Coastal Engineering Technical Note

MEASURING SHORELINE CHANGE

PURPOSE: Knowledge of past and present shoreline changes is essential information for most planning and engineering projects in the coastal zone. This information can be obtained from either continuous field surveys or from current and historic maps and/or air photos. The latter does not require extensive field time nor expensive equipment and, therefore, is often the most economical means of obtaining shoreline change data. Historical maps dating back to the mid to late 1800's and air photos beginning in the 1930's are available for most of the U.S. shoreline, providing a length of record which is not usually available with field surveys.

BACKGROUND: Shoreline change measurements made from maps can be accurate provided the maps meet or exceed National Map Accuracy Standards. These standards prescribe that "on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 0.846 mm measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, .508 mm. These limits of accuracy shall apply in all cases to positions of well-defined points only" (Ellis 1978). Measurement errors due to the map scale are an important consideration. For determination of shoreline change it is important that maps with a large scale be used. At a scale of 1:24,000, stable, well-defined points can have an allowable error of up to 0.5 mm at the map scale, which corresponds to an error of 12 m in the actual location of that point. Other points on the map which are not as well defined, such as those composing the shoreline, are located with less accuracy (Tanner, 1978). Therefore, unless the rates of change in shoreline are large (>4 m/yr) and a long period of record is used, U.S. Geological Survey Topographic quadrangles are not sufficiently accurate to measure the changes occurring along much of the U.S. coastline. National Ocean Service (NOS) maps and charts are another source of shoreline data. Most commonly used are the NOS T-sheets, which are generally the product of field surveys and meet or exceed National Map Accuracy Standards. At a scale of 1:10,000 the potential error in actual location of stable points is 8.5 m. Additionally, these maps

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have a long period of record; the oldest ones going back to the 1830's. Prior to the late 1870's, there were no strict standards for the surveying of these maps. The usual procedure was to use a combination of triangulating and hand sketching. The accuracy of the map, therefore, depends on the ratio of triangulating to sketching, which was dependent on the standards maintained by the individual surveyor. It should be noted that their main purpose was to map the shoreline, so its accuracy was probably not treated lightly. The use of these early maps is reasonable provided potential errors are recognized and stated. Other maps and charts, made for specific locations, may be available as data sources also. When combining several types of maps for use, it is important to note which tidal datum the shoreline is based upon. U.S.G.S. topographic maps use mean sea level, and NOS T-sheets and charts use mean-low-water. On gently sloping beaches with a moderate tidal range, the difference can be significant and corrections to the same tidal datum must be made.

The use of air photos as a tool for the measurement of shoreline change began in the late 1960's (Moffitt 1969; Stafford and Langfelder 1971). Prior to this, photos had been used to qualitatively assess changes in coastal landforms. Vertical black and white air photos date back to the late 1920's, but reasonably good quality stereo photos were a product of the 1930's. Air photo missions have been flown by numerous Federal, state, and private organizations, and photos can generally be ordered for a fee. The first step is to determine what photography is available for the area in question. Indexes to available aerial photography have been compiled for some coastal localities. Copies of flight lines can be obtained from each of the appropriate vendors, from which photo sets can be ordered. An aid in determining the availability of older photography (pre-1978) is the Coastal Imagery Data Bank at CERC, WES (CETN II-1, 2/80). Errors in direct measurement of shore-line change from aerial photography can result from several factors. Slight changes in elevation of the airplane above the mapping target can cause scale variations between successive photos in a flight line. Problems of image tilt can occur if the aircraft was not perfectly horizontal with the ground. Relief or elevation distortion is another potential problem, but generally the low relief of the coastal zone minimizes this distortion. Since only one point on the photo is directly below the camera, there is some radial distortion away from that point on

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every photo. On older photos lens distortion may also introduce an error. In general, using only the central portion of the photo, and using low altitude photos to get maximum resolution, will keep potential sources of error as small as possible. In some cases it may be possible to obtain rectified photos, or to use one of several techniques to rectify the photos that are available. One other point to consider when comparing different photo sets or photos and maps is the tidal stage at the time the photos were taken. The actual tide stage can be determined using the time clock and date shown in the margin of most photos.

PROCEDURE:

1. Maps and Charts

Measurement of shoreline changes from maps requires a recent set of maps and as old a set of accurate maps as possible. Intermediate dates can prove useful for a more complete temporal representation of the shoreline changes. If possible, these map sets should be at a common scale. Control points are then located on the maps from which the distance to the shoreline can be measured. These points must be stable through time, such as road intersections, building corners, benchmarks, etc., and each point must be visible on all map sets being used. Accurate location of these points on the maps is an essential step. In a few cases the scale of the map may be such that no stable control points are visible. Bends in tidal creeks and unusual point in a bay shoreline are examples of points which have been used with some success. When all the map sets in use are of the same type (e.g. all are T-sheets) then the intersections of the geographic coordinate system lines on the map can be used as control points.

The easiest procedure with common scale maps is to overlay them on a light table with control points aligned. Four to six widely scattered control points per map are sufficient. Once overlayed, the differences in shoreline position can be measured directly perpendicular to the trend of the beach at a regular interval. The measurement interval depends on the physical characteristics of the area, the desired spatial resolution, and time/cost considerations. Recent studies have used intervals ranging from 25 m to 500 m. The shoreline changes measured can then be divided by the number of years spanned by the maps to determine the mean annual shoreline change rate. This

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technique also allows tracing of the shorelines onto the most recent base map to produce a shoreline change map.

If the map sets are of varying scales the above procedure will have to be modified slightly. One option is to use a projecting device, such as a Map-o-Graph or Zoom Transfer Scope to enlarge or reduce all the maps to a common scale. At this point the procedure is the same as described above. If no projecting device is available for bringing all the maps to a common scale, measurements of shoreline change can still be made. Unless a digitizer is available, a shoreline change map cannot be constructed. This case requires selection of control points at regular, frequent intervals. Measurement of the distance from each control point perpendicular to the shoreline is then made on each map set. These measurements can be converted mathematically to a common scale. The data for each control point are then compared over the span of years to detemine the net shoreline change and the rate of change at each location.

The use of an X-Y digitizer can improve measurement accuracy and greatly speed up the measurement proces, thereby allowing for a greater density of measurement and a high degree of spatial resolution. The exact procedure will depend on the digitizer used and the computer software available. The control points on each map set can be used to standardize orientation of the maps. Then the shoreline can be digitized at a regular interval. The digitized shorelines for each map set can be compared to determine the shoreline change over the span of years. Attached calculators and plotters may allow for compensation of scale differences and plotting of shoreline change maps.

2. Aerial Imagery

The use of vertical air photos for measuring shoreline change requires the careful selection of air photo sets. Several points should be kept in mind before ordering air photos. Only the central portion of each photo will be used, so order enough photos to allow a 60 percent overlap. Older photos are apt to have more distortions and fewer control points. Photos taken shortly after storms show the beach in an extreme condition and cannot be easily compared to photos taken during average conditions. The scale of the photos should be large to show enough detail to locate control points, but small enough to show some of the area behind the beach where control points are

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located. This is especially important in areas where the beach is uninhabited and stable control points will be difficult to find. Scales ranging between 1:5,000 and 1:20,000 will be adequate for most projects.

The first step in utilizing the photos is the selection of control points. The number of points depends on the resolution necessary for the project. These should be stable points, visible on all the photo sets. Stereo overlap means the same point may be located on adjacent photographs. The control on photos should not be placed on high cliffs or bluffs, or atop tall buildings adjacent to the beach because of the problem of elevation distortion. Stereoscopic viewing of the photos can be a useful aid in accurately locating control points. Once the control points are located, measurement of the distance from the control points to the shoreline can proceed for each photo set. The measurement should be made near the center of the photo and perpendicular to the trend of the beach. In fact, the actual shoreline has usually not been the line used for measurement. The shoreline is variable due to tide and sea energy conditions and is difficult to accurately compare between photo sets. The high tide line, as distinguished by the change from dark (wet foreshore) to light (dry backshore) grey tones, is most often used (Stafford and Langfelder 1971). This line is usually easy to distinguish on the beach, and while it is also variable through time, the range of variation is smaller than the shoreline. In some cases the dune crest or toe has been used as a measurement reference. The dune represents a time averaged shoreline which filters out the daily perturbations. However, in many localities the dune is nonexistent, or at best, discontinuous and low. This makes measurement and comparison of data over a distance difficult. Whichever line is selected for use, annotating it in advance will help insure proper measurement later. The measurements taken from the photos can be corrected to a common scale and compared for each control point on each photo set to permit calculation of the shoreline change rate. When using this procedure, it is important to frequently check the scale of each photo along the flight line. This can be accomplished by carefully measuring the distance between two control points and comparing it with the actual distance between those points as determined in the field or from a map. If the measures differ, the new scale should be calculated and the shoreline distance measures corrected accordingly.

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Construction of a shoreline change map from air photos can be accomplished by several techniques. These procedures generally allow for the correction of photo distortions prior to actual drafting. A purely manual technique, requiring no special equipment, is outlined in most photogrammetry texts (e.g. Lattman and Ray 1965). A stereoplotter is most often used today by mapping organizations. A third technique is to digitize the control points and shoreline and then submit this data to statistical correction by computer.

Combining air photo and map data sets can allow for a more complete record of shoreline change and a simplified technique for construction of a shoreline change map. By using the central portions of the photo only and overlaying the control points on the photo with the same points on the map, the shoreline data can be drafted onto the map. A simple projecting device, such as a Map-o-Graph or projecting light table can be used to adjust the photo to the scale of the map. However, there is no correction for photo distortions in this procedure; it is only minimized by using the center of each photo. A Zoom Transfer Scope will allow for some simple corrections. Manual photogrammetric techniques, as described above, and equipment such as a Vertical Sketchmaster can be used to develop a map with some rectification. More accurate results require stereo plotters or digitizing with computer rectification. Once a map is constructed, the difference in shoreline positions can be measured or digitized directly at regular intervals. The accuracy or confidence level of the final shoreline change rates depends on several factors. When using maps, the original standards for map construction are important. When using photos, the quality of the photos and the steps taken to limit or correct the effect of inherent photo distortions become critical. Finally, the precision used in locating control points, measuring distances, annotating shorelines, and drafting, influence the final result. Estimates of potential error should accompany change rates so that their true value can be assessed. It must be recognized that the rates of shoreline change derived from this type of analysis cannot be considered absolute. The results indicate the trends in erosion or accretion, and give an estimate of the rates of change.

ADDITIONAL INFORMATION: For additional information, contact Mr. Fred Anders, Coastal Processes Branch, Coastal Engineering Research Center, (601) 634-3043.

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