The Economic Value of Watershed Conservation

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1. Overview

Watershed conservation creates benefits within and beyond the management area of interest. Direct benefits are those realized in the watershed itself, such as improved water quality and quantity, and biodiversity protection. Additionally, the health of a watershed has profound implications on near-shore resources below its reaches, including beaches and coral reefs. This chapter reviews the major benefits of watershed conservation and discusses the economic value of these activities.

Within the watershed itself, conservation activities assist in protecting important groundwater sources by maintaining healthy canopies, native plant cover, reducing erosion, and fending off nuisance plant and animal species that degrade the system. These activities are a vital part of overall watershed maintenance and are reviewed in the introduction to this volume. Systems that often are excluded from the discussion of watershed management are those downstream from the area of interest. Improved watershed health leads to less runoff to ecosystems below and therefore cleaner and more valuable beaches and reefs.

Perhaps the most direct benefit from tropical watershed conservation is that of aquifer recharge. The Hawaiian island of Oahu gets about 90% of its fresh water supply from groundwater. Alternative production techniques such as desalination are costly and postponement of their need is a valuable policy goal. Postponement can occur through the supply side by maintaining or potentially enhancing forest quality. The Ko`olau conservation district is a 97,760 acre area along the Ko`olau mountain range running the entire windward (Eastern) side of the island. There are hundreds of inches of rain each year in some locations, and the general trend is for high levels of rainfall along the crest of the range declining with elevation. The form and composition of the forest in large part determines how much of the water will run off, how much sediment it will carry, and how much will recharge the aquifers from which Oahu draws its water supply.

Kaiser et al. (1999) calculate that the net present value lost from a decrease in recharge of 41 MGD to the Pearl Harbor aquifer may be between $1.42 billion and $2.63 billion dollars, depending on the assumptions made regarding the social discount rate. If the current levels of groundwater recharge are maintained, the scarcity rents will rise from $0.6 thousand gallons in year 2000 to nearly $3 in year 2072. On the other hand, if the forest damage reduces the recharge by 41 MGD, the scarcity rents in year 2000 jump to over $1 thousand gallons and rise to nearly $3 by 2057. They also calculate that if recharge to the aquifer from the Ko`olaus ceased altogether, the reduction of inflow to the Pearl Harbor aquifer would be approximately 133 MGD. The lost net present value from such a disruption would amount to $4.57 to $8.52 billion.

Biodiversity and aesthetics are among the other direct benefits provided by tropical watersheds. In the Ko`olau mountains, these forest benefits have been valued between $2,626 and $7,860 million in net present value terms, composed of species habitat benefits ($487 to $1,434 million), biodiversity benefits ($660,000 to $5.5 million), subsistence benefits ($34.7 to $131 million), hunting related benefits ($62.8 to $237 million), aesthetic values ($1,040 to

$3,070 million), commercial harvests ($0.6 to $2.4 million), and ecotourism ($1,000 to $2,980 million) (Kaiser et al. 1999).

Tropical watershed conservation also has important indirect benefits to offsite resources. Runoff from forests may damage nearshore resources such as beaches, reefs, and marine resources. For example, runoff from forest watersheds can contribute to reef sedimentation and nutrient loading in nearshore waters (e.g., Mackenzie 2001), and streams transport toxins to reefs, marine fisheries and recreational areas, resulting in eutrophication and algae growth that smothers out the (hard) scleratinian corals (Dollar & Tribble 1993; Jokiel 1993). Conservation of forests that reduces runoff, therefore, provides benefits for nearshore resources.

2. Direct Benefits of Watershed Conservation: the Pearl Harbor Aquifer

Figure 1 shows the Pearl Harbor coastal aquifer. The aquifer is recharged from the Ko`olau mountain watershed, which rises up to 1000 meters with annual rainfall reaching 4000 millimeters at high elevations (Giambelluca et al. 1996). In the early 1900's, the State removed destructive cattle and feral ungulates (mainly pigs and goats) and replanted vegetation in degraded areas around the watershed. These watershed conservation efforts have helped to protect aquifer recharge.

Currently, anthropogenic pressures and biological changes that work to reduce forest cover and increase runoff, at the expense of recharge, threaten the watershed. Existing feral pig and goat populations destroy vegetative cover and compact the soil, likewise increasing runoff and decreasing recharge. Urban encroachment and increased recreational use of watersheds, e.g., hiking and off-road vehicular traffic have similar effects. A growing threat stems from a possible shift in the forest structure from the spread of an invasive weedy tree, *Miconia calvescens*. Miconia has a shallow root structure, contributing to landslides, and can virtually eliminate the understory, thereby decreasing infiltration and increasing runoff. Miconia currently covers 70% of previously native forest on two Tahitian islands (Meyer 1998) and has already spread to nearly 150 thousand acres of forestland in the State of Hawaii.

Figure 1: Pearl Harbor Aquifer, Oahu, Hawaii.

Source: United States Geological Survey

Groundwater in the Pearl Harbor aquifer, as in many other coastal areas, is commonly modeled as a Ghyben-Herzberg lens where freshwater floats on a saltwater layer underneath (Mink, 1980; Shade and Nichols, 1996; Oki, 1998; Oki et al. 1998), as shown in Figure 2. The freshwater from the lens leaks into the ocean at a rate that varies directly with the head level. If extraction is more than net recharge (net of inflow and leakage), the lens contracts and the head level falls, requiring greater lift, and therefore, increasing costs, for further extraction.

Water is extracted and distributed by the Honolulu Board of Water Supply (HBWS), an agency of the City and County of Honolulu. Users in the area are divided into domestic, commercial, and agricultural categories. Most of the water use is in the first two categories with agriculture being close to 2 % of the total water use (Malla, 1996, Table 4.2). The HBWS charges cost-recovery prices for the water supplied to the users. This amounts to pricing water at the average cost of extraction and distribution, and ignores the opportunity cost of resource drawdown (marginal user cost). A potential alternative but much more expensive source of freshwater, which can be used when the groundwater is depleted, is desalination of seawater.

Figure 2: Ghyben-Herzberg freshwater lens (after Mink, 1980)

Pitafi and Roumasset (2006) have modeled this aquifer to estimate the value of watershed recharge service. They set up a regional hydrologic-economic model to optimize groundwater use, along the lines of Krulce et al. (1997), which extends previous models (e.g., Brown and Deacon 1972, Cummings and Burt 1969, Moncur and Pollock 1988, among others) by allowing recharge to vary continuously with the head level. Water is extracted from a coastal groundwater aquifer that is recharged from a watershed and leaks into the ocean from its ocean boundary depending on the aquifer head level. They find that gains from watershed conservation that prevents a 1% loss of recharge are about $43 million in present value terms. If the watershed conservation prevents a 10% loss of recharge, then the gains are over $546 million. These gains are obtained with the status quo pricing policy, under which average cost pricing is used. However, if the groundwater is being efficiently priced, so that prices equal the marginal user costs across individuals and time, the gains increase dramatically, as discussed in the final section of this chapter.

3. Indirect Benefits of Watershed Conservation: Near-shore Resources

Near-shore resource quality is dependent not only on direct use but also on quality of upland watershed. Recent efforts at economic valuation of Hawaii's coral reef assets have generated values up to $10 billion dollars in present value, or $360 million per year (Cesar 2002). Too often, the role of the watershed in protecting these valuable assets is underplayed or ignored in policy decisions. We investigate the economic implications of expanding near-shore resource policy to include explicit upland conservation efforts. The intent of this section is to promote integrated management of marine and terrestrial environmental resources for the state of Hawaii in particular and to define explicitly the interconnectedness among said resources to examine the potential benefits from such integrated policy efforts.

Near-shore resources are directly damaged by tourists and residents, e.g. through water pollution and alteration of marine ecosystems. Less obviously but not necessarily less importantly, beaches, reefs, and marine resources may also be damaged by runoff from upland areas. For example, runoff from forested watersheds can contribute to reef sedimentation and nutrient loading in near-shore waters, and channelized streams transport toxins to reefs, marine fisheries, and recreational areas. Short-term turbidity episodes may not kill reefs, but they will promote eutrophication and algal growth over coral substrate growth. The reduction in calcifying reef builders may result in smaller, more slowly growing reefs that do not support as much ecosystem diversity or long run biomass production. Long run ecosystem service production will decline, including beach and sand production, habitat quality for recreational divers and snorkelers, and fish nurseries. Since Hawaii's reefs are young, at the edge of the reef-supporting climatic zone, and without great diversity and resilience, they are particularly fragile.

Lacking an approach to integrated resource management, planners tend to impose restrictions on direct use, e.g by closing beaches, limiting the number of visitors, or restricting access. By neglecting the indirect sources of resource degradation, however, these restrictions are partially effective at best. Moreover restricting access to the object of tourism has the dual effects of shifting tourism to other, possibly ecologically fragile, venues and of reducing overall tourism demand. The latter has the additional effect of reducing the economic tax base and rendering conservation projects even more difficult to fund. With lower conservation budgets, user restrictions tend to be used more and more as a conservation device, resulting in a vicious cycle of resource degradation and diminishing fiscal capacity.

A more promising approach to near-shore resource conservation is to consider both direct and indirect sources of ecological damage in formulating an integrated conservation strategy. In particular, reducing runoff by conserving upland watersheds can be an important component of near-shore resource conservation. In addition to protecting near-shore resources, it reduces the need for user restrictions and concomitant erosion of economic activity and fiscal capacity. Upland conservation also increases groundwater recharge thus maintaining the value of groundwater aquifers and further avoiding the drain on the economy and fiscal capacity that would accompany the required increases in water prices.

This section provides a preliminary estimate of the benefits of runoff mitigation, with particular emphasis on the enhanced value of near-shore resources. By demonstrating both the importance and the difficulty of integrated resource management, the section will also provide a prima facie basis for a broader multidisciplinary program of research to examine the detailed linkages between terrestrial and marine resources and between environmental resources and the economy.

A color illustration of the problem (see Figure 1.1 in Kaiser et al. 2005) summarizes the complexity of the problem. We superimpose the reef structure, the watersheds that begin in the Ko`olau conservation district, the island's roads and trails, and known *Miconia calvescens* plants on a landsat photo of Oahu. It is apparent that particularly in the southern portion of the district, changes in forest quality may be affecting downslope reef resources. *Miconia calvescens* is an invasive species of concern because it is believed to reduce forest cover and increase runoff and sedimentation. Roads and trails are longstanding sources of concern for increasing runoff and sedimentation in forested watersheds.

In order to value the benefit of watershed conservation on near-shore resource, we begin by establishing runoff as the linkage between forest quality and beach and reef quality. We then ascertain how forest quality affects runoff, and then explore the relationship between runoff and near-shore resources. Because none of these relationships are understood with certainty, we take several approaches to quantifying these relationships. We then use these relationships to examine two management scenarios: first, status quo management of the Ko`olaus, and second, management under a fully funded KMWPP. We obtain estimates of damages to beach values and reefs under each scenario. The difference in these will be the benefit of upland conservation on these near-shore resources.

4. Watershed Health and Runoff

4.1 Summary Results from Survey of Experts

4.1.1 Water Quality

We surveyed watershed and near-shore resource experts at length to determine the current state of the watershed and the threats it faces for the purpose of water quality. We use these results to generate the expected damages to the watershed and near-shore resources.[1]

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[1] The summarized responses can be found at <http://www.surveymonkey.com/DisplaySummary.asp?SID=445888&U=4458879871> (watershed) and <http://www.surveymonkey.com/DisplaySummary.asp?SID=445085&U=44508598595> (near-shore). The surveys themselves may be read at <http://www.surveymonkey.com/s.asp?u=48025445888> (watershed) and http://www.surveymonkey.com/s.asp?u=36101455085> (near-shore).

The near-shore resource experts were asked to indicate their opinions regarding the current state of runoff and sedimentation affecting ocean resources on the windward and leeward sides of the Ko`olaus.

There is some controversy over the connection between human interaction in the watershed and near-shore resource quality, though most respondents believe that runoff and sedimentation rates are not at their natural background levels. About one quarter of respondents feel that all watersheds are impaired with toxics and other waste products, and over 50% believe there are elevated levels of runoff and sedimentation from all areas except North, while at the same time between 5 and 25% indicate human intervention has reduced runoff and sedimentation, particularly to Kaneohe bay.

There was somewhat greater consensus about what effects runoff and sedimentation might have. Overall, natural background sedimentation was described as allowing high water quality, as were sedimentation rates below background. Sedimentation rates only 10-20% above background reduced confidence both in water quality and in the ability to determine water quality.

The forestry questionnaire also asked about the respondents' understanding of reef impacts from changes in forest quality. The forest experts were provided with a characterization of the watershed's basic connection to near-shore resources, along with some background information regarding construction of the H3 freeway and its impact (discharge, turbidity, and fecal coliform levels) on Halawa stream in the leeward Ko`olaus. This summary was given so the respondents could consider the extent to which runoff and sedimentation may change reef composition and the value of other beneficial assets.

Under the assumption of natural background sedimentation, 32% of the respondents believed that water quality would be high. Given sedimentation rates 10-20% below or 100-150% above background, 30% of respondents answered the same way, with an assumption of high water quality. However, the majority of the respondents were uncertain on each and every condition described.

Overall, there appears to be more consensus that turbidity will rise with increased sedimentation than that biological water quality will fall. Since turbidity is the biggest threat to reef corals, and there is more certainty regarding its impacts, we concentrate on establishing connections between the conservation district and sedimentation rather than between the conservation district and biological properties of water quality.

4.1.2 Reef growth

The near-shore resource experts responded to questions about reef growth, indicating that if sedimentation were at its natural background rate, 55% of the experts believe reef growth would be normal for temperature substrate, etc., and 9% say reef growth is deterred but without significant impact. If sedimentation is at rates 10-20% (100-150%) above its natural background, 14% (5%) think reef growth is normal, 27%(5%) think growth is deterred but without significant impact, 9% (36%) think growth is deterred to the detriment of fisheries, and 5% (45%) think growth is deterred to the detriment of recreation, such as diving and snorkeling. In contrast, if sedimentation rates are 10-20% (100-150%) below natural background, 41% (36%) say reef growth is normal, 5% (0%) say growth is deterred to the detriment of recreation, 9% (5%) say growth is enhance but without significant impact, 5% (18%) say growth is enhanced with gain to fisheries, and 9% (14%) say reef growth is enhanced with gains to recreation. For each alternative, an average of 28% of respondents were uncertain.

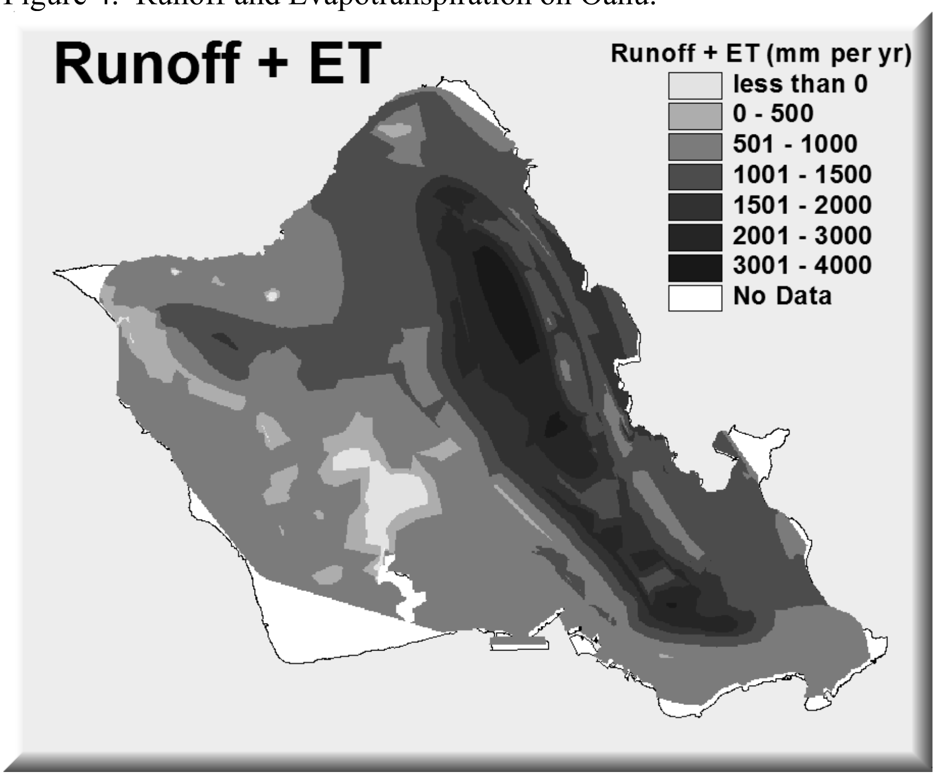
4.2 Econometric Relationships between Watershed Health on Runoff

The survey exercise above was our first approach to determining the relationship between the health of the watershed and runoff to near-shore resources. Now we attempt to determine the connection between forest quality, runoff, and sedimentation affecting the Ko`olau conservation district for ourselves. To do this, we construct raster data of land cover, soils, and relevant hydrological properties for the district and then analyze how changes in the land cover, simulating forest quality changes from invasive species or increased usage, will affect runoff and sedimentation.

4.2.1 Existing upland quality and connection to runoff

We base our understanding of water balance in Oahu on infiltration and rainfall data obtained from the University of Hawaii and the County of Honolulu respectively. Figure 4 illustrates the difference between rainfall and infiltration, which at constant soil moisture storage is the sum of runoff plus evapotranspiration. Note that negative values are possible. These reflect highly irrigated lands.

Figure 4. Runoff and Evapotranspiration on Oahu.



We regress these spatial estimates of runoff with evapotranspiration on solar radiation levels, elevation, slope, soil characteristics, and proximity to roads to determine how runoff changes with respect to these characteristics for each of the land cover types delineated by NOAA's CCAP (Coastal Change Assessment Program) project for Oahu. In this way, we interpolate water balance equations by land cover and can use these equations to predict changes in runoff from changes in land cover. Figure 7.2 in Kaiser et al. 2005 illustrates shows these land classifications. Lands in the Ko`olau Conservation District fall almost entirely into the evergreen forest classification or the scrub/shrub classification.

Table 1 provides summary cell data by select land classifications for variables affecting water balance. Each cell covers 40,000 square meters,[2] and each cell is associated with land cover data and other characteristics, including rainfall, estimated recharge (El-Kadi, 2003), soil type, roads, trails, and streams. Data not otherwise attributed is from the Hawaii Office of Planning.

Land Use and Land Cover data is taken from NOAA's Coastal Change Analysis Program (CCAP) for Oahu in 2000, which is derived from Landsat satellite imagery with 30 meter resolution. The project tracks 22 land covers, 14 of which are present on Oahu, and four of which we discuss below. Evergreen Forest and Scrub/Shrub are the current land covers in the Ko`olau Conservation district, while low and high intensity developed areas describe alternative land covers for all or parts of the area.

Evergreen forest describes areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year, and canopy is never without green foliage. Scrub/shrub describes areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This includes tree shrubs and young trees in early successional stages as well as trees stunted by environmental conditions. Low Intensity Developed land includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 21 to 49 percent of total cover. High Intensity Developed land includes highly developed areas where people reside or work in high numbers. Impervious surfaces account for 80 to 100 percent of the total cover.

Rain, recharge and runoff with evapotranspiration are measured in millimeters per year, elevation in feet, slope in degrees, and solar radiation in calories per cm^2/day. Class A soils are the most absorptive, best draining soils, and Class D are the least. Pineapples have reduced transpiration rates so an indicator variable is used for lands in pineapple cultivation. Road, trail, and stream proximity are measured by cell distances computed by Arcview's spatial analyst.

Table 1. Land Use Classification and Water Balance

	Evergreen Forest	Scrub/Shrub	Low Intensity Developed	High Intensity Developed	Cultivated Land
Rain (mm/yr)	2550 (1417)	1913 (1353)	1066 (440)	864 (293)	1041 (284)
Elevation (ft)	907 (565)	973 (668)	266 (278)	159 (175)	536 (342)
Slope	26.5 (22)	36.1 (25)	7.1 (12)	3.4 (9)	6.9 (9)
Class A Soils	0.01 (0.1)	0 (0)	0.06 (0.23)	0.04 (0.20)	0 (0)
Class B Soils	0.57 (0.49)	0.47 (0.50)	0.48 (0.50)	0.31 (0.46)	0.83 (0.38)
Class D Soils	0.42 (0.49)	0.52 (0.50)	0.34 (0.47)	0.47 (0.50)	0.09 (0.29)
Pineapple	0 (0)	0 (0)	0.04 (0.19)	0.01 (0.11)	0.34 (0.47)
Recharge (mm/yr)	1054 (857)	734 (807)	243 (282)	104 (191)	312 (289)
Proximity to Road	2833 (2001)	2242 (1717)	421 (566)	296 (396)	708 (545)

[2] Oahu is divided into a 253 by 329 grid. Grid size is determined by cell size. Each cell represents 40,000 m^2.

Proximity to trail	3249 (2575)	4889 (4445)	6154 (4074)	5925 (3593)	8512 (3047)
Proximity to stream	262 (474)	619 (1078)	970 (1347)	1256 (1388)	700 (744)
Solar radiation (cal)	366 (52)	381 (51)	419 (47)	438 (43)	423 (30)
Runoff + ET	1496 (675)	1179 (669)	823 (355)	760 (232)	729 (399)
N. Obs.	8000	15924	4013	2094	2488
Runoff + ET as % of rain	59%	62%	77%	92%	70%

4.2.2 Estimation of runoff impacts by land cover

We regress the sum of Runoff and Evapotranspiration (RunET) on land cover, elevation, slope, soil classification, solar radiation, pineapples if applicable, and proximity to roads and streams. We try two scenarios: one where the effects of the non-land cover variables are held constant across land use types, and the second where these coefficients are also allowed to vary by land cover. Results are in Table 2.

Table 2. Regression of Runoff + Evapotranspiration on Land Characteristics

Variable	I (all)	II (evergreen forest)	III (Scrub/ shrub)	IV(low intensity developed)	V (high intensity developed)	VI (cultivated land)
Elevation	0.15* (0.006)	0.44* (.01)	0.04* (0.008)	0.07* (0.02)	0.09* (0.03)	0.31* (0.03)
Slope	-3.00* (0.11)	-2.44* (0.20)	-2.63* (0.14)	-1.84* (0.38)	-1.38* (0.47)	-2.7* (0.60)
Solar Rad	-3.03* (0.06)	-2.84* (0.11)	-3.59* (0.09)	-1.50* (0.14)	-0.79* (0.16)	-2.12* (0.23)
D Soils	125* (4.6)	241* (9.4)	83* (6.7)	39* (9.4)	-4.2 (7.4)	195* (19)
Ko’olau	269.5* (6.9)	75.0* (11.7)	293.0* (10.8)	-9.7 (27)	-69 (44)	-46 (136)
Pineapple	20.8 (12.9)	43 (64)	73.5* (34.2)	-210.7* (22)	-393.8* (32.8)	28.2* (17.1)
Road	0.09* (0.002)	0.05* (0.003)	0.12* (0.003)	0.11* (0.008)	0.06* (0.009)	-0.08* (0.01)
Trail	-0.01* (0.001)	-0.03* (0.002)	-0.006* (0.0009)	0.001 (0.002)	0.00 (0.00)	0.001 (0.003)
Stream	-0.01* (0.002)	-0.01 (0.009)	-0.02* (0.003)	-0.02* (0.004)	-0.02* (0.004)	0.13* (0.008)
Evergreen	--					
Scrub/ shrub	-30* (5.5)					
Low dev	108* (8.6)					
High dev	128* (11)					
Cultivated	23* (10)					
Fogdrip	127.0* (12.03)	560.2* (26.4)	54.8* (14.7)			
East (by	2.44*	4.98*	2.30*	2.81*	2.77*	3.81*

cell)	(0.05)	(0.16)	(0.07)	(0.14)	(0.19)	(0.20)
South (by cell)	-2.58* (0.06)	-2.85* (0.12)	-2.56* (0.08)	-3.29* (0.15)	-3.43* (0.22)	-7.67* (0.19)
Const	1974.0* (28.6)	1445.2* (65.9)	2210.0* (42.6)	1471.7* (71.4)	1233.0* (87.0)	1886.2* (114)
R sq. adj.	.68	0.70	0.67	0.49	0.56	0.57
N. Obs.	32610	8000	15924	4013	2094	2488

We see from the positive, significant coefficient on elevation that rainfall, and therefore runoff, is indeed orographic. We include fogdrip, an indicator variable for cells above 615m, to account for cloud forest. Slope is surprisingly negative, though it is fairly correlated with elevation (0.48), solar radiation (-0.38), and Ko`olau (0.30) which may affect its influence. Solar radiation is negative as expected; more sunshine dries out the land. The least absorptive, Class D soils, are positive and the coefficient is sizeable and significant with the exception of when they are on high-intensity developed land. This corroborates the opinions of experts that high-intensity developed land has little recharge due to much of the surface area being impermeable (e.g. paved, roofed). The indicator variable for land in the Ko`olau conservation district is positive and significant for the land use types that have a presence there; this may be due to the higher rainfall in the area but may also stem from the correlation with slope.

Pineapple has a large significant negative effect in low and high intensity developed land but a positive and smaller effect on cultivated land. It may be that compared to irrigated sugar, pineapple's reduced transpiration does not outweigh this contribution to water balance. By increasing runoff and evapotranspiration on net, distance from a road has the opposite effect one would anticipate, though in the case of cultivated land the increased distance decreases runoff+ET. Distances from trails and streams have small, negative effects.

In the regression holding the impacts of other variables constant, we see that compared to evergreen forest, scrub/shrub appears to have slightly lower runoff, while cultivated land, low intensity developed, and high intensity developed have increasingly higher runoff respectively. These results are expected from the raw percentages of runoff+ET calculated in Table 1 with the exception of scrub/shrub, which has a slightly higher runoff percentage (62%) than evergreen forest (59%). In the individual regressions, scrub/shrub also has a much higher constant value, though certainly for elevations above 615m the gap is significantly smaller. Elevation itself seems to matter much less and solar radiation considerably more for scrub/shrub.

4.2.3 Predicted changes in runoff if land cover changes

The table below shows how runoff and evapotranspiration would change if existing land use/land cover changed to another land use/land cover.

Table 3. Predicted Runoff + ET from land cover change

	Predictions			
coeff:	means			
	evergreen	scrub/shrub	low intensity developed	high intensity developed
evergreen	62.6	64.3	76.8	82.7
scrub/shrub	65.4	68.1	80.6	86.4
low intensity developed	66.8	59.8	79.4	86.3
high intensity developed	59.4	56.8	80.5	89.9

Figures in the table represent the proportions of precipitation that are estimated in regression analysis as runoff or evapotranspiration in the water balance under a given land cover for an area that has the characteristics in terms of elevation, slope, east and north positions, soil hydrology properties, pineapple plantings, distance to road, distance to trail, distance to stream, solar radiation, Ko`olau conservation status, and fog drip potential of existing land uses. Thus, the diagonal shows the estimated current level of runoff+ET from each land cover.

Means for each land cover category are used to generate estimated runoff+ET using coefficients from each regression. Predicted runoff+ET are about 3% higher than means from the raw data. Evergreen forest has lowest predicted runoff-ET (62.6%) and High Intensity Developed has highest (89.9%). Predictions match average data fairly well (see table 7.1). Evergreen forest accounts for about 1/3 of Ko`olaus, with scrub/shrub as 2/3. Transforming Ko`olaus into low intensity developed would increase runoff+ET by about 15%. The potential expanse of such a change is shown in Figures 7.3 and 7.5 in Kaiser et al. 2005.

Figure 7.5 in the report shows transformation of the Ko`olaus from currently forested conditions to low-intensity developed. Forest quality deterioration is likely to mimic effects of impervious surfaces from pig damages that compact soils, canopy reductions that increase erosion and runoff, or urban development and other human access. While this figure shows total transformation of the formerly forested area, each GIS grid cell can be treated individually in analysis if desired.

5. Runoff and Near-shore Resources

5.1 Marine Pollution Due to Runoff from Conservation District

Marine Pollution in the form of suspended sediments and associated particulate nutrients in Oahu's waters arrive mainly through storm events (Hoover, 2002). Hoover has studied storm runoff at sites on Oahu that have conservation land use and compared them to those that have agricultural and urban land uses as well. Using only a few sites, he has insufficient data to identify quantitatively land use impacts, and attributes control of specific discharge to rainfall, while noting that at one site at least (Opaeula) discharge is much lower than would be expected if rainfall were the dominant factor at the site. Table 4 summarizes for the four main sites. Figure 4.1 in Kaiser et al. 2005 shows how the four sites differ significantly in characteristics other than land use. Kahana, while conservation land, is quite steep, while Opaeula (in the Paukauila system) is much longer and passes through a long flat portion of agricultural land. Heeia and Kaneohe offer the most similar geophysical properties and differences between those two areas might suggest more clearly the role of urbanization separate from other factors.

Table 4. Discharge from Hawaiian Streams (Hoover, 2002)

Site	Con-servation % total	Agri-cultural % of total	Urban % of total	Runoff % of rainfall	Base water dis-charge % total	Storm water dis-charge % total	Base suspended sediment discharge, % of total	Storm suspended sediment discharge, % of total
Kahana	100	0	0	76	65	35	1.4	99
Heeia	100	0	0	40	90	9.6	7.8	92
Opaeula	56	44	0.2	31 (upper watershed)	43	57	3.6	97
Kaneohe	84	0	16	41	84	16	32	68

We see that Heeia has more of its sediments discharged during storms than Kaneohe, and slightly less of its water discharge.

Hoover's analysis also provides regression parameters for annual specific sediment yields from the study sites. Though the relationships between yield and runoff are quite different at each site, exponential functions fit the data fairly well for each watershed. Table 5 shows the regression results from Hoover (2002) for the equation $Yield=A*Runoff^{B}$. Yield is measured in kg/ha/yr while Runoff is in cm/yr.

Table 5. Sediment Yield Related to Runoff in Hawaiian Streams

Site	A	B	R-sq	Yield (kg/ha/cm)
Kahana	$6.3*10^{-6}$	3.4	.97	4.1
Heeia	$5.1*10^{-5}$	3.8	.72	43
Opaeula	2.3	1.5	.84	10
Kaneohe	$5.5*10^{-2}$	2.0	.60	8.3

There are no clear trends associated with land use, though it is possible that greater conservation land increases the curvature of the relationship between yield and runoff, especially considering that Heeia's geophysical properties resemble Kaneohe's more than Kahana's though the estimated parameters are closer to Kahana's.

There is evidence of a relationship between land use and the types of nutrients contained in the sediments. Conservation land sites (Kanana and Heeia) exhibit low, constant values for dissolved nitrogen and phosphorus during low-flow conditions (Hoover, 2002: 175), but low-flow concentrations are more variable and higher for the agricultural and urban sites. The agricultural sites have the greater variability. Particulate organic nitrogen and particulate organic carbon appear to be comparatively depleted and less variable at urban sites and urban site sediments contain more non-soil detritus both from urbanization and because increased channelization increases the transport of sediments in general. Urban sites also have elevated particulate inorganic phosphorus, though the reason is unclear. Phosphate (PO4) levels are significantly elevated for urban areas, particularly in storm periods and compared to global figures on similar watersheds. (Hoover, 2002: 185). There are elevated levels of nitrate (NO3) and ammonia (NH3) in agricultural base flows and urban storm flows.

Hoover does not track the contaminants in runoff that generate beach closures (fecal coliform, e. coli) or those that Hawaii is considering using as alternate mechanisms (described below). We use USGS data from 1988 to 1998 for Kaneohe to test for a relationship between fecal coliform (col/100ml) and discharge (cfs). Observations were taken on 34 occasions between Dec.1988 and Feb. 1998. Fecal coliform levels ranged from a low of 870 col/100 ml (Sept 1989) to a high of 20,000 col/100 ml reached in both Dec. 1991 and Feb. 1995. Discharges on these dates were 17 cfs, 19 cfs, and 25 cfs respectively, while the low discharge was 8 cfs in Oct. 96 (fec. col. 5200 col/100 ml) and the high was 44 cfs in Apr. 89 (fec. col. 5400). The correlation between fecal coliform and discharge is 0.25. Regression analysis using several different functional forms and attempting to account for seasonal or annual fluctuations failed to illuminate a highly significant relationship between fecal coliform levels and discharge. Results are shown in table 6.

Table 6.Influence of discharge on fecal coliform levels, Kaneohe Bay
Dependent variable = ln(fecal coliform), std. errors in parentheses.

Variable	I	II	III	IV	V

ln(discharge)	0.48 (0.33)	0.51 (0.32)	0.49 (0.33)	0.50 (0.33)	0.52 (0.33)
Time of day		-0.001 (0.0009)			-0.001 (0.001)
Month			0.013 (0.04)		
Summer dummy				0.12 (0.32)	0.13 (0.32)
Constant	6.68* (0.88)	7.89* (1.32)	6.58* (0.94)	6.61* (0.91)	7.81* (1.35)
Nobs	34	34	34	34	34
Adj. R-sq.	0.03	0.05	0.01	0.01	

Though coefficients are only significant for the constant, they are stable across regressions, with a 1% increase in discharge increasing fecal coliform by 0.5%. Thus, for expositional purposes, and until better scientific data is available, we will assume that if discharge increases 15% from forest quality deterioration that fecal coliform levels and related beach closures will increase 7.5%.

5.2 Beach closure conditions

Beach closures for health standards are determined by the HI State Department of Health (DOH) based on Environmental Protection Agency (EPA) guidelines. For the state of Hawaii, waters within 1000 feet of shore must meet a standard where the geometric mean of enterococcus counts is less than or equal to 7 colonies per 100 ml. The DOH has added an additional test for *Clostridia perfringens*, which must have a median value less than or equal to 5, in an attempt to more closely monitor sewage concerns. Humid tropical soils are capable of supporting enterococcus, E. coli, and fecal coliform bacteria without sewage and the viruses these bacteria generally indicate. Under these conditions, a correlation between enterococcus levels and swimming related illnesses has not been established for Hawaii, though the 7 colonies/100 ml standard was set based on temperate climate studies that suggested this figure corresponded to 10 mild illnesses for every 1000 bathers.

Hawaii's tropical climate fosters the production of other water-borne illnesses that are not tested for and therefore will not induce beach closures. These include approximately half of the 100-200 cases of leptospirosis in the United States each year. Leptospirosis is particularly of concern in any discussion of tropical watershed because it is transmitted to humans through freshwater and mud containing urine of animals carrying the bacteria. *Staphylococcus aureus* is another concern for Hawaii, as it appears to survive in soils and salt water and is increased with the presence of swimmers.

Beach days lost to runoff are therefore an underestimate of the actual water quality problems in Hawaii stemming from watershed forest quality. Beach closures and warnings are relatively rare on Oahu. From 1994 to 2005, individual beaches have been posted as closed or with warnings a total of 414 days in (DOH, 2004; DOH, 2006). Of these a total of 225 days of closures were attributed directly to heavy rains causing the sewage system to overflow. Thus 54% of beach days lost in the past decade or so have been attributed to heavy rains. Using daily average attendance at the beaches affected, there were approximately 266,000 lost beach days for individuals at these beaches over the period (HI Databook, 1999; HI Databook, 2004), from a total of approximately 205 million beach days (46,423 beach goers per day) taken by tourists averaging 110,845 per day and residents numbering approximately 1,437,000 total. If we consider 82% of beach days taken by tourists and 18% by residents, tourists account for 38,067 beach visits per day and residents for 8,356 visits per day. Average visits per year per resident are then estimated to be 2.12 days and average visits per year per tourist are estimated to be 0.47. If 0.13% of these days are currently lost to runoff related beach values, we generate an estimate of current damages in lost economic value (using the Bell and Leeworthy demand curves detailed in Kaiser et al., 2005) equal to per person losses of $0.02 per tourist and $0.07 per resident, for estimated total damages of $207,800.

The current health of the Ko`olaus, for the purpose of beach quality, appears healthy in as much as we can measure beach quality by beach closures. However, the period of 1994-2003 exhibited very low annual precipitation levels, with annual precipitation averaging 27% below longer run levels (Hawaii Data Book, 2003). Heavy rains play an increasing and much more significant role in beach postings from 2004 forward, and have clearly demonstrated that the sewer capacity is currently inadequate to handle higher than average rainfall. Rainfall in 2004 was almost double the long run average (as measured at Honolulu International Airport). There were 75 beach closure postings, 64 of which were attributed to heavy rains. In 2005, there were 143 beach postings, all of which were attributed to heavy rains (DOH, 2006).

Between February and March of 2006, the island of Oahu experienced 44 consecutive days of heavy rain. State agencies blame this extraordinary amount of rainfall for causing the state's largest sewage spill on March 24, 2006. More than 48 million gallons of untreated sewage flowed into the ocean forcing Honolulu city officials to post signs warning tourists on Waikiki Beach to stay out of the water. The spill was significant in that it was the first time in history Hawaii Department of Health closed this valuable the state's most valuable tourist destination due to contaminated water. DOH closed significant portions of Waikiki Beach for approximately 12 days[3], for a loss of over 330,000 beach days, and warning signs were posted at other beaches around the state for over two months.

5.3 Lost value to beaches from change

If runoff were to increase 15%, we would expect to see an increase in beach closures as more sediments and associated pathogens are washed to the shore. As discussed above, we estimate that a 15% increase in runoff would generate an expected 7.5% increase in beach closures due to fecal coliform increases. The relatively low damages described in section 5.2 ($207,800 total) increase to $0.07 per tourist and $0.14 per resident from an immediate 7.5% decrease in beach days, for a total of $679,000 in damages though lost economic value expected per year ($472,000 tourist/$207,000 resident). These sums clearly demonstrate a direct connection between forest quality and water quality. The more likely case where degradation occurs more slowly over 20 years is discussed below, as is the effect of proposed mitigating activities.

5.4 Lost value to reefs from change

Using Hoover's estimates in conjunction with Cesar's presentation of the relationship between sedimentation and coral cover, we find that a 15% increase in runoff is likely to have only a negligible impact on coral cover regardless of the characteristics of the watershed. For each of three watersheds in Hoover's (2002) study, we calculate that daily sedimentation rates

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[3] Several health-related damages can likely be attributed to the sewage spill, although we do not do so here. There were at least three severe incidences (one resulting in loss of life) that have been blamed on bacteria in the water. Signs were not posted at these beaches until 5 days after the spill.

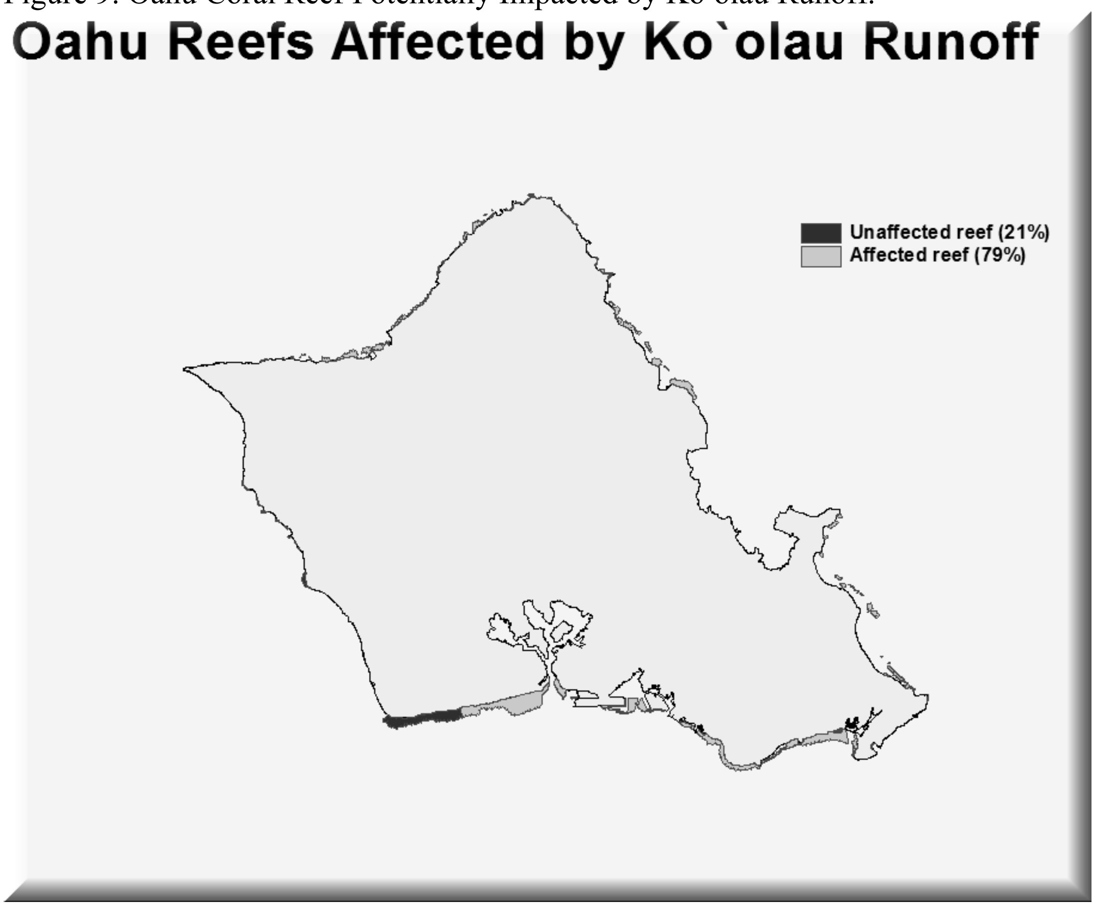
are quite low and that a 15% increase in runoff will lead to increases in sedimentation but they will not impact coral cover. Table 7 summarizes.

Table 7: Change in coral cover from change in runoff and sedimentation rate

	Kahana	Heeia	Kaneohe
Sedimentation rate (mg/cm2/day)	0.070	0.037	0.063
Sedimentation with 15% increase in runoff	0.111	0.056	0.073
Percent coral cover	23.786	23.796	23.788
Percent coral cover, 15% increase in runoff	23.773	23.790	23.785

If these three sites are a reasonable average of the variety of conditions on Oahu, we see that coral cover might only decline 0.007%. If this were the loss of coral cover for the entire island of Oahu, with 504 square kilometers of reef, the loss would be worth a minimum of $105,840 per year (at $0.03 per square meter), and a maximum of $331.3 million (at $93.91 per square meter). Since runoff from the Ko`olaus does not reach all shores, we calculate the percentage of reef that may be impacted by streams and runoff from the Ko`olaus.

Figure 9. Oahu Coral Reef Potentially Impacted by Ko`olau Runoff.



We predict that 79% of Oahu's reefs, or 398.16 square kilometers, are positioned so that runoff from the Ko`olaus affects them (see figure 9). The change in consumer surplus generated by the damages to this reef from a one percent increase in runoff (in its current state) from Oahu to the state of Hawaii is calculated to be between $26,200 and $32,000 per year. An instantaneous fifteen percent increase in runoff would generate $393,000 dollars per year in damages. This figure will increase if reefs are deteriorating across time.

6. Likelihood of Forest Damages

6.1 Threats to Watershed Health

The forest canopy and the forest understory are believed to play different ecological roles in the tropical forested watershed. Loss of understory is expected to be particularly worrisome with respect to near-shore resources as the bare soil will lead to increased erosion and sedimentation of streams and near-shore resources. Loss of canopy is more likely to affect long term groundwater recharge and also to reduce the efficiency of the forest's role in mitigating the speed with which runoff occurs. The two forest levels are treated separately in our discussion. Discussions with experts led us to ask specifically about the following threats to forest quality:

1. Feral pigs
2. Other feral animals
3. Invasive Plants
4. Miconia calvescens, a specific invasive plant
5. Vehicular (ATV or 4X4) access
6. Fire.

These categories then became the focus of survey questions of a broader set of experts, discussed below.

Feral pigs are separated from other feral animals because there is a known and active feral pig population in the district that creates benefits for hunters as well as costs to the ecosystem. Other feral animals have less expected direct benefit and policy implications may differ due to these differences.

Miconia calvescens is separated from other invasive plants because it is credited with the ability to change watershed characteristics due to its particular biological properties, whereas other invasive plants may simply change the forest from one shade of green to another.

Motorized vehicle recreation can be a significant source of damage in the watershed, causing erosion and facilitating the colonization of weeds by exposing bare soil. Trail use is another concern since humans can damage vegetation directly through trampling, and indirectly by providing the ignition source for fire or introducing weeds. Humans can also increase the likelihood of plant pest introductions, and have been implicated as a major culprit in the spread of such major pests as *Clidemia hirta*. In terms of volume, hiking is the highest impact human activity in the conservation district and has the potential to be detrimental. The close proximity of the Ko`olau Mountains to Waikiki allows many of the trails within the watershed area to be readily accessed, subjecting them to high visitor loads.

Fires result in the removal of vegetation cover, loss of the soil-anchor attribute of root masses, and exposure of bare mineral soil (KWPMP 2002). This combination subjects burned areas to high levels of erosion. A large fire may also reduce evapotranspiration and significantly increase runoff. Additionally, heat levels can reduce permeability of soils and reduce recharge levels.

6.2 Results of survey of watershed experts

In our survey of forested watershed experts, we requested the experts evaluate the level of seriousness of the specific threats described above.

Tables 8-11 show the distribution of responses to the question of how serious the forested watershed experts believe each of seven threats, identified as possible issues for the Ko`olaus, are to the forest quality. Since threats are expected to be incremental and slow, the scale for choices is non-linear.

Table 8. Feral Pigs and Other Feral Animals

	Feral Pigs		Other feral animals	
Response	Threat to Canopy	Threat to Understory	Threat to Canopy	Threat to Understory
Not a serious threat (0-5% chance of quality degradation)	0.00	0.00	5.41	5.41
Not Serious (5-10%)	8.11	2.70	8.11	2.70
Mild Threat (10-20%)	13.51	0.00	8.11	8.11
Mild-Moderate threat (20-50%)	13.51	2.70	27.03	8.11
Moderate-serious threat (50-80%)	24.32	13.51	27.03	43.24
Serious threat (80-100%)	29.73	72.97	5.41	16.22
I don't know enough to answer	10.81	8.11	16.22	16.22
Left Blank	0.00	0.00	2.70	0.00
Num. Answering question	37	37	36	37

Table 9. Miconia and other invasive plants

	Miconia		Invasive Plants	
Response	Threat to Canopy	Threat to Understory	Threat to Canopy	Threat to Understory
Not a serious threat (0-5% chance of quality degradation)	0.00	0.00	0.00	0.00
Not Serious (5-10%)	5.41	0.00	2.70	0.00
Mild Threat (10-20%)	5.41	2.70	8.11	2.70
Mild-Moderate threat (20-50%)	5.41	5.41	8.11	2.70
Moderate-serious threat (50-80%)	21.62	13.51	32.43	21.62
Serious threat (80-100%)	45.95	70.27	40.54	64.86
I don't know enough to answer	10.81	8.11	8.11	8.11
Left Blank	5.41	0.00	0.00	0.00
Num. Answering Question	35	37	37	37

Table 10. Vehicular and trail access

	Vehicular Access		Trail Access	
Response	Threat to Canopy	Threat to Understory	Threat to Canopy	Threat to Understory
Not a serious threat (0-5% chance of quality degradation)	5.41	5.41	10.81	10.81
Not Serious (5-10%)	16.22	10.81	32.43	24.32
Mild Threat (10-20%)	18.92	13.51	27.03	32.43
Mild-Moderate threat (20-50%)	21.62	21.62	13.51	13.51
Moderate-serious threat (50-80%)	8.11	13.51	2.70	8.11
Serious threat (80-100%)	10.81	18.92	2.70	0.00
I don't know enough to answer	18.92	13.51	10.81	10.81
Left Blank	0.00	2.70	0.00	0.00
Num. Answering Question	37	36	37	37

Table 11. Fire

	Fire	
Response	Threat to Canopy	Threat to Understory
Not a serious threat (0-5% chance of quality degradation)	2.70	2.70
Not Serious (5-10%)	16.22	18.92
Mild Threat (10-20%)	21.62	10.81
Mild-Moderate threat (20-50%)	18.92	18.92
Moderate-serious threat (50-80%)	13.51	16.22
Serious threat (80-100%)	16.22	21.62
I don't know enough to answer	10.81	10.81
Left Blank	0.00	0.00
Num. Answering Question	37	37

From our results, it appears that most experts feel Miconia and invasive plants pose a most serious threat to the canopy forest cover (46% and 41% agreement, respectively). Feral pigs are another concern in reducing canopy forest cover, as 24% of respondents said they poses a moderate to serious threat, and 30% said they pose a serious threat. The respondents also classified fire as an intermediate level threat to the forest canopy, with 16% calling it serious, 14% calling it moderate to serious, 19% labeling it as mild to moderate, and 22% calling it mild to moderate. Of lesser concern to the canopy is vehicular access, other feral animals, and trail access (in decreasing order).

With respect to the understory forest cover, experts indicated feral pigs and then Miconia have the highest threat levels and both were identified by a significant majority as serious threats (73% and 70% agreement, respectively). Invasive plants in general were another serious concern to the understory, with 65% of respondents classifying this threat as serious. Similar to the canopy question, fire was identified as an intermediate threat, with vehicular access, other feral animals, and trail access again of much smaller concern.

6.3 Status quo conservation level impacts

The survey results indicate that without mitigation there is an expected range of 38% to 71.5% deterioration in overall forest quality. We consider a 38% quality deterioration to be approximated by a land use change from forested watershed to low intensity development as this is roughly equivalent to the impermeable cover in such land use. Similarly, we consider a 71.5% deterioration to be approximated by a mix of 1/2 low intensity development and 1/2 high intensity development. Thus, the increase in runoff under the status quo over the next 20 years is estimated at between 15% and 18%, for an annualized rate of deterioration of between 0.852% and 1.04%.

6.4 Expected outcomes of increased conservation

The survey also asked about the impacts of mitigation under an evolving watershed management plan currently under the auspices of the Ko'olau Mountain Watershed Partnership and supervised by the Department of Land and Natural Resources. [4]We find that full implementation of the actions in the watershed management plan should decrease the likelihood

[4] The plan is available online at http://www.state.hi.us/dlnr/dofaw/wmp/koolau/KMWPMP.PDF

of quality deterioration in the Ko`olaus by an expected 72%. We calculate this figure in a multi-step process delineated below:

1. Create weighted averages of expected damages to canopy and understory for each threat (including a minimum threat using the bottom range of damages and a maximum threat using the top range);
2. Create weighted average of expected damages to canopy and understory for each threat for each of 14 conservation actions that are outlined in the Ko`olau Watershed Partnership Management Plan;
3. Calculate differences between mitigated and unmitigated expected damages for canopy and understory, generating an average difference for the minimum and the maximum damages for each mitigation action and each threat;
4. Calculate cumulative reduction in threats from implemented actions for each threat;
5. Average cumulative reduction in threats across threats.

Details of the calculations may be found in Kaiser et al. (2005). The resulting reductions in expected damages are shown in Table 12.

Table 12. Cumulative Reduction in Threats by Threat

Threat	Remaining threat to canopy after mitigation	Remaining threat to understory after mitigation
Feral Pigs	21%	6%
Other Feral Animals	34%	32%
Miconia calvescens	5%	3%
Invasive Plants in General	3%	1%
Vehicular Access	29%	20%
Trail Access	77%	77%
Fire	45%	39%
Average	31%	25%

Thus the expected deterioration in forest quality with conservation will only range from 11% to 20% on average. This is estimated to be similar to a shift to 1/4 to 1/2 low intensity developed land, and thus an increase in runoff of 3.75% to 7.5% over twenty years, or an annualized deterioration of 0.201% to 0.41%.

7. The Value of Integrated Resource Management

Using runoff as the connecting ecological factor between beach values, reef values, and forest quality, we determine the expected benefits of forest conservation to near-shore resources under the status quo level of conservation (expenditures of approximately $300,000 per year) as well as under a scenario in which the Ko`olau Mountain Watershed Partnership Plan is fully funded with approximately $3 million to spend each year for 5 years followed by $375,000 per year in maintenance expenditures. Under the current conditions, we predict an annualized deterioration in forest quality that leads to an increase of runoff of 0.852% and 1.04%, while the increased spending is expected to reduce this deterioration to an annualized rate of between 0.201% and 0.41%.

Demand for beach days is estimated separately for tourists and residents, with status quo levels of demand at approximately 2.12 resident days per year and 0.47 tourist days per year. We estimate that a one percent increase in runoff increases fecal coliform bacteria counts by 0.5% and will increase beach closure days similarly, given the extremely low threshold for acceptable levels of bacteria in Hawaii's waters and the relatively rare number of beach closures that occur. Without conservation, the expected 15% increase in runoff would generate an expected 7.5% increase in beach closures due to fecal coliform increases.

Measuring the loss in economic value from closed beaches may be considered akin to measuring the burden of a tax where there are no revenues to the tax-assessing agency. We calculate that damages to lost beach days will have a present value of between $12.5 million and $15 million with no mitigation, and between $3.1 million and $6.3 million with conservation activities. The expected net benefit of mitigation is between $6.2 million and $11.9 million using a 1% discount rate over 20 years with mitigating activities.

Savings from mitigating activities under this assumption are between $9.1 million and $17.9 million, about 33% higher than using the marginal user's losses. This higher loss may more accurately reflect the opportunity cost of beach closures that affect the average beach user. Additionally, since 2004 and a return to average rainfall patterns after a decade of drought, beach closures have increased dramatically after heavy rains, and further increases in damages appear imminent. Thus we expect damages to be increasing.

Demand for healthy reef is estimated per square meter and is based on amenity values, recreational values, and fisheries values. We estimate that a 1% increase in runoff will decrease coral cover by only 0.00047%. We estimate that approximately 79% of the 504 square kilometers of reef surrounding Oahu will be impacted by the increase in runoff from the Ko`olaus, and that 8% of reefs lie below predominantly upslope conservation land. Minimum damages from decreased coral cover associated with a 15% increase in runoff range from $393,000 to $1.156 million per year.

If the degradation takes place over 20 years, using 1% discount rates, the minimum damages without mitigation are estimated to have a present value between $478,000 and $583,000 using the values generated by the estimation of coral cover loss due to sedimentation increases. Mitigation decreases these damages to between $113,000 and $230,000 in present value. The savings from mitigation are thus between $240,000 and $470,000 in present value.

Using the values generated by the estimate of coral cover loss due to a change in the upland conservation district, we assume that 225,800 square meters of reef are lost over 20 years at an even rate of degradation of 11,290 square meters per year. The damages without mitigation are estimated to have a present value over 20 years (1% discount rate) of $3,384,000, while successful mitigation will leave the district intact and damages are estimated at zero. This more blunt estimation provides an upper bound for the expected damages as well as savings from mitigation efforts.

The present value of mitigation costs is estimated at $14.9 million above current expenditures over 20 years at a 1% discount rate. The present value of damages with no mitigation is estimated at between $13.0 million and $25.4 million, while the present value of damages with mitigation is estimated at between $3.4 million and $8.8 million. Thus, mitigation expenditures should reduce the present value of damages by between $4.2 million and $22.0 million.

Though it is therefore questionable as to whether the benefit-cost ratio would be greater than one for conservation costs versus near-shore benefits, two important points should be apparent. First, there are near-shore damages occurring due to upslope changes, and these damages are expected by forest and water quality experts to increase over the next 20 years. Second, upslope conservation activities will decrease the probability of damages significantly over this time period, in addition to other benefits they convey directly to forest quality. These benefits should be included in any decision-making for forest conservation expenditures.

8. The Value of Improved Pricing Policy

8.1 The value of price reform

Watershed degradation can lead to reduced recharge of groundwater aquifers (Doolette and Magrath, 1990; Mackay and Band, 1997). Conservation of watersheds can help to preserve the groundwater supplies by avoiding this loss of recharge (Kaiser and Roumasset, 2002). But if groundwater is being misallocated due to under-pricing, the benefits of watershed conservation will be diminished. In effect, the water saved by one program would be wasted by another. One example of groundwater waste is the current policy on Oahu of pricing water at average extraction and distribution costs, resulting in under-pricing and excessive consumption. In contrast, efficient water allocation requires full marginal cost pricing, i.e., charging marginal instead of average extraction costs, charging the actual distribution costs, and charging the opportunity costs of resource drawdown, including the higher extraction costs that drawdown implies (see e.g., Koundouri, 2004, for a recent survey; also see Nieswiadomy, 1985; Agthe et al., 2003; Howe, 2005).

Correcting overuse through pricing reform can provide substantial welfare gains (see e.g. Noel et al., 1980; Feinerman and Knapp, 1983), and make watershed conservation more beneficial. Without watershed conservation, changing from the status quo pricing mechanism to the efficient mechanism should generate up to $877.8 m in present value savings. However, proposals to induce efficient use through pricing reforms often are found to be politically infeasible (Dinar and Wolf, 1997; Postel, 1999; Johansson, 2000). This may lead policy-makers to consider watershed conservation as an alternative to price reform.

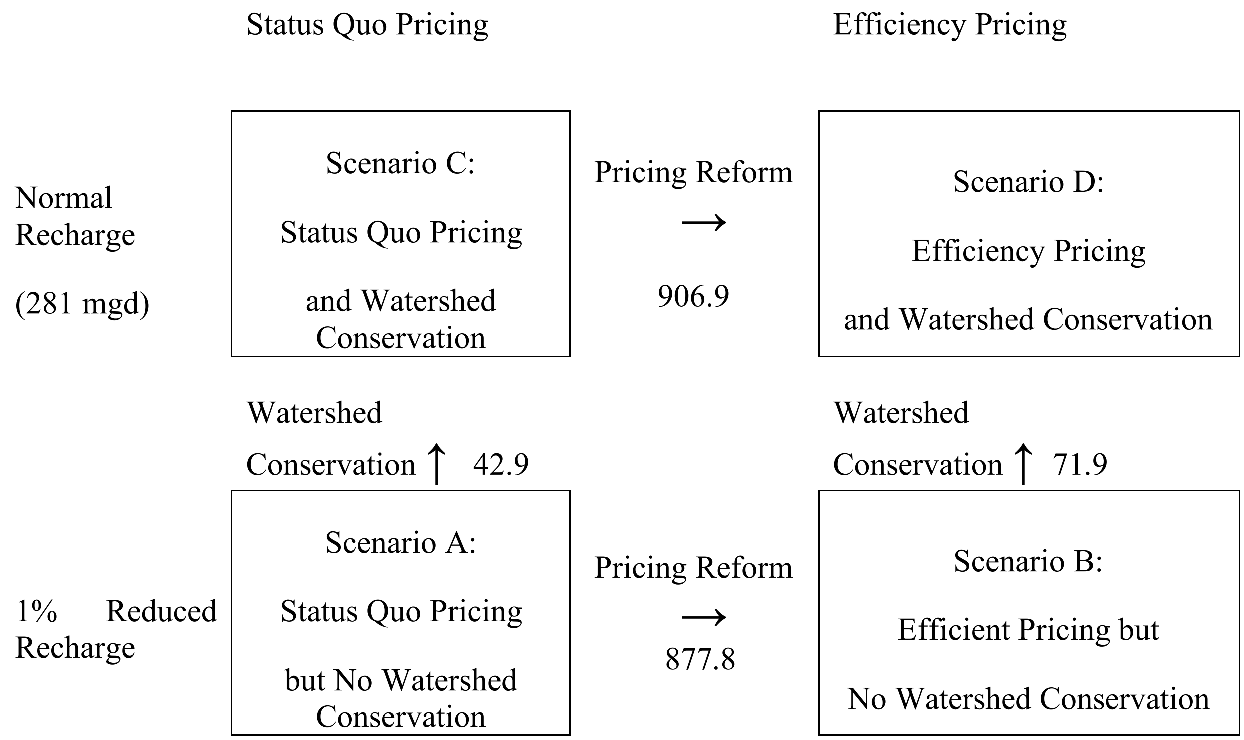
8.2 Combining Pricing Reform and Watershed Conservation

In order to evaluate the available policy choices, Pitafi and Roumasset (2006) compare watershed conservation versus pricing-reform and compare doing either of the options alone versus both reforms together. They also analyze the case of immediate watershed conservation combined with delayed pricing reform versus the case of taking both measures immediately. The analysis is conducted using the Pearl Harbor aquifer on the island of Oahu in Hawaii. They model two pricing scenarios: efficiency and status quo pricing, and three watershed conservation scenarios: no conservation, conservation that prevents a 1 % loss of recharge, and conservation that prevents a 10 % loss of recharge.

Figure 9 summarizes their welfare estimates under four different scenarios. In scenario A, status quo pricing is continued and lack of watershed conservation causes a 1% recharge loss. (In reality, the loss may be greater or smaller, may occur in the future rather than immediately, and/or may happen once or multiple times. Here, the assumption is that the net effect of all the losses from lack of watershed conservation is equal to that of one percent immediate loss of recharge. Analysis with 10% loss is also reported later in this section.) In scenario B, efficient pricing is undertaken but again lack of watershed conservation causes a 1% recharge loss. In scenario C, status quo pricing is continued but watershed conservation prevents recharge loss. In scenario D, efficient pricing is undertaken and again watershed conservation prevents recharge loss. Starting from scenario A, the gains from pricing reform (moving to scenario B) are about

$878 million. In comparison, the gains from watershed conservation (moving to scenario C) are about $43 million.

Figure 9: Present Value of Welfare Gain ($ million) from Pricing Reform and Watershed Conservation (Preventing Loss of 1% Recharge)



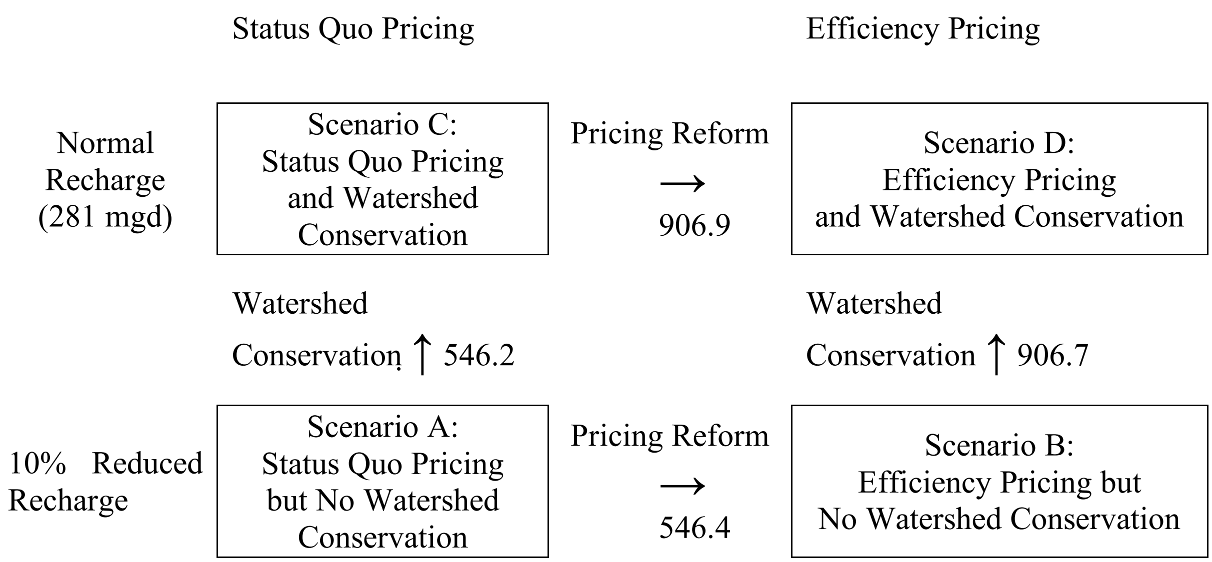
In addition, since status quo pricing involves over-use and wastage, a unit of recharge is more valuable at efficient prices than at status quo prices. To see this, note that if we are in scenario A, and move to scenario C (adopt watershed conservation that prevents the loss of recharge), the welfare gain is about $43 million. Instead, if we are in scenario B, and move to scenario D (adopt watershed conservation), the welfare gain is about $72 million. Watershed conservation is, therefore, more valuable under efficient pricing than under the status quo pricing.

If the present value of conservation costs is greater than $43 million, but less than $72 million, then conservation would be warranted if and only if pricing reform is done first. This may indeed be the case. The costs of watershed conservation, which would prevent potential damages, are particularly difficult to estimates due to the stochastic nature of watershed damage and uncertainty about the effectiveness of different levels conservation efforts. However, in a recent survey (Kaiser, 2004) of conservation experts in Hawaii discussed above, experts indicated that conservation expenditures of $3 million/year for five years followed by continuing annual expenditures of $300,000/year would be needed to avoid deterioration of the Ko`olau watershed that recharges the Pearl Harbor aquifer. The present value of these expenditures is $43.2 million, at 1% discount rate.

The difference between the benefits of pricing reform and watershed conservation depends on the amount of recharge loss that is being prevented by watershed conservation. Figure 10 examines the welfare effects if lack of watershed conservation would cause a 10 %

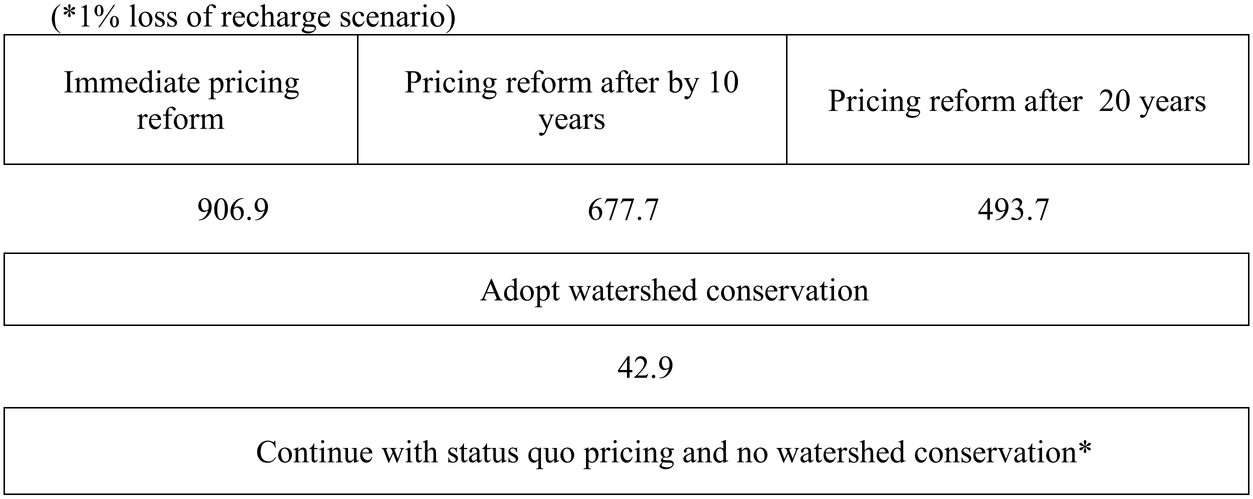
loss of recharge. Once again, watershed conservation undertaken after pricing reform is more valuable than before the reform.

Figure 10: Present Value of Welfare Gain ($ million) from Pricing Reform and Watershed Conservation (Preventing Loss of 10% Recharge)



However, this time, the gain from pricing reform alone (B – A) is almost the same as the gain from watershed conservation (C – A). This is because watershed conservation is now providing a bigger service (preventing a 10% recharge loss). For even larger recharge losses prevented, gains from watershed conservation will be higher than the gains from pricing reform.

Figure 11: Welfare gains from water management reforms ($ million)
(*1% loss of recharge scenario)



Finally, delay in adopting pricing reform can substantially affect the resulting gains as shown in Figure 11.

Thus, welfare gains from watershed conservation are small compared with those from pricing reform unless the recharge benefits of watershed conservation are particularly large. The benefits of conservation increase substantially in the presence of price reform. A conservation project that has positive net benefits at corrected prices may have benefits less than costs if price reform is not concurrently implemented. Relatedly, if watershed conservation is adopted and leads to delays in adopting pricing reform, substantial potential gains are lost.

9. Concluding Remarks

The economic value derived from watershed conservation is a highly variable composite of economic, political, geophysical, and biological or ecological factors. We examine the interlinked ecological services provided by the forested watershed encompassing the Ko`olau mountains on the island of Oahu, Hawaii, to provide a framework for estimating this composite value. Efficient pricing acts to prolong the life of the resource by incorporating the dynamic scarcity of the asset and extends any benefits accrued from conservation activities.

Beyond improved pricing, watershed conservation involving mitigation of long term threats has direct and indirect economic benefits. In particular, expenditures on watershed conservation that increase groundwater recharge will also protect downstream resources from damages due to sedimentation and runoff. Restricting activities, e.g. through beach closures, may mitigate damages but will impose unnecessary costs rather than provide long-term improvements in resource quality.

Forested watersheds like those of the Ko`olau mountains produce a host of valuable ecological services that range from groundwater quantity and surface water quality to maintenance of biodiversity and recreational beach use. The more intensely the resources are used, the more valuable conservation becomes. This is due both to the direct demand for the ecological services and to the increased risk of losing the asset's productivity through inefficient, myopic, use.

The anticipated cost of watershed conservation in the Ko`olaus into the indefinite future has a present value of $43.2 million using a discount rate of 1%. The benefits of watershed conservation stemming from groundwater recharge alone vary widely depending on the assessment of increased recharge but may be more than $900 million provided that conservation is accompanied by pricing reform. Benefits to near-shore resources (beach closures and reef sedimentation) range from $4.2 m to $22.0 m, even before accounting for disasters such as the recent sewage spill into the Ala Wai Canal. Though extremely difficult to measure as a function of conservation plans targeted toward watershed conservation rather than species and biodiversity preservation, benefits will accrue in these categories as well and may be worth billions of dollars. This is particularly likely in the Ko'olaus because two of the largest watershed threats, feral ungulates and invasive plants, are also the greatest threats to biodiversity, and because Hawaii is home to so many endemic species.

To justify watershed protection in this case, we need not quantify their benefits thoroughly, because the direct economic benefits delineated above are well above the costs. Such win-win scenarios are expected to be more common in natural resource conservation than in other economic cases for two important reasons. First, since much natural resource use has evolved from open access exploitation, improved policy mechanisms for use, particularly using pricing that accurately reflects the costs borne by both present and future users, can greatly extend the benefits through time of the resources. Second, since ecological services provided by natural resource assets often are integrated across end uses, activities that enhance the capital stock for the purpose of improving one set of ecological services may jointly provide enhancement of additional sets of ecological services valued by other users.

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