Coastal Change Rates and Patterns: Kaloko-Honokohau National Historical Park, Hawai'i

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Open-File Report 2005-1069

Coastal Change Rates and Patterns: Kaloko-Honokohau NHP, Kona Coast, Hawai’i

By Cheryl J. Hapke,[1] Rick Gmirkin,[2] *and* Bruce M. Richmond[1]

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[1] U.S. Geological Survey, Pacific Science Center, 400 Natural Bridges Drive, Santa Cruz, CA 95060.
[2] Kaloko-Honokohau National Historic Park, 73-4786 Kanalani Street, Suite #14, Kailua-Kona, HI 96740.

LIST OF FIGURES

ADDITIONAL DIGITAL INFORMATION

For additional information about Kaloko-Honokohau NHP, please see:
http://www.nps.gov/kaho/

For additional information about NPS Geologic Resources Inventories, please see:
http://www2.nature.nps.gov/geology/inventory/

For an online PDF version of this report, please see:
http://pubs.usgs.gov.of/2005/2005-1069/

For more information on the U.S. Geological Survey Western Region's Coastal and Marine Geology Team, please see: http://walrus.wr.usgs.gov/

INTRODUCTION

A collaborative project between the U.S. Geological Survey's Coastal and Marine Geology Program and the National Park Service (NPS) has been developed to create an inventory of geologic resources for National Park Service lands on the Big Island of Hawai'i. The NPS Geologic Resources Inventories are recognized as essential for the effective management, interpretation, and understanding of vital park resources. In general, there are three principal components of the inventories: geologic bibliographies, digital geologic maps, and geologic reports. The geologic reports are specific to each individual park and include information on the geologic features and processes that are important to the management of park resources, including ecological, cultural and recreational resources. This report summarizes a component of the geologic inventory concerned specifically with characterizing the coastal geomorphology of the beach system within Kaloko-Honokohau National Historical Park (NHP) and describes an analysis that utilizes georeferenced and orthorectified aerial photography to understand the spatial and temporal trends in shoreline change from 1950 to 2002. In addition, spatial patterns of beach change were examined and a beach stability map was developed. Both the shoreline change rates and the beach stability map are designed to help Park personnel effectively manage the valuable park resources within the context of understanding natural changes to the KAHO beach system.

Study Area

Kaloko-Honokohau NHP (KAHO) is one of three national park lands along the Kona Coast of the Big Island of Hawai'i (Figure 1). KAHO was established in 1978 in order to preserve and protect traditional native Hawaiian culture and cultural sites. The park, a site of an ancient Hawaiian settlement, occupies 1160 acres and is considered a locale of considerable cultural and historical significance. Cultural resources include historic fishponds, petroglyphs and heiau (religious site). The fishponds are also recognized as exceptional birding areas and are important wetlands for migratory birds. The ocean and reef have been designated as a Marine Area Reserve, and green sea turtles commonly come ashore to rest. The park is also a valuable recreational resource, with approximately 4-km of coastline and a protective cove ideal for snorkeling and swimming (Figure 2).

The park is underlain by three Holocene basalt flows (Wolfe and Morris, 1996) that originated from Hualalai Volcano. Both pahoehoe and a'a type flows are represented and age ranges for the flows are 1.5-3.0 ka (ka = thousand years), 3-5 ka, and 5-10 ka. They form a gently seaward-sloping surface upon which the park is situated. The geomorphology of the coast consists of a low-lying basalt platform or bench overlain by carbonate and basalt sand and gravel beaches. Two types of beach are present: intertidal accumulations of beach sediment subjected regularly to wave interaction, and perched beaches that are typically active (movement of sediment by waves) only during large-wave events (Figure 3). The perched beaches make up approximately 60% of the beach resource in the park. They consist of a thin veneer of sand and gravel deposited on the elevated basalt platform. The thickness is presently

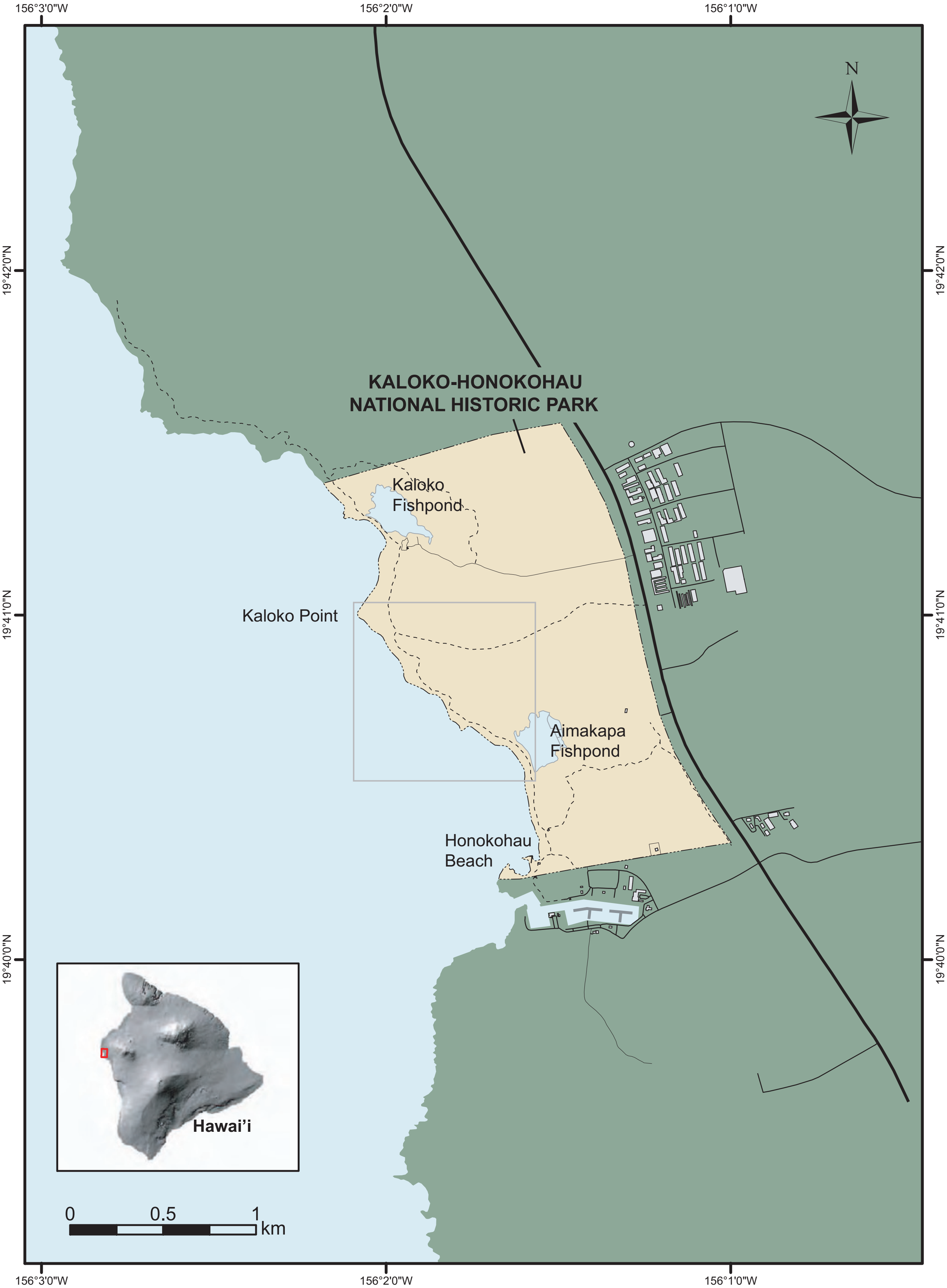


Figure 1. *Index map of Kaloko-Honokohau National Historic Park, showing locations of specific areas within the park that are discussed in the text. The gray box outlines the area shown in Figures 9 - 14.*

Figure 2. *Photographs showing some of the important resources at Kaloko-Honokohau NHP. (A) Beach-goers enjoy the park beach for recreational purposes and can explore the cultural resources. (B) A green sea turtle basking on the beach.*

Figure 3. *Photographs showing the different beach types in the park. (A) Dominantly carbonate intertidal beach near the southern end of the park. Arrow shows the wet-dry line that was used as the shoreline reference feature in the shoreline change analysis. (B) A mixed carbonate-basalt perched beach on topof a lava platform. This type of beach is found in the northern portion of the park. The arrow shows the contact between the beach material and the lava platform that was used as the shoreline reference feature in the change analysis.*

unknown, but probably ranges between less than one to several meters. They are clearly lensoid in shape, pinching out both landward and seaward. Ultimately, the landward extent of the perched beach deposits is controlled by the elevation of the gradually sloping basalt flow and exposure to wave run-up. Locally, basalt flow topography influences where perched beaches are deposited. The intertidal beaches dominate in the southern portion of the park, where the basalt platform is lower in elevation. At Aimakapa Fishpond in the south-central portion of the park, the intertidal beach forms a barrier spit across the mouth of the fishpond (Figure 4).

There is clear evidence of sea-level rise and coastal erosion hazards within the park that threaten park resources (Figure 5). While there is no long-term water level data for the Kona Coast, tide gauge data from near Hilo (NOAA, 2004) indicates that average annual mean high water increased at a rate of 0.34 cm/yr between 1946 and 2002.

METHODS

Aerial Photography

Aerial photographs of the park were obtained for seven dates spanning six decades from 1950 to 2002 (Table 1). The photographs from 1950 through 1992 were scanned on a either a graphic arts or photogrammetric scanner at varying resolutions (see Table 1) and georeferenced in a GIS. The control points used for this process were derived from 2002 orthophotographs of the park as described below. The spatial errors associated with the georeferencing of the 1950-1992 photography are outlined in Table 2 and are believed to be maximum estimates based examples of similar data processing (Hapke, 2004; *in press*). Unfortunately, a more accurate error assessment cannot be conducted as the specifics of the processing were not documented in detail. The 2002 photography was orthorectified using surveyed ground control points and a digital terrain model using stereo photogrammetry. Therefore the errors inherent in these images are substantially less than the pre-2002, and are listed separately in Table 2. The total error is estimated using a square root of the sum of the square method based on Hapke (2004; *in press*). The error analysis results in Table 2 are shown separately for the pre-2002 and the 2002 dates of photography because they were processed using different techniques. Relief displacement was not included in the error analysis because it is considered negligible due to the very low relief of the study area. The total error is the estimate for the true positional error at any given location. However, this analysis focuses on the rates of shoreline change, and thus the summed error is divided by the 52-year time period of the analysis (1950-2002). The result, as shown in Table 2, demonstrates that the maximum error on the shoreline change and beach polygon change analyses is 0.12 m/yr.

Shoreline Change and Beach Area Analysis

Georeferenced photographs were incorporated into a GIS for digitization of the shoreline reference feature as part of the change analysis. Due to the variable coastal geomorphology within the park, two different shoreline reference features were identified. For the intertidal beaches, the wet-dry line, identified by a difference in the

TABLE 1. AERIAL PHOTOGRAPH SPECIFICATIONS

Year	Film*	Nominal Scale	Pixel Res. (m)	Scanning Res. (dpi)	Scanner
1950	B/W	1:30,000	0.5	600	graphic arts
Apr. 1954	B/W	1:25,000	0.9	600	graphic arts
Jan. 1965	B/W	1:31,000	1.0	300-600	graphic arts
Nov. 1970	B/W	1:15,000	0.7	300-600	graphic arts
June 1988	CIR	1:12,000	0.4	300-600	graphic arts
Feb. 1992	CIR	1:12,000	0.9	300-600	graphic arts
Oct. 2002	CIR	1:4,800	0.5	1200	photogrammetric

*B/W=black and white; CIR = color infrared

TABLE 2. ERROR SOURCES

	Year	
Error Source (m)	1950-92	2002
Scanner, media	2.0	--
Radial distortion	1.3	--
Pixel resolution	0.4 – 1.0	0.5
Ground control	2.0	0.5
Georef./rect.	5.0	2.0
Total error	6.3	
Total rate error (m/yr)	0.12	

tonal contrast between wet and dry sand, was used as the shoreline reference feature (Figures 3 and 6*A*). For the perched beaches, the contact between the light-colored beach sediment and the underlying basalt platform was digitized as the shoreline reference feature (Figures 3*B* and 6*B*).

Once the shoreline reference features were digitized, the Digital Shoreline Analysis System (DSAS; Thieler and others, 2003) was used to perform the change analysis. This technique requires first creating a shore-parallel line to be used as a baseline. Once the baseline is drawn, baseline-normal transects are generated at a designated spacing (in this analysis, 20 m). Both linear regression and end-point shoreline change rates were calculated where each transect crosses a shoreline reference feature.

In addition to quantifying the spatial distribution of shoreline change rates in the park, an analysis of the patterns of beach area change was undertaken. Both the seaward and landward beach margins were digitized from the seven dates of georeferenced aerial photographs. The seaward sides of the beach area polygons are coincident with the shoreline reference features described above and shown in figure 6*A* and 6*B*. The landward side is the furthest inland extent that beach sediment can be

Figure 4. *Photomosaic of an intertidal beach forming a sand barrier spit across the mouth of Aimakapa Fishpond.*

Figure 5. *Photographs showing evidence of sea-level rise and coastal erosion in the park. (A) Walls of an ancient Hawaiian enclosure are inundated. (B) Erosion has resulted in the loss of beach around the roots of this palm tree(note arrow), photo taken in February 2004. (C) By August 2004, erosion has resulted in the loss of the palm tree from the beach.*

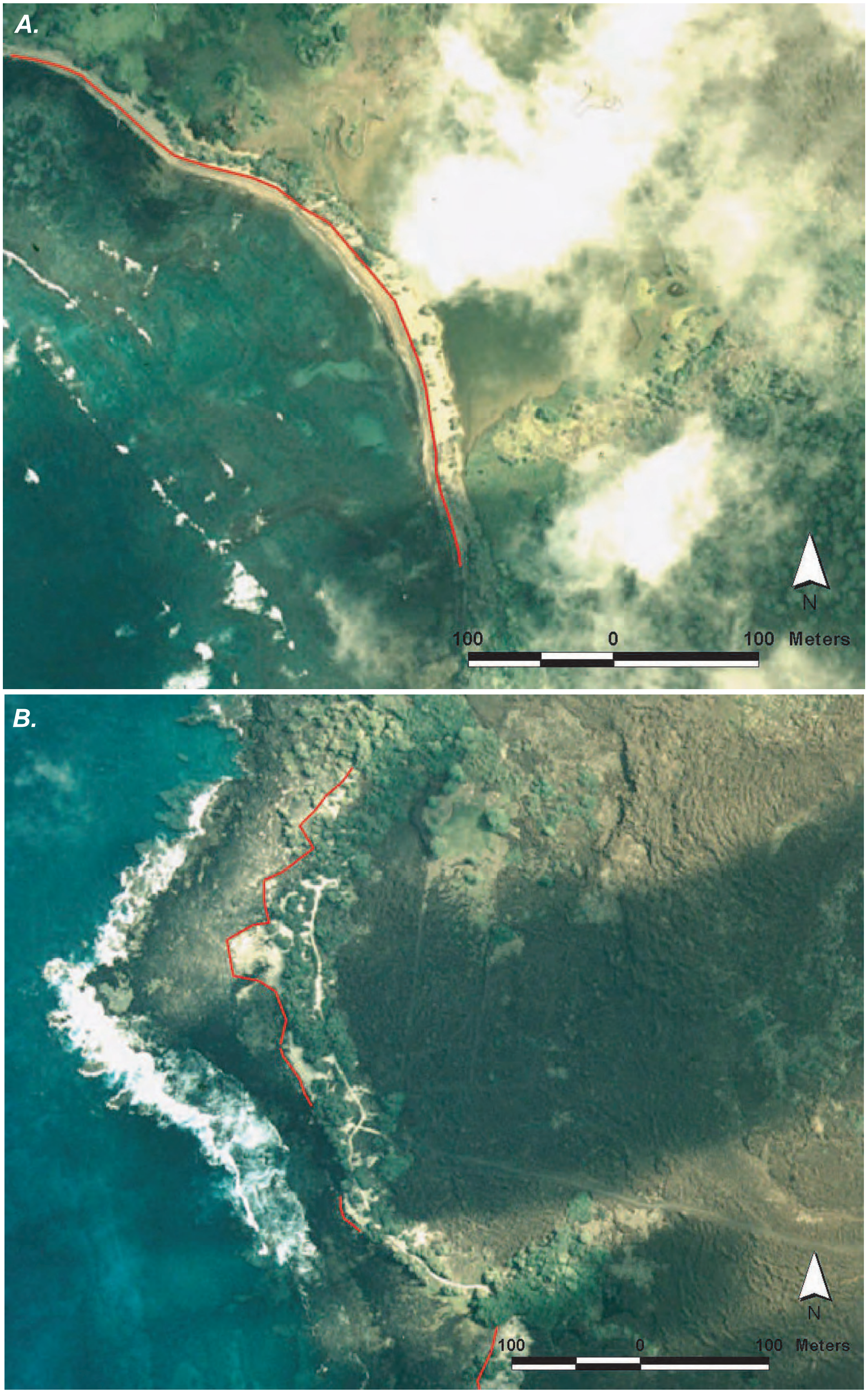


Figure 6. *Aerial photographs from 2000 showing the digitized shoreline reference feature (in red) for the two beach types. (A) The wet-dry line is the shoreline reference feature on the intertidal beaches. (B) The seaward contact between the beach material and the basalt platform is the erosion reference feature where the beaches are perched.*

identified on the aerial photographs. The polygons and their significance will be discussed later in the text (see Beach Area Change Rates and Patterns, below).

RESULTS AND DISCUSSION

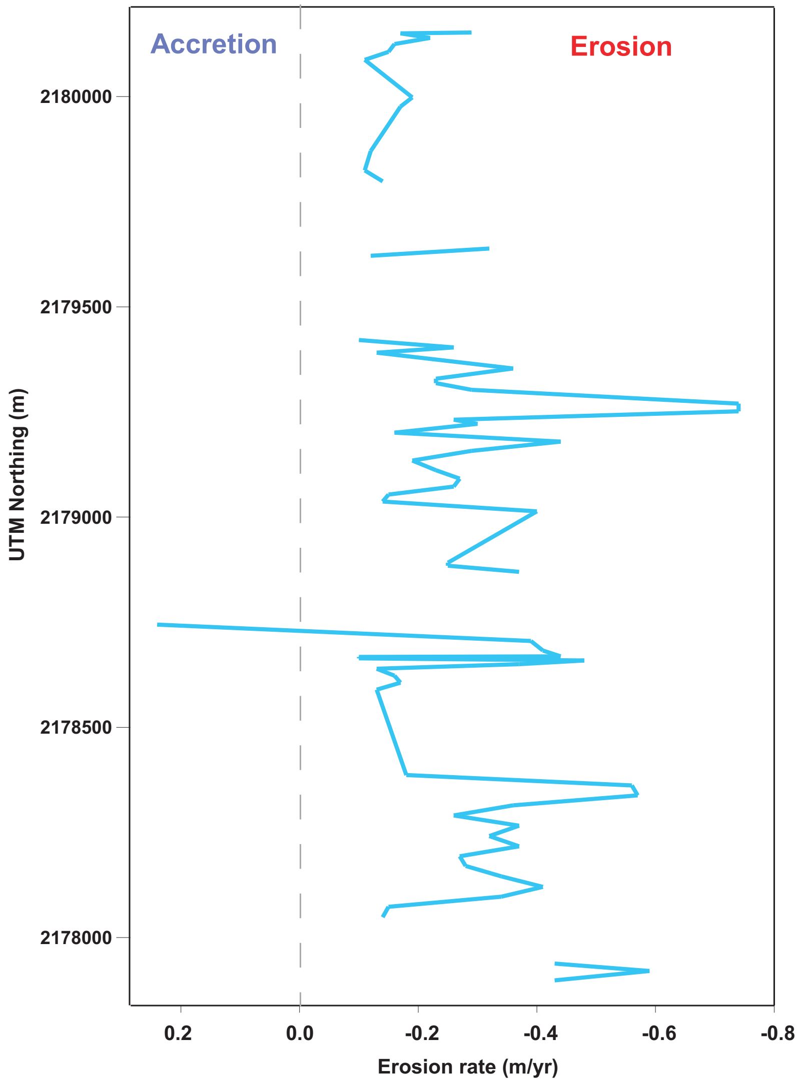
Shoreline Change Rates

The results of the linear regression shoreline change analysis from 1950 – 2002 show that the dominant shoreline change signal in the park is erosional. The combined average of all the measurements taken yields an average erosion rate of -0.3 m/yr for the beaches in the park. Erosion rates vary along the coastline in the park and are shown graphically in Figure 7. There is a considerable alongshore variation in the rates, with several pronounced erosion hotspots, and one location where the long-term signal is accretional. The rates are lowest overall to the north of Kaloko Fishpond and along the barrier spit across the mouth of Aimakapa Fishpond (< 0.1 m/yr). The highest rates (>0.7 m/yr) were measured at Kaloko Point. The other hotspots occur north and south of Aimakapa Fishpond (0.6 m/yr) and at Honokohau Beach (0.6 m/yr) (Figure 7).

Average rates of shoreline change provide baseline information about the overall trends in the park. However, they provide little information as to the episodic nature of shoreline change processes. This analysis covers time periods ranging from four years (1988-1992) to eighteen years (1970-1988), and thus provides a snapshot of the state of the beaches for each year of photography; there is little information of what actually occurs on an annual basis. In order to gain additional understanding of the short-term signal within the average long-term change trend, end-point rates (average of all measurements) were calculated for each two adjacent time periods (i.e. 1950-1954, 1954-1965, etc). This provides a record of how the rates themselves are changing through time. Figure 8 shows the results of the end-point analysis and suggests that the beach system in KAHO is in a state of dynamic equilibrium (Chorley and others, 1984; Richmond, 1992). In this situation, dynamic equilibrium is defined as variations about a characteristic form which itself has a trend through time. In KAHO, the beach system has a dominantly erosional trend, with average rates ranging from < 0.1 m/yr to ~0.5 m/yr. The long-term erosion of ~ 0.3 m/yr is interrupted by periods of increased erosion or accretion that disrupt the system, after which it gradually returns to the equilibrium state. This is illustrated in (a) the doubling of the average erosion rate from the 1954-65 to the1965-70 time period, and (b) the accretionary phase in the interval from 1988-92.

Beach Area Change Rates and Patterns

The shoreline change analysis provides baseline data on the change through time of a linear feature (in this case the shoreline). This is a common technique of assessing erosion hazards and was developed primarily for measuring change on U.S. East and Gulf Coast beaches (Smith and Zarillo, 1990; Crowell and others, 1991). The beaches at KAHO, however, are small, discontinuous bodies of sediment that are dynamic and complex, and the shoreline change analysis alone cannot provide information on whether the beaches are becoming smaller through time (loss of area) or if the entire beach is shifting landward but not changing substantially in area. Knowledge of the loss rate or stability of the area of the beaches would be useful to the development of management plans for the park resources.



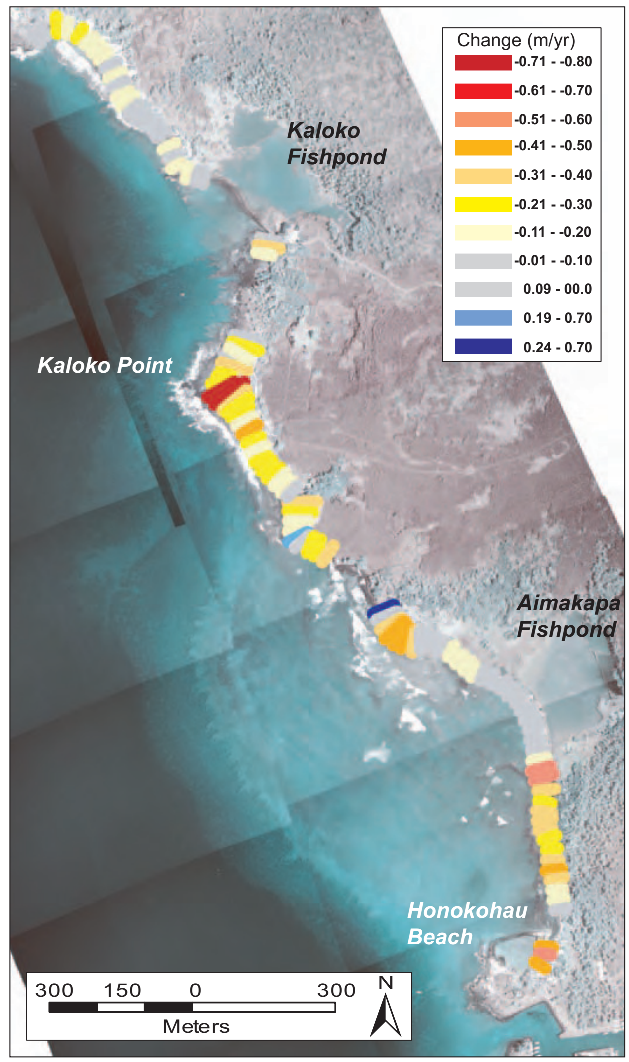


Figure 7. *Results of shoreline change analysis showing along-shore variation. The overall trend is erosional with an average rate of -0.3 m/yr. Note that along-coast stretches shown as gray on the righthand image represents transects where the rate is smaller than the technique used can accurately measure change.*

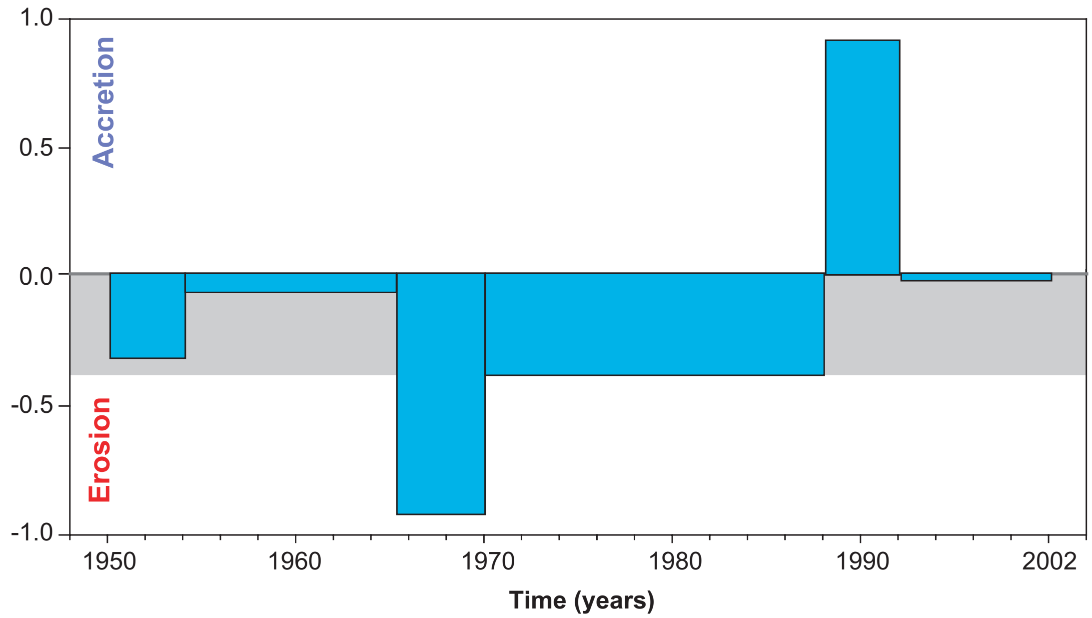


Figure 8. *Averaged end-point rates for the time intervals defined by the date of the photographs used in this analysis. It appears there is a dynamic equilibrium in the system (shaded box) whereby the erosion rate is between 0.0 - 0.4 m/yr, punctuated by periods of of increased erosion (1965-70) or accretion (1988-92).*

As shown in Figures 9-14, polygons of the beach areas were digitized for each date of photography and the areas were calculated in a GIS. As shown in the superimposed polygons, the beaches change shape and size through time. There is a distinct increase in beach area in 1965 (Figure 10), which receded by 1970 (Figure 11). Erosion continues but appears to be slowing from 1970 through 1992 (Figures 12 and 13). In 2002, the beach area again shows a dramatic increase (Figure 14) similar to that which was measured in the 1965 photography. The graph in Figure 15 summarizes these beach area changes through time. Similar to the shoreline change analysis, it appears that there is an equilibrium state of the park beaches in which the beach area ranges from 45,000 to 50,000 m^2. This state is punctuated by periods (1965 and 2002) when the area of the beaches increases dramatically, followed by erosion over a relatively short time (decade or less) period during which it returns to an equilibrium state. If this pattern is typical, the beaches at KAHO should presently be undergoing accelerated erosion throughout the park, as the last phase of area increase occurred in 2002. Increased beach recession has been observed by one of the authors (Rick Gmirkin), who has been qualitatively monitoring the park beaches for several years. If this trend continues, Park managers are likely to observe this increased erosional trend throughout the park until the beach areas reach extents similar to what they were in 1992.

Beach Stability Analysis

The beach area change analysis provides an additional level of information beyond the shoreline change analysis that can be valuable for understanding coastal change within the park and for the effective management of park resources. In addition to quantifying the temporal patterns of change in beach area, this study also provides an analysis of the spatial variations of the beach through time and results in the development of a beach stability map.

The analysis of beach change clearly shows the dynamic nature of the beach system within KAHO. Figure 16 shows the superimposed polygons of beach area from Figures 9-14, which clearly shows the shifting nature of the beaches. It also indicates that some beach areas within the Park may be fairly stable. However, it is difficult to visualize the specific areas of stable versus unstable beach due to the dynamic nature of the changing beach areas. In order to address this problem we have summarized the changing beach areas within one map (Figure 17). This was accomplished by merging beach polygons into one map to encompass the areal extents of all the polygons from each time period. Next the polygons from each individual date of photography were gridded at a 1-m cell size, and each cell was assigned a value of one. The polygons were then summed within the bounds of the combined polygon. The resulting map (Figure 17) shows areas where a beach has existed for all of the seven dates of photography from which the polygons were digitized (value = 7), and where the beach has only existed for one or two dates (value = 1 or 2, respectively). We interpret this as a measure of relative beach stability which shows the spatial distribution of stable versus unstable beaches within the park for the period covered by the analysis (1950-

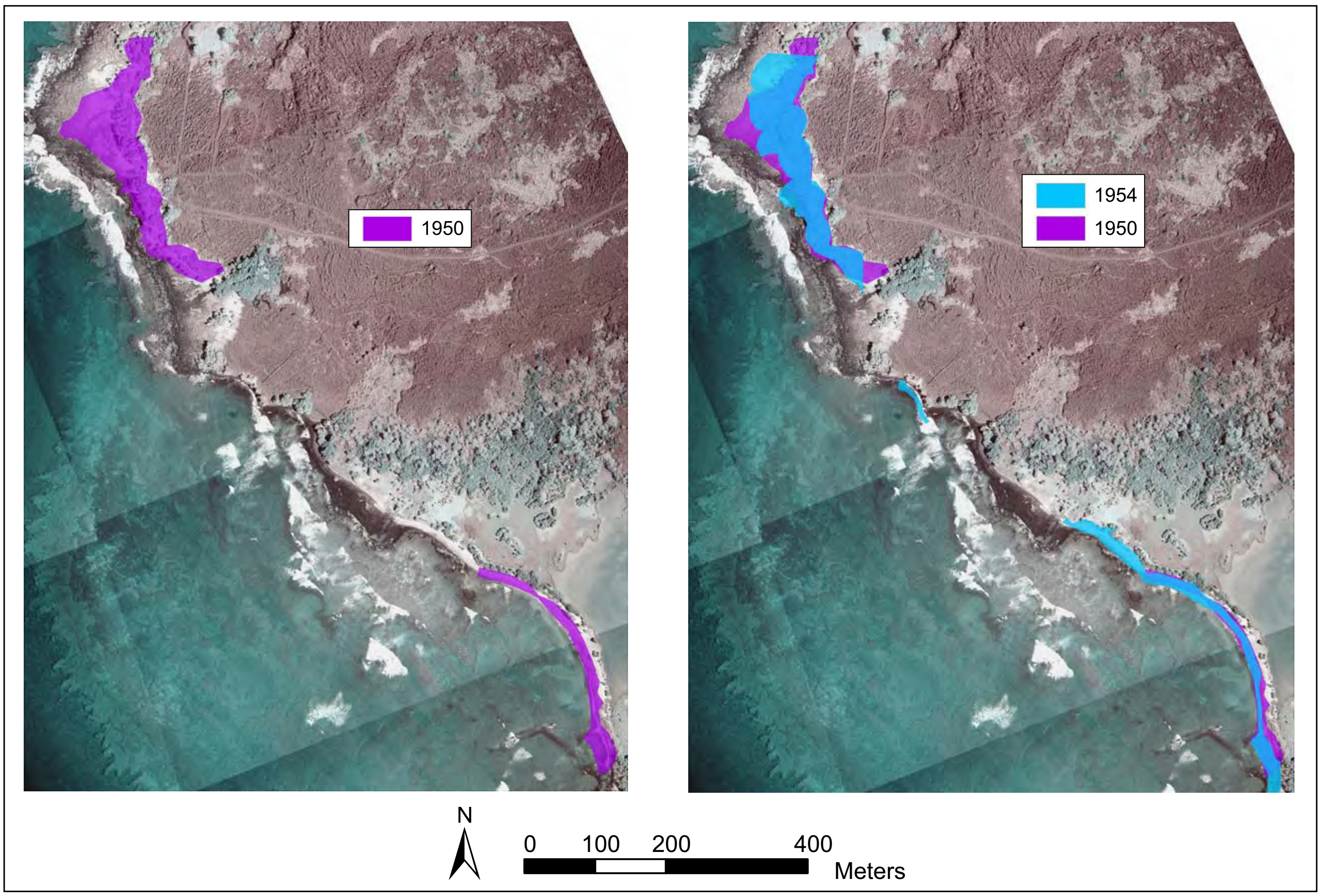


Figure 9. *Digitized polygons of beach area from 1950 and 1954 overlain on a 2002 photomosaic. Only the central portion of KAHO, as outlined on Figure 1, is shown.*

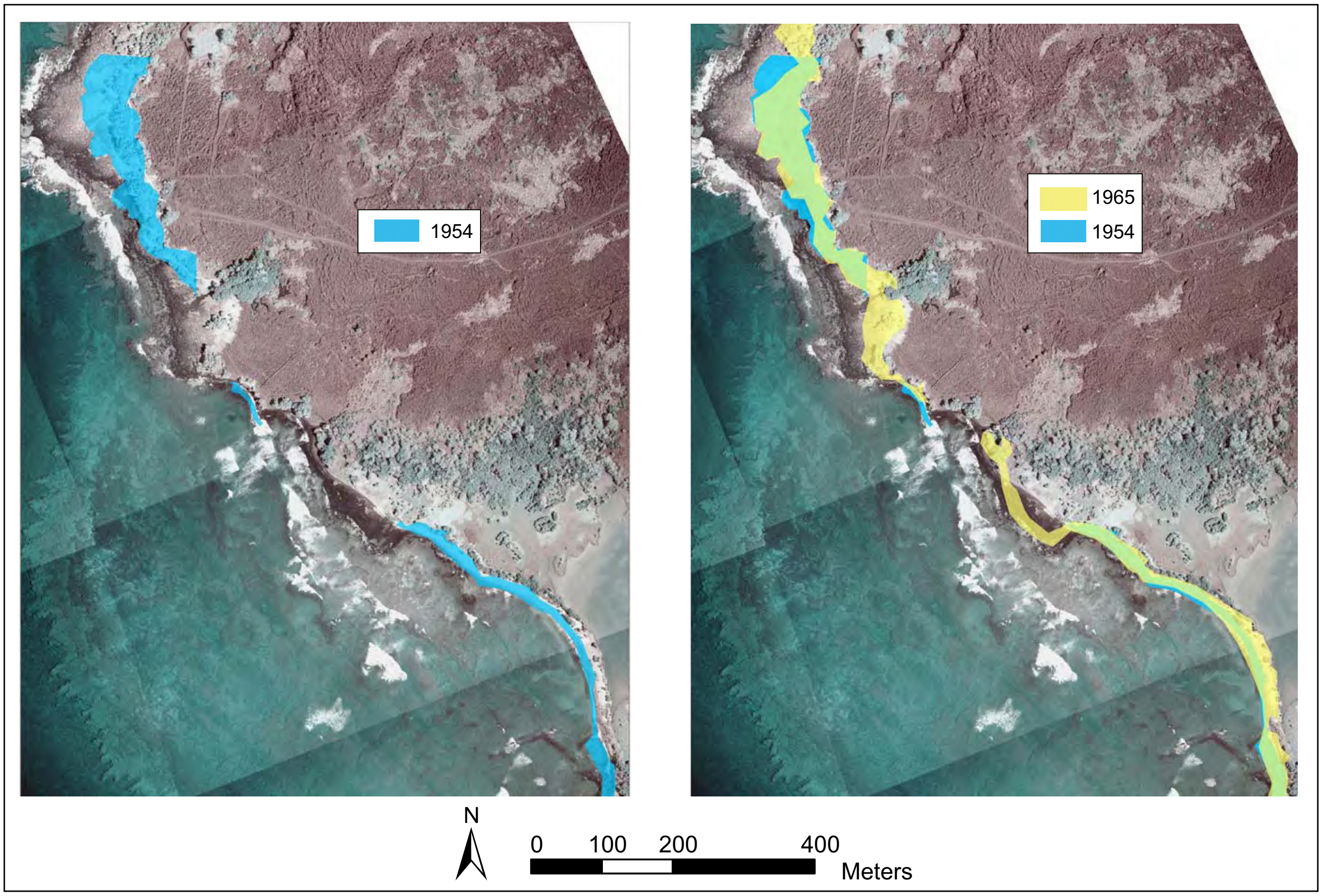


Figure 10. *Digitized polygons of beach area from 1954 and 1965 overlain on a 2002 photomosaic. Only the central portion of KAHO, as outlined on Figure 1, is shown. Note the increase in beach area during this time period.*

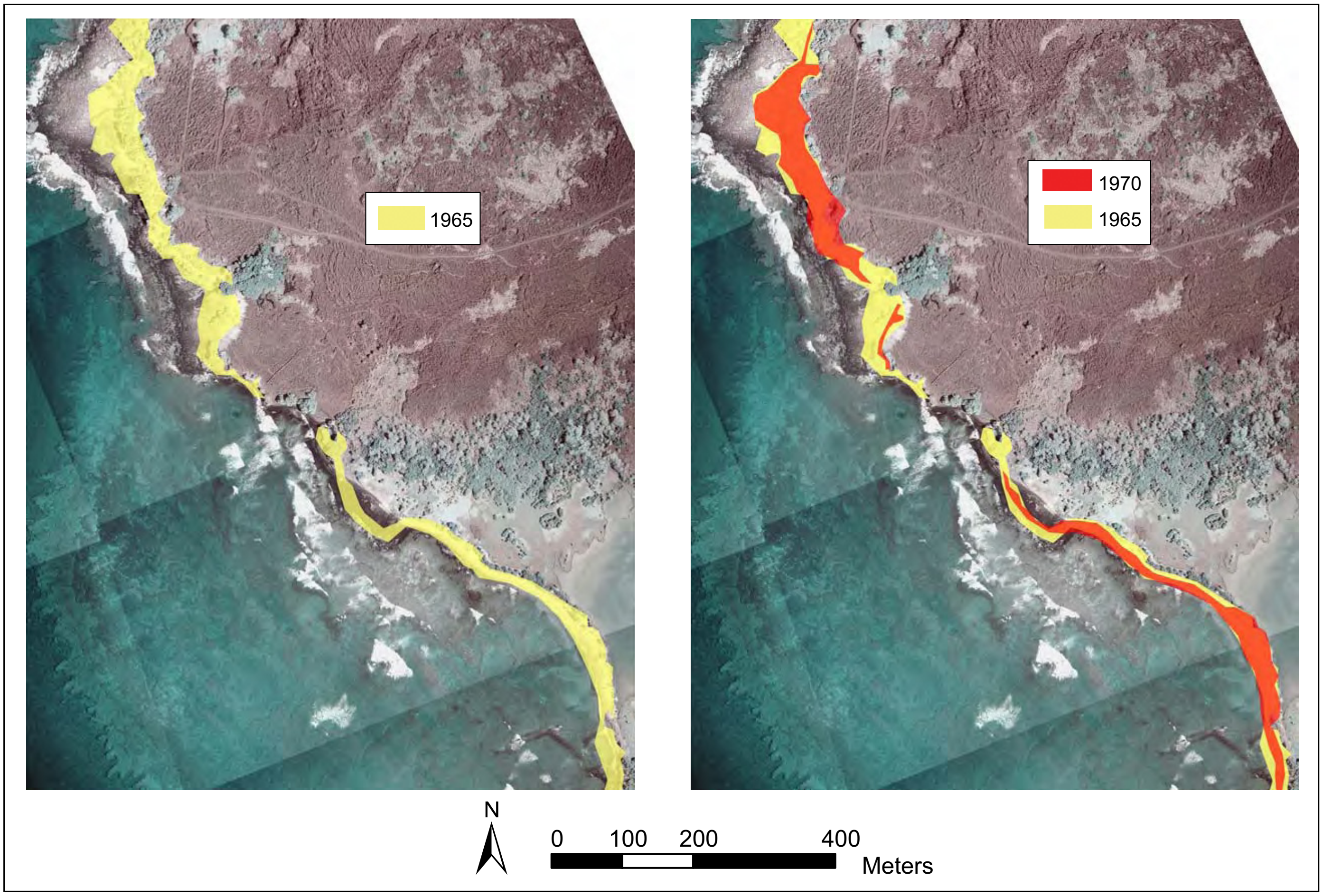


Figure 11. *Digitized polygons of beach area from 1965 and 1970 overlain on a 2002 photomosaic. Only the central portion of KAHO, as outlined on Figure 1, is shown. Note the loss of beach area during this time period.*

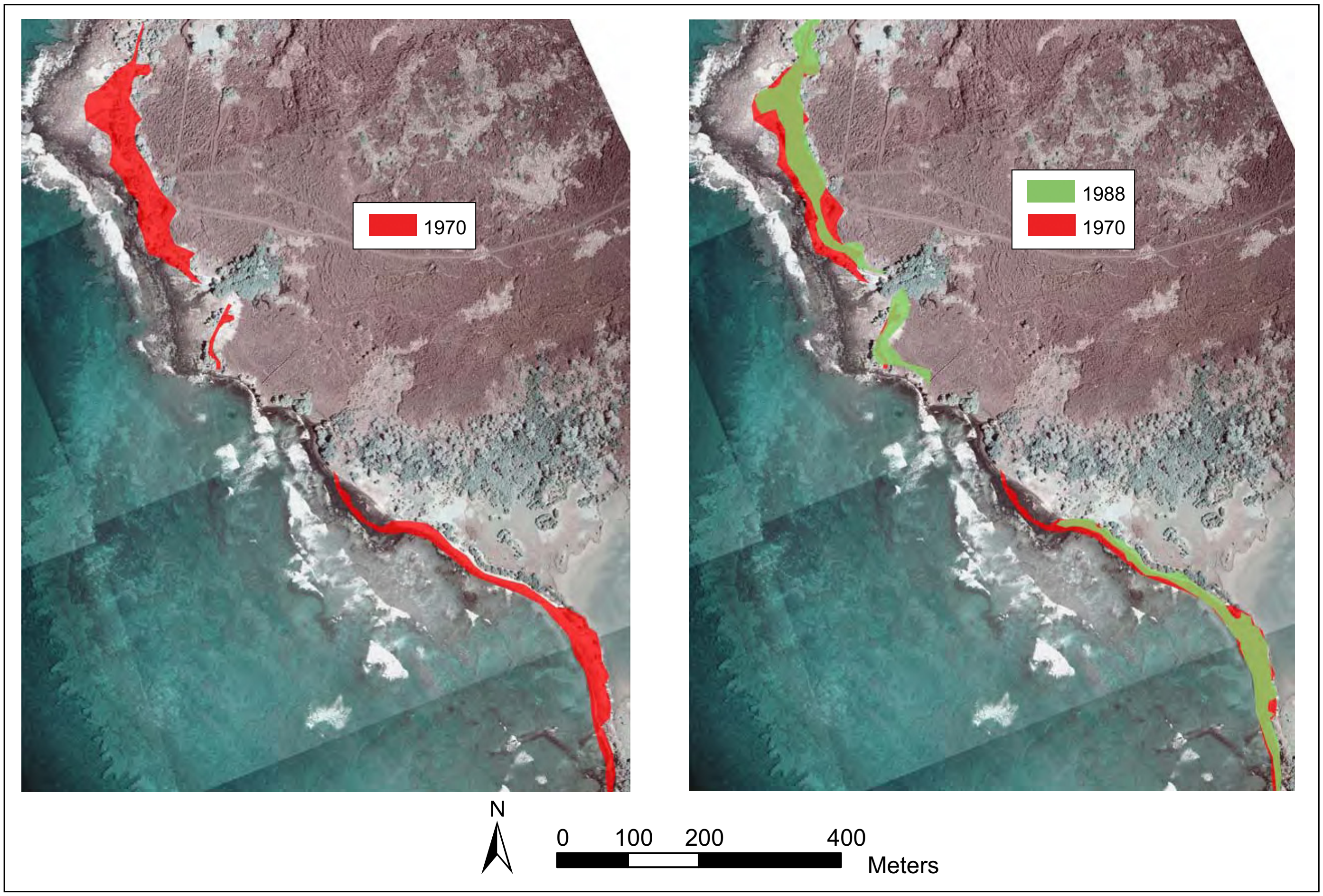


Figure 12. *Digitized polygons of beach area from 1970 and 1988 overlain on a 2002 photomosaic. Only the central portion of KAHO, as outlined on Figure 1, is shown.*

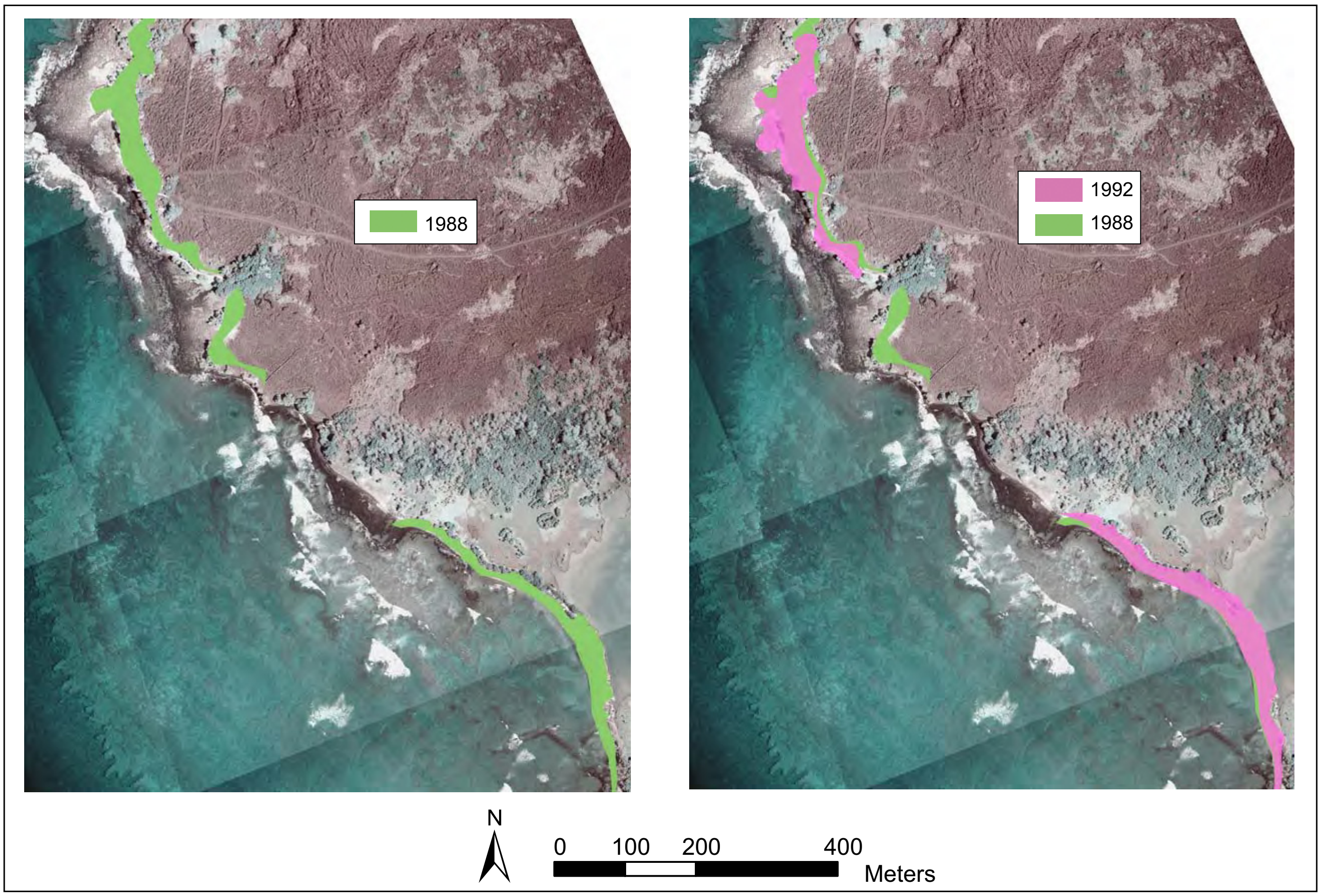


Figure 13. *Digitized polygons of beach area from 1988 and 1992 overlain on a 2002 photomosaic. Only the central portion of KAHO, as outlined on Figure 1, is shown.*

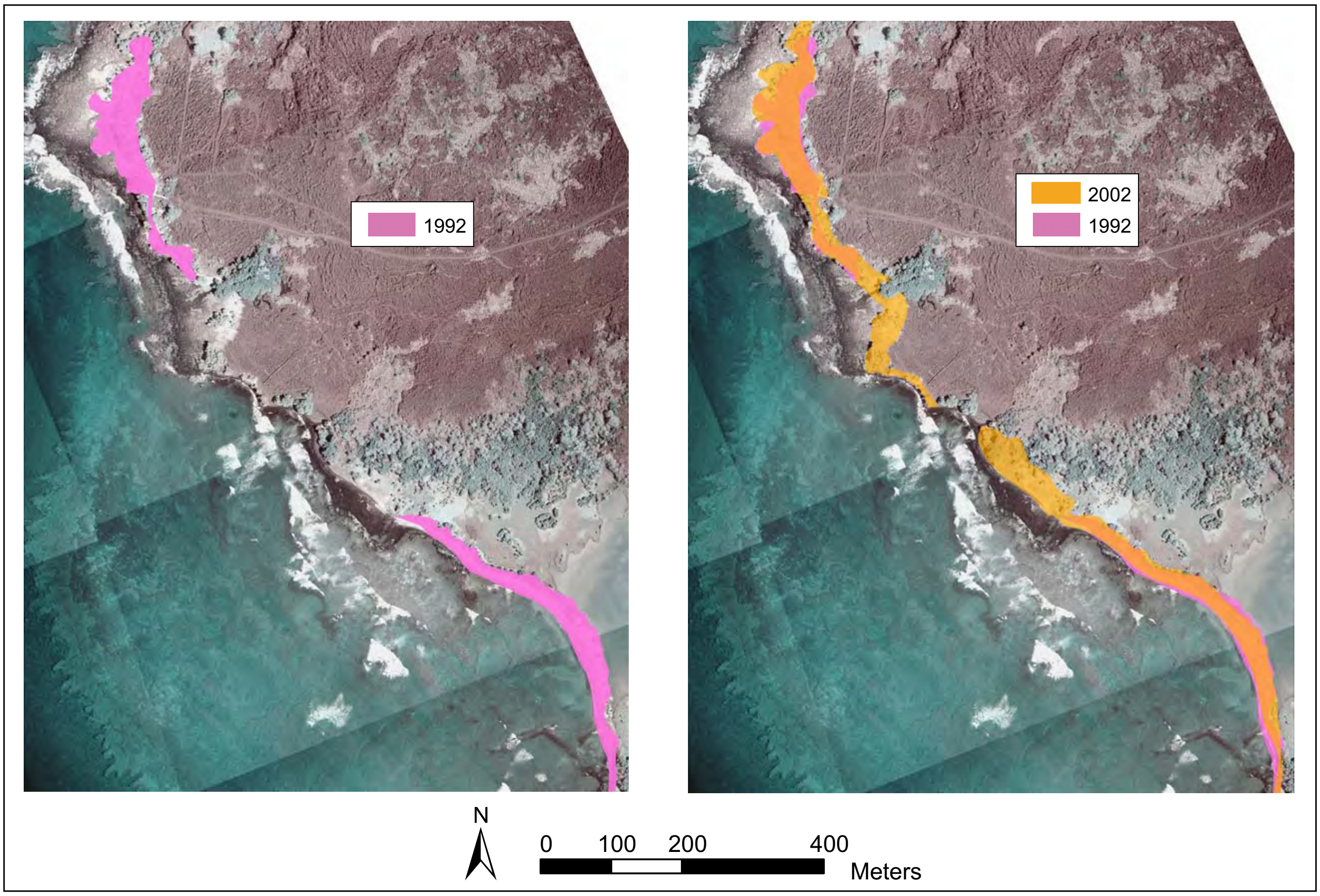


Figure 14. *Digitized polygons of beach area from 1992 and 2002 overlain on a 2002 photomosaic. Only the central portion of KAHO, as outlined on Figure 1, is shown. Note the increase in beach area during this time period.*

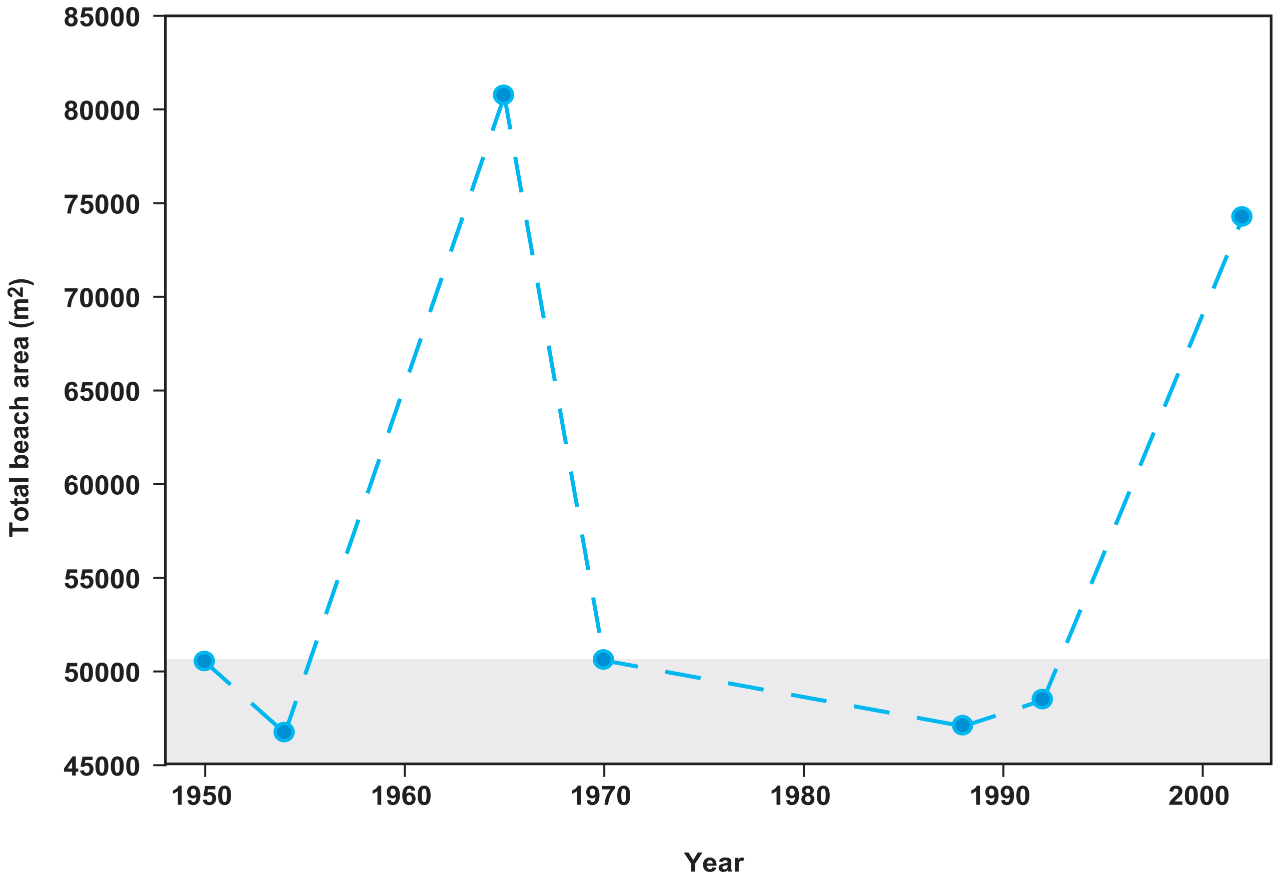


Figure 15. *Change in beach area over time for the seven dates of the analysis. There appears to be an equilibrium area ranging from 46,000 - 50,000 m^2 (shaded gray) that is punctuated by periods of visible area increase (1965 and 2002). Beach area rapidly decreased to 62% of its previous size during the 5-year period from 1965 - 1970. This followed a substantial increase (~34,000 m^2) in area from 1954 -1965. There is a similar increase in area between 1992 and 2002.*

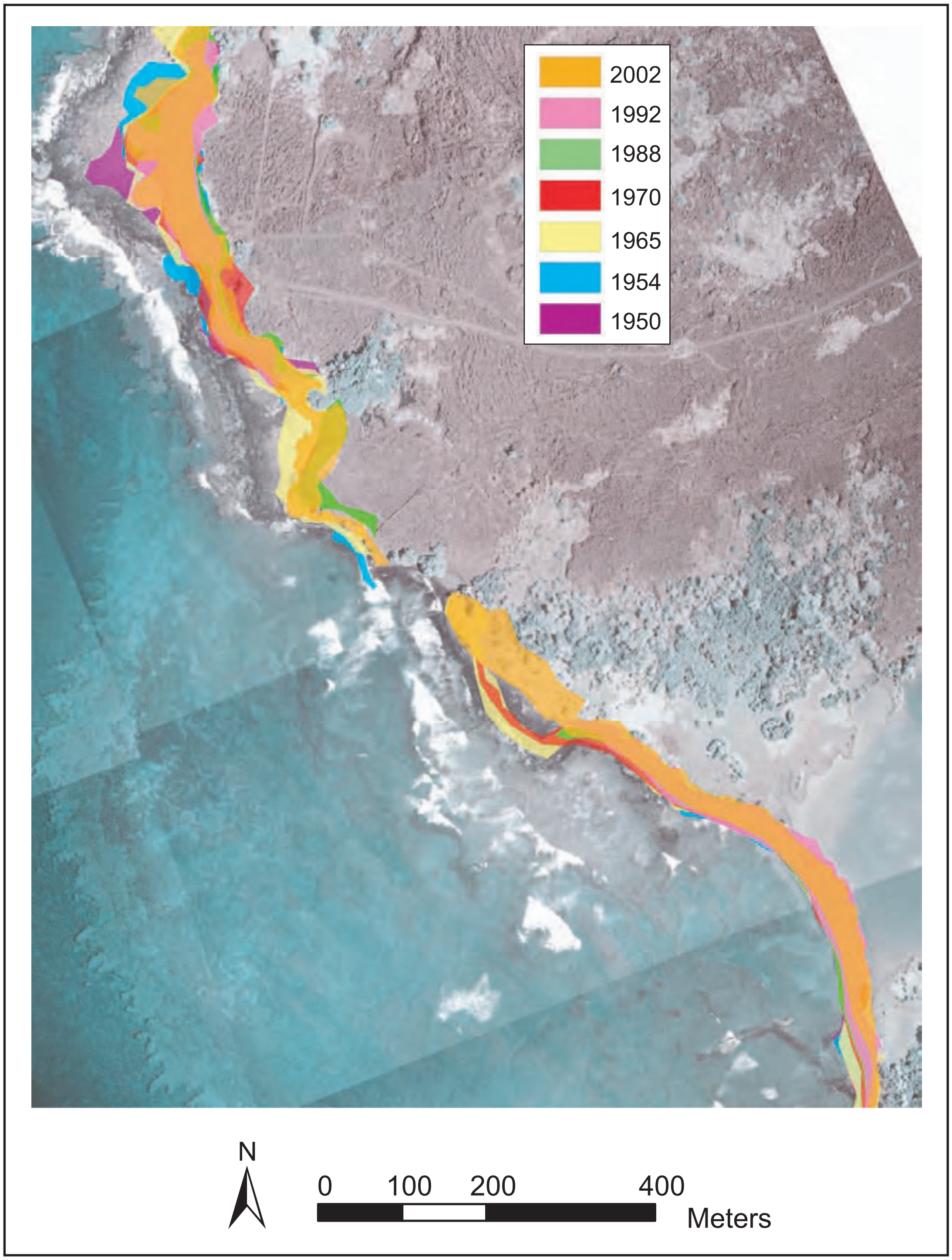


Figure 16. *Digitized polygons of beach area from the seven sequential dates of photographs overlain on a 2002 photomosaic. The beach system in the park is clearly quite dynamic.*

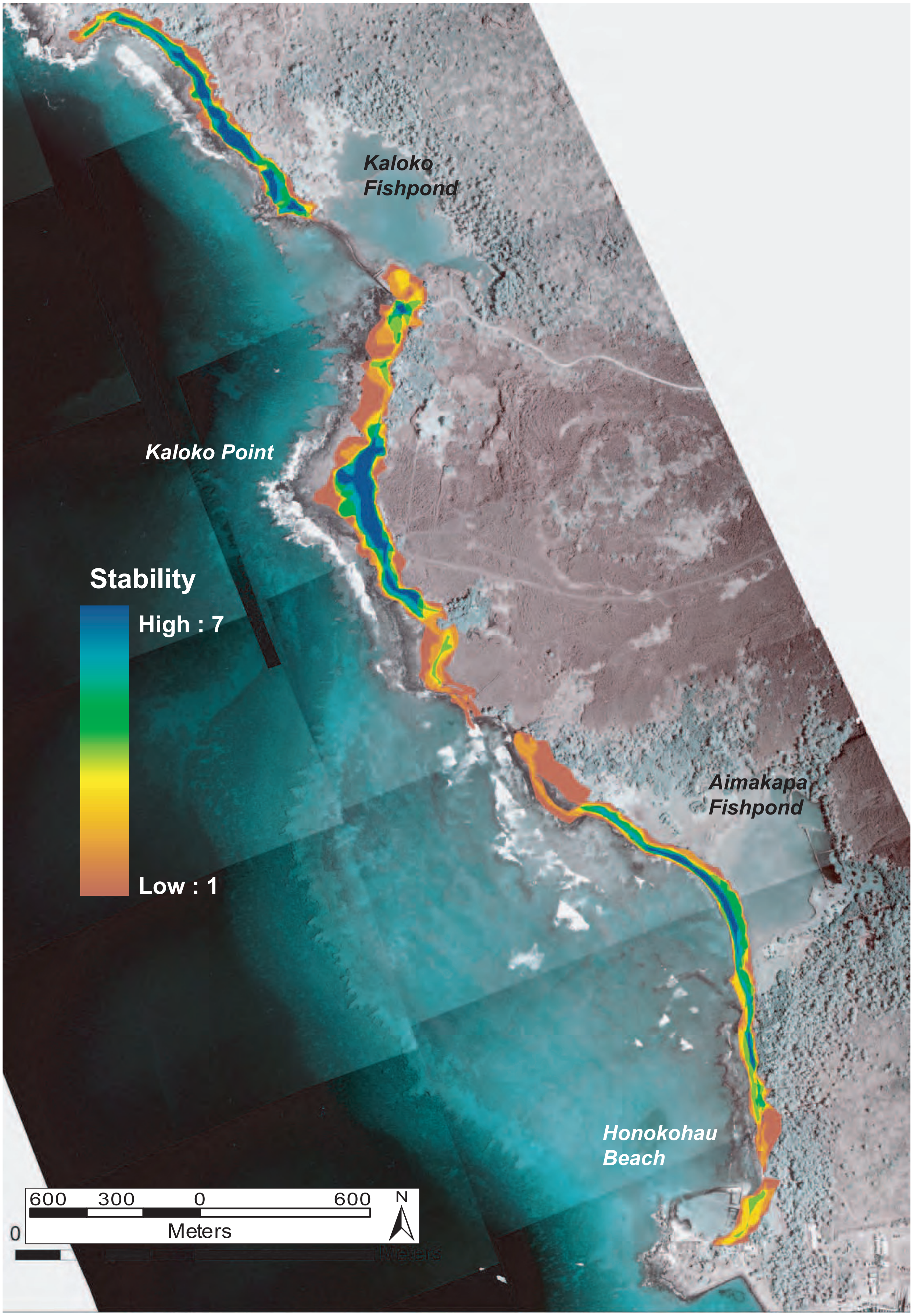


Figure 17. *Beach stability map of KAHO beaches. The index is based on the frequency of occurance of a beach over the duration of the analysis. High stability indicates the frequent presence of a beach as mapped in the photography; in areas shown as low stability, a beach was observed only once or twice in the duration of the analysis.*

2002). The blue and greens are the most stable beach areas and the reds and oranges are the least stable.

Some of the most stable beach areas coincide with the lowest erosion rates in the shoreline change analysis (see Figures 7 and 17), such as the barrier spit across Aimakapa Fishpond and the perched beach north of Kaloko Fishpond. However, this relationship is not consistent throughout the park. One noticeable location of this correlation between beach stability and shoreline erosion rate is poor is at Kaloko Point, which demonstrated the highest shoreline erosion rates but, based on the beach stability map, has one of the most stable sections of beach in the park.

CONCLUSIONS

The beaches within KAHO, although they only extend 4 km in length, form a very dynamic and complex system. Two distinct types of beach occur within the park bounds:(1) a tidal-dominated intertidal beach, and (2) a storm-dominated perched beach. A linear regression shoreline change analysis, conducted using seven dates of georeferenced aerial photographs between 1950 and 2002, indicates that there is a consistent erosional trend in the park, with an average annual rate of -0.3 m/yr. The shoreline erosion is likely a combined result of the rise in annual mean high water and the subsidence of the island due to the loading from the active volcano. The shoreline erosion rate appears to be in a state of dynamic equilibrium, whereby the average rate is periodically punctuated by episodes of order-of-magnitude increases in the erosion rate, or even reversal to an accretional trend, followed by a return to the average. These periods of distinct variation from the average rate possibly represent a climatic signal (i.e. periods of more frequent Kona storms or higher than normal sea levels) within the average data; this will be explored in future analyses.

The shoreline change study is supplemented by a beach area analysis that, similar to the shoreline change analysis, shows a system that is in an equilibrium state, punctuated by periods where the beach area nearly doubles in size. This suggests that either there is a volumetric increase in the amount of beach material during the periods of greater beach area, or that the amount of sand is simply being spread over more area (and therefore thinner) during periods of increased wave energy. In either case, the system returns over a few years to the equilibrium state. Based on this analysis, the beaches are currently in a state of returning to an equilibrium area following a period of increase in area in 2002. Thus, continued loss of beach area may be expected over the next few years.

A beach stability map was developed from the polygons of beach areas to conceptualize the spatial consistency of the presence of a beach in any given location. Based on the seven dates of photographs, the map shows areas where the beach has been present during all, or most time periods and thus is stable, versus areas where the beach has only existed during one or two dates and is thus considered much more ephemeral or unstable. Inconsistencies between the beach stability map and the shoreline change rates show that identifying erosion hotspots based solely on a shoreline change analysis may lead to erroneous conclusions. The beach stability map provides a valuable tool for effective management of park resources as managers can now identify stable areas in which to focus efforts such as habitat preservation or infrastructure development that will sustain the least erosional impact in the future. Future studies should include investigations into the geomorphic controls on the stability, such as elevation, topography, or geologic controls such as flow age or texture.

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REFERENCES

Chorley, R.J., Schumm, S.J., and Sugden, D.E., 1984. Geomorpholog*y*. London, Methuen, 605 pp.

Crowell, M. Leatherman, S., and Buckley, M., 1991, Historical shoreline change: Error Analysis and Mapping Accuracy: Journal of Coastal Research, v. 7, n. 3, p. 839-852.

Hapke, C.J., *in press*, Estimated material yield from coastal landslides based on historical digital terrain modeling, Big Sur, California, Earth Surface Landforms and Processes (scheduled pub date 05/05).

Hapke, C. 2004, The Measurement and Interpretation of Coastal Cliff and Bluff Retreat, *In* Hampton, M. and Griggs, G. (editors), U.S. Geological Survey Professional Paper 1693. p. 39-50.

Hawaiian Volcano Observatory, 1995, Volcanoes of the Big Island, Volcano Watch. http://hvo.wr.usgs.gov/volcanowatch/1995/95_09_15.html.

NOAA, Center for Operational and Oceanographic Products and Services, Mean Sea Level Trends for Hilo, Hawaii.
Electronic data, http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml.

Smith, G. and Zarillo, G., 1990, Calculating long-term recession rates using aerial photographic and beach profiling techniques: Journal of Coastal Research, v. 6, n. 1, p. 111-120.

Richmond, Bruce, 1992, Development of atoll islets in the Central Pacific: Proceedings of the Seventh International Coral Reef Symposium, Guam, June 22-25, 1992, v. 2, p. 1185-1194.

Thieler, E.R., Martin, Daniel, and Ergul, Ayhan, 2003, Digital Shoreline Analysis System: Shoreline change measurement software extension for ArcView; USGS Open-File Report 03-076.

Wolfe, E.W. and Morris, J. (compilers), 1996. Geologic Map of the Island of Hawaii, U.S. Geologic Survey, Misc. Investigations Series Map I-1-2524-A.