Appendix 1: Environmental Index for Green Payments

Indexes are used widely in conservation programs to gauge the potential environmental gain from the application of proposed practices in a specific location. The environmental index described here is designed to capture the potential for environmental gain across a broad range of resource concerns. Resource concerns refers to resource attributes such as water quality, soil quality, and air quality, which are linked to agricultural production through physical effects such as soil erosion, nutrient runoff, and/or pesticide leaching.

Environmental indexes can be specified as indexes of potential environmental gain or environmental performance. For indexes that measure potential gain, a high value denotes higher potential for environmental damage (e.g., water quality damage from nutrient runoff) in the absence of conservation treatment (e.g., nutrient runoff control) or potential for lost opportunity to improve environmental performance in the absence of treatment (e.g., lost opportunity to enhance wildlife populations though habitat enhancement). Indexes of environmental performance are a mirror image: index values are high when there is little opportunity for environmental gain. When nutrient runoff has been controlled through nutrient management or other means, for example, the potential for further environmental gain is low, but environmental performance is high.

In our analysis, we use a performance-based index. Basic index derivations, however, are for a potential gain type index. The two types of indexes can be related as: $S_f = \max(I) - I_f$. Where S_f is the performance-based index value for farm f, I_f is the potential environmental gain-based value for farm f, and $\max(I)$is the largest possible value of I.

For a given farm, the environmental index is an acre-weighted average of components that correspond to various treatments producers can apply to land in specific uses, such as water erosion control on land in crop production (the farm subscript is suppressed to avoid clutter):

$$(1) \quad I = \frac{\sum_k \sum_j A_{kj} I_{kj}}{\sum_k \sum_j A_{kj}}$$

Where

A_{kj} is the number of acres eligible for treatment k on land in use j;

I_{kj} is the index component representing the potential environmental damages or benefits that could be mitigated through application of treatment k on land in use j.

Each index component is the weighted sum of subcomponents representing the potential for damage from the physical effects (m) that could be addressed by applying treatment k on land in use j:

$$I_{kj} = \sum_{m \in k} w_{jm} N_{jm}$$

Where
m indexes physical effects;

w_{jm} is the index weight for land use j and physical effect m;

N_{jm} is the normalized index subcomponent for land use j and physical effect m;

The treatment index (k) is not used at the subcomponent level because each corresponds to a specific physical effect which, in turn, corresponds to only one treatment (although a treatment can correspond to more than one physical effect).

Finally, the basic building block of each index subcomponent (each N) is the relative damage (or benefit) estimate or RDE. Each RDE is the product of variables that describe (1) the intensity of the relevant physical effect (on the individual field) and (2) the potential for that physical effect to cause environmental damage:

$$RDE_{mj} = E_{mj} D_{mj}$$

Where

E_{mj} is the intensity of the physical effect m on land in use j;

D_{mj} is the potential damage associated with the physical effect m on land use j.

The index subcomponents are a normalization of the RDE, see page 33.

Intensity of Physical Effects (E)

The intensity variable generally measures the on-field risk for adverse physical effects such as soil erosion or nutrient runoff.

Wind Erosion: Intensity is measured as the average estimated excess wind erosion (wind erosion in excess of T) per acre for land that has excess erosion, by county. Estimates of wind erosion and the soil loss tolerance (T) are obtained from the National Resources Inventory (NRI). NRI is an area-based survey of land conducted by USDA’s Natural Resources Conservation Service (NRCS) in cooperation with Iowa State University. NRI provides information on land use, land characteristics, and land condition (including estimated erosion rates), for about 800,000 points of non-Federal land across all U.S. counties, except those in Alaska.

Water Erosion: Intensity is measured as the average estimated excess water erosion (water erosion in excess of T) per acre for land that has excess erosion, by county. Estimates of water erosion and the soil loss tolerance (T) are obtained from the NRI.

Table A1.1

Intensity and damage variables, by index component and subcomponent

Component (treatment (*k*) and land use (*j*))	Subcomponent (physical effect (*m*))	Intensity	Damage
Wind erosion (cropland)	Dust	Excess erosion, NRI[1]	$/ton of erosion, ERS
	Soil productivity	Excess erosion, NRI	$/ton of erosion, ERS
Water erosion (cropland)	Sediment	Excess erosion, NRI	$/ton of erosion, ERS
	Soil productivity	Excess erosion, NRI	$/ton of erosion, ERS
Nutrient management (cropland)	Nitrogen leaching	NRI-based index	NA[2]
	Nitrogen runoff	NRI-based index	Transport to estuary, USGS SPARROW[3]
	Phosphorous runoff	NRI-based index	NA
Pest management (cropland)	Pesticide leaching	Index of pesticide concentration in water leaching below root zone[4]	NA
	Pesticide runoff	Index of pesticide concentration in runoff[4]	NA
Grazing land health (grazing land)	Grazing land health	Index of potential productivity improvement[5]	NA
Nutrient mgmt and riparian erosion (grazing land)	Nutrient runoff and sediment	Index of nonconfined animals/acre and stream density on grazing land	NA
Wildlife (cropland and grazing land)	Habitat restoration	Number of imperiled species in county[6]	NA

[1]National Resources Inventory (see text for description of NRI data).

[2]NA = data not available

[3]US Geological Survey, Spatially Referenced Regressions of Watershed Attributes. See http://water.usgs.gov/nawqa/sparrow/

[4]Goss et al.

[5]Atwood et al.

[6]Based on NatureServe natural heritage data, see www.NatureServe.org.

Source: USDA, Economic Research Service.

Nutrient Management: Indexes that measure the risk of nitrogen and phosphorous runoff and nitrogen leaching to groundwater are developed using NRI and other data. See appendix 1 in Claassen et al. (2004) for details on the construction of the indexes.

Pest Management: Data obtained from Goss et al., (1998) indicates the number of acres, by watershed (as defined by 8-digit hydrologic unit codes (HUC)), for which pesticide concentration exceeds human health standards in surface runoff and water leaching below the root zone. They also note the number of acres where runoff and leaching contain pesticides in concentrations that are 2 times, 3 times, 5 times, etc., up 25 times, the safe concentration for human health. The intensity measure for pesticides is: $E = \sum_t tc_1$

where t is the number of times pesticide concentration in runoff or leaching exceeds the human health standard and c_t is the number of acres for a given t.

Grazing land health: The grazing measure is based on Atwood et al., (2005). Here pasture productivity is considered a proxy for good grass cover which controls erosion and active weed control which makes it more difficult for invasive species to take hold. The index is calculated as the difference between local (watershed) average forage yields and “high” forage yields (defined as the local mean yield plus two standard deviations of forage yield. In other words, the index measures difference between what is typically obtained versus what could be obtained though superior management.

Nutrient management and riparian erosion on grazing land: The index subcomponent value varies spatially based on the intensity of grazing (number of animal units per acre) and the density of streams relative to grazing land. By county, we estimate the number of grazing animal units and grazing land acreage from the Census of Agriculture. The U.S. Department of Commerce's U.S. Census Bureau conducted the Census of Agriculture for 156 years, 1840-1966. Starting with the 1997 Census of Agriculture, Congress moved that responsibility to USDA's National Agricultural Statistics Service, which collects data in a 5-year cycle for years ending in 2 and 7. Stream density is measured by the average distance of grazing land from perennial streams within counties using National Land Cover Data, National Hydrography Data, and the National Elevation Dataset. The raw index subcomponent is the ratio of stocking density to average distance of grazing land to streams. The higher the stocking density and the shorter the (average) distance to water, the higher the index value.

Wildlife: The wildlife component score is based largely on actions rather than location. Ten percent of index points are based on an intensity variable, defined as the number of potentially imperiled species in the county, as measured by NatureServe (see www.NatureServe.org). The balance of wildlife points are awarded for taking action to improve habitat.

Potential Damages (D)

The damage variable is a measure of the potential for physical effects to cause damage to specific resource attributes such as water quality or soil productivity. These damages may be expressed in monetary terms, may be represented by proxies, or may be absent altogether.

Wind Erosion: Ribaudo et al., (1990) developed measures of the cost of reduced air quality due to particulate pollution caused by wind erosion. Wind-born dust costs include cleaning and maintenance of businesses and households, damage to non-farm machinery, and adverse effects on human health (Piper and Huzar, 1989). Cost per household is modeled as a function of the wind-erosion rate, income, and other household characteristics. The cost model is estimated using contingent valuation techniques and data from a survey of households in New Mexico. The cost model is applied to households west of the Mississippi River using Population Census data and wind erosion estimates. Results are aggregated across households within USDA Farm Production Regions. Damage (benefit) estimates are provided per ton of soil eroded (conserved).

Reductions in soil erosion (for wind or water erosion) will increase the future productivity of farmland. Ribaudo et al., (1990) used yield losses and production-cost increases due to erosion estimated using the Erosion Productivity Impact Model (Williams et al., 1985). The economic value of the gain in productivity is the net current value of the increase in productivity resulting from a marginal reduction in soil erosion.

Water Erosion: The change in consumer surplus associated with water-based recreation due to a change in soil erosion within a watershed is based on Feather and Hellerstein (1997) and Feather et al., 1999). Demand for water-based recreation is estimated using behavioral data from the 1992 National Survey of Recreation and the Environment (NSRE) and soil erosion estimates from the NRI. Demand is modeled as a function of the individual's characteristics, travel costs, erosion levels and other environmental factors. Across the 2,111 HUCs, a 1-ton erosion reduction can increase societal benefits of water-based recreation from 0 to $8.81.

Hansen et al. (2002) estimate the water quality damages of soil erosion within a HUC based on the cost of sediment to downstream navigation. They develop a hydrologic model that accounts for the hydrology and the subsequent flow of sediment within and across watersheds. Their hydrologic model links erosion within a watershed to the downstream cost of dredging harbors and shipping channels. The hydrologic data are from the Environmental Protection Agency's River Reach File, which shows interconnections among 3.2 million miles of streams. Estimates of agricultural erosion by HUC are based on data from the NRI. Dredging-cost data are from the U.S. Army Corps of Engineers. Results show that, across HUCs, a 1-ton reduction in soil erosion can reduce dredging costs from zero to $5.00.

A range of other water quality benefits are obtained from Ribaudo (1990) including:

- *Commercial fishing* benefits, which result from reduced sediment loads in coastal estuaries that serve as breeding grounds for many species;
- *Flooding*-related benefits derive from reduced cost of flood clean up due to reduced sediment concentrations in flood waters;
- *Water conveyance* benefits result from reduced cost of removing sediment from water conveyance facilities, primarily drainage ditches and irrigation canals;
- *Water treatment* benefits are the result of lower water treatment costs due to reduced sediment loads;
- *Municipal and industrial* benefits are due to reduced damage to water-use equipment from minerals, salts, and other materials associated with soil erosion;
- *Steam-electric power plants* that rely on water-cooling benefit from reduced sediment through reduced wear on facilities.

Nutrient Management (nitrogen runoff): Water quality damage due to nitrogen can occur anywhere, but is more common in coastal estuaries where nitrogen, rather than phosphorous, is most often the limiting nutrient in excess algae growth and eutrophication. The likelihood of nitrogen transport to coastal areas is used as a proxy for potential water quality damage. Transport coefficients, which represent an estimate of the proportion of nitrogen runoff that is transported to the coast, were drawn from the SPARROW model developed by U.S. Geological Survey researchers (Smith, Schwartz, and Alexander, 1997).

Normalizing Index Subcomponents

Relative Damage Estimates (RDEs) are normalized to the unit interval:

$$N_{jm} = \frac{\max(RDE_{jm}, P95(RDE_{jm})) - \min(RDE_{jm})}{P95(RDE_{jm}) - \min(RDE_{jm})}.$$

where RDE_{jm} indicates a farm-specific value and $\min(RDE_{jm})$ and $P95(RDE_{jm})$ indicate the minimum and 95th percentile values across all farms, respectively. The 95th percentile is used, rather than the maximum, to prevent outliers in the data from depressing index scores for other farms.

A special consideration applies to the soil productivity component. Because loss of soil depth to wind or water erosion can cause productivity damage, the soil productivity weight is the same for wind and water erosion and is designed to capture the full value of soil loss from both sources. Including independently normalized intensity/damage terms for each would result in double-counting for soil productivity in relation to the normalized intensity/damage terms for sediment runoff or windblown dust. To correct for this possibility, the soil productivity terms are normalized as:

$$0 \leq \varphi N_{crop,water} + (1-\varphi) N_{crop,wind} \leq 1,$$

where $\varphi = \frac{RDE_{crop,water}}{RED_{crop,water} + RDE_{crop,wind}}$. These additional weighting factors are included with the normalized subcomponents for water and wind erosion.

Index weights

Initial weights are based roughly on the EBI, with points added for the inclusion of grazing land in the model:

- Roughly one-third of points are for soil erosion on cropland. Points are given for potential of erosion control to reduce dust (improve air quality), preserve soil productivity and reduce sediment loads to water.
- Another third are for other water quality-related treatments, including nutrient management and pest management on cropland, nutrient management and riparian erosion on grazing land, and grazing land health.
- Remaining points are for wildlife habitat enhancement (split evenly among all 3 land types).

The weights that are actually used in the model are given in table A1.2.

Table A1.2
Initial index weights

Component (treatment (k))	Subcomponent (physical effect (m))	Weights		
		Nonirrigated cropland	Irrigated cropland	Grazing land
Wind erosion	Dust	.03	.03	--
	Soil productivity	.10	.10	--
Water erosion	Sediment	.07	.07	--
	Soil productivity	.10	.10	--
Nutrient management	Nitrogen leaching	.04	.04	--
	Nitrogen runoff	.04	.04	--
	Phosphorous runoff	.04	.04	--
Pest management	Pesticide leaching	.04	.04	--
	Pesticide runoff	.04	.04	--
Grazing land health	Grazing land health	--	--	.06
Nutrient management and riparian erosion	Nutrient and sediment grazing land	--	--	.14
Wildlife	Habitat restoration	.20	.20	.20
Totals		.70	.70	.40

Source: USDA, Economic Research Service.