A METHOD AND SELECTED APPLICATION FOR USING AERIAL PHOTOS IN DELINEATING HISTORIC PATTERNS OF BEACH ACCRETION AND RETREAT

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INTRODUCTION

General Problems Addressed

In Hawaii, there is no single geomorphic feature which is more unstable than the beach zone. Over periods of time ranging from many years to a few days, the beach may be markedly altered in its size, shape, volume and other characteristics. These changes may be caused by numerous factors such as storms, seasonal and long term variations in wave conditions, reductions in the rate of sand production, increases in exposure due to erosion of protecting headlands or reefs, and human activity.

The constantly shifting sands on a beach have posed some serious problems with regard to coastal zone management. These problems are summarized below:

<u>Siting of New Beach Structures</u>

1) On some beaches, houses were built on what were once back beach areas, disregarding the potential for beach erosion. Subsequent beach retreat has resulted in undermining of these structures. The houses built on Lanikai Beach on Oahu are an example of this problem. Obviously, the potential for beach retreat must be considered before structures of any kind are built. The root of this management problem is determining how far inland nearshore structures must be placed to be safe from natural changes.

<u>Remedial Measures to Save Present Structures from Beach Retreat</u>

2) In the case of beach retreat relative to now-existing structures, the correct remedial policies are dependent on the scope of the problem. For example, if a well developed beach with many buildings is threatened by erosion, then protective works or artificial beach maintenance may be justified. However, for a slowly retreating shoreline containing a few old houses, no governmental action may be required. In determining the best management policy, it should be realized that some remedial measures may make it unlikely that the beach will grow back, even if the conditions that led to its retreat are changed. Therefore, it would be useful to know if a particular beach has a historic record of continuous erosion, or cyclic accretion and retreat.

Regulation of Sand Mining

3) The removal of sand from backbeach areas within the reach of uncommon storm waves or tsunamis should be prohibited because beach retreat may result if sand from the littoral cell is transferred to the removal site. In defining the boundaries to which sand mining is prohibited, the possibility of beach erosion must be recognized. The problem in this policy area is determining the inland extent of prohibitive sand removal.

Acquisition of Land for Public Beach Parks

4) In acquiring beach front and adjacent lands for public beach parks, the potential for beach erosion must be considered. For example, if a plot of land extending 100 feet from the shoreline is needed, it would be of little use to acquire just the 100 feet if the shoreline were retreating 10 feet per year especially if the plot was backed by private lands subject to future development of permanent structures within the next few years. (Cox, 1978).

Extent of Private Ownership

5) Many of the boundaries between public and private portions of the beach are presently defined by the debris line, vegetation line or different sea-level lines. Since beaches are so unstable, the use of any of these boundaries means that the total area of private property is constantly changing. In order to assess land values for taxation purposes, it may be necessary to periodically resurvey an area. The appropriate time interval for resurvey would depend on the instability of the beach in question.

In any of the five management problems mentioned, the best effective decisions must be based on the magnitude of beach instability. Therefore, it is extremely important to have information on beach areas likely to prograde or retreat as well as data about the trends, ranges and rates of long term beach change.

Although there have been several studies in the past dealing with the beaches of Hawaii, there is actually very little information concerning long term beach variations. Moberly and Chamberlain (1964) describe characteristics of 112 beach sites for the seven major Hawaiian islands. This comprehensive report is the major source of information concerning seasonal beach changes. However, the short period of field work conducted in this study precluded a description of long term beach trends.

Campbell (1972) provided additional information on beach erosion for 33 selected beach sites. Resurveys were conducted to compare with the data of Moberly and Chamberlain. While most study sites showed insignificant changes in the volume of beach sand, a few areas did display net accretion or erosion. For Hawaiian beaches, this work provides the most information on the magnitude of long term changes. However, the ten year observation period may have been insufficient to define the ranges and trends in past shoreline positions.

The Army Corps of Engineers in 1971 compiled available information from previous studies to define 54 circum-Hawaiian beaches which are criticallyeroding. In the report, the description of beach changes were mostly qualitative and served mainly to identify existing erosion hazard areas. More quantitative data can be found in many of the Army Corps of Engineers individual case reports on beach erosion. A recent study by the Corps in 1975 includes survey data from 1967 to 1970 for Barking Sands, Hanalei Bay and Kekaha on Kauai; Haleiwa, Kailua and Sunset on Oahu; Kaanapali on Maui and Papohaku on Molokai. In this study surveys were conducted over 6 month intervals at many of the original Moberly and Chamberlain survey ranges.

No study has yet provided concise information on the magnitude of long term beach change for more than a few sites. While survey methods are very accurate in determining short term beach changes, their use in monitoring historic shoreline movements repeatedly encounters one serious problem: a lack of past surveys through which beach changes can be compared. Past measurements of the beach may be scarce because the need to make them was not recognized at the time.

Accurate surveys for some Hawaiian beaches may exist for only a ten-year span. Extrapolating descriptions of beach change beyond this time interval can be difficult. For example, surveys made in 1962, 1963 and 1972 may indicate that a particular beach is relatively stable. Does this mean that beach structures with a 30 year life span and greater may be built free from the threat of beach retreat?

The Use of Aerial Photographs in Monitoring Historic Shoreline Changes

One alternative to the survey method, which forms the basis of this report, lies in the utilization of aerial photographs. By crosstime comparison of aerial photos, the past and present shoreline positions can be defined and perhaps future changes predicted.

The technique of photo comparison to monitor shoreline changes has been successfully employed for many sections of the United States. In the earliest studies, descriptions of beach change were mostly qualitative and utilized oblique as well as vertical photographs (Howard, 1939; Dietz, 1947; Shepard, 1950). The emphasis on vertical photographs gradually increased as their versatility allowed qualitative and quantitative descriptions of coastal morphologic changes (Tanner, 1961; Athearn, 1963; El Ashry and Wanless, 1965; Cameron, 1965a; Cameron, 1965b; El Ashry and Wanless, 1967; El Ashry and Wanless, 1968).

In the last ten years, aerial photographs have been extensively used to collect precise measurements on historic shoreline changes. Moffitt (1969) studied beach erosion in Monterey Bay, California, by orienting reference points and shoreline points on the photo into the State Plane Coordinate System. While this procedure may give accurate results, its use is not required unless the absolute position of the shoreline is needed.

Langfelder et. al. (1970) used aerial photographs to document beach changes over a 30 year period for the North Carolina coast. In this study, transects were established every 1,000 feet and distances from stable reference points to the shoreline were measured.

Beach erosion of the Georgia barrier island system was documented over a 30 year period using methods similar to Langfelder (Oertel, 1973). Shoreline changes at Sargent Beach, Texas, were revealed by a study of topographic maps and aerial photographs (Seelig and Sorensen, 1973). Studies on beach instability in Pamlico Sound, North Carolina, were based on the use of aerial photographs over a 33 year period (Stirewalt and Ingram, 1974). Fisher and Reegan define procedures for using transects on photographs for a study of beach erosion on Rhode Island (in Tanner, 1978). For the state of Hawaii, an air photo survey on past shoreline movements was conducted for Kailua Beach Park (Noda, 1977).

Past studies indicate that aerial photographs are an excellent tool to document historic shoreline changes. Their use in the coastal zone is especially advantageous for several reasons. In general, imagery of the Hawaiian coastline has been obtained more frequently in the past 30 years than maps, charts on surveys have been made. Also, aerial photographs provide an efficient and economical means of collecting data since information can be obtained without the expense of costly survey parties. Finally, an aerial photograph records an almost infinite amount of ground detail as opposed to maps and charts which contain selected detail subject to human interpretation (Stafford and Langfelder, 1970).

The use of aerial photographs to collect beach instability data is not without its drawbacks. First, the aerial photograph may record conditions which are not typical of mean conditions. For example, strong winds may cause unusually high waves giving the beach a narrow appearance. This problem is somewhat alleviated by the fact that photographs are obtained only on clear days suitable for photography. Another problem is distinguishing on a photograph between long term beach changes and short term changes due to seasonal fluctuations and storms. Ideally, only photographs taken at the same time of the year should be used. Unfortunately, this is not always possible as the quality, quantity and periods of photo coverage vary for each beach. Problems also exist in the photo resolution as well as errors inherent in the image itself. It is clear that these problems must be resolved before the photographs can be effectively used in this study. The methods used to reduce or eliminate these problems and to estimate their magnitude are outlined in later sections of this report.

METHODOLOGY

The first phase of this project was determining the aerial photographs which were available for study. This was an important part of the project because the periods of time coverage and the type of imagery available are sometimes determined by what exists.

Photographic inventories were conducted for the files of the R.M. Towill Co., Air Survey Hawaii, Hawaii Institute of Geophysics, and Army Corps of Engineers. An investigation of potentially useful aerial photographs was made for the United States Geological Survey, United States Air Force, Coast and Geodetic Survey, National Ocean Survey, Bishop Museum, State Archives and Library Hawaii.

Once the inventory of the available photographs was completed, flight lines of a particular beach were ordered for different years. When possible, photographs taken at the same time of the year were selected to minimize the affects of short term seasonal changes.

In the first prototype study of Kailua Beach, flight lines for 1949, 1963, 1971, 1975, and 1978 were provided by the Department of Planning and Economic Development. These photographs were used along with a 1957 Army Corps of Engineers flight line. The sets of photos varied in scale from about 1:2,400 to 1:4,800 and were used to estimate the accuracies involved in measurements at different scales.

An important part of this study concerned determining the best time interval between photographic flight lines. Obviously, increasing the number of monitoring flight lines would document beach changes more accurately. Beaches which have a history of reversing trends in accretion or erosion require more continuous monitoring than areas which have undergone stable unidirectional change. Unfortunately, the diversity in beach types and their processes precludes a predetermination of the optimum monitoring interval (Morton: in Tanner, 1978). The optimum monitoring interval would be the point when the value in labor and money equals the value in information obtained from additional flight lines.

In this study, photographs were selected at roughly five year time intervals. The exact time interval depended on the imagery available. A five year observation period should allow documentation of significant long term beach changes while reducing the affects of short term variability due to seasonal changes. On a few beaches on Oahu, the observation period will have to be increased due to the lack of photo coverage.

After suitable imagery was obtained, points along the beach were selected on each photograph. These points, which will be referred to as stable reference points, must satisfy three requirements. First, stable reference points must have a fixed ground position over the beach monitoring period. These points can then serve as a marker by which beach changes can be measured against. Secondly, the points selected must be located as close to the beach as possible. Since photographic scales are determined between stable reference points within close proximity of the beach, the variation of scale within a photograph due to tilt becomes a significantly less important factor. Finally, the stable reference points must have a minimum of ground elevation in order to reduce relief displacement problems.

In general, the corners of single level houses were used as stable reference points. These structures tend to have clear distinct boundaries which can be easily distinguished on a photograph. After suitable structures had been selected, the points on the photograph were sequentially numbered.

Determining Scale on a Photo

A scale determination for each photograph is required because of the variable flying height of an airplane along the flight line. The scale of each photograph is determined by use of the following formula:

$$\text{Photo Scale} = \frac{\text{Photo Distance}}{\text{Ground Distance}} = \frac{\text{Photo Distance}}{\text{Map Distance}} \times \text{Map Scale}$$

Orthophoto maps produced by the R.M. Towill Company were used to determine the photographic scales for Kailua Beach. These maps are controlled photo mosaics which have been corrected for tilt and scale variations along the flight line. Orthophoto maps allow very accurate measurements of the ground distance between stable reference points. An example is given to illustrate this point.

It is generally agreed that the "strict" limit in accuracy to which the human eye can consistently locate a point on a photo or map is .01 inch (Tanner, 1978). Since measuring a distance requires locating two points, an error of up to .02 inch can be expected. However, by using precise measuring scales and a ten times magnifying glass, the maximum measuring error is about .005 of an inch (Table #1). This figure will be used as a working number throughout the remainder of this report.

On an orthophoto map, at a scale of 1 in. = 200 ft., a measurement error of .005 of an inch represents a ground distance error of 1 foot. The average distance between stable reference points used in this study is approximately 5 inches on the orthophoto map or 1,000 feet on the ground. Taking the measuring errors into consideration, the ground distance between the two stable reference points is 1,000 $\pm$ 1 foot.

Therefore, using the orthophoto maps as ground control allows a very accurate scale determination for each photograph. Unfortunately, orthophoto maps have not been compiled for all sections of the Oahu coastline and for some beaches, the coverage is partial or non-existent.

For beaches with partial orthophoto coverage, ground control can be extended by using the 60% overlap of the photos. In this procedure, a flight line is selected with the least amount of tilt and scale variations. This is determined by comparing the relative positions of selected points on adjacent overlapping photos (Fig. #1). After a suitable flight line is selected, ground control is extended by successive measurements on adjacent photographs (Fig. #2). In this method, the errors accumulate for each photograph in which control is extended. However, in later sections of this report, it is shown that this procedure yields more than acceptable error levels.

Table #1-An Evaluation of Measurement Accuracy

Five students measured the distances between well defined points. To prevent biasing, none of the measurements between the same points were made consecutively. All results were concealed from the students.

Student #	Distance #1	Distance #2
#1	2.685 in. 2.685 in.	2.407 in. 2.405 in.
#2	2.690 in. 2.690 in.	2.412 in. 2.412 in.
#3	2.687 in. 2.687 in.	2.408 in. 2.410 in
#4	2.687 in. 2.687 in.	2.412 in 2.410 in.
#5	2.688 in. 2.688 in.	2.410 in. 2.410 in.
	$\bar{X} = 2.687$	$\bar{X} = 2.410$

Assuming that the mean value of the measurements approaches the correct distance, the maximum error between any of the twenty measurements is .005 inch. As a conservative estimate, this value is established as the limit in measurement accuracy.

On beaches without orthophoto coverage, the only alternative for ground control would be field measurements. In this case, a few ground distances could be measured and the control extended to all sections of the beach by photographic measurements. This method would yield accurate results and reduce the time of field work considerably.

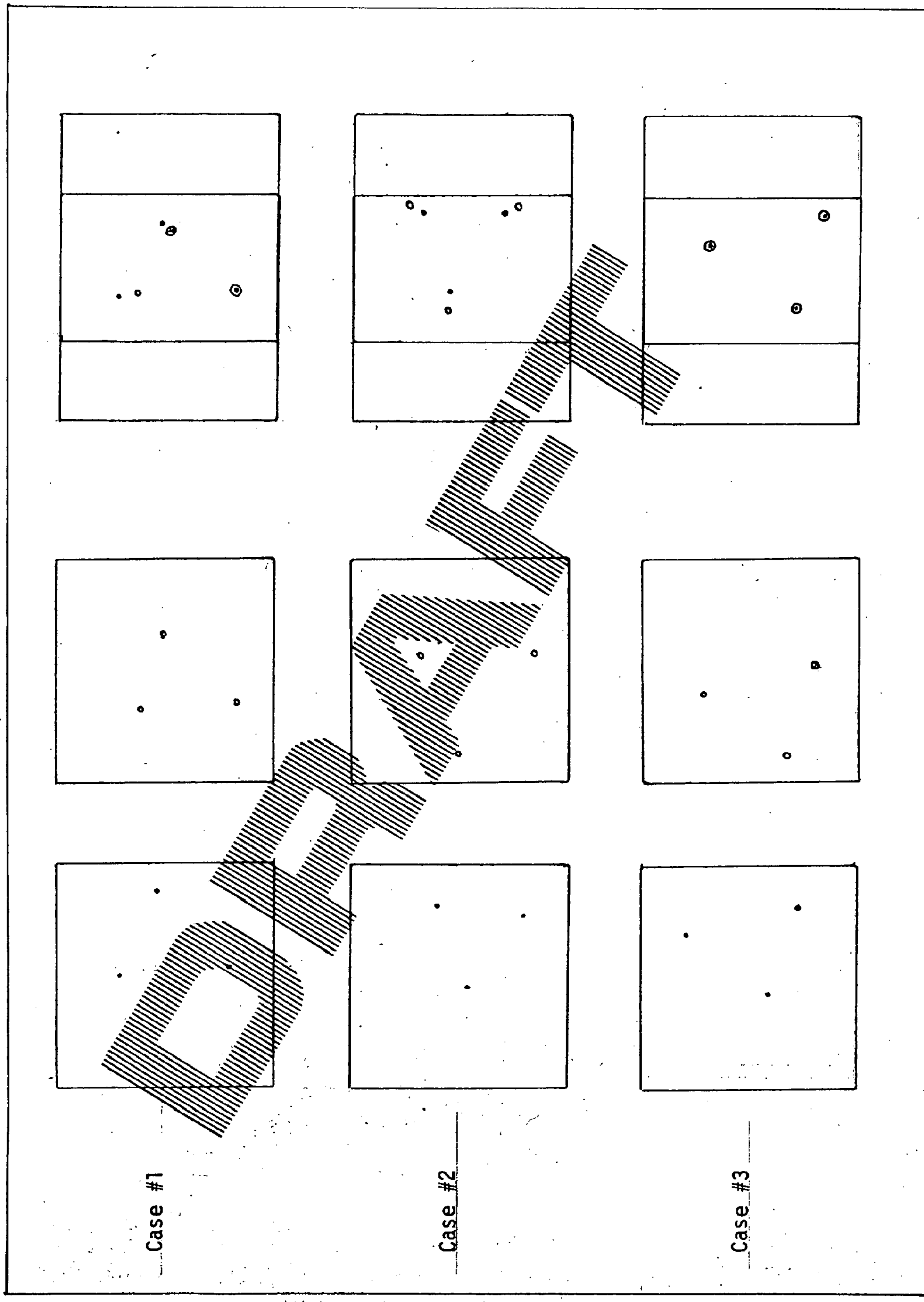


Fig. #1. Selecting photographs with a minimum of tilt. Case #1: Either or both of the photographs are tilted. Case #2: Photographs of different scale- no tilt. Case #3: Photographs of the same scale- neither are tilted.

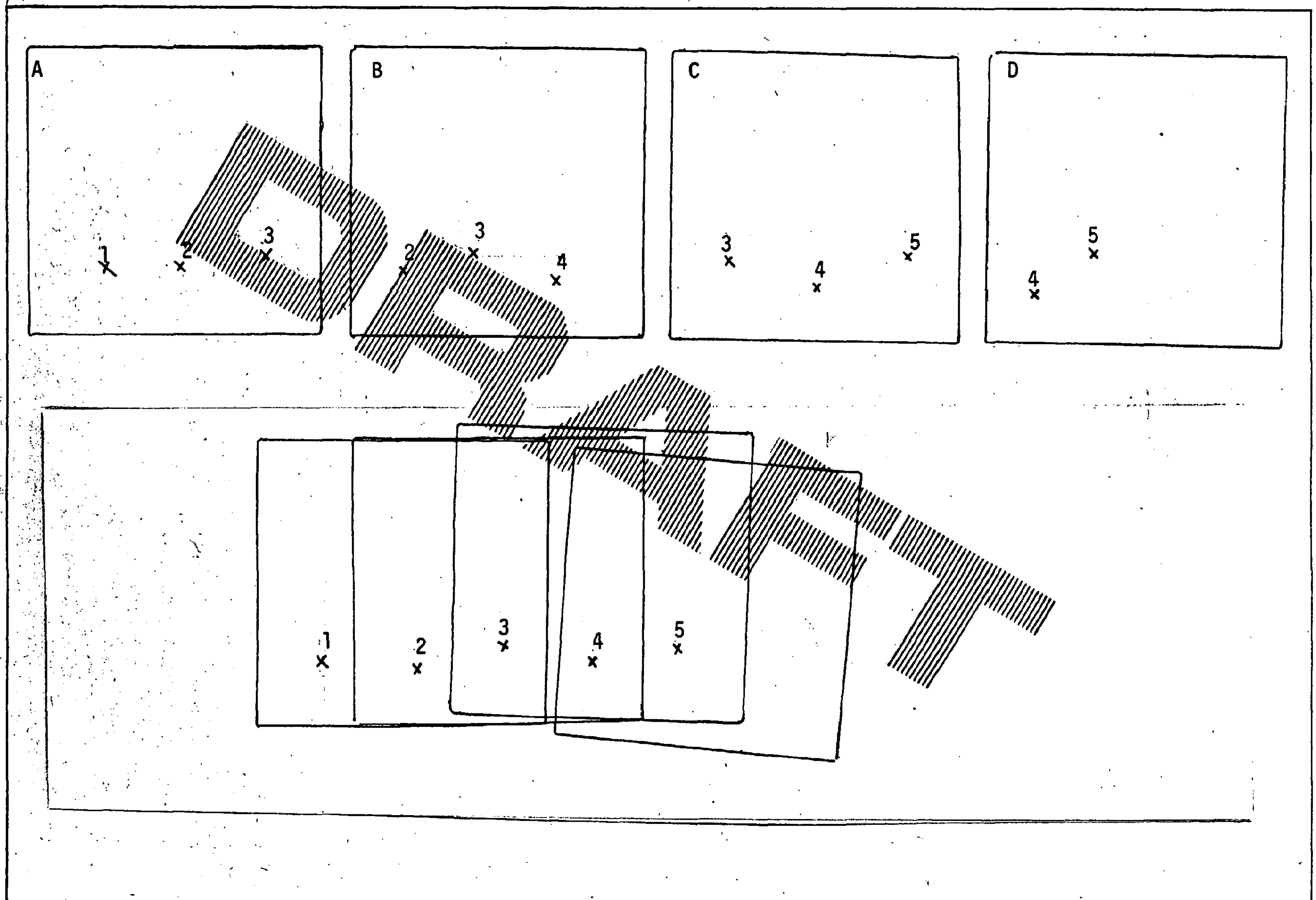


Fig. #2. On beaches with partial orthophoto coverage, the ground control can be extended. If the distance between pt. 3 and pt. 4 is known, then scales can be determined for photos B and C. This will allow the distances between pts. 2 and 3, and between pts. 4 and 5 to be determined. Scales for photos A and D can then be computed.

Beach Index Lines

After the photographic scales have been calculated, the distance between stable reference points and a beach index line is measured for all photographs. There are three index lines on the beach which can be used to represent actual beach location (Fig. #3). Previous aerial photographic studies of beach areas have used the vegetation line, high water line and water line. Each has its advantages and disadvantages.

The vegetation line, marked by the seaward limit of existing perennial vegetation, is an indicator of the highest annual wave runup (Cox, 1978). This index line is especially useful because of its clear image on the photograph. In addition, the position of the vegetation line would reflect long term beach changes while the affects of seasonal variations would be minimized.

The use of the vegetation line is not without its problems. The position of this line on eroding beaches would change more readily than on accreting beaches. However, a five year monitoring interval should allow the vegetation to reach some degree of equilibrium with an accreting beach. Another problem in using the vegetation line is that human activity or windblown sand may alter its position. Generally, these modifications can be identified on a photograph by the highly irregular appearance of the vegetation. On some beaches, the vegetation may be located on the top of a berm and may cause relief displacement problems. In some limited areas, the vegetation line may not exist because of manmade structures or unusual beach features.

The high water mark is distinguished on the photograph as a line separating dry sand from moist sand. Ideally, the position of the high water line is not affected by tidal fluctuations because the line records the extent of highest wave runup during high tide. However, for coarse porous sands, the high water line may not exist (Rib, 1957). If the high water line is present, its position is highly variable and dependent on the following factors: 1) the extent of wave runup; 2) atmospheric conditions related to evaporation; 4) the location of the ground water table; 5) the elevation of the previous still water level (Weber, 1969). Probably the greatest problem in using the high water mark is distinguishing between wet and dry sands on a photograph.

The third index mark which may be used to document beach change is the water line. On a photograph the position of this line depends on the degree of light penetration of the water, the extent of wave runup, and the tide level at the time of the photograph. On beaches which have high tidal ranges and gentle slopes, the water line may be displaced significantly between high and low tides.

Using the prototype study of Kailua Beach as an example, the displacement of the water line caused by tidal changes can be calculated. For Oahu, an average of eight different tide stations yields a mean diurnal tide range of about 1.9 feet (Tide Tables, U.S. Dept. of Commerce, 1973). The diurnal range is defined as the

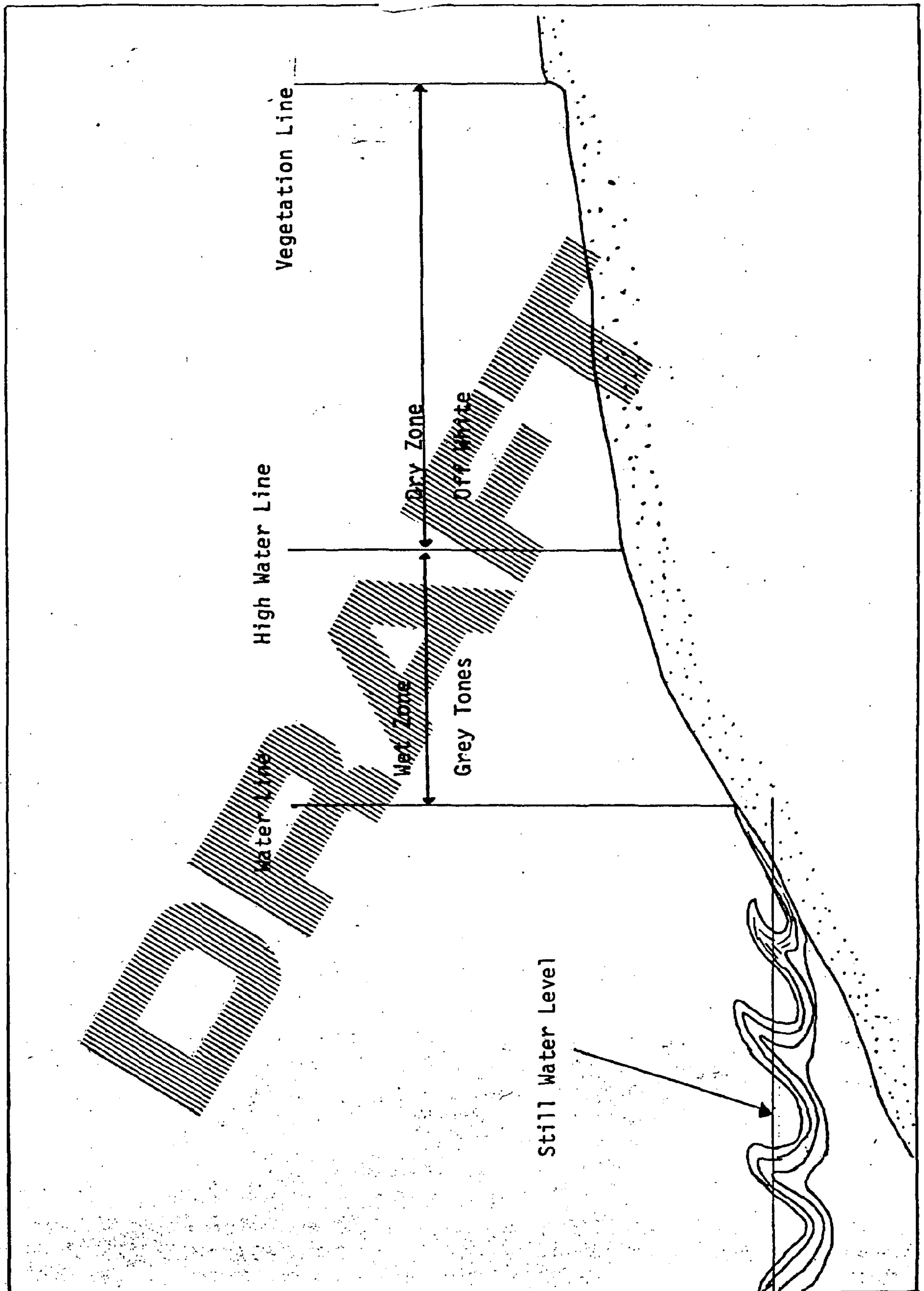


Fig. 3. Beach Index Lines
(Adapted from, Weber, 1970)

elevation difference between mean higher high water and mean lower low water. For some sections of Kailua Beach, the slope is approximately 1:15 (Noda, 1977). Using these figures, a displacement of the water line of up to 28.5 feet may result from tidal changes alone. For this reason, some aerial photographic studies have made tidal corrections when using the water line (Moffitt, 1969). However, the use of any constant tidal correction factor for a beach with varying slopes introduces further inaccuracies (Langfelder et. al., 1968). In this study, no tidal corrections were made.

Another problem in using the water mark is distinguishing the line on a photograph. Poor contrasts exists between the water and land because the wavelengths of the light spectrum that black and white panochromatic film record are characteristically reflected by land and water (Weber, 1969).

For this study, two beach index lines are used. It is believed that the vegetation line provides the most information concerning long term beach changes. Distinguishing the vegetation line on a photograph is easier and thus more accurate than any of the other two lines. The position of the water line is also used to collect beach instability data. In order to use this line effectively, it is important to know how tidal fluctuations may affect its position. The position of the water line is also sensitive to long term and short term changes in the beach profile. This must be fully realized in order to avoid measuring long term changes which are in reality only short term changes. On areas of the beach where the vegetation line is missing or the water line is undeterminable, a gap will be left in the data.

Calculating Beach Change

On each photograph, the distance between stable reference points and the beach index lines is measured. The photographic distance multiplied by the scale of the photograph gives the ground distance between the reference point and the index lines at the time of photography. The change in ground position for beach index lines can then be compared for successive monitoring intervals. The net change in position for each observation period, divided by the monitoring time interval gives an incremental rate of change for the beach location.

The incremental rates of change computed for any observation period assume that the trend and rates of change were constant for the beach section under study. If either of these assumptions is incorrect, then the calculated rates of change will tend to be underestimated. For example, suppose ten feet of beach erosion was recorded on two photographs over a five year time lapse. Then the incremental change in the beach position would be -2 ft./year. However, if the beach accreted during the first three years 12 ft. and eroded in the next two years 22 ft., then the true rates of change are +4.0 ft./year for the first three years and -11 ft./year for the next two years. Thus, the estimated rate of change has been underestimated by assuming the beach underwent constant unidirectional change.

The five year monitoring interval selected in this study should be sufficiently frequent to determine long term beach trends, to calculate rates of change and perhaps for predicting future rates of change. However, the limitations inherent in calculating rates of change from net shoreline movements should be realized (Morton: in Tanner, 1978).

MEASURING SHORELINE CHANGES: ACCURACY LIMITATIONS

Whenever data on shoreline changes is presented, the measurements should be accompanied with a statement on the probable limits in accuracy. In this report, the magnitude of these limits is estimated for the three different situations in which ground control may be obtained: full orthophoto coverage; partial orthophoto coverage; and field measurements. The computations which follow employ the specifications of the photographs used in the prototype study for Kailua Beach.

According to Scherz (1974), the types and ranges of errors in using photogrammetic materials are listed in decreasing order:

1) Relief Displacement (varies with terrain)	
2) Measurement Errors (varies with technique)	
3) Paper Shrinkage	0 to .5%
4) Tilt	0 to .3%
5) Film Shrinkage	0 to .1
6) Lens Distortion	0 to .1%
7) Lack of Focal Plane Flatness	0 to .01%
8) Differential Film Shrinkage	0 to .005%

For this study, a ninth item should be added to the list. The error in determining the scale of a photograph may be an important factor in limiting the accuracy of the methodology.

Of the nine errors listed, only relief displacement, tilt, measurement errors and photographic scale errors are included in the accuracy analysis. Paper shrinkage and film shrinkage are not important factors since a scale is determined for each photograph. Lens distortion, differential film shrinkage and lack of focal plane flatness are insignificant when compared to other possible errors.

Relief Displacement

The displacement of an object on a photograph due to its relief is shown on Fig. #4. At sea level there is no relief, so one might think that relief displacement problems are not a factor in measuring shoreline changes. However, the position of a beach index line is usually measured relative to structures having elevations considerably greater than sea level (Tanner, 1978).

The magnitude of relief displacement is given by the following formula:

$$m = \frac{rh}{H}$$ Moffitt (1967, p. 68)

where m = the displacement on the photograph of the top relative to the base
h = height of the object
H = altitude of the plane
r = radial distance from photo center to the image of the ground point

The value of the parameters used in the following computations are:

H = 5,000 ft.	(The flying height of the 1949 flight line for Kailua Beach)
r = 10 in.	(The overlap of the photographs allowed all stable reference points to be selected within 10 inches of the photo center. The size of the photographs are 27 x 27 inches)
h = 25 ft.	(This is the estimated difference in elevation between the stable reference points and the water line)

The relief displacement of the object is then:

$$m = \frac{(10 \text{ in.})\ (25 \text{ ft.})}{5{,}000 \text{ ft.}} = .05 \text{ in.}$$

The photographic scale for the 1949 flight line is approximately 1 in. = 200 feet. The error in ground distance due to relief displacement on the photo would then be ten feet. This horizontal displacement may be misinterpreted as beach erosion or accretion.

Relief displacements on a photograph are the most serious photogrammetric error in this study. Even by selecting single level buildings and staying as close to the photographic center as possible, an error of up to ten feet may still result when measuring distances to the water line. Fortunately, relief distortion problems are less serious for measurements to the vegetation line. On Kailua Beach, the

Relief Displacement : $m = r - r'$

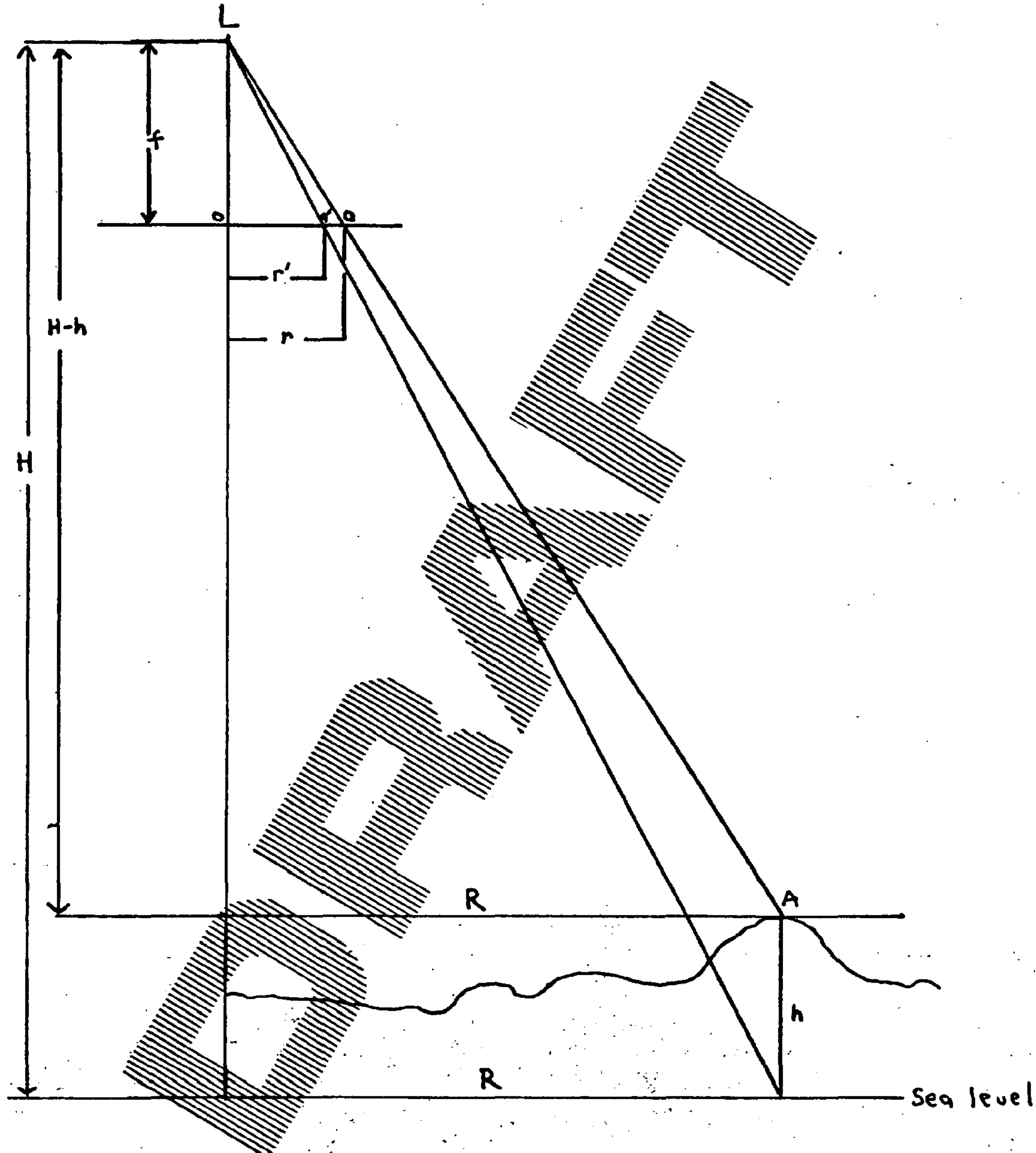


Fig. # 4. Relief displacement on a photograph (Moffitt,1967).

elevation difference, parameter h, is about 15 feet between stable reference points and the vegetation line. This elevation would result in a relief displacement error of 6 feet.

One additional factor may alleviate the problems of relief distortion. Any relief displacement on a photograph can be divided into components parallel and perpendicular to the shoreline. When measuring distances to a particular part of the beach, the perpendicular components are the most detrimental. On the 1949 photographs for Kailua Beach, the maximum component perpendicular to the beach is 9 inches. Substituting this value into parameter r results in a distance error to the vegetation line of 5 feet.

The component of relief displacement parallel to the shoreline is a more serious problem when computing photographic scales. This factor is considered in section #4 of the error analysis.

Measurement Errors

The distance between any two points on the photograph can be measured to an accuracy of about .005 of an inch (Table #1). On the 1949 flight line of Kailua Beach, at a scale of 1 in. = 200 ft., this measurement error represents a ground distance error of 1 foot.

Tilt

Generally, tilts on a photograph of up to 3° may result from weather conditions, pilot errors, etc. (Scherz, 1974). Figure #5 shows the geometry of a vertical photograph and a photograph with a 3° tilt. The ground distance between AB measured from the tilted photograph is .3% off compared with the correct distance computed from the vertical photograph.

For the 1949 flight line of Kailua Beach, the average distance between stable reference points and the vegetation line is about one inch. The effect of a .3% tilt error on the computed ground distance is:

$$\frac{\text{ground distance error from tilt}}{\text{ground distance}} = \frac{X}{1.00 \text{ in.}} = .3\%$$

$$X = .003 \text{ in}$$

At a photographic scale of 1 in. = 200 ft., the change in ground distance resulting fom a 3° tilt on the photo is .6 feet. Thus, photographs with a 3° tilt or less may be used for accurate measurements of the beach.

A few of the photographs used in this study were excessivley tilted. In this case, accurate measurements are still possible provided several scale determinations are made perpendicular to the beach for <u>each</u> photograph.

Error in Computing Photographic Scales

In order to convert photographic distances to ground distances, an accurate sale determination is needed for each photograph. The scale of a photograph can be found by use of the following formula:

$$\text{Scale} = \frac{\text{Photo Distance}}{\text{Ground Distance}} = \frac{P}{G}$$

The photo distance measured between any two points may be in error from two major sources. The actual measurement may be off by .005 inch (Table #1). This would be the only error if all the points on the photograph were at their true ground positions. However, relief displacement of stable reference points relative to the vegetation line may contribute an additional error of .03 inch (section #1). This value is a maximum estimate for two reasons: (a) not all the components of relief displacement is parallel to the shoreline and (b) the two stable reference points selected for each scale determination were located sufficiently close so that in all cases the relief displacements were either negligable or compensating. The combined effects of both errors result in a maximum error in the measured photo distance of .035 inch.

In the section of this paper on "Determination of Scale," it was shown that the ground distance could be measured to an accuracy of 1 foot from orthophoto maps. The effect of this error on the scale accuracy can be computed using the 1949 flight line of Kailua Beach as an example.

Suppose the photo distance measured is 5.00 ± .035 inches and the ground distance is 1,000± 1 foot. The expected scale of the photo, if no errors were involved is:

$$\text{Scale} = \frac{P}{G} = \frac{5.00 \text{ in.}}{1,000 \text{ ft.}} = 5.00 \times 10^{-3} \text{ in./ft.} = \frac{1 \text{ in.}}{200 \text{ ft.}} \text{ or}$$

$$1 \text{ in.} = 200 \text{ ft.}$$

The effects of the estimated errors on the scale can be computed by taking partial derivatives of the scale formula.

$$\frac{dS}{dP} = \frac{dP}{G} = \frac{.035}{1,000 \text{ ft.}} = 3.50 \times 10^{-5} \text{ in./ft}$$

$$\frac{dS}{dG} = \frac{-P(dG)}{G^2} = \frac{(5.00 \text{ in.})(1 \text{ ft.})}{(1,000 \text{ ft.})^2} = 5.0 \times 10^{-6} \text{ in./ft.}$$

Combining the two error values and adding them to the expected scale of the photo results in the following change.

$$(5.00 \times 10^{-3} \text{ in./ft.} + (4.00 \times 10^{-5} \text{ in./ft.}) = 5.040 \times 10^{-3} \text{ in./ft.}$$
$$= 1 \text{ in./198 ft. or } 1 \text{ in.} = 198 \text{ ft.}$$

a) If: f= 8.25 in.
Z= 5,000 ft.
ap= pb = 3.33in.
then; $\alpha = \tan^{-1}(3.33/8.25) = 21.98$
AB= 2 (tan 21.98) (5,000 ft.)
=4036.2 ft.

b) For a photograph with a 3° tilt:
f= 8.25 in.
Z=5,000 ft.
$\alpha = 21.98°$
$\beta = 18.98°$
$\lambda = 24.98°$
AN= (5000 ft.) (tan 18.98°)= 1,719.6 ft.
NB= (5000 ft.) (tan 24.98°)= 2,329.4 ft.
AB= AN + NB= 4,049.0 ft.

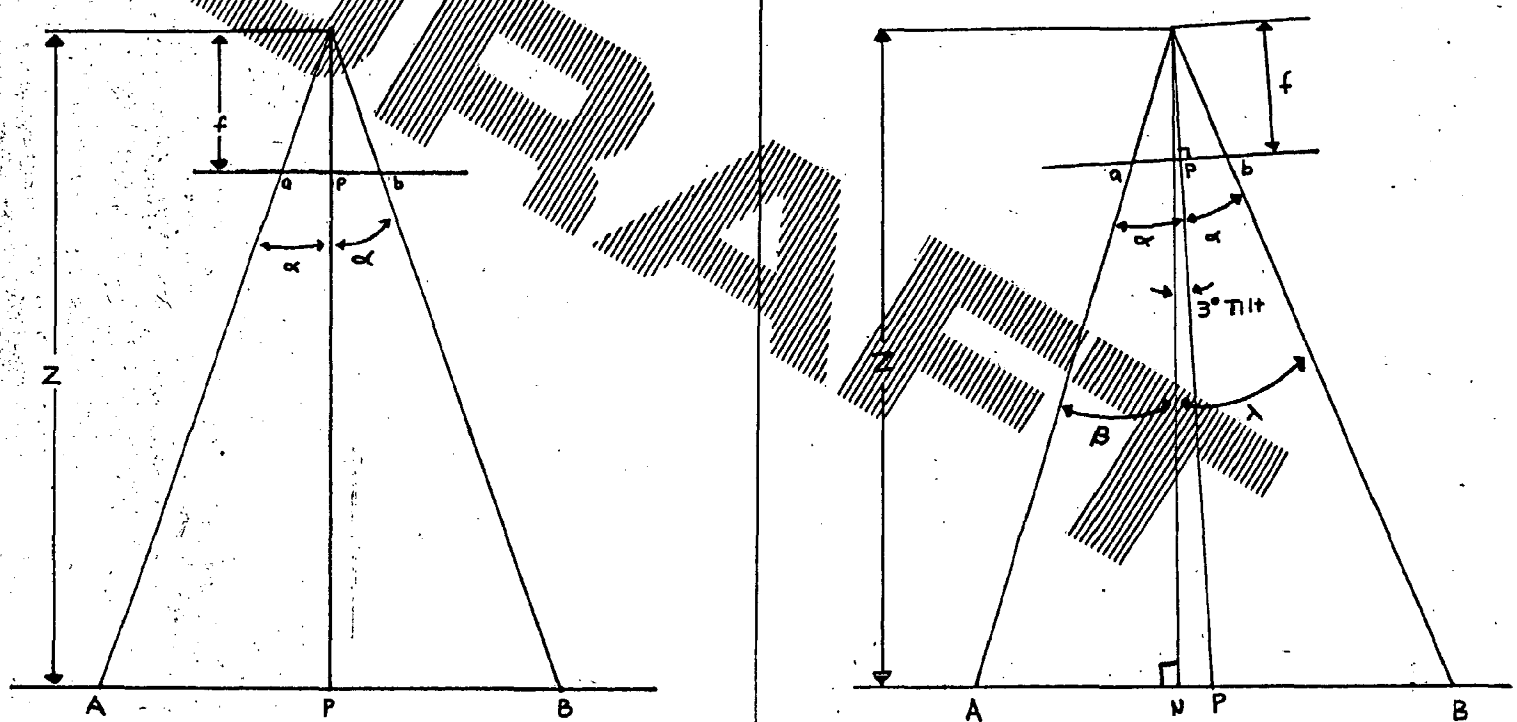


Fig. 5. Tilt on a photograph. For the vertical photograph, the computed distance between AB is 4036.2 feet. On a photograph with a 3° tilt, this distance is computed as 4,049.0 feet. The error is (12.8/4036.2) (100)= .3%.
(Adapted from Scherz,1974)

The range in scale resulting from the estimated errors is 1 in. = 200 $\pm$ 2 feet. Since the distance between stable reference points and the vegetation line averages 1 inch on the photo, the scale error results in a ground distance error of 2 feet.

Summary of Error Analysis

Table #2 summarizes the estimated errors which may result from using orthophoto maps as ground control for the 1949 and 1978 flight lines. The procedures used for estimating the errors on the 1978 photographs were similar to those outlined in this report.

The total sum of errors for the two flight lines appear at the bottom of the table. These figures are most likely an overestimation because any of the errors may be accumulating or compensating and may range from zero to their maximum estimated limits. For this reason, the probable error has been calculated and appears below the total error figures.

The probable error is estimated by making three assumptions. First, the errors are assumed to follow a Gaussian or normal error distribution. This is a reasonable assumption because all the errors have a finite variance and seem, to the first approximation, to be random events. Secondly, it is assumed that the maximum estimated errors are two standard deviations away from the mean error values. As a result, about 95% of all the errors are within the interval defined by plus or minus the maximum estimated error. This is believed to be a conservative estimate. Finally, it is assumed that the errors are uncorrelated or independent of each other. This requirement is satisfied for relief displacement, tilt and measurement errors but not for photographic scale errors. In this study, the total probable error is approximated by assuming the photographic scale error is an independent deviation.

Based on these three assumptions, the total probable error can be computed to a 95% confidence interval by summing the squares of the individual error components (Bevington, 1969). When comparing beach changes on the 1949 and 1978 flight lines, the limit in accuracy can be computed by the procedures shown at the bottom of Table #2. In this case, the limit is about 11 feet.

Since the scale for the six flight lines used in this study varies from 1:2,400 to 1:4,800, the accuracy in comparing any two of the flight lines also changes. For the prototype study of Kailua Beach, the maximum error in comparing any two of the data points is about 12 feet. The procedures used in estimating this figure are similar to those outlined on Table #2.

For beaches which have partial orthophoto coverage, the ground control is extended by successive measurements on adjacent overlapping photographs (Fig. #2). In the first test study for Kailua Beach, this procedure was used to extend ground control from the middle portions of the beach to both ends. Scales for all photographs were then determined. Distances between selected points on the photographs were converted to ground distances and compared with field measurements. This comparison was made only for points at opposite ends of the beach. Since ground control was extended, the accuracy of measurements at the end portions of the beach would be dependent on those in between.

Table #3 shows the results of the accuracy test. The maximum error is 1.1% for all the measurements made. It is clear that extending control by this method can yield very accurate results provided photographs with the least amount of tilt are used. As mentioned previously, these photographs are selected by comparing the relative positions of common points on adjacent overlapping photos (Fig. #1).

For this study of Kailua Beach, the accuracies involved in using photographs with extended ground control and photographs with orthophoto coverage are assumed to be about equal. Therefore, on photographs with extended ground control, the maximum error for any measured beach change is about 12 feet.

TABLE #2 - Summary of Errors for the 1949 and 1978 Flight Lines Using Orthophoto Maps

The 1978 photographs were taken at a flying height of 6,000 feet with a 6 inch focal length camera and enlarged to a scale of 1:4,800.

	1949	1978
Relief displacement	5.4	8.0
Measurement Errors	1.0	2.0
Tilt	0.6	0.6
Photograph Scale Errors	2.0	3.1
Total Error	9.0	13.7

Calculating the probable error to a 95% confidence interval by use of the following formula:

$$\sigma^2_{tot} = \sigma^2_1 + \sigma^2_2 + \sigma^2_3 + \sigma^2_4 \text{ (Bevington, 1969)}$$

where σ = the standard deviation of the errors involved.

Assume:

$2\sigma_1 = 5.4$	$2\sigma_1 = 8.0$
$2\sigma_2 = 1.0$	$2\sigma_2 = 2.0$
$2\sigma_3 = 0.6$	$2\sigma_3 = 0.6$
$2\sigma_4 = 2.0$	$2\sigma_4 = 3.1$

$$\sigma_{tot} = \sigma^2_1 + \sigma^2_2 + \sigma^2_3 + \sigma^2_4$$

$$\sigma_{tot} = \sqrt{(2.7)^2 + (0.5)^2 + (0.3)^2 + (1.0)^2} \qquad \sigma_{tot} = \sqrt{(4.0)^2 + (1.0)^2 + (0.3)^2 (1.6)^2}$$

$$\sigma_{tot} = 2.9 \qquad \sigma_{tot} = 4.4$$

$$2\sigma_{tot} = 5.8 \qquad 2\sigma_{tot} = 8.8$$

The limit in accuracy for comparing beach change is:

$$2\sigma/1949\text{-}1978/ = (5.8)^2 + (8.8)^2$$

$$2\sigma/1949\text{-}1978/ = 10.5$$

TABLE #3- A Comparison of Field Measurements
With Ground Distances Computed from Aerial Photographs

Measurements #1 and #2 were taken near Kailua Beach Park. Measurements #3 and #4 were taken at the north end of the beach. The maximum error is 1.1% for all measurements made

Measurement	Aerial Photograph	Field	% Error
#1	159 ft.	158 ft.	0.6%
#2	538 ft.	544 ft.	1.1
#3	78 ft.	78 ft.	0.0%
#4	537 ft.	542 ft.	0.9%

DISCUSSION

Fifteen transects were established perpendicular to Kailua Beach at approximately 1,000 ft. intervals. The exact spacing was dependent on the stable reference points available. The location of these transects is shown on a map for Kailua Beach (Fig. #6).

On each transect, the distance from stable reference points to the water line and vegetation line was measured over the 30 year observation period. For transects #1 and #2, data was available only for the past eight years due to a lack of suitable reference points.

For the Kailua Beach Park area, transect #13 on the map, additional photographs were provided by the Army Corps of Engineers for 1959, 1961, 1962, 1966 and 1970. This historic data was combined with the six flight lines used in this study to draw cumulative movement curves for the vegetation and water lines (Fig. #7). On the diagram, the results are compared with a previous aerial photographic study for Kailua Beach Park (Noda, 1977). The maximum deviation between any of the data points for the two curves on the water line is about 14 feet. These deviations are due to the errors inherent in the methods involved as well as different interpretations on the correct position of the land-water boundary on a photograph. Even with the deviations present, the two curves show the same historic trends in the position of the water line.

The exact location of the water line is dependent on seasonal and long term changes in the beach profile. Therefore, a better indication of long term beach trends is the position of the vegetation line. When the cumulative movement curve for the vegetation line is compared with the two water line curves, a very strong coincidence is shown except for two major differences (Fig. #7). For the period from 1963 to 1966, the net change in the water line was +45 feet while that for the vegetation line was -12 feet. The cumulative curves also deviate in the indicated range in beach change. From the water line curve, the apparent long term range is approximately 158 feet while the vegetation line indicates a historic range of about 134 feet.

Generally, the water line and vegetation line can be used to determine past long term trends provided the seasonal fluctuations are small in relation to the long term changes. For the Kailua Beach Park area, this requirement is satisfied. However, on some sections of Kailua Beach where the long term changes are relatively small, the apparent trends from the water line and vegetation line are quite different (Fig. #8). From the diagram, the vegetation line appears relatively stable except for the period from 1957 to 1963. Information obtained on the water line shows a considerbly different trend. The net changes in this line are greater than 24 feet for all observation periods from 1949 to 1975. Only for the time from 1975 to 1978 does the position of the water line indicate any degree of stability. Since the location of the water line is affected by seasonal fluctuations of the beach, the description of long term beach trends in this report is based primarily on vegetation line data.

Historic shoreline movement curves for each transect are drawn from six photographic flight lines, except for the Kailua Beach Park area, where eleven flight lines are used. A comparison of cumulative movement curves based on six and eleven data points reveals the problems in determining historic trends from alimited time sample of the beach (Fig. #9). The curves for the eleven observation points document beach changes more accurately. In this example, the total range in shoreline movement has been underestimated by using only six flight lines. However, the six monitoring points do define all significant trends in long term beach change. Also, using eleven data points is almost twice as expensive and time consuming as six. When all factors are considered, it seems that for Kailua Beach, an approximate five year monitoring interval represents a good compromise between economy and accuracy of results.

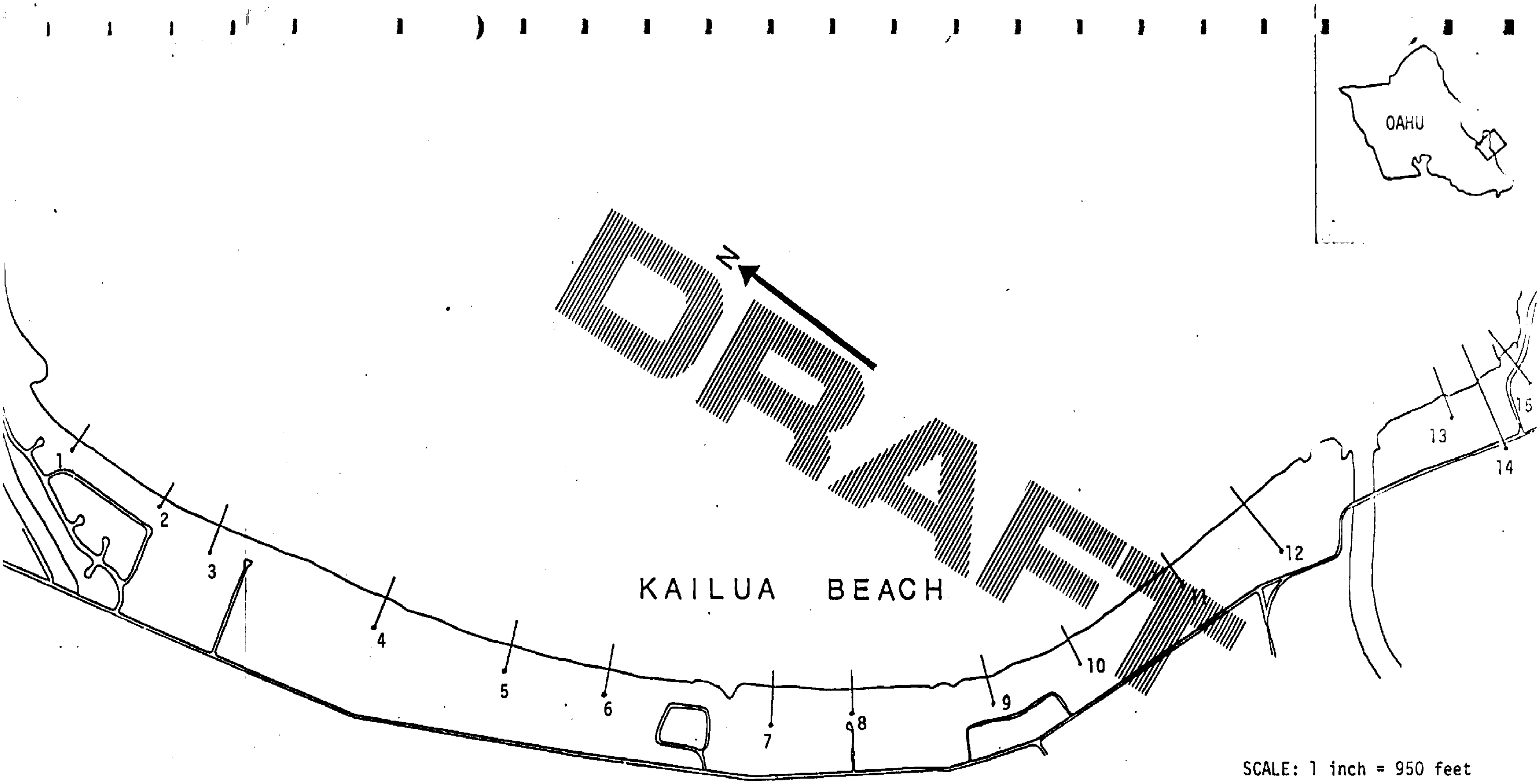
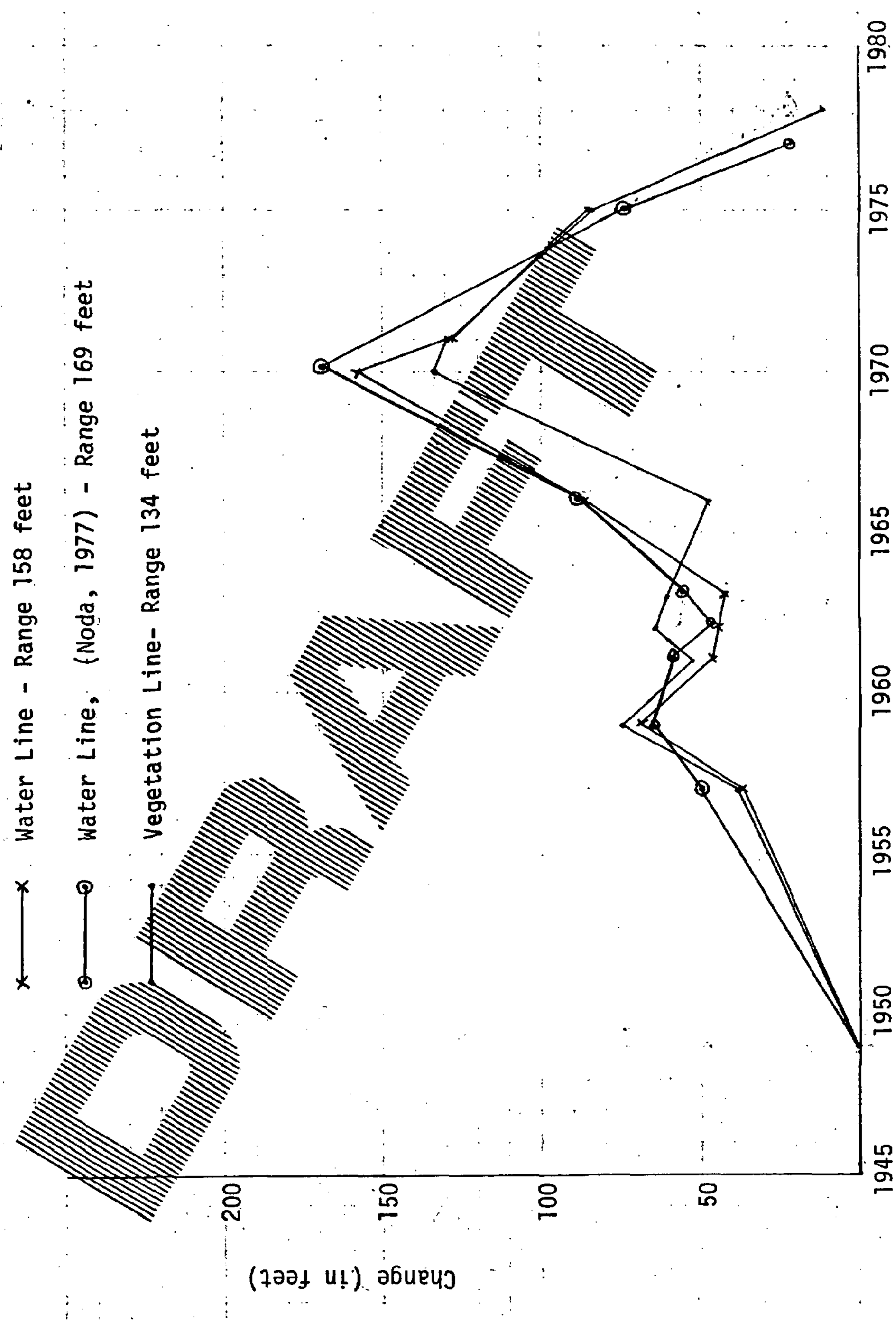


Fig. #6. The location of the transects established at Kailua Beach.

Fig. # 7 Historic Cumulative Shoreline Changes for Transect #13



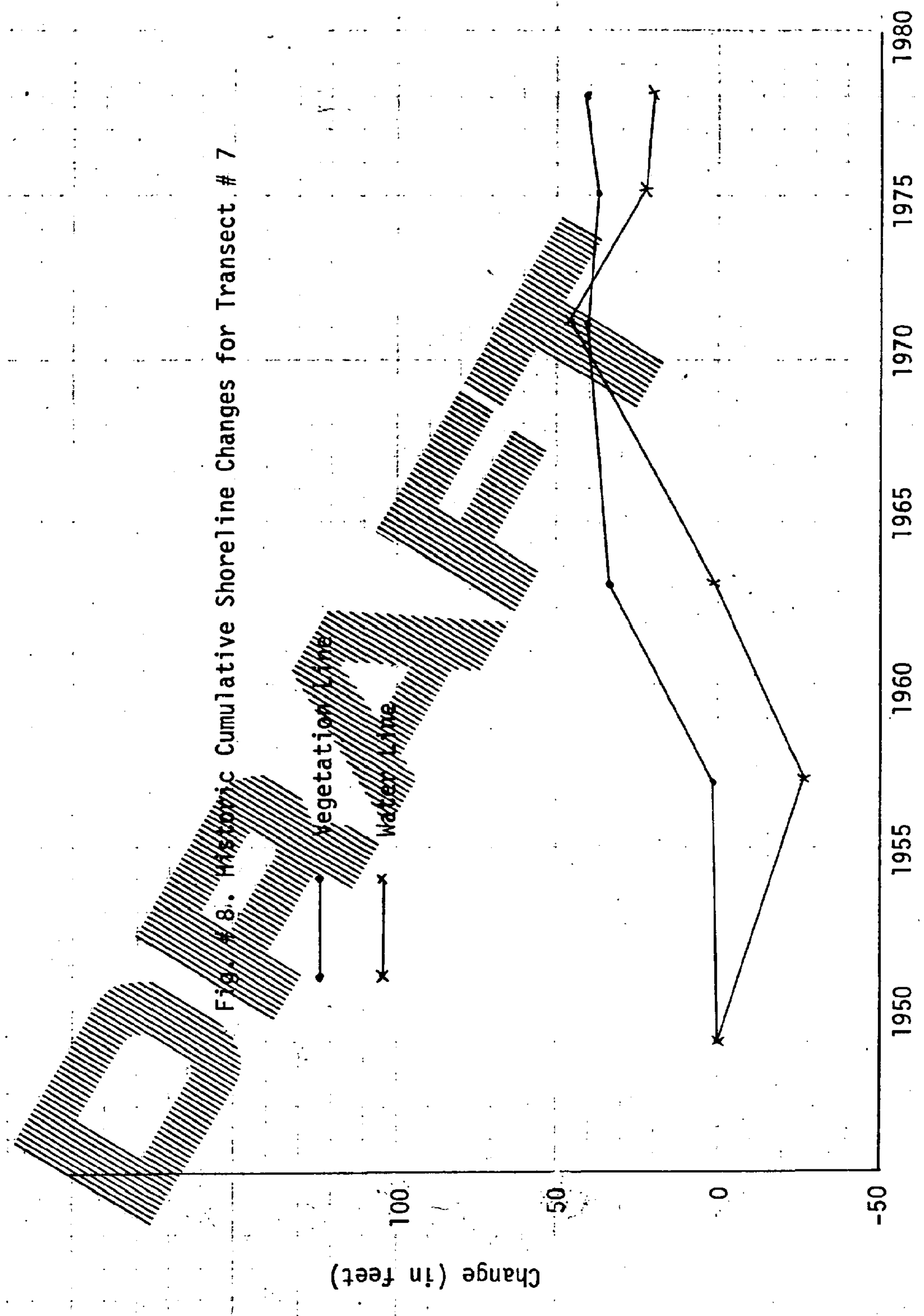
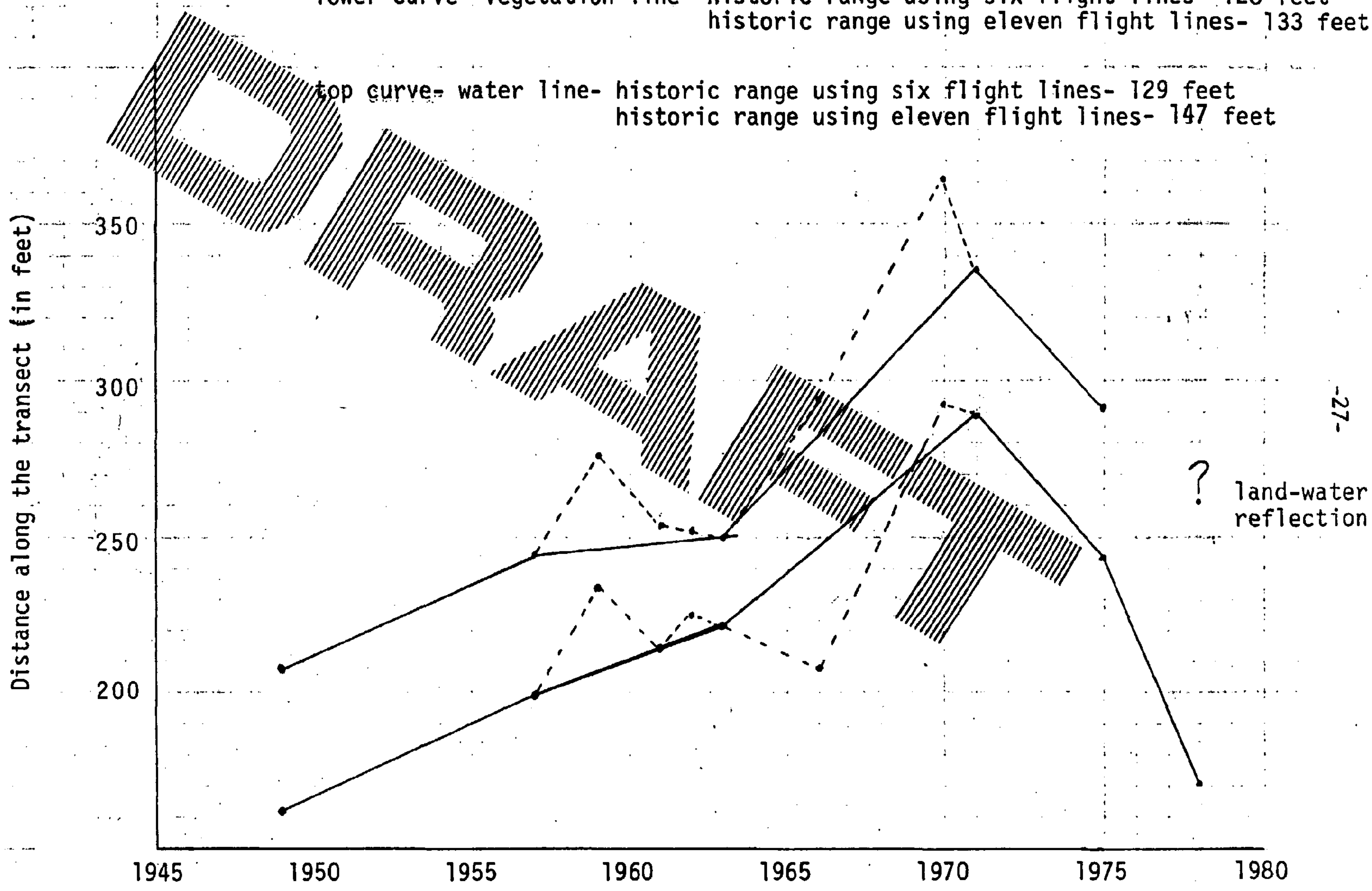


Fig. #8. Historic Cumulative Shoreline Changes for Transect # 7

Fig. #9. Cumulative movement curves based on six and eleven flight lines for transect #13.

lower curve- vegetation line- historic range using six flight lines- 128 feet
historic range using eleven flight lines- 133 feet

top curve- water line- historic range using six flight lines- 129 feet
historic range using eleven flight lines- 147 feet



RESULTS

Table #4 summarizes the historic changes in the position of the vegetation line for the fifteen transects. From the data, several interesting trends are apparent. Within the total littoral cell known as Kailua Beach are three distinct units or subcells. Although the sand transport processes in any of the subcells is dependent on the others, each unit seems to behave as a separate entity.

For the period from 1949 to 1957, Kailua Beach grew throughout its entire length except for the middle portion between transects #7 and #9. During the monitoring interval from 1957 to 1963, accretion was also prevalent with especially high growth in the middle section of the beach.

It is not obvious why the middle portion of Kailua Beach changed the way it did for these two observation periods. However, when the two monitoring intervals are combined, and net changes computed from 1949 to 1963, all transects show the beach growth to be more regular. This fact may be an important clue to the beach processes operating at that time. Since an aerial photograph represents only a spot observation, it may be possible that the 1957 photographs recorded unstable conditions for the central part of the beach. An examination of the 1957 photographs does show the shoreline changing its orientation abruptly in this area. During the monitoring interval, from 1957 to 1963, the middle portion of the beach grew about twice as much as adjacent parts to realign itself with other sections of the shoreline.

For the next three observation periods, from 1963 to 1978, an interesting pattern of beach change is clearly seen from the data. While one end of Kailua Beach is accreting, the other end is retreating. The middle sections tend to remain relatively stable. This conclusion is also supported by the historic ranges in the position of the vegetation and water lines.

During the monitoring interval from 1963 to 1971, the southeast of Kailua Beach was in an accreting cycle while the opposite end retreated by as much as 40 feet. For the two observation periods from 1971 to 1978, the trend reversed, and resulted in significant erosion at Kailua Beach Park while the Kaneohe end of the littoral cell grew considerably.

The cyclic trend of erosion and accretion at opposite ends of Kailua Beach is similar to the seasonal changes on other Hawaiian beaches, such as on Lumahi Beach on Kauai (Moberly and Chamberlain, 1963). This pattern indicates that sand eroded at one end of the beach is transported to the opposite end. Therefore, it should be realized that any structures designed to horde sand at one end of the littoral cell may starve all down drift sections of the beach.

Any shifts in the trend of beach change reflect reversals in the direction of long term littoral transport. Two possibilities are presented to account for these reversals.

Table #4 Net Changes of the Vegetation Line for the Five Observation Periods

Transect #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1949 - 1957	-	-	+25	+42	+41	+32	-1	+18	-13	+23	+30	+34	+37	+30	-1
1957 - 1963	-	-	+20	+17	+7	+19	+34	+34	+45	+18	+3	+14	+22	+51	+77
1963 - 1971	-	-	-40	-13	-20	-15	+6	-3	-9	+6	+18	+40	+69	+65	+51
1971 - 1975	+34	-	+45	+17	+29	+18	-3	-12	-13	-6	+1	-23	-46	-72	-26
1975 - 1978	+10	+17	+11	-6	-3	+2	+3	+7	-7	+9	+7	-2	-73	-48	-14
Maximum range in the vegetation line between 1949 and 1978	-	-	61	63	57	56	40	52	54	50	59	88	128	146	128
Maximum range in the water line between 1949 and 1978	-	-	68	63	79	69	73	57	56	65	59	115	129	170	175

- no data

1) It has been suggested that the direction of littoral transport varies seasonally for Kailua Beach (Noda, 1977). During the summer months, strong persistent trade wind waves tend to transport sand to the northwest. In the winter, sand transport may be to the northwest or southeast, depending on the interaction of trade wind waves with North Pacific Swell. According to this concept, the direction of long term littoral transport would be to the southeast if unusually strong or persistent North Pacific Swell occurred over a multi-yearly period.

2) It is also possible that a shift in the direction of the trade winds causes the reversals. Since the orientation of Kailua Beach is almost perpendicular to the northeast trade wind direction, any fluctuations in this wind system would have a pronounced affect on the direction of littoral drift. If over a ten year period, the trade winds blew from a more easterly directon than usual, erosion may result at Kailua Beach Park and accretion at the opposite end of the littoral cell. This trend may be reversed if the trade winds blew from a more northerly direction, when averaged over a multi-yearly period.
According to Wentworth (1949), the trade winds shifted in direction from northeast to east and back to northeast over a period of 40 years (Fig. #10). If trade wind cycles of this periodicity are the rule, then beach changes at Kailua Beach may also have a natural cycle of 40 years.

While the two hypothesis presented have been mentioned separately, they are not mutually exclusive. For example, the long term direction of littoral drift may be to the southeast for active winter wave activity accompanied with a northerly shift in the trade winds.

Since the littoral processes on Kailua Beach are dependent on meteorological factors, an accurate prediction on beach changes would require a knowledge of future weather conditions. While our ability to forecast trade wind directions or North Pacific Swell activity is limited, it should be realized that the historic record for Kailua Beach shows a tendency towards cyclic erosion and accretion. Therefore, these cycles may occur in the future. This means that trees, houses or any other sructures must not be placed on that portion of an accreting beach which may retreat many years later as part of the natural cycle. Unfortunately, this practice has not been followed for several sections of Kailua Beach. For example:

1) During the period from 1949 to 1971 the vegetation in front of transect #13 grew about 128 feet. Within this time interval, two rows of trees were planted approximately 95 feet and 40 feet inland of the 1971 vegetation line. Between 1971 and 1978, the vegetation retreated about 119 feet to the position where the 1978 vegetation line was within ten feet of its 1949 location. Needless to say, many trees fell in the water.

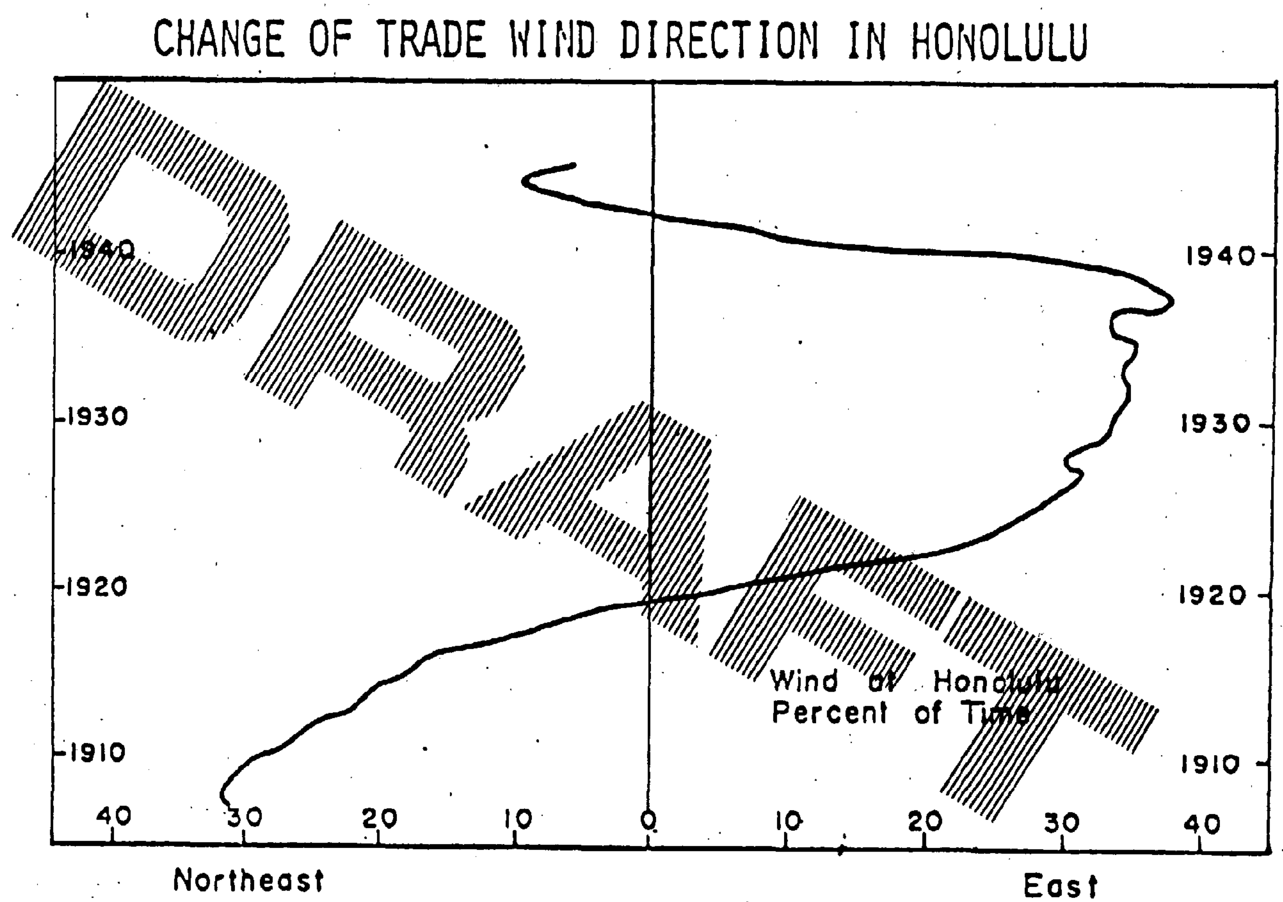


Fig. #10 The five-year running mean of the frequency of wind direction at Honolulu according to Wentworth (1949). A point at the center line indicates that wind from the easterly and northeasterly sectors was observed equally often. A point at 10 East indicates that the ratio of winds observed from the easterly and northeasterly sectors is 60:40.

(in Wyrtki, 1975)

2) From 1949 to 1978, the net change in the position of the vegetation line for transect #8 was +44 feet. During this period a house was built 35 feet inland of the 1978 vegetation line. If the beach retreated to its 1949 position, this house would be undermined.

3) Between transects #5 and #6, the vegetation grew about 54 feet over the 30 year observation period. Five houses have been built along this stretch and are located from 47 to 40 feet landward of the 1978 vegetation line.

4) Approximately 300 feet south of transect #3, the vegetation grew 61 feet over the 30 year monitoring period. A house was constructed at this location about 32 feet inland of the 1978 vegetation line. In fact, this house is situated within 10 feet of the 1949 land-water boundary. This is an especially precarious position since the house is located near the end of the beach where changes are of greater magnitude.

It cannot be predicted whether any section of the beach will retreat to its 1949 position. The cumulative movement curves for most of the transects show a general increasing trend (Appendix A). However, the Kailua Beach Park area showed a general increasing trend for 22 years until rapid erosion began without any forewarning. Since our knowledge of the littoral cycles at Kailua Beach is imperfect, it would be wise to keep all future development well inland of the most withdrawn historic position of the vegetation line, as determined by aerial photographs. If this practice is followed, extensive property damage may be avoided in the near future. For, the historic record indicates that Kailua Beach is a dynamic zone which will continue to change through natural cycles of erosion and accretion.

CONCLUSION

The use of aerial photographs to document historic shoreline changes is an economical and time efficient method.[1] Most of the work can be conducted in the office, except one field trip should be made to check or obtain ground control. Even then, the use of aerial photographs greatly reduces the amount of field measurements because ground control can be accurately extended by the methods prescribed in this report. Another advantage in using aerial photographs is that imagery of the Hawaiian coastline has been obtained more frequently in the past 30 years than maps, charts or surveys have been compiled. Perhaps, the lack of aerial photographic studies for beaches on Hawaii can be attributed to the questionable accuracy of the measurements made.

In this study, a method is presented with a maximum estimated error of about 12 feet for measuring beach changes. This is believed to be an accurate estimate, as indicated by a comparison of field and photographic measurements and by the consistent distances obtained for nearby sections of the beach in the Kailua pilot study. While a 12 foot measurement limitation may seem large, this figure is sufficiently accurate to meet the objectives of this project for two reasons. First, any anomalous measurements can be checked because the almost infinite amount of ground detail on a photo allows more transects to be established. Secondly, the extreme ranges in long term beach change make any accuracy limitations less critical. For example, the minimum historic range in the position of the vegetation line for the Kailua Beach study was 40 feet while the maximum was 146 feet.

The methods described in this report were applied for a pilot study of Kailua Beach. It was found that the entire beach grew from 32 to 81 feet during the period from 1949 to 1963. During the next three monitoring intervals, a pattern of erosion at one end of the beach and accretion at the opposite end is clearly shown from the data. From 1963 to 1971 the south end of Kailua Beach grew by as much as 69 feet while the Kaneohe end of the littoral cell retreated up to 40 feet. The direction of net littoral drift shifted, as indicated from data for the next two observation periods, which show significant erosion at Kailua Beach Park while the north end of the beach grew considerably.

Effective management of the beach requires information about the long term changes to be expected in this zone. To actually forecast beach changes may be difficult or impossible due to a number of unpredictable variables such as storms or long term weather conditions. However, by studying historic shoreline movements, a knowledge is gained of the trends, rates and ranges of change which are possible for any particular beach. These possible changes must be considered whenever proper planning decisions are made. For example, development on portions of Kailua Beach in the process of an accreting cycle should be avoided because beach retreat may result in the future as part of the normal sequence. This practice has not been followed for several sections of the beach, although the historic record shows a definite cycle of erosion and accretion.

When the time and cost of an aerial photographic study is weighed against the wealth of information to be obtained,[1] it is evident that this method of beach monitoring should be extended to all sections of the coast. This report has shown that aerial photographs may be used for a general reconnaissance as well as for planning purposes and sedimentological studies.

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1. Based on the Kailua Beach Study, it has been calculated that each mile of beach requires approximately 20 man hours and $130.00 of photographs.

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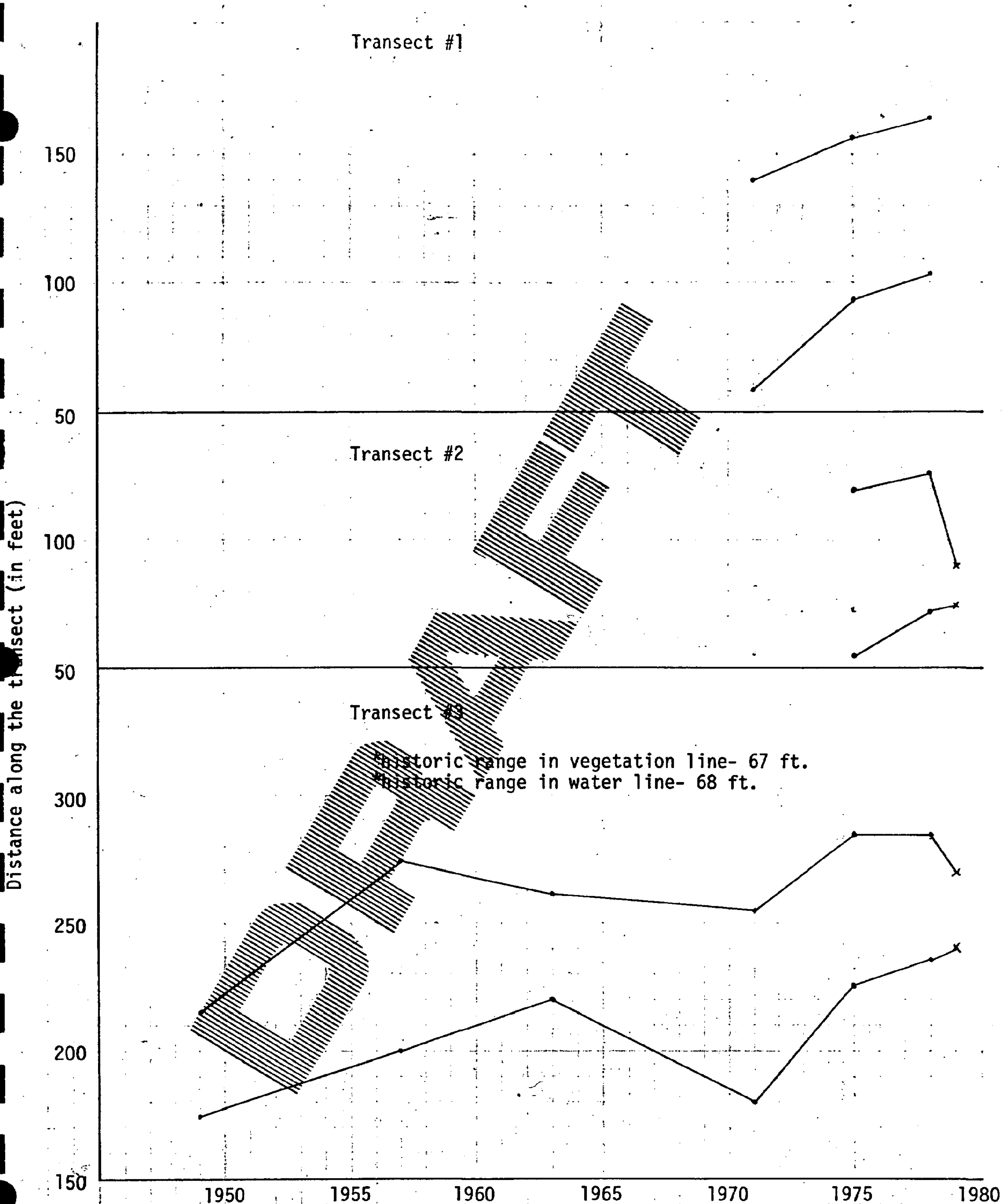
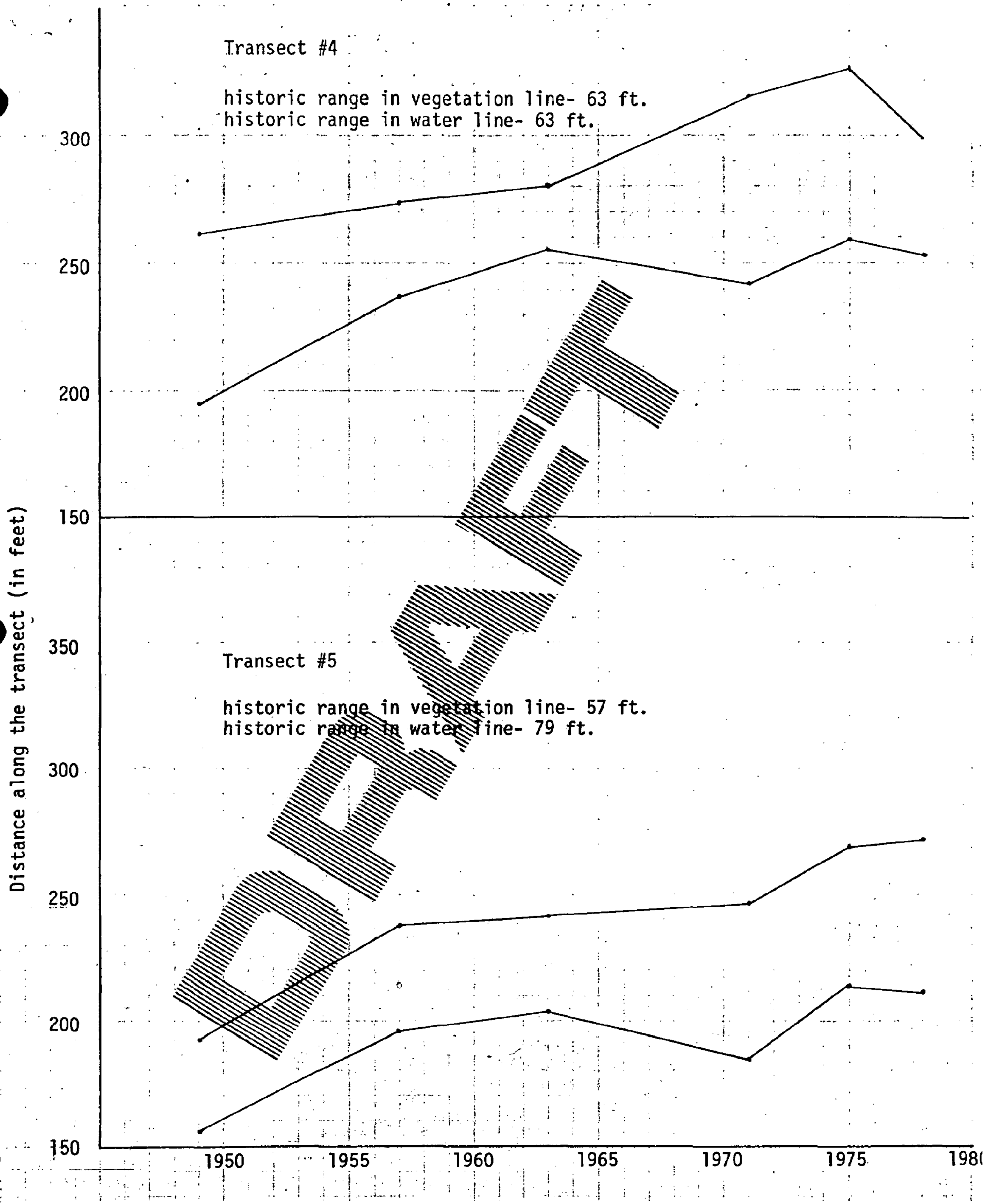
DRAFT

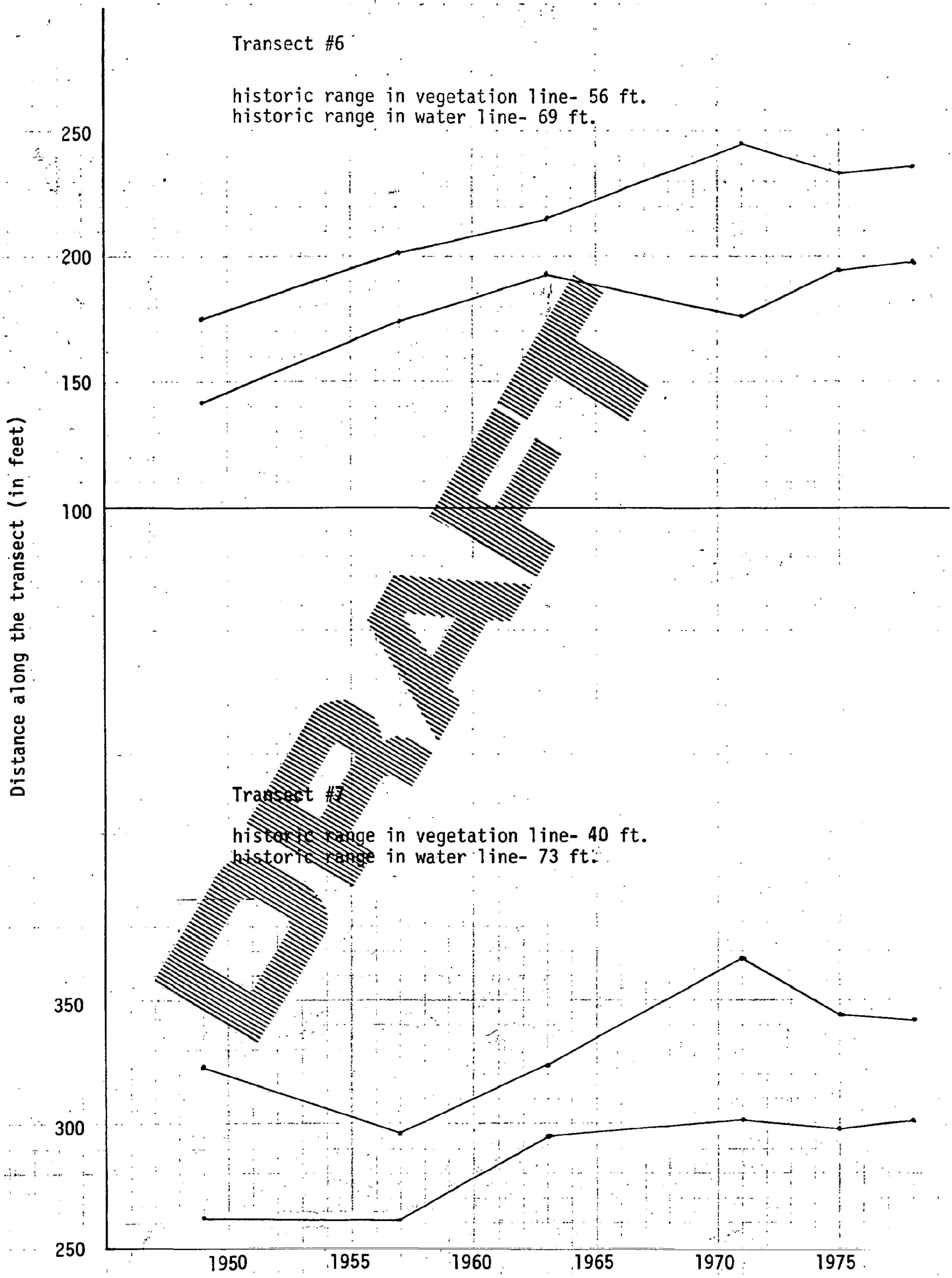
APPENDIX A

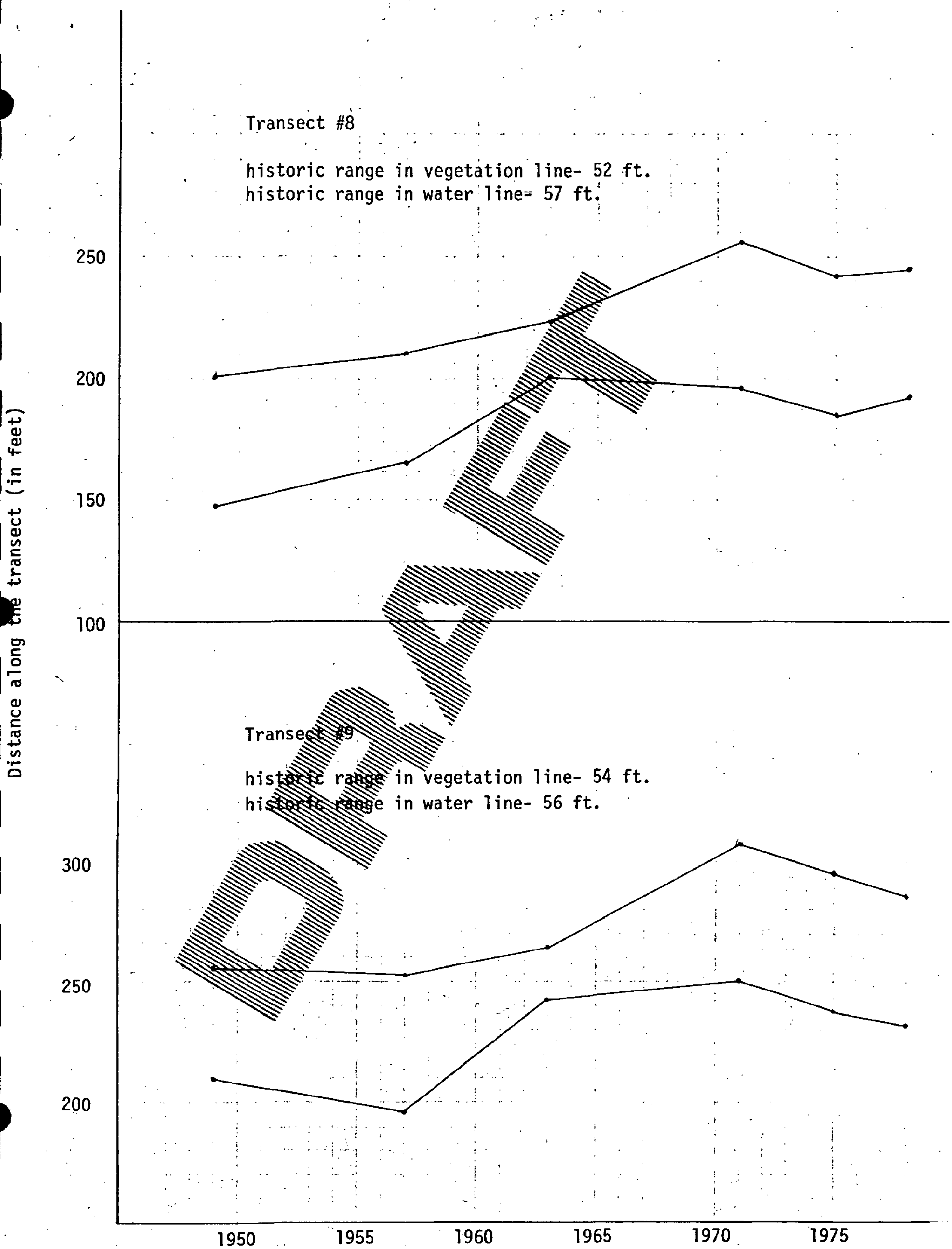


x - based on June, 1979, field measurements

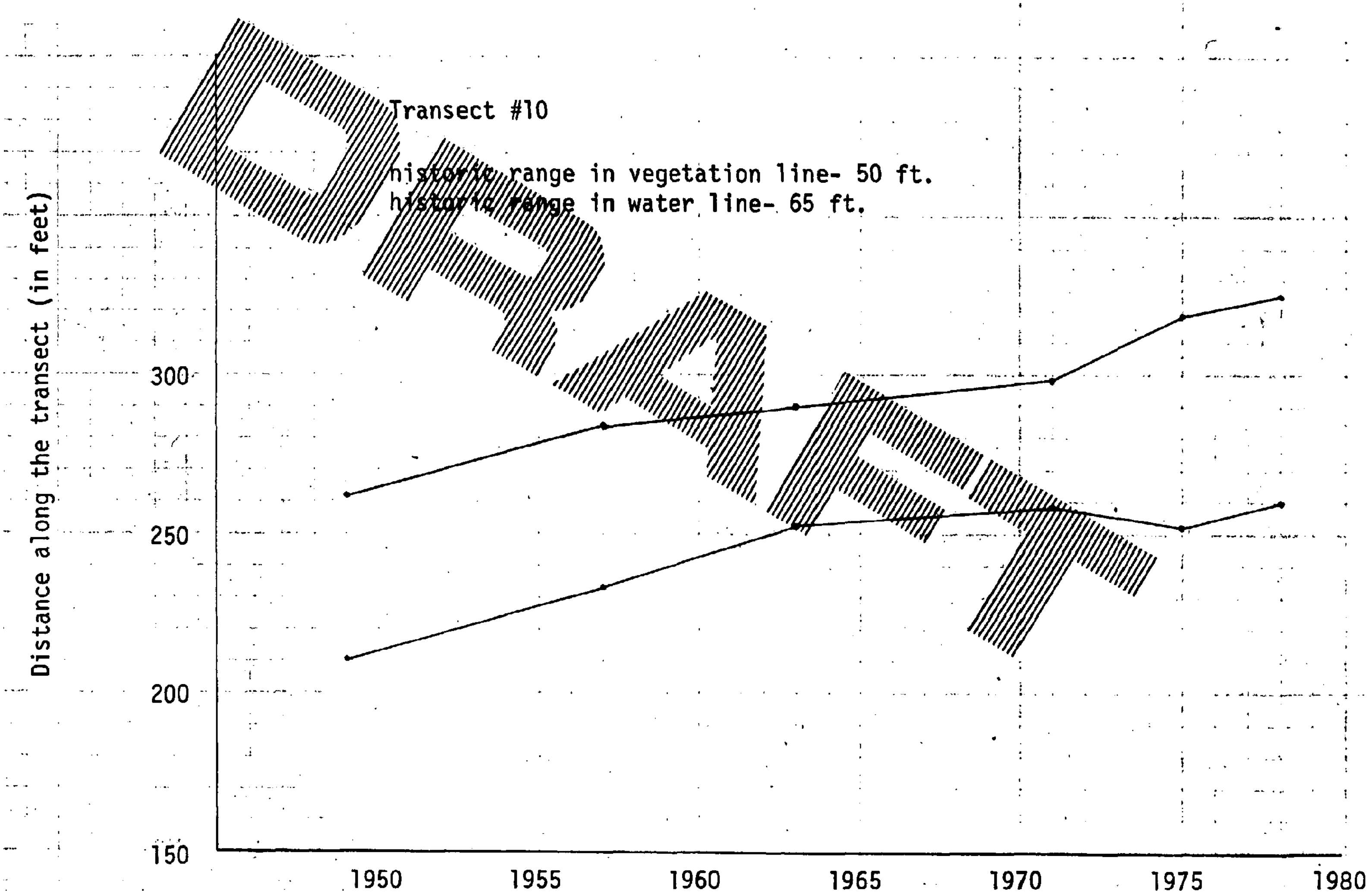
* - includes June, 1979, field measurements


Transcect #4
historic range in vegetation line- 63 ft.
historic range in water line- 63 ft.
Transect #5
historic range in vegetation line- 57 ft.
historic range in water line- 79 ft.
Distance along the transect (in feet)
300
250
200
150
350
300
250
200
150
1950
1955
1960
1965
1970
1975
DRAFT


Transect #6
historic range in vegetation line- 56 ft.
historic range in water line- 69 ft.
Transect #7
historic range in vegetation line- 40 ft.
historic range in water line- 73 ft.
Distance along the transect (in feet)
250
200
150
100
350
300
250
1950
1955
1960
1965
1970
1975
DRAFT

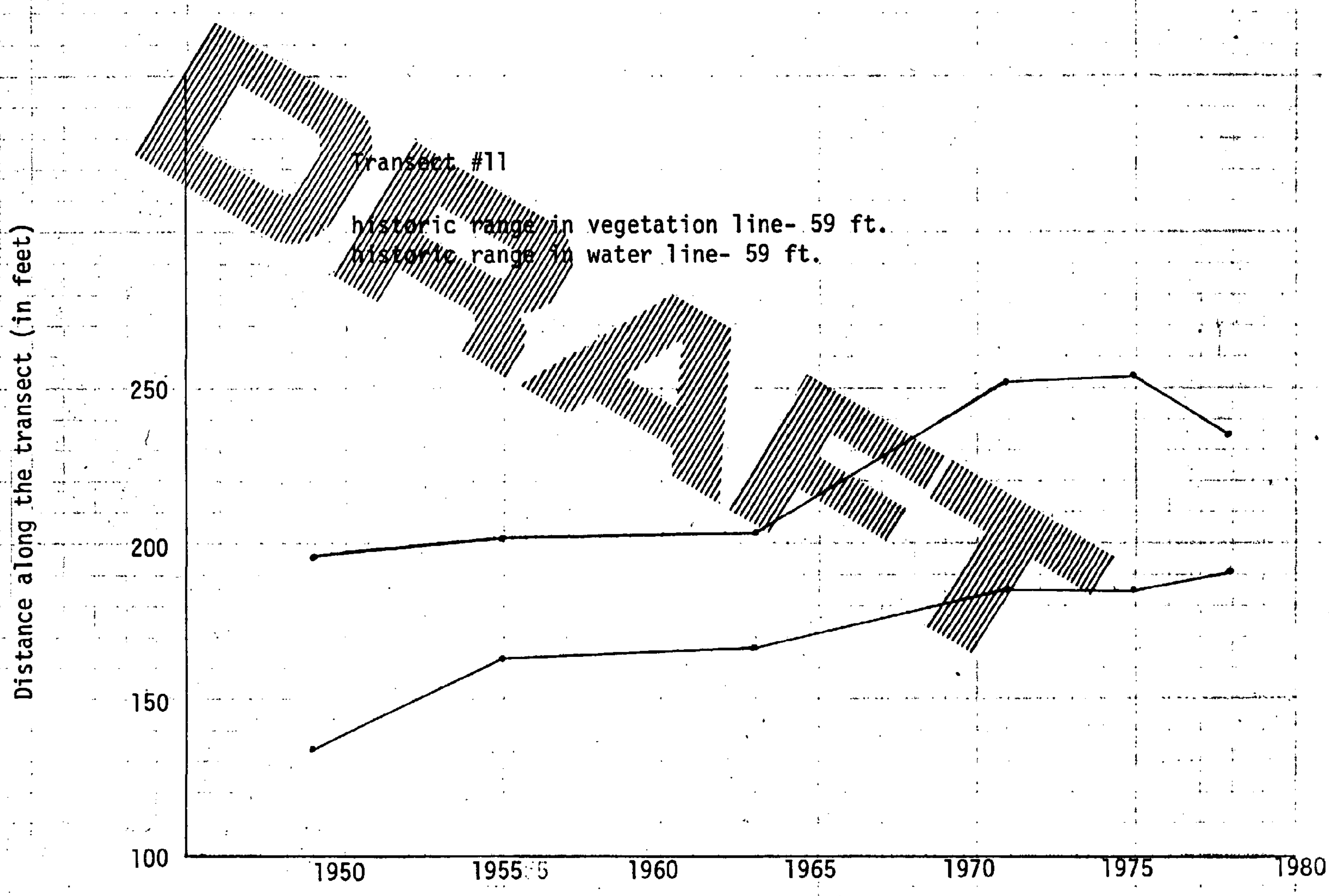

Transect #8
historic range in vegetation line- 52 ft.
historic range in water line= 57 ft.
Transect #9
historic range in vegetation line- 54 ft.
historic range in water line- 56 ft.
Distance along the transect (in feet)
250
200
150
100
300
250
200
1950
1955
1960
1965
1970
1975

57-10

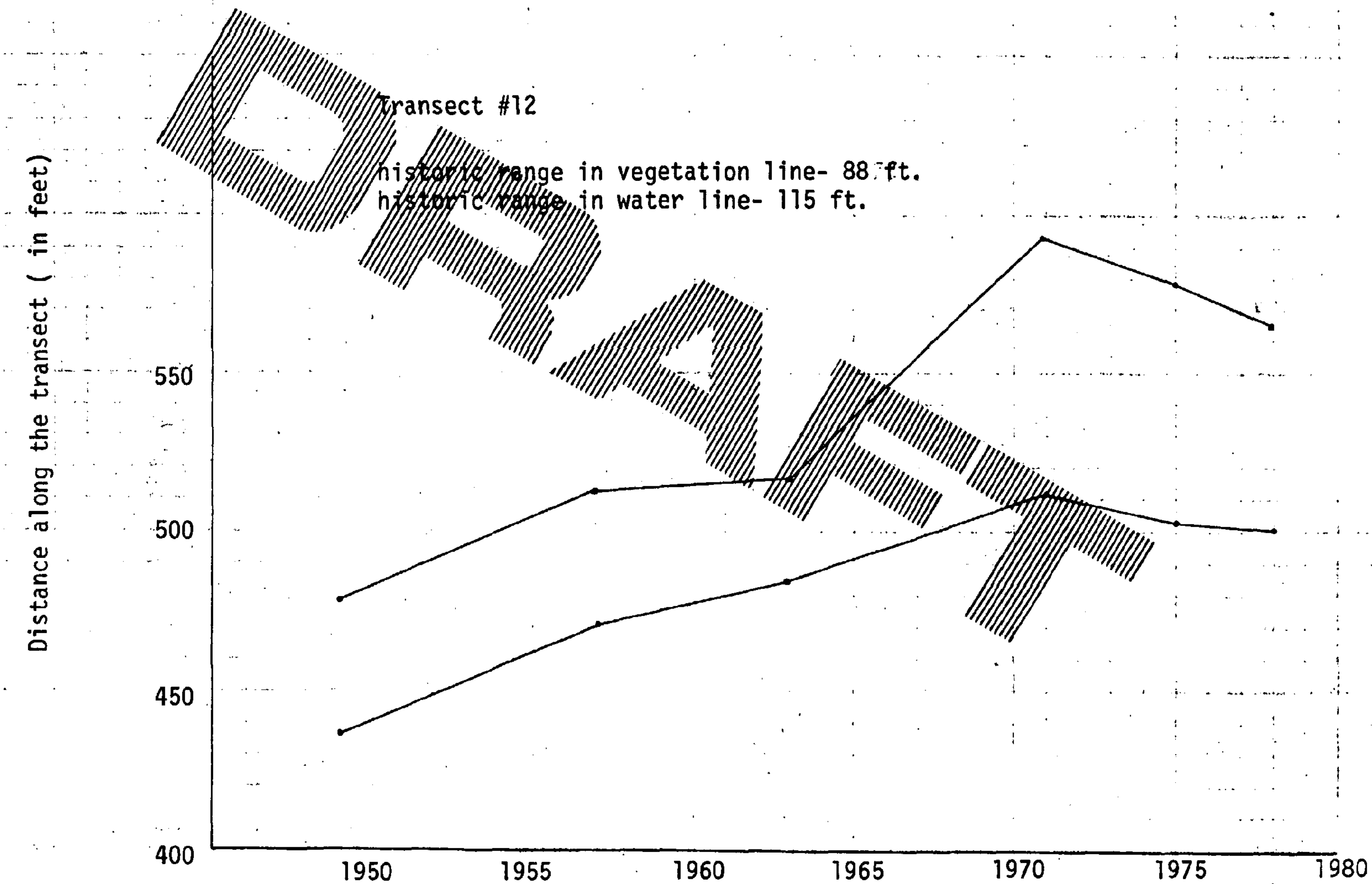

Transect #10
historic range in vegetation line- 50 ft.
historic range in water line- 65 ft.
DRAFT
Distance along the transect (in feet)
300
250
200
150
1950
1955
1960
1965
1970
1975
1980

55
49-78

55

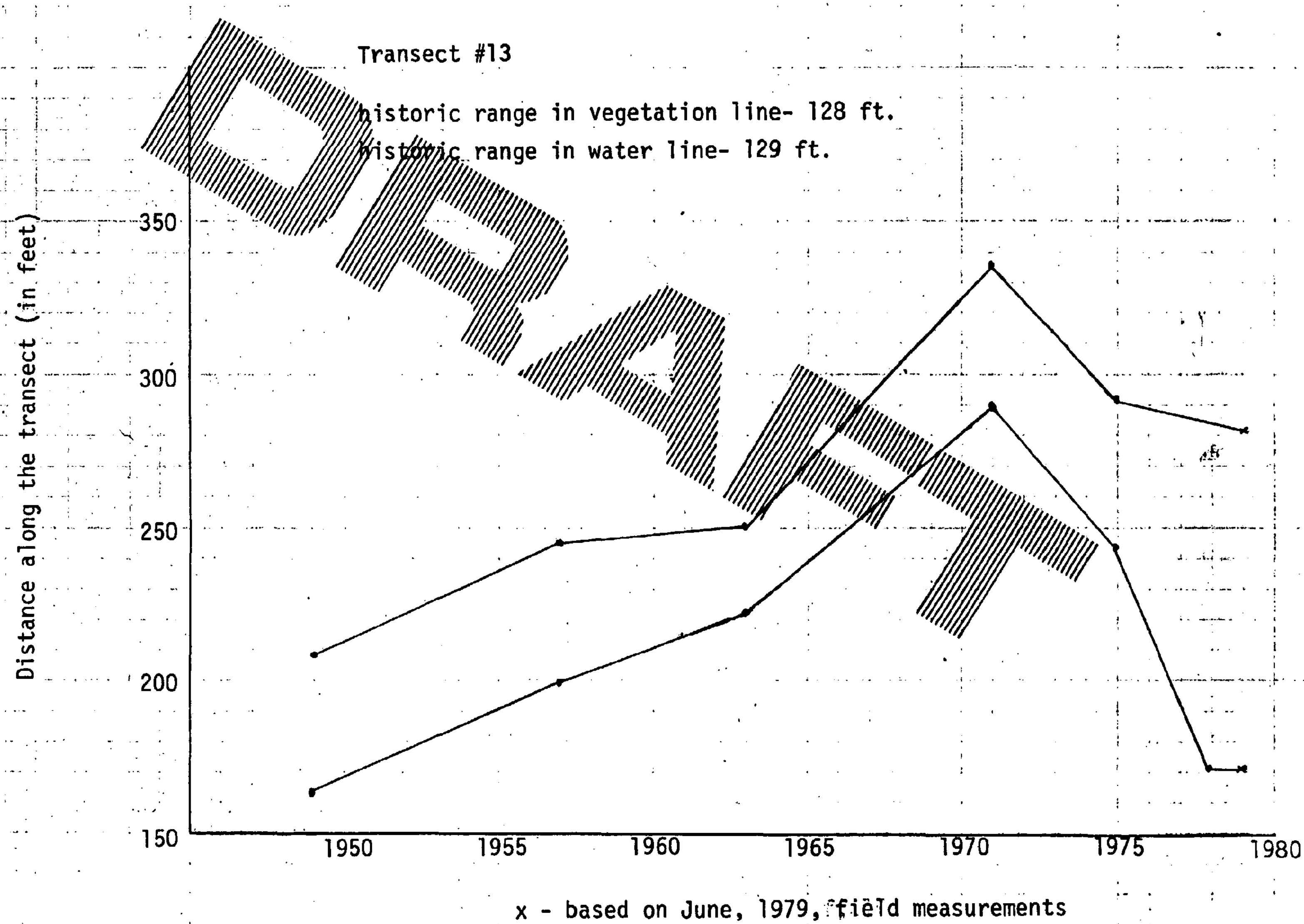

Transect #11
historic range in vegetation line- 59 ft.
historic range in water line- 59 ft.
DRAFT
Distance along the transect (in feet)
250
200
150
100
1950
1955
1960
1965
1970
1975
1980

54



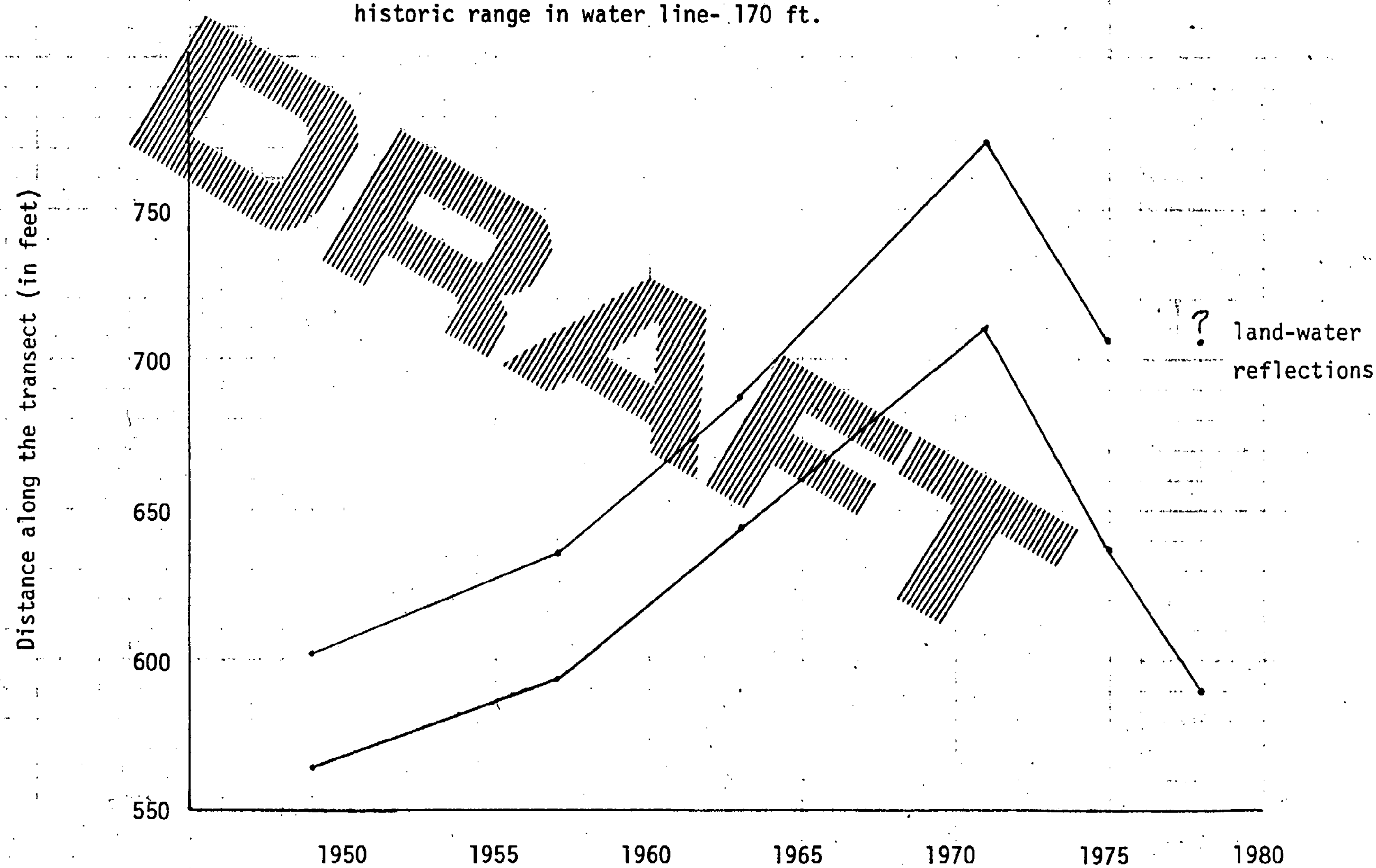
Transect #12
historic range in vegetation line- 88 ft.
historic range in water line- 115 ft.
DRAFT
Distance along the transect (in feet)
550
500
450
400
1950
1955
1960
1965
1970
1975
1980

52


Transect #13
historic range in vegetation line- 128 ft.
historic range in water line- 129 ft.
DRAFT
350
300
250
200
150
1950
1955
1960
1965
1970
1975
1980
Distance along the transect (in feet)
x - based on June, 1979, field measurements

Transect #14

historic range in vegetation lines- 146 ft.
historic range in water line- 170 ft.



50

Transect #15

historic range in vegetation line- 140 ft.
historic range in water line- 188 ft.