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Air Photo Survey of Coastal Erosion

The use of aerial photographs to conduct a reconnaissance over a long section of coast represents an efficient and economical procedure.

Introduction

Data on coastal erosion trends constitute one of the basic prerequisites for the proper planning of coastal development and the design of coastal facilities. The beach is a transient feature and this fact must be fully considered in locating either residential or commercial development in coastal areas. Information on coastal erosion trends is necessary and must be used properly if coastal development is to be planned, designed, and constructed with due regard for the changing beach, with adequate safety, and in the most economical manner from the standpoint of all concerned.

Abstract: *A procedure to utilize existing aerial photographs to conduct a survey of coastal erosion is evaluated. The procedure consists of selecting stable reference points on aerial photographs taken in different years and measuring the distance between these points and points on the transient beach. The measurements obtained are multiplied by the scale of the aerial photographs to produce ground distances. The differences in ground distances determined from aerial photographs taken with several years of time lapse represent the change in location of the beach over the period of the time lapse. The aerial photographic approach has several important advantages as well as limitations. Illustrations are included of the type of erosion data obtained in a survey of coastal erosion along the 330 miles of North Carolina coast.*

Unfortunately, in the past adequate data on coastal erosion have not been readily available and the necessity for using the meager data that were available was not realized. The experiences of the past 20 years have shown that disregard for the transient nature of the beach can have serious economic consequences. These have appeared as property losses to both private owners and the public as a result of storm damage and long-term erosion, financial losses to coastal resort businesses as a result of the loss of the recreational qualities of the beach, and the expense to both private individuals and the public of providing protective structures to prevent damage to coastal facilities or attempting rehabilitation of damaged structures and beaches. Past economic losses could have been decreased considerably, but certainly not eliminated, if coastal erosion data had been used intelligently in planning past coastal development. Unfortunately, data on coastal erosion trends which would be adequate for use in planning coastal development do not exist in many areas of the United States.

The collection of accurate data on coastal erosion is not a simple task. Existing methods of collection typically employ extensive field measurements which are very expensive, or they rely on the analysis of historical observa-

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tions that may be of questionable accuracy. Attempts to use erosion data obtained from field survey methods encounter the serious problem of extrapolating results obtained from short-term field observations into long-term erosional trends. The use of historical observations is limited by the fact that the observations that would be ideally suited for making accurate determinations of changes in the beach were not made in the past because the need for them was not recognized. Regardless of whether the field survey method, the historical observation procedure, or some combination of the two techniques is utilized, the data collection process requires considerable time, effort, and expense.

Starting with a realization of the serious problems associated with the existing methods of coastal erosicn data collection, a search was conducted for a less expensive and less time-consuming procedure to use in conducting a survey of erosion along the 330 miles of North Carolina coast. The primary means selected to obtain data on coastal erosion was a comparison of beach location on existing aerial photographs. The detailed procedures to be followed in utilizing aerial photographs to collect coastal erosion data were developed and evaluated by studying the coast of two counties in North Carolina. Upon encountering success in the initial study, the procedures developed were subsequently used in conducting a survey of coastal erosion along the entire 330 miles of North Carolina Coast. The technique was found to be a very effective and efficient means of collecting information on coastal erosion trends over an extensive section of coast line.

Advantages and Disadvantages of using Aerial Photographs

The unique characteristics of aerial photographs enable them to serve as an ideal means of collecting coastal erosion data and provide the aerial photographic approach with several advantages over other possible methods. Most importantly, aerial photographs permanently record the location of the beach at the time the aerial photographs were taken. Therefore, where the existing aerial photographic coverage extends over a sufficiently long period of time, studies of long-term coastal erosion trends can be undertaken by comparing the historical records of beach location contained in the aerial photographs.

The photographic record is better than a map or chart because the photograph captures an almost infinite amount of ground detail in contrast with maps or charts which show only selected detail, all of which has been subject to human interpretation. The advantage of the large amount of detail recorded on aerial photographs was illustrated in an investigation of shore line changes at Cape Hatteras, North Carolina, conducted by Athearn and Ronne (1963) where a small area barren of vegetation appearing on aerial photographs was used to reference the beach location over a 17-year period. This area would not have been shown on maps or charts even if they had existed.

Another advantage of using aerial photographs to study coastal erosion is that the coastal areas of the United States have been photographed more frequently in the past 30 years than maps or charts have been compiled. The fact that the only field work required in making aerial photographs for pictorial purposes is the photographic mission has permitted frequent photographing of coastal areas without excessive cost. The fact that coastal areas have been photographed by different federal and state governmental agencies for several different purposes insures that aerial photographic coverages exist at frequent intervals. For example, the majority of the North Carolina coast has been photographed at intervals of about five years since 1949 and one 10-year interval between 1938 and 1949 exists for most of the coast. These multiple coverages allow at least four increments of change to be measured over the past 30 years. This is much better than can be accomplished by comparing maps and charts. The four increments of change measured over a period of 30 years cover a sufficiently long time span that long-term erosional trends can be determined and also insure that shorter-term trends are likely to be discovered.

Using aerial photographs to conduct a coastal erosion survey is more economical than field survey methods because the work can be done in the office and less labor is required. The elimination of the expense of field survey parties and the need to establish and maintain permanent reference markers in the field provides the aerial photographic approach with an important economic advantage over field methods. The largest expense, other than labor, is the cost of the aerial photographs. The index sheets, contact prints, and enlargements of the existing aerial photographs needed to conduct a survey of erosion can be obtained for approximately 15 dollars per mile of coast line. This is a rather small cost compared to the cost of field surveys.

The use of aerial photographs to study long-term coastal erosion is not without disadvantages or limitations. One disadvantage of relying solely on the comparison of aerial photographs to determine beach changes is that the changes are subject to errors caused by the fact that the photographs record beach conditions and locations existing at a specific time that may not be typical of mean conditions. The essence of the problem is that aerial photographs record the beach location and conditions obtained by taking one sample of the transient beach location. This appears to be a serious problem in view of the known fact that beaches undergo cyclic seasonal changes and are also sensitive to environmental conditions and factors such as storms. The fact that aerial photographs represent spot observations that may not record typical conditions is made less serious by the favorable times in which photographic missions are usually made.

With the exception of aerial photographs taken especially to survey storm damage, existing photographs have been taken most commonly during the fall or spring when foliage was absent from the trees. This leads to a degree of stability because fall and spring conditions usually approximate the average beach location. In an investigation of long-term changes, the problem caused by the recording of abnormal conditions on the aerial photographs due to seasonal or monthly variations would not be as serious as it would be in a survey of short-term coastal erosion or a detailed study of coastal geomorphology. In long-term coastal erosion studies, the effects of seasonal variations would be overshadowed by any significant erosion that had occurred. However, the possibility of seasonal variations causing an erroneous change to be computed for essentially stable beaches exists. The problem of seasonal variations in beach location is also encountered in conventional coastal erosion surveys that rely on short-term field surveys. Indeed the problem is probably even more critical in this instance because the results obtained from short-term field surveys are usually extrapolated into long-term trends.

A limitation of the coastal erosion data obtained from aerial photographs is that only horizontal changes in beach location and areas of change can be determined and not volumes of materials eroded or accreted. Volumes of material involved in coastal changes are not necessary in a reconnaissance survey of coastal erosion but in more detailed coastal engineering studies to remedy erosion effects, the volume of material being transported is an important characteristic. The volume of material can best be computed by comparison of beach profiles obtained from field surveys that include the nearshore areas. In the absence of field survey data of beach profiles, an empirical relationship that one foot of beach erosion perpendicular to the beach is equivalent to one cubic yard of material per linear foot of beach has been used (U.S. Army Corps of Engineers, 1964).

Tanner (1961), in a study of beach changes determined from aerial photographs of a section of the west coast of Florida, assumed a constant depth of five feet for each square foot of eroded or accreted area to convert areas of change to volumes of material. The validity of these empirical relationships for general usage has not been firmly established. The use of an empirical relationship to convert areas of change to volumes of material is the only feasible alternative if volumes of material must be computed from coastal erosion data obtained by aerial photographic techniques. However, an analysis to determine an accurate relationship that might be applicable in the specific area under investigation would be advisable. Although a photogrammetric technique utilizing a plotter could be developed to determine volumetric changes in the beach, such an approach is not economically feasible for using historical aerial photographs in the analysis of long stretches of beach.

One other problem encountered in using aerial photographs is the inherent errors that exist in the photographic image. The most important errors are scale variations between photographs caused by altitude variation of the photographing aircraft, scale variation within photographs caused by camera tilt at the instant of exposure, and relief distortions caused by elevation differences within the terrain depicted on the aerial photographs. The first of these errors, scale variation between photographs, must be overcome if accurate results are to be obtained in the measurements made on the photographs. The problem of the inherent photograph errors is especially critical in the situation in which a comparison of measurements made on different aerial photographs constitutes the primary item of interest because scale variations and relief distortions can produce differences in the measurements between the stable reference points and the beach which do not really exist. Fortunately, a study procedure can be designed to eliminate or minimize the detrimental effects of the inherent errors. The steps necessary to overcome these errors will be discussed in the section on study procedure description below.

Description of the North Carolina Study

UTILIZATION OF PREVIOUS STUDIES

The idea of using aerial photographs in the study of coastal features and coastal processes is not a new concept. The literature contains a large number of reports in which aerial photographs were used to some extent in investigations of coastal conditions, although the literature is scattered throughout several subject areas. In many of the reports that have appeared, aerial photographs were used primarily as graphic display tools. In other studies qualititative interpretation of aerial photographs was used in the analysis of the coastal problem under consideration. Many reports describing coastal studies in which quantitative data were extracted from aerial photographs were consulted in the process of developing the procedure to be used in the study of coastal erosion along the North Carolina coast.

Several important aspects of the previous studies were incorporated into the study procedure. The more important studies that contributed to the development of the North Carolina study procedure were conducted by Chieruzzi and Baker (1958), Tanner (1961), Waugh (1962), El-Ashry (1963 and 1966), Athearn and Ronne (1963), Sonu (1964), Harris (1964), El-Ashry and Wanless (1965 and 1967), Plusquellec (1966), and Gawne (1966). A significant study in which aerial photographs were used as historical records in investigating changes in a short section of the shore line of Monterey Bay in California has been reported recently by Moffitt (1969). A detailed review of the literature on the applications of aerial photographs to coastal studies has been presented by Stafford (1968).

DESCRIPTION OF THE STUDY PROCEDURE

The initial step in the study procedure was the determination of the number of coverages of aerial photographs available from all sources. This was an important phase of the study because the availability of aerial photographs determines to a large extent the success of the aerial photographic approach to measuring coastal changes. When the study was initiated, it was believed that one of the primary limitations of the aerial photographic approach would be the limited availability of existing aerial photographs. However, this was found not to be true as more existing aerial photographs were subsequently located than could be purchased and properly utilized in the study.

The first effort made to compile a list of available aerial photographs was to contact the federal governmental agencies that maintain records of existing aerial photographs and also state agencies that were likely to have some knowledge of available aerial photographs. Correspondence and personal contact with a number of agencies revealed that aerial photographs of the North Carolina coast could be obtained from the Agricultural Stabilization and Conservation Service (ASCS) and the Soil Conservation Service of the U.S. Department of Agriculture, the U.S. Coast and Geodetic Survey, the Map Information Office of the U.S. Geological Survey, the Wilmington District Office of the U.S. Army Corps of Engineers, the National Park Service of the Department of the Interior, and the Photogrammetry Department of the North Carolina State Highway Commission. The aerial photographs held by ASCS and the North Carolina State Highway Commission proved to be the most extensive and most suitable for use in the coastal erosion study.

After all available aerial photographs had been located and information on their pertinent characteristics had been obtained, index sheets were purchased from the respective agencies for use in determining the individual aerial photographs that were needed to provide the desired coverage of the beach. The index sheets were used subsequently to order the contact print aerial photographs that permitted stereoscopic viewing of the beach, and in some instances the prints were used in making measurements of changes in beach location.

The index sheets and other supplemental data were used to order rectified enlargements and scaled enlargements where such prints were available. The enlargements were obtained in an effort to fulfill a specific aim in the development of the aerial photographic approach to measuring beach changes; the minimization of the effects of the inherent errors in the aerial photographs. The variation in scale of individual photographs from the nominal scale was overcome by using ASCS photographic enlargements that had been produced by a variable amount to produce a known uniform scale, or by computing the scale of individual photographs from measurements on the photograph and other photographs of known scale. In the limited areas where rectified enlargements prepared by ASCS were available, these photographs were used in making measurements of beach change because errors due to both tilt and scale variations between photographs had been removed. Where rectified enlargements were not available and errors caused by tilt

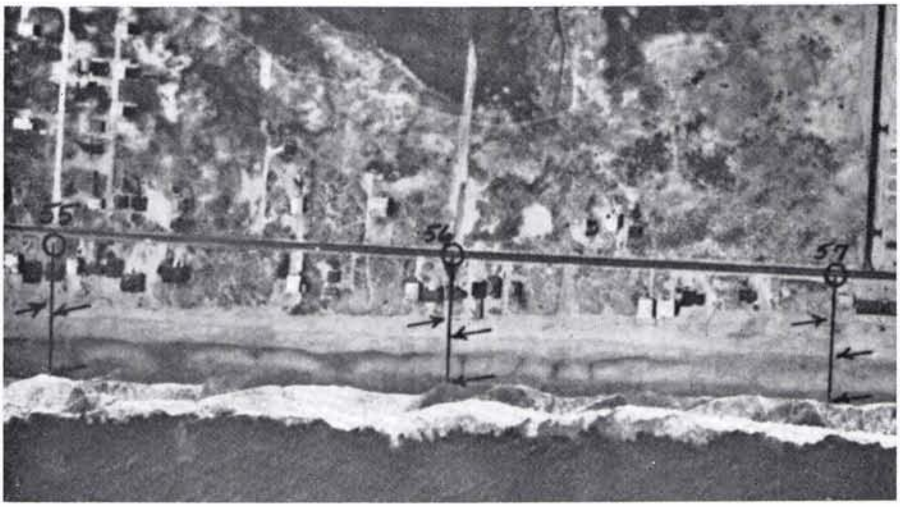

FIG. 1. A portion of a large-scale contact print aerial photo showing selected reference points and associated measurement points at the dune line, high-water line, and water line with arrows pointing to pricked measurement points.

of the aerial camera could not be eliminated, the tilt errors were accepted and were found to have a minor effect on the values of coastal change obtained. Although the errors in the aerial photographs due to relief distortions could not be removed, certain precautions were taken in developing the study procedure to insure that the effects of such errors on the study results would be minimal. The precautions consisted of avoiding the use of any tall objects or terrain features in making measurements on the aerial photographs and of using the overlapping portion of the photographs to avoid measurements near the edges of the photographs. Considering the low relief existing along the North Carolina coast, the effects of relief distortions are probably insignificant.

The next phase of the study procedure was the selection of stable points to reference the location of the transient beach. The same stable reference points were located carefully on two photographs (taken on different dates) that were being compared so that differences in ground distances between the reference points and points on the beach would reflect changes in beach location. Objects having sharp, well-defined images on the photographs were desirable as reference points because the points could be located accurately and quickly on both photographs. The reference points were defined by a pin prick in the aerial photograph and circled with a colored pencil for ease of location. The reference points were numbered sequentially from the south or west county boundary so that each point could be identified by a unique number. Figure 1 is a portion of a large-scale aerial photograph of the beach that illustrates several reference points that have been marked and numbered.

The horizontal spacing of the reference points along the beach was chosen so that the frequency of measurement was sufficiently large to give ample sampling of the beach changes but not so large that making the measurements would require an inordinate amount of time and labor. A spacing of approximately 1000 feet was selected as a compromise between a close spacing desired from an accuracy standpoint and an infrequent spacing desired from an economy viewpoint. The actual spacing was approximate because well defined reference points could not always be located at exactly 1000 feet intervals. Along the entire North Carolina coast, approximately 1400 reference points were located for measuring beach changes for each pair of dates for which a comparison of beach location was made on the aerial photographs.

The next phase of the study procedure was the selection and marking of the points on the beach to which measurements were to be made. Measurements were made from the reference points to the dune line and the high-water line because each has characteristics that make one more suitable than the other as a measure of beach changes in some sections of coast. Of the two, the high-water line is applicable to a wider range of conditions of coastal development and type of coast and is generally a more adequate and accurate measure of erosional trends.

The dune line is the furtherest inland and appears as a topographic break or scarp between the wind and/or wave deposited sand dunes and the seaward sloping beach. Stereoscopic viewing of the photographs is generally required to locate the dune line. The dune line is significant as an indicator of erosional trends because of the protection against wave damage and flooding offered by the sand dunes. One problem encountered in using the dune line as an indicator of coastal changes is that the dune line erodes more easily than it accretes, particularly during major storms. This problem results from the fact that erosion of sand dunes by wave action occurs easily and rapidly whereas the opposite process, accretion, occurs slowly because of the slow rate of the dune building process. Another problem associated with the use of the dune line is that the dune line cannot be used effectively as an indicator of coastal changes in the limited areas where the dune line is extremely low or completely nonexistent. In these areas, the dune line cannot be located accurately on the aerial photographs and some other line must be used to reflect changes in beach location.

The high-water line is depicted by a change in color or gray tone on the aerial photographs. The difference in gray tone is caused by differences in water content of the sand on each side of the high-water line with the seaward side having a darker tone than the area inland from the high-water line. The high-water line reflects erosion and accretion equally well and is a better measure of change in beach location than the dune line in areas where the dune line is difficult to locate on the aerial photographs. Complications such as the fact that the water line actually is formed at the limit of the variable wave runup on the sloping beach and that wind tides affect the high-water line location do exist in the use of the high-water line but these problems cannot be eliminated and their small effects must be accepted.

Another possible line that could be used to measure coastal changes is the water line or the land-water boundary which is also shown by a variation in gray tone on the aerial photographs. If this line is used, a correction must be applied to remove the effects of tidal stage. Computations and application of the tidal stage correction factor for data obtained in early stages of the investigation indicated that change data developed from measurements made at the water line were not consistent with dune line and high-water line change data. Generally, the water-line change data exhibited a higher degree of variability, as measured by the standard deviation, than did the data obtained at the dune line and high-water line. The higher degree of variability is due to variable wave runup on the beach, difficulty in delineating the water line on the aerial photographs, and the fact that the beach slope varies within a section of beach whereas a constant value was used for computing the tidal stage correction factor. Furthermore, an evaluation of the additional data obtained by using the water line revealed that the minimal value of the additional information did not justify the expenditure of the additional effort necessary to compute changes in the water line, particularly in view of the necessity for computing the tidal-stage correction factor and the doubtful accuracy of the correction factor. Consequently, further attempts to use the water line as a measure of beach change were abandoned.

The points along the transient beach to which measurements were to be made were defined by pricking the aerial photograph at the points where the dune line and high-water line intersected a line drawn from the reference point perpendicular to the beach. Where minor changes in orientation of the beach occurred during the time interval between the exposure of two aerial photographs being compared, the measurement points were always located along a common line from the reference points to the beach although one of the lines was not perpendicular to the beach. This practice was used so that differences in ground distances along the line would reflect changes in the location of the dune line and the high-water line. Figure 1 shows several points selected at the dune line, high-water line, and also the water line on a large scale aerial photograph.

The distance between the reference points and the points located along the dune line and high-water line was measured with a patented Microrule (Theo. Altender and Sons) which allowed the distance to be read to the nearest 0.001 inch. The measurements were recorded on a specially designed data sheet along with other pertinent data such as the scale and date of each aerial photograph being used to make a comparison of beach location. The data sheet was designed to facilitate transfer of the data to punch cards for input to a computer program. Each line of the data sheet contained the data necessary to compute the change in the dune line and high-water line at one reference point as reflected by a comparison of two aerial photographs showing a common area of beach. Each line of data on the data sheet was placed on one punch card to serve as input to the computer program.

A computer program was written that would perform the computations necessary to compare the location of the dune line and high-water line on two aerial photographs taken at different times and compute the changes in location over the time interval between exposure of the two aerial photographs. The computations necessary to convert the measurements to changes in the dune line and high-water line were highly repetitive and suited ideally for solution by digital comcomputer. The program was written in the Fortran language and was adaptable to either the Model 30, 40, or 75 versions of the IBM System/360 computer.

The computer program read a card containing the measurement data and aerial photograph data and calculated the difference in the location of the dune line and high water line over the elapsed time period. Also, the rates of change in the dune line and high-water line were computed by dividing the difference in beach location by the time interval between exposure of the two aerial photographs being compared. The program also computed the land areas lost by erosion and gained by accretion of the dune line and high-water line by assuming that beach changes varied linearly between reference points.

At various locations within a county such as an inlet interrupting the beach or where changes in erosion characteristics were expected, the program summarized the data for the immediately preceding section of beach and computed certain values and data summaries that characterized the changes in the section of beach. The program computed the mean change and mean rate of change in the dune line and high-water line and the standard deviations of the individual changes and rates of change computed at the reference points in the section of beach. The mean values serve to typify changes within the sections of beach whereas the standard deviations provide a measure of the variability of the beach change values computed at the reference points within a section of beach where the program compiled data summaries.

DEVELOPMENT AND APPLICATION OF THE STUDY PROCEDURE

Two coastal North Carolina counties, Onslow and Carteret, were used initially in developing and testing the study procedure. These two counties were chosen because they exhibited variations in type of coastal development, coastal physiography, and type of aerial photographic coverage that were typical of the various conditions found along the North Carolina coast. The primary reason for taking this approach was the assumption that if a study procedure could be developed that was suitable for use in Onslow and Carteret Counties, the procedure would be universally applicable in all of the coastal North Carolina counties and indeed in most coastal areas; they contain approximately one-third of the total coast line of the state. The study procedure described previously is the end result of an evolutionary development which occurred during the process of obtaining the coastal erosion data in Onslow and Cateret Counties. A detailed description of the coastal erosion data produced by the aerial photographic technique in Onslow and Cateret Counties has been presented by Stafford (1968).

Upon encountering success in the initial study in two counties, the aerial photographic approach subsequently was applied to the remaining portions of the North Carolina coast on a county-by-county basis. A county unit of study was chosen because aerial photographic coverage generally varied by county. The changes in the dune line and high-water line were determined for several time increments during the period of aerial photographic coverage. Table 1 shows the dates of the aerial photographs used in the study of the North Carolina coast. For the majority of the North Carolina coast, four increments of change were measured while only three increments of change were measured in limited portions of the coast because of incomplete coverage or unavailability of aerial photographs having the proper scale or date.

TABLE 1. DATES OF AERIAL PHOTOGRAPHY USED IN THE NORTH CAROLINA STUDY.

County	*Dates of Photography*				
Brunswick	1938	1949	1956	1961	1966
New Hanover	1938	1949	1956	1960	1966
Pender	1938	1949	1956	1961	1966
Onslow	1938	1949	1956	1960	1964
Carteret					
Southern Section	1939	1953	1958		1964
Eastern Section	1945*	1955	1958	1960	1962
Hyde	1945*	1953*	1956	1959	1962
Dare	1945*	1949*	1955	1958	1962
Currituck	1952	1955	1958	1961	1965

* Indicates Partial Coverage

The mean incremental changes in the dune line and high-water line determined for each section of beach were conbined to produce composite changes which reflect the total or net changes that occurred over the total period of aerial photographic coverage. The composite changes were divided by the total time interval to develop mean composite rates of change that reflect the net rate of change in the beach location over the entire period of study.

EXAMPLE COASTAL EROSION DATA

Due to the space limitations, only an example set of coastal erosion data can be presented herein. The primary items of data produced by the study procedure are the incremental mean annual rates of change and the composite mean annual rates of change obtained by combining the incremental values. Of the two types of data, the composite mean annual rates of change are most important because they more accurately reflect the long-term changes that have occurred. By using the net or total change that occurred over the entire period of aerial photographic coverage to compute the composite mean rates of change, a realistic estimation of the long-term erosion rate can be obtained.

An example set of the composite mean annual rates of change is presented in Figure 2. The data cover the section of the North Carolina coast contained in New Hanover and Pender Counties. The rates of change at both the dune line and high-water line are shown. The numerical values are the composite mean annual rates of change for a series of reference points. Erosion rates are positive and are shown above the base line whereas accretion rates are negative and are shown below the base line in solid black. It is interesting to note that the Wrightsville Beach area has experienced a net accretion due to the artificial dunes and berm that were constructed recently. However, as was true for the North Carolina coast as a whole, erosion was definitely the predominant process.

The incremental mean annual rates of change also represent a significant part of the study results. The incremental rates of change show the extent of variation in the rates of change during different periods throughout the period of aerial photographic coverage. These data give an indication of the degree to which the rates of change deviate from the long-term average, an indication which may be very important in coastal planning.

The incremental mean annual rates of

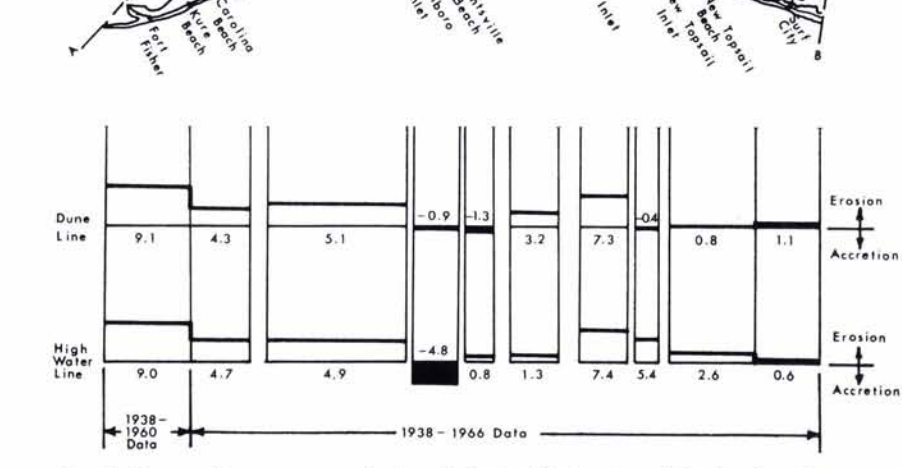

FIG. 2. Composite mean annual rates of change (feet per year) in the dune line and high-water line in New Hanover and Pender Counties, North Carolina.

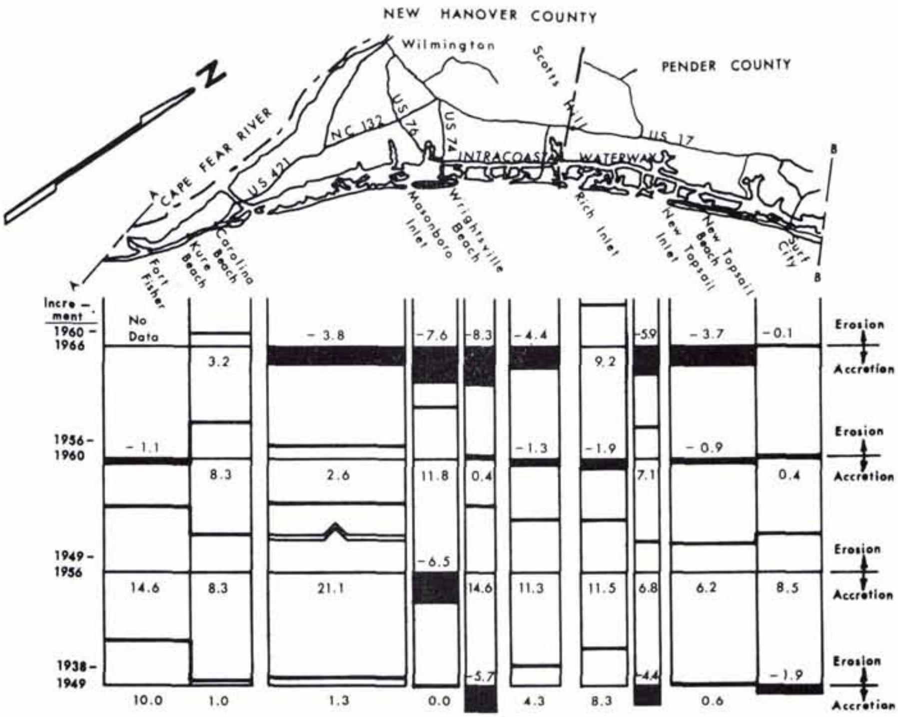

FIG. 3. Incremental mean annual rates of change (feet per year) in the dune line in new Hanover and Pender Counties, North Carolina.

change in the dune line for the section of the North Carolina coast included in New Hanover and Pender Counties is presented in Figure 3. The incremental data show that there is a large amount of variation in rates of change during the four time intervals. One significant factor shown by the incremental mean annual rates is that the highest erosion rates occurred during the 1949–1956 time increment, a period when several severe hurricanes struck the North Carolina coast. The incremental mean annual rates of change for some other sections of the North Carolina coast illustrated this tendency more dramatically than the data in New Hanover and Pender Counties.

Another type of data produced by the study procedure was a tabular county summary of mean changes and mean rates of change in the dune line and high-water line for each time increment and the composite period. The county summary for New Hanover County is shown in Table 2. The data represent the mean values for the changes and rates of change at all reference points in the county. The county summary data also illustrates the high erosion rate during the 1949–1956 time interval when hurricanes were frequent. The predominance of erosion rather than accretion was indicated by an analysis of the county summaries for all eight coastal North Carolina counties which showed the composite mean annual change in the dune line and high water line to be erosion in all instances except one. The exception was the dune line in Hyde County which was affected by the National Park Service program of building dunes on Ocracoke Island.

Another type of data generated in the study but not included herein was area change values, which were also compiled in a tabular county summary. These county summaries show the area changes and rates of area change at the dune line and high-water line for each increment of time and the composite period. The total areas of erosion, accretion, and net change in the county were computed. The composite period net changes were erosion in all counties except Hyde County.

A complete presentation of the coastal erosion data obtained in Onslow and Carteret Counties has been presented by Stafford (1968). Another report by Langfelder, Stafford, and Amein (1968) presents the coastal erosion data obtained for the entire 330 miles of North Carolina coast.

TABLE 2. SUMMARY OF CHANGES IN THE DUNE LINE AND HIGH-WATER LINE IN NEW HANOVER COUNTY.

	Rates of Change (feet/year)		
Increment	*Time Interval (years)*	*Dune Line Mean Rate*	*High-Water Line Mean Rate*
1960–1966	5.3	−3.2*	−1.2*
1956–1960	4.7	3.3	1.2
1949–1956	6.4	13.3	7.9
1938–1949	11.6	2.8	3.9
Composite 1938–1966	28.0	4.2	3.4
	Total Changes (feet)		
Increment	*Time Interval (years)*	*Dune Line Mean Change*	*High-Water Line Mean Change*
1960–1966	5.3	−16.8*	−6.0*
1956–1960	4.7	15.8	6.1
1949–1956	6.4	86.5	51.5
1938–1949	11.6	31.1	43.7
Composite 1938–1966	28.0	116.6	95.3

* Negative values denote accretion

EVALUATION OF THE STUDY PROCEDURE ACCURACY

An additional phase of the investigation that was conducted using the Onslow and Carteret County data was an attempt to evaluate the accuracy of the results obtained from the study procedure. Although it was found to be impossible to separate the error contributed by the aerial photographs from the error resulting from the measurement process, it was possible to determine the composite error produced by both sources.

A rather unique method of evaluating the composite error was devised in which a series of reference points consisting of stable images and associated error measurement points were selected on comparative aerial photographs. Two points were selected at each reference point in the error evaluation study so that the process would be analogous to the selection of the dune line and high-water line in the actual study procedure. However, in the error evaluation study, the measurement points were stable images rather than transient points on the beach. By making measurements between common reference points and common stable measurement points as imaged on two different aerial photographs of the same area and converting the measurements to ground distances, it was possible to determine the difference (error) in ground distance that was caused by aerial photograph and measurement error on the two photographs being compared. The difference represents the composite error present in the study procedure.

An analysis of the error data showed that the composite error increased as the degree of control of the inherent error in the aerial photographs decreased. Rectified enlargements were found to have the smallest composite error, scaled enlargements produced an intermediate amount of composite error, and contact prints generated the largest composite error. For a particular type of aerial photograph, the composite error increased with decreasing scale as measured by a representative fraction because a given measurement error on the photograph produced a larger difference in ground distance.

The error data analysis also indicated that the composite errors were roughly randomly distributed rather than biased in such a manner as to have a consistent sign. Although the magnitude of the error was rather large in some instances, it was noted that the mean of the composite differences was very small. This indicated that, although the value of change in beach location at a particular reference point may be in error by a significant amount due to composite error, the mean value of coastal change over a section of beach is not likely to be affected appreciably by composite error. Consequently, the composite error was concluded to be sufficiently small so as not to have a detrimental effect on the study results expressed by mean beach location changes as long as adequate care was taken in the measurement process and provided that the most accurate type of aerial photograph available in a particular area was used.

CONCLUSIONS

The use of aerial photographs to conduct a reconnaissance of coastal erosion over a long section of coast represents an efficient and economical procedure. Given the sufficient number of aerial photographic coverages that exist for most areas along the eastern United States coast, the procedure described herein provides a means of obtaining detailed data on the changes that occurred in a coastal area over the period of aerial photographic coverage. The procedure has been used to conduct a reconnaissance of coastal erosion along the entire 330 miles of North Carolina coast and was found to be quite satisfactory. The study procedure requires a minimum amount of labor and expense for the extensive amount of coastal erosion data that are generated. The aerial photographic approach produces data which are indicative of both long-term changes and short-term changes in the beach location.

Regarding the data obtained along the North Carolina coast, it was found that considerable variability existed in the rates of change that have been experienced by different sections of coast and also during different time periods within a particular section of coast. The predominant process is erosion although accretion has occurred along some limited sections of the coast. The data also indicate that major storms play an important role in determining the rates of change in beach location.

There are many other coastal engineering investigations that can benefit from the use of aerial photographs. Due to the transient nature of many coastal landforms, historical aerial photographs are particularly useful in studying the frequent changes that have occurred in coastal features. Indeed, the technique of comparing features on existing aerial photographs also has tremendous potential for studying a wide variety of dynamic natural processes and time-varying activities of man. The large amount of aerial photography that has been accumulated in the United States over the past 30 to 40 years, particularly the multiple coverages of the same area, represents a valuable source of data that can be employed effectively in investigating a number of dynamic phenomena and features that can be observed on aerial photographs.

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