Measuring Historical Shoreline Change on Maui

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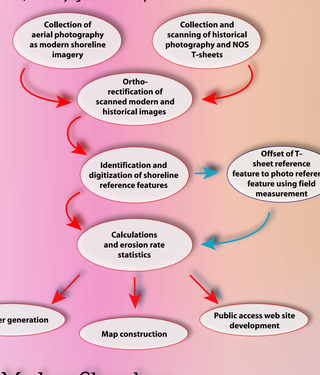
Step 1 — Conceptual Approach

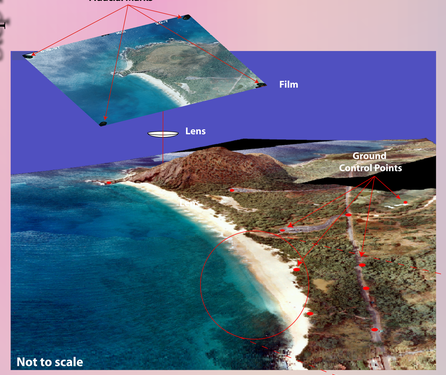
Shoreline areas contain fragile yet dynamic environments that pose potential hazards to human investment in the coastal zone. Because the coastal zone is worthy of special management status, high-precision and high-resolution data depicting the rate and direction of shoreline movements due to erosion and accretion are useful to natural resource managers tasked with preserving coastal resources and regulating development.

The University of Hawaii, under contract with Maui County and with grant funding from NOAA Coastal Services Center, has prepared a map series depicting the erosion and accretion history of beaches on the Island of Maui. Orthorectified aerial photographs and National Ocean Service topographic charts (T-sheets) provide historical documentation of shoreline positions seven to eleven times over the period 1900 to 1997. The history of shoreline movement, spaced every 20 meters (~65.6 feet) along the beach, provide for two calculations of erosion and accretion rates using the End Point and Linear Regression methods. The map series graphically depict these rates, and project the 30-year erosion hazard zone, for use by agencies and the public.

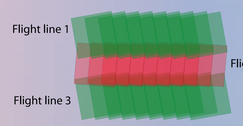


Step 2 — The Modern Shoreline

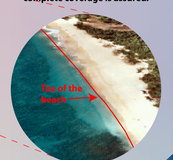
Fiducial Marks



Aerial photos are collected at 1:5000 or larger scale using aircraft with special cameras built to precise specifications. All dimensions of a camera are monitored, called "Geometric Stability", this allows for later corrections to be made to the photos removing distortions due to the physical geometry of the camera.



The changing position of the aircraft introduces uncertainty in the position of ground objects in the flight line. By flying a stereo aerial survey with 60% overlap between consecutive photos and 20% overlap between adjacent flight lines, complete coverage is assured.

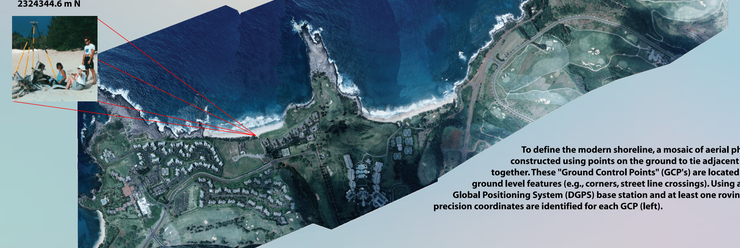


The toe of the beach is equivalent to the base of the foreshore and reflects a change in slope and water depth that is usually well defined in both modern and historical photography. It is stable over diurnal changes in wave state and on over 70 beaches monitored for five years (USGS, 2001, OFR 01-308). The tidal variation of the toe is significantly less than the wet/dry line or other beach face SCRF.

We identify the toe of the beach as our Shoreline Change Reference Feature (SCRF). The toe of the beach is the approximate position of mean lower low water (mllw) on many Hawaiian beaches. The toe is a stable morphologic feature that displays relatively little lateral variation due to individual waves, changes over a tide cycle, and seasonal beach variations. When compared to other common SCRF's such as the wet/dry line, the instantaneous run-up line, the high tide debris line and the vegetation line, the toe of the beach is preferable as a mapping feature because:

1. **The wet/dry line varies directly with tide, wave run up and beach slope such that it represents different physical processes on different beaches;**
2. **The instantaneous run-up line fluctuates laterally several meters on a given beach, as such it delineates a zone rather than a discrete shoreline (see out-set at right);**
3. **Many beaches do not display a high tide debris line because of Hawaii's relatively debris-free waters and high contrast historical photographs usually mask any debris line that is present;**
4. **The vegetation line is a particularly poor SCRF as it is artificially landscaped on most Hawaiian shorelines.**

WGS84 zone 4
743332.3 m E
2324344.6 m N



To define the modern shoreline, a mosaic of aerial photos is constructed using points on the ground to tie adjacent photos together. These "Ground Control Points" (GCP's) are located at clear ground level features (e.g., corners, street line crossings). Using a Differential Global Positioning System (DGPS) base station and at least one roving station, precision coordinates are identified for each GCP (left).

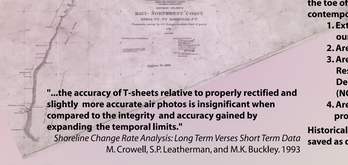
Step 3 — Historical Shorelines

Historical shorelines are mapped using two sources: historical aerial photography and T-sheets.

Historical aerial photographs must meet certain criteria. They must be high quality, vertical aerial photographs with no obscuring cloud cover and a minimum scale of 1:12,000 producing a pixel size of 0.5 meters (~1.6 feet) when scanned.

NOS T-sheet 11915 (surveyed 1912) for Hanakaoo Point originally scanned and rectified by NOS and received in digital format.

1987 (left) and 1949 (right) aerial photos of Kekaa Point on the west coast of Maui.



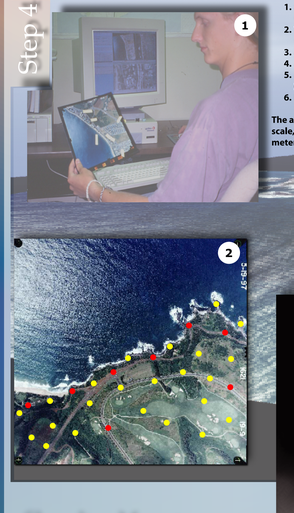
"...the accuracy of T-sheets relative to properly rectified and slightly more accurate air photos is insignificant when compared to the integrity and accuracy gained by expanding the temporal limits."
Shoreline Change Rate Analysis: Long Term Verses Short Term Data
M. Crowell, S.P. Leatherman, and M.K. Buckley. 1993

On T-sheets, the scale usually exceeds our minimum scale requirement, however the mean high water line (MHWL) is specifically mapped. Using a geometric model of the horizontal distance between the MHWL and the toe of the beach based on 5 years of semi-annual beach profile data, we convert the MHWL to a contemporaneous beach toe. We use T-sheets because they:

1. **Extend the length of our time series by 70% to 100% and therefore reduce the overall uncertainty of our rate measurements;**
2. **Are readily rectified to match modern rocky headlands;**
3. **Are recommended for historical shoreline mapping by the National Academy of Sciences-National Research Council (Managing Coastal Erosion,1990), Federal Emergency Management Agency (FEMA), Department of Interior (DOI-USGS), and the National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center;**
4. **Are identified by these federal agencies in their specifications for national erosion rate mapping programs.**

Historical photographs and T-sheets are collected and scanned on a photogrammetric-grade scanner and saved as digital files.

Step 4 — Ortho-Rectification

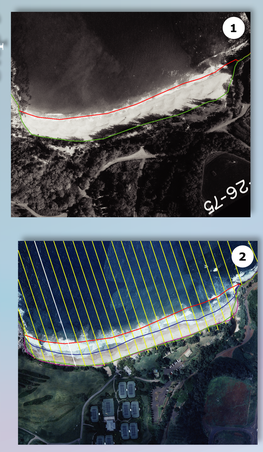


Ortho-rectification is a process of correcting imagery for distortion introduced by topography and camera geometry. The images beginning at left and continuing below illustrate the ortho-rectification processing steps:

1. **GCP's are placed on a scanned photo (left - image 1) by visually siting the appropriate pixel on the image and assigning it a GCP coordinate (red - image 2).**
2. **Tie points (yellow - image 2) are identified that tie historical and modern photos together to a common framework and are used in a triangulation process to correct for camera distortion between photos.**
3. **A Digital Elevation Model (DEM) provides the basis for correcting the photo for topographic distortion (image 3).**
4. **A new image is produced that has been corrected for camera and topographic distortions (image 4).**
5. **A 3-dimensional oblique perspective of the study area is easily generated using the new ortho-rectified image (background - image 5).**
6. **Using tie points, an ortho-rectified image becomes a datum for ortho-rectifying the historical time series of photographs.**

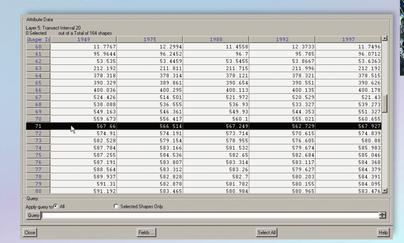
The accuracy of the final ortho-rectified images are dependent on the number of GCPs and tiepoints. Also important are the scale, year, topographic relief, and land to water ratio of the images. 1997 images are the most positionally accurate (RMS ~ 0.5 - 2 meters) while 1949 images tend to be the least positionally accurate (RMS ~ 3 - 4 meters).

Step 5 — Shoreline Mapping



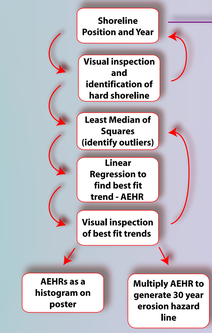
Ortho-rectified images are mosaicked to create contiguous maps of shoreline. A computer operator visually digitizes the toe of the beach and the vegetation line on a computer screen (image 1). At rocky headlands and other hard shoreline features the approximate high water mark is digitized.

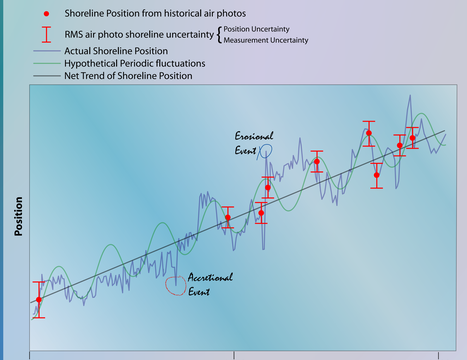
A shore-parallel baseline is drawn offshore on the 1997 mosaic from which shore-normal transects are generated and spaced every 20 meters (~65.6 feet) (image 2). Due to the non-linear nature of shorelines and features, some of these transects are deleted during the transect process where they overlap each other or intersect the shoreline at multiple points (images 3 to 4).



A table of historical shoreline distance from the baseline is generated from the transect information and used in calculations of erosion and accretion rates. These data are used in calculating rates of shoreline change.

Step 6 — Calculations and Rate Statistics

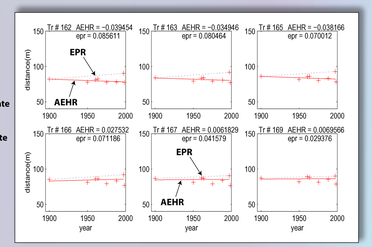




The graph above illustrates the relationship between shoreline positions (from historical aerial photographs and T-sheets) and the uncorrelated and independent RMS uncertainties.

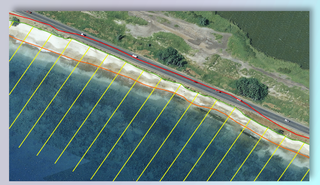
Position uncertainty includes errors due to tidal and seasonal fluctuations in the shoreline that alter the position of the shoreline as reflected on aerial photos and T-sheets.

Measurement uncertainty refer to errors in recording the position of the beach toe on aerial photos and T-sheets. These include digitization errors, T-sheet shoreline inaccuracy and rectification uncertainties.



Shoreline positions are modeled using the least median of squares technique in order to identify statistical anomalies or outliers to the overall trend (e.g. storm shorelines).

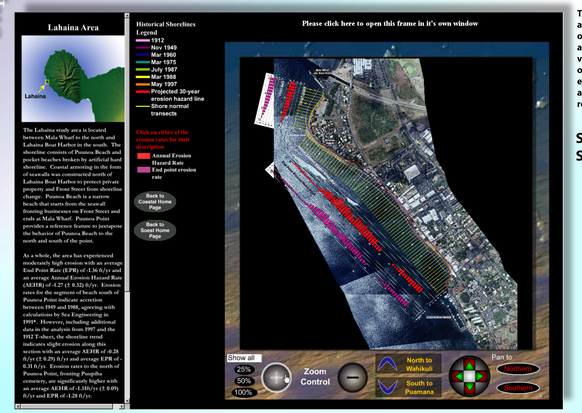
The historical trend of the shorelines is modelled using linear regression as suggested by Crowell et al, 1997. Two rates are identified: the end point rate (EPR) , and the annual erosion hazard rate (AEHR). The AEHR is identified by the linear regression technique



30-year erosion hazard line (red) projected along each transect (yellow) from the 1997 vegetation line (green) is derived from the slope of the best fit linear regression line (AEHR) using beach toe data (1997 toe in orange) multiplied by a factor of thirty.

"If random errors are present in the dependent variable Y, no new problems are created if these errors are uncorrelated and not biased...As long as such measurement errors are of a random nature, uncorrelated, and not biased, these measurement errors can simply be absorbed in the model error term."
Applied Linear Statistical Models J. Neter and W. Wasserman. 1974

Step 7 — Poster Production and Public Access Web site Creation – http://www.soest.hawaii.edu/coasts/erosion.html



The "final" step in shoreline analysis is the assembly of a poster displaying results and the mounting of data onto a public access web site. Data and image files are assembled into products that may be downloaded and viewed as images, GIS layers, or interactive products on the internet (left). Hard copy, full-scale posters for each area are constructed using commercially available illustration software and printed on a high-resolution printer.

Shoreline Erosion Information Sources on the internet

USGS - Center for Coastal & Regional Marine Studies - http://coastal.er.usgs.gov/

NOAA Coastal Services Center - http://www.csc.noaa.gov/

Federal Emergency Management Agency (FEMA) - http://www.fema.gov/

References

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