30, 1972.

Date	Wave Height (feet)	Wave Period (seconds)	Wavelength (feet)	Wave Vel. (ft./sec.)	Wave Steepness	Energy (pds./ft^2)	Pressure (tons/ft.^{2})
March 2	2.8/2.9	4.5/4.8	31.59/35.20	12.68/13.40	0.09/0.08	1857/2232	0.37/0.38
2	3.1	5.0	39.0	14.10	0.08	2832	0.40
3	2.0/2.0	4.0/4.0	25.00/25.00	11.30/11.30	0.08/0.08	755	0.26
5	3.0/4.5	4.0/5.5	25.00/47.19	11.30/15.51	0.12/0.10	1630/7120	0.39/0.59
5	4.0	5.0	39.00	14.10	0.10	4615	0.52
5&6	3.8	5.0	39.00	14.10	0.10	4083	0.49
7	2.0	3.6	20.22	10.15	0.10	600	0.26
7&8	3.4	4.8	35.94	13.53	0.10	3098	0.44
8&9	5.0	6.5	65.91	18.33	0.08	12,488	0.65
17&18	3.5	6.2	59.97	17.48	0.06	5634	0.46
22	4.9	5.7	50.68	16.07	0.10	9054	0.64
22	2.9	4.5	31.59	12.69	0.09	1986	0.38
23	4.0/5.3	5.2/6.5	42.18/65.91	14.66/18.33	0.10/0.08	5031/13981	0.52/0.69
25	2.3	4.2	27.52	11.84	0.08	1096	0.30
26	2.4	4.2	27.52	11.84	0.09	1190	0.31
27	2.7/3.0	4.5/5.-	31.59/39.00	12.69/14.10	0.09/0.08	1732/2658	0.35/0.39
30	1.9/2.7	3.4/4.4	18.03/30.20	9.59 /12.41	0.11/0.09	480/1650	0.25/0.35
April							
1	2.5	4.3	28.84	12.12	0.09	1354	0.33
4	3.8	5.3	43.82	14.94	0.09	4753	0.50
13&14	2.4	4.2	27.52	11.84	0.09	1190	0.31
24	3.3	5.1	40.58	14.38	0.08	3335	0.43
27	2.8	4.7	34.46	13.25	0.08	2039	0.37
May							
6&7	3.4	5.2	42.18	14.66	0.08	3682	0.44
9	3.1/3.5	4.8/5.1	35.94/40.58	13.53/14.38	0.09/0.09	2595/3735	0.40/0.46
11	3.0	5.0	39.00	14.10	0.08	2658	0.39
20	2.0	4.1	26.22	11.56	0.08	795	0.26
21	2.0	3.9	23.73	11.00	0.08	715	0.26
30&31	3.0	5.6	48.92	15.79	0.06	3371	0.39

Appendix VIII : cont'd.

Date	Wave Height (feet)	Wave Period (seconds)	Wavelrngth (feet)	Wave Vel. (ft./sec.)	Wave Steepness	Energy (pds./ft.^{2})	Pressure tons/ft.^{2})
June							
4	3.5	5.2	42.18	14.66	0.08	3894	0.46
6	2.5	4.2	27.52	11.84	0.09	1287	0.33
9&10	3.0/4.0	4.7/5.9	34.46/54.30	13.25/16.63	0.09/0.07	2329/6595	0.39/0.52
16	2.6	4.8	35.94	13.53	0.07	1846	0.34
17	2.7	4.4	30.20	12.41	0.09	1650	0.35
21&22	3.5/4.7	5.0/6.3	39.0/61.92	14.10/17.76	0.09/0.08	3579/10366	0.46/0.61
23&24	4.4	6.6	67.95	18.61	0.07	10049	0.57
July							
3	2.3	4.0	25.00	11.30	0.09	989	0.30
25	4.0	6.0	56.16	16.92	0.07	6834	0.52
27	2.0	4.0	25.00	11.30	0.08	755	0.26
August							
3	2.8/2.9	4.6/4.8	33.01/35.94	12.97/13.53	0.09/0.08	1947/2282	0.37/0.38
4	2.6	4.5	31.59	12.69	0.08	1610	0.34
9	3.7	5.2	42.18	14.66	0.09	4333	0.48
27&28	2.3	4.2	27.52	11.84	0.08	1096	0.30
September							
3	2.8/2.8	4.6/4.6	33.01/33.01	12.97/12.97	0.09/0.09	1947/1947	0.37/0.37
8&9	3.0	4.8	35.94	13.53	0.08	2436	0.39
9	2.8	4.7	34.46	13.25	0.08	2039	0.37
14	3.0/3.8	4.7/5.6	34.46/48.92	13.25/15.79	0.09/0.08	2329/5346	0.39/0.50
21&22	3.7	5.9	54.30	16.63	0.07	5666	0.48
26&27	2.2/2.7	4.2/5.2	27.52/42.18	11.84/14.66	0.08/0.06	1006/2350	0.29/0.35
29	2.3/2.3	4.2/4.2	27.52/27.52	11.84/11.84	0.08/0.08	1096	0.30
30	4.5	6.1	58.05	17.20	0.08	8897	0.59

Appendix VIII : cont'd.

Date	Wave Height (feet)	Wave Period (seconds)	Wavelength (feet)	Wave Vel. (ft./sec.)	Wave Steepness	Energy (pds./ft.^{2})	Pressure (tons/ft.^{2})
October							
6&7	2.0/2.6	4.2/5.0	27.52/39.00	11.84/14.10	0.07/0.07	836/2011	0.26/0.34
8	2.3/3.2	3.7/4.7	21.36/34.46	10.43/13.25	0.11/0.09	831/2635	0.30/0.42
8&9	8.0	8.0	99.84	22.56	0.08	48263	1.04
12	3.0/3.9	4.7/5.8	34.46/52.48	13.25/16.36	0.09/0.07	2329/6057	0.39/0.51
14	3.0	4.7	34.46	13.25	0.09	2329	0.39
14&15	6.1	7.4	85.43	20.86	0.07	24172	0.80
16&17	4.3	5.4	45.49	15.23	0.10	6272	0.56
17	2.4/2.4	3.9/3.9	23.73/23.73	10.99/10.99	0.10/0.10	1012/1012	0.31/0.31
23&24	2.1/2.7	4.2.4.9	27.52/37.46	11.84/13.82	0.08/0.07	920/2076	0.27/0.35
29	2.1/2.1	4.1/4.1	26.33/26.22	11.56/11.56	0.08	873/873	0.27/0.27
November							
2&3	4.1	5.1	40.58	14.38	0.10	5053	0.54
8&9	3.5/4.7	4.9/6.2	37.46/59.97	13.82/17.48	0.09/0.08	3425/10020	0.46/0.61
11	2.0	3.7	21.35	10.43	0.09	637	0.26
14&15	2.9/3.5	4.6/5.3	33.01/43.82	12.97/14.94	0.09/0.08	2083/4055	0.38/0.46
20	2.2	4.2	27.52	11.84	0.08	1006	0.29
23	3.0	4.6	33.01	12.97	0.09	2223	0.39
23&24	2.5/3.5	3.7/4.9	21.36/37.46	10.43/13.82	0.12/0.09	971/3425	0.33/0.46
26,27,28, &29	2.5/3.5	3.6/4.8	20.22/35.94	10.15/13.53	0.12/0.10	911/3274	0.33/0.46

Appendix IX: Soil Types.

1. Original Channel :

Middlesex County - major soil groups with descriptions

(i) Huron Clay Loam - brown clay loam and silt loam over reddish brown and then grey stony clay loam, frequent stones.

(ii) Perth Clay Loam - dark grey-brown clay loam over grey and mottled stony clay, some stones and boulders.

(iii) Perth Silt Loam - Brown silt loam over yellowish silt loam grading into mottled reddish-brown and then grey stoney silt and clay loam, some stones in surface soil.

(iv) Burford Loam - brown gravelly loam underlain by mootled yellow and reddish-brown and then grey gravel, clay at about 3 to 6 feet, few stones.

(v) Tuscola Silt Loam - Dark grey to brownish silt loam over yellowish mottled, stratified silt and clay, stone free.

(vi) Haldimand Clay Loam - greyish to light brown clay loam over reddish and then grey gritty clay, few stones.

Lambton County :

(vii) Blackwell - sand or clay, essentially ston free.

(viii) Toledo Clay - lacustrine clay, essentially stone free.

(ix) Plainfield - sand, old beach material, well sorted sandy outwash.

The Cut: after the Toledo Clay, goes through the Blackwell Clay, a small portion of the Brisbane Loam, (stratified gravelly outwash), Granby Loam, (well sorted sandy outwash), and finally the Plainfield Sand, (well sorted sandy outwash).

Appendix X : Outline of the Recent History of the Mouth of the Ausable River, (courteousy of Mr. Roger Martin, Resources Manager, Ausable-Bayfield Conservation Authority).

January 1951	- new cut and mouth completed, sand bar built across mouth of cut almost immediately.
1952	- river going out original mouth
1953	- mouth of cut still silted up, river in its original course.
February 17, 1954	- river loop blocked with ice, mouth of cut broken open, some flooding before cut broke open.
Spring 1955	- mouth of cut open, also mouth of river.
Summer 1956	- mouth of cut open but severe erosion on northwest corner of island, lake levels start to fall, over 100 feet of sand bank had been washed away, sand bar across the mouth of the river.
Spring 1957	- low levels in Lake Huron, severe silting in the mouth of the Ausable River which is closed, mouth of cut still open.
April 1957	- 3 claims for damages received by authority from cottage owners.
August 1957	- Chisholm apointed to make a survey of the river mouth at Port Franks, and to prepare a report.
Spring 1958	- Chisholm report presented.

Appendix X : cont'd.

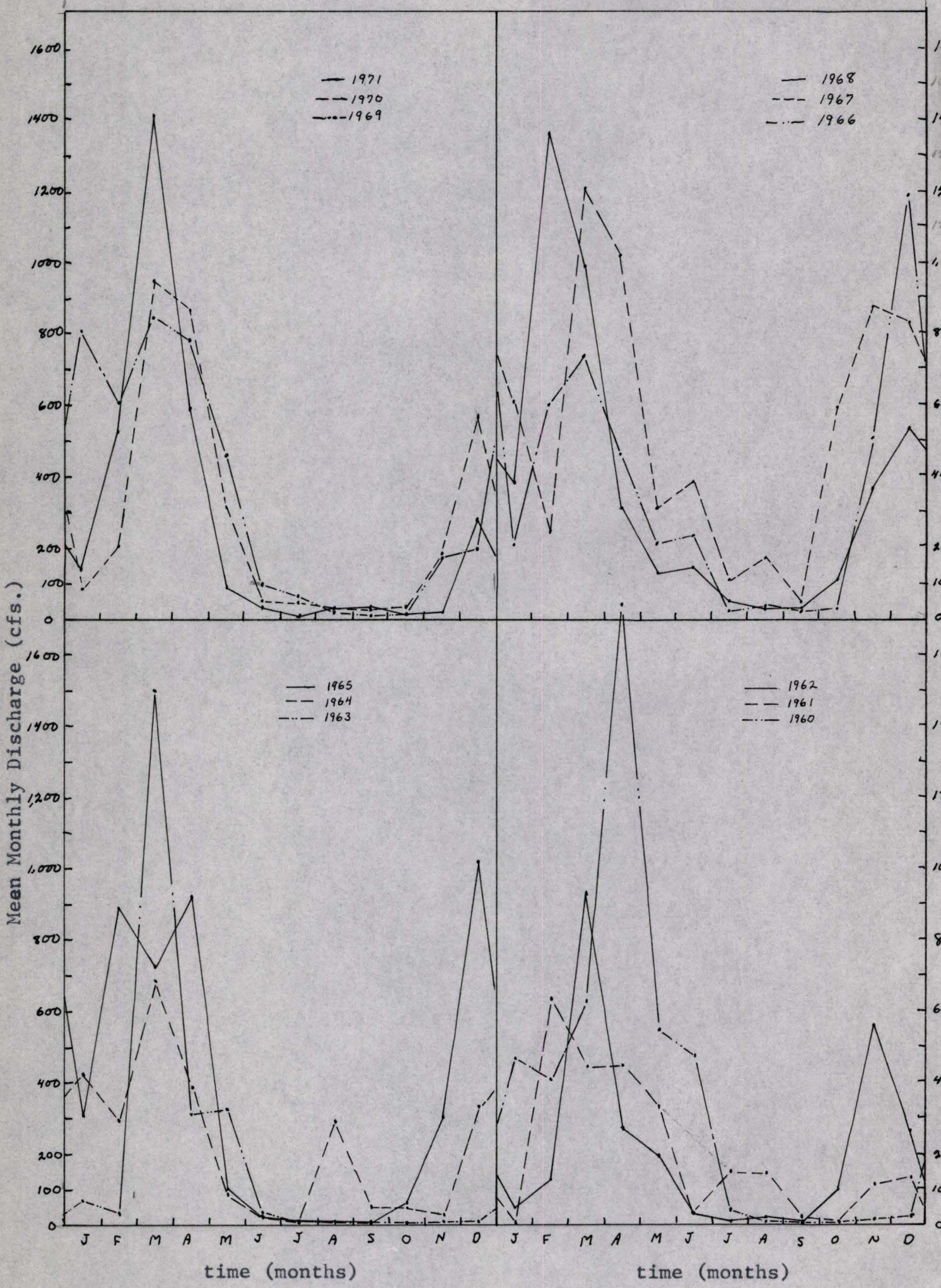
Spring 1960 - ice jam at mouth of cut because of lake ice, caused flooding in Port Franks, water rose over causeway built across old mouth and began to wash out roadway, old mouth completely reopened, washing away large amounts of the island and south bank; by April 2, mouth of cut also free of ice and water distributed between the two mouths.

Spring 1961 - Mouth of cut silted up and has remained closed to present date.

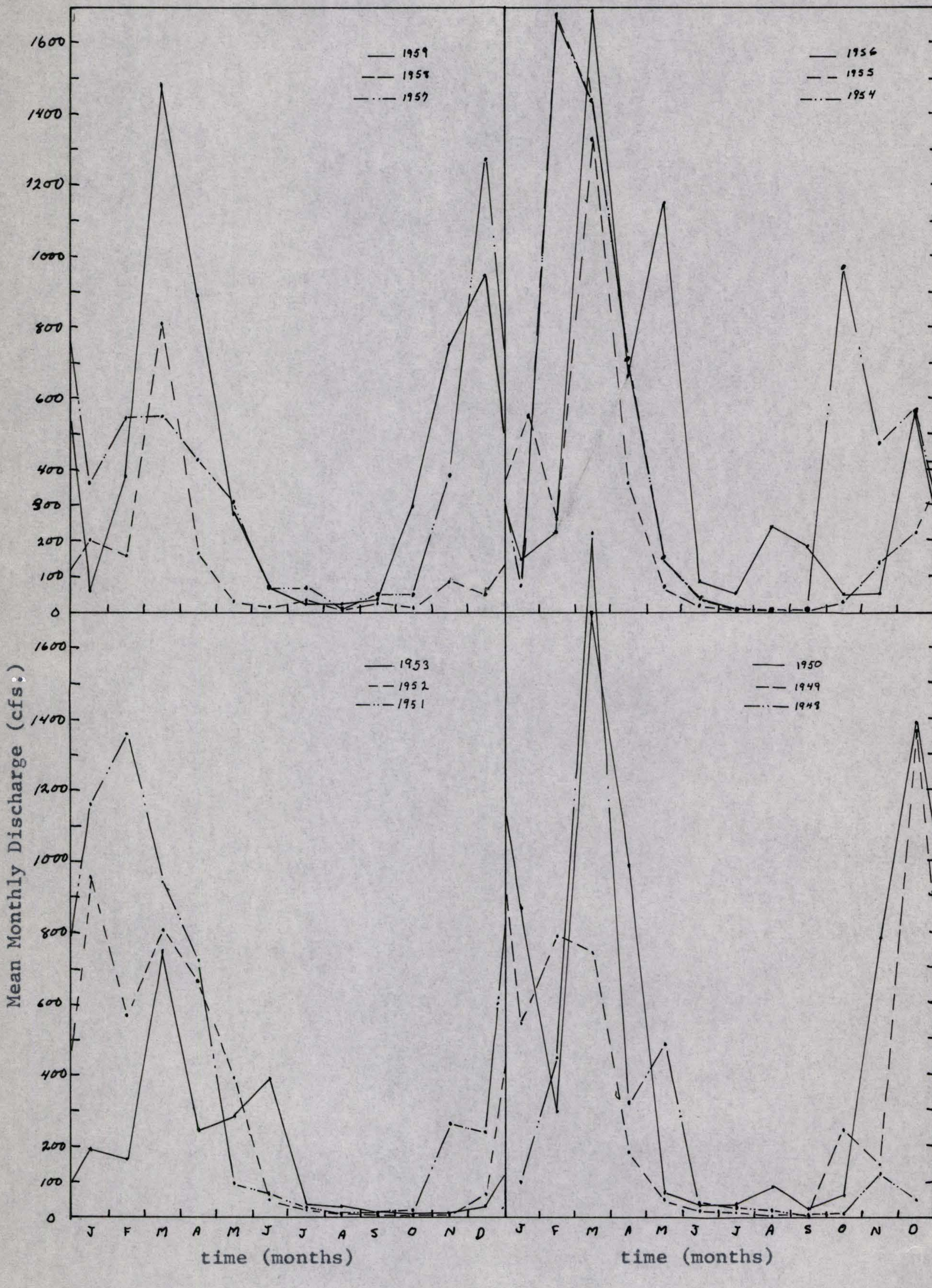
Note : Some discrepancies occur in the recent history, when comparing this outline with that of local residents and with the air photos of the river mouth. However since this report was not intended to document this history, Mr. Martin's outline has been included as at present it is the most complete.

Appendix XI : Hydrographs of the Ausable River

Appendix XI : Hydrographs for the Ausable River, 1971 to 1948.



Appendix XI : cont'd.



Appendix XII : Meander Statistics for the Ausable River.

(i) $K_1 = \frac{\text{meander length}}{\text{channel width}}$

mean = 12.62

1. 6.8/0.50 = 13.6
2. 8.0/0.40 = 20.0
3. 8.0/0.55 = 14.6
4. 3.6/0.05 = 72.0 ?
5. 1.6/0.25 = 6.4
6. 1.8/0.30 = 6.0
7. 3.4/0.35 = 9.7
8. 2.9/0.25 = 11.6
9. 2.6/0.20 = 13.0
10. 3.8/0.20 = 19.0
11. 2.5/0.30 = 8.3

(ii) $K_2 = \frac{\text{channel length}}{\text{radius of curvature}}$

mean = 1.87

1. 4.55/2.35 = 1.94
2. 4.55/2.30 = 1.98
3. 4.40/2.25 = 1.96
4. 2.40/1.25 = 1.92
5. 1.10/0.65 = 1.69
6. 1.15/0.60 = 1.92
7. 1.80/0.80 = 2.25
8. 1.65/0.85 =1.94
9. 1.35/0.85 = 1.59
10. 2.15/1.10 = 1.95
11. 1.70/1.20 = 1.42

(iii) $K_3 = \frac{\text{radius of curvature}}{\text{channel width}}$

mean = 3.86 (omitting 4.)

1. 2.35/0.50 = 4.7
2. 2.30/0.40 = 5.75
3. 2.25/0.55 = 4.09
4. 1.25/0.05 = 25.0 ?
5. 0.65/0.25 = 2.60
6. 0.60/0.30 = 2.00
7. 0.80/0.35 = 2.29
8. 0.85/0.25 = 3.40
9. 0.85/0.20 = 4.25
10. 1.10/0.20 = 5.50
11. 1.20/0.30 = 4.00

(iv) $K_4 = \frac{\text{meander length}}{\text{channel length}}$

= Sinuosity

mean = 1.67

1. 6.80/4.55 = 1.50
2. 8.00/4.55 = 1.76
3. 8.00/4.40 = 1.82
4. 3.60/2.40 = 1.50
5. 1.60/1.10 = 1.46
6. 1.80/1.15 = 1.57
7. 3.40/1.80 = 1.89
8. 2.90/1.65 = 1.76
9. 2.60/1.35 = 1.93
10. 3.80/2.15 = 1.77
11. 2.50/1.70 = 1.47

BIBLIOGRAPHY

1. Bajournas, L., and Duane, D. B., Shifting Offshore Bars and Harbour Shoaling; Journ. Geophys. Research, v. 72, 1967.
2. Bascom W. N., The Control of Stream Outlets by Wave Refraction; Journal of Geology, 62(b), 1954.
3. Blatt, H., Middleton, G., and Murray, R., Origin of Sedimentary Rocks, Prentice Hall Inc., New Jersey, 1972.
4. Bruun, Per, Measurements Against Erosion at Groins and Jetties, Proceedings of the 3rd Conference on Coastal Engineering, Cambridge, Massachusetts, 1952.
5. _________, Breakwaters for Coastal Protection, Hydraulic Principles in Design, 18th International Navigation Conference, Rome, 1953.
6. ________, Small Scale Experiments in Plans for Coastal Protection, reprinted from the Transactions of the American Geophysical Union, vol, 35, no. 3, 1954.
7. Carlson, R. E., Lakeshore Physiography and Use, Shore and Beach, vol. 40, no. 1, 1972.
8. Chapman, L. J., and Putnam, D. F., The Physiography of Southern Ontario, 2nd edition, University of Toronto Press, Toronto, 1966.
9. Davis, R. A., Jr., and Fox, W. T., Coastal Processes and Nearshore Sandbars, Journal of Sedimentary Petrology, June, 1972.

BIBLIOGRAPHY (cont'd)

10. Davis, R. A. Jr., et al, Comparison of Ridge and Runnel Systems in Tidal and Non-Tidal Environments, Journal of Sedimentary Petrology, June, L972.

11. Evans, O. F., The Low andBall of the Eastern Shore of Lake Michigan, Journal of Geology, vol. 48, 1940.

12. ----------- , The Origin of Spits, Bars, and REIated Structures, Journal of Geology, vol. 50, 1942.

13. Fox, W. S., T'ain't Runnin' No More, The Story of Grand Bend, The Pinery, and the Old River Bed, Wendell Holmes Ltd., London, Canada, 1946.

14. Fox, W. S., Twenty Years After, a sequel and addition to T'ain't Runnin' No More, Oxford Book Shop Ltd., 1958.

15. King, C. A. M., Beaches and Coasts, Edward Arnold Ltd., London, 1972.

16. ____________ , and Williams, W. W., The Formation and Movement of Sand Bars, by Wave Action, Geographical Journal, vol. 72 .

17. ____________, Techniques in Geomorphology, Edward Arnold Publishers Ltd., London, 1967.

18. Komar, Paul D., and Innman, D. L., Longshore Sand Transport on Beaches, Journal of Geophysical Research, vol. 75, no. 30, 1970.

19. Leopold, L. B., and Langbein, W. B., River Meanders, Scientific American, vol. 214, no. 6, 1966.

BIBLIOGRAPHY (cont'd.)

20. Leopold, L. B., Wolman, M. G., and Miller, J. P., Fluvial Processes in Geomorphology, W. H. Freeman and Co., San Francisco, 1964.

21. Minnikin, R. R., Winds, Waves, and Maritime Structures - Studies in Harbour Making and Protection of Coasts, 2nd ed., Griffin, London, 1963.

22. Morisawa, M., Streams, Their Dynamics and Morphology, McGraw-Hill Book Co., Toronto, Canada, 1968.

23. Nicholson, N. L., A Geogrphic Study of the Watershed of the Ausable River, Ontario, submitted as a Master's of Science Thesis, University of Western Ontario, Sept., 1949.

24. Sparling, J. H., The Sand Dunes of the Grand Bend Region of Lake Ontario, The Ontario Naturalist, 1965.

25. Spencer, J. W., The Deformation of the Algonquin Beach and the Birth of Lake Huron, American Journal of Science, series 3, vol. 41, 1891.

26. Taylor, Frank B., The Moraine Systems of Southwestern Ontario, Transactions of the Royal Canadian Inst., 10, 1913.

27. Shore Protection, Planning and Design, Tech. Report no. 4, 3rd edition, U. S. Army Coastal Engineering Research Centre, 1966.

28. Ausable River Conservation Authority Report of Flooding and Erosion, Port Frank, Ontario, Kilborn Engineering Ltd., Toronto, March, 1972.

BIBLIOGRAPHY (cont'd.)

29. *The Ausable Valley Conservation Report*, Department of Planning and Development, Toronto, 1949.

30. *Soil Survey of Lambton County*, report no. 22, of the Ontario Soil Survey, January, 1957.

31. Soil Survey Map of the County of Middlesex, report no. 6 of the Ontario Soil Survey.