WATER MANAGEMENT AND THE VALUATION OF INDIRECT ENVIRONMENTAL SERVICES

by

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Abstract

Comprehensive water basin and watershed planning and management require valuation of the intermediate ecological services provided to the water resources themselves. Valuation of forest cover in the augmentation of water resources is discussed in the context of aggregate economic planning, water-basin or sectoral planning, and conservation project evaluation. The importance of valuing intermediate non-market goods is illustrated for each planning tool in the context of an illustrative example of the Pearl Harbor/Ko‘olau watershed in Hawaii. In the context of water allocation and investment in waterworks, considerations of full income valuation imply that the value of water should incorporate the risk of watershed degradation contingent on the expected conservation effort. What appear to be new objectives of economic planning, such as sustainable development, do not require new criteria but rather the augmentation of existing methods of income accounting and project valuation to include the values on non-market goods. We also show that measurement of non-market valuation does not necessarily require the use of contingent-valuation methods, even when the usual alternatives (hedonics, household production, etc.) are not directly applicable.

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I. Introduction

Water resource planning and management should occur at three levels. The most familiar of these is the project level, appropriate for the design, construction, and maintenance of irrigation projects, urban water systems, and other water-related projects. The second is at the sectoral level, wherein the water sector is viewed as a whole, typically for assessing critical needs and priorities regarding water-related services and the water resources that support them. The third level is that of the whole economy, wherein policy issues involving relationships between the water sector and the rest of the economy are addressed, for example, the role of the water sector in achieving sustainable economic growth. In what follows, we discuss performance indicators for each of the three levels and the role of environmental valuation in each. The particular case of interest for the present paper involves the interdependence of aquifers and the watersheds that recharge them.

More generally our problem concerns the relationship between a form of natural capital that supplies a final service and one that provides an input to the first (Ellis and Fisher, 1987; Mäler, 1991). We address below the problem of evaluating such indirect ecosystem services for project, sector, and economy-wide analysis.

Full income accounting, or the inclusion of non-market goods and bads and the depreciation of natural capital into net national product accounts, allows for comprehensive examination of water resource use within an established economic framework. This examination reveals the importance of the linkages between indirect ecosystem services provided by watersheds and provides a mechanism for valuing these connections. The valuation furnishes the critical link between policy and management.

The absence of markets for the indirect goods and services produced by watersheds has rendered the value of watersheds lower than optimal management of the resource would decree. Distortion of water markets also contributes to an undervaluing of the resource (Young and Haveman, 1985). Full income accounts, sectoral accounts (e.g. for a water basin), and projected evaluation procedures which value the contributions of these indirect services and correct for pricing inefficiencies in water markets enable decision makers to determine efficient management procedures for use of the water resource and the accompanying watershed. These accounts and procedures do not require reliance on the development of new measurement techniques nor the use of controversial techniques such as contingent valuation.

A. Performance indicators

Net National Product accounts should reflect the production of all new goods and services in an economy, net of capital depreciation. Accounting procedures are plagued with difficulties ranging from an inability to monitor activities, as one finds with black markets, to an inability to simply value improperly priced or unpriced goods and services, as one finds with many environmental goods. As a result, conventional net national product accounts have omitted natural capital, pollution, and the distinction between actual price and social value. The attempt to include these missing components of economic activity in net national products has led to the development of full income accounting (Costanza et al, 1997; Ahmad et al, 1989). The same techniques can be used at the sectoral level. Notably, the full income accounts for the *Chesapeaka* economy (Grambsch et al, 1993) can also be used to construct "nature sector accounts" that isolate the benefits that the environment has bestowed on the economy, net of the extent of natural capital depreciation. While these pioneering attempts have stimulated substantial interest and activity in full income accounting, a number of methodological questions remain. In particular there has been scant attention paid to the problem of valuing indirect ecological services.

B. Water market failures

Water is commonly undervalued and under-priced. Of particular interest here, groundwater prices do not in general incorporate the full user cost of the resource (Moncur and Pollack, 1988; Young and Haveman, 1985). Coastal groundwater is a renewable but exhaustible natural resource with alternative technologies capable of producing water at generally higher marginal extraction costs. This combination of factors means that water that is fully or partially sourced by groundwater will be under-priced and overused. The benefits of maximizing the market value from the flow of water across time periods do not accrue to any one holder of property rights and are therefore dissipated rather than captured through optimal usage. Decisions based on values for water should be corrected for these market imperfections through the calculation of the optimal pricing path for the resource over time.

C. Indirect ecosystem services

Forested watersheds provide water supply essential for drinking, cooking, other domestic needs, tourist-related services, fishing, agriculture and manufacturing. Forests store appreciably more water than the same soils planted with agricultural crops or cleared land (Wood, 1977) for a variety of reasons. Several of these are enumerated here:

- Forests allow for increased percolation rates (movement of water through the soil) which recharge underground aquifers.
- Tree leaves, branches, and understory plants in a forested watershed act as an umbrella and intercept rain before it reaches the ground. This reduces rain's erosive capacity and increases the infiltration of the rainwater into the ground.
- In wet areas, forested watersheds act as a sponge and soak up rainfall into the soil, roots, mosses, ferns, and leaves. When fully saturated, water is released slowly so that it is delivered consistently and dependably, available for use long after the rain fell to the ground.
- Fog condensing on trees and other vegetation is an important component of water supply and evapotranspiration cycles.

- Forests may act as a pump where plants use water that is released back into the atmosphere through evaporation and transpiration (ET). With dense forest cover, suppressed ET allows much of the rainfall and condensed fog to infiltrate into the ground, percolate through the soil, and appear as clean water in streams or ground water (Hamilton et al., 1994).

To make rational economic decisions about the use of the water resource and the forested watershed, one must value these services' ability to contribute to the production of the resource. Since the services are intermediate in nature, the usual revealed preference and contingent valuation (CV) methods used for the valuation of non-market services are not directly applicable.[2]

II. Valuing the watershed by valuing the water

Our problem is to assess the value of the intermediate products provided by the watershed to an aquifer. Attempts to value indirect services are somewhat rare. The difficulties encountered in attempting to value indirect ecosystem services include an inadequate understanding of the scientific relationship between the market good and the indirect environmental support service, a hesitancy to use contingent valuation methods, and a lack of a market good from which one might develop a valuation function for the indirect service. These difficulties, however, may be overcome in some unexpected cases. For instance, our study links the indirect services provided by the forest with the replenishment of groundwater, a renewable resource. Though groundwater is not an

[2] See e.g. Kolstad (2000) for a description of direct (CV) and indirect (revealed preference) methods of valuation.

optimally priced market good, the value of the forested watershed's contribution to the groundwater can be determined through first using optimal control theory to value the water resources and second using a potential change in forest conditions to determine the value of the forest in groundwater replenishment.

Other studies to address the valuation of indirect ecosystem services include Barbier, 1994, where the indirect environmental functions being discussed come from tropical wetlands. By solving for the dynamically optimal production of two goods, one of which uses converted wetlands while the other uses wetland services, Barbier solves for the optimal path of wetland conversion. Optimal conversion requires that in each period, the marginal value of wetlands in the production of each good must be equal.

Our research values the groundwater itself using a related production function approach, but one with an additional step. Instead of modeling the contribution of the watershed as a direct contribution to the production of water, we consider the watershed as an input to aquifer recharge, which is in turn a factor in the production of water.

The first step in valuing the additional recharge provided by the watershed involves calculating the present value of the aquifer under the present conditions of forest cover. The second step involves calculating the change in that present value effected by a change in forest cover within the watershed. The forested watershed is appraised through presenting a counterfactual situation in which the forest's contribution to groundwater is reduced, thereby reducing the availability of groundwater and its total value. Using our technique, an indirect resource's value can be calculated without resorting to the controversial use of contingent valuation methods.

A. Correcting for existing market imperfections with first-best shadow prices

In order to value the contribution of the forested watershed to the aquifer, we need to estimate the true value of water in the aquifer, but actual water charges are insufficient for that purpose. Water is not bought and sold in a decentralized market without external costs and benefits, and current water prices for Oahu do not result in optimal usage rates by the population. Water prices tend to underestimate the full social cost of water use, so the quantity used is likely to be higher than optimal and the price lower than optimal. Krulce et al (1997) created a model which allows one to calculate these optimal prices given assumptions about the growth in demand for water and the cost structure for extracting water from the aquifer for the Pearl-Harbor Aquifer on Oahu.

Efficient use of groundwater resources requires that one incorporate the exhaustible nature of the resource, in the form of its availability for future generations' use, into the allocation decision. There is an opportunity cost, in the form of a marginal user cost or scarcity rent, due to the fact that water used today will not be available for future use. This marginal user cost will increase over time as the aquifer head level falls, since each unit of the remaining water will be more valuable. In efficient water markets, the price of water should increase over time to incorporate this user cost. (Tietenberg, 1996)

Krulce et al. extend the model of resource management for a nonrenewable resource with a backstop price determined by a ready substitute good to renewable resources and apply it to the case of coastal groundwater. (Krulce et al,1997). Groundwater is considered a renewable but exhaustible resource with benefits to both current and future generations. The model addresses the problem of the inter-temporal allocation of groundwater resources so as to maximize the social welfare of the resource users.

Because the value of future welfare is discounted and the marginal user cost is increasing, the extraction path for exhaustible resources, including groundwater, should, *ceteris paribus*, be weighted more toward the present, with use declining over time. However, if demand for the resource is also growing as the population grows, then it may be worthwhile to conserve the resource in the present time in order to accommodate the higher value future users will place on the water. It is assumed that the water from the aquifer can be substituted for desalinated water, the cost of which provides an upper limit to the price which can be charged for the water from the aquifer.

The model accounts for growth in the demand for water resources due to population expansion as well as the reduction in usage that would accompany higher prices. Krulce et al.'s findings indicate that with efficient use of the groundwater, the aquifer head will reach a steady state level after the backstop price is reached. With the expectation of growth in demand for the resource, optimal management may indicate an initial period of conservation followed by a period where the extraction rate exceeds the recharge rate before the steady state head level is reached. A formal presentation of the model is included in Appendix A.

The optimal-groundwater-use model is used here in two stages to determine the contribution of the forested watershed to the value of the aquifer. In the first stage, inter-temporal social welfare is maximized to find the current optimal wholesale (net of distribution charges) price path and quantity path for water usage from the Pearl Harbor aquifer. In the second stage, these optimal paths are recalculated under the assumption of a significant forest disturbance. The difference in the net present values of the scarcity rent of the resource under the two scenarios provides the estimate of the contribution of the aquifer from the forested watershed's quality level. This value may in turn be used to make appropriate policy decisions at the project, sector, and full economy levels.

The *in situ* value of a unit of water (also known as its *scarcity rent*) is simply the social value of water minus its extraction cost. For example, the scarcity rent for 1,000 gallons used today at an efficient wholesale price of $1.01 and an extraction cost of $0.41 would be $0.60. This is shown as the y-intercept on Graph A of Figure 1. To approximate the total scarcity rent for all the water used in each time period one first multiplies the difference between each period's extraction cost and optimal price (the scarcity rent) by the optimal quantity used in that time period (not shown).[3] Then one can calculate the

[3]For example in the first period, the optimal quantity extracted is 149 million gallons per day (mgd).

net present value by summing the discounted rents in each period over the infinite future, given assumptions about the growth in demand and the social discount rate.[4]

B. Incorporating indirect ecosystem services

1. A General Case

Forested watersheds increase the recharge of coastal aquifers through the mechanisms described above. In short, the quality of the forested watershed will affect the recharge rate of the aquifer and the availability of groundwater for present and future uses. A greater recharge level will increase aquifer head levels and decrease the marginal user costs, increasing the social welfare benefits of the groundwater. A deterioration in forest quality may result in a decrease in groundwater recharge levels and the social welfare derived from the resource. A project level analysis of groundwater use where recharge is supplemented by the quality of its watershed must include the level of forest quality to optimally allocate resources for the management of the groundwater and its renewal.

The analysis of appendix A confirms what may appear to be common sense, but which is commonly overlooked nonetheless. Project evaluation of new waterworks, decisions about water allocation, and watershed conservation projects all require the estimation of the first-best shadow price (efficiency price) of water. But the shadow price of water in an aquifer depends not only on its optimal use trajectory, as discussed in the previous section, but on the quality of the watershed and its capacity for recharging the aquifer. Since the quality of the aquifer in the future cannot be known with certainty, one must rely on the expected state of the watershed, after accounting for risks of degradation,

[4] For a discussion of scarcity rent, present value and social discount rates, see Tietenberg, *Environmental and Natural Resource Economics*, 4th edition, 1996.

contingent on expected conservation effort. Conservation expenditures ("maintenance" in the appendix) should be increased until the value of the marginal unit of water saved thereby is equal to the marginal value of water. Just as overuse of water unnecessarily accelerates the advent of desalination, so does the under-maintenance of the watershed. Both render water more scarce than it needs to be.

At the sectoral and full economy levels, the forest stock should be included in management decisions as cumulative maintenance expenditures determine the forest's quality. Efficient decision-making requires that maintenance be increased until the marginal benefit of maintenance equals its marginal cost. The marginal benefit of maintenance expenditures in each year equals the marginal increase in the forest stock effected by that expenditure, times the marginal increase in recharge induced from that stock, all times the resource rent. This requirement directly ties the forest quality expenditures to the availability of the groundwater resource.

That a relationship exists between forest quality and watershed quality has been well known for some time. Under the Organic Act of 1897 (30 Stat. 34-36; codified U.S.C. vol. 16, sec. 551), the Forest Service was begun with the mandate to provide healthy watersheds to improve water flows as well as to provide a continuous supply of timber. Around this same time period, most of the Koʻolau Mountains were put into the land management district of "Conservation," limiting the development of this land, and increasing watershed quality. Today, the island's water supply and the Pearl Harbor Aquifer benefit from this investment. Expenditures on maintenance of the watershed should be seen in this historical context. The Conservation district requirements limit the threats to development but do not eliminate the threats of forest quality deterioration. Groundwater and surface water can both meet the population's water needs. The benefits of groundwater over surface water are manifold: (1) the infiltration process provides a lengthy period (about 12–25 years for Hawaii's geology) during which sediments and other contaminants are filtered out, (2) the ground provides a convenient storage facility in which water can be kept clean for times of future demand, and (3) the ground does a better job of capturing the water for use than we could without drastic alteration to the forest environment and the other amenities it provides.[5] These benefits mean that changes in the ratio of runoff (surface water) to ground water infiltration will affect the overall quantity and quality of the water supply. Our study uses this potential change to calculate the value of the forest in the production of ground water quantity.

The environmental conditions that mark forest quality for the provision of groundwater resources stem from a variety of hydrological conditions. Steep slopes will clearly have more runoff and less infiltration than flatter slopes. Streams that meander or pass over more rubbly and less smooth, or channeled waterways, will have higher infiltration rates. Intense rainfalls that may be experienced in severe storms, particularly as on the windward sides of the Ko‘olaus, will tend to increase channelization and runoff. Layers of vegetation help slow this process by providing slope stability, more even stream flow, and fallen debris in the water, creating a mechanism to slow the flow and provide freshwater organisms with conducive habitat.

[5] For instance, evaporation and transpiration losses could be eliminated by replacing the forest with large catchment and storage systems.

The soil type will determine the permeability of the landscape below ground level. Compacted soil can prove quite impermeable if not broken up.[6] The soil types in Hawaii generally have a high clay content and are permeable until disturbances occur. When these clay soils are packed, however, as can occur through feral pig activity, they can quickly form an impenetrable layer.

Finally, vegetation cover determines much of the process of ground water recharge. A healthy, multiple tiered forest will collect more raindrops through its leaves, protect the soil from both sheet and rill erosion,[7] and will keep the soil permeable through its root systems. Each of these services increases groundwater recharge levels. Ecosystem services are highly valuable in places like Hawaii, where population demands for water are taxing supplies. Their inclusion in project analysis is necessary for efficient decision-making and resource use.

Costs of lost services are measured here by estimating the lost value (replacement cost) accrued through a deterioration in environmental quality. Forest quality is in this case an input into groundwater recharge. This is thus a damage cost aversion approach to the question of production value generated from the indirect environmental service (Barbier, 1994; Smith, 1991). These estimates should then be used as guidelines for project, sectoral, and economy-wide resource use.

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[6] Some of the early irrigation ditches were in fact made of packed soil. The soil base for the Koʻolaus is volcanic. The Natural Resources Conservation Service (NRCS) has conducted soil surveys for the islands (NRCS, 1972 (Island of HI, 1973)). Many of the original irrigation ditches were not lined, and were sufficiently watertight just through packing the soil tightly (NRCS, 1972 (Island of HI, 1973)).

The threats to forest quality and the associated ecosystem services could come from several types of disturbances. A large decrease in recharge could come from a variety of changes in the forest. Perceived threats to the watershed range from the introduction of invasive alien species to urban development or fire. In general, an activity such as road building or a natural occurrence such as a landslide due to forest disturbance will increase precipitation runoff and decrease recharge to the aquifer. The most likely scenario for degradation of forest quality with respect to recharge levels is briefly discussed elsewhere in this document.

2. The Pearl Harbor Aquifer and Koʻolau Conservation District

The Pearl Harbor Aquifer underlies much of Oʻahu and water flow on the leeward side of the Koʻolaus contributes significantly to the recharge of this aquifer. Some officials of the State Water Commission believe that current withdrawal rates are such that all renewable island water resources will be fully developed and in use in 25 years. Any additional growth in demand for water resources after that time can only be accommodated either by depleting aquifer heads below replaceable levels or by exploiting external sources such as desalination.[8]

In Hawaii and elsewhere, forest preserves were set aside at the turn of the century to protect watersheds and by the 1930s replanting occurred in deforested areas to restore the vital ecosystem services the forests could provide. In Hawaii, these deforested areas were

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[7] Sheet erosion is caused primarily by raindrop impact. Rill erosion is caused primarily by surface runoff.

the result of cattle grazing and other forest degrading land use practices in the previous two centuries. Much of the need to protect water in these early days stemmed from the high levels of water needed to produce sugar.[9] With the importance of sugar dwindling, residential usage is quickly becoming the most important beneficiary of the Ko‘olaus’ water.

The deterioration in forest quality anticipated in this analysis is a decrease in groundwater recharge of 41 mgd, or 31% of the current recharge level from the Ko‘olaus. Figure 1 shows a visual representation of the scarcity rent for 1,000 gallons in each time period prior to using desalination under current forest conditions (Graph A) and under a change in forest conditions which leads to this decrease in recharge (Graph B). Under current conditions (A) a steady state is reached in the year 2072 wherein the optimal wholesale price of water from the aquifer is equal to the wholesale price of desalination. At this point, the same amount of water should be extracted from the aquifer in each year, maintaining an optimal aquifer head level and extraction cost, with new demands being accommodated by desalination. In scenario B, the desalination steady state is reached much sooner, in the year 2057. Thus, a significant benefit of the healthy forest is that the necessity for desalination, and investment in desalination facilities, is substantially delayed.[10]

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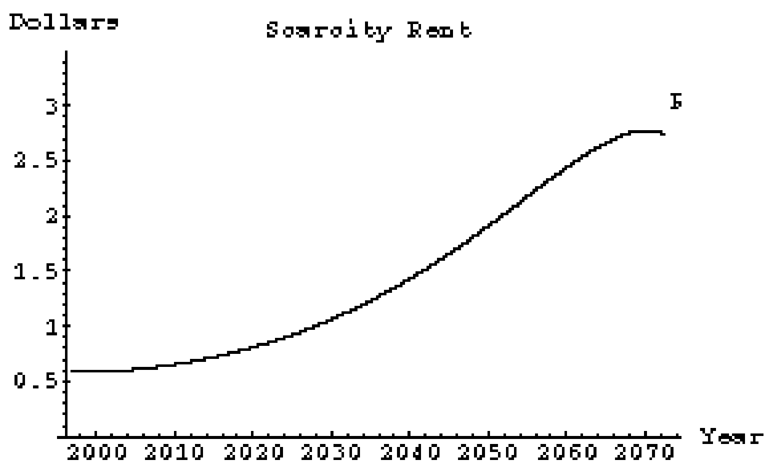
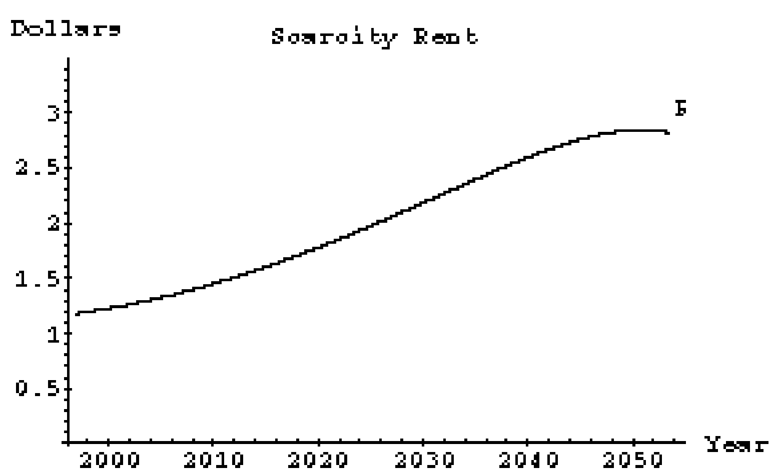
[8] Roy Hardy, Water Commission, personal communication, 7/24/98. Other studies (e.g. Krulce et al., 1997) have shown that this does not have to be the case if water management is improved in the interim.
[9] It takes one million gallons to produce one ton of sugar (Wilcox, 1996).
[10] Such costs are not estimated in this analysis.

Figure 1: Scarcity rent for recharge to Pearl Harbor Aquifer

Graph A: Current, recharge of 281 mgd



Graph B: Post-forest quality change, recharge of 240 mgd



The perceived threats to the watershed are, in brief, any combination of fires, roads, logging, urban development, feral ungulates, and introduced species like *Miconia calvescens*. Given current forest zoning and threat levels, the most likely way in which large scale devastation could occur would be through a combination of rapidly spreading *Miconia calvescens* (an invasive introduced plant species) and/or leaf hopper infestation (an invasive introduced insect species), thereby changing the composition of the forest canopy; urban creep along the edges of the district replacing key areas of streamside vegetation with pavement; and an increase in feral pigs, causing lower rates of soil infiltration.[11]

Using the technique outlined above, we calculate the net present value of the aquifer with its current forest quality and with a deteriorated quality level. We find that the net present value lost from a decrease in recharge of 41 mgd to the Pearl Harbor aquifer is $1.42 billion, given a social discount rate of 3%.[12]

As a caveat, note that groundwater and surface water levels might actually be increased by similar changes in the forest quality to those described above. For instance, a reduction in vegetative cover could lead to decreases in evapotranspiration (ET) which

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[11] While any of these threats might be capable of reducing groundwater recharge significantly, the scientific uncertainty involved when discussing changes in vegetation cover, and the many possible types of mitigation procedures possible during development mean that a combination of impacts is assumed necessary for such a significant change in recharge levels.

[12] The optimal social discount rate is a controversial topic within economics. James Kahn has suggested the use of 30-year U.S. Treasury bond rates because they are a low-risk, diversified investment, or the average real rate of growth of GDP, historically 2-3%, because any one part of the economy growing exponentially larger than the economy as a whole could not be sustained for long (Kahn, 1995).

more than compensate for decreases in recharge due to lower levels of soil moisture storage and infiltration rates.[13]

In summary, groundwater recharge is a valuable product of the Ko‘olau forest, with a net present value of at least $1.42 billion. Oahu gets about 90% of its fresh water supply from groundwater. Alternative production techniques such as desalination are costly and the postponement of their need is a valuable policy goal. Postponement can occur on the supply side by maintaining or potentially enhancing forest quality.

III. Incorporating water-resource valuation into the three levels of water planning

The inclusion of these estimates of forest value is valuable for partial project level decisions regarding watershed usage. Before manipulating the forest cover for watershed purposes, however, the benefits of the additional water must be weighed against the costs of the changes in the forest to other amenities, such as water quality, wildlife habitat and aesthetic pleasure. This highlights the value of full income accounting, which would create a nature sector account for the Ko‘olaus.

Net National Product can be calculated from the expenditure side and the income side. Table 1A shows the standard components of Net National Product while Table 1B adds in the environmental sector.

[13] Giambelluca (1983)

Table 1A: Standard Components of Net Domestic Product	
Net Domestic Product Expenditures	National Income + Indirect Business taxes less subsidies Income
Agriculture, forestry, fisheries, mining	Compensation to Employees
Manufacturing, construction, transportation and public utilities, retail and wholesale trade	Interest, rental income and profits
Financial insurance and real estate, Services	Depreciation allowance
Government and government enterprises	Indirect business taxes net of subsidies
(Depreciation)	
Table 1B: Additional Sectoral components required for full income accounting	
Value of non-market environmental goods and services	Value of non-market environmental inputs
(Environmental Depreciation)	Natural capital depreciation allowance
Value of other non-market goods and services (e.g. black market goods)	Value of other non-market goods and services (e.g. volunteer labor)
	Rents and profits from natural capital

Within this context, a profit-loss statement for the environmental sector of the economy becomes a useful performance indicator. The components of a profit-loss statement would take a form similar to Table 2. This table has been tailored to the case of the Koʻolau Conservation district. For a quantitative example using the Chesapeake Bay area, see Grambsch (1993).

Table 2: Sample Profit-Loss Performance Indicator for the Ko‘olau Sector (figures are rough estimates of annual flows, in millions of dollars(1997))[14]

Value of Environmental Goods and Services Produced from watershed		Inputs to watershed resource	
Groundwater quantity	$137	Forest maintenance expenditures	$0.2
		Natural capital contribution to groundwater recharge	$136.8
Water quality and in-stream uses	$4.84	Dredging (Defensive Expenditures and damages)	$0.4
		Natural capital contribution to water quality and in stream uses	$4.44
Species habitat and biodiversity	$42.6	Additional Invasive species prevention and eradication	$0.1
		Natural capital returns from lack of invasive species	$42.5
Subsistence, hunting, and commercial harvests	$2.3	Natural capital contribution to commodity use	$2.3
Aesthetic values and ecotourism	$92.4	Natural capital contribution to aesthetic values and ecotourism	$92.4
Other natural capital depreciation	$-2?	Other natural capital depreciation	$-2?
		Total “Natures Profits” (net returns to nat. capital)	$276.44 (Est.)
Total	$277.14 (Est.)	Total	$277.14 (Est.)

Currently, the Ko‘olau district and many other places appear to enjoy significant profits from their environmental sectors. From Table 2, the profits attributable to nature from the Ko‘olau Conservation district sum up to as much as $276.44m. These accounting procedures do not, however, incorporate the risk of significant natural capital depreciation through occurrences such as natural disasters or new or uncontrolled invasive species. Significant natural capital deterioration, such as species extinction and

[14] From Kaiser, Krause, and Roumasset, UHERO Online Report, *www2.hawaii.edu/~uhero*, 1999.

decreases in biodiversity, may also go unseen, confounding its measurement further. A large portion of these windfall profits from nature, $136.8m, come from groundwater recharge provided by the forest.

The potential threat to these profits is uncertain. At the project level, one can use this approach, combined with information about the planned action, to evaluate the expected change in value from an action. For example, assume that there is a 30% chance that within 10 years there may be a natural event such as partial destruction to the forest by invasive species as described above. This event would, as calculated above using optimal control theory, lead to a net present value of $1.42 billion dollars in damages. To determine the benefits of the project, one would then estimate the impact that a specific conservation project has on the probability of said damages occurring. If for example, a one million dollar conservation project reduced the probability of the specified damage occurring within 10 years to 5%, then the investment would generate an expected return of more than $300 million. This figure does not even include the non-aquifer related benefits of the project. A favorable net present value is expected even if the assumptions about the effectiveness of the conservation project are less optimistic.

This sort of information can be used at both the sector and economy-wide levels to improve policy decisions. Clearly, the risk of natural capital depreciation warrants more significant attention given the profitability of the environmental assets. Accounting in this format demonstrates the importance of full information for optimal decision-making. At the project level, this information shows the value of calculating the environmental balance sheet for the case of project completion as well as the status quo. A comprehensive project evaluation would therefore use a similar calculation as demonstrated in this paper to determine the full value of the environmental resources used in the project.

IV. Conclusions

This paper provides a method for estimating the value of an indirect environmental service for purposes of full income accounts, nature sector accounts, and project evaluation. The method is briefly illustrated for the Koʻolau forested watershed in Oahu, Hawaii. In the process, we illustrate the importance of valuing intermediate non-market goods for planning and management of both water and watershed resources.

The particular watershed service of interest is the enhanced recharge of the Pearl Harbor Aquifer provided at three levels of forest cover – present cover, no cover, and cover with moderate damage. In full income accounting ("green" net product accounts), the value of the water provided by the aquifer is an item on the final goods and services side of the national or regional product account. That part of the water services attributable to the forest (present cover vs. no cover) shows up as an intermediate input on the right side of the ledger.

Nature sector accounts isolate the outputs and intermediate inputs portions of the full income accounts and restate them in a conventional profit-loss fashion. In the Koʻolau example, nature can be seen to be running an extremely "profitable" operation. This does not necessarily mean that the government agency responsible for watershed conservation, along with various non-governmental organizations and private citizens, have been successful, but nature sector accounts nonetheless provide a performance indicator useful for planning by such agencies and groups. The natural benchmark for nature's profits is not zero, as it is for a conventional business, because of the unpriced inputs that come from outside the system under investigation (sunshine) and the assets inside of the system (e.g. water basin) that may be relatively easy to maintain (e.g. the geo-physical integrity of the aquifer itself). Nonetheless, increases or decreases in such accounts will be reflective of successful or ineffective conservation efforts. Moreover, these accounts allow planners to isolate the value of intermediate ecological services, e.g. from a watershed , and are a potentially useful tool in setting conservation priorities.

Particular conservation proposals can be assessed with present value techniques augmented by the valuation of the indirect ecological services in question.
In the example provided, the conservation project is the maintenance required to avoid depreciation of the natural capital of the forested watershed. The value of the project is determined by finding the difference in the values of the Pearl Harbor Aquifer, with and without the conservation project. Using optimal control techniques, we find that the net present value of the potential loss from a decrease in recharge of 41 mgd to the Pearl Harbor aquifer is $1.42 billion. In order to proceed to the next step of the project evaluation, one would estimate the impact that a specific conservation project has on the probability of said damages occurring. If for example, a one million dollar conservation project reduced the probability of the specified damage occurring within 10 years, then

the investment would generate an expected return of more than $300 million, without considering the non-aquifer related benefits of the project. Even with much more cautious assumptions, the project would have a very favorable net present value.

The general lesson for project evaluation of new waterworks, decisions about water allocation, and watershed conservation projects is that all of them require estimating the efficiency price of water. But water's efficiency value may require not only estimating the optimal use of the water resource but the nature and contribution of the ecology and its capacity for degradation. Just as overuse of water unnecessarily accelerates the advent of desalination, so does the under-maintenance of the watershed. Both render water more scarce than it needs to be. Thus water planning and watershed management need to be pursued jointly. Where they are not, it is likely that water will be even more undervalued and overused than previous analysis has suggested.

In situations where decentralized mechanisms are adopted to implement efficient water allocation, the risk of watershed degradation should be similarly taken into account. In the case of water pricing, one may distinguish two methods for such incorporation. If conservation policies and expenditures are taken as given, the efficiency price of water may be estimation. The preferable ("first-best") approach is to simultaneously estimate the efficiency price of water and the optimal conservation policies. In the case of water markets, similar considerations should be made in setting the total quantity of water rights.

In reality, the State of Hawaii has not yet institutionalized a procedure for joint management of watersheds and water resources and turned down a modest conservation proposal, thus exemplifying a policy decision at apparent variance with sustainable growth.[15] Nature has returned a large "profit" to Hawaii for many years, but the returns are at risk. Should the populations of the alien species discussed above substantially increase, Hawaii's economy would suffer extensive losses. Other states and countries may be risking similar degradation and be practicing thereby stochastically unsustainable development policies.

It is also important to note that the concern for environmental amenities, sustainability, and intergenerational equity do not necessitate the invention of new criteria for project evaluation and policy analysis. In the Hawaii context, the perceived problem that economic development will inevitably degrade the environment can be avoided by simply extending conventional income accounting and project evaluation tools to account for non-market benefits and costs.

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Appendix A: Mathematical model of groundwater usage with a forested watershed contributing to recharge.

Coastal groundwater is a renewable and replaceable resource. With an alternative technology for production available through desalination, the framework for determining the optimal prices and quantities used over time is shown in Equation A.1. This optimization maximizes the social welfare derived from the use of the resource using a demand function for the resource over time.

Choose quantities of groundwater and desalinated water consumed, q_t and b_t, respectively, and forest maintenance expenditures m_t, to maximize

$$\int_0^{\infty} e^{-rt}\left[\int_0^{q_t+b_t} D_t^{-1}(x)dx - c(h_t)q_t - b_t\bar{p} - m\right]dt \qquad \text{(Eqn. A.1)}$$

subject to $\dot{h}_t = w(s_t, h_t)$ s.t. , $q_t \geq 0$, $b_t \geq 0$, with h_0 given, where h_t is the time denoted stock of groundwater and $w(s_t, h_t)$ is the net recharge to the aquifer.

Here $\int_0^{q_t} D_t^{-1}(x)dx - c(h_t)q_t - b_t\bar{p}$ is the consumer surplus associated with water consumption in time t, $c(h_t)$ is the cost of providing the resource given the indirect service $s(\sum_t m_t)$, D_t^{-1} is the inverse demand function for the natural resource, and $\bar{p}$ is a backstop price in the form of another source for an equivalent good (desalination). Here, the aquifer head level, h, is a function of net recharge, $w(s_t,h_t)$, which is a function of forest stock and aquifer head level respectively. The forest stock is a function of cumulative maintenance expenditures, $\sum_t m_t$. Note that s_t enters the objective function only through its role as a contributor to net recharge; the value for the forest as a good with end-user demand of its own is not part of this model. Maximization of a joint demand function would be required to incorporate the other aspects of the forest resource. Expenditures, m_t, made here provide returns in the form of increased groundwater valuation though they may have other benefits elsewhere. This illustrates the need for full-income accounting; in order to optimally determine expenditures on forest maintenance, all aspects of the resource must be included. The appropriate current value Hamiltonian and necessary conditions for an optimal solution can then be derived. The current value Hamiltonian for this problem is

H= $\int_0^{q_t+b_t} D_t^{-1}(x)dx - c(h_t)q_t - b_t\bar{p} - m - [w(s_t,h_t) - q_t]\lambda_t$ where $\lambda_t \geq 0$.

Following Kamien and Schwartz (sections 8 and 10), the necessary conditions for an optimal solution are

(1) $\dot{h}_t = \dfrac{\partial H}{\partial \lambda_t} = w(s_t,h_t) - q_t$,

(2) $\dot{\lambda}_t = r\lambda_t - \dfrac{\partial H}{\partial h_t} = r\lambda_t + c'(h_t)q_t - \dfrac{\partial w}{\partial h_t}(s_t,h_t)\lambda_t$,

(3) $\dfrac{\partial H}{\partial q_t} = D_t^{-1}(q_t + b_t) - c(h_t) - \lambda_t \leq 0$, if < then $q_t = 0$,

(4) $\dfrac{\partial H}{\partial b_t} = D_t^{-1}(q_t + b_t) - \bar{p} \leq 0$, if < then $b_t = 0$,

(5) $\frac{fH}{fm_t} = -\frac{fw}{fs}\frac{fs}{fm}\lambda_t = 1$.

Rearranging equation (2) yields

(6) $r\dot{\lambda}_t - \frac{fw}{fh_t}(s_t, h_t)\lambda_t = \dot{\lambda}_t - c'(h_t)q_t$

which can be interpreted as an arbitrage condition where the right-hand side is the marginal benefit of conserving the water for future use, and the left-hand side is the foregone marginal benefit of extracting water in terms of dollars realized after one period. This follows the analysis in Krulce et al., 1997.

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