Environmental Risk Management in the Horticultural Industry

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Short Abstract

This paper uses environmental risk assessment as a nutrient management planning tool to determine the best set of actions to control nutrient nonpoint source pollution in the horticultural industry. The framework minimizes costs subject to obtaining an environmental risk management score at or below a threshold value.

Introduction

The issue of regulatory structure has received increased attention as the U.S. EPA and the USDA have sought to control more pollution from agricultural nonpoint sources (USDA and USEPA, 1999). Regulations of point sources have traditionally employed a command and control (C&C) structure whose constraints were often set by assessing the abilities of the best available technology to reduce pollutants. Economists have long argued that this type of approach is costly to the industries involved (for a review see Batie and Ervin, 1999). This type of regulatory control can stifle innovation by making it more difficult to use new technologies and by reducing the potential benefits from new technologies. Still, for many point source pollutants, the homogeneity within an industry tends to limit the losses from uniform C&C regulations.

As regulators increase their focus on nonpoint source pollutants, the disadvantages of a uniform C&C type structure become more apparent. The heterogeneous nature of many nonpoint pollution sources limits the ability to use a C&C structure and impedes its effectiveness. Many nonpoint source pollutants (NSP) result from agricultural sources (US EPA, 1996). The wide range in inputs to agricultural production (crop variety, soil and field characteristics, management skills) limits the effectiveness of single technology or best management practice solutions to agricultural NSP. Control of agricultural NSP requires a multitude of best management practices and other innovations tailored to the individual farm's characteristics. Optimal regulation of this type of pollutant should enlist flexible controls that allow each polluter to choose that set of practices and technologies that best enables her/him to reduce pollutants to some regulated level. Flexible regulations of agricultural NSP allows the industry to meet regulatory goals at the least cost to individual farms and fields.

Managing NSP from Maryland's Horticultural Industry

Locally, environmental incidents such as the 1997 outbreak of *Pfiesteria piscicida* in the Chesapeake Bay are putting increased pressure on agriculture to reduce NSP. The Chesapeake Bay region has been particularly active in trying to control agricultural NSP. The federal government and state and local governments have been cooperating for the past 17 years in an effort to improve water quality in the Bay (US EPA, 1983). This effort has significantly reduced pollution from point sources. Unfortunately, overall levels of pollution in the watershed have not been reduced as much as had been anticipated. Recent actions to reduce nutrient pollution have focused on controlling the agricultural industry's handling of both commercial fertilizers and animal manures. In 1998, the state of Maryland passed a law to regulate all nutrient applications to agricultural land. This law requires all farmers to obtain and follow a nutrient management plan that is designed to control the amount of nutrients leaving the farm's fields (either through surface waters or ground waters). Federal agencies are looking at this state program as a model for national regulations to reduce NSP. Maryland's comprehensive approach will impact its crop farmers and animal producers, as well as the less traditional agricultural producers such as the horticultural and turf grass industries.

The horticultural industry uses high levels of nutrients to produce high quality plants in short periods of time. Traditionally, this industry has been overlooked when regulating the agricultural industry. Although a relatively small industry in terms of acreage, the horticultural industry is a significant agricultural industry in terms of revenues produced (over 40% of the value of all crops grown in Maryland) (Hanson, 1989). The nutrient use practices of Maryland's horticultural industry are now regulated as part of the state's 1998 nutrient management law (Simpson, 1999).

Nutrient management planning is new to the horticultural industry, and no accepted method of developing and implementing nutrient management plans exists. The key difference between nutrient management for the horticultural industry and for other crops is the number of crops that must be considered in the plan. Some horticultural producers grow over 300 different types of plants in a year. Traditional nutrient management plans are written to meet the nutrient needs of a specific crop. Managing the nutrient needs of 300 individual crops makes traditional nutrient management an unreasonable approach to nutrient management in the horticultural industry. Researchers at the University of Maryland have been working to create a nutrient management planning process for the horticultural industry that uses environmental risk assessment to determine the best set of actions to control nutrient NSP. This paper describes the environmental risk assessment process and develops a framework for evaluating alternative strategies to control environmental risk.

Environmental Risk Assessment

The environmental risk management approach uses a weighting matrix to assess the contribution of different factors to NSP (Tables 1A-E). Ranking the set of environmental risk factors in the environmental risk management table produces a total environmental risk score (Table 1F). Environmental risk management seeks to identify those factors that can be modified to bring, or keep, that risk score below some threshold value. The cost of reducing the environmental risk of NSP depends on the set of factors that are modified to reduce the environmental risk score. Controllable factors that influence environmental risk can be separated into two categories: site-specific factors and management-specific factors.

Site-specific factors are analogous to fixed factors of production (Tables 1A and 1E). Most site-specific factors can be modified, but usually at a significant cost or only in the long run. These factors can be physical characteristics of the land, or long-term investments in facilities or major production equipment. Site-specific factors that influence the movement of nutrients from a horticultural production site include such items as the slope of the site, distance to water bodies, riparian buffers, containment ponds and recycling of irrigation water. Modification of site-specific factors may significantly impact the environmental risk score, but often at a very high cost to the producer.

Management-specific factors are those flexible factors that can be changed to reduce environmental risks (Tables 1B-D). Some management-specific factors include plant density/spacing, soil/pot volume, plant growth rates, fertilizer rates, fertilizer type, application timing, irrigation systems, and irrigation management. While many management-specific factors can be altered at relatively low costs, their impacts on the environmental risk assessment score vary significantly.

The framework developed in this paper seeks to minimize production costs subject to obtaining an environmental risk management score at or below a threshold value. The cost-effectiveness of environmental risk-reduction strategies differs by site characteristics, production practices, and plant material. Therefore, there are many possible combinations of activities that may reduce the risk of nutrient runoff to the environment. The framework assesses the tradeoffs between the costs of altering a site specific or management-specific production factor, and the effectiveness of that alteration in bringing the total environmental risk score into compliance.

Model of Environmental Risk Management

The environmental risk assessment score relates a set of management practices and technology choices to the quantity of pollutants leaving the nursery. The quantity of pollutants has two components: quantity of water and concentration of pollutants in the water.

Let X be the quantity of water runoff per acre from a cost-minimizing set of management practices and technology choices. The determinants of X include many items from the environmental risk assessment matrix. Let A be the size of the nursery.

Therefore, XA is the total quantity of pollutants leaving the site. The concentration of nutrients in the runoff is dependent upon the quantity of nutrients used, less the quantity absorbed within the nursery. The quantity absorbed within the nursery will depend upon the timing and source of nutrients and upon plant uptake. Plant uptake is going to be dependent upon the nutrient demands of the particular plants grown by the nursery.

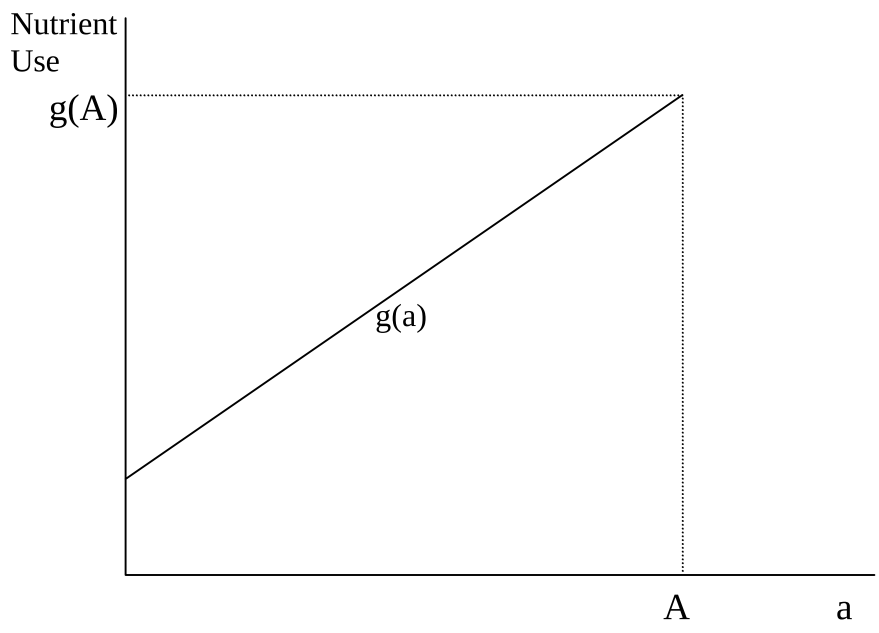
The horticultural industry produces hundreds of different types of plants in a year. Different varieties require different levels of nutrients. However, it is not possible for the nursery to set a different nutrient level for each of the varieties. Thus, the industry uses high levels of nutrients to produce high quality plants in short periods. High levels of nutrients are necessary for the industry to ensure that each type of plant gets sufficient nutrients.

One management option is thus to split the nursery into different management units so that different levels of nutrients can be applied to different groups of plants. Before considering the decision whether to split the nursery, we will develop the single management unit case.

Single Management Unit

Ignoring the other nutrient uptake factors, we can order the nursery's stock of plants according to nutrient demand such that we produce a function g(a) that gives nutrient uptake across the range of plants in the nursery. Thus, $g'(a) > 0$. For instance, for a nursery with an equal number of plants at each level of nutrient use, ordered from low-nutrient users to high-nutrient users, we can show g(a), as in Figure 1.

Figure 1. Distribution of Nutrient Users Across Nursery



The nursery needs to set the nutrient level such that each of the plants gets the minimum level of nutrients it requires. As a result, the highest nutrient user is the only plant to get the exact required level of nutrients. Thus, the nursery would set nutrient supply levels at g(A) for all plants in the nursery, producing Ag(A) levels of nutrients for the nursery as a whole. For all plants ranked below A, the supplied nutrients are higher than required. The function g(a) gives us the absorption rate of nutrients by the nursery such that the total concentration of excess nutrients in the nursery can be written $Ag(A) - \int_0^A g(A)da$. If we combine this with the water runoff factor, the total quantity of nutrients leaving the nursery can be written $X\left[Ag(A) - \int_0^A g(A)da\right]$.

The total cost function for the nursery can be written $\underline{C}(A, X) = AC(A, X)$. Assume that $C_X < 0$, and $C_{XX} > 0$: reducing runoff increases costs at a decreasing rate. Solving the standard cost minimization problem subject to the regulatory constraint, $X\left[Ag(A) - \int_0^A g(A)da\right] \le KA,$ where K is the regulatory constant, reveals the marginal cost of pollution control for the nursery when managed as a single unit.

$$\frac{AC_X}{Ag(A) - \int_0^A g(A)da}. \tag{1}$$

Multiple Management Units

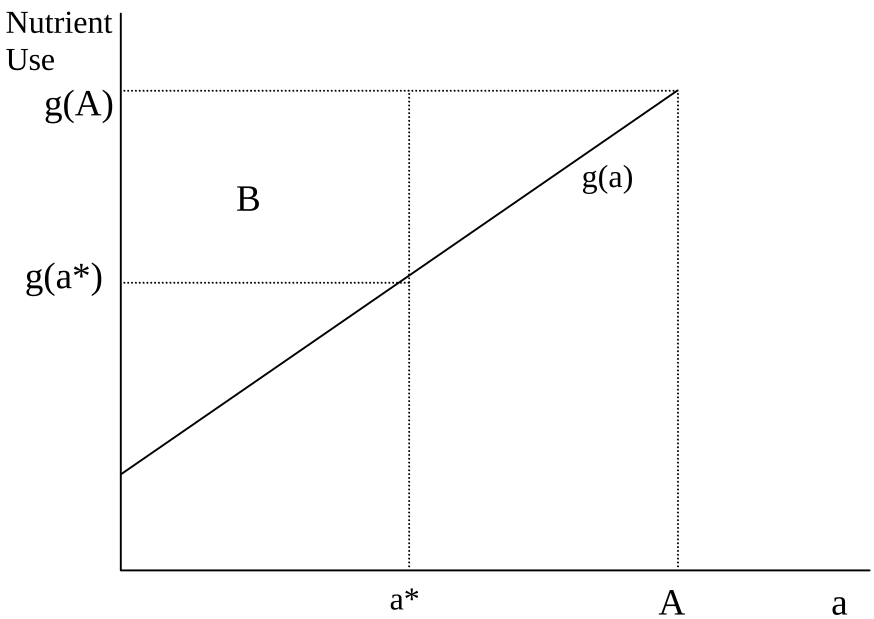
We begin with the decision to split the nursery into two management units. Each unit may choose a different level of runoff, X, to meet the combined water quality restrictions for the nursery. An additional decision for the model is how to split the nursery along the nutrient use scale, shown in Figure 1. We are splitting the nursery in such a way that any plant in plot 1 ($0 \rightarrow a^*$) requires lower levels of nutrients ($g(a^*)$) than any of the plants in plot 2 ($a^* \rightarrow A$) with nutrient application level $g(A)$, where A is the total area of the nursery (Figure 2).

For the split nursery, pollution run-off can be written

$$X_{a^*}\left[a^* g(a^*) - \int_0^{a^*} g(a)da\right] + X_A\left[(A-a)g(A) - \int_{a^*}^A g(a)da\right], \tag{2}$$

where X_{a^*} is the quantity of runoff from the optimal set of management practices and technologies associated with the management unit from $0 \rightarrow a^*$, and X_A is the quantity of runoff from the optimal set of management practices and technologies associated with the management unit from $a^* \rightarrow A$. Returning to Figure 2, it is obvious that the decision to split the nursery results in a reduction in pollution concentration in the runoff that is equal to area B.

Figure 2. Distribution of Nutrient Users Across Split Nursery



The cost of production for the combined nursery is $\underline{C}(a, A\text{-}a, X_a, X_A)$. If we assume this is additively separable (for easier exposition!), we can write the cost for the multiple management case

$$\underline{C}(a, A-a, X_a, X_A) = aC(a, X_a) + (A-a)C(A-a, X_A) + F(a), \quad (3)$$

where F(a) is the additional management costs involved in managing the nursery as more than one unit. In general, the choice of X implies a choice of a combination of factors such as management efficiency, slope, and irrigation technology. Assume that $C_a \leq 0$ and $C_{aa} \geq 0$, which allows for economies of scale.

It is worth mentioning that $\underline{C}$(a, A-a, X_a, X_A) simplifies to $\underline{C}$(A, X)=AC(A, X) for the usage of a single technology, i.e., when a* = 0. Here we assume that F(0)=0, F(a)>0 for a>0, and F is invariant in positive a.

Analysis of the multiple management unit case seeks to split the whole nursery, calculate the benefits from lowering pollution in this way, and compare this benefit with the cost of splitting. The problem for the nursery is to minimize the cost it incurs for its output of X_{a*} and X_A, and its choice of a* subject to four constraints. Mathematically the problem is to choose X_{a*}, X_A, and a* to solve the following problem:

$$\begin{aligned}
&\underset{X_a, X_A, a}{Min}\ aC(a, X_a) + (A-a)C(A-a, X_A) + F(a)\\
&\qquad subject\ to:\\
&\qquad\quad a \geq 0\\
&\qquad\quad X_a \geq 0\\
&\qquad\quad X_A \geq 0\\
&\qquad\quad X_{a*}\left[a^* g(a^*) - \int_0^{a^*} g(a)da\right] + X_A\left[(A-a)g(A) - \int_{a^*}^{A} g(a)da\right] \leq KA.
\end{aligned}$$

The first three constraints simply restrict the amount of X_{a*} and X_A used, and the choice of a* to be nonnegative. The final constraint controls the amount of nutrients (i.e., pollution) leaving the nursery through water runoff to be below some regulated level.

The constraint $X_{a*}\left[a^* g(a^*) - \int_0^{a^*} g(a)da\right] + X_A\left[(A-a)g(A) - \int_{a^*}^{A} g(a)da\right] \leq KA$

must hold as an equality in the optimal solution. Since higher X's are associated with lower costs, it is in the nursery's interest to set X's as big as possible to minimize costs. Let's consider the interior (i.e., a>0, X_{a*} >0 , X_A >0) solution. As a result, the original problem translates into the following:

$$\underset{X_a, X_A, a}{Min} \; aC(a, X_a) + (A-a)C(A-a, X_A) + F(a)$$

$$subject\ to:$$

$$X_{a*}\left[a * g(a*) - \int_0^{a*} g(a)da\right] + X_A\left[(A-a*)g(A) - \int_{a*}^{A} g(a)da\right] \leq KA.$$

This is a simple constrained minimization problem. The solutions to the Lagrangian function associated with this are

$$\frac{\partial L}{\partial X_a} = aC_{X_a}(a, X_a) - l\, ag(a) = 0, \tag{4}$$

$$\frac{\partial L}{\partial X_A} = (A-a)C_{X_A}(A-a, X_A) - l\,(A-a)g(A) = 0, \; and \tag{5}$$

$$\begin{aligned} \frac{\partial L}{\partial a} = C(a, X_a) + aC_{X_a}(a, X_a) - C(A-a, X_A) - (A-a)C_{X_A}(A-a, X_A) - \\ l\left\{X_{a^*}\left[g(a*) + a * g'(a*) - g(a*)\right] - X_A\left[g(A) - g(a*)\right]\right\} = 0. \end{aligned} \tag{6}$$

From equations (4) and (5), we obtain

$$l = \frac{C_{X_a}(a, X_a)}{g(a)} = \frac{C_{X_A}(A-a, X_A)}{g(A)}, \tag{7}$$

where represents the cost of the pollution constraint. Equation 7 implies that the marginal cost of pollution reduction through a reduction in runoff, adjusted for pollutant concentrations, should be set equal across the two management units of the nursery. In other words, we choose X_{a*} and X_A in such a way that they equalize the marginal benefits per dollar spent on each of these factors.

Equation (6) can be simplified to

$$\frac{C(a, X_a) + aC_{X_a}(a, X_a) - \left[C(A-a, X_A) + (A-a)C_{X_A}(A-a, X_A)\right]}{X_{a^*} a * g'(a*) - X_A\left[g(A) - g(a*)\right]} = l. \tag{8}$$

The numerator in equation (8) is the change in cost associated with the change in runoff that results from a change in the division of the nursery's management units, a*. The first two terms of the numerator show the increase in costs from increasing a*. The increase in costs are equal to the extra costs of an additional unit of the nursery being added to the low nutrient level user's management group, plus the increase in costs to the entire management group associated with the decrease in runoff per acre which will be necessary to maintain the pollution restriction. The term in square brackets is the decrease in costs to the high nutrient user group from a reduction in size of the group. The decreases in costs are equal to the decrease in costs from having one less unit to produce, plus the decrease in cost from the increase in runoff per acre that will be associated with the relaxation of the constraint on pollution runoff.

The denominator in equation (8) is the change in pollutant runoff from a shift in the size of the two management units. The first term of the denominator shows the increase in pollutant runoff associated with the increase in pollutant concentration that affects the low nutrient level group. The second term of the denominator shows the decrease in pollutant runoff from the high nutrient user group. The decrease in pollutant runoff is equal to the decrease in pollutant load to the portion of the nursery that was shifted to the low group minus the nutrient absorption by that portion of the nursery.

The entire term in equation (8) states that the size of the two management groups should be adjusted until the costs of changing the relative sizes, adjusted for pollutant runoff, is equal to the costs of maintaining the constraint. Equations (6) and (8) show that the two strategies of water runoff control and adjusting the nutrient user groupings should simultaneously reduce pollution runoff to the point where the costs of reducing another unit of pollution runoff from altering any of the strategies is just equalized. Thus, using equations (6) and (8), we can find the optimal values for X_{a*}, X_A, and a*.

Discussion

Choices in management and technology that affect X_{a*} and X_A can be found in the Environmental Risk Index (Table 1A-F). The nursery owner can alter such items as irrigation technology, slope of the nursery, containment basins, pot size and spacing, or irrigation management. The pollutant concentration function depends upon parameters in the Environmental Risk Index such as fertilizer levels, fertilizer type, fertilizer management, irrigation technology, and irrigation timing. Pollutant concentration also depends on the distribution of nursery stock.

So far, we have assumed a uniform distribution of stock over nutrient users. This produces a linear g(a) function where the optimal solution for a* is approximately $A\frac{1}{2}$ (Figure 2)[1]. Each nursery will have a different distribution of nutrient users. In the long run, it may be optimal for nurseries to further limit their stock and focus on similar nutrient users. In the short run, nurseries are assumed to maintain their current stock distributions. The distribution of nursery stock will depend upon the nursery management's preferences and its market position.

Three other distributions are shown in Figure 3. The predominantly high nutrient user nursery (concave function) would set a low a*. A predominantly low nutrient user nursery (convex function) would set a high a*. If the cost functions are similar to each other, the mixed nutrient level nursery (S-shaped function) would choose a* in the

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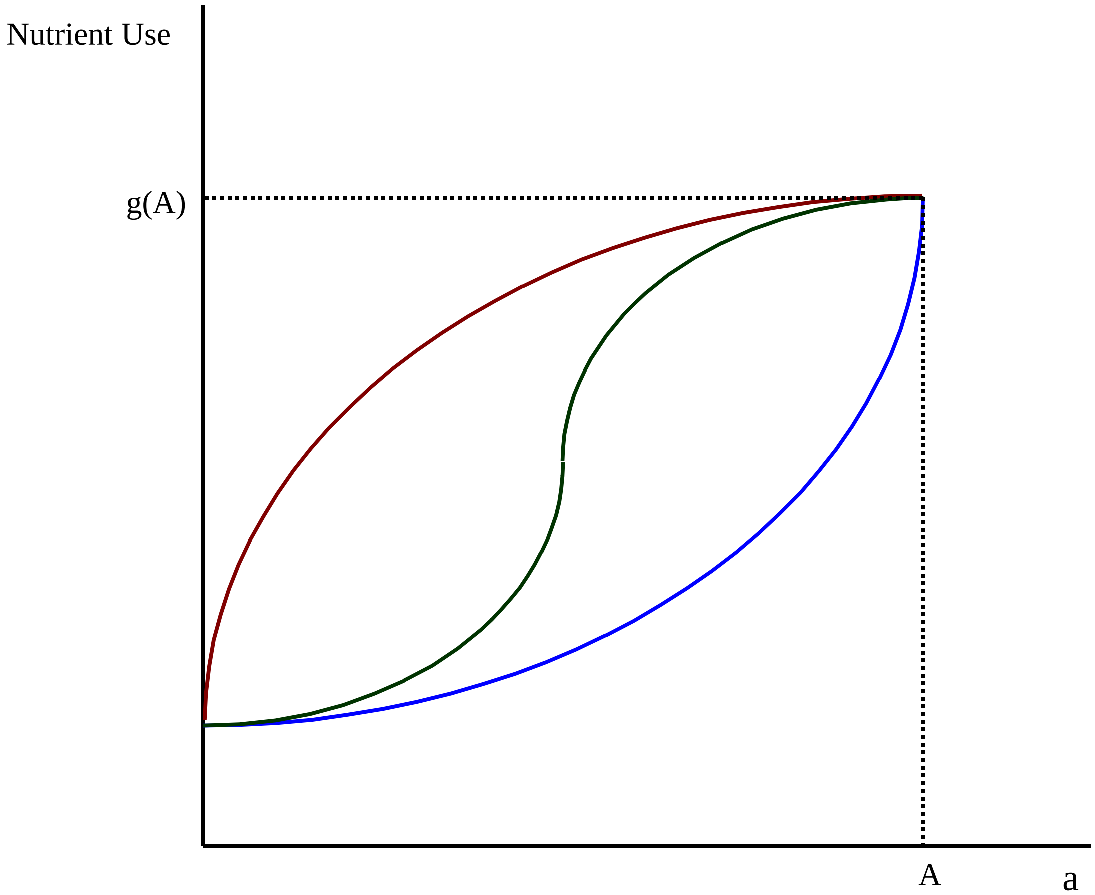
[1] In fact, if the cost of runoff functions have the same shapes, the optimal solution is $a^* = A\frac{1}{2}$.

convex portion of the curve. Large differences in the cost function could push a* into the concave region.

Figure 3. Alternative Nutrient Use Distributions



Conclusions

The framework for economic environmental risk management developed in this paper is being tested on a limited scale using data from ongoing field studies of horticultural management. These studies, being carried out by researchers at the University of Maryland, are assessing the environmental risks from different types of irrigation equipment, different fertilizer sources, different fertilizer application rates, and different pot sizes and spacings. Economic information on the physical and management costs of these alternatives will be simulated using data from industry sources.

The goal of this paper is to show that managing environmental risks of NSP can be done in a manner that protects the horticultural industry while addressing environmental concerns. The environmental risk management approach allows us to evaluate the impact of implementing site-specific modifications and alternative management practices to reduce leaching and runoff of nutrients. Incorporating the environmental risk management approach into an economic framework allows us to assess the tradeoffs between modifying high, medium, and low environmental risk activities, and assess the economic costs of alternative strategies to control environmental risk.

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Table 1A. Site Risk Assessment

	Risk Assessment Score				Risk Factor Explanation
Fixed Variables	**Zero (=0)**	**Low (=1)**	**Medium (=2)**	**High (=4)**	
Topography (Grade/Slope)					
Site Compaction					
Average Monthly Rainfall					
Proximity to Flowing Water					
Riparian Buffers (Presence)					
Soils					
Water Source (Well)					
Depth to Groundwater					
Subtotal					
Dynamic Variables (Ilex)					
Roadways (Paved, Dirt)					
Ditch Condition					
Containment Ponds					
Growing Structures					
House Surface					
Subtotal					
Total					

Table 1B. Soils and Substrates Risk Assessment

	Risk Assessment Score				Risk Factor Explanation
Fixed Variables	**Zero (=0)**	**Low (=1)**	**Medium (=2)**	**High (=4)**	
Growing Method (Spacing?)					
Container Size					
Subtotal					
Dynamic Variables (Ilex)					
Growing Substrate					
Total Porosity					
Substrate Testing Proc.					
Substrate Composition					
Infiltration					
Water-holding Capacity					
Bulk Density					
pH					
EC					
Subtotal					
Total					

Table 1C. Irrigation Risk Assessment

	Risk Assessment Score				Risk Factor Explanation
Fixed Variables	**Zero (=0)**	**Low (=1)**	**Medium (=2)**	**High (=4)**	
Irrigation System					**Water Application Risk**
					Complete this assessment **only** for growing
					areas with a **medium** or **high** risk
					contribution in the Surface Water Assessment
					a) Zero risk = Microirrigation or subirrigation
					with less than total capture and recycling of water,
					regardless of container size
					b) Low risk = Microirrigation or subirrigation
					with less than total capture and recycling of water,
					regardless of container size, **OR** Overhead irrigation
					applied to pot-to-pot (placed) containers smaller than
					1 gallon (<1242 cm3 container volume).
Subtotal	**0**	**0**	**0**	**0**	
Dynamic Variables					
Irrigation Strategy (cyclic or not)					**c) Medium risk** = Overhead irrigation applied to
Average Irrigation Time					pot-to-pot (placed) containers from 1 to 5 gallons
Leaching Fraction					(1,242 to 20,360 cm3 container volume), **OR** overhead
					irrigation applied to spaced containers smaller than
					3 gallons (<12,860 cm3 container volume).
					d) High risk = Overhead irrigation applied to
					spaced containers from 3 to 5 gallons (12,860 to
					20,360 cm3 container volume), **OR** overhead
					irrigation applied to containers larger than 5 gallons
					(>20,360 cm3 container volume), regardless of spacing.
Subtotal	**0**	**0**	**0**	**0**	
Total	**0**	**0**	**0**	**0**	

Table 1D. Fertilization Risk Assessment

	Risk Assessment Score				Risk Factor Explanation
Fixed Variables	**Zero (=0)**	**Low (=1)**	**Medium (=2)**	**High (=4)**	
Soil Substrate					
Granular Fertilizer					
Slow Release					
Standard					
Liquid Fertilizer					
Subtotal	**0**	**0**	**0**	**0**	
Dynamic Variables					
Subtotal	**0**	**0**	**0**	**0**	
Total	**0**	**0**	**0**	**0**	

Table 1E. Surface Water Risk Assessment

	Risk Assessment Score				Risk Factor Explanation
Fixed Variables	**Zero (=0)**	**Low (=1)**	**Medium (=2)**	**High (=4)**	**A. For Growing areas draining to**
					Containment Basins:
					a) Zero risk = Growing area covered; Precipitation does not contact
					substrate, **AND** Growing area is on Impervious surfaces, **AND** there
					is total capture and recycling of water
					b) Low Risk = Containment Basins sized to hold >90% of max. daily
					irrigation, **AND** some recycling or water from basins, **OR** some
					provision(diking, containment, wetlands) for overflow of basins
					c) Medium Risk = Containment basins sized to hold >90% max.
					daily irrigation, **AND** there is no recycling of water from basins, **AND**
					there is no provision for overflow from containment basins
					d) High Risk = Containment basins sized to hold <90% of max.
					daily irrigation.
Subtotal	**0**	**0**	**0**	**0**	
Dynamic Variables					
					B. For Growing areas <u>NOT</u> draining to Containment Basins:
					a) Zero risk = Growing area covered; Precipitation does not
					contact substrate, **AND** Growing area is on Impervious surfaces,
					AND Total capture and recycling of water
					b) Low Risk = Drainage is spread out to sheet flow, **AND** flows
					through at least 50 ft. of vegetation
					c) Medium Risk = Drainage is spread out to sheet flow, **AND** flows
					through < 50 ft. of vegetation
					d) High Risk = Drainage remains channeled to surface water; **OR**
					drainage flows through no vegetation
Subtotal	**0**	**0**	**0**	**0**	
Total	**0**	**0**	**0**	**0**	

Table 1F. Summary Risk Assessment

	Risk Assessment Score			
Fixed Variables	**Zero (=0)**	**Low (=1)**	**Medium (=2)**	**High (=4)**
Site	0	0	0	0
Soils and Substrates	0	0	0	0
Irrigation	0	0	0	0
Fertilization	0	0	0	0
Surface Water	0	0	0	0
Subtotals	**0**	**0**	**0**	**0**
Dynamic Variables				
Site	0	0	0	0
Soils and Substrates	0	0	0	0
Irrigation	0	0	0	0
Fertilization	0	0	0	0
Surface Water	0	0	0	0
Subtotals	**0**	**0**	**0**	**0**
Totals	**0**	**0**	**0**	**0**

Grand Total =	**0**