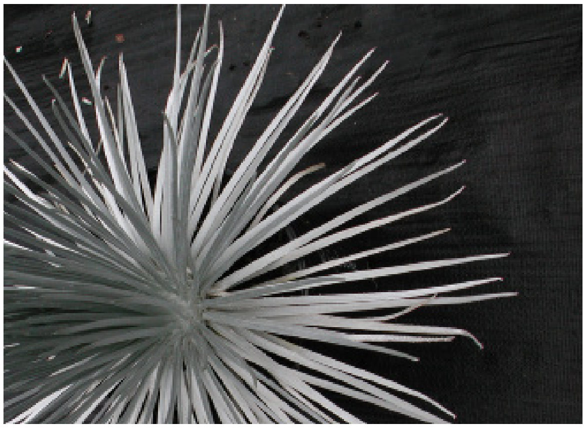
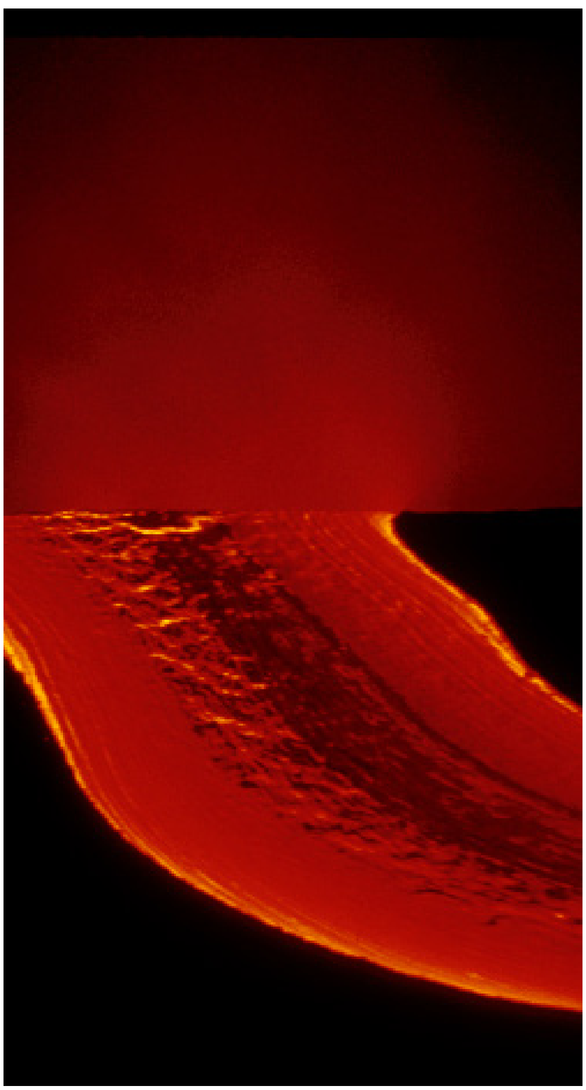


UHERO
THE ECONOMIC RESEARCH ORGANIZATION
AT THE UNIVERSITY OF HAWAIʻI

PROJECT ENVIRONMENT

Economic Valuation of The Nature Conservancy's Watershed Conservation Activities in Waikamoi Preserve, Maui

APRIL 2018



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Economic Valuation of The Nature Conservancy's Watershed Conservation Activities in Waikamoi Preserve, Maui

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1. EXECUTIVE SUMMARY

The objective of this research was to estimate the value of ecosystem services protected by watershed conservation activities at The Nature Conservancy's Waikamoi Preserve on the island of Maui. Projections of monetized benefits, together with trajectories of conservation costs, were used to calculate net present value, payback period, and return on investment.

Key results are summarized below:

1. Watershed conservation activities at Waikamoi preserve protect an estimated 63.7 billion gallons of freshwater yield and 32.5 billion gallons of groundwater recharge over the next 100 years.
2. By year 2072, annual freshwater yield benefits reach 1.1 billion gallons per year (3.1 million gallons per day) and groundwater recharge benefits reach 571 millions of gallons per year (1.6 million gallons per day).
3. The estimated present value of Waikamoi's freshwater benefits is $36.2 million.
4. The payback period for investment in Waikamoi is 52 years.
5. The net present value of conservation in Waikamoi Preserve, when taking into account conservation expenditures compared with ecosystem services in addition to freshwater provision, is estimated at $19.1 million.
6. The return on investment (ROI) to Waikamoi's conservation activities is 46% for the planning period ending in 2117.
7. In addition to the monetized benefits, by 2072 conservation activities prevent an estimated 4,300 tons of sediment per year from going into the ocean.

2. PROJECT OVERVIEW

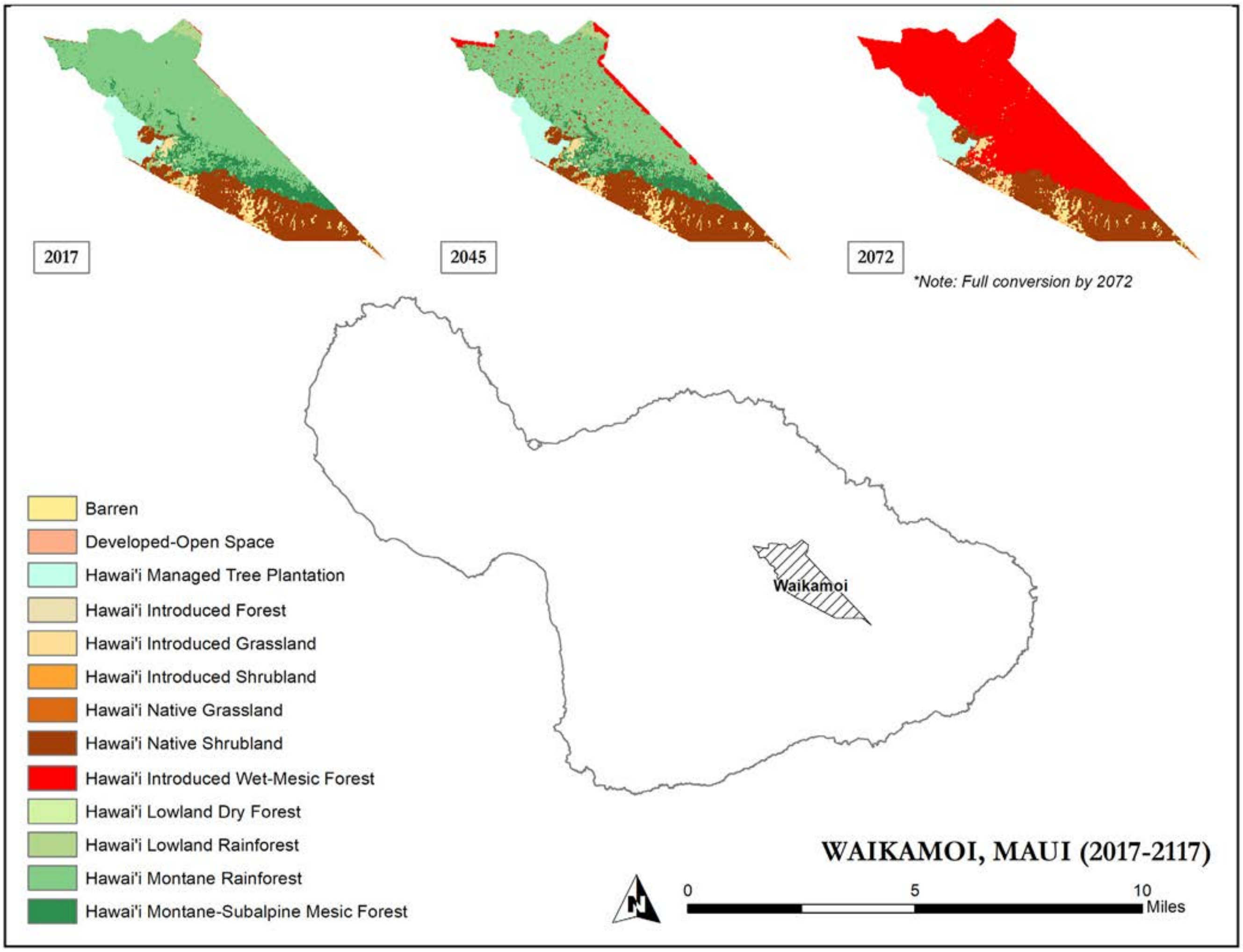
The primary objective of this research is to quantify and monetize groundwater recharge services protected and enhanced by watershed conservation activities in The Nature Conservancy's (TNC) Waikamoi Preserve on the island of Maui. We utilize estimates from the published literature to apply benefit transfer in order to value other ecosystem services in Waikamoi.

3. STUDY SITE

Established in 1983 through a perpetual conservation easement with landowner Haleakalā Ranch Company, Waikamoi is a 5,230-acre preserve on the slopes of Mt. Haleakalā in East Maui (Figure 1). In 2014, an agreement between TNC and East Maui Irrigation Company added 3,721 acres of native rainforest, for a combined total of 8,951 acres, the most extensive private nature preserve in the state. The preserve lies west of the state's 7,500-acre Hanawī Natural Area Reserve (NAR), and its southern boundary runs along Haleakalā National Park (HALE). These managed areas, together with other state and private lands on the northeast slopes of Haleakalā, represent East Maui Watershed, one of the largest intact native rain forests in the state, comprising more than 100,000 acres.

Conservation activities in Waikamoi include fencing, ungulate removal, invasive species control, and monitoring. Snaring and hunting for ungulates were adopted in 1986, and a fencing and animal removal program focused primarily on pigs and goats began in 1989. The feral goat population has been reduced to

Figure 1. Study site and simulated conversion of native to non-native forest over time in the absence of management. Without management actions, complete invasion of existing native forest is projected to occur in 65 years in year 2072.



zero through organized hunts. Through fencing, snaring and hunting, over 1,000 pigs have been removed since 1986. Dramatic recovery of native vegetation resulted in the late 1990s and early 2000s after a vast majority of goats and pigs were removed. The Maui Axis Deer Group (MADG) was created with TNC's assistance after the discovery of axis deer (*Axis axis*) in Waikamoi. Axis deer are a major threat to restoration efforts, as evidenced by the severe damage to native vegetation observed on Lānaʻi and Molokaʻi. The last axis deer was removed from the Waikamoi preserve in 2004.

Invasive, habitat-modifying weeds, such as Himalayan ginger (*Hedychium gardnerianum*), strawberry guava (*Psidium cattleianum*), and miconia (*Miconia calvescens*) are threats to native forest and shrubland biodiversity. Invasive plants, in particular Himalayan ginger and gorse (*Ulex europaeus*), have been treated or removed extensively throughout Waikamoi Preserve. Removal methods include manual and mechanical methods such as pulling and containment, as well as herbicide application. TNC began contracting with Resource Mapping Hawaiʻi, Inc. in 2009 to map the distribution and abundance of invasive plant species in East Maui and guide follow-up control of invasive weeds. TNC staff installed boot brushes and signs at entry points to Waikamoi to prevent seed dispersal and follow a strict cleaning protocol for all trucks and gear to remove seeds and insects in order to prevent accidental introduction of pest species to the preserve.

Resource monitoring is an essential component of management in Waikamoi. Monitoring is conducted to collect data on plant species composition, distribution, abundance, and percentage cover. TNC collaborated with East Maui Watershed Partnership (EMWP) to develop a standard baseline threats assessment and biodiversity and management database with consistent monitoring protocols to evaluate the success of their management programs over time.

4. FRESHWATER YIELD BENEFITS

In addition to protecting and restoring native biodiversity, an important goal of forest conservation efforts in Hawai‘i is often to maintain or increase groundwater recharge and regulate surface flow. At the watershed scale, the type of forest cover can affect freshwater yield (groundwater recharge and surface flow) through three primary mechanisms: 1) changes in vegetation type and cover can affect actual evapotranspiration (AET), influencing the total amount of freshwater yield available; 2) changes in ground cover and vegetation structure can affect infiltration rates, impacting the amount of water that runs off as surface flow versus groundwater recharge; and 3) changes in vegetation type can affect fog interception rates, affecting the overall amount of precipitation (Brauman et al. 2007).

To evaluate the potential impacts of conservation activities (which maintain intact native forest and avoid spread of fast growing invasive species) on freshwater yield, we focus on pathway 1 –changes in AET rates. Although there is substantial uncertainty around estimating differences in AET between native and non-native forest type, a number of plant and stand level studies have found lower water use among native Hawaiian species compared with non-native species (Cavaleri and Sack 2010; Cavaleri et al. 2005; Giambelluca et al. 2008; Kagawa et al. 2009). Recent watershed studies have utilized this data to estimate changes in water yield at the watershed scale, including a U.S. Geological Survey (USGS) study, which found a 12% increase in groundwater recharge with native forest restoration (Engott 2011), a U.S. Forest Service study which found a potential 2.8% increase in water yield with native forest conservation and restoration (Povak et al. 2017), and a University of Hawai‘i Economic Research Organization (UHERO) cost-benefit study which found a 1,487 liter per dollar savings with forest conservation efforts across Hawai‘i Island (Burnett et al. 2017).

Fog interception was also found to be 16% higher in a single replicate of native forest (dominated by *M. polymorpha)* compared with non-native forest (dominated by *P. cattleianum)* in Hawai‘i Volcanoes National Park (Takahashi et al. 2011). However, we lack sufficient spatially explicit quantitative information to be able to rigorously include this difference in fog interception rates in our spatial modeling effort on Maui. Similarly, although qualitative observations suggest that intact native forest would have higher infiltration rates than an invaded, disturbed forest, there are no quantitative data to be able to adequately include this in our modeling framework. Given the current state of data on fog interception and interception, we take a conservative approach as followed by USGS (Johnson et al. 2014) and focus on changes in AET between native and non-native forest. Hydrologic studies of water use, infiltration, and fog interception in varying types of native and non-native forest currently being carried out by the USGS, and University of Hawai‘i Mānoa will shed light on these fluxes.

We take advantage of a statewide spatial AET dataset (Giambelluca et al. 2014), which utilized estimates of the maximum stomatal conductance of *P. cattleianum* (as a proxy for non-native forest) and *M. polymporpha* (as a proxy for native forest). TNC and the East Maui Watershed Partnership are particularly concerned with the highly invasive Himalayan ginger (*H. gardnerianum*), which threatens native biodiversity and alters hydrologic and biogeochemical cycles (Asner and Vitousek 2005). Research from Volcanoes National Park on Hawai'i island has shown that ginger invasion effectively prevents regeneration of native canopy species, but that strawberry guava is able regenerate in a ginger-invaded area (Minden et al. 2010a,b). Accordingly, non-native canopy species (including strawberry guava) invasion is likely facilitated by ginger expansion. We currently lack estimates of the maximum stomatal conductance of ginger (data is currently being collected by USGS and the University of Hawai'i and will likely be available in several years), precluding our ability to directly model the impact of this species on evapotranspiration. However, given the link between ginger invasion and eventual non-native canopy invasion, we utlilize existing data on native vs. non-native canopy species. Although all areas in Waikamoi are not currently suitable habitat for strawberry guava specifically, all areas are susceptible to invasion by other non-native canopy species, which likely have similar hydrologic characteristics. Moreover the critical habitat area vulnerable to invasive species in Hawai'i is expected to increase by 12% with climate change, particularly in high elevation areas (Vorsino et al. 2014).

4.1 LAND COVER SCENARIOS:

We developed land cover scenarios representing likely spread of non-native forest over time in the absence of conservation activities (the *without conservation* counterfactual scenario). Year 0 (2017) is based on the LANDFIRE land cover map (LANDFIRE 2012), which we updated based on conversations with TNC staff. We assumed that if conservation activities were to stop in 2017 (current year), non-native forest would emerge along the northern border of Waikamoi in areas where non-native canopy species have been controlled over the period 2000-2017 (based on TNC and EMWP treatment data). We then applied a spread rate of 10% per year, based on past observations of 9-12% (Geometrician Associates LLC 2010), to adjacent pixels. We also assumed an additional 1% of growth in non-native cover per year through satellite pixels. We assumed that native forest is the only land cover type that can be converted (we exclude grassland and shrubland areas from non-native forest expansion). Given that spread can occur in different spatial configurations, we ran 1,000 simulations of potential spread pathways for each year (see average land cover maps for each year in Figure 2). Non-native forest increased from 27 to 5,962 acres from 2017 to 2117, replacing all native forest by 2072 (Figure 3).

4.2. CALCULATING AVOIDED LOSS OF FRESHWATER YIELD:

Freshwater yield can be estimated using a water balance approach where:

Freshwater yield = Precipitation (rainfall + fog interception) – AET (Actual evapotranspiration)

Given insufficient spatial information about the influence of forest type on fog interception (see above), we focused on how forest type may change AET rates. Freshwater yield benefits were calculated as the avoided increase in AET that would likely have occurred in the absence of conservation activities and subsequent invasion of non-native forest.

AET is a function of atmospheric conditions, water availability, and vegetation characteristics. To estimate how invasion of non-native forest might change AET, we utilized a spatial dataset of current annual AET and a series of climatic and vegetation predictor variables across Maui categorized by LANDFIRE land cover type (~54,000 points) (Giambelluca et al. 2014). Within the subset of points classified as introduced wet-mesic forest (non-native forest), we created a linear regression with AET as a function of atmospheric conditions

Figure 2. Land cover in the "without conservation" counterfactual scenario from 2018 to 2117 (red represents non-native forest and green represents native forest). Note only current native forest areas are eligible to be invaded.

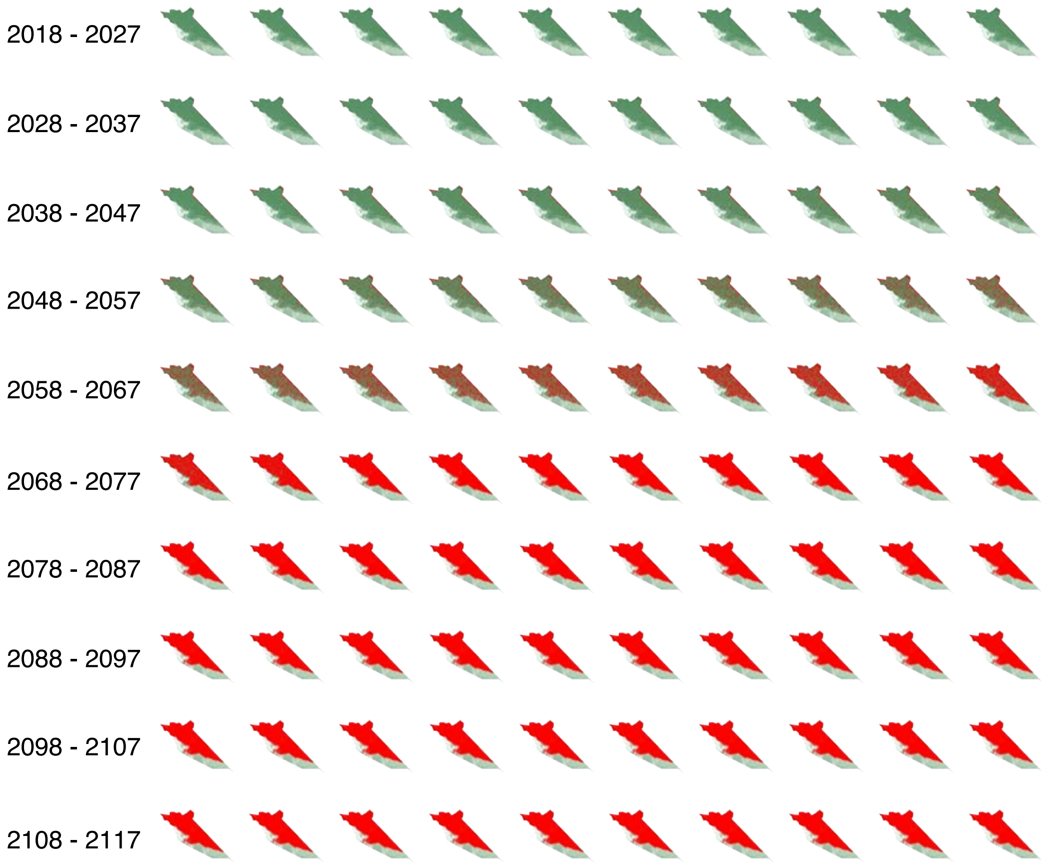
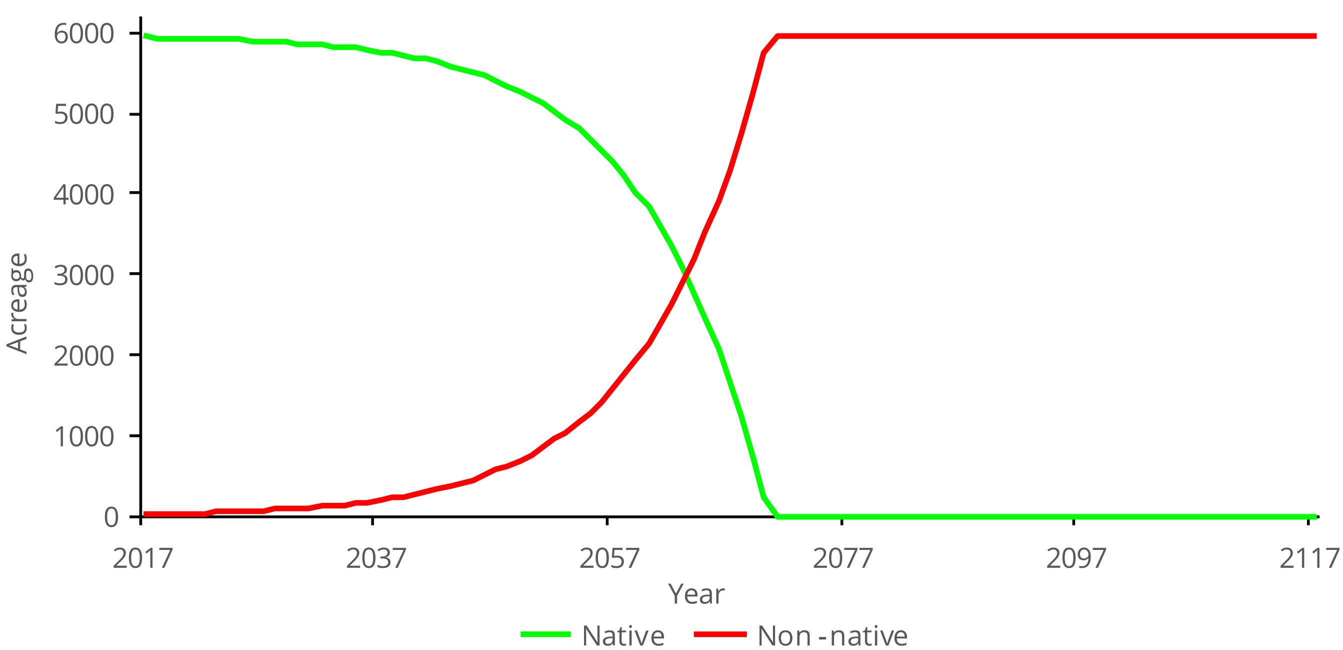


Figure 3. Acres of native forest and non-native forest over time.

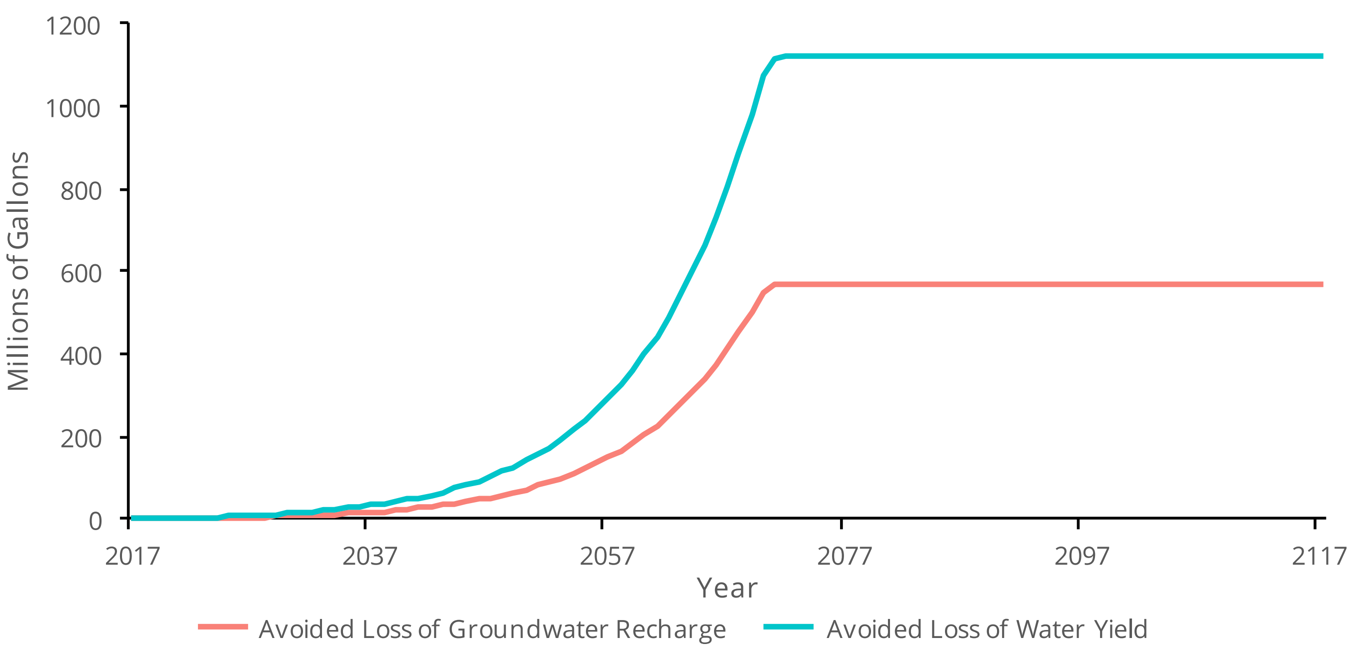


(represented by Priestley Taylor Potential ET) and water availability (represented by available soil moisture). Vegetation characteristics are inherent in that the model was based on the introduced wet-mesic forest land cover class only in the LANDFIRE data set. Priestley Taylor potential ET was a much stronger predictor (lower AIC - Akaike information criterion – an estimator of the relative quality of statistical models) than reference ET (ET_o), which is commonly used in ET modeling (Sharp et al. 2017). Similar to ET_o, Priestley-Taylor PET is a function of atmospheric conditions rather than vegetation characteristics and is therefore an appropriate alternative to ET_o given the superior model fit. Available soil moisture (as calculated by Giambelluca et al. (2014)) is influenced by rainfall only and not forest type. We tested for spatial autocorrelation (Zuur 2009) and selected the regression model with the lowest AIC value. R^2 on a testing data set was 0.64.

We then used this regression to estimate how AET is projected to change over time in the absence of conservation utilizing the *without conservation* (counterfactual) 2017-2117 land cover scenarios described in the previous section. For each year's *without conservation* land cover scenario we applied the regression equation to all pixels which had changed to introduced wet-mesic forest (non-native forest) from the original native forest cover. Baseline AET (from Giambelluca et al. 2014) was utilized for non-invaded unchanged pixels. AET of invaded pixels was calculated 1,000 times for each year in accordance with the land cover maps generated by the invasion simulation described above. Avoided freshwater yield loss over time was estimated as the difference between the modeled AET *without conservation* and the baseline AET.

To estimate the amount of avoided freshwater yield loss that could be considered avoided loss of groundwater recharge, we use a weighted average (0.51) of the previously calculated freshwater yield to runoff ratios in the four aquifers intersecting Waikamoi (Johnson et al. 2014). As there is currently insufficient data to currently estimate how forest type affects infiltration rates, we do not change infiltration rates with invasion.

Figure 4. Annual avoided loss of freshwater yield overall (blue) and annual avoided loss of groundwater recharge (red). Groundwater recharge is estimated as 51% of freshwater yield.



4.3. FRESHWATER YIELD RESULTS:

Aggregated over time, total avoided loss of freshwater yield was 63.7 billion gallons and avoided loss of groundwater recharge (based on GW recharge approximated at 51% of water yield) was 32.5 billion gallons (see Figure 4 for freshwater benefits over time). By 2072—the point of full conversion of native forest without conservation—water yield benefits reach 1.1 billion gallons per year (3.1 MGD or millions of gallons per day) and groundwater recharge benefits reach 571 millions of gallons per year (1.6 MGD). This was driven by non-native forest having approximately 25% higher AET than native forest. Uncertainty produced by varying pathways of spread at a 10% rate were insignificant given the magnitude of change produced. Our spread rate was based on limited existing observations of a 9-12% spread rate of non-native canopy (Geometrician Associates LLC 2010). If the spread were faster, full invasion would be reached more quickly and the avoided freshwater losses higher. Conversely, if the spread were to be slower, the avoided freshwater loss would be lower. The spread pattern also depends on the initial cover of non-native forest. Given the history of conservation, non-native forest cover was low in Waikamoi, so initial spread was slow. In other areas where there is a higher initial non-native forest area, the spread would be faster and avoided losses higher.

5. MONETIZING GROUNDWATER RECHARGE BENEFITS

Roughly half of the freshwater yield protected by ongoing TNC management in Waikamoi recharges underlying aquifers, while the remainder runs off and contributes to streams in the area. In this section, we estimate the monetary benefits of protecting recharge in the Waikamoi watershed. Precipitation in Waikamoi replenishes the Ko‘olau aquifer in East Maui, which has an estimated sustainable yield of 175 MGD. The aquifer is subdivided into four hydrologic units: Haiku (27 MGD), Honopou (25 MGD), Waikamoi (40 MGD), and Keanae (83 MGD). Although these numbers suggest that a large volume of freshwater is potentially available for use, accessing most of these subunits is prohibitively costly; new pumping and distribution infrastructure would be required, and the cost of transporting the water over long distances to high population areas on Maui would be nontrivial. Through discussions with Maui County Department of Water Supply (DWS), we have determined that the Haiku subunit is currently the most feasible groundwater option for meeting future water demand growth, given its relative proximity to Central Maui, where much of the island's future population growth is expected to occur.

Projected water consumption based on population growth rates in Maui's Central and Wailuku Aquifer Sector Areas requires an additional 14 MGD (beyond what is available from existing potable water sources) in the year 2035 with a low to high range of 10-17 MGD (County of Maui DWS 2016). We extrapolated the 2035 baseline consumption projection out 100 years to 2117 using a fitted exponential curve (Table 1). The shortfall in each year after 2035 was calculated as 14 MGD plus any excess in extrapolated consumption above the 2035 level.

Table 1. Projected Water Consumption in the Central/Wailuku Aquifer Sector Areas

	2035	2045	2055	2065	2075	2085	2095	2105	2115
Baseline Consumption (MGD)*	32.6	40.0	49.1	60.4	74.2	91.2	112.0	137.6	169.1
Shortfall (MGD)	14.0	21.4	30.6	41.8	55.7	72.6	93.5	119.1	150.6

* Trendline equation beyond year 2035: $y=21.556e^{0.0206x}$ ($R^2=0.99871$)

The current sustainable yield of the Haiku hydrologic unit is estimated at 27 MGD, and current average pumpage is approximately 3.4 MGD. To avoid designation of the Haiku unit as a special groundwater management area, we constrained the maximum allowable pumping rate to 90% of sustainable yield. Under current TNC watershed management, assuming constant recharge, available pumpage from the Haiku groundwater unit totals 20.9 MGD. Additional strategies for supplying 2035 projected consumption have been explored by Maui DWS in the process of advancing the Maui Island Water Use & Development Plan (County of Maui DWS 2016). Available yields of potential potable sources and corresponding unit production costs are listed in Table 2 in order of least cost, given current estimates of sustainable yield.

Table 2. Future Potable Water Supply Options

Source	Sustainable yield (MGD)	90% of SY (MGD)	Current pumpage (MGD)	Available pumpage (MGD)	Unit cost ($/MG)	Unit cost ($/TG)
Haiku	27	24.3	3.4	20.9	3,710	3.71
Waihe‘e	8	7.2	3.5	3.7	3,800	3.80
Waikapu	3	2.7	0	2.7	4,250	4.25
Makawao	7	6.3	0.4	5.9	4,500	4.50
Seawater Desalination					12,700	12.70

We estimated the total cost across all sources of meeting annual projected consumption from 2017-2117, assuming recharge is maintained under current TNC watershed management and future potable sources are used in order of least cost. In year 2045, for example, groundwater from the Haiku subunit can provide a maximum of 20.9 MGD, while the remaining 0.5 MGD of the shortfall is supplied by slightly more expensive groundwater from the Waihe‘e subunit. The total present value cost of meeting projected additional potable water needs beyond currently developed sources in Central Maui was estimated at $2.01 billion, assuming a discount rate of 3 percent. This value serves as the baseline for our recharge benefit calculations.

The recharge benefit of TNC's watershed management in Waikamoi was calculated as the difference in costs between the baseline scenario with constant recharge, and a counterfactual scenario, in which recharge is declining over time due to a hypothetical spread of non-native forest. As discussed in section 4, if watershed management ceased and an invasion were to occur over the next century, the land cover change would alter annual freshwater yield in Waikamoi, and hence groundwater recharge. The change in recharge to the Haiku aquifer would reduce available pumpage, thus requiring an increased share of additional demand being met by more costly alternatives. Using the declining recharge trend estimated in Section 4, we estimated the total cost of meeting projected consumption in every year as we did for the baseline case. If TNC management of Waikamoi stopped in 2017, the present value cost of supplying additional potable water needs over the next 100 years was estimated at $2.05 billion (as compared to $2.01 billion as described above). The avoided recharge cost, or equivalently the recharge benefit, of TNC's watershed management can be expressed as the difference in baseline water supply costs and no-management water supply costs, or $36.2 million in present value terms.

5.1 ADDITIONAL NON-WATER ECOSYSTEM SERVICE BENEFITS

The modification of native forest by invasive species may, in addition to reducing freshwater availability, have an influence on other ecosystem services including provisioning services such as genetic and ornamental resources, regulating services such as erosion prevention and pollination, habitat services such as nursery services and gene pool protection, and cultural services such as inspiration and recreation. Forest degradation can alter ecosystem function and services provided due to disturbance and loss of native biodiversity. Invasion of native forest by pigs and invasive plants in Hawaiʻi, for example, has been found to alter biogeochemical cycles (Asner and Vitousek 2005), increase erosion and bacterial concentrations (Strauch et al. 2016; Cole et al. 2012), and reduce a suite of cultural services. Since many of these services are not traded in markets, estimating the monetary value of such benefits requires additional tools. We cannot assign values based on prices if markets do not exist. Ideally, we would apply non-market valuation techniques (e.g., contingent valuation, hedonic pricing, travel cost, production function, etc.) to each service. However, our ability to directly estimate many non-water services was limited by data availability. Moreover, measuring every ecosystem value protected by watershed management in Waikamoi was beyond the scope of this study. Given these limitations, we instead employed a benefit transfer approach, using data and results from a recent study conducted by de Groot, et al. (2012). We additionally quantify the sediment retention value of conservation in biophysical terms (in section 6 below).

Benefit transfer is a technique used to estimate ecosystem service values in monetary terms by transferring information from valuation studies completed in other similar locations. De Groot, et al. (2012) reviewed and collated data from over 300 case study locations worldwide and coded approximately 665 values, representing more than 20 ecosystem service types, each of which was sorted into one of the following four general categories: provisioning services, regulating services, habitat services, cultural services. Those values were further subcategorized according to biome type. Since the effects of land cover change on freshwater yield were estimated for Waikamoi, water provisioning and water flow regulation service values were omitted from the benefit transfer estimate. The value of services for an ecosystem similar to Waikamoi, not including water-related services, totaled $498 (2017 dollars) per acre per year (Table 3). While this number should be used with caution given that it comes from different areas of the world than Hawaiʻi and values are place and context specific, it is based on the most comprehensive review of tropical forest ecosystem service values available and likely serves as a reasonable estimate of the ecosystem services provided. While the value of some services (particularly provisioning services) may be lower in Waikamoi, in general this valuation underestimates the large cultural value of Hawaiian native forest as well as links between forest conservation, surface water quality, and coral reef and fisheries health.

The non-water ecosystem service benefits of TNC's watershed management in Waikamoi were calculated in several steps. First, the annual benefit of native forest cover was estimated annually for the counterfactual scenario, in which a hypothetical invasion occurs over time. In each period, native acreage was multiplied by the per-acre non-water service value of $498. Because native cover is decreasing over time in this scenario, the total annual value is also declining. Second, we estimated the annual benefit of the current native cover, which would be maintained under TNC management. Third, the difference between the value of current land cover and the value of land cover in the invaded scenario was calculated for each year and can be interpreted as the avoided service loss or, equivalently, the non-water benefit of TNC management. For a discount rate of 3%, the estimated present value benefit of additional non-water ecosystem services is $24.3 million. Therefore, the present value of all benefits, both water-related and non-water-related, totals $60.5 million. Figure 5 illustrates the increase in management benefits over time.

The non-water benefit estimate of $24.3 million includes habitat services (Table 3), which is one way to represent biodiversity and the value of endangered species present in Waikamoi or adjacent lands. The Waikamoi watershed provides habitat for ten native forest birds (TNC Maui 2014), including four federally listed endangered species: crested honeycreeper (*Palmeria dolei*, ʻākohekohe), Maui parrotbill (*Pseudonestor xanthophrys*, kiwikiu), Hawaiian petrel (*Pterodroma phaeopygia sandwichensis*, ʻuaʻu), Hawaiian goose (*Branta* *sandvicensis*, nēnē). Populations in the Waikamoi watershed region are estimated at 3,800 for the crested honeycreeper (Camp et al. 2009), 500 for the Maui parrotbill (Brinck et al. 2011), and 416 for the Hawaiian goose (VanderWerf 2012). An alternative way to evaluate the benefits of these important forest bird species independently would be to employ an approach developed by Richardson and Loomis (2009), which would increase the estimated value of Waikamoi's activities substantially.[1]

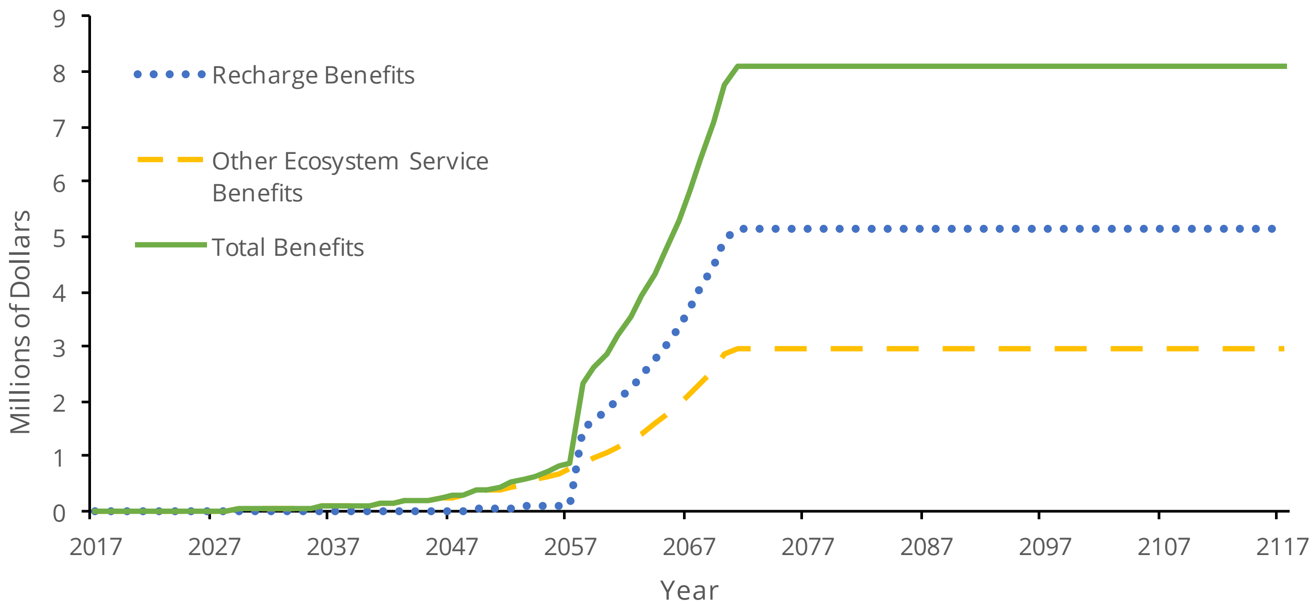
Table 3. Summary of Monetary Values Used in Benefit Transfer Calculation (Adapted from de Groot et al. 2012)

Service	Description	Value ($/acre/year)
Provisioning services		
Genetic resources	The diversity of organisms developed over evolutionary time, measurable at species, molecular and sub molecular levels.	6
Regulating services		
Air quality regulation	Ecosystems influence rainfall and water availability both locally and regionally, and play an important role in regulating air quality by removing pollutants from the atmosphere.	6
Disturbance moderation	Ecosystems and living organisms create buffers against natural disasters, potentially reducing damage from floods, storms, tsunamis, avalanches, landslides and droughts.	33
Erosion prevention	Vegetative cover helps to prevent soil erosion, a key factor in the process of land degradation.	7
Nutrient cycling	The storage, cycling, and maintenance of nutrients by organisms and their associated processes in an ecosystem.	1
Habitat services		
Nursery service	Ecosystems may provide important habitats for the propagation and the growth of young individuals.	8
Genetic diversity	The variety of genes between and within species populations. Genetic diversity distinguishes different breeds or races from each other, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock.	8
Cultural services		
Recreation	Recreational benefits to visitors (hiking, bird watching, etc.) and income opportunities for nature tourism service providers.	428
Total value of services*		498

*Summary statistics for tropical forest biome (n=96) in the original study ($/acre/year): mean=2,596; standard deviation=3,218; median=1,161; min=780; max=10,283. The value we use for the current study includes 8 of the 22 services considered in de Groot et al. (2012) and is therefore a conservative estimate of non-water values in Waikamoi.

1 Richardson and Loomis (2009) estimated a log-log regression equation that can be used to calculate WTP (willingness to pay) to prevent the reduction in population of an endangered bird species. Adjusting relevant policy variables and plugging in sample means for the methodological variables, we estimated that each household on Maui would hypothetically be willing to pay $6.08 per year to prevent a 1% loss of endangered bird species in Waikamoi. Assuming proportional habitat loss is approximately equal to proportional population loss, we estimated that TNC's watershed management in Waikamoi is potentially preventing the loss of up to 3,997 endangered birds over the management period. If we further assume the WTP estimate represents an average for the 53,886 households on Maui, the total PV benefit of TNC management in terms of avoided bird losses alone is close to $58 million.

Figure 5. Annual monetized ecosystem service benefits over time



5.2 WATERSHED MANAGEMENT COSTS

TNC management in Waikamoi watershed supports the continued provision of many ecosystem services. As discussed in the previous section, the monetary value of these benefits over the next hundred years is on the order of tens of millions of dollars. In this section, we discuss the expected costs of maintaining those benefits into the future.

TNC management efforts at the study site began over 30 years ago. Historical expenditures from 1995-2012 were estimated based on TNC Maui's Long-Range Management Plans (1993, 1999, 2006, 2011). Proposed budgets were divided into seven general expenditure categories: ungulate control; weed control (invasive plant control); invertebrate and small mammal control; monitoring; rare species protection and research; public outreach programs; and personnel, equipment, and facilities. Personnel costs accounted for more than half of the budget, while remaining expenditures were largely attributed to helicopter time ($1,100/hour in 2017), equipment and supplies. Fence construction costs prior to 2013 were estimated based on the total length of regularly inspected fenceline in Waikamoi (19 miles) and unit costs of $200,000/mile and $75/foot for pig and deer fences respectively. Historical expenditures from 2013-2017 were based on actual spending (i.e. not proposed budgets) by TNC Maui. Recent expenditures were notably higher than in the past, due largely to the conservation easement over 3,721 acres of East Maui Irrigation Co. Ltd. (EMI) lands adjacent to the 5,230-acre Waikamoi Preserve. This included a contract for the construction of a 3-mile fence (~$200,000/mile) to extend protection to the EMI addition. After inflating past expenditures to 2017 dollars, we estimated that approximately $20.1 million have been spent thus far on watershed management in Waikamoi.

Because we used the current land cover as the starting point for our benefit calculations, it is important to include past expenditures in our present value cost estimate. If those funds had not been expended to manage the watershed in previous years, the proportion of native to invaded forest in Waikamoi would likely be much lower than it is today. In other words, we would be working with a different starting point, which would affect the projection of benefits over the next hundred years. The next step in our present value calculation is to add projected costs to the past expenditure total. Expenditures over the period 1995-2017 averaged $679,630 per year in 2017 dollars, with an uptick in 2013-2015, largely due to the fixed costs associated with establishing the EMI addition. Expenditures after the addition remained higher than pre-2013 levels, totaling approximately $775,000 in 2017. Because expenditures have been trending downward over the period 2015-2017, the annual cost of maintaining the current level of management over the next 100 years may be more in line with the average over the period 1995-2017. If we assume that maintaining the current land cover in Waikamoi would cost on average $679,630 per year over the next 100 years, the total PV cost of watershed management is $41.4 million.

5.3 COMPARISON OF BENEFITS AND COSTS

The net present value (NPV), measured as the difference between PV benefits ($60.5 million) and PV costs ($41.4 million), of TNC management in Waikamoi is $19.1 million. A positive NPV suggests that the current investment in watershed management adds value to the overall human-environment system. The benefit-cost ratio (BCR), measured as the ratio of PV benefits to PV costs, of TNC management in Waikamoi is 1.46. An investment with a BCR less than 1 is not desirable from an economic perspective. If two or more projects achieve the same outcome, then the one with the highest BCR is typically preferred. The return on investment (ROI), measured as the ratio of NPV to PV cost, of TNC management in Waikamoi is 46%. ROI is like BCR in that it provides a metric for evaluating the efficiency of an investment or for comparing the efficiency of multiple investments. The payback period, i.e., the length of time until cumulative benefits equal cumulative costs, is 52 years.

The first three metrics (NPV, BCR, ROI) collectively suggest that the overall value for money of investment in the protection of Waikamoi watershed is positive. However, costs are largely front-loaded, while benefits gradually increase over time, resulting in a breakeven point several decades into the future. It is important to note some caveats in the calculations of both the benefits and costs. On the cost side, there is some uncertainty surrounding historical expenditures, given that estimates for many years were based on budgets rather than actual spending. On the benefit side, the values of non-water ecosystem services were drawn from a meta-analysis, and average values for similar biomes in other locations may not perfectly match our study site. In addition, our management timeline is 100 years, but as Figure 5 illustrates, projected benefits increased over time and will continue to exceed costs beyond the 100-year horizon. Moreover, the estimate of present value benefits did not include the years prior to 2017, due to data limitations. Taking all of these uncertainties into consideration, the calculated NPV, BCR, and ROI values are likely conservative estimates.

6. ESTIMATED SEDIMENT RETENTION BENEFITS IN BIOPHYSICAL TERMS

While we are not able to monetize the value of reduced erosion or sediment retention beyond benefit transfer, we include an estimate of avoided sediment export in biophysical terms. Fencing and ungulate removal prevents pig behaviors (browsing, digging, rooting, and trampling) which damage diverse, multilevel understory and makes the soil surface more susceptible to downslope movement by rain drops (Strauch et al. 2016; Cole et al. 2012). Soil erosion, in turn, decreases freshwater quality by mobilizing soil particles, including bound nutrients and bacteria. Decreased water quality can impact habitat for native stream organisms (for instance *Awaous guamensisi*), and also for intertidal and coastal species (such as *Cellana sp.*) that rely on clean freshwater to feed and reproduce. Sediment delivery to coral reefs can also negatively affect coral and fish communities (Wedding et al. 2018).

All soil that is eroded does not necessarily make it to surface water systems and out to the coast – some sediments are entrained on the landscape because of topography, distance to stream or understory that creates roughness. In order to estimate sediment retention and export, we used the InVEST Sediment Delivery Model (InVEST SDR) (Hamel et al. 2015). The model operates by first calculating a predicted soil erosion using the Universal Soil Loss Equation (USLE), and then determining a sediment delivery ratio (SDR) to assess what percentage of eroded soil is exported (Glymph 1954). Sediment export was estimated for years 2017, 2045, and 2072 (full conversion) (Figures 6 and 7) in the 50 watersheds that intersect with Waikamoi (Figure 8). The largest of these 50 watersheds are Wailuanui, Pi'ina'au, Honomanu, Wailuaiki and Kailua.

6.1 SEDIMENT MODELING METHODS

The SDR InVEST model uses the USLE, which calculates soil eroded for each pixel i (E_i) as follows:

$$E_i = (R \cdot K \cdot L \cdot S \cdot C \cdot P)_i$$

where: R is the rainfall erosivity (MJ mm ha^{-1} h^{-1}), K is the soil erodibility (ton ha hr MJ^{-1} ha^{-1} mm^{-1}), LS is the slope length-gradient factor, C is the crop-management factor and P is the support practice factor (Renard et al. 1991). The inputs to the model used in this study were as follows: digital elevation model – USGS 10m (http://www.soest.hawaii.edu/coasts/data/hawaii/dem.html), rainfall erosivity – Natural Resource Conservation Service, digitized to 250m per Falinski (2016), and soil erodibility – SSURGO soils database (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627). C-factors were adapted for the custom Landfire maps per the National Engineering Handbook (NRCS 1983).

The C-factor, or cover factor, was estimated for each forest, shrubland and grass cover class based on estimates of the % cover for canopy and understory, and the estimated height of the canopy. Larger heights and less understory had higher erosion rates. There are few studies in Hawai'i that specifically estimate C-factors for ginger or strawberry guava, so the best available estimates were used. C-factor for wet mesic non-native introduced forest was 0.014, while native wet mesic forest (Hawai'i Montane Rainforest) had the lowest value of 0.003. The model proved sensitive to the values for Wet Cliff and Dry Cliff land uses, because of the high slopes in the Pi'ina'au watersheds which are generally over-predicted using the USLE model. Maliko watershed was sensitive to the Agriculture C-factor (estimated at 0.12, per conservative FAO guidance), but this did not affect the predicted changes in the Waikamoi preserve.

The InVEST SDR model is calibrated using a threshold flow accumulation parameter, which changes the density of the stream network, a parameter called the Borselli k factor, which changes how eroded soils move to streams, and an initialization parameter (IC0) which alters the shape of the SDR curve. For this study, we adopted the work of Falinski (2016) to use values of 2.0 and 0.1 for the Borselli k factor and IC0 parameter, respectively. Falinski (2016) calibrated these values using 60 watersheds throughout the Hawaiian Islands but did not have available data for Maui island. In order to improve the model for northeast Maui, we used available USGS discharge data from gaging station 16552800 (Waikamoi Stream above Kula PL intake at Olinda) and recent turbidity data available from The Nature Conservancy. Turbidity data was acquired every 1 hour for 18 months (Eureka Manta Probe with turbidity sensor and wiper), collocated at the USGS discharge gaging station. Average turbidity was 7.5 NTU, and the range was small, between 6.3 and 10.3 NTU. Using average turbidity values we estimated total suspended solids using a 1:1 ratio to mg L^{-1} (per Tomlinson and DeCarlo 2003), and calculated loads by multiplying by discharge. We were able to roughly estimate total sediment export loads to this point in the watershed as 12 tons per year. The final calibration of the model used a threshold flow accumulation of 3000.

Table 4. C-factors used in this study. For percent cover, the first value is the primary canopy cover (forest, shrub or grass), the second is an estimate of the understory cover as either grass (G) or broad-leafed herbaceous plants (W) (National Engineering Handbook Table 3-2). All numbers come from NRCS (1983), with the exception of agriculture, which comes from Kassam (1992).

Land cover	usle_c	usle_p	Percent cover
Hawai'i Montane Rainforest	0.003	1	75% (F); 95% (G)
Hawai'i Introduced Deciduous Shrubland	0.012	1	75% (S); 80% (G)
Developed Open Space	0.03	1	
Barren	0.001	1	
Hawai'i Introduced Dry Forest	0.17	1	75% (F); 20% (G)
Agriculture	0.12	1	
Hawai'i Introduced Wet-Mesic Forest	0.014	1	75% (F); 80%(W)
Hawai'i Lowland Rainforest	0.003	1	70% (F); 95% (G)
Hawai'i Introduced Perennial Grassland	0.032	1	75% (G); 40% (G)

6.2 SEDIMENT MODELING RESULTS

Based on modeling results, without conservation, sediment export would increase from 1,540 tons per year in 2017, to 1,710 tons per year in 2045, to 5,840 tons per year in 2072 (full conversion). Thus, sediment export would increase by an estimated 4,300 tons per year without conservation by 2072, representing a 280% increase in sediment export from the Waikamoi preserve. However, given that the Waikamoi preserve only covers part of key watersheds reaching the coast (Figure 8), this translates to an 11% increase in sediment export to the entire northeast Maui coast by 2072. The majority of the changes in sediment export would be seen in Pi'ina'au, Wailua'iki and Wailuanui watersheds, where sediment export would increase by 43%, 53% and 50%, respectively without conservation activities (Table 5). In contrast, sediment export would likely increase by 18% in the Waikamoi watershed which is most directly related to implications for water treatment[2]. While changes in overall sediment load do not directly translate to changes in turbidity related to water treatment, given that we assume the same quantity of runoff, the percent increase in turbidity is likely similar. Thus, results indicate that continued efforts to manage the eastern watersheds in the preserve would have the most benefit for retaining sediment in terms of coastal health while a focus on watersheds important for surface drinking water would have the most benefit for potentially preventing an increase in treatment costs.

2 Although we focus on monetizing groundwater recharge benefits of watershed protection in this study, changes to forest cover can also affect surface water treatment costs. Using water quality data for 37 treatment plants in the United States, Warziniack et al. (2017) find that converting 1% of a watershed from forest to developed land increases turbidity by 3.9%, and a 1% increase in turbidity increases chemical costs for treatment by 0.19%. In our counterfactual scenario, native forest cover is converted to invasive forest rather than to developed land, so the effect of conversion on turbidity will not be identical. Assuming the effect of turbidity on treatment costs is similar for our study site, however, costs at the Piiholo and Olinda water treatment facilities, which are supplied by Waikamoi surface water, would increase by $3.42 and $3.23 per million gallons respectively for every 1% increase in turbidity, based on estimated current treatment costs of $1.80 and $1.70 per thousand gallons (T. Linder, Maui Department of Water Supply, Water Treatment Plants Division, personal communication). If the effect of native forest protection on turbidity is large in Waikamoi, the avoided cost (benefit) of management could be substantial. Preventing an 18% increase in turbidity, for example, would avoid approximately $98,291 in treatment costs annually at the two treatment facilities, which together currently produce 135 million gallons per month. There may be a water quality threshold, however, beyond which Maui DWS would shut down the treatment plants and increase potable water production elsewhere to compensate. Given that we are not including monetized surface water quality benefits in this study, the recharge benefits reported should be viewed as a lower bound for total freshwater benefits.

Figure 6. Sediment export by pixel under current land cover (Year 2017; top) and without conservation (Year 2072; bottom) in the Waikamoi preserve.

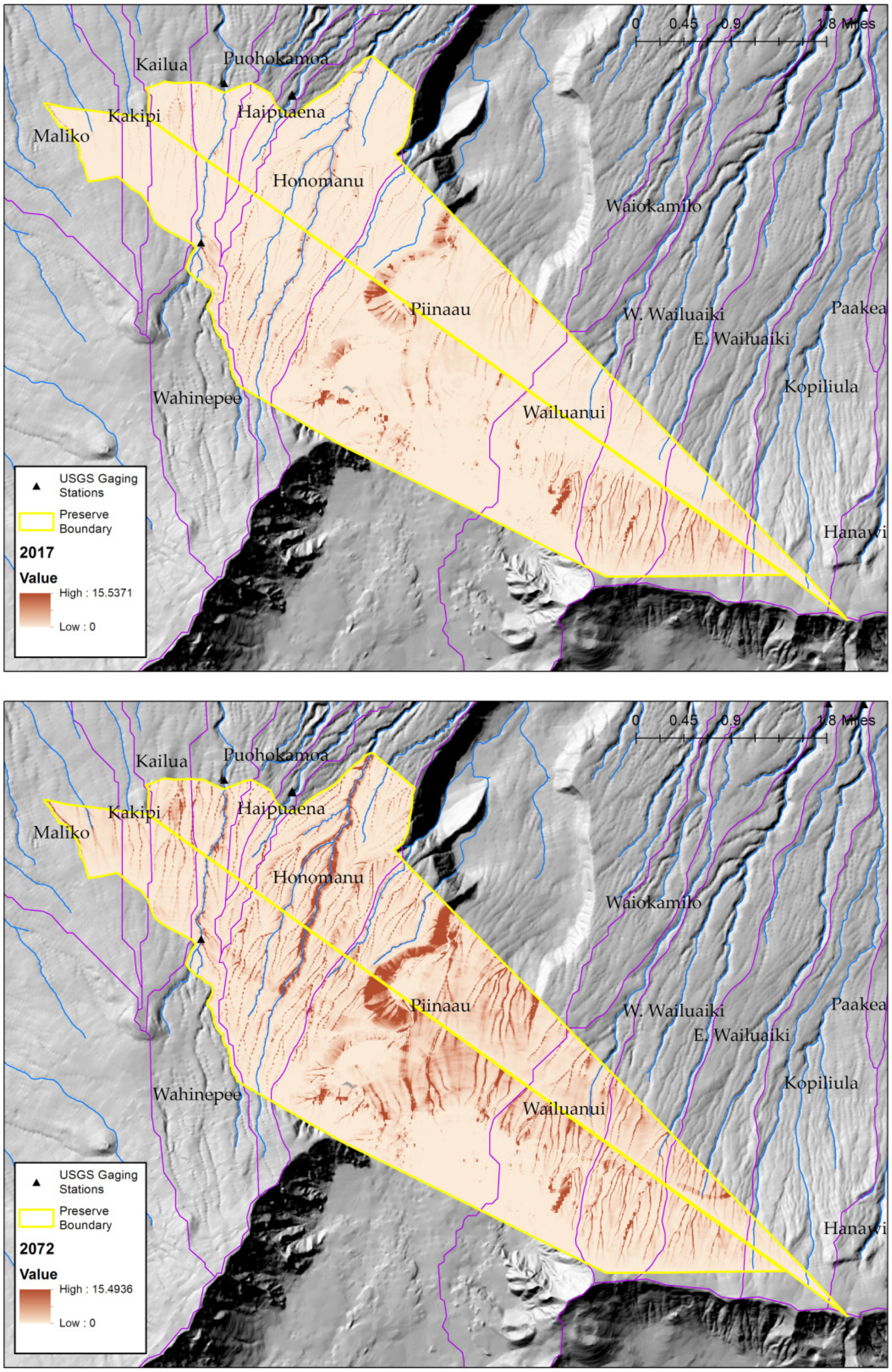


Figure 7. Sediment export from Waikamoi Preserve in 2017 and potential increase in sediment export in the absence of conservation activities. The difference in sediment export between 2045 and 2017 and between 2072 and 2017 represents the avoided sediment export benefit provided by conservation. For the Waikamoi Preserve, sediment export is predicted to increase by 2.8 times the current annual estimate.

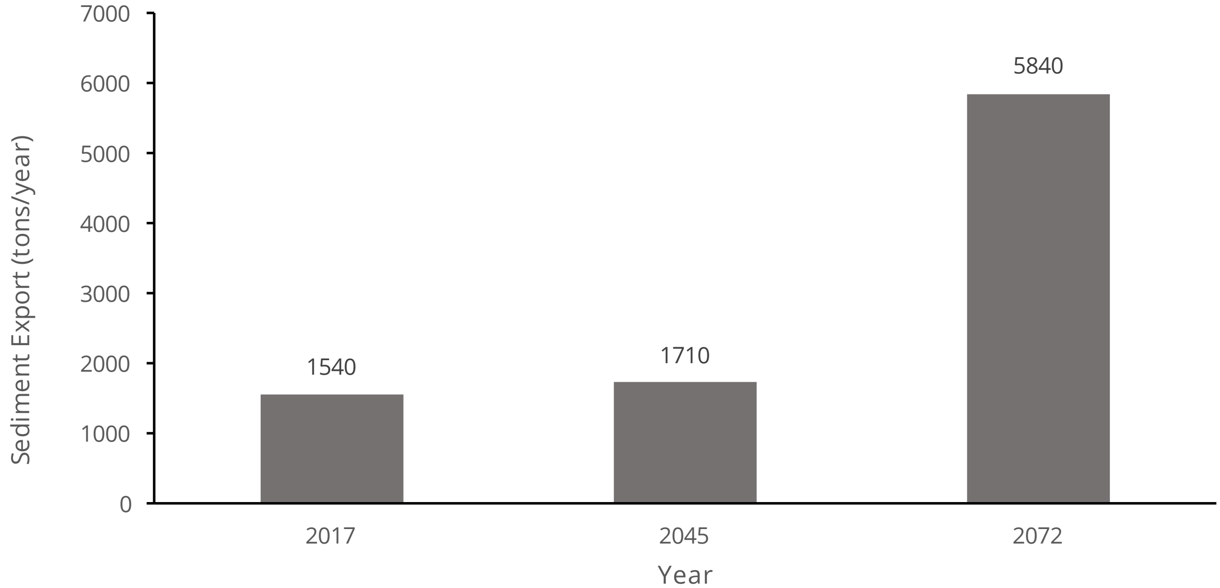


Figure 8. East Maui sediment export in 2017 in tons per year including the 50 watersheds that intersect with Waikamoi preserve.

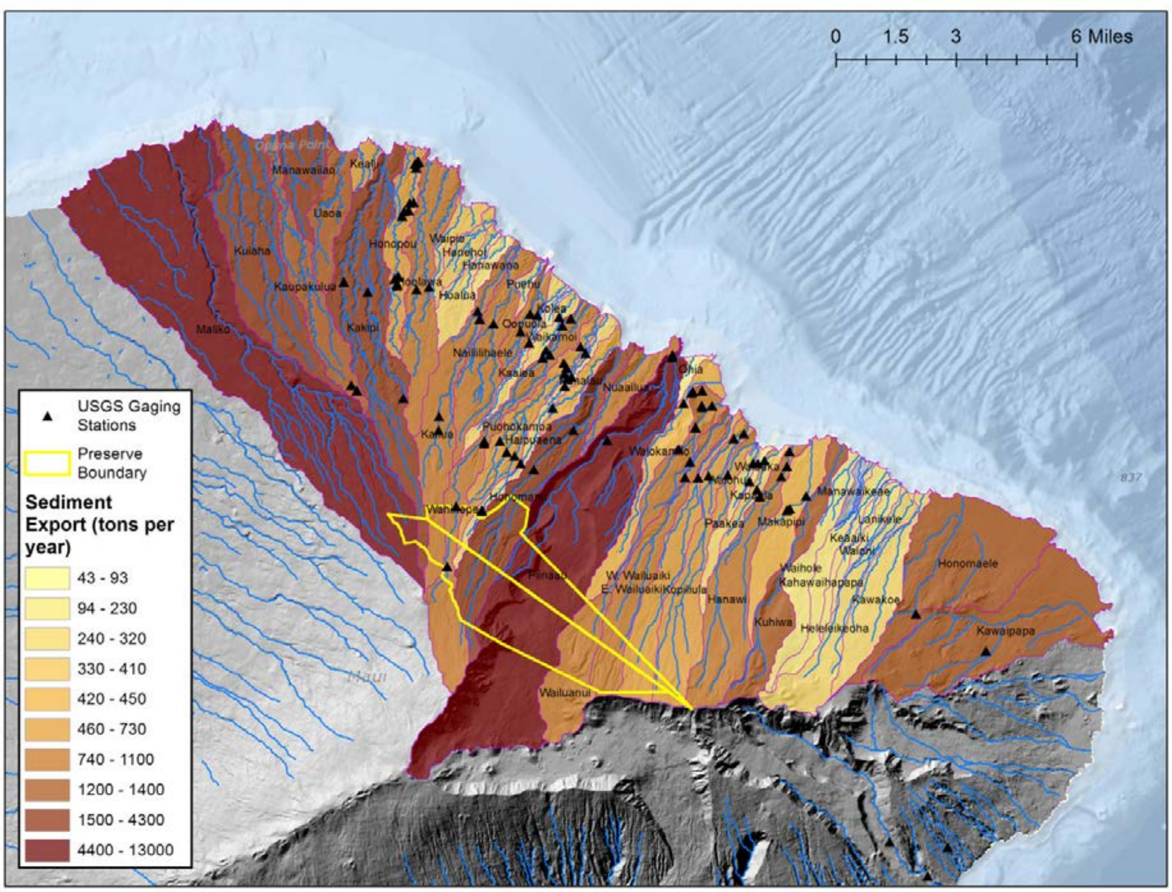


Table 5. Estimated sediment export by watershed for current land cover (2017), partial conversion (2045) and full conversion (2072) to non-native forest. Percent change reflects the increase in sediment export for the full watershed between 2017 and 2072.

Watershed Name	2017	2045	2072	Area (km^2)	% Change
W. Wailuaiki	815	927	1250	10.84	53%
Wailuanui	883	956	1324	15.41	50%
E. Wailuaiki	585	632	849	9.86	45%
Piinaau	5872	6024	8403	53.52	43%
Honomanu	2913	2974	3953	16.83	36%
Kolea	64	84	84	0.49	33%
Haipuaena	291	330	391	4.25	31%
Kailua	828	881	1049	12.58	27%
Wahinepee	962	1035	1155	14.15	20%
Waikamoi	320	379	379	1.82	18%
Oopuola	862	1014	1014	3.32	18%
Kapaula	364	415	415	2.24	14%
Waiaaka	141	155	155	0.53	10%
Puehu	249	273	273	0.97	10%

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