Sediment Budget Model

West Kauai and South and East Oahu

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EA/HHF Joint Venture

SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY

Introduction

Most studies of shoreline change use the single transect (ST) method, where rates are calculated at fixed intervals along a beach (say, every 66 ft [20 m]) assuming these locations behave independently. In reality, sand is shared along a shoreline and closely spaced measurements are mainly noise. What is wanted is a method of calculating shoreline change that is based on long-term sediment budgets, rather than short-term noise. For example, can the shoreline change in a given area be explained entirely by alongshore sediment transport, or is it necessary to invoke cross-shore transport? These questions are addressed by the following model and inversion procedure.

Study Area

The study area includes shorelines on the southern and windward coasts of Oahu, and the west coast of Kauai. The Oahu study area is further divided into regions: 1) windward, 2) east Honolulu, and 3) Diamond Head to Pearl Harbor (D2P) (Figure 1a). The Kauai study area contains only one region – West Kauai (Figure 1b).

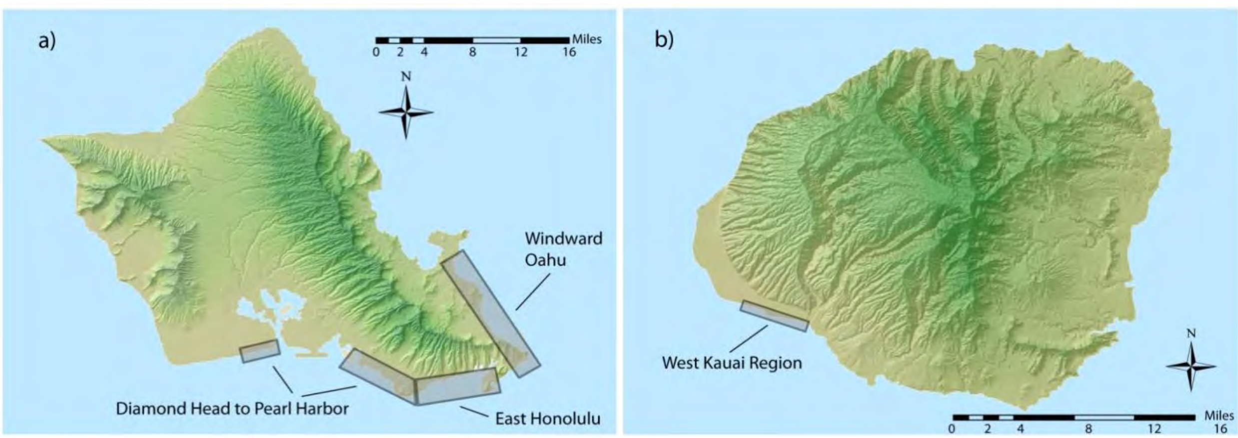

Figure 1. Study area regions on a) Oahu and b) Kauai.

Windward Oahu The Windward Oahu region spans the southeast coast of Oahu from Mokapu Point to Sandy Beach. The entire area is exposed to easterly tradewind waves year round and occasional refracted waves from the north during winter months. In addition to these wave exposures, Sandy Beach is also exposed to southern swells during the summer. The carbonate sand beaches of Kailua, Lanikai, and Waimanalo are fairly well protected by a wide fringing reef platform. Lanikai is additionally protected by two islands, but erosional problems have spurred homeowners to armor most of the southern portion of the beach with seawalls. The beaches at Makapuu and Sandy

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Beach are also carbonate, but are known for their large shore-break due to deeper fringing reefs that do not offer as much protection from open ocean waves.

East Honolulu The East Honolulu region is composed of the Maunalua embayment – Black Point to Port Lock – and Hanauma Bay. Fronting the Maunalua shoreline is a wide, shallow (depths typically < 1ft) offshore reef flat, dissipating most of the incoming wave energy. Sea walls, revetments, and groins armor much of this formerly sandy shoreline. Paiko Peninsula is a barrier spit, growing eastward, as sediment is transported and deposited by alongshore currents. Just to the east of Paiko Peninsula, the Hawaii Kai shoreline is largely man-made, with development starting in 1959. Both dredging and landfill have significantly altered the coast. Thus, only Hawaii Kai shorelines from 1967 – 2005 were used in this study.

Hanauma Bay is an old volcanic crater, whose side was breached by waves, creating a deep, crescent shaped bay. Hanauma Bay contains a wide calcareous beach, protected by a shallow fringing reef. The calcareous sediment is also mixed with olivine fragments eroded from the surrounding crater. Hanauma Bay is a highly valued recreational and educational destination for visitors and locals.

Diamond Head to Pearl Harbor (D2P) In addition to occasional Kona storms (winds that arrive from the south and southwest), the Diamond Head to Pearl Harbor region is exposed to easterly tradewind swells that wrap around the island year-round, and southern swells mainly during summer months. All sandy beaches in this area are carbonate, but the carbonate sand at Diamond Head is also mixed with olivine eroded from the surrounding cliffs. Both Diamond Head and Waikiki are protected from open ocean waves by a shallow fringing reef, although Waikiki's reef offers better protection. The Waikiki shoreline has been heavily altered by engineering efforts including groins, seawalls, and beach nourishment. Due to the extensive alteration of the shoreline, only beach surveys that have the most current shoreline configuration were used in this study.

Ala Moana beach was constructed by dredging and filling the nearshore reef. Sand Island is an artificial island constructed in the 1940's by depositing dredge material on a shallow reef. Most of the southerly exposed beach is armored with a revetment, and the remaining calcareous beach is partially protected by a fringing reef. Iroquois Point and Ewa beach are also calcareous, and fronted by a shallow fringing reef.

West Kauai The West Kauai region extends from beyond Waimea River past Kikiaola Harbor almost to Oomano Point. Kekaha is situated on the southernmost portion of the Mana Plain, a dry, low-lying accretionary plain formed by the convergence of alongshore sediment transport from the northeast and southeast. The shoreline from Kekaha to Oomano Point consists of carbonate sand, but quickly shifts to a mainly basaltic composition to the east of Oomano Point as the Waimea River deposits sediment eroded from Waimea Valley. The shoreline is hardened around Oomano Point with a rock revetment. The West Kauai region is in the lee of dominant tradewind waves, but is affected by both southern swell and Kona storm waves, and by north Pacific swells that wrap around the west side of the island during winter months. In the early 1960's Kikiaola Small Boat Harbor was constructed west of the Waimea river mouth, and the harbor is thought to disrupt the westward longshore sediment transport, causing heavy erosion directly west of the harbor.

Methodology

Overview A forward shoreline change model is created, combining the Pelnard-Considère (1956) planform evolution equation with a linear regression model of shoreline change, and a term describing the rate of sand transport (advection). The model uses an inversion procedure to extract optimal values describing alongshore and cross-shore sand transport to resolve the series of historical shorelines. Combinations of these parameters are compared with an information criterion (IC), so the most parsimonious model can be identified, given the data available. For example, the model investigates whether the shoreline change in a given area can be explained entirely by alongshore sediment transport, or if it is necessary to invoke cross-shore transport. These questions are addressed by the following model and inversion procedure.

Shoreline Data The digital shoreline vectors created by the University of Hawaii Coastal Geology Group, and used in their Oahu and Kauai shoreline change studies (www.soest.hawaii.edu/coasts) were used. Vectors were produced following the digitization process described in Romine et al (2009) and Fletcher et al (2003). Each vector is a contiguous line representing a shoreline location in a UTM coordinate plane at one snapshot in time. Legendre polynomials were fit to historic shorelines to create smooth baselines for each shoreline area that resemble the general shape of the shoreline. An information criterion was used to select the most appropriate Legendre polynomial. Transects were cast perpendicular to the baseline at 66 ft (20 m) intervals, and the distance from historic shorelines to the baseline recorded, producing a time series of shoreline positions at each transect.

Due to the impacts of engineering alterations such as dredging and beach nourishment, only shorelines that had the same configuration as the latest shoreline were used in this study. For example, Hawaii Kai shorelines prior to 1967 do not match the current shoreline because of extensive dredging and filling before this time, so they were omitted.

Forward Model Let $y(x,t)$ be the shoreline location as a function of alongshore distance *x*, and time *t*. The standard model for shoreline change is the differential equation $\partial_t y = r$ in which $r = r(x)$ is the long-term cross-shore advection rate (yd^3/yr per yd of shoreline). Here the standard model is extended to include alongshore advection with velocity $v(x)$ and diffusivity $D(x)$. It is assumed that the cross-shore beach profile is the same everywhere, so $y(x,t)$ is proportional to the volume of shoreline material per unit of alongshore distance, and *r* is proportional to the rate of accretion or erosion of sediment per unit of alongshore distance. For both *r* and *y* the constant of proportionality is the active profile height, *Z*, the sum of the berm height above sea level and the bathymetric depth of closure. Thus $y(x,t)$ may be treated as a concentration of sand. Physically, the advection and diffusion are assumed to be confined to a boundary layer $\tilde{y}(x,t)$ defined as the difference between the actual shoreline $y(x,t)$ and the mean shoreline $\bar{y}(t) = L^{-1}\int y(x,t)dx$ where *L* is the length of the shoreline. Alongshore diffusivity is denoted by *D*, and the alongshore advection velocity by *v*, and the advection-diffusion operator is $A = \partial_x(D\partial_x - v)$. The governing shoreline equation is then $\partial_t y = A\tilde{y} + r$.

Inversion Procedure and Model Selection To obtain a data inversion procedure, it is assumed that *D*, *v*, and *r* are independent of time, but not *x*. The differential equation is re-written as $\partial_t y = \partial_x(D\partial_x\tilde{y}) - \partial_x(v\tilde{y}) + r$ and each side integrated with respect to both *x* and *t*. A key point is that the integrals are definite integrals and that ∂_x commutes with time integration. The result is a matrix equation of standard form $d = Gm$ in which *m* is a column vector of model parameters, *d* is a column vector whose components are alongshore integrals of the data $y(x,t)$, and *G* is a matrix containing time integrals and alongshore derivatives of the residual data $\tilde{y}(x,t)$.
Uncertainty values for parameter estimates were calculated using a bootstrap method. This method processes 500 model runs, using a random sample of existing shorelines with replacement. The results of these 500 iterations produce a probability distribution from which a 95% confidence can be calculated.

It is expected that very few data sets will have the resolution needed to give *D*, *v*, and *r* at each transect, so an information criterion was used to select an aperture for alongshore spatial averaging, and then inverted directly for the spatially averaged model. Diffusivity is taken to be independent of *x* as well as time, and the set of models examined includes models with constant-*v*, models with variable-*v*, models with constant-*r*, and models with variable-*r*. If *r* and *v* are both variable, the same spatial averaging aperture is used for both. Goodness of fit is examined by using an information criterion (IC) to penalize unparsimonious models. As expected, the spatial averaging aperture affects the IC, and models with low-IC scores (i.e., good models) inevitably have spatial averaging apertures larger than the transect spacing, although that is not required by processing. To condition data prior to modeling, historical shoreline vectors were truncated at headlands and other littoral cell boundaries; hence aperture scale is typically a fraction of the alongshore distance in a littoral cell.

Uniqueness For most data sets, the partitioning of shoreline change between alongshore and cross-shore effects is theoretically unique. To see why, recall the differential equation $\partial_t y = \partial_x (D \partial_x \tilde{y}) - \partial_x (v\tilde{y}) + r$ and notice that $-\partial_x (v\tilde{y}) + r$ is effectively a source term. Perturbations to *v* and *r* that leave the source term are looked for, and thus the data, unchanged at every point. Such perturbations must satisfy the relation $0 = -\partial_x (\delta v\, \tilde{y}) + \delta r$ in which δv is the perturbation to advection speed and δr is the perturbation to cross-shore rate. Integrating from x_1 to x_2, and differentiating with respect to time, gives $\delta v(x_2) \partial_t \tilde{y}(x_2, t) - \delta v(x_1) \partial_t \tilde{y}(x_1, t) = 0$, which can be satisfied for all x_1, x_2 only if $\partial_t \tilde{y}(x,t)$ has the same time behavior at every *x*.

Transport Rates

The direct products of data analysis are the alongshore diffusivity D, the alongshore advection speed $v(x)$, and the cross-shore rate $r(x)$. Recalling the differential equation $\partial_t y = A\tilde{y} + r$, $A\tilde{y}$ is referred to as the shoreline change rate due to changes in alongshore flux, or simply the alongshore rate—this quantity should not be confused with the alongshore advection speed *v*. The cross-shore sediment flux in cubic meters per year per meter of shoreline is $Q_y = r(x)Z$, in which *Z* is the active profile height introduced above. The alongshore sediment flux in cubic meters per year is $Q_x = [-D\partial_x \tilde{y} + v\tilde{y}]\, Z$. The sediment accumulation due to variation in alongshore flux is $-\partial_x Q_x = (A\tilde{y})Z$ with units of cubic meters per year per meter of shoreline, the same as the units of Q_y. Some alongshore advection may be invisible to processing because it is seen only if it causes the shape of the shoreline to change. For example, if the shoreline remains a straight line, sediment can be moving very fast with no outward sign. The alongshore sediment flux estimate Q_x is thus a lower bound for the true Q_x. However, the sediment accumulation flux $-\partial_x Q_x$ is an unbiased estimate of the true accumulation flux if the cross-shore beach profile is the same at every alongshore location.

The values used for active profile heights, Z, are in Table 1. The profile height used in the D2P study region (except Kuhio Beach) was the same 12 ft value found appropriate in the Preliminary Regional Sediment Budget by Moffatt & Nichol, based on beach profiles (USGS 2001; Moberly 1964; Gerritsen 1978; Sea Engineering 2008). For other areas, due to differences in wave climate, beach shape, and surrounding reef topography, survey grade beach profiles conducted by the University of Hawaii Coastal Geology Group available (http://www.soest.hawaii.edu/coasts) were used to produce profile heights.

Table 1. Active profile heights used in converting linear to volumetric rates.		
Location	**Active profile height (ft)**	**Source**
Windward Oahu		
Kailua	19.105	UH Coastal Geology Group (CGG) profiles
Lanikai	16.513	UH CGG profiles
Bellows and Waimanalo	24.934	UH CGG profiles
Makapuu	23.950	UH CGG profiles
Sandy Beach	20.341	UH CGG profiles
East Honolulu		
Hanauma Bay	9.843	5 meter DEM extraction. UH CGG
Black Pt to Hawaii Kai	9.186	UH CGG (Waialae Beach Park profile)
D2P		
All D2P except Kuhio Beach	12	D2P Preliminary Regional Sediment Budget (Moffit & Nichol)
Kuhio Beach	9.514	UH CGG profiles
West Kauai		
Waimea and Oomano Point	18.880	UH CGG profiles
Kekaha	22.443	UH CGG profiles

Model Output and Interpretation

Overview Results are reported for every beach within each study region. Three types of figures are displayed: 1) model parameters, 2) sediment transport rates (sediment fluxes), and 3) sediment transport maps. The parameter and transport rate figures are collected in Appendix A, and the sediment transport maps are given in Appendix B. The results for Kailua Beach are examined below as an example.

Figure 2 shows the combination of parameters of the best model for Kailua Beach, i.e., the model with the lowest value of the information criterion. As noted above, in the interests of model simplicity, diffusivity is assumed to be independent of x. The extreme parameter values seen at the edges of the study sections may be due to inaccurate or inappropriate boundary conditions. For example, is it correct to assume zero flux at an endpoint, or zero derivative of the flux at that endpoint? This boundary condition issue requires further investigation, and is outside the scope of this report.

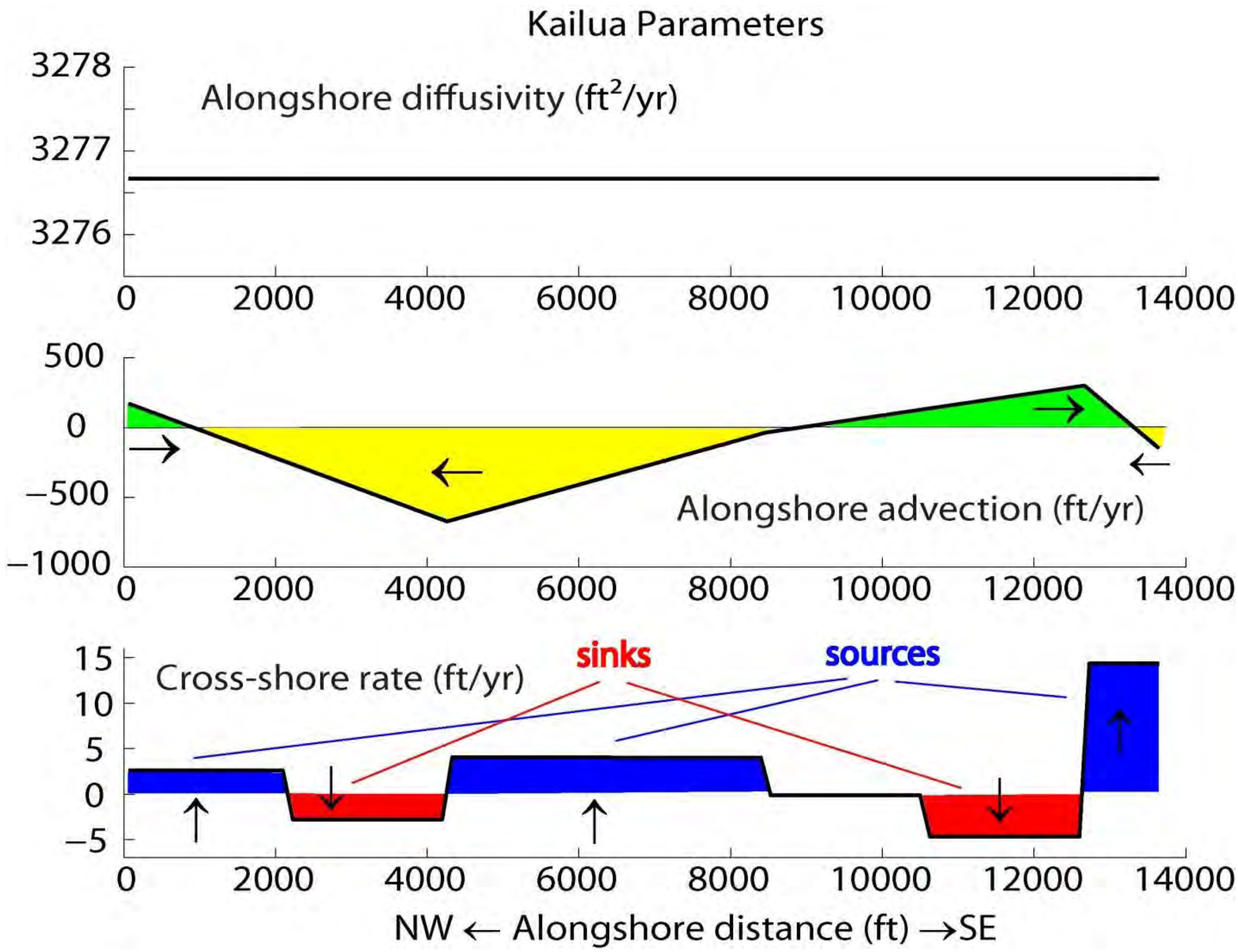

Figure 2. Parameters for Kailua Beach, Oahu. Arrows indicate direction of shoreline movement (positive x-axis is roughly southeast). Upper panel: alongshore diffusivity *D*, assumed independent of *x*. Middle panel: alongshore advection speed *v(x).* Lower panel: cross-shore rate *r(x).*

Figure 2 shows the entire length of Kailua Beach. Alongshore advection speed shows dominant movement in the negative x-axis direction corresponding to a northwest movement across the bay, especially in the mid-left portion of the bay. Cross-shore rate shows sediment sources (erosion) in the middle and ends of the bay, and sinks (accretion) in between. The middle cross-shore source supports the hypothesis that the sand-filled paleochannel located in the middle of the bay is a source of sediment to the beach. The source at the south end of the bay may be due to sediment entering the bay from around Alala Point, consistent with prevailing tradewind directions. The sediment source at the north end of the bay is unknown at this time.

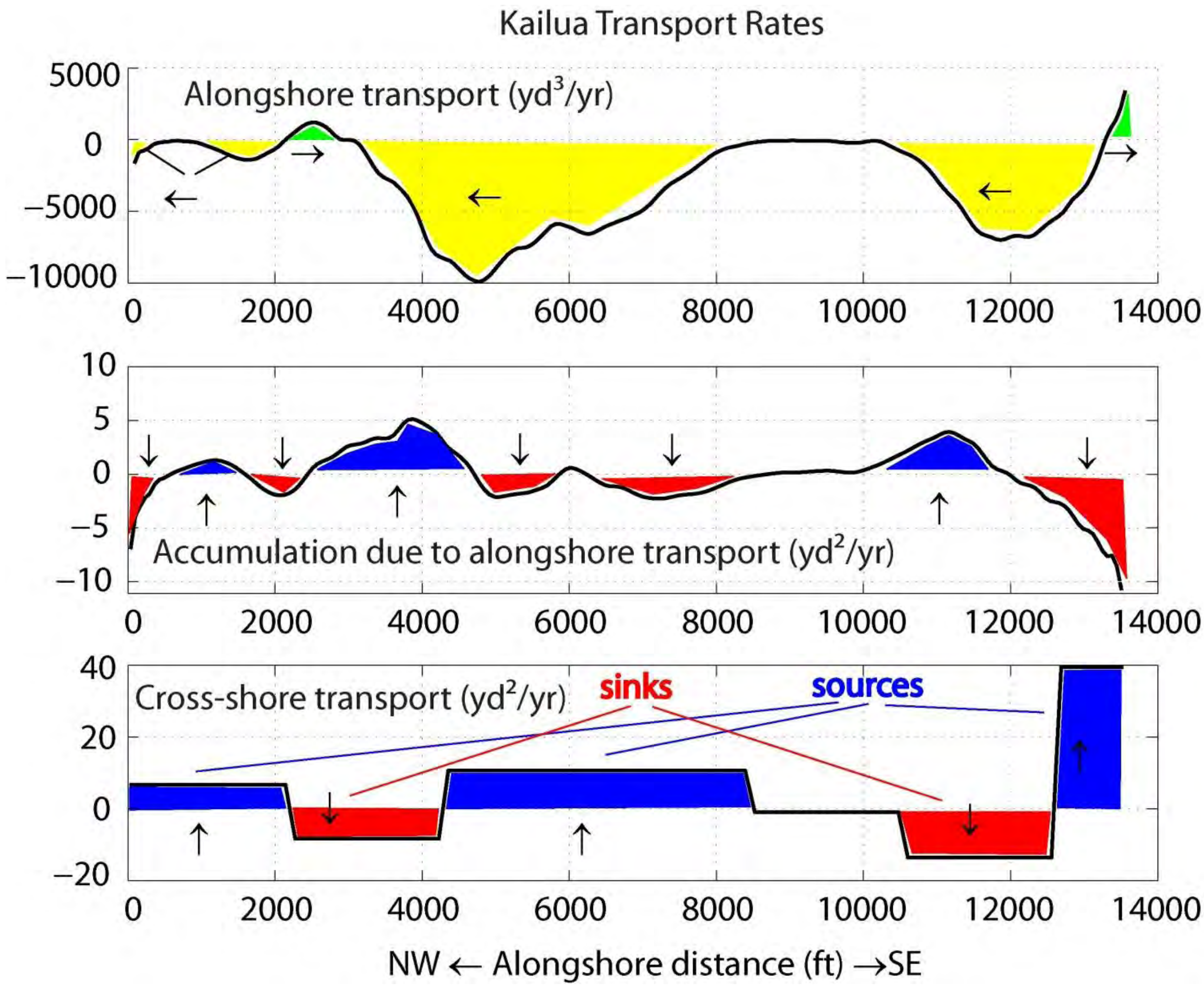

Figure 3. Kailua sediment transport rates. Arrows indicate direction of shoreline movement (positive y-axis is off-shore, positive x-axis is south). Upper panel: longshore transport (Q_x) in yd^3/yr. Middle panel: sediment accumulation due to changes in longshore transport, ($-\partial_x Q_x$) in yd^3/yr per meter of shoreline. Bottom panel: cross-shore transport, (Q_y) in yd^3/yr per meter of shoreline.

Figure 3 gives the alongshore sediment flux in cubic meters per year, and the cross-shore sediment flux in cubic meters per year per meter of shoreline length. These fluxes are calculated from the parameters in figure 2, along with the 19.105 foot active profile height obtained from beach profile surveys. The sediment accumulation rate due to changes in alongshore transport is the derivative of the alongshore flux with respect to alongshore distance ($-\partial_x Q_x = (A\tilde{y})Z$). For example, alongshore transport is negative from 3000 to 8000 feet, indicating sediment transport to the left. From 1000 to 3000 feet, there is little alongshore advection. As a result of this change in advection speed, sediment moving left accumulates as it hits a portion of shoreline that does not move. This is illustrated by the positive curve between around 2500 – 4500 feet in the alongshore sediment flux. Similarly, at the right end of the figure, where alongshore flux is positive, sediment is moving out of the system faster than it is being replaced.

The sediment transport map (Figure 4) is a general interpretation of the results presented in the parameter and transport rate figures. These maps illustrate general sediment directional behavior, as well as overall sediment gain or loss to the area, calculated as the sum of integrals of cross-shore transport and change in alongshore transport over the entire length of study shoreline. Overall, Kailua beach is accreting, at a rate of about 10,700 yd^3/yr.

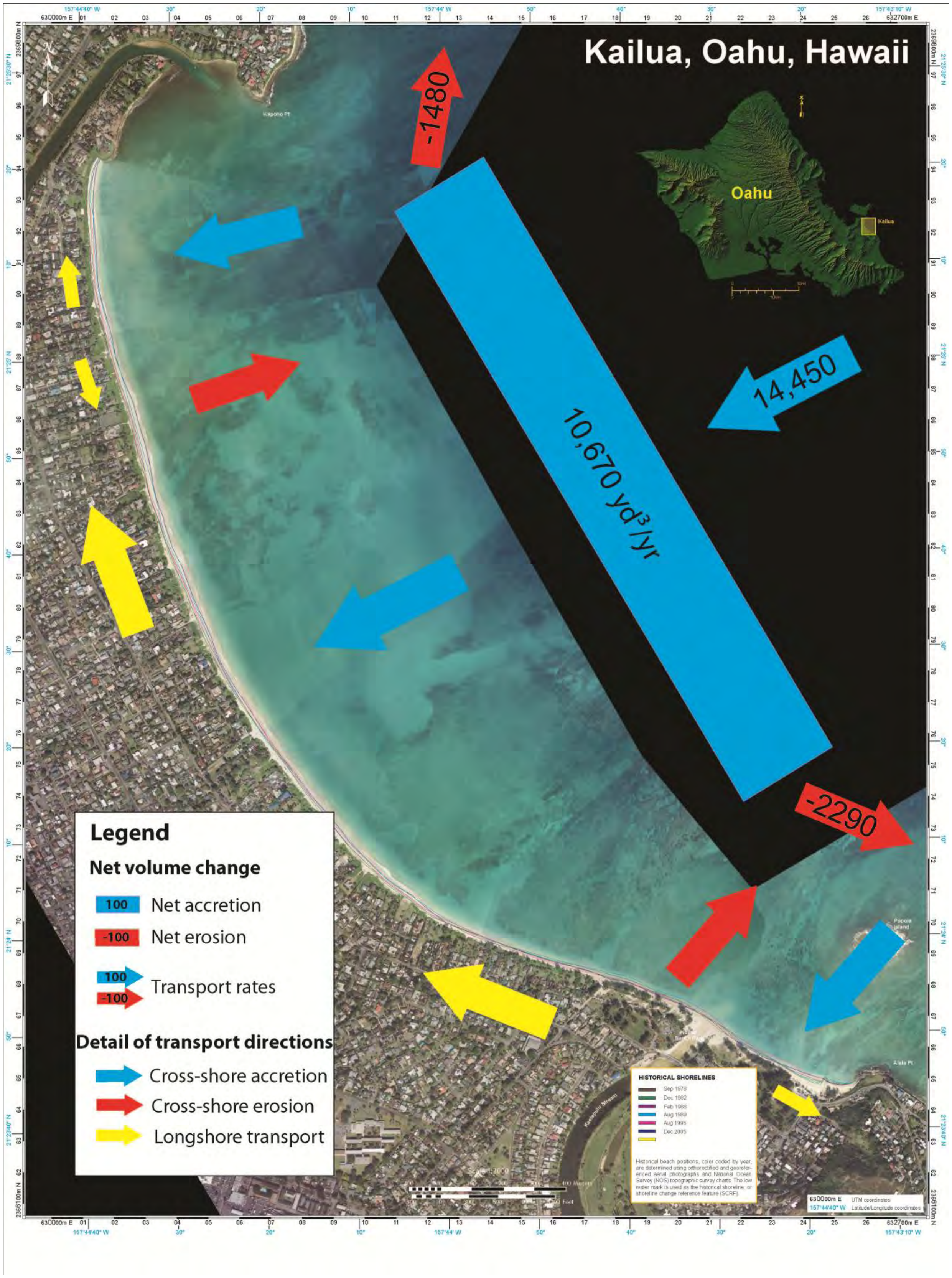

Figure 4. General sediment transport behavior and overall sediment change rates.

Results

Model parameters and sediment transport rates along each study area are displayed in Appendix A. Maps containing sediment transport calculations, and arrows displaying sediment transport directions for each area are contained in Appendix B.

Conclusions

As a first attempt at modeling such a large study area, automated processes appear to capture general shoreline behavior, but there are several improvements that could greatly improve model fits. These include expanding the set of potential models by including more scenarios of node placement in spatial averaging, constraining boundary conditions, and careful selection of study areas.

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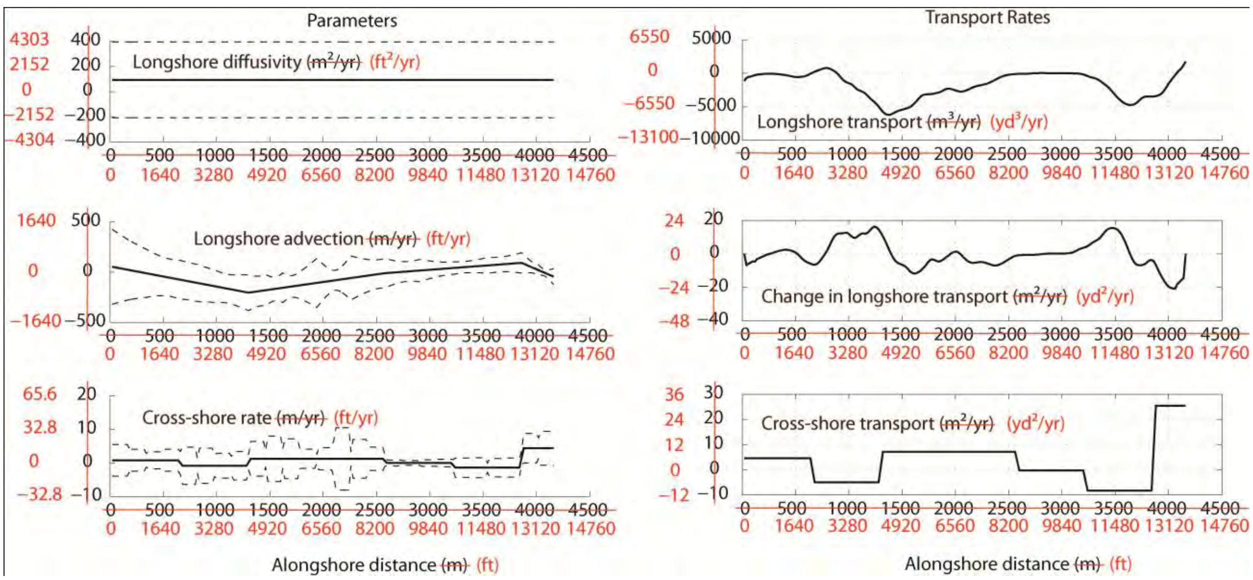
Appendix A – Parameters and transport rates

All figures in this section are represented in metric units. To convert from metric to English units, simply multiply the metric unit by the appropriate conversion factor displayed in the table below.

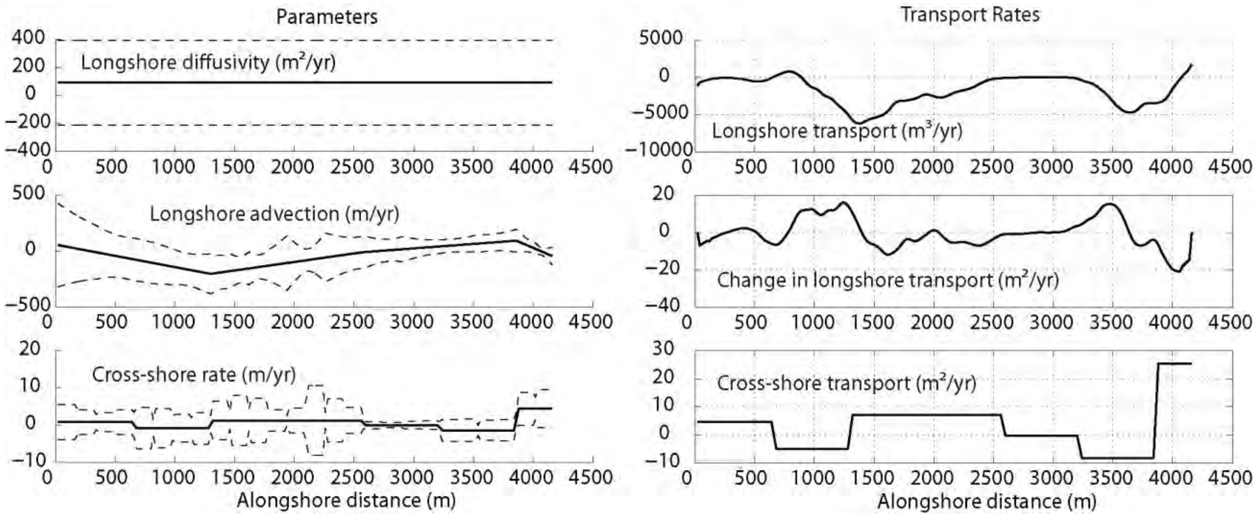
Metric to English Unit Conversion Chart			
Metric units	English units	Conversion factor	Value(s) represented
meters (m)	feet (ft)	3.28	Alongshore distance (x-axes)
meters per year (m/yr)	feet per year (ft/yr)	3.28	Alongshore advection, cross-shore rate
meters squared per year (m2/yr)	square feet per year (ft2/yr)	10.76	Alongshore diffusivity
meters squared per year (m2/yr)	square yards per year (yd2/yr)	1.20	Cross-shore transport, accumulation due to alongshore transport
meters cubed per year (m3/yr)	cubic yards per year (yd3/yr)	1.31	Alongshore transport

For example, the following figure (results for Kailua, Oahu) displays English units in red.

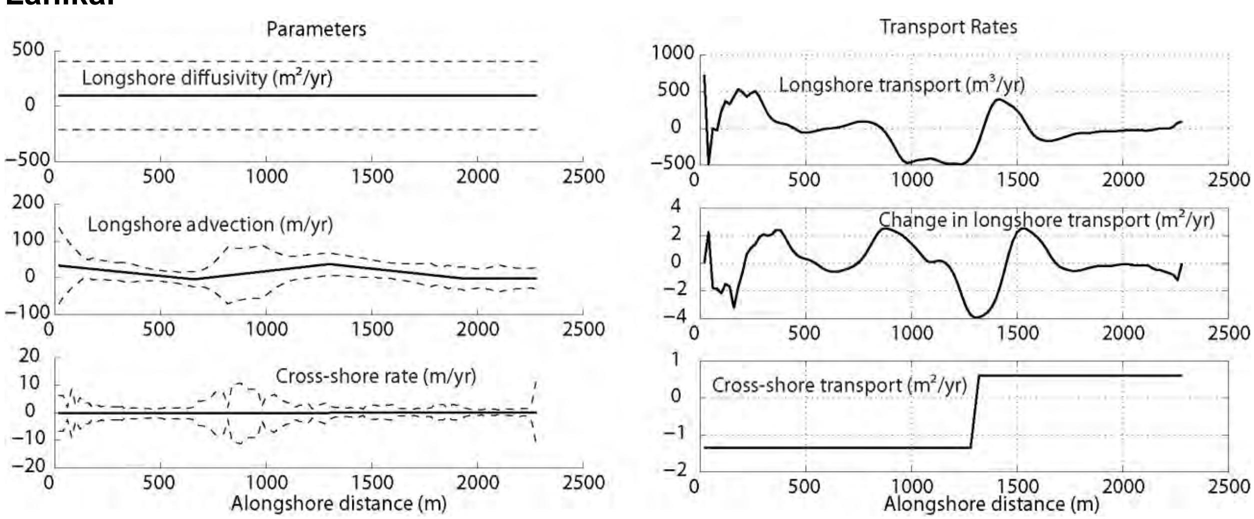


Windward Oahu

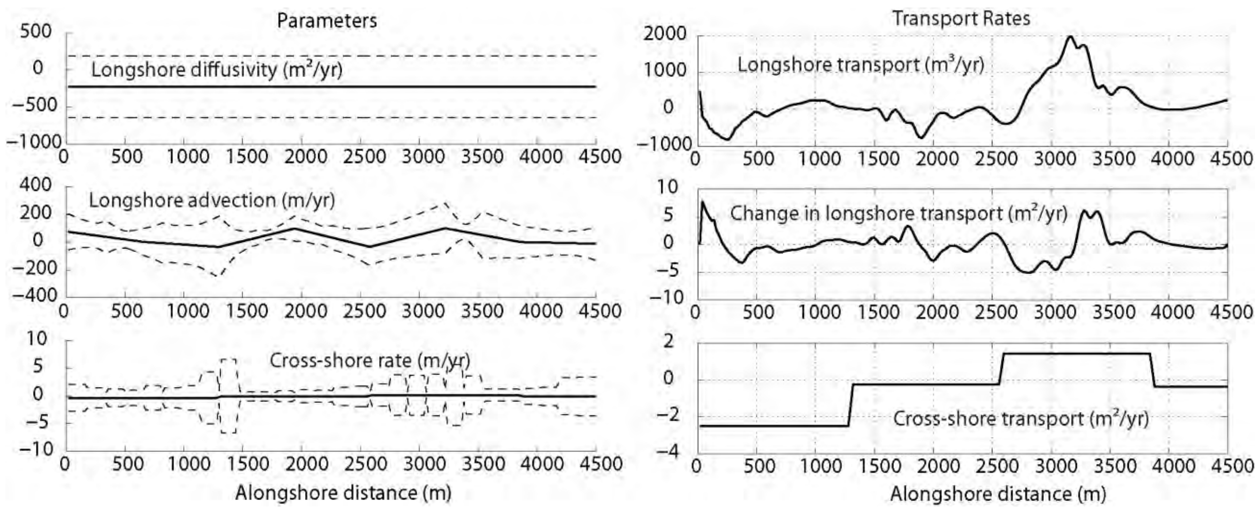
Kailua



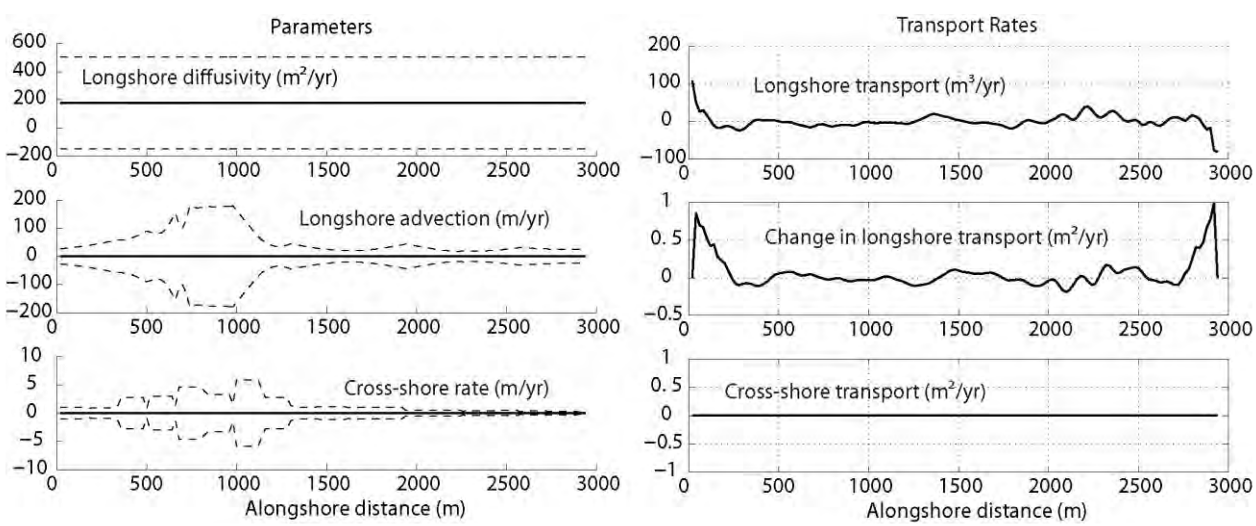
Lanikai



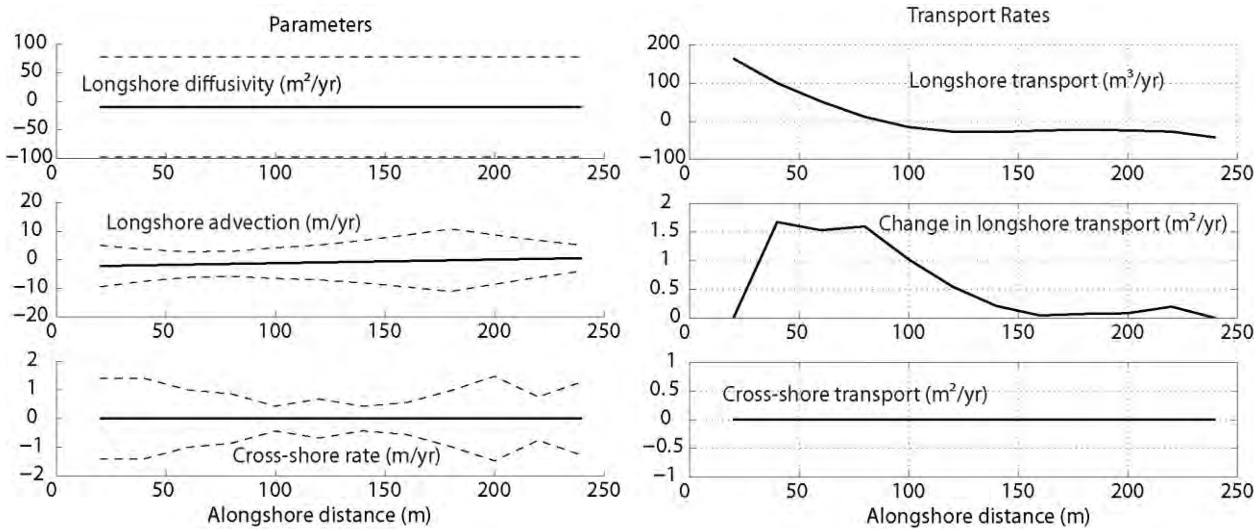
Bellows



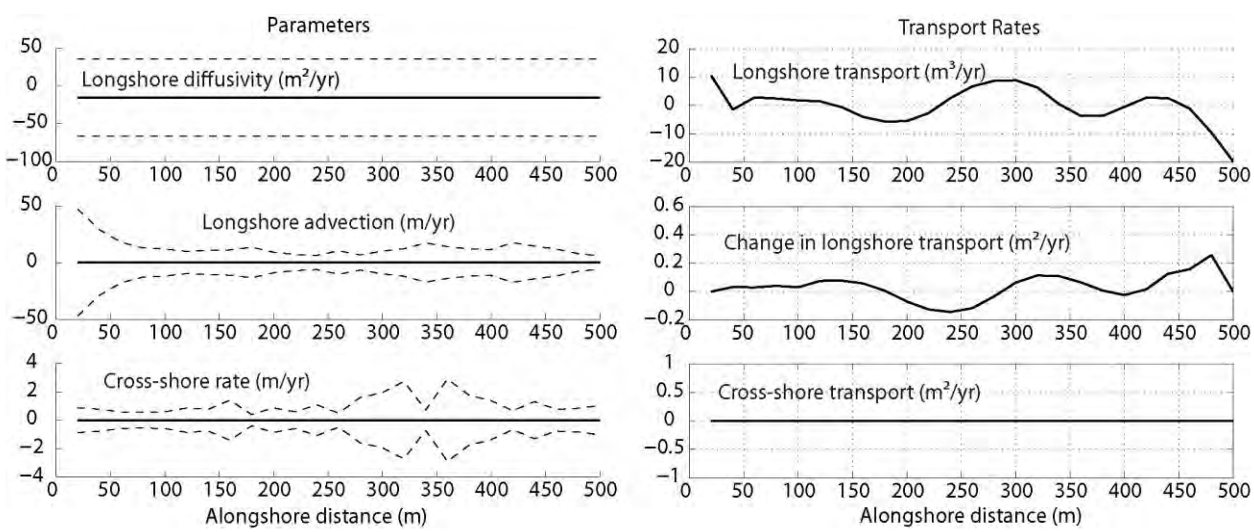
Waimanalo



Makapuu

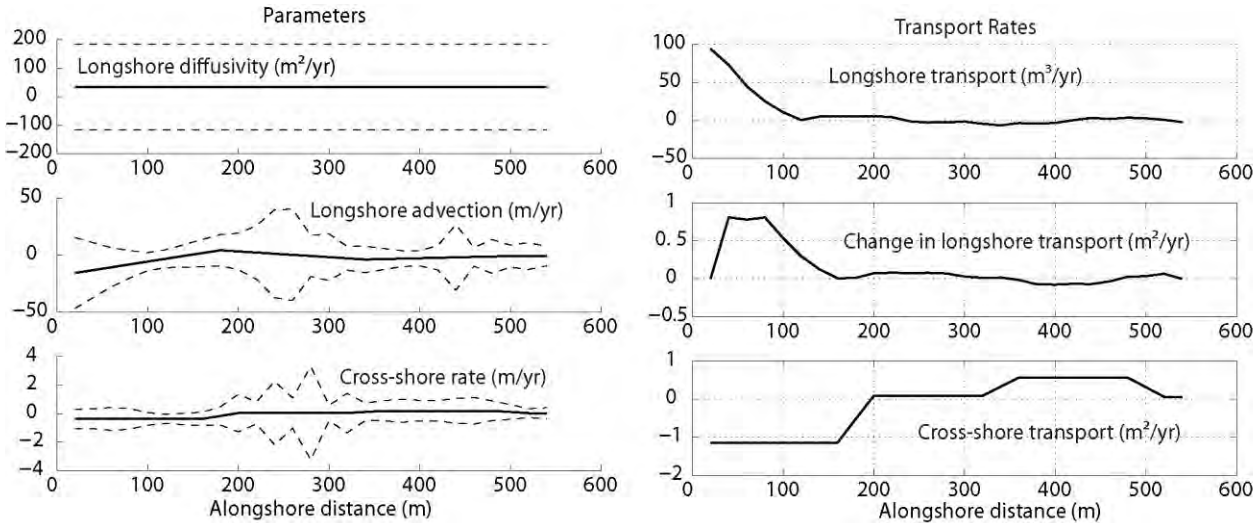


Sandy Beach

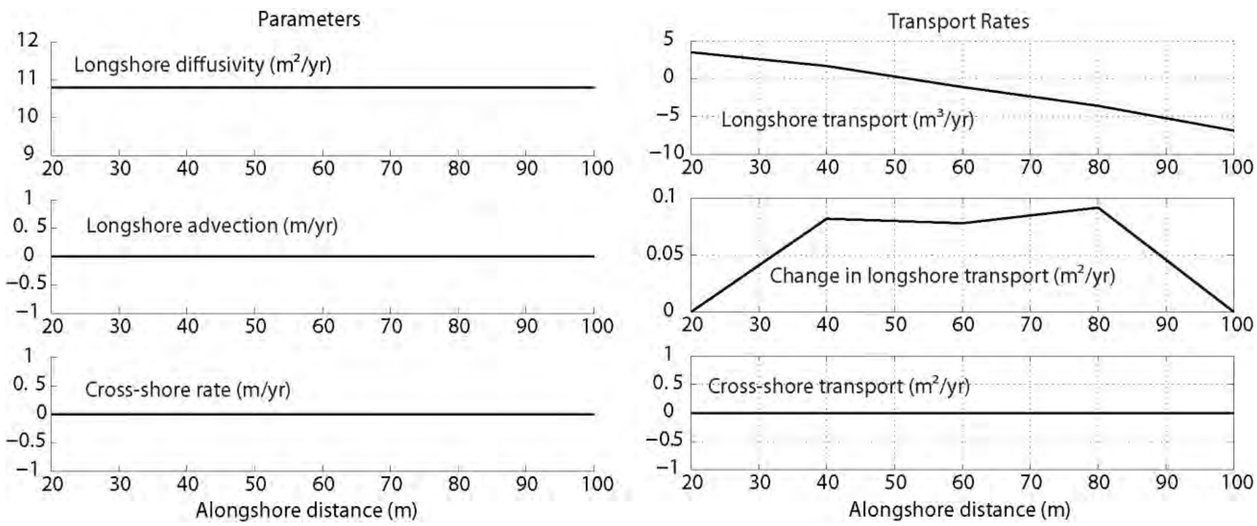


East Honolulu

Hanauma Bay



Hawaii Kai 1



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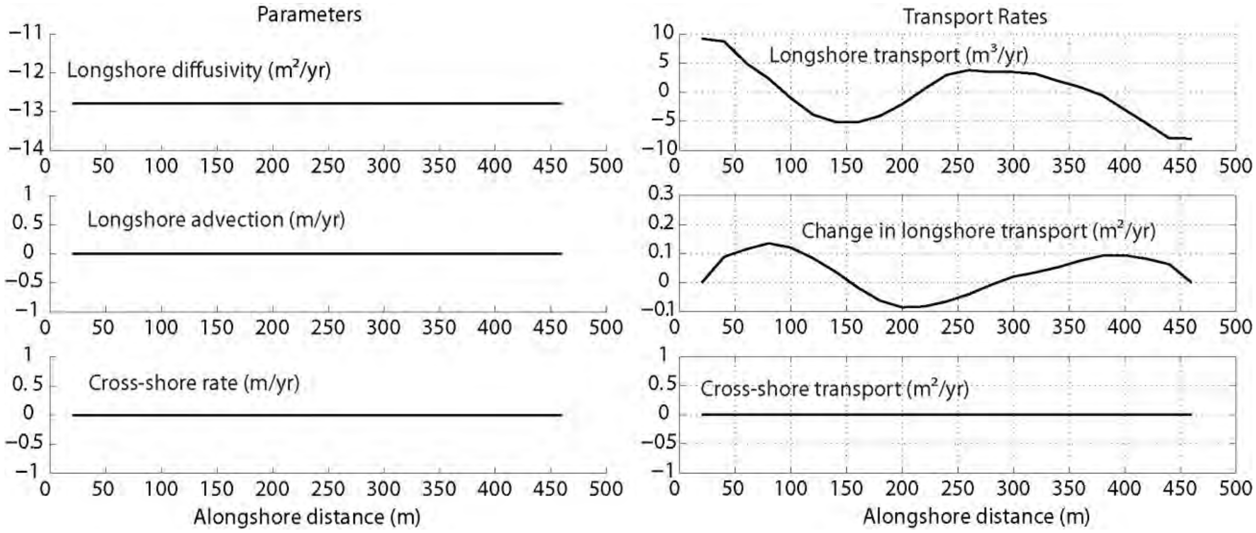
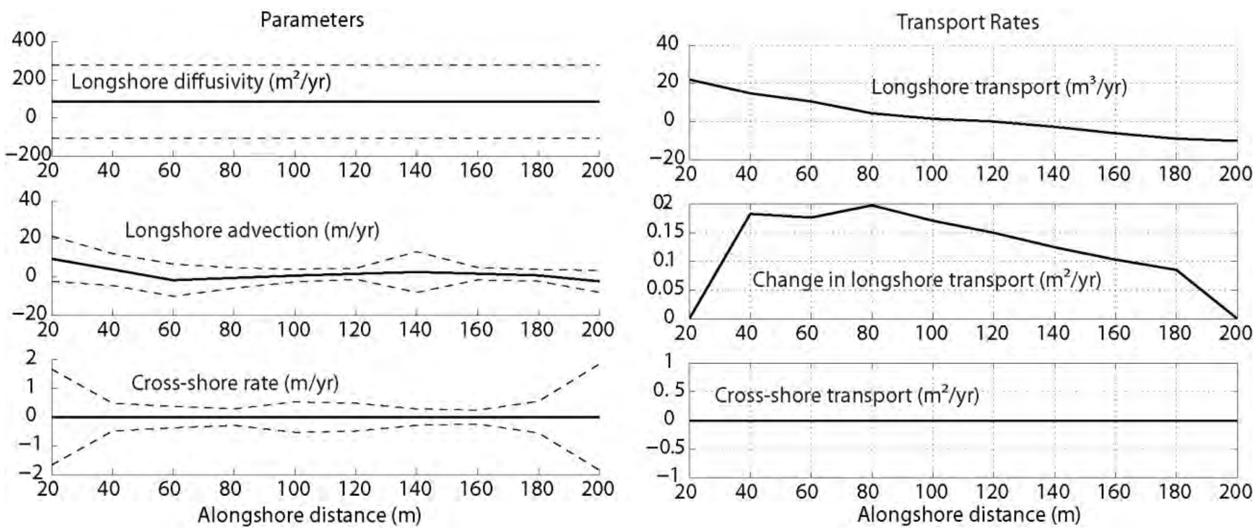
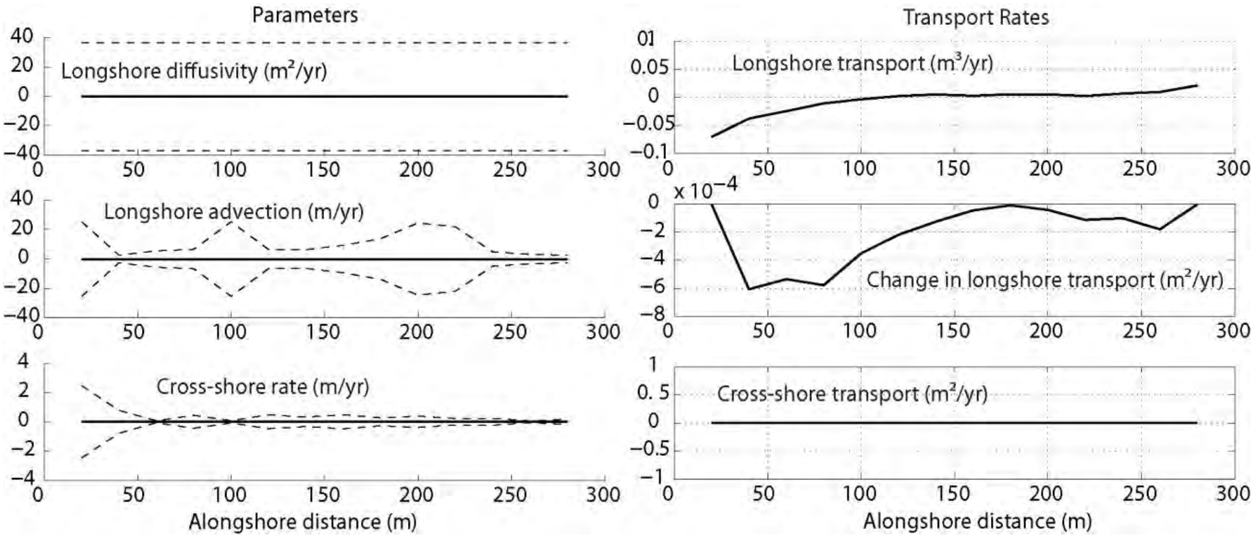


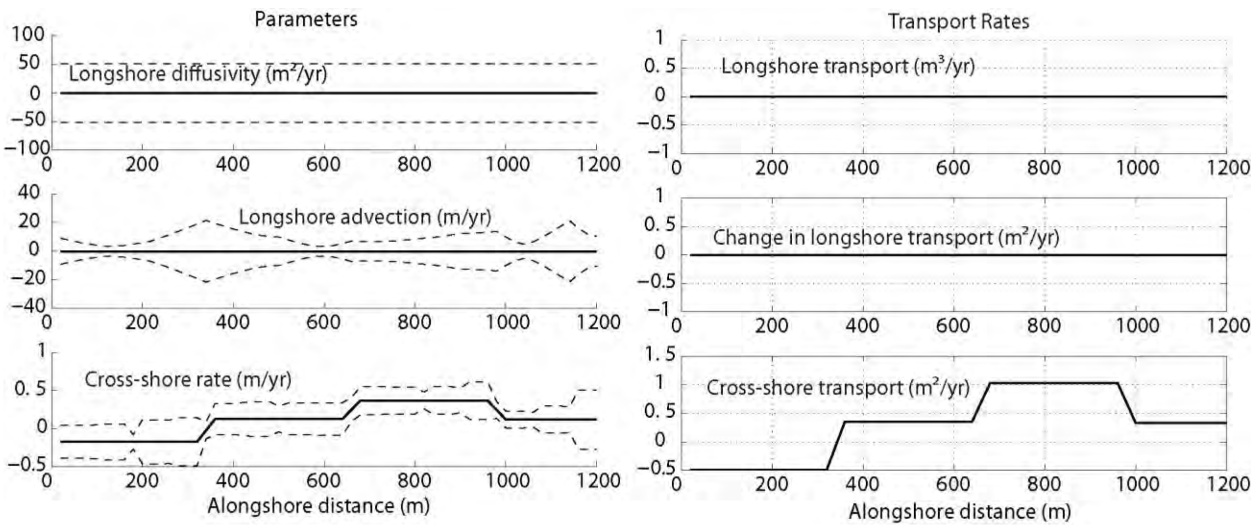
Hawaii Kai 3



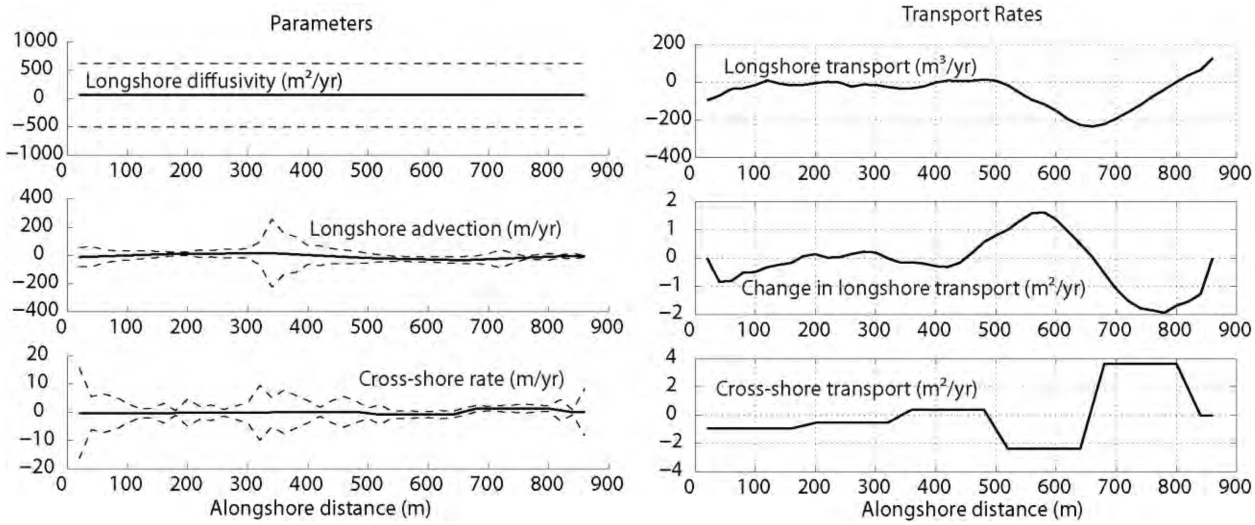
Hawaii Kai 4



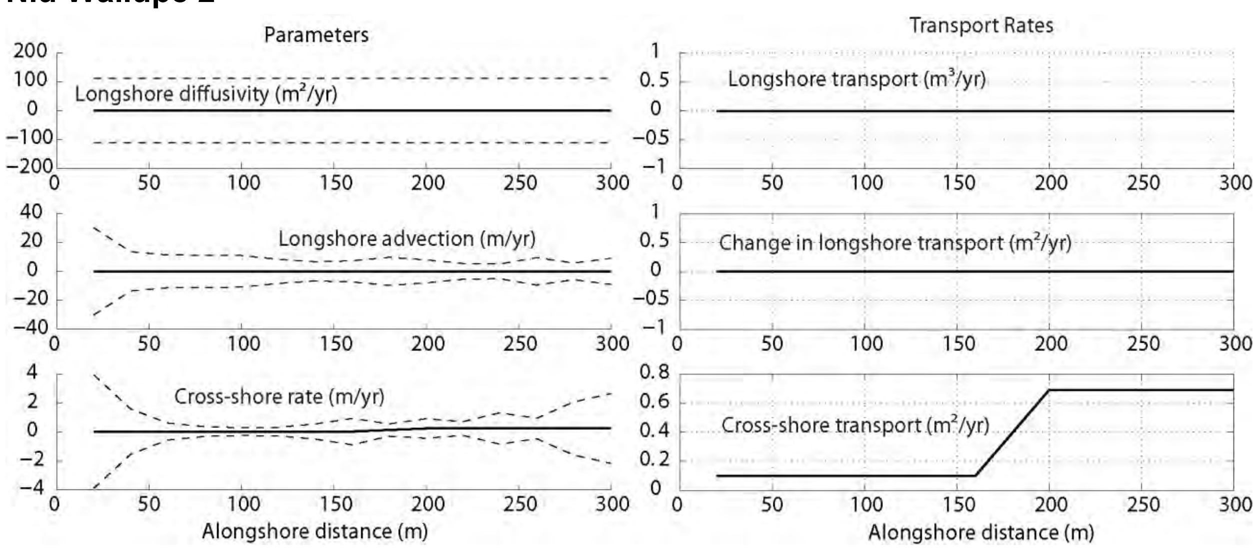
Paiko



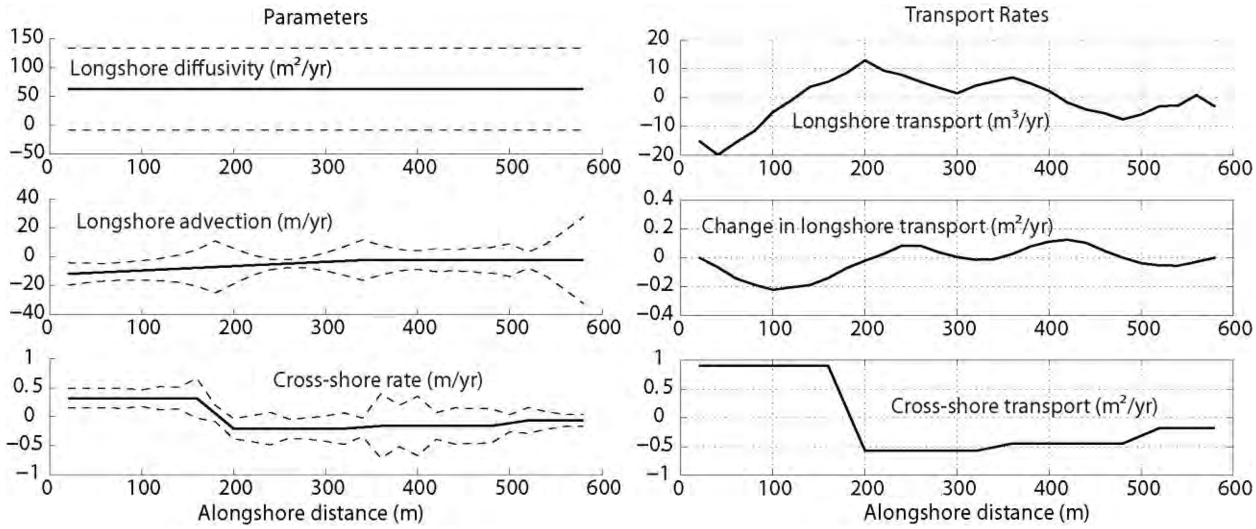
Niu Wailupe 1



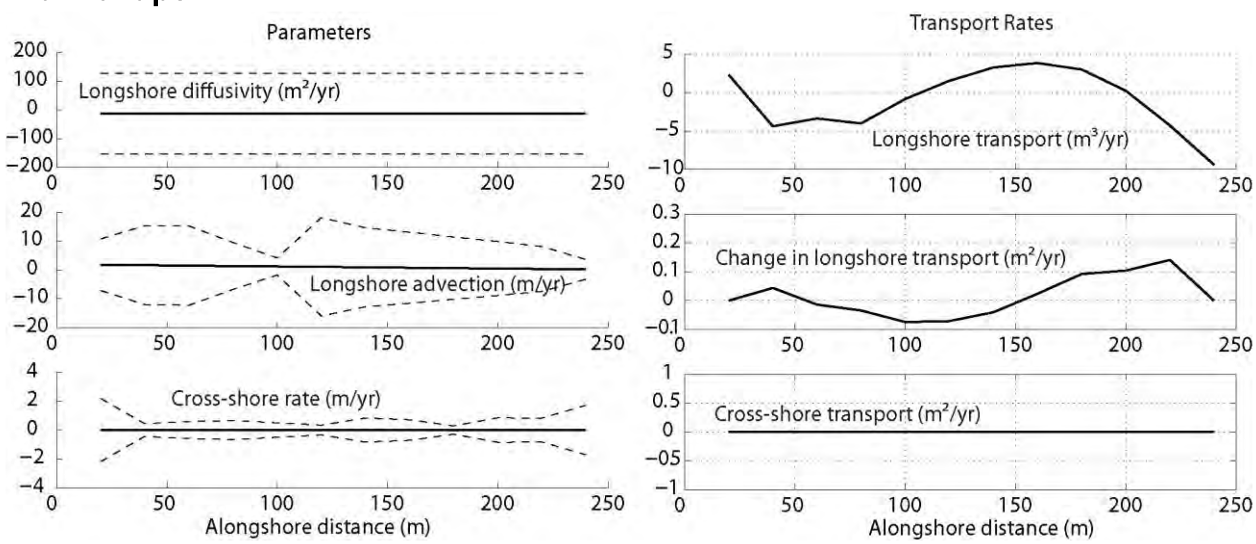
Niu Wailupe 2



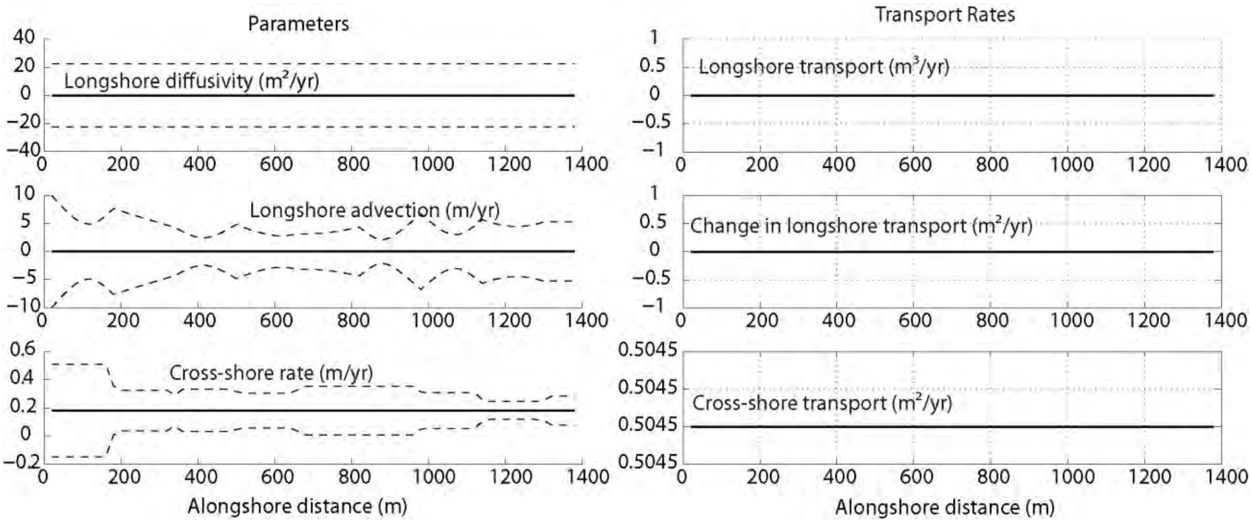
Niu Wailupe 3



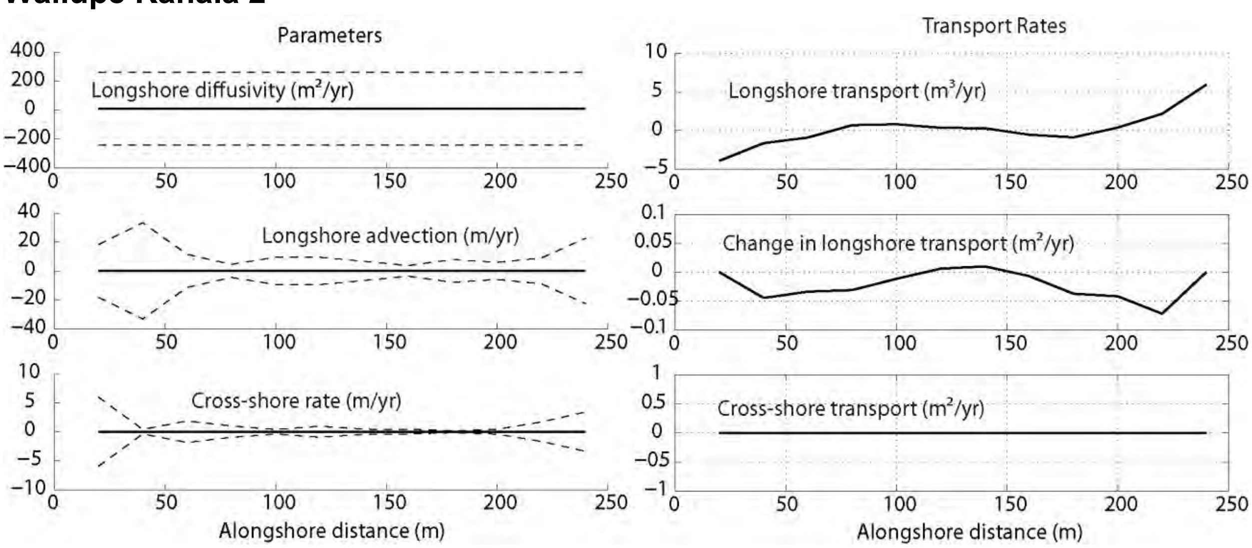
Niu Wailupe 4



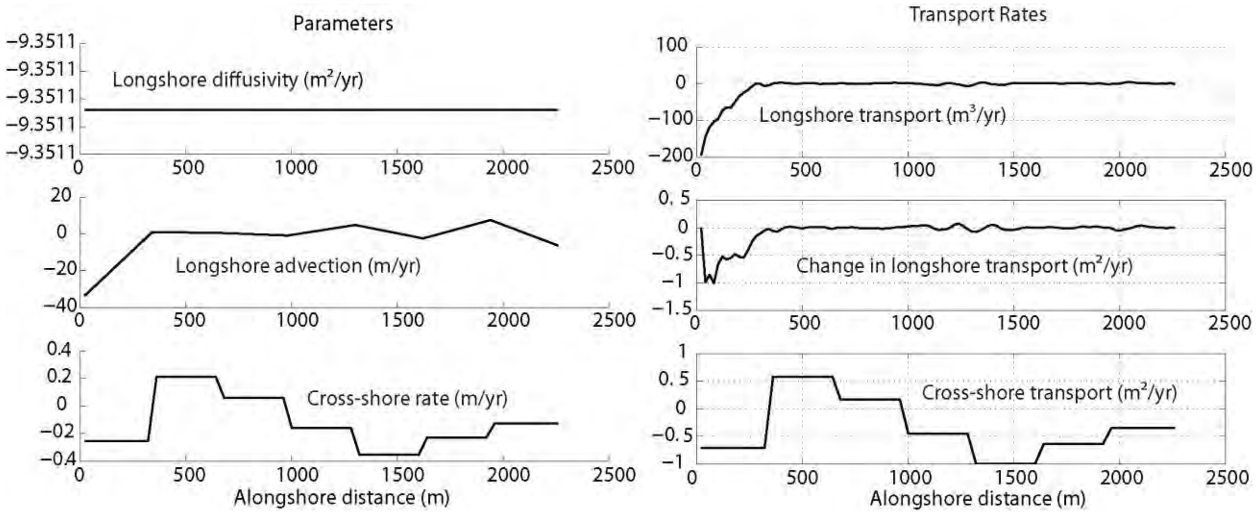
Wailupe Kahala 1



Wailupe Kahala 2

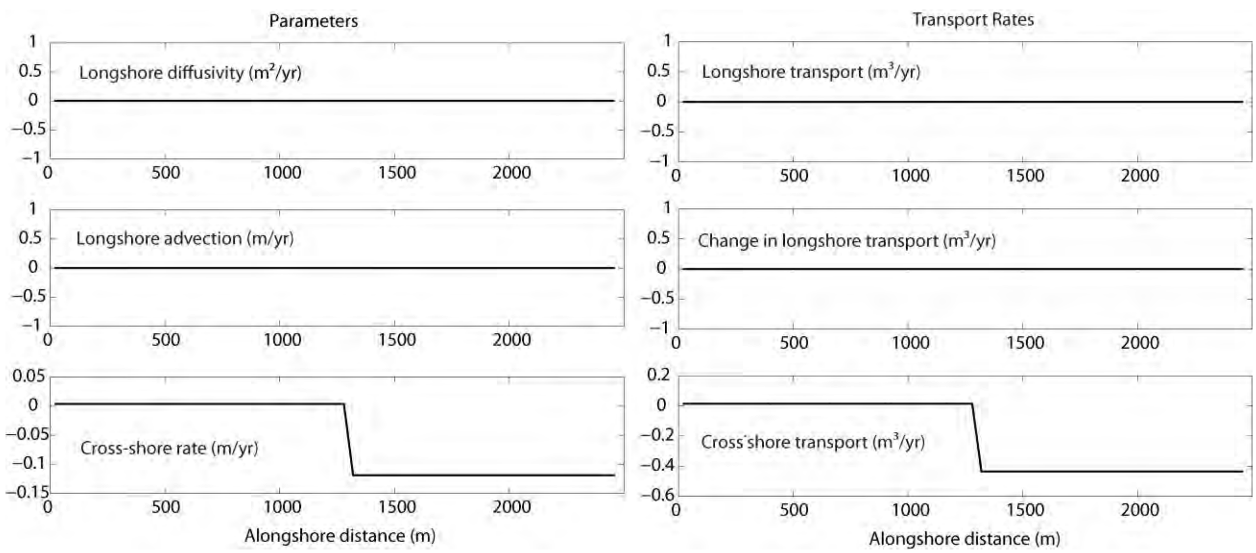


Kahala – Black Point



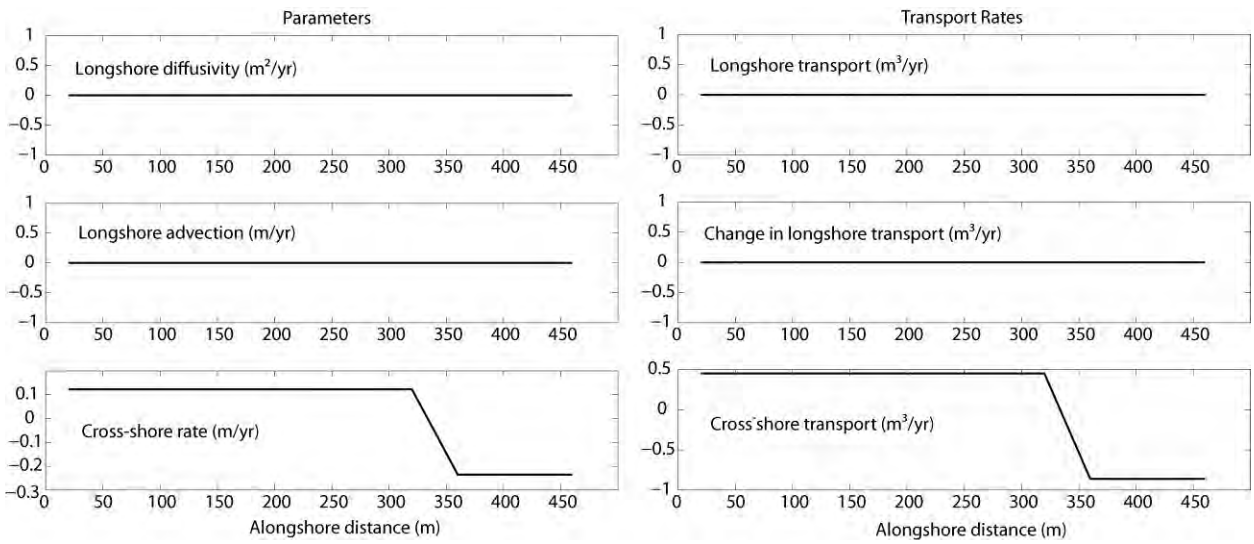
D2P

Diamond Head

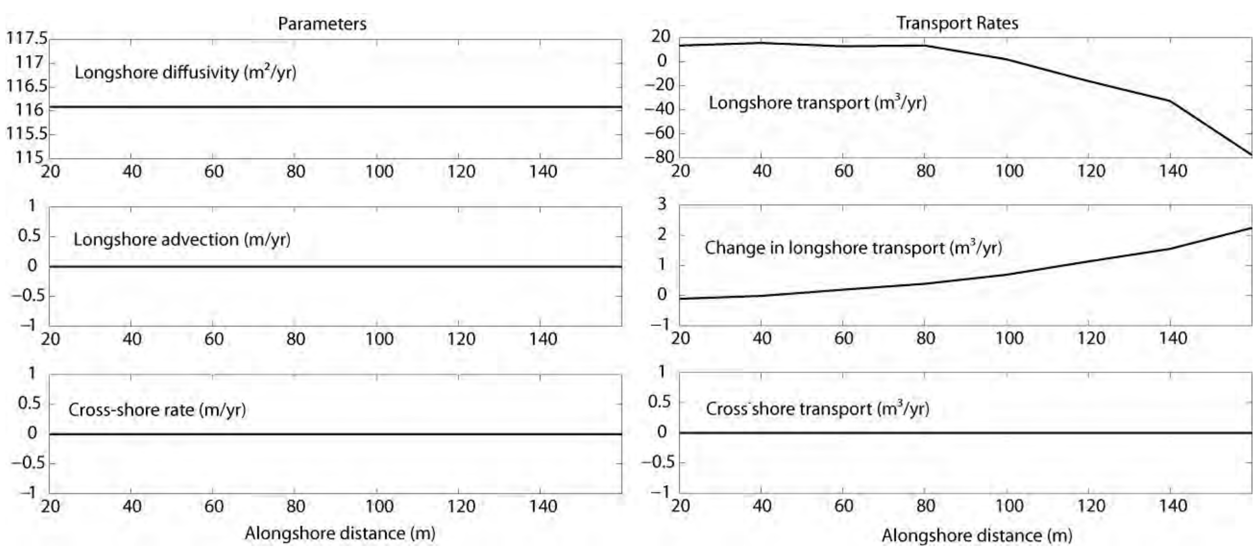


Waikiki

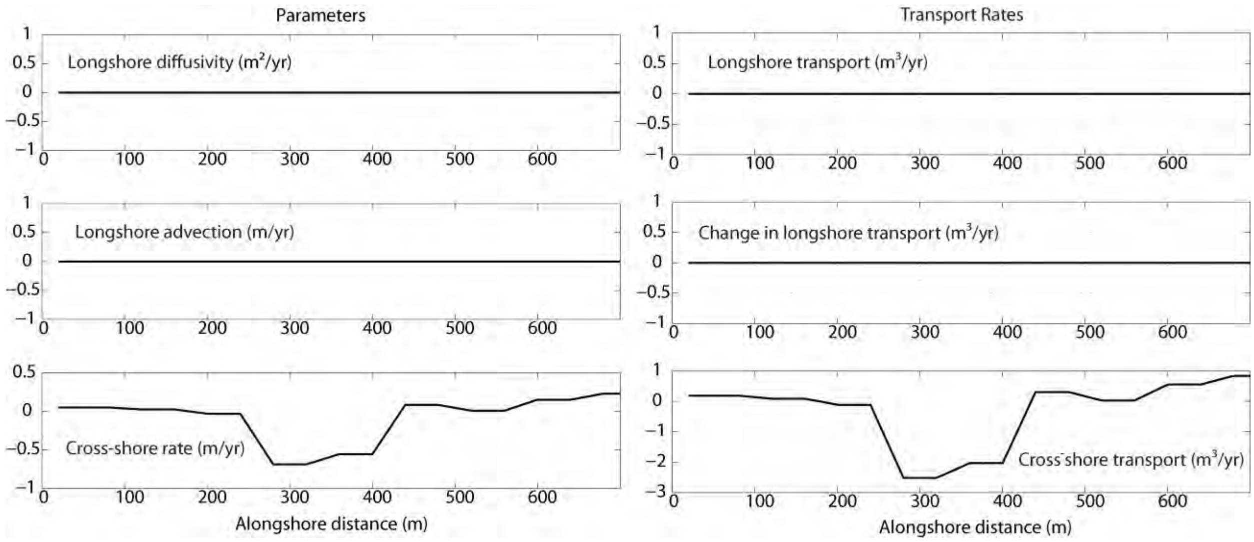
Outrigger



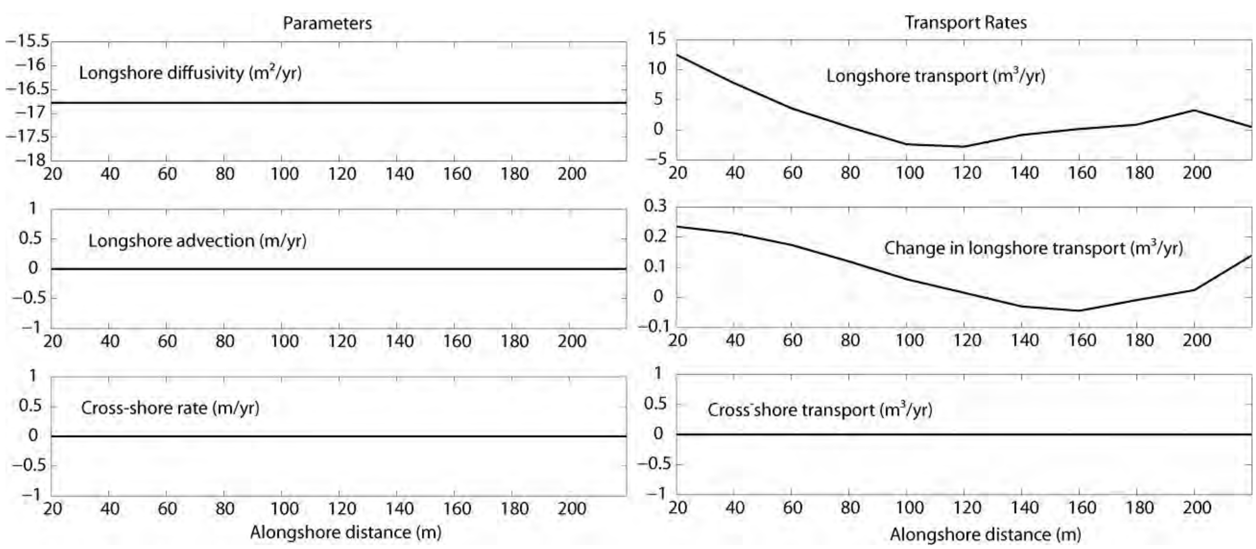
Kaimana



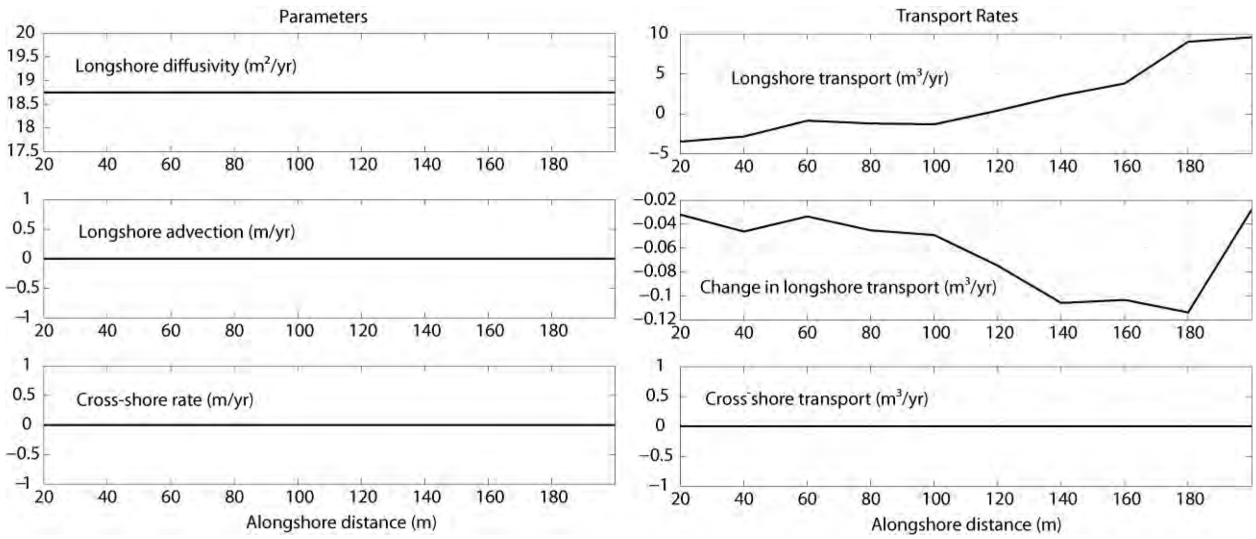
Aquarium/Queens Beach



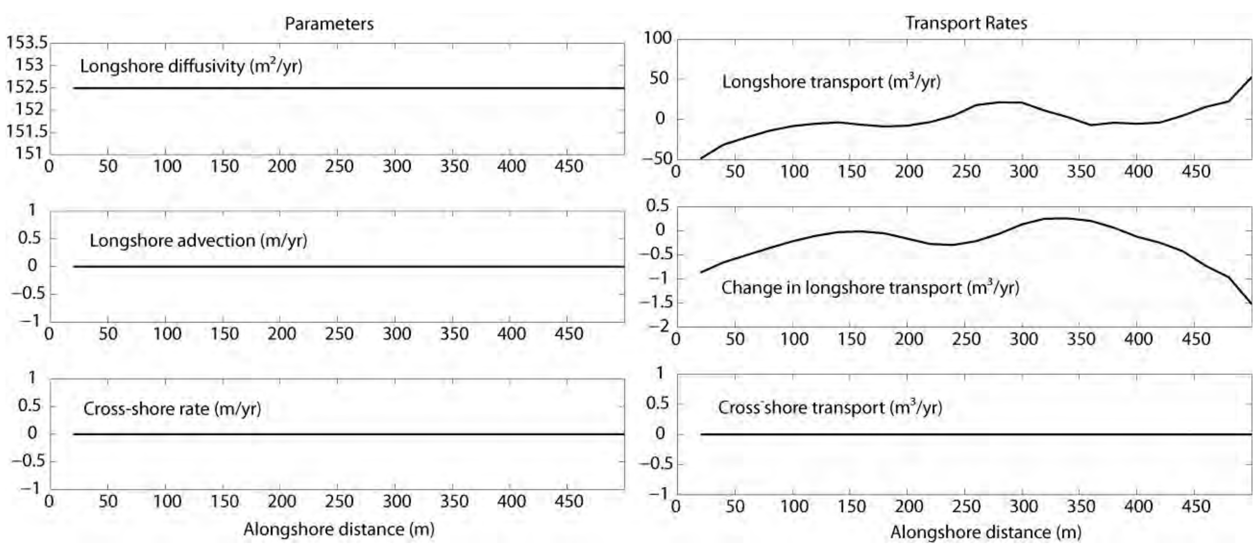
Kuhio South



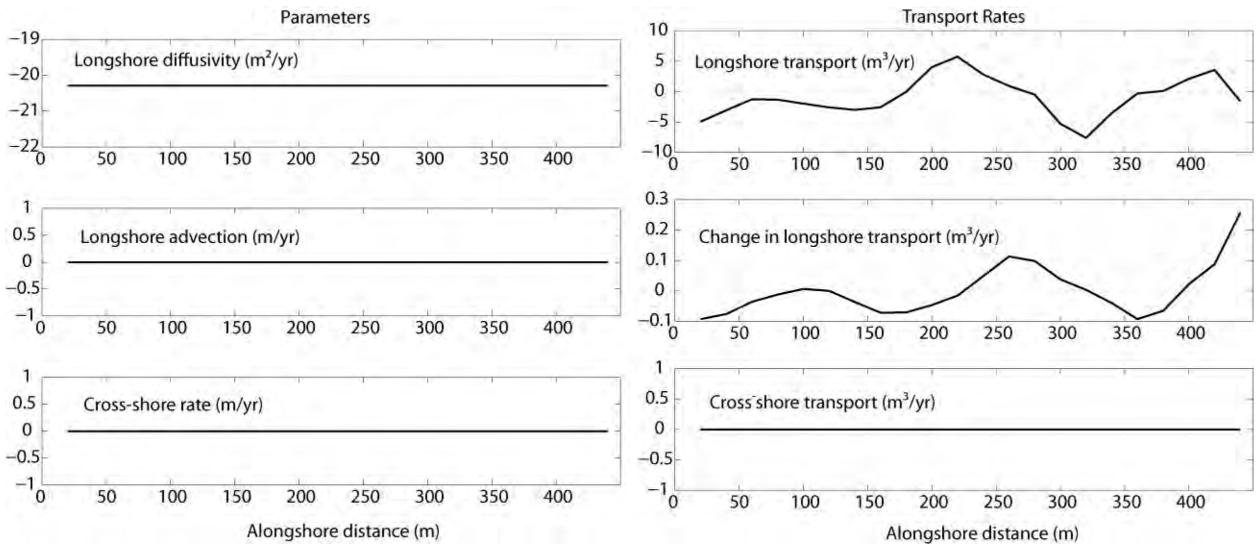
Kuhio North



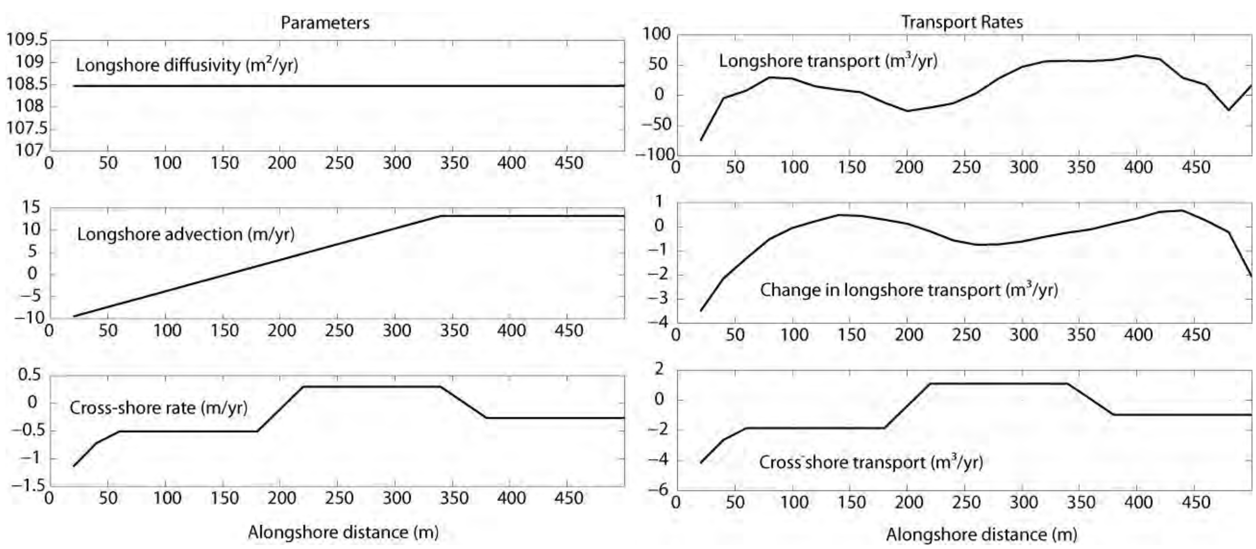
Royal Hawaiian



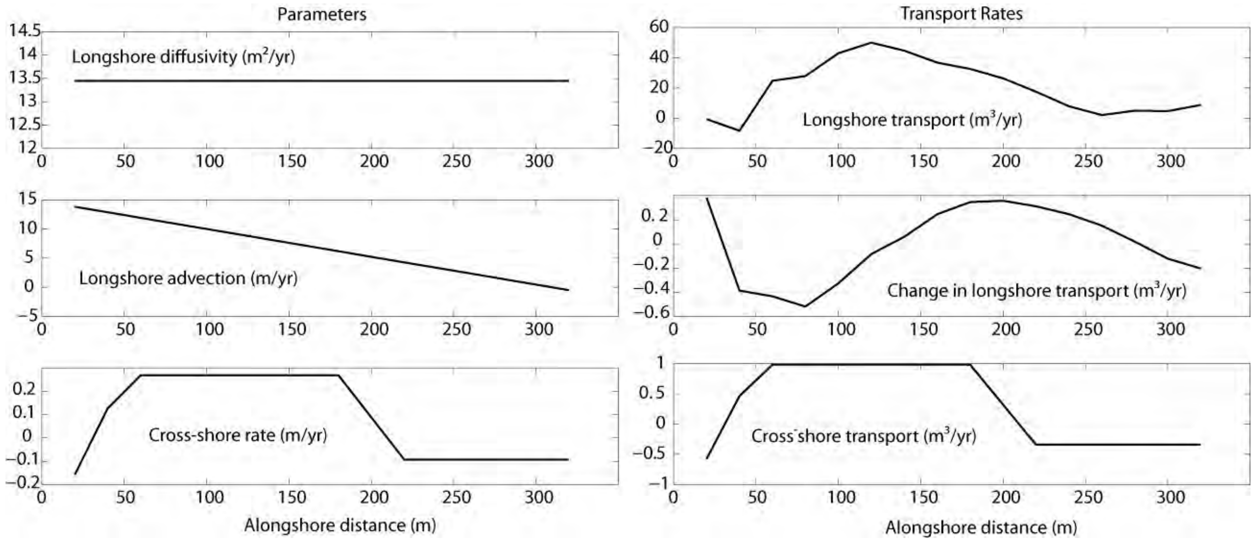
Sheraton



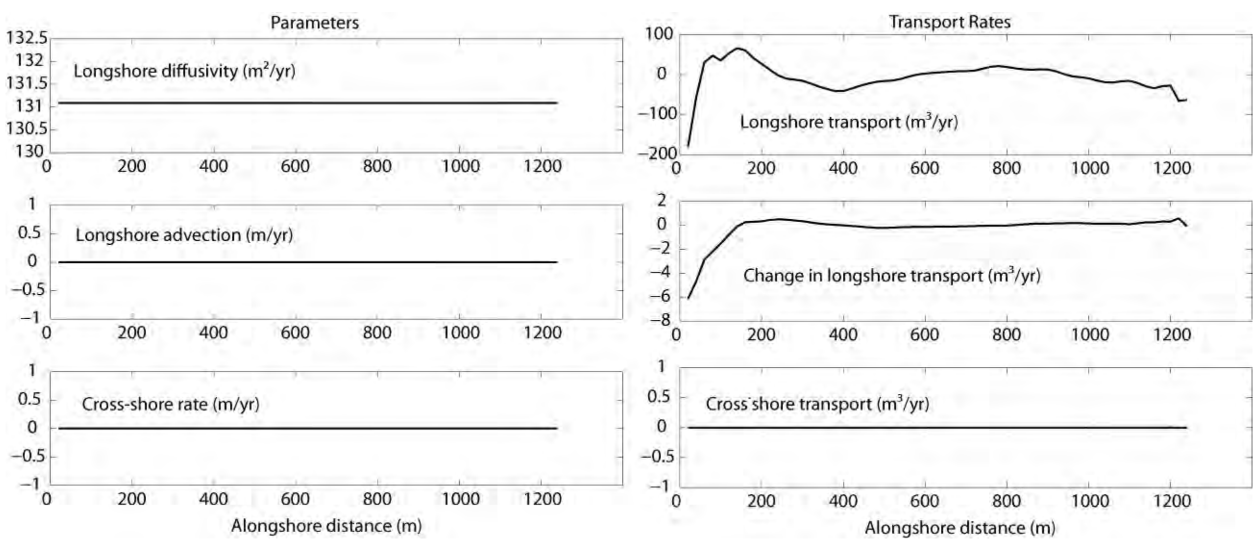
Ft DeRussy



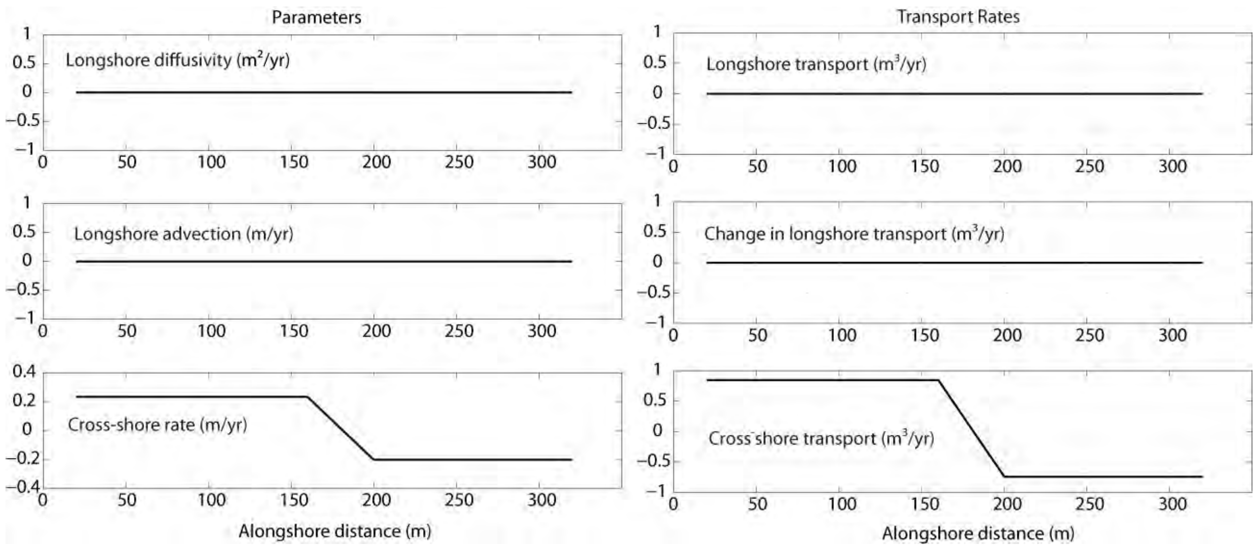
Kahanamoku



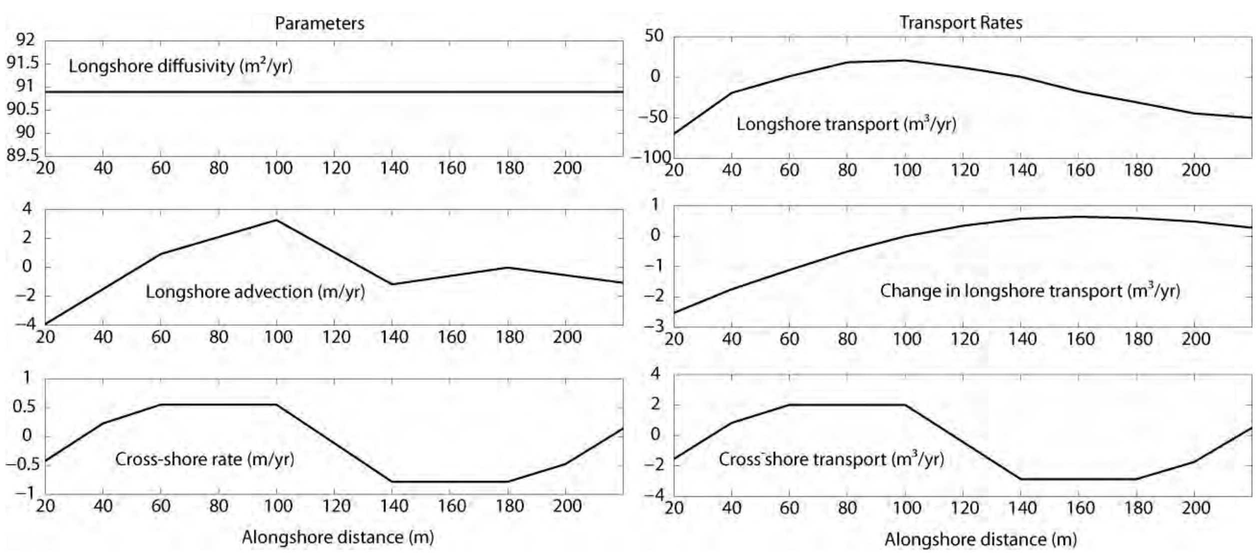
Ala Moana



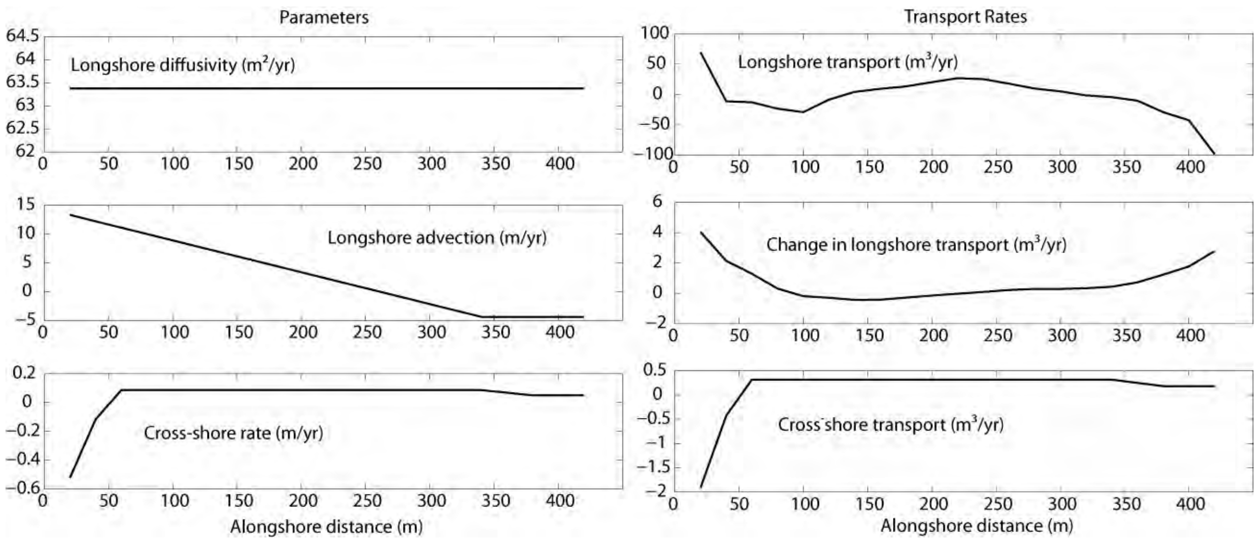
Magic Island



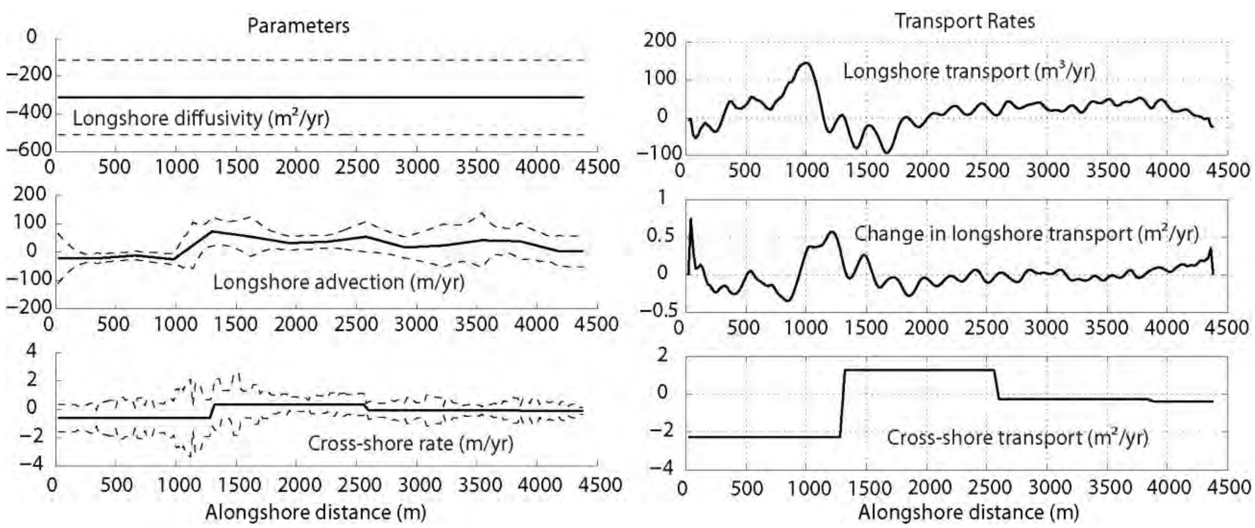
Sand Island West



Sand Island East

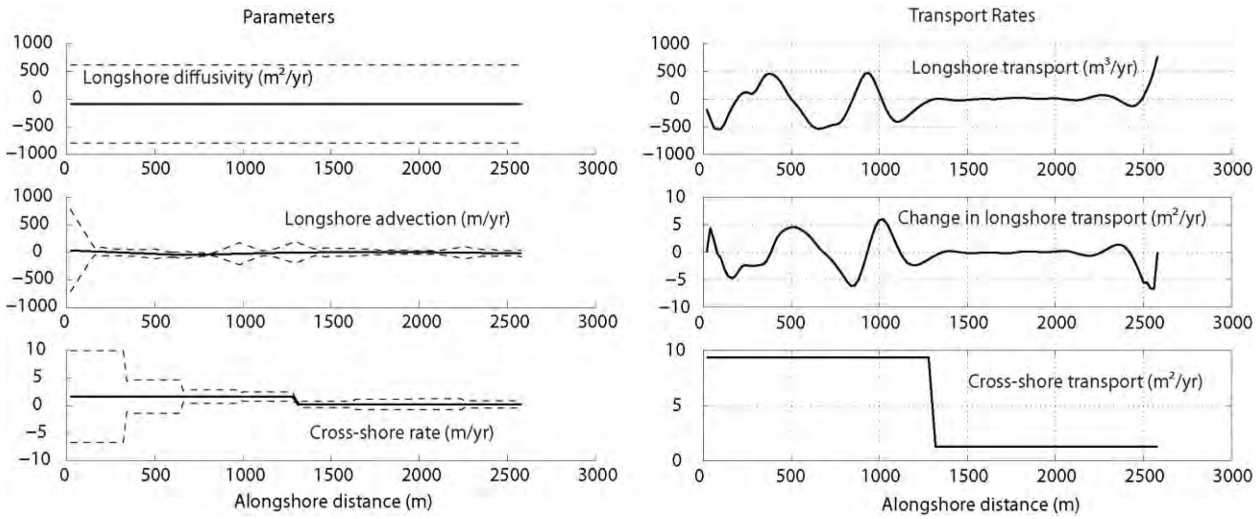


Iroquoi Point and Ewa

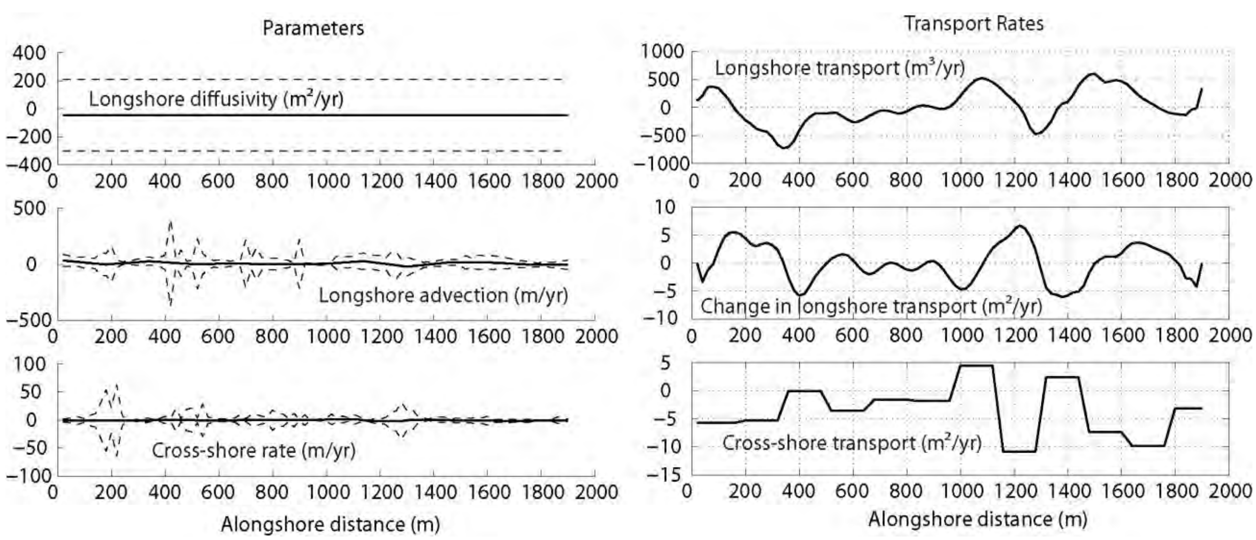


West Kauai

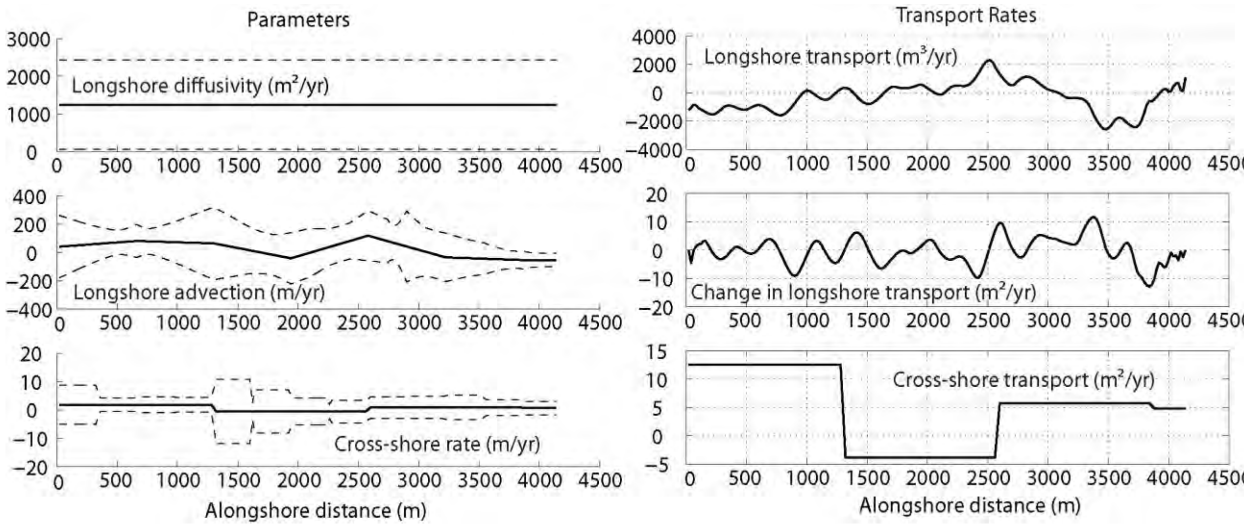
Waimea



Oomano



Kekaha



Parameters
Longshore diffusivity (m²/yr)
Longshore advection (m/yr)
Cross-shore rate (m/yr)
Alongshore distance (m)
Transport Rates
Longshore transport (m³/yr)
Change in longshore transport (m²/yr)
Cross-shore transport (m²/yr)
Alongshore distance (m)

Appendix B – Sediment transport maps

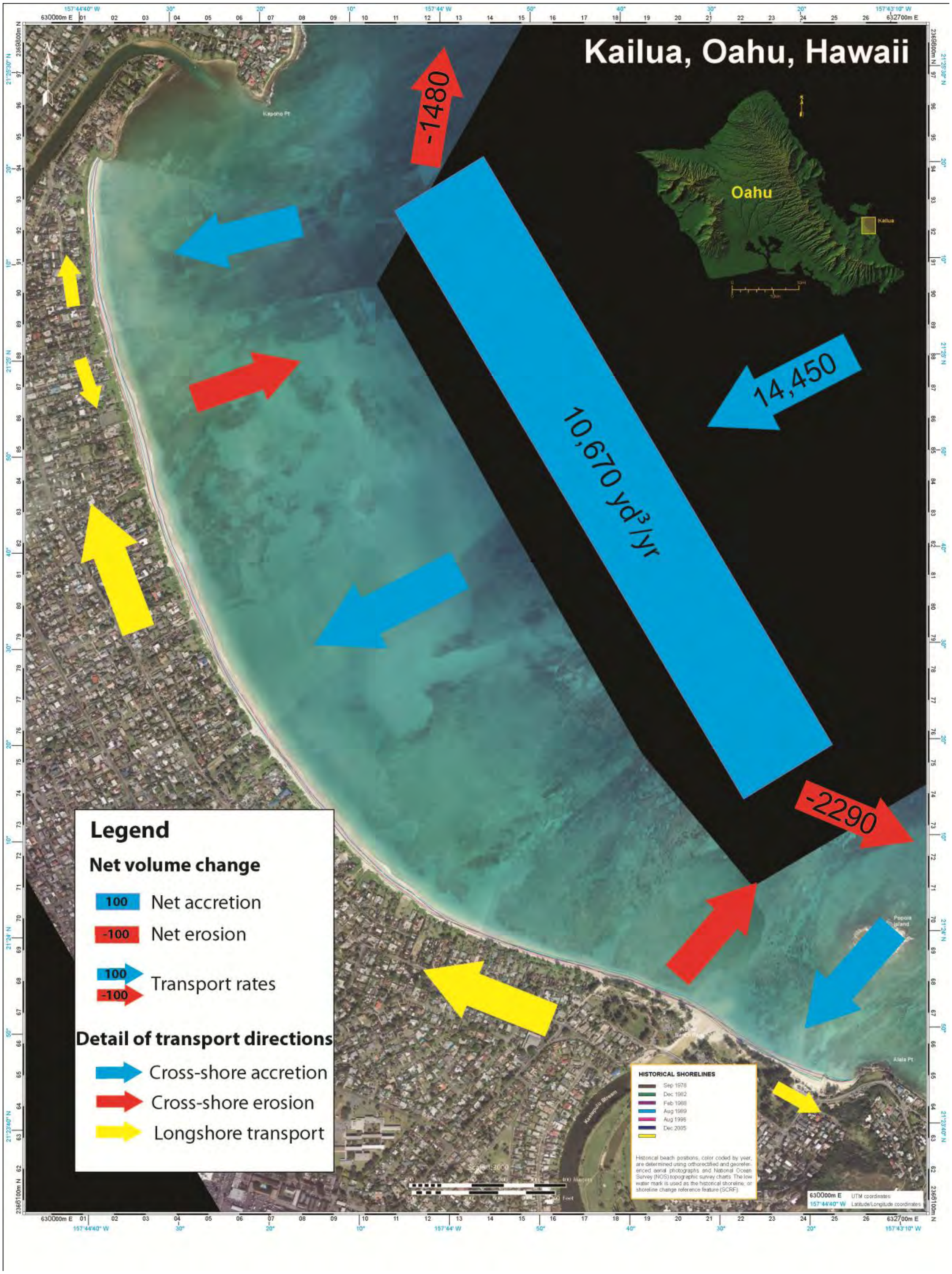
Windward Oahu

Summary

Windward Oahu beaches are generally long stretches of beach (miles) with relatively large active profile depths of 16-25 feet. Because of these large datasets, optimal models that include all parameters were often selected. The results range from large trade-offs between alongshore and cross-shore transport, as seen in Kailua Beach, to more conservative rates as seen in the Waimanalo area.

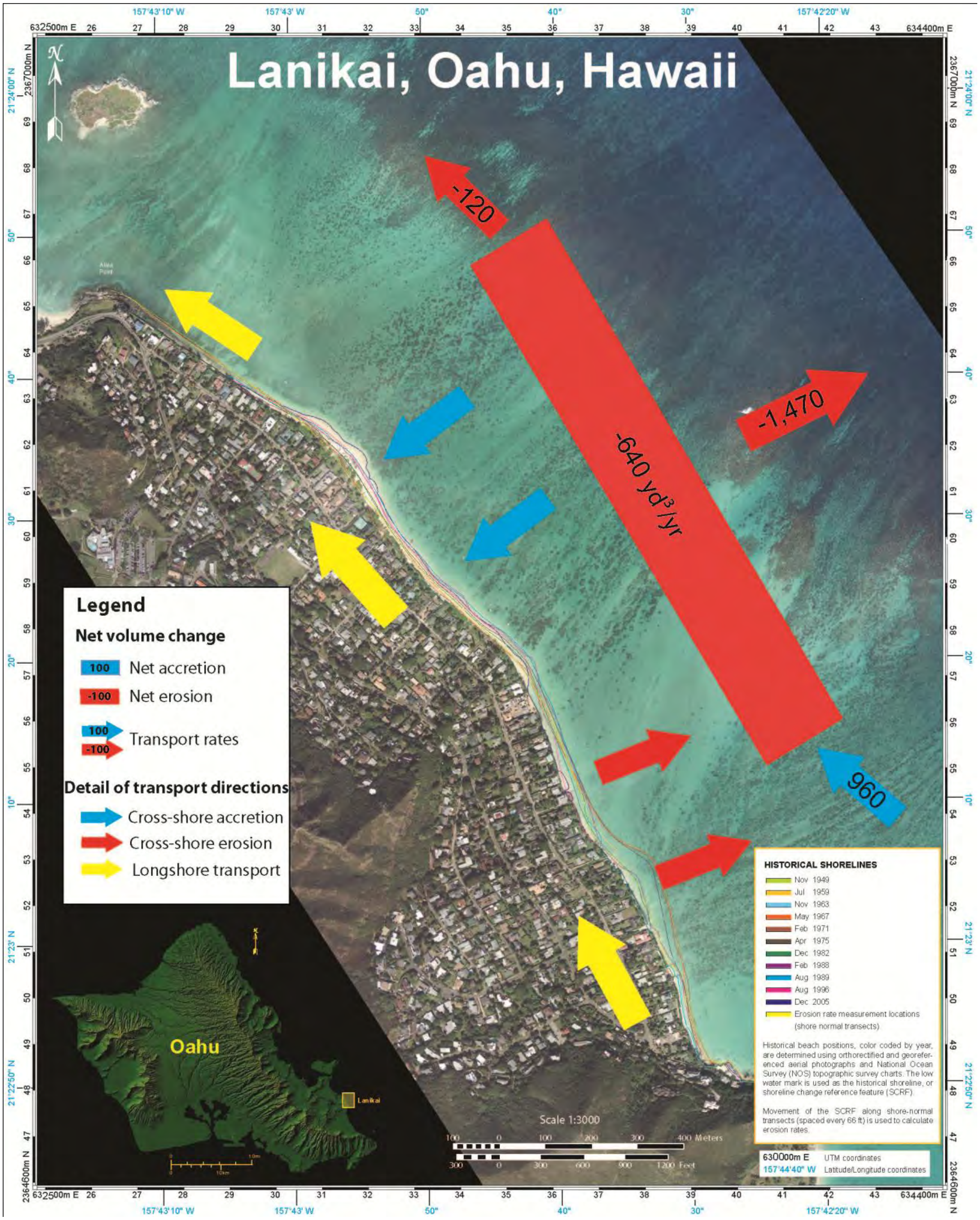
Kailua

The best model of sediment transport for Kailua included a constant diffusivity, and variable alongshore advection and cross-shore rates. Results are consistent with an off-shore sediment source near the center of the bay where a sand filled paleo-channel is thought to supply sand to the accreting beach. Alongshore transport appears to be dominantly in the northwest direction, consistent with tradewind patterns. Sediment lost through alongshore advection appears alarmingly high at the ends of the beach. Overall, Kailua beach is accreting, at a rate of about 10,680 yd^3/yr.

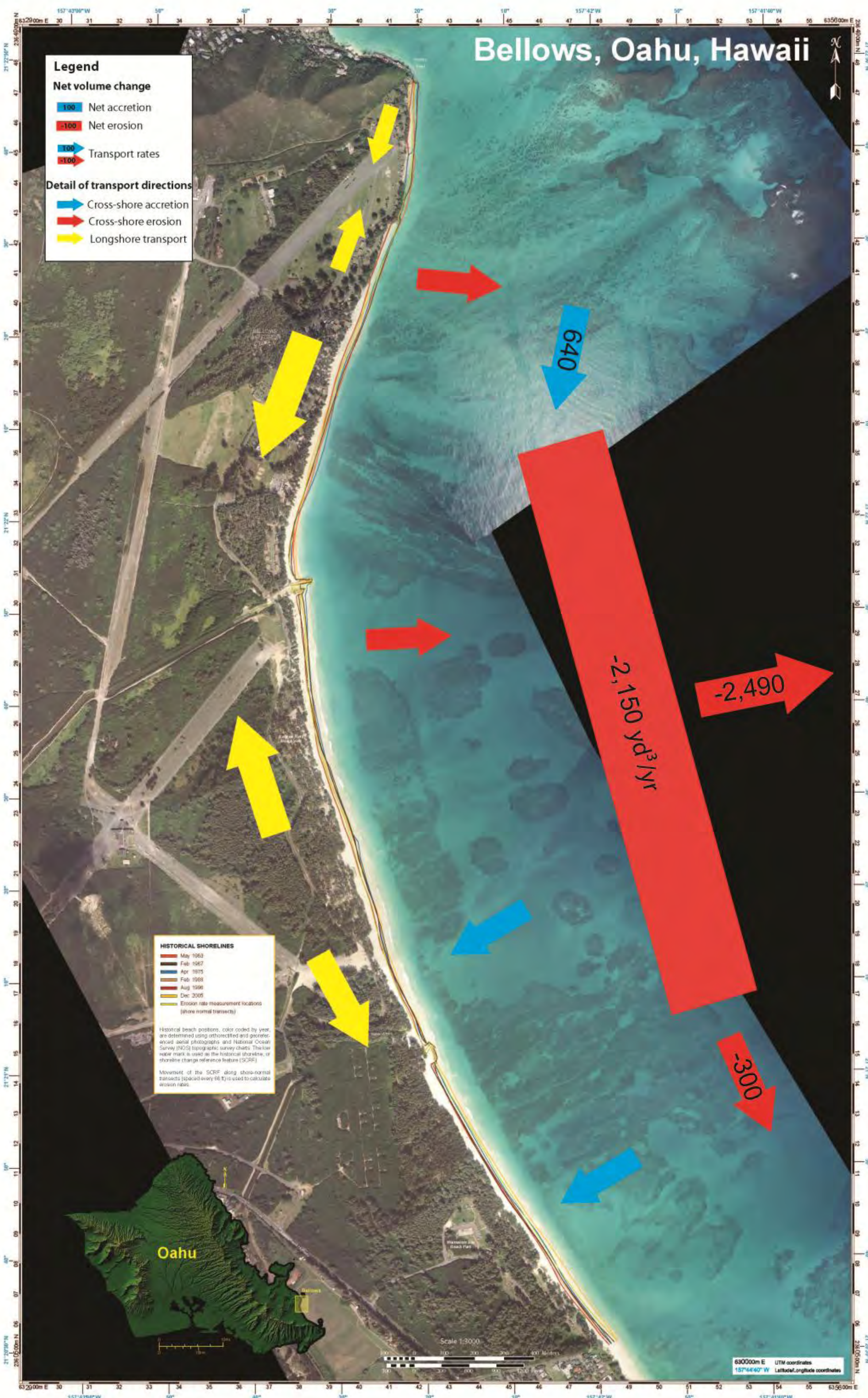


Kailua, Oahu, Hawaii
Oahu
-1480
14,450
10,670 yd³/yr
-2290
Legend
Net volume change
100 Net accretion
-100 Net erosion
100
-100
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
HISTORICAL SHORELINES

Lanikai

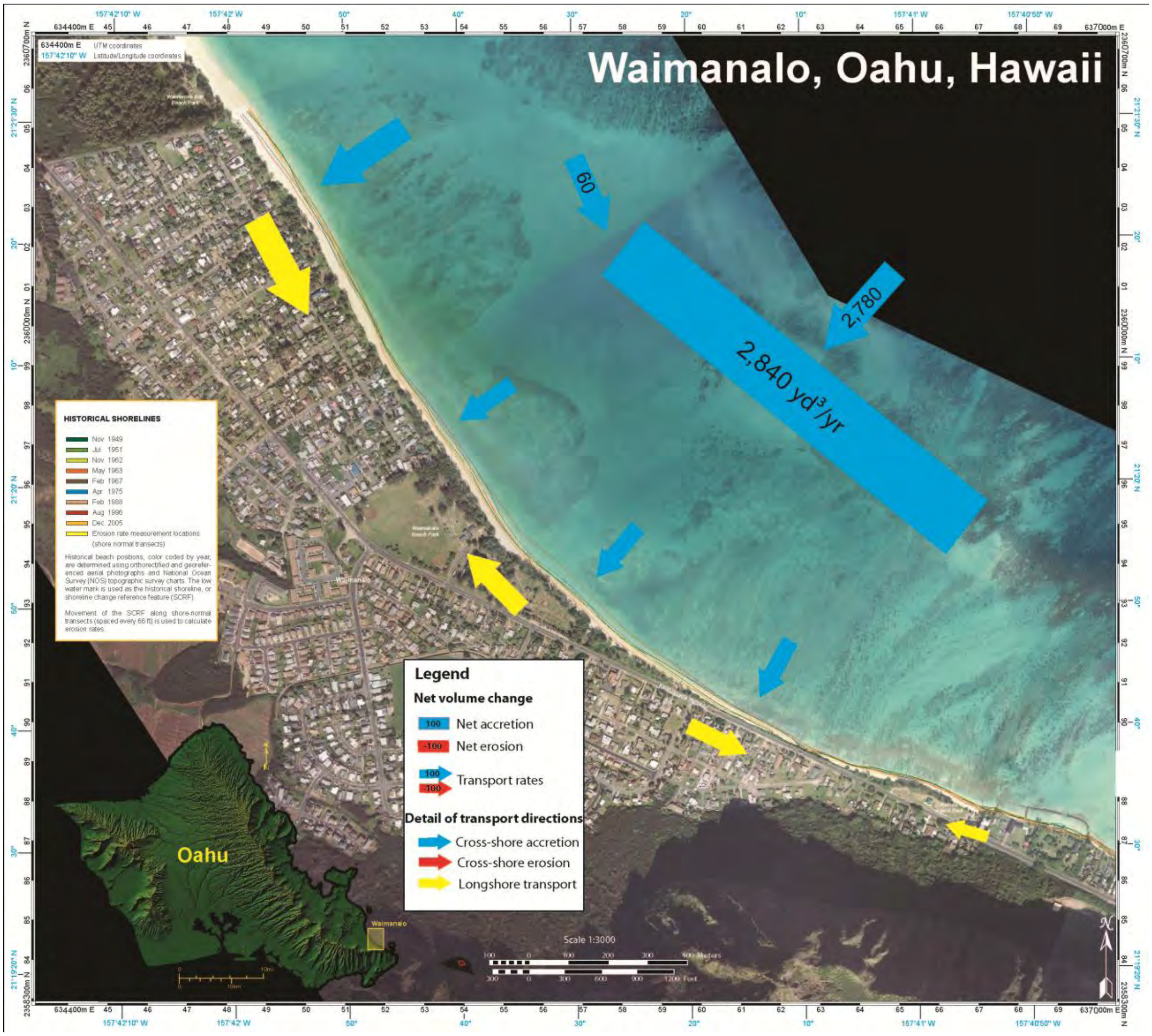

Lanikai, Oahu, Hawaii
-120
-640 yd³/yr
-1,470
960
Legend
Net volume change
100 Net accretion
-100 Net erosion
100 -100 Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
HISTORICAL SHORELINES
Nov 1949
Jul 1959
Nov 1963
May 1967
Feb 1971
Apr 1975
Dec 1982
Feb 1988
Aug 1989
Aug 1996
Dec 2005
Erosion rate measurement locations (shore normal transects)
Historical beach positions, color coded by year, are determined using orthorectified and georeferenced aerial photographs and National Ocean Survey (NOS) topographic survey charts. The low water mark is used as the historical shoreline, or shoreline change reference feature (SCRF).
Movement of the SCRF along shore-normal transects (spaced every 66 ft) is used to calculate erosion rates.
630000m E UTM coordinates
157°44'40" W Latitude/Longitude coordinates
Oahu
Lanikai
Scale 1:3000
400 Meters
1200 Feet
632500m E
634400m E
2367000m N
2364600m N
157°43'10" W
157°43' W
157°42'20" W
21°24'00" N
21°23' N
21°22'50" N

Bellows



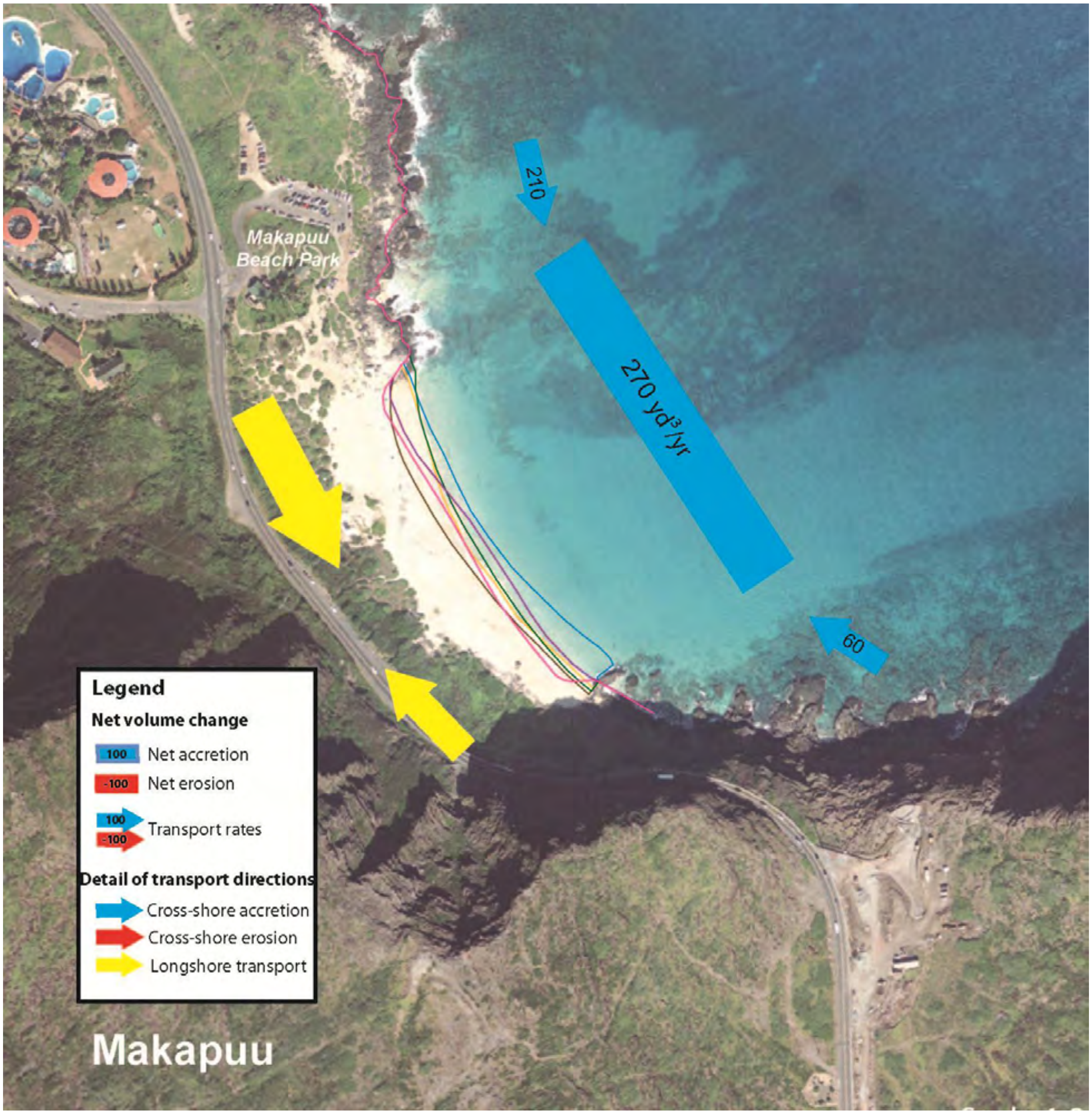
Bellows, Oahu, Hawaii
Legend
Net volume change
Net accretion
Net erosion
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
640
-2,150 yd³/yr
-2,490
-300
Oahu
HISTORICAL SHORELINES

Waimanalo



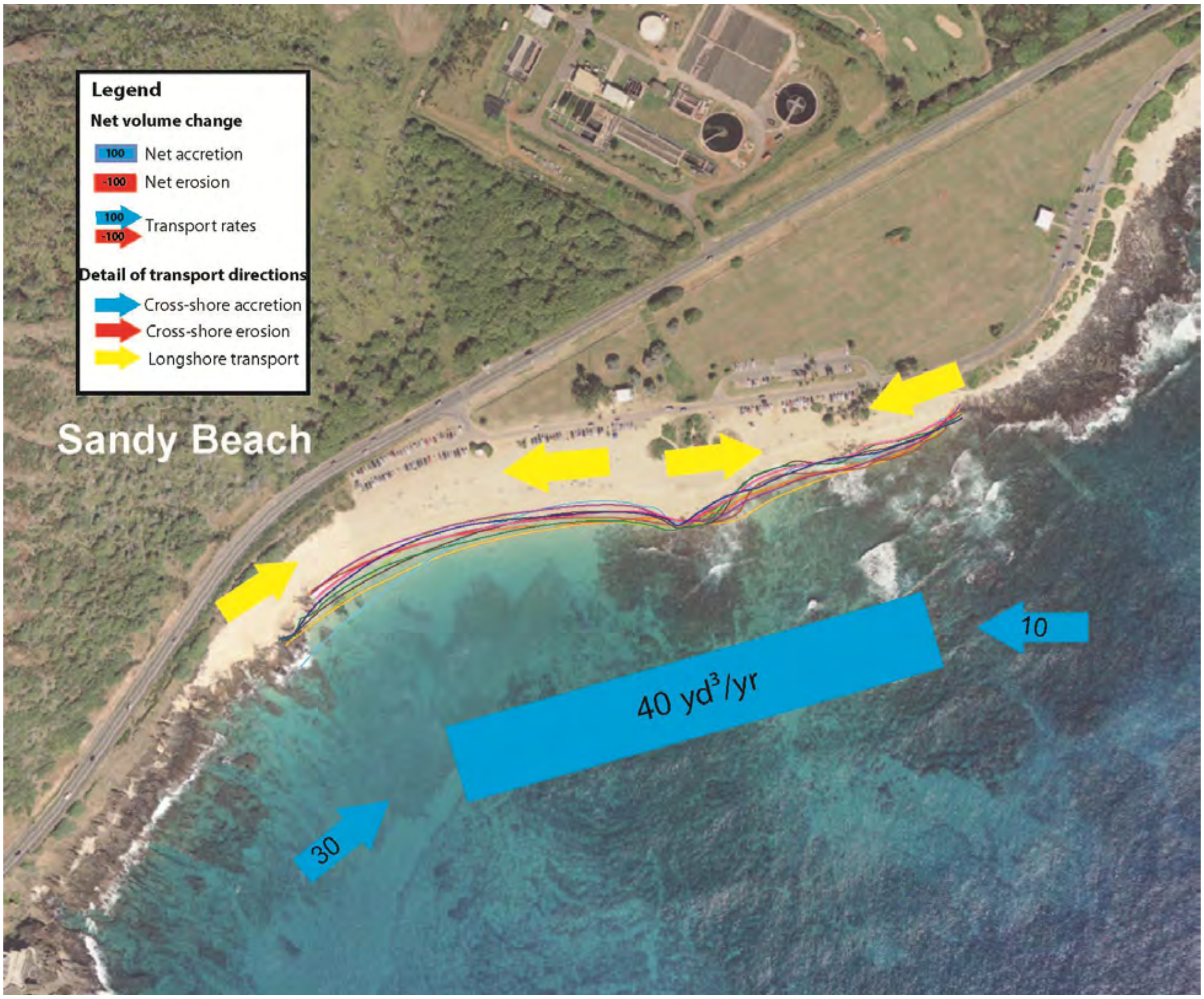
Waimanalo, Oahu, Hawaii
60
2,780
2,840 yd³/yr
HISTORICAL SHORELINES
Legend
Net volume change
Net accretion
Net erosion
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Oahu
Scale 1:3000

Makapuu



Makapuu
Beach Park
210
270 yd³/yr
60
Legend
Net volume change
100
Net accretion
-100
Net erosion
100
-100
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Makapuu

Sandy Beach

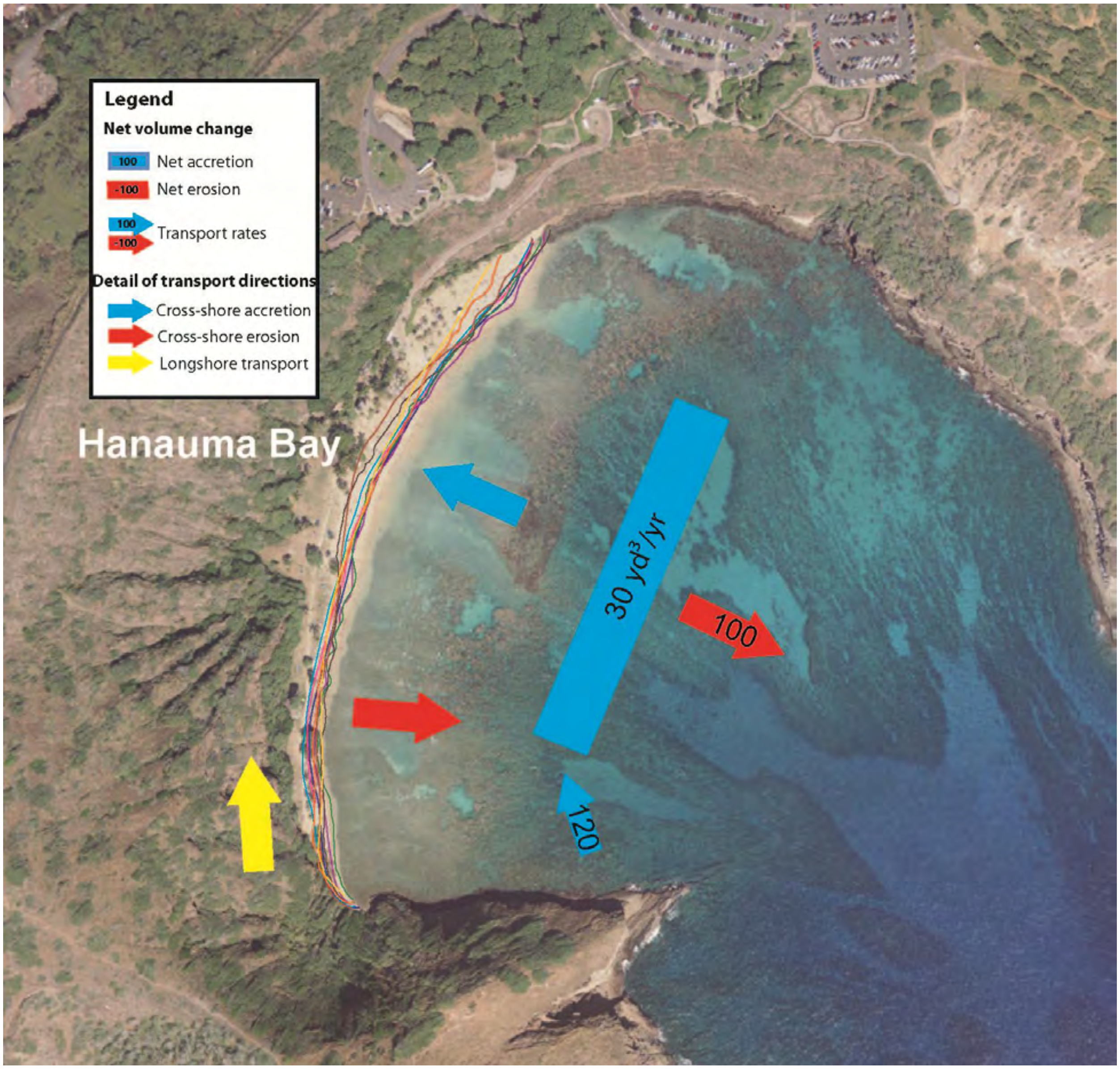

Legend
Net volume change
100
Net accretion
-100
Net erosion
100
-100
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Sandy Beach
10
40 yd^3/yr
30

East Honolulu

The East Honolulu region is composed of the Maunalua embayment – Black Point to Port Lock – and Hanauma Bay. Fronting the Maunalua shoreline is a wide, shallow (depths typically < 1ft) offshore reef flat, dissipating most of the incoming wave energy. Sea walls, revetments, and groins armor much of this formerly sandy shoreline. Paiko Peninsula is a barrier spit, growing eastward, as sediment is transported and deposited by alongshore currents. Just to the east of Paiko Peninsula, the Hawaii Kai shoreline is largely man-made, with development starting in 1959. Both dredging and landfill have significantly altered the coast. Thus, only Hawaii Kai shorelines from 1967 – 2005 were used in this study.

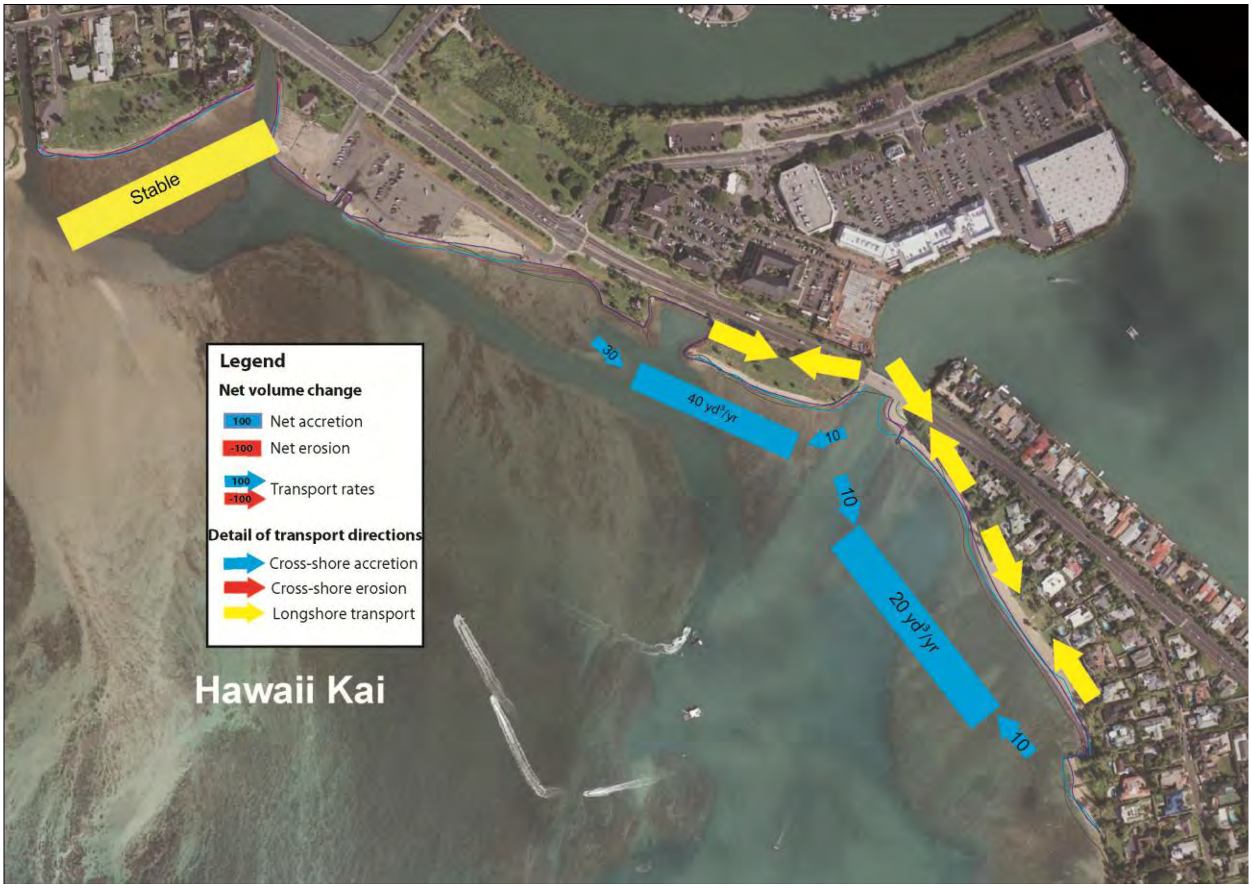
Hanauma Bay is an old volcanic crater, whose side was breached by waves, creating a deep, crescent shaped bay. Hanauma Bay contains a wide calcareous beach, protected by a shallow fringing reef. The calcareous sediment is also mixed with olivine fragments eroded from the surrounding crater. Hanauma Bay is a highly valued recreational and educational destination for visitors and locals.

Hanauma Bay



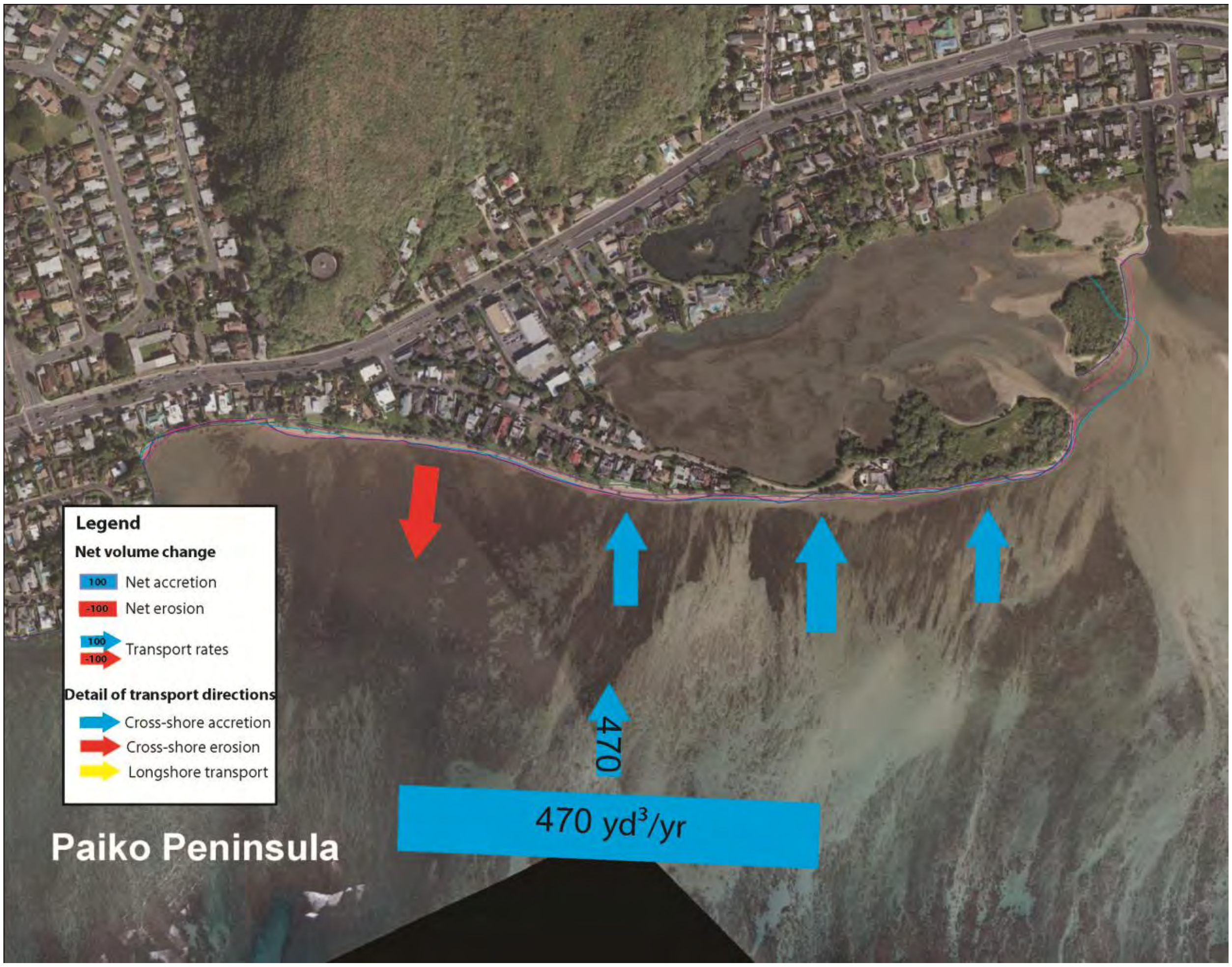
Legend
Net volume change
100 Net accretion
-100 Net erosion
100
-100 Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Hanauma Bay
30 yd³/yr
100
120

Hawaii Kai



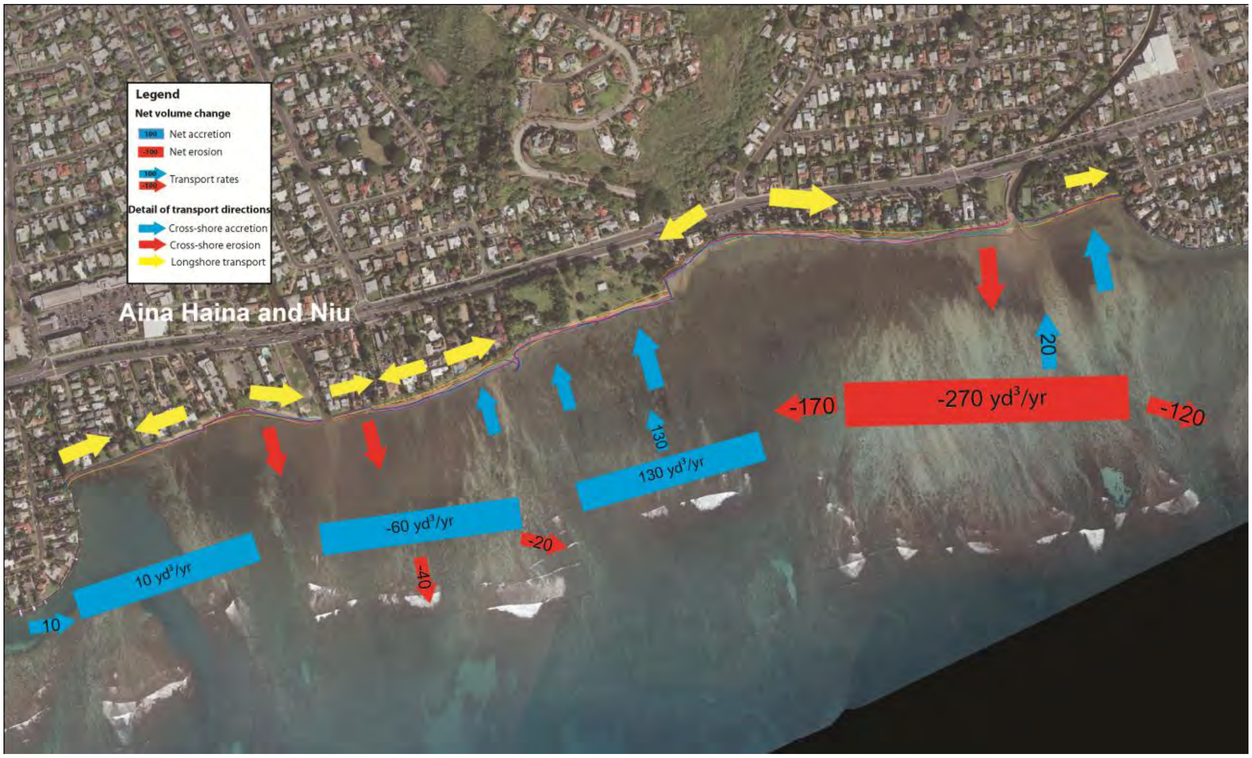
Stable
30
40 yd³/yr
10
10
20 yd³/yr
10
Legend
Net volume change
100
Net accretion
-100
Net erosion
100
-100
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Hawaii Kai

Paiko

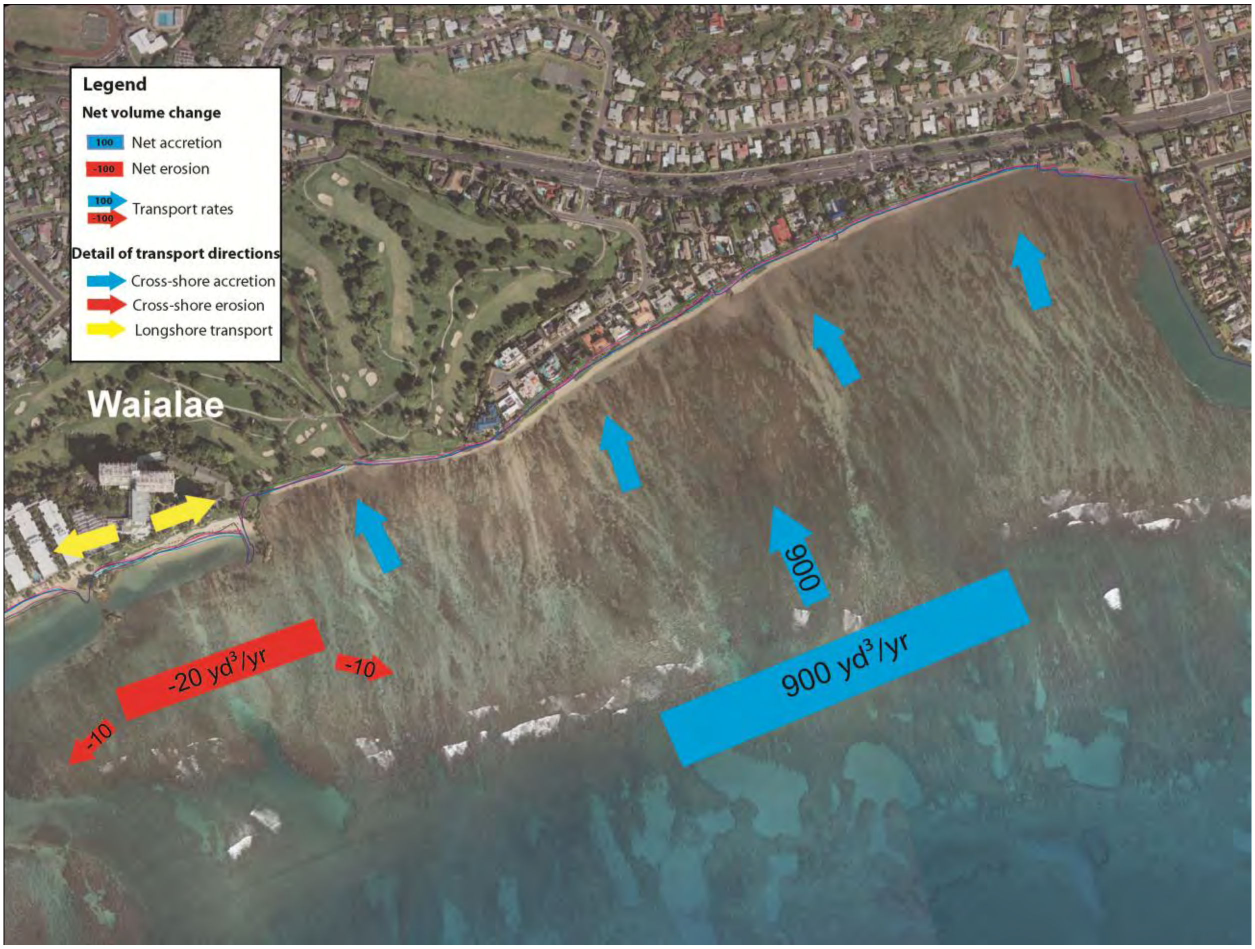


Legend
Net volume change
100 Net accretion
-100 Net erosion
100
-100 Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
470
470 yd³/yr
Paiko Peninsula

Aina Haina and Niu

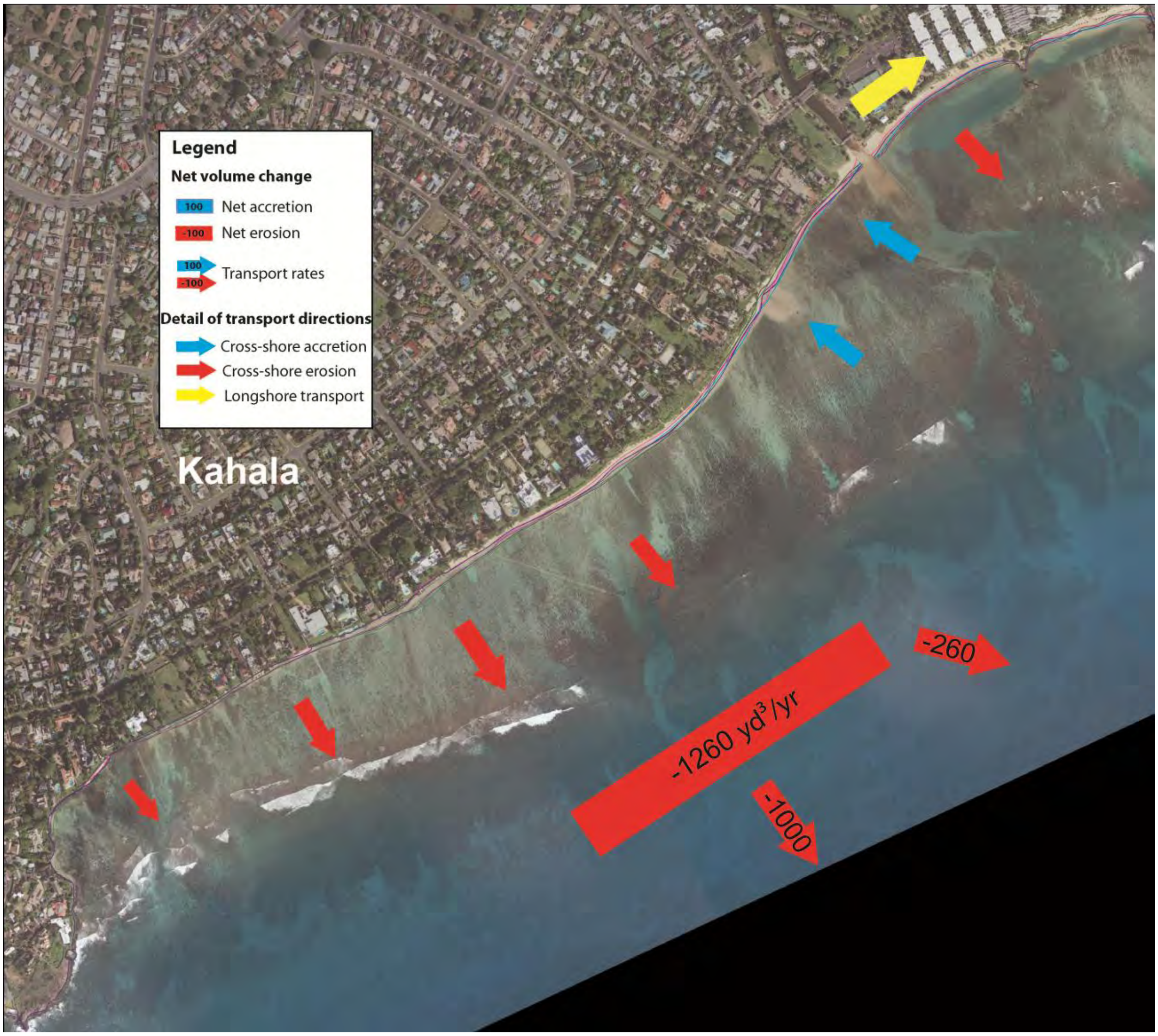


Waialae



Legend
Net volume change
100
Net accretion
-100
Net erosion
100
-100
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Waialae
900
900 yd³/yr
-20 yd³/yr
-10
-10

Kahala

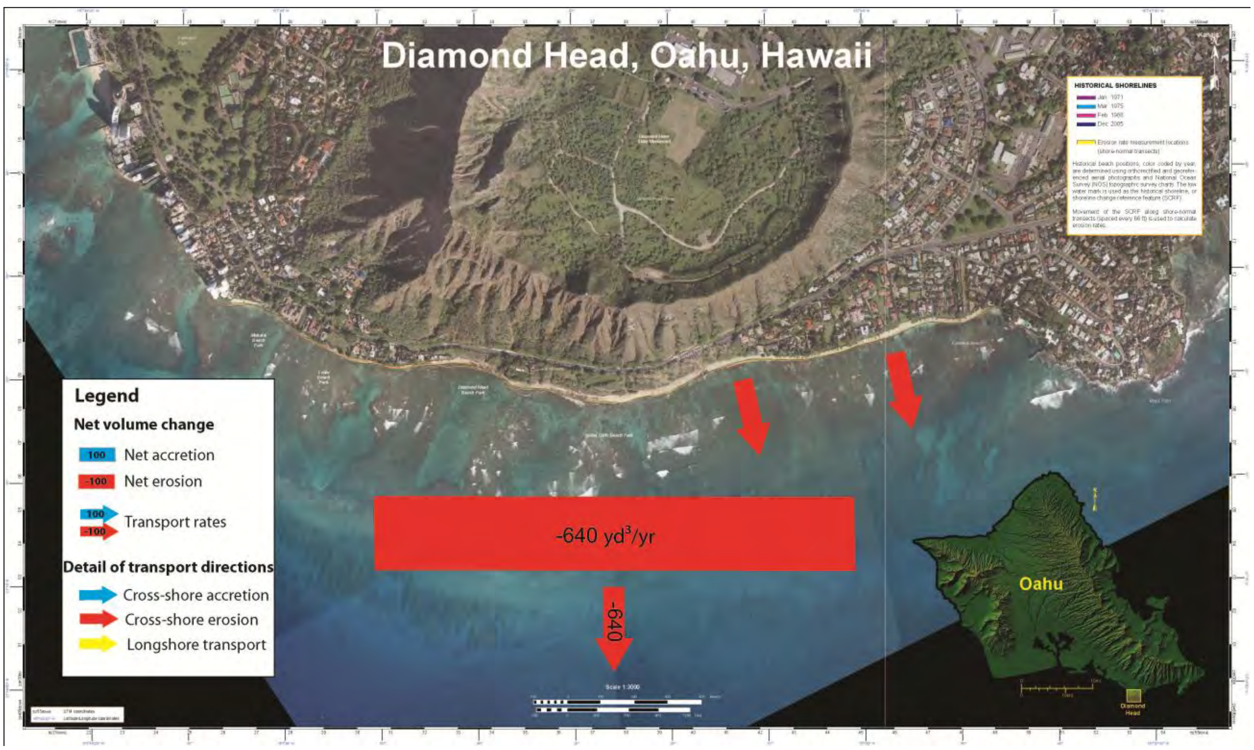


Legend
Net volume change
100
Net accretion
-100
Net erosion
100
-100
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Kahala
-1260 yd³/yr
-260
-1000

D2P

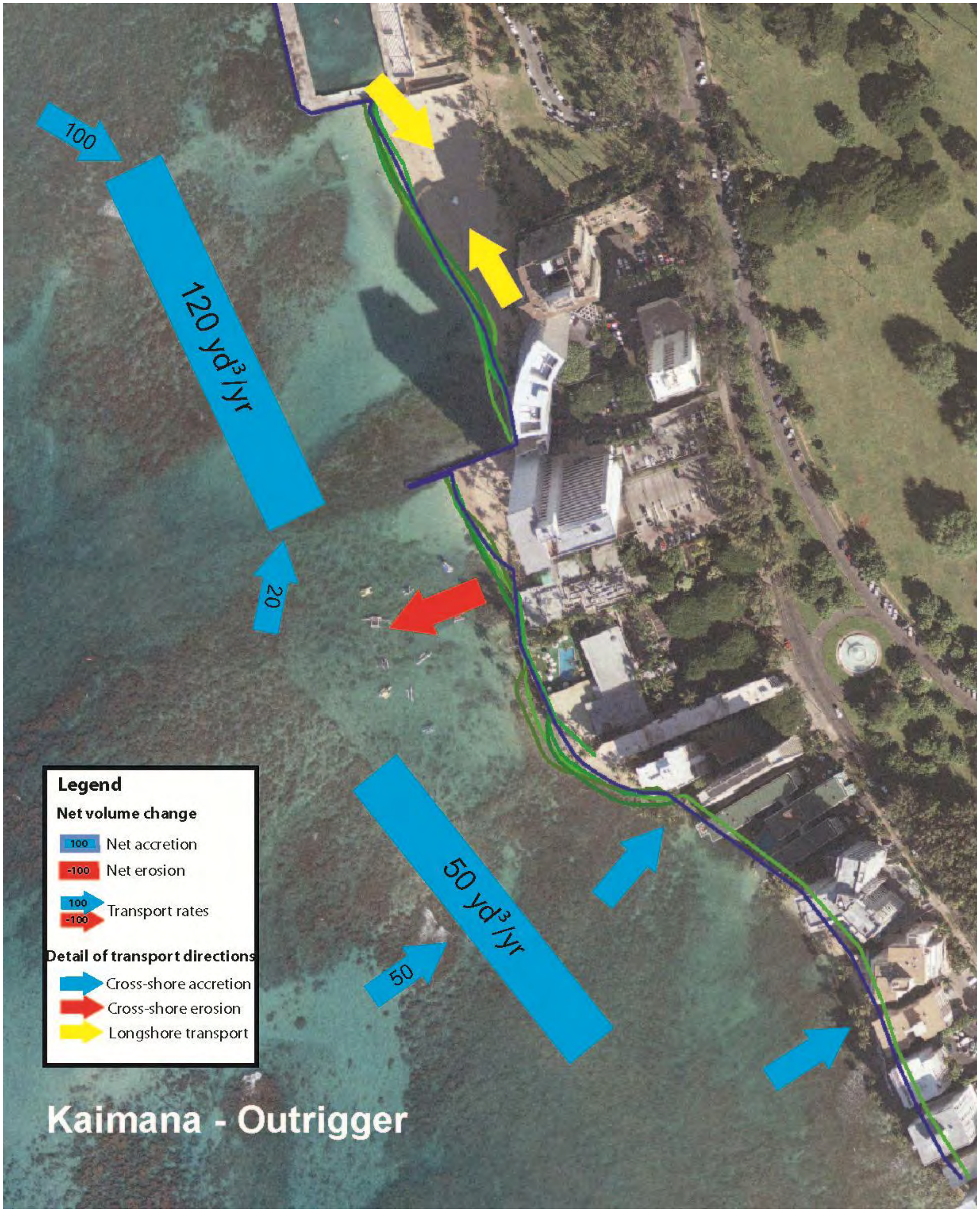
Beaches in the Diamond Head to Pearl Harbor region are less dynamic than the large sandy beaches on the windward side of Oahu. Additionally because of the large amount of human alteration to the shoreline, only a few (3-5) shorelines were used in many areas. This affects the model selected because fewer data points do not support elaborate models with many parameters. Thus, very simple models were often found to be optimal, and we suspect that cross-shore behavior may be forced into alongshore model components (and vice versa) to allow a model with a very small parameter count.

Diamond Head

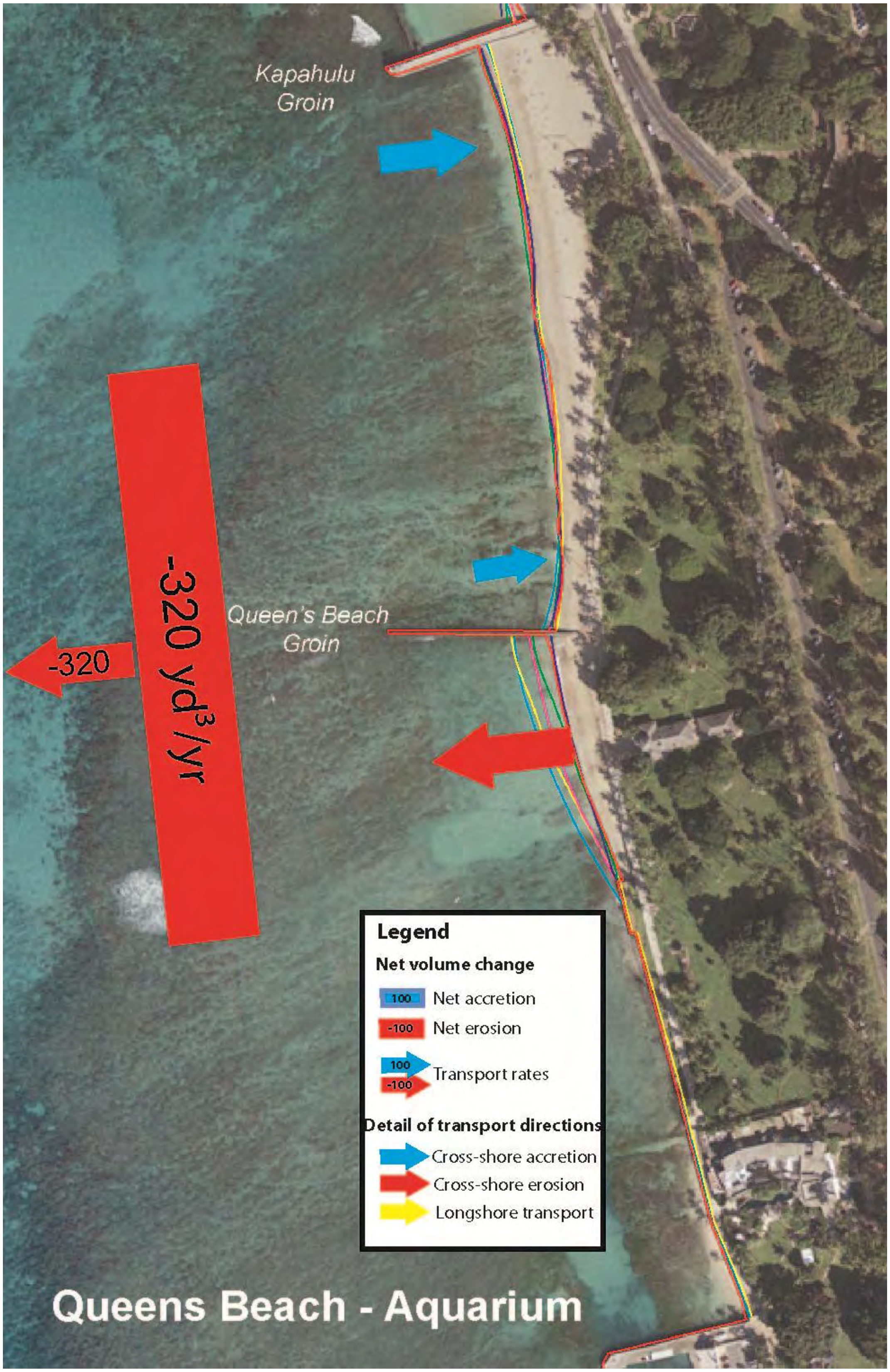


Waikiki

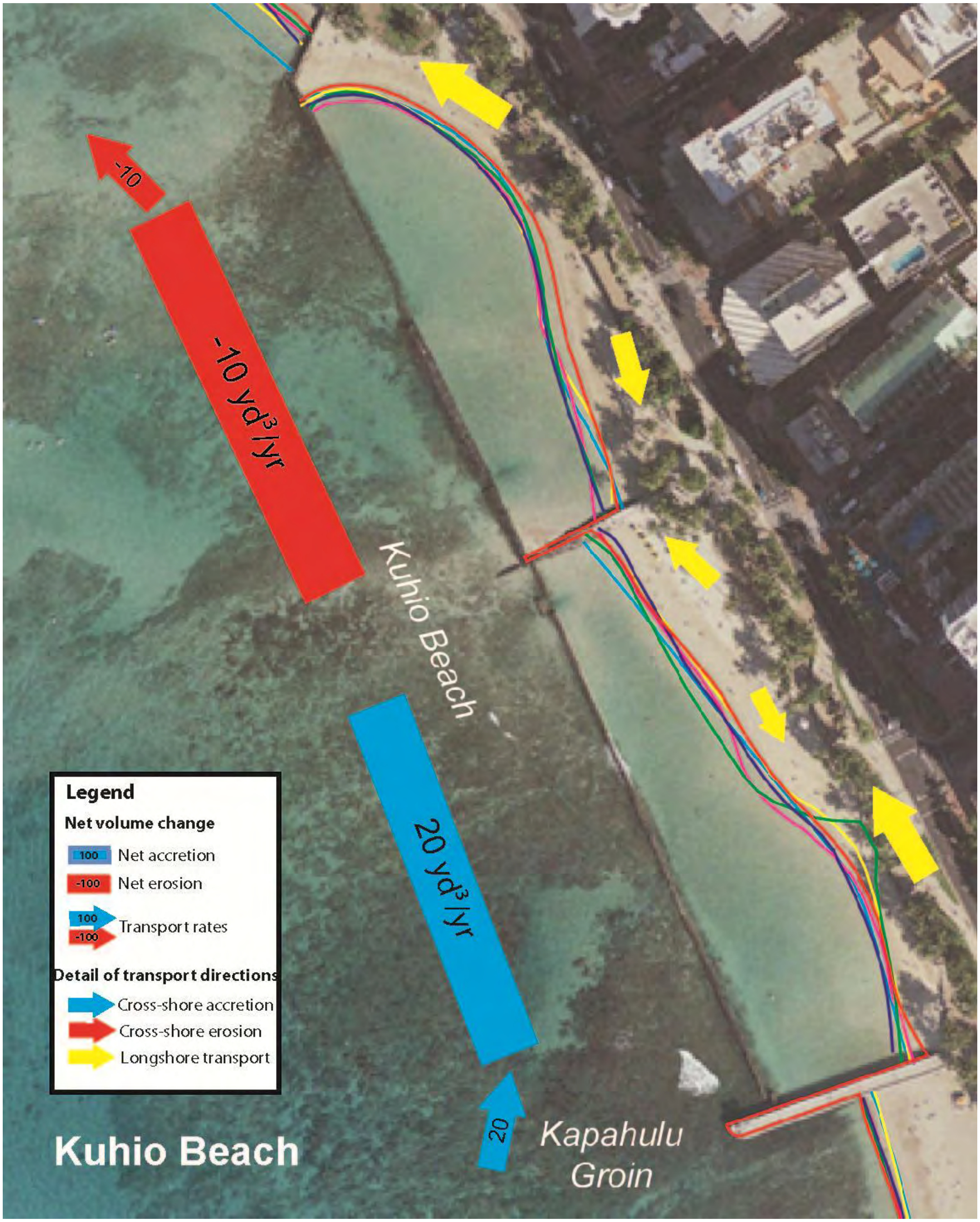
Kaimana – Outrigger



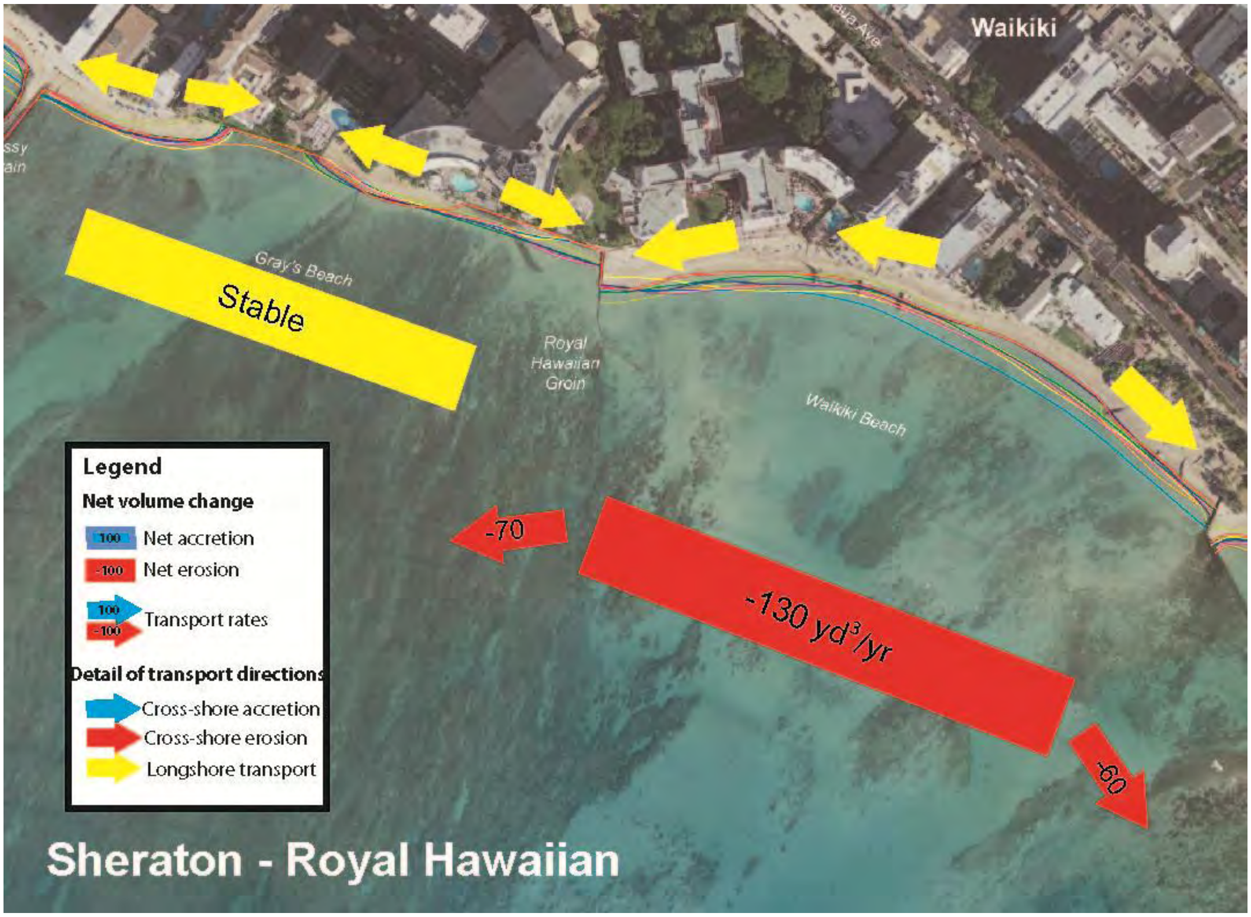
Aquarium/Queens Beach



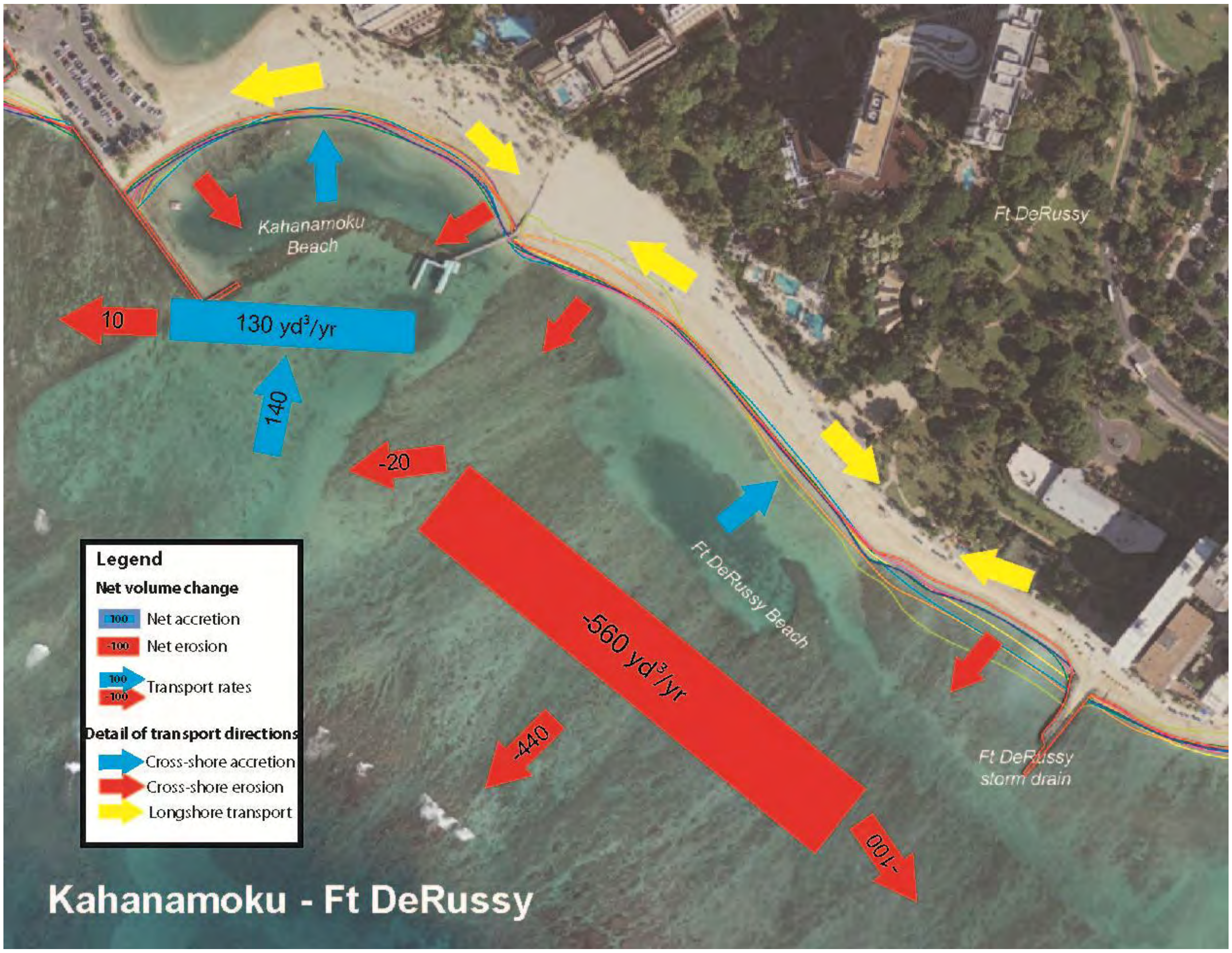
Kuhio Beach


-10
-10 yd³/yr
Kuhio Beach
20 yd³/yr
20
Legend
Net volume change
100 Net accretion
-100 Net erosion
100
-100 Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Kuhio Beach
Kapahulu
Groin

Sheraton – Royal Hawaiian

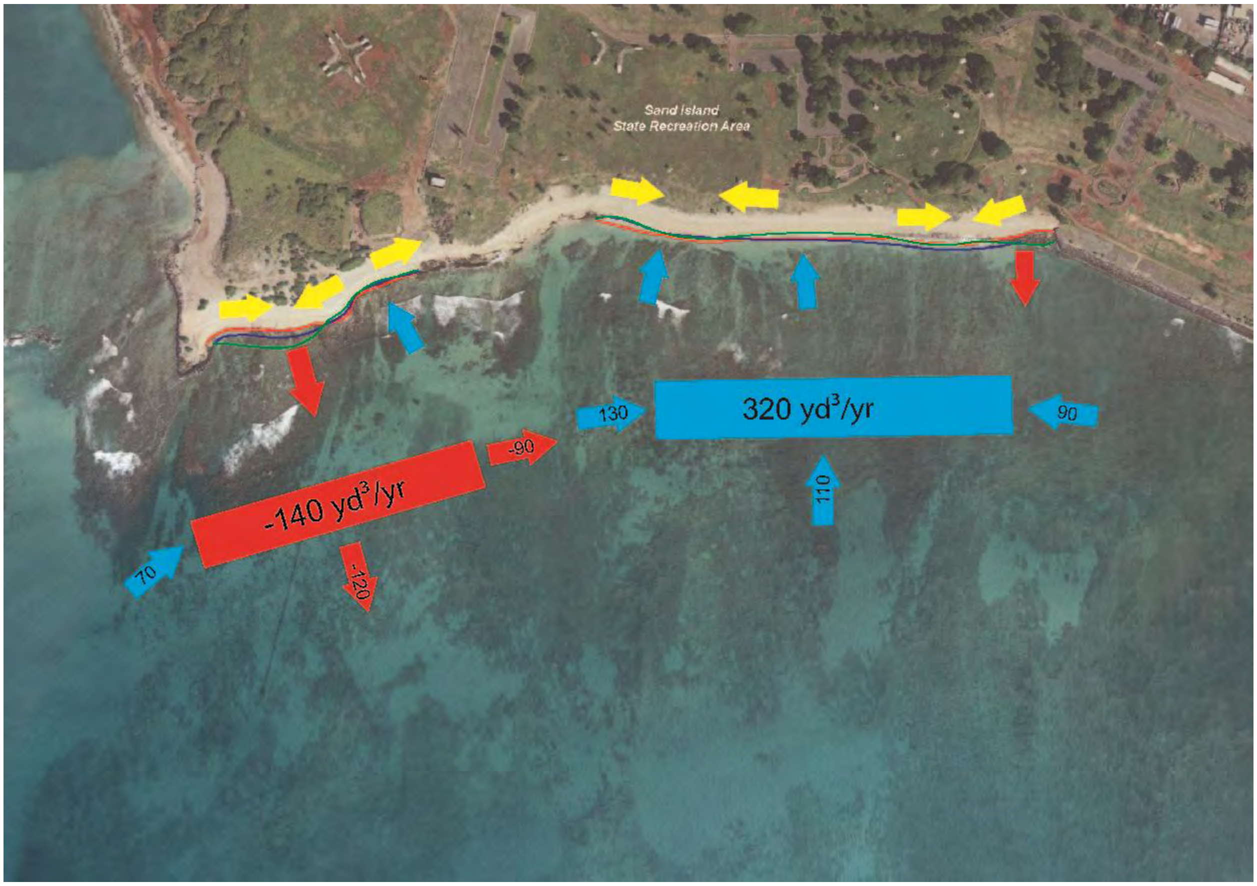


Kahanamoku - Ft DeRussy

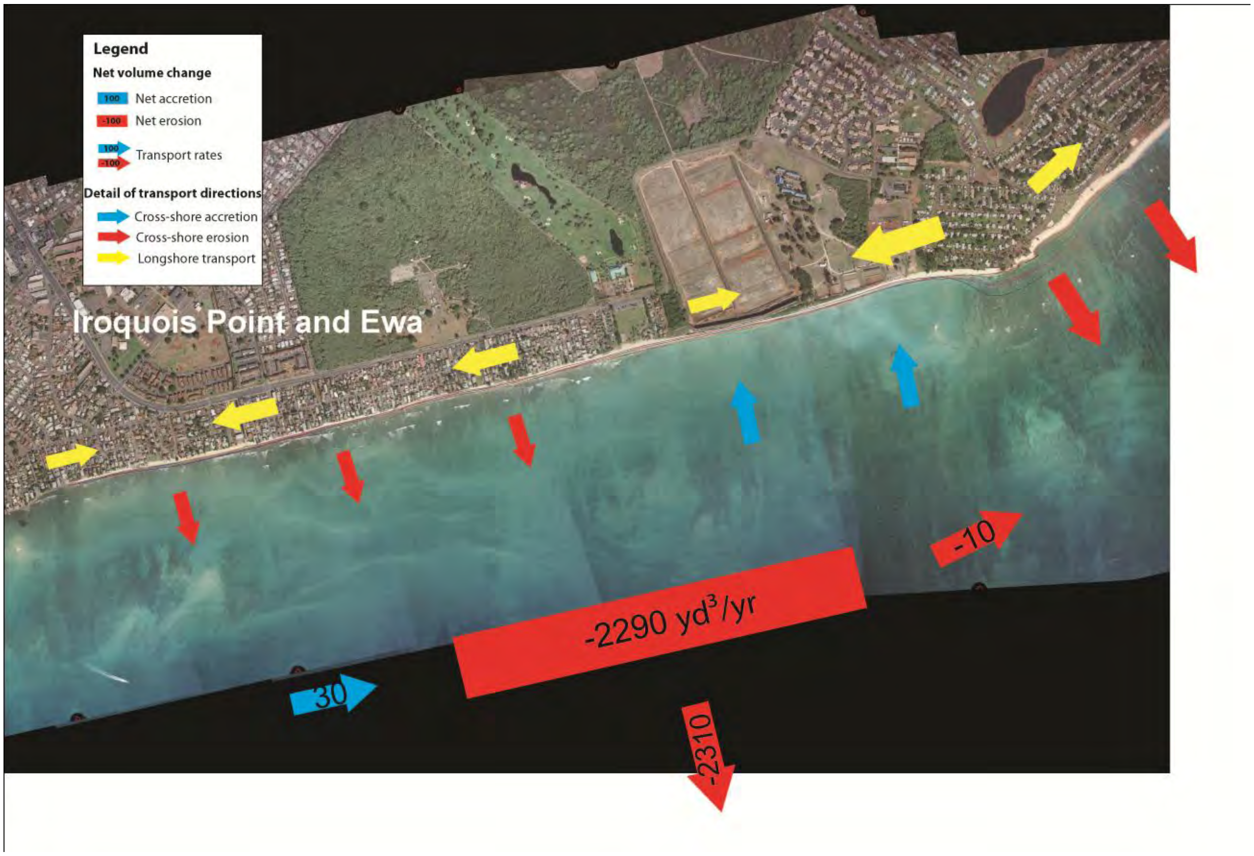


Ala Moana and Magic Island

Sand Island


Sand Island
State Recreation Area
320 yd³/yr
130
90
110
-140 yd³/yr
-90
70
-120

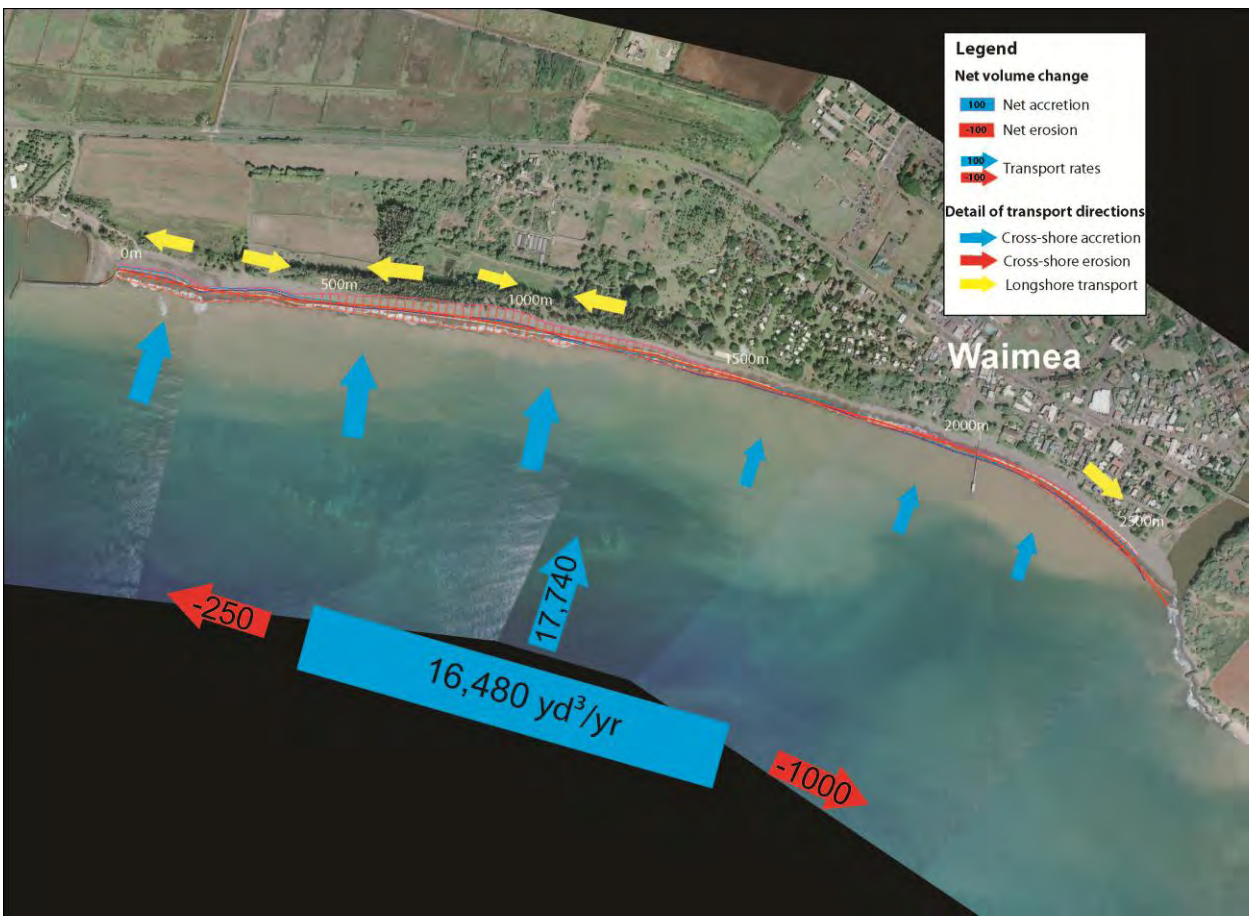
Iroquois Point and Ewa



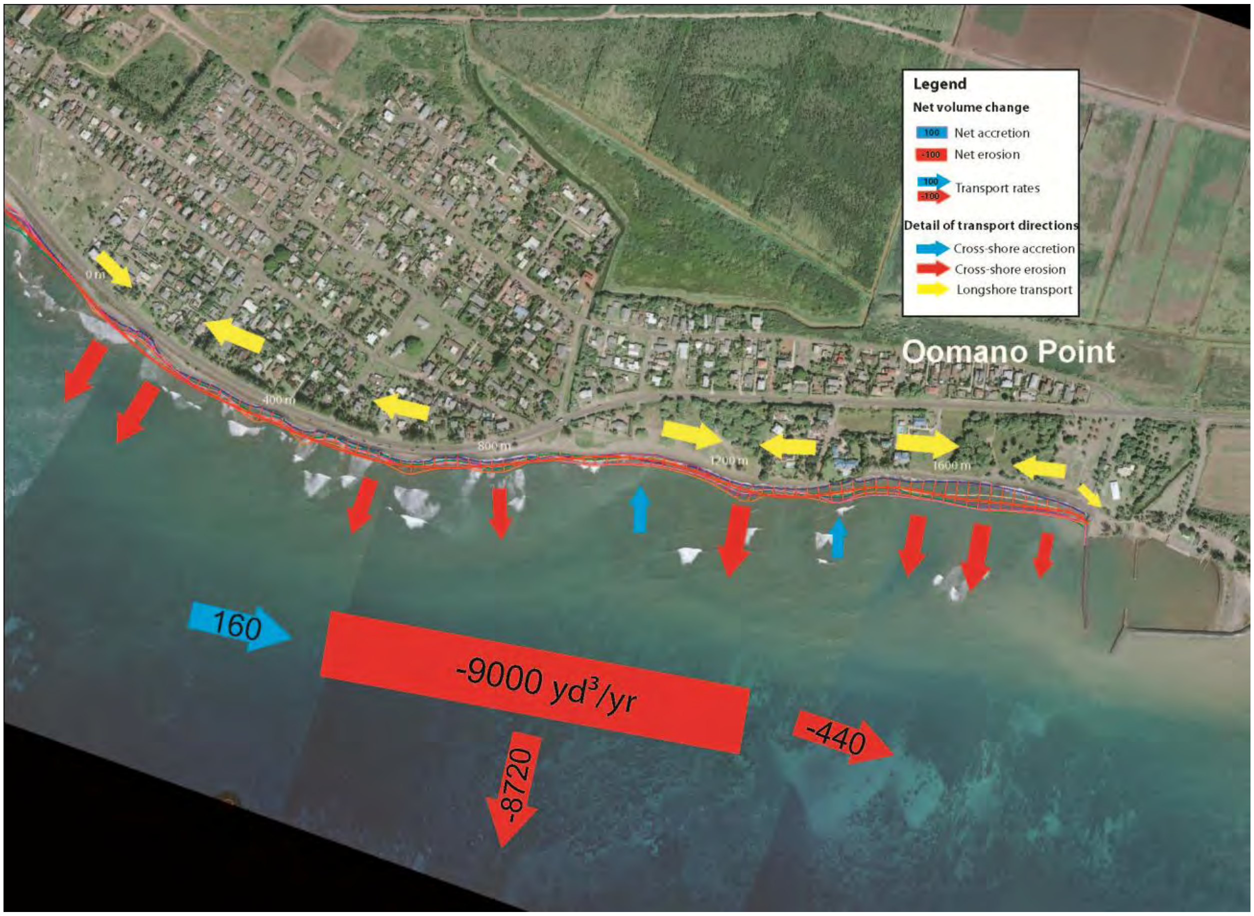
West Kauai

The West Kauai region extends from Kekaha to the Waimea river mouth. Kekaha is situated on the southernmost portion of the Mana Plain, a dry, low-lying accretionary plain formed by the convergence of alongshore sediment transport from the northeast and southeast. The shoreline from Kekaha to Oomano Point consists of carbonate sand, but quickly shifts to a mainly basaltic composition to the east of Oomano Point as the Waimea River deposits erosional material from Waimea Valley. The shoreline is hardened around Oomano Point and along Kekaha with a rock revetment. The West Kauai region is in the lee of dominant trade wind waves, but is affected by both southern swell and Kona storm waves in the summer, and by north Pacific swells that wrap around the west side of the island during winter months. In the early 1960's Kikiaola Small Boat Harbor was constructed west of the Waimea river mouth, and the harbor is thought to disrupt the westward alongshore sediment transport, causing heavy erosion directly west of the harbor.

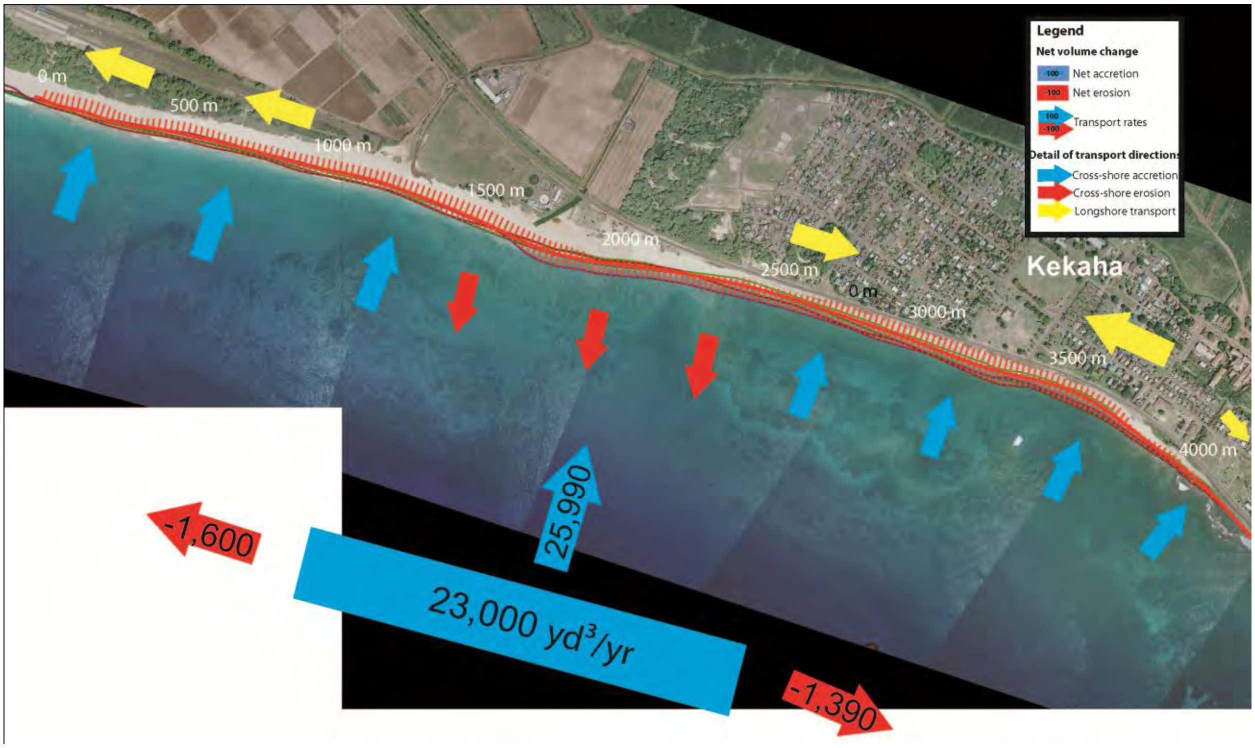
Waimea



Oomano


Legend
Net volume change
Net accretion
Net erosion
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Oomano Point
160
-9000 yd³/yr
-440
-8720

Kekaha



Legend
Net volume change
Net accretion
Net erosion
Transport rates
Detail of transport directions
Cross-shore accretion
Cross-shore erosion
Longshore transport
Kekaha
0 m
500 m
1000 m
1500 m
2000 m
2500 m
0 m
3000 m
3500 m
4000 m
-1,600
25,990
23,000 yd³/yr
-1,390