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MAPPING STAMP SAND DYNAMICS:  
GAY, MICHIGAN

by

Thomas H. Rasmussen

A Thesis  
Submitted to the  
Faculty of The Graduate College  
in partial fulfillment of the  
requirements for the  
Degree of Master of Arts  
Department of Geography

Western Michigan University  
Kalamazoo, Michigan  
June 2000

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A Hearty Thanks to All.

Thomas H. Rasmussen

MAPPING STAMP SAND DYNAMICS:  
GAY, MICHIGAN

Thomas H. Rasmussen, M.A.

Western Michigan University, 2000

Monitoring coastal change is an important undertaking because a high percentage of the population lives within close proximity to coastal areas. This paper examines a portion of Lake Superior's shoreline where coastal change has been shaped by the introduction of 25 million tonnes of stamp sand, a man-made sediment. Longshore currents erode and deposit sediment changing the geomorphology of the coastline on both a short- and long-term basis. This movement may be documented through comparison of archival and current air photos. A series of historical air photo mosaics were input to a Geographic Information System (GIS). The GIS was used to create spatially registered maps that graphically illustrated the areas of historical erosion and deposition along the shoreline. Measurements from the GIS indicate that the length of shoreline affected by the stamp sand increased by 2.4 kilometers during a 59-year period. Measurement of area indicates a decrease of 8 hectares in the same amount of time. Areas of erosion and deposition vary from discernable erosion of 630 meters of shoreline width at the northward end, and depositional increase of 410 meters of shoreline width 1500 meters southward along the coast. The intuitive nature of the coastal change detection maps is such that the methodology could be used as a suitable technique for monitoring historic coastal change for a broad spectrum of users not trained in interpretation of remotely sensed data.

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# CHAPTER I

## INTRODUCTION

### Background

North America's five Great Lakes (Figure 1.) embrace an area of 243,460 Sq. Kilometers (94,000 square miles) with a combined Canadian and US coastline of 17,540 Kilometers (10,900 miles). The biggest of the Great Lakes, Lake Superior, has the largest surface area of any freshwater body in the world (82,100 square kilometers, 31,700 square miles) and 4385 kilometers (2726 miles) of shoreline.

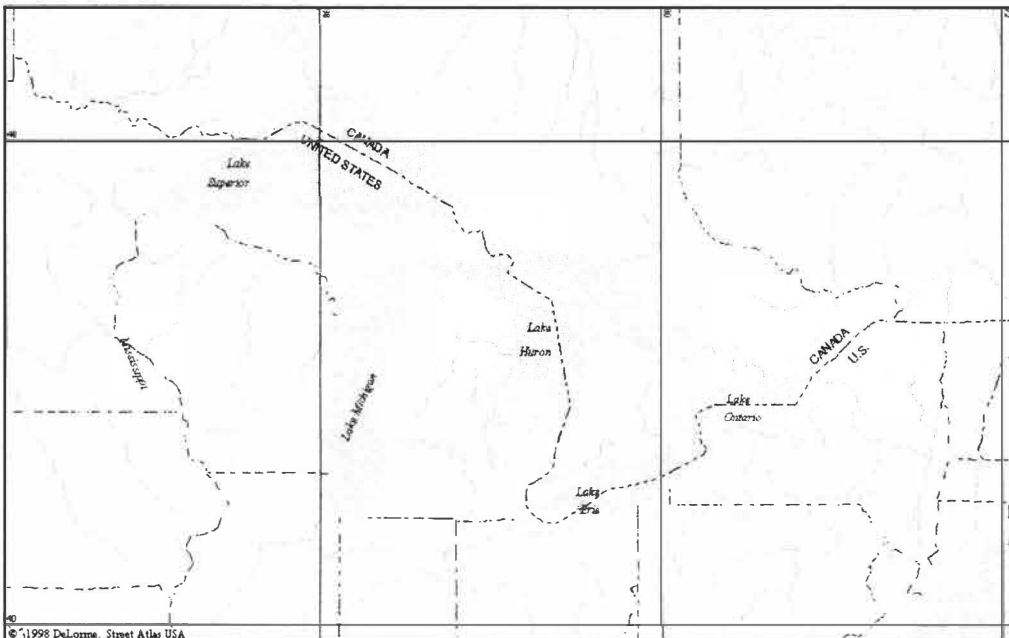


Figure 1. The Great Lakes Region.



approximately 3000 BC to 1000 BC. Modern Indians did not mine copper. However, they did gather and use loose surface pieces of native copper known as “float copper.” French explorers forwarded reports of copper in the area to Paris as early as 1636 in the “Relactions” of Lagarde (Dorr 1970). While native copper deposits are found in other parts of the world, Michigan was blessed with the largest known deposits.

Douglas Houghton, Michigan’s first state geologist, reportedly published a paper in 1844 reporting copper bearing rock in the Upper Peninsula that urged development of the resource. Mining by European-Americans began shortly afterwards at Copper Harbor (Dorr 1970). Mining continued in the Keweenaw until 1968 when it became unprofitable to operate deep shaft copper mines. Although large deposits of nonmetallic chalcocite still exist in Michigan, the cost of deep shaft mining is prohibitively expensive (Dorr 1970).

During the Copper Mining Era (1845-1968), the Keweenaw Peninsula was known as the "Billion Dollar Copper Mining District" and was host to 100 deep shaft copper mines. The mining district was concentrated in a belt approximately 45 kilometers (28 miles) long, paralleling the Keweenaw Fault, with downward sloping shafts that were over 2438 meters (8,000 feet) deep and horizontal galleries that extended nearly 12 kilometers (7.5 miles) underground. Keweenaw mines extracted about 4.989 billion kilograms (11 billion lbs.) of refined native copper in approximately 123 years of mining activity (Bornhorst 1983).

The Kearsarge Amygdaloid Lode was the second most productive deposit in the district. Mining began in the Kearsarge Amygdaloid in 1887 and ceased in 1967 with the production of 1.04 billion kilograms (2.3 billion lbs.) of refined copper.

Two mines that worked the Kearsarge Amygdaloid were the Wolverine and Mohawk. Their procedure was to bring the copper ore to the surface and transfer it to stamp mills at Gay, Michigan for processing. Upon receipt of the ore, the stamp mills used steam-powered hammers to crush it to particles 4.76 mm (3/16th in.) in diameter. The copper and rock were separated and the waste (stamp sand tailings) was discarded (Monette 1988).

After processing was completed, the stamp mills at Gay dumped the waste onto the Lake Superior shoreline. This waste material, known locally as stamp sand, had a significant impact on coastal landforms near the stamp mill site.

The term “stamp sand” may be confusing to the reader who might mentally associate stamp sand with naturally occurring beach sand. In the Keweenaw, the two materials are dissimilar. Visually, beach sand is light yellow in color, while stamp sand is dark gray. There are chemical differences in that where one expects beach sand to be predominately quartz; stamp sand has traces of copper, silver, iron, and many other compounds (Appendix A). In the case of stamp sand, quartz represents about 50% of the total compounds present with the remainder mostly basalt.

## Problem and Objectives

Winds, particularly those in storms, drive waves that in turn power shoreline currents (National Research Council 1989). These currents continuously mold and reshape Lake Superior's coastline. Coastal engineers endeavor to understand coastal geomorphology by reducing shoreline processes to mathematical formulas (Yalin 1972; Fox and Davis 1971; Viles and Spencer 1995). The formulas quantify wave velocity, wave energy, current velocity, current energy, and sediment budget to predict sediment transport in the coastal environment (Yalin 1972). The formulas are then used to construct mathematical and computer models as aids in exploring how shoreline processes interact with coastal structures that in turn affect the coastal geomorphology (Le Mehaute and Soldate 1980).

Early in the research, the coastal engineer makes a reconnaissance of the coastline either on site or through media such as charts and photographs. The purpose of the reconnaissance is to study patterns of shoreline erosion and to identify and isolate the sources and sinks of sediments along a particular stretch of coastline (Viles and Spencer 1995). This reconnaissance also defines the area, the geomorphologic features present, and is the first step in developing an understanding of the geomorphological processes involved in shaping the coastline (Komar 1976).

Komar suggests that geographers and geomorphologists assist coastal engineers by mapping stretches of coastline and comparing contemporary coastal forms with historical photos and maps. He asserts that describing and mapping the shoreline features' historical development is a valuable time saving to the coastal engineer

while enhancing the engineer's understanding of the shoreline's currents and sediment flows that shape that section of coastline (1976). Further support for the study of historical maps and remote sensed data is provided by the following statement from Viles and Spencer (1995, p. 15).

The comparison of old and new maps has been used intensively to show the nature of coastal change and repeatedly air photography and satellite imagery have also proved valuable for the detection and measurement of coastal morphological and vegetative changes.

It is evident that the geomorphology of a section of Lake Superior's shoreline has been heavily influenced by millions of tonnes of stamp sand (stamp mill tailings) from the stamp mill previously located at Gay, Michigan. However, the impact and dynamics of the stamp sand on the coastal geomorphology of Lake Superior's Keweenaw Bay have not been documented either cartographically or quantitatively. The creation of historically sequenced maps, as suggested by Komar (1976), will assist coastal engineers and geomorphologists to understand the impact of massive volumes of stamp sand on the shoreline geomorphology.

Historically sequenced maps of stamp sand movement will be of interest to others as well as engineers. The stamp sand is a part of the history of the copper mining era as surely as mill ruins and abandoned mineshafts are, with one difference, ruins and shafts are stationary while stamp sand is mobile. Historians will find that tracking this legacy of the mining era may be an important chapter in the history of the Keweenaw.

Another group that is interested in stamp sand movement is environmentalists. Nearby is the Torch Lake EPA SuperFund site. Toxic compounds identified in the

200 million tonnes of stamp sand deposits at Torch Lake are copper, arsenic, lead, chromium, and other heavy metals (Environmental Protection Agency 1998). Twenty-five million metric tonnes (24.6 million tons) of stamp sand were placed on the shoreline at Gay, Michigan during the operational life of the stamp mills (Babcock and Sprioff 1970). Kerfoot and Nriagu express an interest in stamp sand movement for several reasons. One reason is the possible, “threat to fish rearing areas” and “nearshore benthic habitats.” A second reason is, “Because the tailings were deposited in coastal scour zones, the fine fraction contributes to the contaminate load of nearshore coastal waters.” Their third concern is that the coarse fraction “is progressively contaminating the beaches of the Keweenaw Peninsula coastline as particles are transported and redeposited along the shoreline (1999). These questions of Kerfoot and Nriagu, and other environmentalists, about movement are addressed by this study.

The portion of the shoreline affected by the stamp sand lies in two counties, the largest section (7.3 kilometers) is in Keweenaw County, and the remainder (1.3 kilometers) is in Houghton County. As of this writing, Keweenaw County has zoned their shoreline as “Recreational Residential.” The zoning commission has no current plans to change the designation as they feel this is the “best possible use” for the area. Houghton County has similarly designated their portion as “Residential” and feel that is the best classification. Maps that illustrate the historical movement of the stamp sand may have an impact on future land use decisions by the counties.



During the field work for this study, landowners expressed an interest in knowing if the stamp sand is going to get wider or narrower in front of their property and what impact these changes may have on their land values. Some of them purchased their recreational property 30 years ago and have seen their yellow beach disappear and have witnessed the water line move outward 50 meters with encroachment by the stamp sand. Interestingly, conversations with members of the tax equalization boards for both counties revealed that the land values have not been influenced by the stamp sand movement. They attribute the increased inland values to the continuing demand for lake front property.

In order to provide information about the impact of the stamp sand the first objective of this research was to create a series of maps using air photos that illustrate trends in the changing geomorphology of an 8.7-kilometer (5.4 mile) section of Lake Superior's Keweenaw Bay shoreline over a 59-year period. The second objective was to use these maps in a Geographic Information System (GIS) as the basis for measurements of the location, area, and breadth of the shoreline occupied by stamp sand.

### Location of Study Area

Gay, Michigan, in Keweenaw County, was home to stamp mills used by the Mohawk and Wolverine mines (Figure 3). Ore processing began in 1902 reaching a capacity of 4,166 metric tonnes (4,100 tons) per day by 1907, though the mills did not always operate at full capacity. The Wolverine mill closed in 1925 reducing capacity

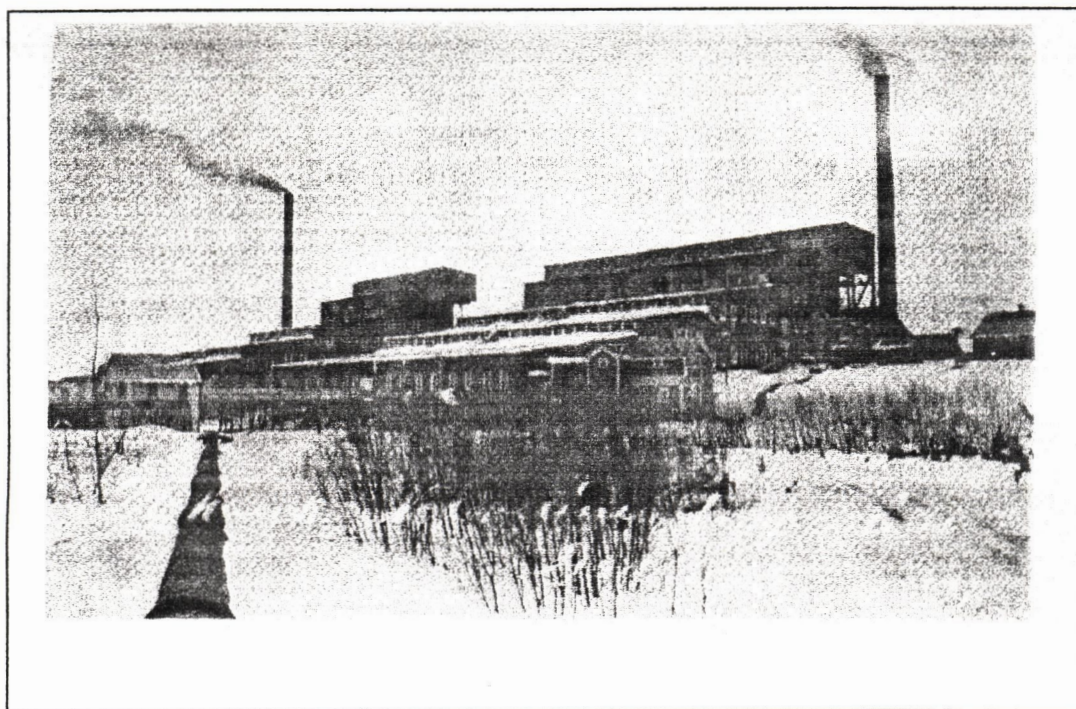


Figure 3. The Mohawk and Wolverine Stamp Mill at Gay.  
Source: Monette, 1988. Photo is courtesy of Mr. Tony Vranesich,  
Lake Glason, Copper Harbor, Michigan.

to 3,048 metric tonnes (3,000 tons) per day. Processing was consolidated at the Mohawk mill until it closed in 1933 due to the “Great Depression” (Monette 1988). Demand for copper during the depression decreased to the point that the cost of production was higher than the price received forcing many mines in the Keweenaw to cease operations (Lankton 1991).

Copper ore was crushed (stamped), mixed with water and chemicals to “float” the copper separating it from the bulk of the material. Crushed ore, copper, and water were separated and the dry waste, known as stamp sand, was deposited onto the lake-shore by conveyor belt. Water, sediment, and chemicals, which were about thirty

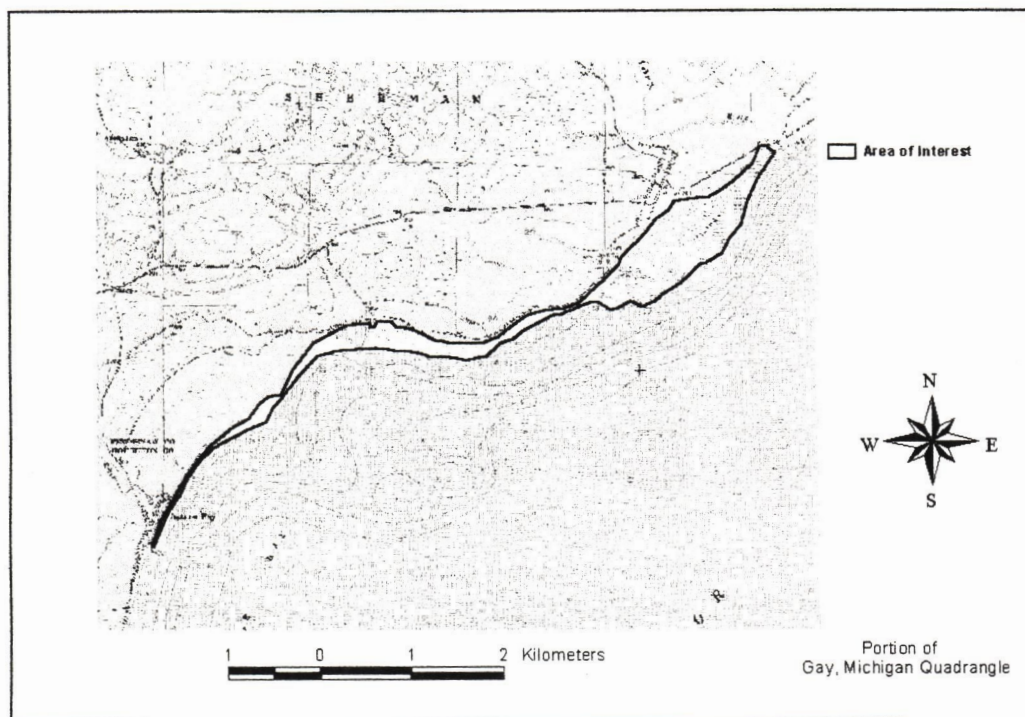


Figure 4. Portion of Gay Quadrangle.

### Literature Review

Literature whose specific focus is on mapping historical changes in the geomorphology of Lake Superior's 4385 kilometer (2,726 miles) of shoreline is limited (Great Lakes 1997). Sources that describe coastal geomorphology in the Great Lakes are primarily engineering studies that concentrate on sediment transport processes in the lower lakes, specifically Lake Michigan, rather than geographic and temporal trends.

Studies by Davis (1994), Fox and Davis (1971), and Davis, Fingleton and Pritchett (1975) addressed the dynamics of beach and shoreline environments on Lake Michigan's eastern shoreline. Fox and Davis (1972) conducted a research

project on the western shoreline of Lake Michigan at Sheboygan, WI for comparison with data from the eastern shoreline. Their primary goal was to understand the dynamics of wind, weather, and waves on the beach profile. The research was oriented toward developing relationships between these factors to determine which of the factors were potential indicators of dynamic processes. They found that most of the changes in beach profile occurred during periods of high wave energy (Fox and Davis 1972). Davis (1994) summarized the work on beach profile changes by stating that the determining factors are the amount of sediment available, strength and shape of waves, slope of the near shore area, and subtle site-specific factors.

Kerhin (1971, p. 55) found that the "foreshore geometry responds to the physical lake conditions." His work has led to further engineering studies of changes in beach profiles undertaken on Lake Michigan's east coast between 1970 and 1972 (Davis, *et al.* 1972). A previous study, used by Davis, *et al.*, was of shoreline erosion conducted at multiple sites along the Lake Michigan shoreline. These studies were focused on sediment transport and the physical conditions that promote sediment transport (Fingleton 1973). Fox and Davis (1972, p. 46) report that most "topographic changes in the beach and nearshore occur during times of high wave energy." These studies were on shorelines consisting of natural sand not shorelines of man-made waste material.

Engineering studies of coastal processes also include measurements of particle size and a statistical analysis of the distribution of particle weights and sizes. It should be pointed out that in trying to quantify sediment-transporting currents a

distinction is made based on the two types of sediment "loads." The first type is a "suspended" load. A suspended load consists of particles that are very light in weight and small enough to remain in suspension during conditions of low energy when small waves and a low rate of longshore drift are the norm. Suspended load particles flow with the longshore current until entering calm water where they slowly settle out of the water column. The second load is referred to as a "bed load." This consists of particles that are too heavy for water to support whatever the energy level. Because water cannot support bed load particles in suspension, during periods of high energy they move by "saltation" in which the heavier particles bounce along the bottom propelled by the longshore current (Komar 1976).

Some studies concentrate on the mechanics of sediment transport in the coastal environment. For example, Davis (1970) examined coastal sedimentation on Lake Michigan's southeastern shore and Graf (1971) studied the dynamics of sediment transport in fluids and field locations other than the Great Lakes. Yalin (1972) wrote an exhaustive textbook concentrating solely on the fundamentals of sediment transport. Further investigation has led to the construction of numerical models describing the processes of erosion, transport, and deposition of sediment (Le Mehaute and Soldate 1980). Models are used to simulate how the morphology of a coastline changes due to erosion, sediment transport, and deposition (International Symposium on Sediment Transport Modeling 1989).

In a Master's Thesis at Michigan Technological University (MTU), Zarling (1997) quantified the shear characteristics of hematite mine tailings when dry as

compared with when the tailings are wet or saturated. His study of iron mine tailings stability did not address the specific properties of copper stamp mill tailings and whether stamp mill tailings act differently in the environment than iron mine tailings. Pawloski's (1979) thesis work at MTU studied the stability of a hematite mine tailings' embankment. Copper stamp mill tailings and iron mine tailings may have different physical characteristics such as shape, size, and specific gravity, which would have an impact on how the particles behave in a wave driven shoreline environment.

While the referenced sources have contributed to the body of knowledge about sediment erosion, transport, and deposition none address the particular circumstances of historically mapping changes in shoreline geomorphology caused by the presence of massive amounts of stamp sand from copper refining located on the active shoreline of a major water body. The engineering applications have focused on one aspect of the shoreline, which is explaining and modeling transport processes.

To survey beach erosion in a study area in North Carolina, Stafford collected air photos spaced several years apart to map and illustrate the shoreline's sequence of historical development. He noted that the advantages of air photos are that they are a permanent record of the time and location, are more detailed than maps (allowing a more comprehensive analysis of the location), and provide more frequent data sets (Stafford 1971).

However, some limitations of air photos exist. Internal limitations are errors of scale within the photo caused by lens distortion, tilt, and relief. External limits include storm events that may skew shoreline data and in air photos only areas of

change are detectable not the volume of the material removed or deposited in a particular location (Stafford 1971).

Guo and Psuty (1997) published an article in the *Journal of the American Society for Photogrammetry and Remote Sensing (PE&RS)* in which they described using air photos, maps, and a GIS to construct maps they subsequently used to study the "Sequential Spatial Evolution" of deltaic wetlands. Guo and Psuty used the GIS for linear measurement and spatial analysis of the wetlands depicted in the maps. Their procedure was to create maps by manually digitizing hardcopy photos and maps. Once digitized, the maps were referenced to a coordinate system and projection. The last step was to input the maps into the GIS for analysis.

The literature of Stafford, Guo, and Psuty offer techniques for historically mapping the stamp sand's movement. First, Stafford with his reasons for using air photos and his cautions about limitations of air photos. Secondly, Guo and Psuty's procedures for geo-referencing the photos, which mitigate some of Stafford's cautions about distortion, to create mosaics followed by a GIS analysis. Combined, these ideas are used as guidelines for the procedures used in this project.

## CHAPTER II

### DATA PROCESSING

#### Primary Data Sources

Primary source materials were sets of air survey photos of the stamp sand site taken at intervals of five to ten years. The project objectives required photos to be at a relatively large scale, on the order of 1:15,840 or 1:20,000. From personal experience this researcher was aware that photos of these scales would have an image scale large enough to allow for accurate discrimination between stamp sand, beach sand, vegetation, and water. These observations related to scale are supported by Stafford's (1971) advice that it is easier to work with larger scale air photos.

The search for usable air photos began with the Michigan Department of Natural Resources' (MNDR) Real Estate Division, Lansing, MI. The MDNR provided black and white infrared photos from 1986 and 1997. The 1997 photos were the most current images of the area at the time of this project. The MDNR also had available false color infrared taken in 1978. The National Archives, Washington, D.C., provided black and white panchromatic photos from 1938 and black and white infrared from 1954. The last set were black and white infrared from 1964 and were located at the United States Geologic Survey (USGS), Sioux City, IA.



The selected sets of photos, 1938, 1954, 1978, 1986, and 1997 have spacing of 16, 10, 14, 8, and 11 years. The total period covered is approximately 59 years with the base line photo series in 1938. This base year is significant because this set of photos were taken only five years after production ceased at Gay in 1933.

### Secondary Data Sources

United States Geologic Survey (USGS) topographic and other historical maps were used as secondary data sources. One example is the Gay 7.5-minute quadrangle dated 1954 and photo-revised in 1975. This map illustrates the mill tailings' changes between map data acquisition, 1954, and when the USGS acquired updated photographic data in 1975. This map is available in both a hardcopy version and as an electronic version from the USGS. The hard copy map was used as a reference for obtaining basic site information. The electronic copy has geographic coordinated data imbedded and was particularly useful as a source of Ground Control Points (GCP) as an aid in geo-referencing the photos.

Several sources were investigated to locate a source of information illustrating the shoreline geomorphology before the introduction of stamp sand. Searches were made at the National Archives, Army Corps of Engineers, Maritime Museums, and the State of Michigan Archives for appropriate maps. The State of Michigan Archives was found to have the 1866 plat-maps for the State of Michigan on microfilm that showed the Keweenaw Bay shoreline. The microfilm viewer had a photocopier attached that facilitated printing hard copies of the plat-maps. After scanning,

geo-referencing and creating a mosaic the 1866 plat-maps were added to the GIS to illustrate the pre-stamp sand shoreline.

Other secondary data used were stockholder's reports that contained information regarding the estimated amounts of ore sent to the mills and the amount of refined copper shipped from the mill. The difference between these two pieces of information provided an estimate of the volume of mill tailings (stamp sand) in the study area.

### Methodology

The methodology used in this research produced a series of temporally sequenced mosaics based on historical sets of air photos. The photos required correcting to remove distortion produced by the lens optics per Stafford's cautions. The distortion was mitigated by geo-referencing the photos, which is correlating the reference system of the photos to the coordinate system, NAD 1927, of the Gay Topographic quad. After these corrections, the photos were used to create mosaics of the shoreline study area. These mosaics showed the mill tailings' movement and the resulting changes in coastal geomorphology. ArcView 3.1™ (GIS) was utilized to create maps from the mosaics defining the stamp sand's movement. These maps were the source for measurements made of the research site. Details of this process are outlined below.

## Photo Processing

Several preparatory steps were required before the air photos could be used to construct mosaics. Before any of the photos could be input to the GIS analysis environment, it was necessary to transform them from hardcopy to a digital format. Therefore, they were optically scanned using a Microtek Scanmaker 9600XL with Adobe Photoshop™ and stored as a digital file in TIFF format. Scanning was at 300 dpi, the ground resolution was approximately 1.34 meters per pixel, allowing adequate detail without creating files so large that storage was a problem. The TIFF file format was utilized for optimal compatibility with the geo-referencing software.

Software used for constructing the mosaics was Blue Marble's Geographic Transformer™. The software uses a three-step procedure. The first was to establish a relationship between the coordinate system of the photos, pixels, and a reference coordinate system, which for this project was latitude and longitude. Once this relationship was established, the second step was to "transform" the image. Transformation creates a new file converting the referenced "image map" into the coordinate system and projection selected (in this case NAD 27). The final step was to create a composite image (mosaic) of the component photos for each year (Blue Marble Geographics 1996).

Preparation for referencing and transforming required locating GCPs around the immediate area of the project's location (Figure 5, for coordinates see Appendix B). The positional data of the GCPs served to "anchor" the images to fixed points on the ground in the target coordinate system. Criteria for selection of GCPs sites was

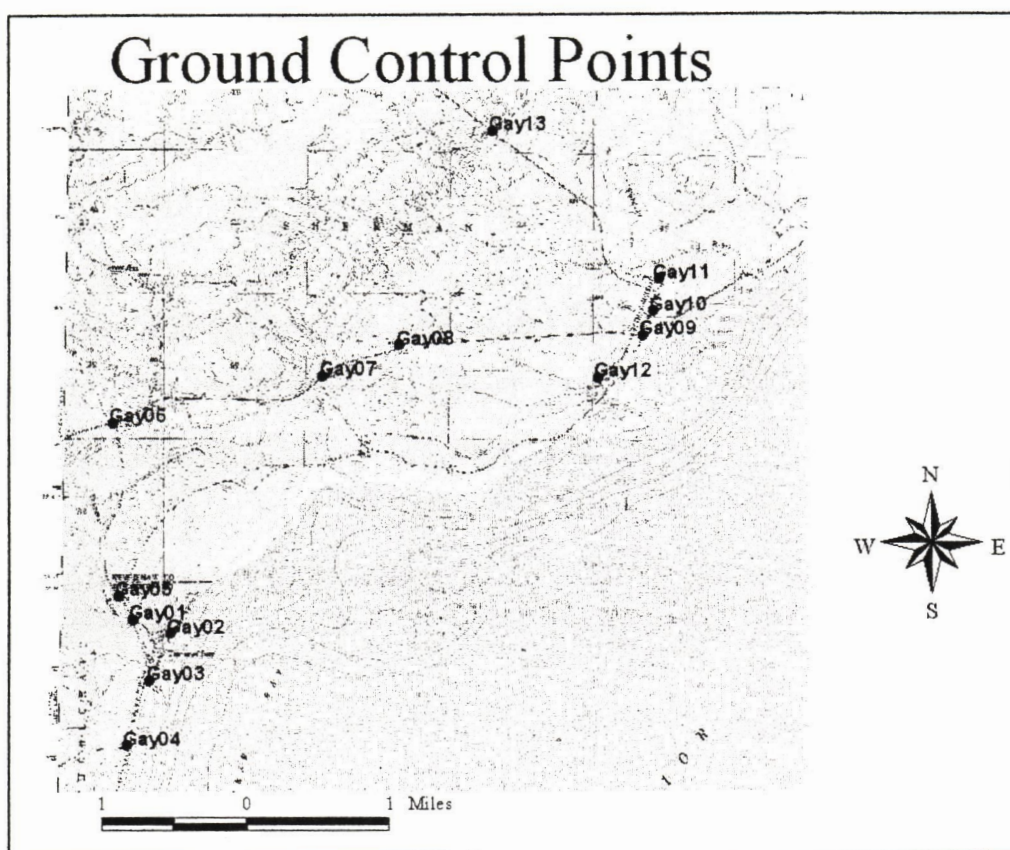


Figure 5. Field Collected Ground Control Points.

that the sites be easily identifiable in the photos and that they be present in each of the six photo sets over the 59-year period. Latitude-longitude information for the GCPs was obtained in the field by accessing the Global Positioning System (GPS) satellite network and taking multiple readings over a period of time as suggested by Kardoulas, Bird, and Lowen, (1996). The GPS unit used was a Garmin *GPS II PLUS™* fitted with Garmin's adapter for reception of "real-time" differential GPS correction data. The accuracy of the differential calculations benefited from close proximity to a differential data transmission station located on the Keweenaw Peninsula; the unit's display panel showed that the study area was located less than 32 kilometers (20 miles)

from the transmission tower. The unit updated the positional reading once a second and was left in a given location for five minutes to average the readings. Post processing of the coordinates was not employed since the display panel on the *GPS II PLUS™* showed that in the X-Y axis the error was in the range of 0.46-0.61 meters (1.5-2 feet), which was smaller than the dimensions of a scanned pixel, 1.34 meters. Elevation data were not collected by GPS because either the elevation data were surveyed and recorded on the Gay Quadrangle for the GCP site, or the GCP site was at or near the surface elevation of Lake Superior.

Locating GCP sites was a problem because a large portion of each photo is either lake surface or forestland, neither of which offered features that could be discerned in the photos. Adding to the dilemma was that the GCPs that were collected are clustered along or near the shoreline.

Geographic Transformer™ has the capability to display simultaneously up to three screens. Two screens are the image being referenced, in both an overview and a close up of the cursor's location. The third screen can be of an image that was previously geo-referenced and transformed, thereby supplying additional position data for the area. The electronic copy of the Gay Quadrangle became an alternate source to supplement the original thirteen GCPs by displaying it in the third window on the screen.

The geo-referencing process in Geographic Transformer™ is to import and open each photo and match up all possible GCPs with the appropriate pixels on the image. As the GCPs are entered, Geographic Transformer™ applies one of three

referencing solutions to calculate error between the computed values and the entered values. The particular equation is chosen based on the number of GCPs entered. The optimal for referencing air photos was the “2<sup>nd</sup> Order Polynomial” which required a minimum of six GCPs for the image (Blue Marble Geographics 1996). GCPs may be selected or deselected from the list to obtain the minimum possible error before committing to the transforming process (Blue Marble Geographics 1996).

Error data are displayed as a table or a graph. Error values are given in pixels. Actual error values can be calculated if the resolution of each pixel is known for the particular scanned image being referenced. If the scale of the photo was 1/15,840 and scanned at 300 dpi, then each pixel would represent 1.34 meters.

Transformation creates a new destination image that is in the specified coordinate system that can be used in ArcView 3.1™ (Blue Marble Geographics 1996). This means that the pixels of the photograph are now referenced to the specified coordinate system, which was latitude and longitude for this project.

The final use of Geographic Transformer™ was to create composite images (mosaics) from the individual image files. This mosaic process requires that all images must share a common coordinate system, pixel size, and the same range of colors or tones. The process combined the separate image files for a particular year into one file representing the mosaic for that year. This final image file is in a format that can be imported into ArcView 3.1™ while retaining coordinate information for use by the Geographic Information System.

## Problems Encountered During Rectification and Mosaic Construction

Proper selection of GCPs is critical to accuracy in photo rectification. GCPs provide the link between the reference system of the photo, pixels, and the target reference system. The process of selecting GCP locations and determining the latitude-longitude of the GCPs was discussed earlier. However, another consideration is the actual number of GCPs used and the geometry of the GCP sites.

During a telephone conversation with Blue Marble's customer assistance staff, they advised that for the best possible referencing approximately 100 GCPs were required for each photo. They added that a smaller number would suffice if the GCPs were distributed evenly across the photo.

The particular area chosen for this project presented problems for GCP site selection because a considerable portion of each photo was water and equally featureless forestlands. These features severely limited the number of possible sites and restricted the geometry of site selection. The total number of GCPs with field collected positional data for this project was thirteen (Appendix B) that were not distributed evenly across the photos possibly introducing errors in geo-referencing that would have prohibited construction of mosaics. However, the geometry of the GCP sites was relatively linear in that they were along or roughly parallel to the shoreline (Figure 5).

As previously discussed, the number of sites was augmented by using the capability of Geographic Transformer™ to coordinate sites on a referenced image to the target image. This improved the number of available GCPs and their geometry for

use in the rectification formula. The resulting rectification produced image files that were acceptable to form a mosaic.

Problems with referencing became apparent during the mosaic process by minor misalignments in the images, which became visible when greatly enlarged. In some instances, alignment problems were corrected or minimized by repeating the referencing process while changing the order that the GCPs were entered into the formula.

#### Geo-referencing vs. Orthorectification

Mindful of Stafford's (1971) cautions concerning the limitations of air photos caused by lens distortion and platform tilt, two forms of correction, geo-referencing and orthorectification, were considered. Orthorectification was considered for the project but was discarded. Orthorectification would have removed most of the distortion from the images making them nearly as accurate as USGS topographic quadrangles. This level of accuracy would have been optimal but with the minimum number of GCPs available, the possibility of successful orthorectification was in doubt. It was therefore decided that because of the particular characteristics of the study area, that is its being a roughly linear feature lying along a single plane (the surface of Lake Superior), geo-referencing would produce mosaics with acceptable precision.



## Geographic Information System Processing

The mosaic images were imported to ArcView 3.1™ to construct temporal maps. The purpose of these maps was: (a) to illustrate the sand's movement over time; (b) to make linear measurements of the width of the stamp sand at selected sites; and (c) to calculate the area of stamp sand coverage on each of the photo dates.

The finished maps were polygons that enclosed the area interpreted to be stamp sand. Interpreting the stamp sand was done by visually examining the photo mosaics and using the eight photo interpretation recognition elements. The recognition elements are shape, size, pattern, shadow, tone or color, texture, association, and site. The first requirement of interpreting the mosaics was to determine which parts of the mosaic were water, vegetated areas, or beach (beach in this case refers to areas of natural beach sand and stamp sand). The most useful of these elements for making distinctions between water, vegetation, and beach were tone or color, texture, and association.

Texture readily set the "rougher" appearance of the vegetated areas apart from the "smoother" textured beach and water. Tone and texture differences separated water from beach areas. Water was darker toned with a "glassier" texture than the beach. Supporting tone and texture in making these distinctions was association, in this area beach is positioned between water and vegetation. Once the beach area had been determined, the dark tone of the stamp sand distinguished it from natural beach sand. Figure 6 demonstrates the tonal differences in natural beach sand to the left of the stream mouth and the darker stamp sand to the right.

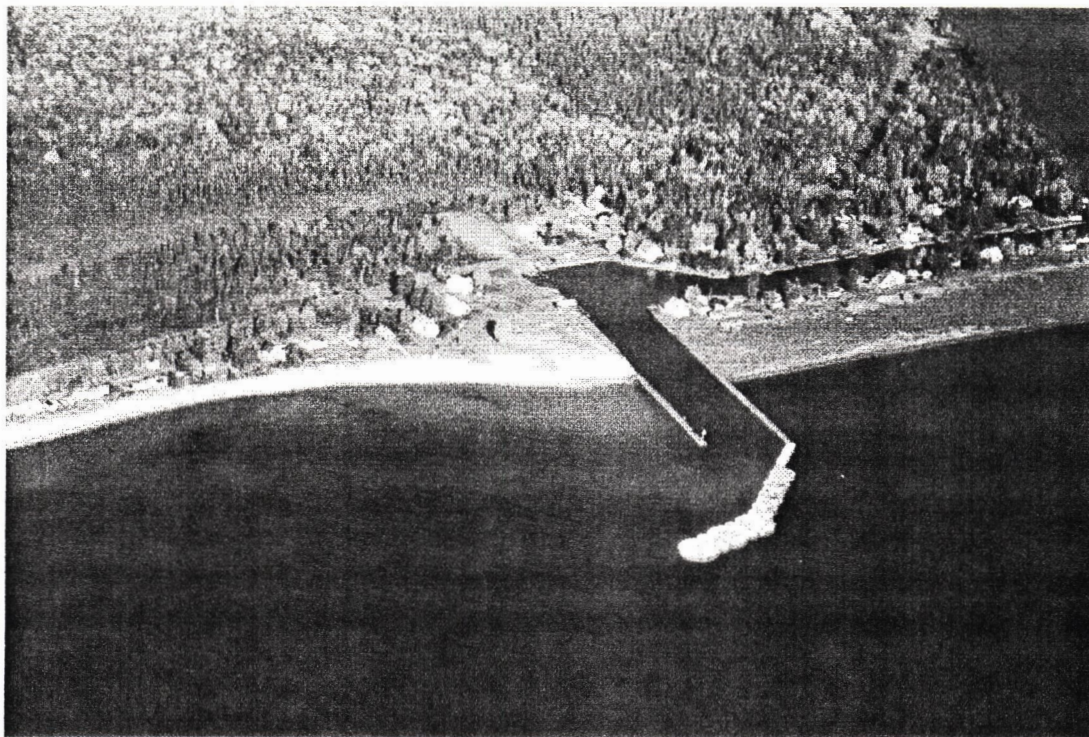


Figure 6. Comparison Photo of Beach and Stamp Sand.

Because each of the mosaics were geo-referenced, it was possible to create polygons that overlay onto any of the mosaics to show how the location and dimensions of the stamp sand have changed over time. Polygons were constructed by first displaying the mosaic, then using ArcView's digitizing extension in the "heads-up" mode to create the polygon. Polygons were saved then reopened in the editing mode for adjustments to line placements.

During digitizing, the image was magnified so that individual pixels were visible. By working at the pixel level, placement of the polygons was more precise. The scale of the photo and the dpi used for scanning the images determined accuracy in polygon construction, that is to say, a photo with a scale of 1/15,840 scanned at

300, or greater, dpi would have a smaller pixel size than a photo with a scale of 1/200,000 scanned at 150 dpi. The smaller pixel size is more precise than a large pixel; it represents a smaller dimension of the ground.

### Polygon Delineation Accuracy Factors

Environmental factors may have an impact on defining the shore water boundary and consequently may affect the positional accuracy of the digitized polygons. How critically water level impacts polygon placement depends on two factors: first is the amount of change in water level; second is the slope of the shoreline.

Lake Superior experiences water level changes that are the product of several environmental processes. The water level fluctuates seasonally, with the highest levels generally in the summer and lowest during the winter (Figure 7). These changes

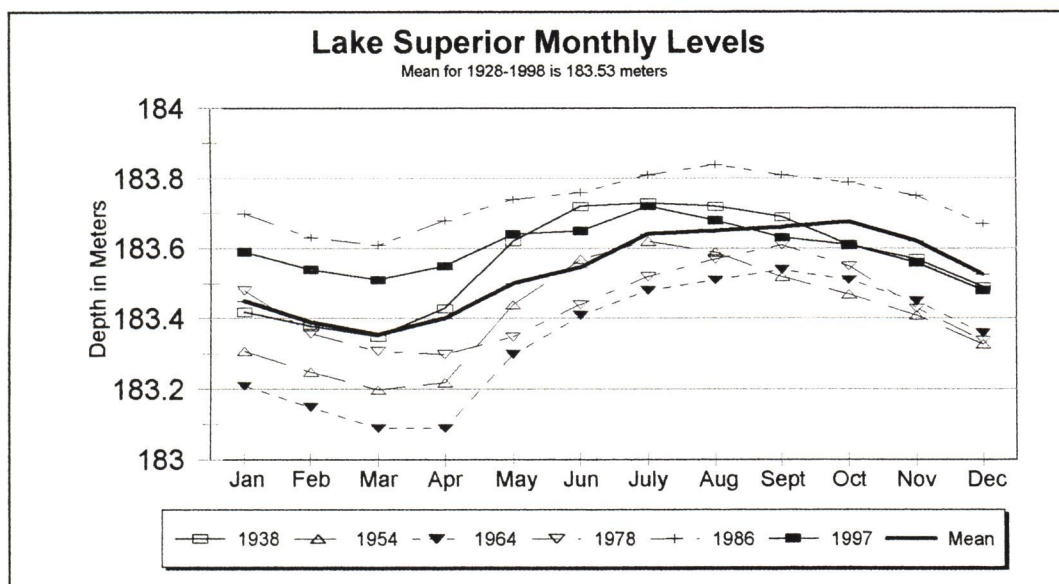


Figure 7. Lake Superior Monthly Levels Based on NOAA Water Level Data.

are due to variations in rainfall, snowfall, evaporation, ground water levels, and runoff. These same factors may cause long-term changes in water level through climatic change.

There also may be short-term changes in water level. One daily source of short-term change is due to tidal forces. However, Great Lakes' tides are minor and are in the range of 2.5 to 7.6 cm (1 to 3 inches) (Dorr and Eschman 1970).

A more significant source of short-term change is wind. Wind friction powered by strong winds in a storm may drive water from one side of the lake to the other causing significant changes in water level over a short time period (Dorr and Eschman 1970).

Differences in atmospheric pressure from one end of the lake to the other may cause short-term changes in water level. Water level under a high-pressure area may depress the water level while under a low-pressure area on another part of the lake the water level may raise. When the pressure centers move off the lake surface the water will return to the equilibrium level and may oscillate several times in the basin during the process. This oscillation is known as a seiche. "Seiches on Lake Michigan are reported to have caused local changes in water level as great as 5 feet (1.5m) and as great as 9 feet (2.7m) on Lake Huron (Dorr and Eschman 1970, p. 224)." Similar fluctuations are likely on Lake Superior. Water level change due to seiches may occur in a matter of minutes (Dorr and Eschman 1970).

Table 1 shows the horizontal distance that the waterline would move in response to changes in the lake's water level for a given shoreline slope. That is, if the

Table 1

## Waterline Movement With Changes in Beach Slope and Water Level

Change in Water Level	- 0.6 m	- 0.3 m	+ 0.3 m	+ 0.6 m
Slope of Beach	Horizontal Change in Waterline			
40 Degrees	- 0.7 m	- 0.4 m	+ 0.4 m	+ 0.7 m
30 Degrees	- 1.1 m	- 0.5 m	+ 0.5 m	+ 1.0 m
20 Degrees	- 1.7 m	- 0.9 m	+ 0.8 m	+ 1.7 m
10 Degree	- 3.5 m	- 1.7 m	- 1.7 m	+ 3.5 m

water level increases the waterline will advance shoreward and if the water level drops the waterline will recede. The distance that the waterline moves, for a given vertical change, is affected by the slope of the beach. It can be seen from this table that a beach with a steeper slope has less horizontal shoreline movement than a beach with a shallow slope.

The impact that the combination of water level and slope has on polygon placement at the Gay, Michigan stamp sand is in turn influenced by the particular profile of the stamp sand near the water line. At Gay, the shoreline profile varies from a steep wave-cut bluff onshore to a gently sloping abrasion (or wave cut) platform offshore; hence, the area of shore ward gently sloping beach is limited. With rising lake levels water will quickly meet a vertical face of stamp sand halting the

water line's movement away from its normal location (Figure 8). However, in conditions of a lowering lake level water is free to recede a greater distance moving the waterline further away from the normal location. Thus, a seiche that is piling water into Keweenaw Bay will have less of an impact on polygon placement than an event that lowers the water level of Lake Superior.



Figure 8. Profile of Stamp Sand Shore.

The relationships between water level, slope, and beach profile to polygon placement must be considered in relationship to the resolution of the pixels in the scanned image. In this project, each pixel represents approximately 1.34 meters on the ground. Referring to Table 1, a change of .3 meter in water level on a 10% slope could produce a one-pixel displacement of the waterline, which would have a minor

impact on area calculation accuracy. However, this minor dilution of accuracy would not significantly impact relationships when comparing the approximate area of one year against that of another year.

### Measurement Calculations

In order to determine the extent of the stamp sand coverage change over the period, ArcView 3.1™ was used to calculate its surface area represented by the digitized polygons for each year's mosaic. Area was constantly recalculated as the polygons were constructed around the stamp sand. ArcView has the ability to display area calculations in several different units of measure; in this instance, hectares were used.

Linear measurements of the width of stamp sand beach were made on transects defined as "perpendicular" to the shoreline at each of a number of reference locations. Because the images were geo-referenced, a point and azimuth on one mosaic would be the equivalent on each of the other mosaics allowing a comparison of measurements. Measurement points were located along the line where the beach and sand dunes met in 1938. The junction of beach/dune was present in all the mosaics but did move toward the lake up to 20 meters in some locations between 1938 and 1997, probably due to wind and rain erosion of the dune's slope depositing natural beach sand on top of the stamp sand. The choice of the 1938 line was to provide a consistent initial measuring point.

The starting point for measuring sites was north of Gay on the south bank of the Tobacco River. Sites were located every 500 meters with the final site positioned at the north bank of the Traverse River. Nineteen measurement points were placed between the two rivers.

The points were first constructed on the mosaic for 1938 and then overlaid onto the five other mosaics. In order to make linear measurements between mosaics as comparable as possible they were made along a transect “perpendicular” to the shoreline at each of the nineteen sites. Three formulas were used to determine the bearing from each point for this transect.

Equation 1 calculated the slope of the line connecting the two sites on either side of the target site. The equation for the calculation of the slope of the line was:

$$(\text{Slope } (M_1) = \text{Rise} / \text{Run} = (Y_2 - Y_1) / (X_2 - X_1)) \quad (1)$$

Where  $X_2Y_2$  and  $X_1Y_1$  are coordinates of sites adjacent to the target site,  $M_1$  is the slope of the line connecting the two adjacent sites.

Use of this equation required two additional sites, #1 and #21. Site #1 was placed 500 meters north of the Tobacco River and #21 was placed 500 meters south of the Traverse River.

Slope  $M_2$  is determined as the slope of a line perpendicular to the slope of the line in equation 1. Equation 2 was:

$$(M_2 = -1 / M_1) \quad (2)$$



where slope  $M_2$  is the slope perpendicular to the slope  $M_1$  from equation 1.

Equation 3 was the point / slope equation. This equation defines a line given the coordinates  $(X_1 Y_1)$  of one point on the line (the measurement site), the slope ( $M_2$ ) of the new line (from equations 1 and 2), and one of the coordinates ( $X$ ) or ( $Y$ ) of a second point on the new line. The original configuration of the equation was:

$$(Y - Y_1 = M_2(X - X_1)) \quad (3)$$

If  $X$  is known, this equation is modified algebraically to solve for the unknown  $Y$  by changing it to:

$$(Y = (M_2 (X - X_1)) + Y_1) \quad (4)$$

To position the line, two sets of coordinates,  $(XY)$  and  $(X_1 Y_1)$ , were located and a line drawn connecting them.

In practice this process generated a transect from each site that was perpendicular to the line segment connecting the two sites adjacent to the target site in three-dimensional space (Figure 9). Width measurements were made along this transect on each of the mosaics so changes in width of the stamp sand would be comparable from one year to another.

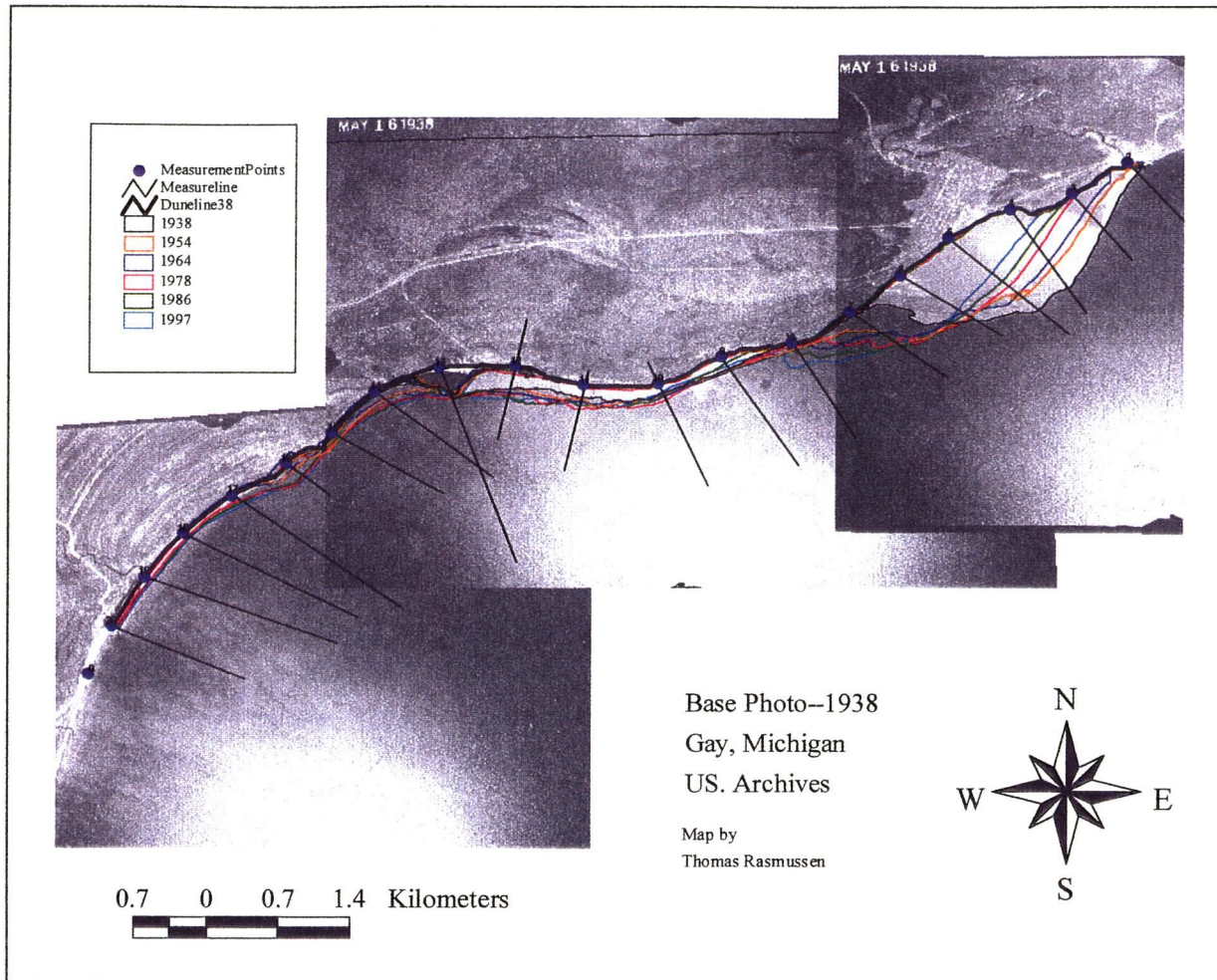


Figure 9. Shoreline Positions Showing Progressive Stamp Sand Migration 1938-1997.

## CHAPTER III

### RESULTS

#### Description of Movement by Map Analysis

Examination of the stamp sand's extent can be observed on a mosaic of the complete area (Figure 9). However, study of the sand's movement was simplified by separating the shoreline into three sections. These sections are the areas between measurement lines 2 and 8, 9 and 13, and lines 14 through 20. The colored lines on the mosaic are the digitized stamp sand area for each year. The symbols in the map legend show a colored rectangle for each year indicating that each map is a closed polygon. The legend also shows each measurement site and the line from each site along which measurements were made. The heavy dark line in the legend represents the 1938 dune/beach line.

We can observe that in the shoreline of the first section (transects 2 – 8; Figure 10) the area where the stamp sand was deposited by the mill on to the Lake Superior shore. From the 1938 image of this area, it is apparent that as new material was deposited the stamp sand moved to both the northeast and southwest from the end of the conveyor system, which was located between transects 4 and 5. However, the presence of stamp sand in the sections several kilometers to the southwest of this area indicates that a dominant southwesterly longshore current exists (refer to

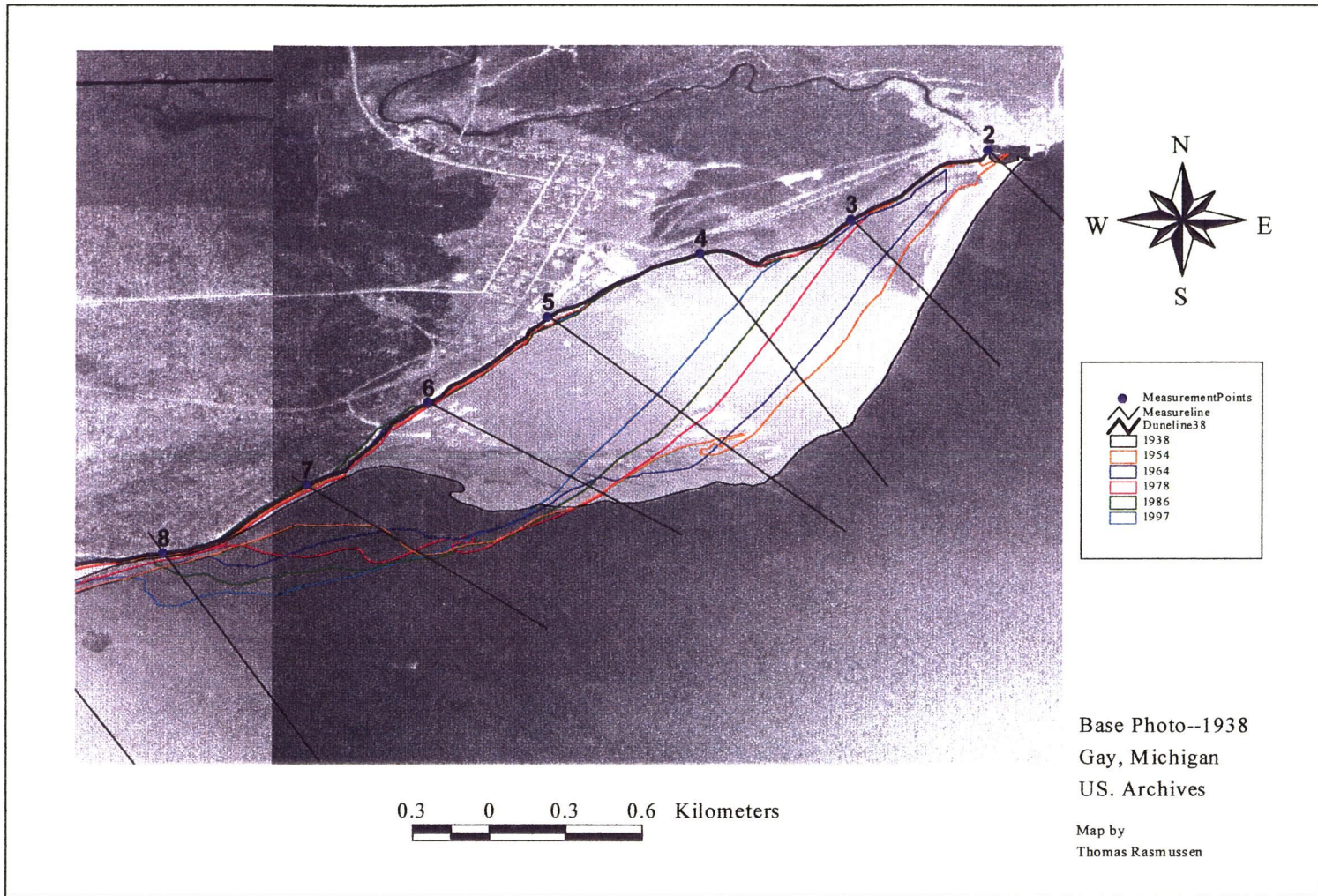


Figure 10. Section 1, Transects 2 – 8.

Figure 9). This southwest flow is produced by the generally counterclockwise circulation found in Lake Superior (Sloss & Saylor 1976).

Examination of the photo-year polygon maps, which represent the shorelines subsequent to 1938, reveals that this section of the stamp sand has experienced significant erosion by Lake Superior. The stamp sand has retreated, over time, from the 1938 shoreline to the pre-mill shoreline from transect 2 to almost transect 4 and has been decreasing in width southward to transect 6. However, southwest of transect 6 to south of transect 8 the stamp sand is seen to be increasing in width during the later decades of the time line. This decreasing width in the northeast and increasing of width in the southwest within this section again is indicative of a generally southwesterly flow to the longshore current.

While at the southern-most point of the first section the stamp sand width was relatively constant, with minor fluctuations, from 1938 until some time between 1978 and 1986. In the second section, (transects 9 - 13; Figure 11), the 1986 shoreline begins to demonstrate the effects of the southwesterly movement of the stamp sand by showing evidence of an increase in width. This increase in width continued through the 80's and 90's as reflected in the 1997 shoreline. The stamp sand width at 9 and 10 is relatively constant from 1938 through 1986 but is actually narrower in 1997 than the earlier periods while transect 11 gradually increases in width until 1978 but then starts to decrease through 1997. Transect 12 shows a small increase in width with each map. Transect 13 exhibits some fluctuation but the transect lies across the end of the old coal dock which probably creates turbulence in the longshore current's

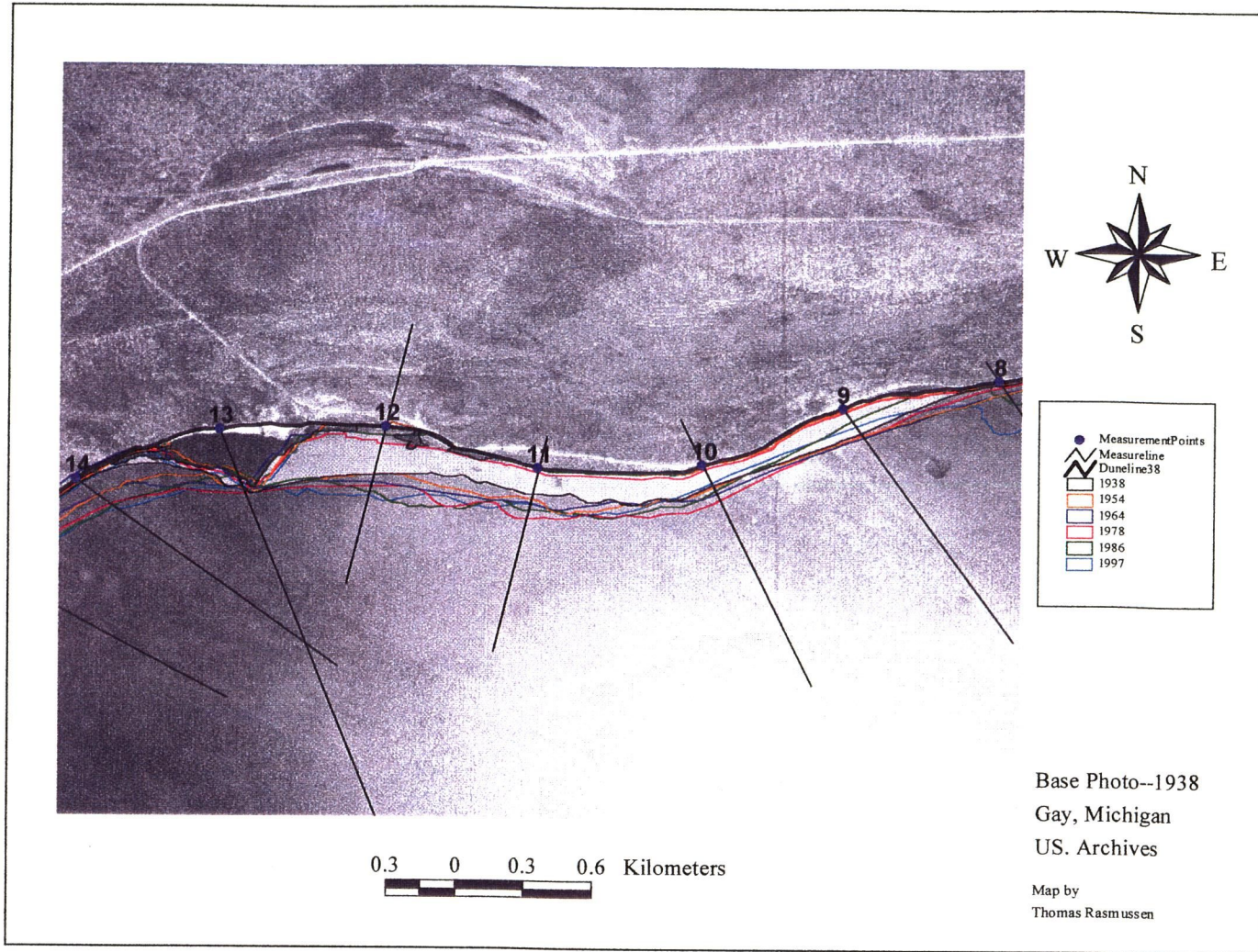


Figure 11. Section 2, Transects 9 – 13.

flow disrupting deposition of sediment. This area of relative stability quickly at 13 gives way to an area of consistent deposition and increasing width.

The third section (Figure 12) shows the area between transects 14 and 20. By transect 14 the shoreline begins an area of small but relatively consistent deposition of stamp sand throughout 1938-1997. In the 1938, photo the advance of the stamp sand is just southwest of transect 15, by 1954, it is halfway between 16 and 17, and by 1964, it is just short of 18. In the 1978 photo, the first elements of the advancing stamp sand have reached transect 20, which is the north breakwater at the Traverse River. From 1978 through 1997, the width of the stamp sand makes small but steady increases from 18 through 20. Measurement ceases at transect 20 because the stamp sand has not yet moved around the end of the Traverse River breakwater.

In summary, examination of the maps indicate that at the north end of the study area the stamp sand is decreasing in width through erosion and demonstrates general shifting of mass to the southwest. In the middle section the stamp sand alternates between increases and decreases in width. While in the south it can be observed that the stamp sand is moving southward and slowly increasing in width over the decades until southward movement is halted by the north breakwater at the Traverse River.

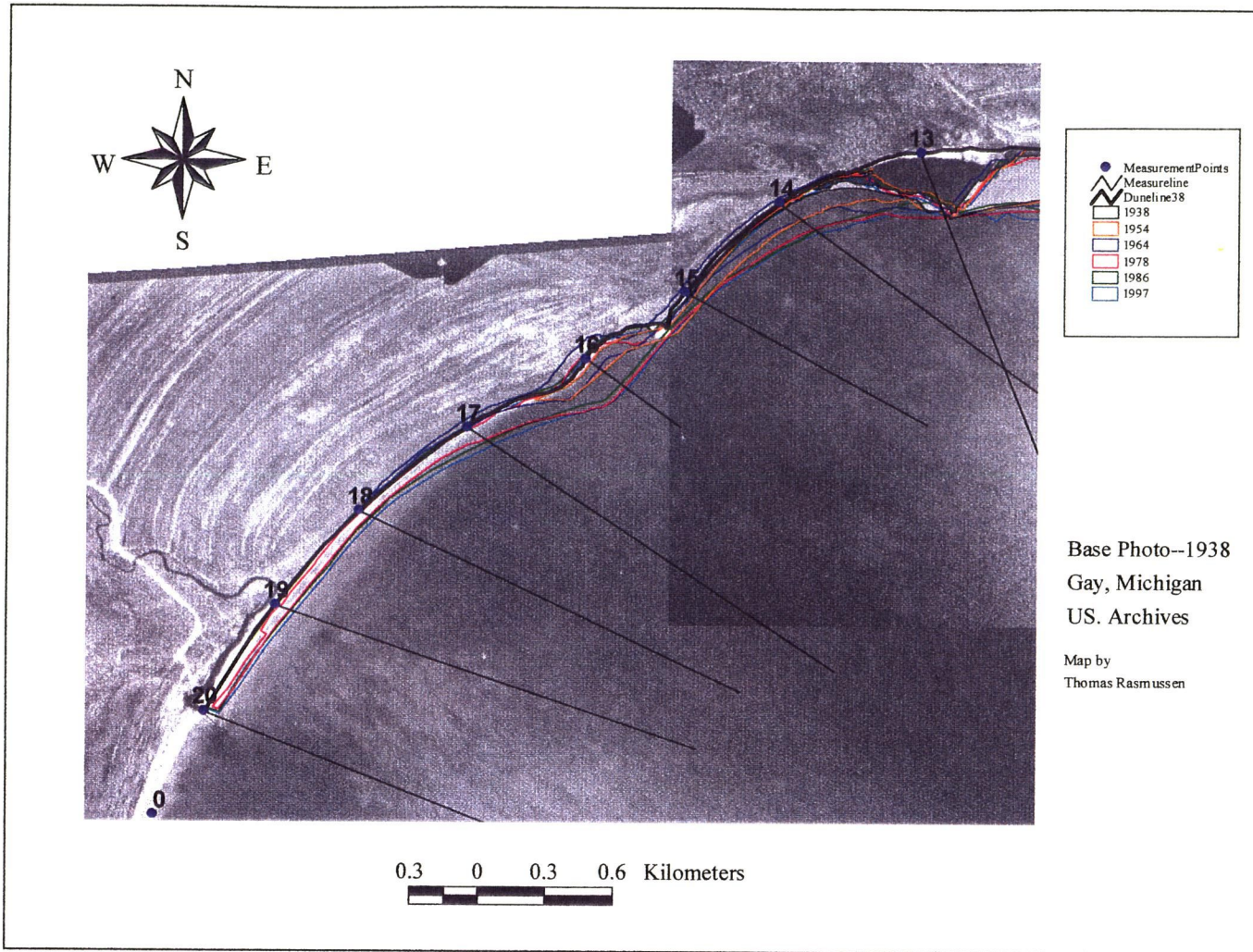


Figure 12. Section 3, Transects 14 – 20.



### Quantitative Movement by Line Graph Analysis

Figure 13 shows graphical plots of stamp sand width at each transect. These values were derived by using the “Measurement Tool” from the ArcView™ toolbar. Each transect was measured five times with the average of the five used as the value in the graph.

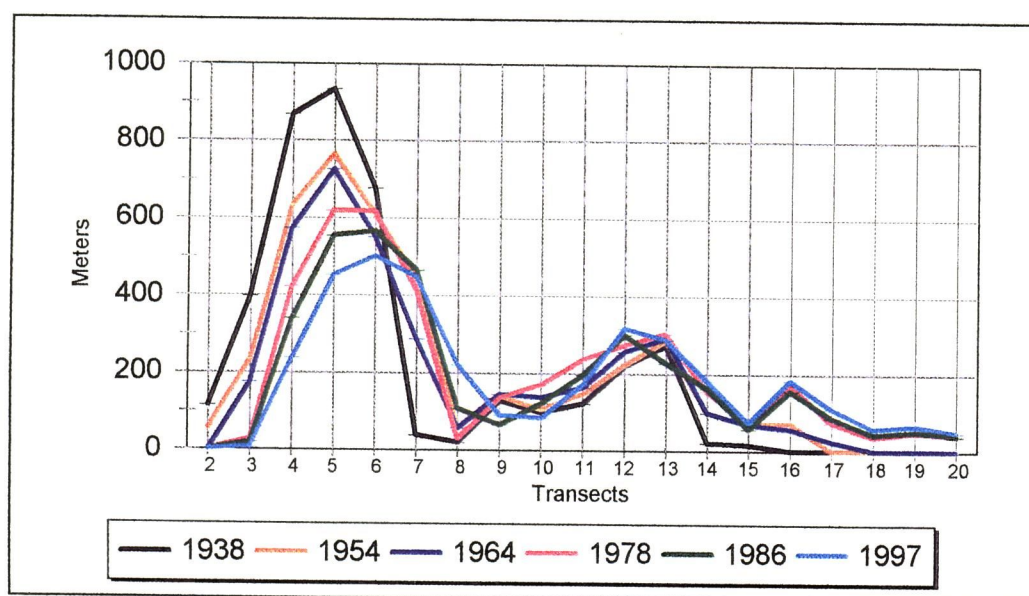


Figure 13. Stamp Sand Width.

The plots in Figure 13 quantify the observations about the stamp sand movement derived from the maps. We can observe that in the shoreline of the first section (transects 2 – 6; Figure 10) the area has been narrowing. Also, note that the main mass of stamp sand has been shifting to the right on the graph, which represents southward movement along the shoreline. It is apparent in the graph that the point of greatest stamp sand width is migrating southward also from about transect 5 toward

transect 6. Transect 8 shows the widening in 1986 and 1997 due to the southward migration of the stamp sand. In the second section, (transects 9 – 13; Figure 11) it can be seen the stamp sand is narrower in 1997 than previous years. Farther southwest at transect 12 we can see a slow increase in width while again we see at transect 13 the measurement from the original dune line to the water is relatively constant.

In the third section (transects 14 – 20; Figure 12), we can observe the southern advance of the stamp sand. In 1938, the southern-most extent does not yet reach transect 16. By 1954, the advance almost reaches transect 17, and in 1964 it almost reaches transect 18. The graph shows that by 1978 the stamp sand has arrived at transect 20, the breakwater for the Traverse River. The third section indicates that the stamp sand is not only migrating southward but also is slowly increasing in width as material is moved from the northern sections and deposited in this area.

Analysis of the graph supports the observations made directly from the maps regarding stamp sand movement. In addition, the graph reveals that the widest part of the stamp sand in the first section is moving southward.

#### Quantification of Changes in the Stamp Sand's Surface Area

It has been noted in a previous section that the maps that define the extent of stamp sand are "closed polygons." The reason the maps were constructed as such was that ArcView calculates the area enclosed by polygons. Therefore, the approximate surface area of the stamp sand was determined for each year and the totals can be compared (Figure 14). It should be noted that the particular method used for

defining the polygons that represent the stamp sand only define the area of stamp sand above the water line.

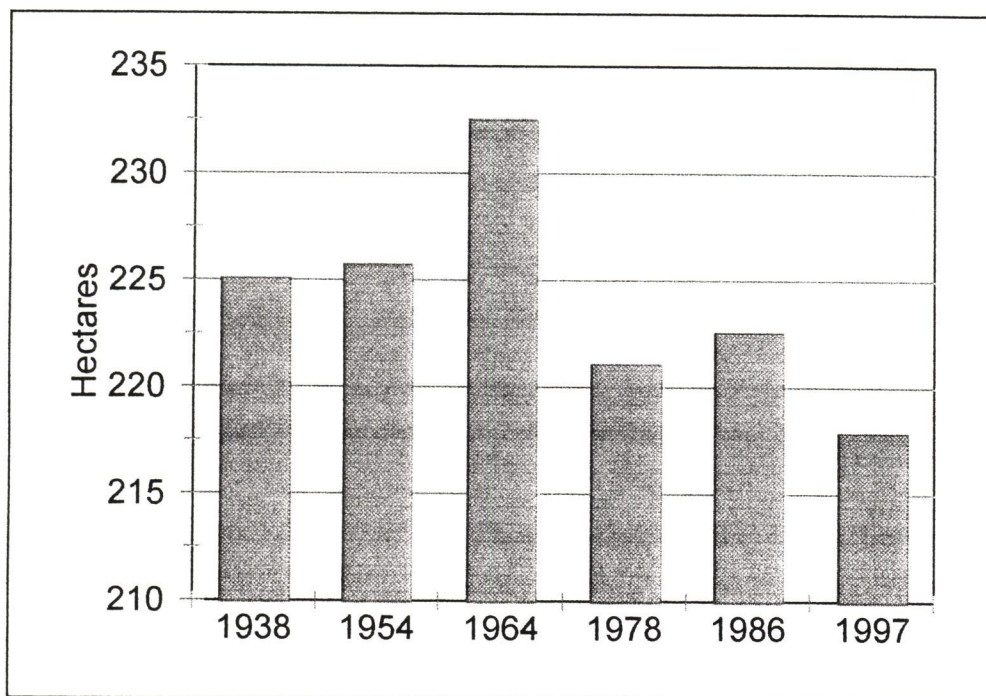


Figure 14. Area of Stamp Sand.

The initial area of stamp sand in 1938 was approximately 225.08 hectares and by 1997, the area had decreased to about 217.88 hectares. However, the change in area was not one of continuous loss. In the period from 1938 to 1964, the stamp sand experienced a slight increase in area from the 1938 base to an area of approximately 232.5 hectares gaining only about 7.4 hectares. Most of the increase occurred between 1954 and 1964.

In the fourteen years between 1964 and 1978, the surface area decreased about 11.4 hectares from the high of approximately 232.5 hectares to about 221 hectares.

This trend underwent a reversal between 1978 and 1986 with a slight increase in area of about 1.5 hectares. The downward trend resumed between 1986 and 1997 with about a 4.3-hectare decrease to the 1997 approximate of 217.9 hectares.

The fluctuations in the stamp sand's area have been relatively minor over 59 years. These fluctuations are the result of erosion reducing the stamp sand area and then depositing the sediment underwater where it cannot be detected in the air photos. After the area of deposition reaches the water surface, it can be detected again and registers as an increase in area. The current trend toward decreasing area may continue into the future or it may increase as sediment continues to accumulate and widen the area of stamp sand north of the Traverse River.

## CHAPTER IV

### DISCUSSION AND CONCLUSIONS

#### Discussion

The first goal of this research was to create a series of maps that would graphically illustrate long-term trends in the changing coastal geomorphology of the Lake Superior shoreline south of Gay, Michigan caused by the presence of massive amounts of man-made sediment. A possible problem to mapping the shoreline was limitations to the geo-referencing of the air photos imposed by large expanses of featureless spaces in them. However, this limitation did not prohibit construction of photo mosaics, which were indispensable for successfully mapping the shoreline changes.

Once mosaics were constructed, introducing them into a GIS was a straightforward process. To fulfill the second goal of the research, ArcView™ was used to delineate the extent of the stamp sand in each of the photo mosaic years. During the delineation process, ArcView™ calculated the surface area covered with stamp sand. After the maps were complete ArcView™ was utilized to construct transects across the stamp sand to make width measurements. While the map data are not adequate for evaluation of the volumes of material in motion, end users are still able to obtain useful information about changes from the maps (Stafford 1971).

The procedures demonstrated in this paper are a method of graphically representing coastal changes. Usage of these procedures would provide for useful monitoring of long-term trends in coastal change.

Monitoring coastal change is important because over 60% of the world's population lives within a few kilometers of a coastline (Pethick 1984; Viles and Spencer 1995). The coastline of any lake or ocean is a dynamic zone undergoing continual modifications due to natural processes (Viles and Spencer 1995). For example, in February 1995, at the Sleeping Bear Dunes National Lakeshore a 1,600-foot section containing more than 35 million cubic feet of sand slumped into Lake Michigan probably because of increases in fluid pressure between the grains of sand (U.S. Department of the Interior 1998). These events are large-scale occurring during a short time-span that attracts the public's attention. However, what appears in the short term to be very dynamic may exhibit characteristics that are relatively stable over the long-term thus the importance of a historical survey of changes (Pethick 1984).

Coastal monitoring can take many forms. At the Sleeping Bear Dunes National Lakeshore, the United States Geological Survey (USGS) is monitoring intergranular fluid pressure in the dunes by drilling holes and inserting piezometers (U.S. Department of the Interior 1998). During a phone conversation with Max Holden, a Sleeping Bear Dunes National Lakeshore staff member, it was noted that the USGS is also using satellite imagery to monitor change in the dunes (Holden 2000).

## Conclusions

The maps created with the procedure used in this paper will be useful for many interested parties. For the coastal engineer, the maps provide a general reconnaissance of the area. The historical sequencing of the maps show the development of shoreline features suggesting the forces at work. Identified in the maps are geomorphologic features, and sediment sources and sinks saving coastal researchers time and resources allowing them to better concentrate their efforts studying sediment transport (Komar 1976; Viles and Spencer 1995).

Maps illustrating the historical trends in shoreline change will be useful to groups other than engineers. The intuitive nature of the coastal change detection maps is such that the methodology could be used as a suitable technique for monitoring historic coastal change for a broad spectrum of users not trained in interpretation of remotely sensed data. For example, historians can use them to show the stamp sand's movement updating their information on the whereabouts of this legacy of the copper mining era. Environmentalists may find that the time-line of stamp sand movement correlates with environmental changes either past or present. The nature of this mapping highlights environmental changes that occur over periods of time great enough that they may be overlooked by the average person. Environmentalists can compare maps of stamp sand movement to locate fish habitats that are threatened, probable areas of nearshore contamination by fine fraction sediments and beaches threatened with contamination by the coarse fraction. Landowners, or those contemplating purchases of land, will find studying the geomorphologic trends in these maps

enlightening. Information gleaned from such a study may give then insight into possible long-term land value changes influencing their decisions to purchase or sell property along this shore.

The main beneficiary's of historically mapping the stamp sand's movement may well be local land-use planning commissions. Maps illustrating long-term sources and sinks of sediment might prompt local planning commissions to re-evaluate how they utilize some stretches of shoreline. Rather than having blanket regulations for shoreline construction, it may be appropriate to establish construction setbacks for particular stretches of shoreline based on historical zones of erosion or deposition. Some areas may have an erosion rate great enough that allowing residential dwellings may be unadvisable and the best use may be to reserve the area for recreational purposes.

Considering the intuitive nature of the maps produced, it is reasonable to suggest that any local governmental body wishing to study historical coastal changes could conduct a survey utilizing this methodology. An agency considering a survey would need to examine their resources, that is computer hardware, software, and personnel, to determine if it would be possible to do the survey "in house." Software and personnel costs acquiring field data, if travel time is significant, would be the major investments required. If it were decided to proceed in house, the next step would be to explore federal and state sources to locate appropriate historical air photos for the specific area. Difficulty geo-referencing the photos is a function of location. The geo-referencing for this project was accomplished with a minimum of GCPs more



developed areas would have a greater selection of possible GCPs available which would increase map accuracy and ease geo-referencing. Data processing is straightforward and personnel costs involved should not be excessive. It is recommended, for areas of a few square kilometers, that latitude/longitude not be used as the coordinate system for referencing the photos, State Plane or UTM would be superior.

#### Areas for Further Research

While examining photos of the stamp sand and observations during field trips to the area, questions arose about the stamp sand that were not addressed for this report. Researching the problems would provide a more complete understanding of the stamp sand as a system.

What is the volume of stamp sand present? Research in the 1960s tried to determine the volume present, but there was a discrepancy of several million tonnes in what was found and what was recorded in the annual stockholder's reports. The calculations were based on estimates of the density of the stamp sand per cubic yard (Babcock and Spiroff 1970). Use of modern technology such as ground penetrating radar might shed new light on the volume and the depth of the stamp sand over bedrock.

The stamp sand is different visibly and compositionally with increasing distance from the site where the conveyor was located. As one moves away, particle size visibly decreases and becomes increasingly uniform. A reliable analysis of

particle size, shape, and weight with defined precision and accuracy would contribute toward an understanding of sediment movement along the shore (Pethick 1984).

Related to particle shape is anecdotal evidence from landowners that the slope of the lake bottom at Traverse Bay is steeper with stamp sand present than it was with natural sand. A particle shape study may reveal information about the angle of repose for the stamp sand. Ground penetrating radar might reveal the original bottom slope and the slope of the stamp sand for comparison. Changes in the slope of the lake bottom affects wave energy, which in turn affects the energy available for the longshore current to transport sediment (Pethick 1984). Combined with analysis of movement based on the maps, knowledge of particle morphology and sediment transport details would lead to educated speculation about the future movement of the stamp sand.

Not only are there physical features of the stamp sand site that seem unique, during field trips the scarcity of vegetation on the stamp was conspicuous. The lack of vegetation is also noticeable in the air photos. The only photo that is different is the one from 1938 showing the shoreline area north of the village of Gay. In that photo, there is a definite growth of dune grass on areas north of the conveyor location. To the present day, south of that area, there is no vegetation other than isolated clumps of dune grass. Why do dunes and other areas of natural sand have a vegetative cover and not the stamp sand?

Defining historical trends in the movement of the stamp sand has many applications. However, there are many areas of research that need to be addressed before the stamp sand environment is understood.

## Final Observations

Analysis of the stamp sand movement indicates that it will keep moving southward toward the Traverse River's mouth. This movement can be expected to pause at the north side of the river until the width of the stamp sand beach equals the length of the breakwater. The southward movement then will continue until another barrier is encountered or the supply of stamp sand is exhausted.

It is reasonable to assume the stamp sand fine fraction is being carried offshore and the bottom of the lake may well be its final destination. The stamp sand's coarse fraction may remain close to shore and distributed along the shoreline (Kerfoot *et al* 1999). However, without sediment transport studies, core sampling, or investigation of the lake bottom by remote sensing techniques this assumption is speculation.

The presence of stamp sand does have an aesthetic impact on the area. Some people seeking to purchase lake frontage may choose other areas for aesthetic reasons. Others may find that the stamp sand is compatible or may even enhance their recreational interests and, therefore, would not consider it a negative factor in their purchasing decision. Stamp sand beaches may not attain the dollar value of pristine natural sand beaches but the recreational interests of potential purchasers are broad enough and demand great enough that lake front property should remain a profitable investment.

The methodology used here to produce the maps and analysis has been demonstrated to be relatively simple and straightforward. These data do not require

extensive remote sensing training for a user to understand. Despite limitations encountered, because of the remoteness of the area and lack of reference sites, useful data were produced indicating that this type of study should be repeatable in a variety of circumstances with little difficulty.

## Appendix A

### Chemical Analysis of Gay Stamp Sand

## Chemical Analysis of Gay Stamp Sand

Mineral	Common Name	Proportion
Cu	Copper	0.30%
Ag	Silver	0.06
SiO	Quartz	50.35
CaCO <sub>2</sub>	Calcite	7.02
MgO		4.86
Al <sub>2</sub> O <sub>3</sub>	Corundum	13.06
Na <sub>2</sub> O		5.02
K <sub>2</sub> O		0.70
FeO	Iron Oxide	2.30
Fe <sub>2</sub> O <sub>3</sub>	Hematite	10.40
MnO		0.33
TiO		1.88
P <sub>2</sub> O <sub>5</sub>		0.201
S	Sulfur	0.016
	Volatile Compounds	3.11

Babcock, L.L. and K. Spiroff, "Recovery of Copper from Michigan Stamp Sands, Vol. 1." Michigan Technological University, 1970.

Appendix B

Field Collected Ground Control Points

## Field Collected Ground Control Points

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Site	Longitude	Latitude	Elevation
Gay01	88° 14.372' W	47° 11.754' N	181.8 m
Gay02	88° 14.030' W	47° 11.686' N	181.5 m
Gay03	88° 14.204' W	47° 11.383' N	180.9 m
Gay04	88° 14.406' W	47° 10.994' N	181.5 m
Gay05	88° 14.495' W	47° 11.897' N	183.9 m
Gay06	88° 14.555' W	47° 12.911' N	189.0 m
Gay07	88° 12.708' W	47° 13.239' N	190.5 m
Gay08	88° 12.002' W	47° 13.418' N	190.8 m
Gay09	88° 09.880' W	47° 13.497' N	195.9 m
Gay10	88° 09.782' W	47° 13.644' N	195.9 m
Gay11	88° 09.727' W	47° 13.831' N	190.5 m
Gay12	88° 10.262' W	47° 13.250' N	198.9 m
Gay 13	88° 11.222' W	47° 14.709' N	208.2 m

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Appendix C  
Width Measurements

## Width Measurements

Transect	2	3	4	5	6	7	8	9	10	11
1938	114	397	868	934	677	038	019	128	097	121
1954	055	234	633	765	609	443	057	138	104	144
1964		175	573	726	561	288	057	144	136	162
1978		027	422	619	616	412	029	135	169	235
1986		018	341	554	565	466	107	065	121	196
1997		005	238	453	502	448	221	090	083	170

Transect	12	13	14	15	16	17	18	19	20
1938	219	273	021	015					
1954	222	285	097	067	072				
1964	256	291	099	068	056	025			
1978	273	304	154	069	171	073	036	048	040
1986	301	227	161	056	155	086	043	051	042
1997	317	288	182	073	183	110	058	066	049

All Distances are in Meters

Appendix D  
Area of Stamp Sand

## Area of Stamp Sand

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	Hectares	Sq. Km	Acres	Sq. Miles	Sq. Yards
1938	225.08	2.1788	562.69	0.8792	2,723,440
1954	225.74	2.1852	564.36	0.8818	2,731,506
1964	232.49	2.2505	581.24	0.9082	2,813,179
1978	221.06	2.1399	552.65	0.8635	2,674,832
1986	222.58	2.1546	556.45	0.8695	2,693,209
1997	217.88	2.1091	544.70	0.8511	2,636,355
Avg.	224.14	2.1697	560.35	0.8756	2,712,087

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