Chapter 4

Standards

Standards legally require or mandate that producers behave in a specified manner. Policymakers use standards to control nonpoint pollution by mandating that producers act in a more environmentally conscious manner. In this chapter, we detail a variety of standards that may be used for nonpoint pollution control and evaluate them according to several criteria related to instrument design and implementation.

Introduction and Overview

Economic incentives use the price system to get producers to take into account externalities such as polluted runoff. An alternative approach is to legally require or mandate that producers behave in a specified manner. For example, producers may be required to limit input use to a specified level, or they may be required to adopt a specific technology. Behavioral mandates are traditionally referred to as command and control regulations or standards. Traditional water quality policies in the United States, aimed primarily at point sources, have relied on standards.

Standards can be applied either to producers' actions (design standards) or to the results of their actions (performance standards). For point sources, the preferred basis for choosing a standard is emissions because emissions are closely tied to damages and are easy to measure (Baumol and Oates, 1988). However, the choice is not so clear for nonpoint sources, where runoff and other physical processes are difficult or even impossible to observe.

In this chapter, we detail two classes of incentive bases that may be used for nonpoint pollution control:
(1) performance-based standards (i.e., standards in the form of runoff or ambient concentrations), and
(2) design-based standards (i.e., standards in the form of restrictions on inputs and technology). We discuss the major characteristics of and policymakers' experience with a variety of specific standards (table 4-1 lists the standards that are covered in this chapter and provides examples of actual applications of each). Specifically, the optimal form of each standard is developed and evaluated according to (1) its relative efficiency, (2) its relative complexity, (3) informational requirements of regulators in designing the standard and of producers in using the standard to evaluate their decisions, (4) the flexibility of the standard to changing economic and environmental conditions, and (5) potential administration and enforcement costs.

Performance Standards

Performance standards consist of regulations placed on observable outcomes of a polluter's decisions. For point sources, performance standards are placed on the amounts of pollutants in the effluent leaving the plant. Such discharges are easy to observe and to monitor. The situation is more complex for agricultural nonpoint pollution, however. Agricultural performance bases (i.e., runoff, ambient pollution levels, or damages) cannot be controlled deterministically (without randomness) due to the natural variability associated with the nonpoint process. Therefore, agricultural performance-based standards must be defined in terms of the probability of attainment. For example, consider a standard based on runoff. The standard could be defined in terms of the mean or variance (or other moments) of runoff levels, or it could be defined in terms of a probability (e.g., runoff must not exceed a target level more than 95 percent of the time).

Performance-based standards have several drawbacks. Monitoring would have to occur over a period of time to determine the sample distribution of the base. For example, suppose the standard requires that a producer's mean monthly runoff levels are no greater than z. In this situation, it would not be appropriate to take a single monthly measurement and determine a producer to be noncompliant if actual runoff levels are greater than z. Instead, measurements must take place over a

Table 4-1—Types of standards and examples

Standards	Actual applications
Performance-based:	
Runoff	None in existence
Ambient	None in existence
Design-based:	
Inputs	Pesticide label rates; nutrient control laws in several States
Technology	Water quality protection laws in a number of States; Coastal Zone Act Reauthorization Amendments
Expected runoff	Erosion law in Ohio

number of months to obtain a large enough sample to have a good estimate of mean monthly runoff levels. Only then could a producer be determined to be in or out of compliance. The required timeframe for monitoring may be significantly longer for some pollutants due to long time lags associated with the delivery of the pollutant to a water body. Some agricultural chemicals, such as phosphorus, can build up in the soil. Changes in management may not result in changes in water quality until the chemical stored in the soil is depleted. It may therefore take years to determine if producers are in compliance with an ambient standard.

Neither the resource management agency nor producers can observe runoff, so it is not possible to determine whether or not a producer is in compliance with such a standard. For ambient standards, producers must have perfect information about their own contribution to ambient pollution levels and also the contributions of others for the standard to be effective (because they must be able to predict how their actions will influence ambient pollution levels). In addition, all producers must have identical expectations about random processes. These requirements severely decrease the likelihood of an ambient standard's being an effective policy measure.

In summary, performance standards based on runoff or ambient quality are not feasible policies for controlling nonpoint-source pollution, given current monitoring technology. Fortunately, removing runoff- or ambient-based performance standards from the set of possible policy tools does not necessarily imply a loss of efficiency. Shortle and Dunn (1986) have shown that design-based standards are more efficient than those based on runoff when economic and environmental uncertainty exists.

Design Standards

Design standards place restrictions on the use of polluting inputs and/or production and pollution control technologies that are consistent with meeting particular environmental goals. A producer's actions, which are inherently observable by a resource management agency, are therefore the basis for compliance as opposed to whether or not an environmental goal is actually achieved.[1] Two subclasses of design-based standards are discussed in this section. The first subclass is based on expected runoff. The second subclass is based directly on inputs and technology.

Expected-Runoff Standards

Expected runoff is the level of runoff that is expected to result from a producer's production and pollution control decisions (i.e., input use and technology choices). A design standard based on expected runoff differs from a performance standard based on mean runoff levels because compliance under the former is determined by monitoring each producer's input and technology choices, and then using computer models to determine expected runoff levels. Under such a standard, producers are free to choose input levels and technology in the most efficient combinations as long as the standard is achieved. In addition, an expected runoff standard allows producers to make use of any private knowledge they might have about combining inputs and technology, but only to the extent that the private knowledge can be captured by a model. Special knowledge that is not recognized by the model is of no use to the producer.

Important to note is that there may be legal problems with basing standards on the resource management agency's expectations about runoff as opposed to actual runoff, especially given the current limited ability of models to accurately predict runoff from input use and technology choice. A summary of expected runoff-based instruments is presented in table 4-2.

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[1] Design standards have played an important role in U.S. water quality policy toward point sources of pollution. The 1972 amendments to the Federal Water Pollution Control Act require all industrial and municipal point sources of water pollution to install "best practicable treatment," "best available treatment," or "best conventional treatment." Implementation of these rules involved defining specific technologies that had to be adopted.

Table 4-2—Evaluation of expected runoff-based standards

Criteria	Efficient (maximize social welfare)	Cost-effective (runoff targets)	Second-best (Uniform standard, imperfect information)
Incentives provided	Instrument does not exist	Good Provides incentives for optimal technology adoption. Additional instruments required to ensure optimal entry/exit. efficiency.	Fair Cost-effective but not efficient. Does not account for heterogeneity in pollution contributions. Additional instruments targeted at technology adoption and entry/exit may increase
Overall complexity	N/A	Medium Optimally designed instrument is site-specific. Use of model simplifies implementation.	Low Optimally designed instrument is uniform across farms. The use of a model simplifies implementation.
Information required by producers	N/A	Medium Access to same model as resource management agency simplifies producer's understanding of link between farming practices and runoff.	Medium Access to same model as resource management agency simplifies producer's understanding of link between farming practices and runoff.
Flexibility	N/A	Medium Producers are able to respond to changing market conditions, within the constraints imposed by the model.	Medium Producers are able to respond to changing market conditions, within the constraints imposed by the model.
Administration and enforcement costs	N/A	High Input and technology choices of each farm must be determined.	High Input and technology choices of each farm must be determined.

N/A = Not applicable.
Note: These rankings are subjective, based only on theoretical properties as opposed to empirical evidence. A more reliable table would be based on empirical results that compare each type of policy according to a consistent modeling framework that is representative of the nonpoint problem.

Incentives Provided

Any set of runoff standards will lead to a cost-effective solution. A runoff-based, cost-effective solution is one in which producers will endeavor to meet a mean runoff standard at least cost. As long as producers are profit maximizers, this will be their goal when faced with any expected runoff standard. Optimal entry/exit in the sector is ensured by setting the standard at a level such that it is more profitable for extramarginal farms to retire land from production.

The relative efficiency of the outcome depends on what standards are set. As illustrated in appendix 2B, the use of expected runoff standards will lead to an efficient outcome or an outcome that achieves a mean ambient pollution goal at least cost only under highly restrictive conditions (Horan 1998).[2] Even so, a target that better reflects a site's contribution to expected damages will be more efficient than one that does not.

Applying uniform standards to all farms is a relatively inefficient method of controlling nonpoint pollution. Given that a resource management agency would have to construct a model of each site to determine compli-

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[2] Specifically, an efficient standard exists when either (1) the producer makes only a single decision that influences runoff or (2) the covariance between marginal damages and marginal runoff levels is zero for each input (Horan, 1998).

ance, the cost savings of a uniform approach would likely be minimal. Failing to tailor standards to site-specific or regional circumstances results in poor allocative efficiency. As with uniform taxes, uniform standards result in high- (low-) damage-cost farms using more (less) of each pollution-increasing input than is efficient and less (more) of each pollution-decreasing input than is efficient. In addition, uniform standards may not limit acreage in production in the region. Thus, uniform standards do not provide for the efficient scale of the sector. Failure to impose additional standards or other instruments on producers operating on extramarginal acreage further compromises efficiency.

An expected runoff standard will be effective only if producers understand how their production and pollution control decisions will influence expected runoff. The resource management agency may provide producers with this information by giving them access to runoff models that are used for determining compliance. Note that heterogeneous expectations are not a concern here as they are for performance-based standards because compliance is determined using the resource management agency’s expectations. There would be no benefit to producers from using their own expectations.

Relative Complexity of the Standard

An expected runoff standard is administratively complex because input use and technology choices must be monitored for each site to determine expected runoff levels (using a model). In addition, producers have to understand how their production and pollution control decisions influence runoff from their farms.

Informational Requirements

The resource management agency requires no special information to set cost-effective standards since the mean runoff target is specified exogenously (i.e., the mean runoff target is not based on any sort of cost-benefit analysis). The resource management agency also requires information on technology and input use from each farm so that runoff can be estimated with a model. The resource management agency’s informational requirements are decreased only slightly when a uniform expected runoff standard is used. Only a single standard needs to be set, rather than a standard for each farm, but information from each farm is still necessary to determine whether the expected runoff standard is being met.

Finally, each producer would have to know how his/her production decisions affect runoff if the instrument is to be effective. Information on the relationship between runoff and production decisions may be provided to each producer by the resource management agency.

Flexibility Provided by Standard

An expected runoff-based standard is moderately flexible. Producers are not restricted in how they meet the standard and have some flexibility in adapting to changing economic conditions. However, their ability to take full advantage of their special knowledge is limited by the sophistication of the models being used to predict expected runoff. Compliance is based on the model predictions.

Administration and Enforcement Costs

Administration, monitoring, and enforcement costs are high for expected runoff standards due to their site-specific nature and because the use of each input and technology by each producer must be monitored to determine (through the use of a model) expected runoff. Costs may be only slightly reduced if uniform standards are implemented, as the expected runoff model must still be applied to each farm to determine whether the standard is being met. Finally, any government assistance to ensure that producers have information about runoff relationships for their farm would likely be expensive.

Input- and Technology-Based Standards

The second subclass of design standards is based more directly on inputs (e.g., levels and forms of agricultural chemicals) and technology (e.g., erosion and runoff controls, irrigation equipment, and collection and use of animal waste). Currently, agricultural design standards have limited use at both the Federal and State levels. Common standards include pesticide use restrictions and bans, the design of animal waste storage lagoons for large concentrated animal feeding operations, and use of nutrient management practices in areas where drinking water is threatened by polluted runoff.

A summary of input- and technology-based standards (not including expected runoff-based standards) is presented in table 4-3.

Table 4-3—An evaluation of design-based standards

Evaluative criteria	Efficient or cost-effective (maximize social welfare or runoff target)	Second-best (uniform, limited set of inputs, imperfect information)
Incentives provided	Good Provides incentives for optimal input use, optimal technology adoption, and efficient entry/exit	Fair Not efficient. Additional instruments may be required to ensure optimal technology adoption and optimal entry/exit.
Overall complexity	High Standards are site-specific, and must be set for each input and technology.	Low Standards set for few inputs or are uniform across fields.
Information required by producers	Low No special information required	Low No special information required.
Flexibility	Low Regulator must change standards as prices change or new technologies are introduced.	Low Regulator must change standards as prices change or new technologies are introduced.
Administration and enforcement costs	High Use of each input and technology choice must be monitored.	Medium Use of easily observed inputs must be monitored.

Note: These rankings are subjective, based only on theoretical properties as opposed to empirical evidence. A more reliable table would be based on empirical results that compare each type of policy according to a consistent modeling framework that is representative of the nonpoint problem.

Incentives Provided

Input and technology subsidies can be designed to achieve an efficient or (any type of) cost-effective outcome (i.e., an outcome that achieves a mean ambient water quality or runoff goal at least cost. See table 2-1). The reason is that input and technology choices, while not equivalent to specific policy goals, are the means by which a resource management agency can achieve its goals. For example, if a resource management agency had absolute control over farm production in a region and wanted to achieve an efficient outcome, it could achieve that outcome by choosing "correct" input use and technologies for the region.

Instruments must target all inputs and technology choices to attain an efficient or cost-effective outcome. Assuming a competitive agricultural sector with no market distortions, ex ante efficient standards would require each producer to employ the efficient site-specific technology and input levels characterized by the three efficiency conditions ((2A-1), (2A-2), and (2A-4)) in appendix 2A. Similarly, cost-effective standards would be the solution to the optimality conditions derived in appendix 2B. Efficient or cost-effective standards are site specific due to land heterogeneity. For example, identical fertilizer application rates on two fields may result in different discharges to surface water because of differences in topography and vegetation between fields and water resources. In addition, standards must be applied to each input that influences pollution, including those that are not currently being used. Input standards typically represent a maximum level of input use that is allowed by law. However, for inputs that reduce runoff, input standards must be defined as the minimum level of input use allowed.

Using standards to control technology is more straightforward than using incentives because the technology choice is mandated as opposed to induced. As a result, the choice of technology in the following discussion is trivial. The resource management agency chooses the technology that yields the greatest level of expected net benefits for society under the framework imposed (i.e., efficient or second-best).

Finally, the efficient scale of production in the industry is guaranteed by setting technology and input standards for production on extramarginal land at levels to prevent profitable operation on this land.

Policies may be designed optimally even when producers retain private information. The resource management agency may have imperfect information about production practices, land productivity, and other site-specific characteristics that affect runoff or economic returns, and producers may be reluctant to truthfully reveal any private information they possess. The resource management agency may therefore have to design a second-best benchmark that does not require obtaining producers' private information.[3] Optimal standards would be the solution to such a benchmark.[4]

Without considering administration and enforcement costs, policy designed with limited site-specific information will generally be less efficient than policy designed under perfect information. However, given the large costs of obtaining site-specific information, policy designed without the benefit of producers' private information may actually be preferred.

Political or legal reasons or costs may limit the ability of a resource management agency to implement site-specific standards for each input that contributes to pollution. Instead, standards may be applied uniformly across sites and applied to only a few inputs, generally reducing administration costs. Inputs to target could be based on ease of observation or measurement. Some management practices, such as the rate at which chemicals are applied, are very difficult to observe without intensive and obtrusive monitoring.

As with incentives applied to a limited number of inputs, optimal standards must be designed to account for input substitution (see appendix 4A). Placing standards on the most easily observed inputs can lead to substitution distortions and undesirable changes in the input mix (Eiswerth, 1993; Stephenson, Kerns, and Shabman, 1996). For example, a standard on herbicides would reduce herbicide use, but may increase mechanical cultivation and soil erosion, which in turn impairs water quality. The resource management agency would have to carefully consider the management alternatives to the undesirable practices, and have in place other measures to counter any undesirable characteristics of the alternatives.

Failing to tailor standards to site-specific circumstances results in poor allocative efficiency. The resource management agency cannot easily target low-cost pollution abaters, and therefore cannot efficiently allocate pollution control efforts to minimize abatement costs. As with uniform taxes, uniform standards result in high (low) damage-cost farms using more (less) of each pollution-increasing input than is efficient and less (more) of each pollution-decreasing input than is efficient. However, unlike the case of uniform input taxes, marginal per acre profits are not equated across farms under uniform standards. In addition, uniform standards may not limit the acreage in production in the region. Thus, uniform standards do not provide for the efficient scale of the sector. Failure to impose additional standards or other instruments on producers producing on extramarginal sites further compromises efficiency.

In general, there is a tradeoff between administration costs and allocative efficiency. Nationwide design standards that are easy to observe, to administer, and to enforce can lower administration costs. Gathering information to better target where controls are applied and developing a broader set of design standards that apply to diverse conditions can significantly increase administration costs. Efficiency is improved if local, rather than national, standards are applied.

Relative Complexity of the Standard

Input- and technology-based standards are relatively simple because they are applied directly to the most basic production decisions. However, these standards are administratively complex because each input and technology choice must be monitored for each farm. Other things equal, site-specific standards will be administratively more complex than uniform standards, and standards applied to each input will be more complex to administer than standards applied to

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[3] Policies designed under imperfect information cannot be designed to attain a specific outcome. With limited information, the resource management agency can design policy based only on how it expects producers to react. Therefore, policy would have to be designed to attain an expected outcome.

[4] Second-best standards, while having many of the same properties as second-best incentives, will generally result in different outcomes. This is addressed in chapter 8.

only a few inputs. Finally, standards designed with limited information will be less complex from an administrative perspective.

Informational Requirements

The resource management agency must have perfect information about production and runoff functions for each acre of land in production to achieve efficient or cost-effective pollution control. However, second-best policies may be designed with only limited information about site-specific characteristics. Producers have no special informational requirements with (efficient, cost-effective, or second-best) input- and technology-based standards. They simply operate under the constraints imposed by the standards.

Flexibility Provided by the Instrument

Input- and technology-based standards (efficient or second-best) leave producers and administrators with little flexibility in making decisions or in adjusting policies to meet changing economic and environmental conditions. Specifically, producers are constrained by the standard, and all adjustments to changing economic conditions must be made through changes in the use of unrestricted inputs and technologies. Changes in economic conditions require the resource management agency to set new standards if pollution control is to be cost effective.

Administration and Enforcement Costs

Administration, monitoring, and enforcement costs are high for all efficient (or cost-effective) design-based standards due to their site-specific nature and because use of each input and technology must be monitored. Second-best standards are less costly to apply because they do not have to be site-specific, nor does every input and technology choice have to be monitored for each acre of land in production.

Application of Design-Based Standards

Until recently, standards had only a limited history of application to agricultural nonpoint-source problems. Performance standards have not been applied to nonpoint-source pollution because it cannot be observed. However, design standards are becoming a more important part of nonpoint-source pollution control policies, primarily at the State level. The performance of most of these programs has yet to be evaluated. Some of the examples presented below are empirical studies of hypothetical nonpoint pollution control programs.

Input Standards

Helfand and House (1995), in a study of lettuce production in Salinas Valley, California, determined cost-effective and second-best input standards when only two inputs—nitrogen and water—influence runoff. To achieve a 20-percent reduction in nitrogen runoff, they found that a uniform rollback of both water and nitrogen use resulted in a welfare loss (relative to the cost-effective baseline) only slightly higher than input taxes. A single standard on water or nitrogen use only resulted in a greater welfare loss.

A study of the economic impacts of alternate atrazine control policies concluded that a partial ban, targeted to particular areas to meet Safe Drinking Water Act standards, was more cost effective than a total ban on atrazine (Ribaudo and Bouzaher, 1994). The cost of reducing surface-water exposure to herbicides under the partial ban was about one-fifth the cost per unit under a total ban. Partial bans allow most producers to continue to use the pesticide, thus limiting increased production costs to relatively few producers. Administration and enforcement costs are higher for partial bans.

Technology Standards

Many States have incorporated enforceable mechanisms for agricultural runoff in their water quality policies (table 1-5 in chapter 1). These mechanisms almost always consist of a farm-level management plan built around “acceptable” management practices. In areas where water quality impairments are known to occur, more stringent practices and enforcement are called for. Most of these laws have been passed only recently, and results in terms of reduced runoff, costs to producers, and costs to States have yet to be documented.

Design Standards With Triggers

A program in Nebraska uses design standards in conjunction with performance measures (Bishop, 1994). Increasing concentrations of nitrate in groundwater led to a 1986 law requiring Natural Resource Management Districts (NRD’s) to require best-management practices to protect water quality. The practices required depended on nitrate concentrations in groundwater. In Phase I areas (the least contaminated), fall applications of commercial nitrogen fertilizer are banned on sandy soils. In Phase II areas (12.6-20 ppm nitrate-N concentrations in groundwater), irrigation wells are to be sampled, irrigation applications metered, deep soil analysis for nitrate required on every field, a ban on fall fertilizer applications instituted on sandy soils, and a ban on any application on heavier soils until after November 1. Phase III (greater than 20 ppm) is the same as Phase II, plus all fall and winter fertilizer applications are banned, and spring applications must be split applications or must use an approved inhibitor.[5] This policy approach is similar to a design standard with imperfect information. The NRD does not know *a priori* which set of management practices will achieve the groundwater quality goal. Design standards are instead changed in response to observed changes in groundwater quality.

Monitoring in the Central Platte NRD, which had the greatest problem, has shown a decrease in groundwater nitrate (Bishop, 1994). No economic assessment on the benefits and costs of the policy has been conducted.

Wisconsin's programs for protecting groundwater from pesticides derive from the Wisconsin Groundwater Law (1983) (Wisc. Stats., Chapter 160), which requires the State to undertake remedial and preventive actions when concentration "triggers" are reached in groundwater for substances of public health concern, including a number of pesticides. Two triggers are established for each chemical, an enforcement standard and prevention action limit (PAL). The PAL is 10, 20, or 50 percent of the enforcement standard, depending on the toxicological characteristics of the substances. When a PAL is exceeded, a plan for preventing further degradation is prepared. When the enforcement standard is exceeded, the chemical is prohibited in that area overlaying the contaminated aquifer.

For example, the enforcement standard for atrazine is 3.5 ppb, and the PAL is 0.35 ppb. Well monitoring found atrazine concentrations in many areas of the State above the PAL (Wolf and Nowak, 1996) and in some areas above the enforcement standard. This prompted the passage of the Atrazine Rule, which established maximum atrazine application rates and conditional use restrictions for the State (Wisc. Admin. Code, Agri. Trade & Cons. Prot. Ag30), as well as zones where additional restrictions are imposed on top of the statewide rules. The result is a three-tiered management plan: statewide atrazine restriction, Atrazine Management Areas where concentrations exceed the PAL, and Atrazine Prohibition Areas where concentrations are above the enforcement standard. Statewide atrazine restrictions impose soil-based maximum application rates, restrict when atrazine can be applied, and prohibit applications through irrigation systems. Further restrictions are placed on application rates in the Atrazine Management Areas. In 1993, 6 management areas and 14 prohibition areas had been established (Wolf and Nowak, 1996).

An assessment of the Atrazine Rule reported that producers in the Atrazine Management Areas were not at a disadvantage to producers who were not in such areas, as represented by comparisons of yield loss predictions and assessment of weed intensity (Wolf and Nowak, 1996). However, an assessment of compliance costs was not made.

Summary

Standards use the regulatory system to mandate that producers adopt more socially efficient production methods. These mandates may leave producers with little freedom when it comes to their production and pollution control choices. This chapter has focused on the two main classes of standards: performance-based and design-based. The choice of base is important in determining (1) the relative efficiency of the standard, (2) the degree of flexibility producers retain in their production and pollution control decisions, (3) the complexity of policy design, (4) the informational requirements of both producers and the resource management agency, and (5) the administration and enforcement costs of the policy.

The relative efficiency of the standards is greatest when they coincide with or support the goals of the resource management agency. Expected runoff standards are cost effective because they can always be used to achieve a mean runoff goal at least cost. However, an expected runoff-based instrument cannot be used to achieve an efficient outcome or to achieve an ambient water quality goal at least cost. As another example, suppose nitrogen runoff is a problem in a particular watershed. In this case, standards applied to fertilizer use and irrigation are likely to be more effective than standards that are applied to the type of crop grown.

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[5] Soil inhibitors reduce the rate at which nitrogen is converted to the soluble nitrate form, thus reducing losses to leaching or runoff.

Performance standards can be inferior to design standards on several grounds. All of the drawbacks for performance-based incentives hold for standards as well, with an additional drawback for performance standards that is probably even more troublesome. Due to the natural variability associated with the nonpoint process, performance-based standards must be defined in terms of a limit on mean ambient pollution or runoff levels or in terms of a probability associated with the occurrence of certain outcomes. As a result, monitoring would have to occur over a period of time to determine the sample distribution of the base. Only then could a producer be determined to be in or out of compliance. The required timeframe for monitoring may be years for some pollutants due to long time lags associated with the delivery of the pollutant to a water body.

Standards leave producers with little flexibility. Standards, since they mandate or limit specific actions, leave producers with little flexibility in adapting to a changing economic environment. Expected runoff standards leave producers with the most flexibility because specific production methods are not specified and producers are free to adjust production as economic conditions change (as long as the standard is met). In contrast, standards on inputs and technologies are totally inflexible. Producers can respond to changing economic conditions only by altering the use of inputs and technologies that are not targeted by the standards.

Some flexibility may be imparted by basing standards on environmental triggers. Allowing continued use of a pesticide after it has been detected in groundwater, but at lower rates, is less costly to producers than immediately banning it. Such an approach lessens excessive regulatory burden resulting from the uncertainties of the effectiveness of best management practices in reducing nonpoint-source pollution. This flexibility comes at a cost of greater administration and monitoring costs.

Second-best input and technology standards are more practical from an implementation standpoint. Ideally, standards should be applied to all inputs and technologies used, and be site specific. However, empirical evidence suggests only a moderate welfare loss from using uniform policies applied to only a few key inputs and technologies. The degree of uniformity, inputs and technologies targeted, and the amount of site-specific information utilized in policy design that provides the best level of control at lowest welfare and administration cost is an empirical question. These issues will generally depend on the local setting, availability of information, and the skill of the resource management agency.

Input and technology standards may be constructed to perform relatively well in promoting least-cost control when the standard is closely correlated to pollution control (Russell, 1986). For example, if fertilizer application rates are closely correlated with nutrient loadings to a stream because of local geographic and hydrologic conditions, then a standard on fertilizer applications will achieve a level of control almost as efficiently as a standard on nutrient loadings (Russell, 1986).

In contrast, expected runoff standards are likely to be more costly to administer than other design standards because the resource management agency has to monitor input use and technology choices for each production site and develop a model to predict runoff from all sites.

Broadening the scope of current programs and improved targeting would lead to further water quality improvements. A limited number of programs now include design standards as a method of improving water quality. These exist primarily in two forms: standards on technologies and bans on hazardous chemical inputs. A chemical ban is probably reasonable for extremely hazardous chemicals being used in environmentally sensitive areas. However, for areas that are less sensitive and for chemicals with limited risk, a more flexible approach may be more efficient. Some States are addressing this issue by using water quality measures to define specific geographic areas where design standards are imposed and environmental triggers within these areas to define the particular set(s) of standards that are required.

While input use may be altered as an indirect effect of mandating alternative practices or technologies, more direct effects may be desired. Programs will be more successful if policies are applied directly to input use when this use is highly correlated to water quality impairment.

Appendix 4A— A Limited Set of Input Standards[6]

For simplicity, suppose standards are site-specific but applied only to a subset of the total number of inputs. Also for simplicity, we do not explicitly consider technology choices. Let z_i denote the ($m' \times 1$) vector of inputs whose use is standardized, and let y_i denote the ($[m - m'] \times 1$) vector of inputs that are chosen freely by producers (note that $x_i = [y_i \; z_i]$). Each producer faces the following problem for production on each acre:

$$\begin{aligned} &\max_{x_{ij}} \quad \pi_i(y_i, z_i) \\ s.t. \quad & z_{ij} \le \bar{z}_{ij} \quad \forall j \in [1, k] \\ & z_{ij} \ge \bar{z}_{ij} \quad \forall j \in (k, m'] \end{aligned}$$

where $\bar{z}_{ij}$ represents that standard for the jth restricted input. Inputs denoted by $j \in [1, k]$ are assumed to be pollution-increasing while inputs denoted by $j \in [k, m']$ are assumed to be pollution-reducing. The Lagrangian corresponding to the ith acre is

$$L_i = \pi(y_i, z_i) + \sum_{j=1}^{m} \lambda_{ij}[\bar{z}_{ij} - z_{ij}]$$

where λ_{ij} is the Lagrangian multiplier for the jth restricted input used on the ith acre. Assuming an interior solution for all inputs and that all constraints are binding, the necessary conditions for a maximum are

$$\frac{\partial \pi_i}{\partial y_{ij}} = 0 \quad \forall i, j \qquad \text{(4A-1)}$$

$$\frac{\partial \pi_i}{\partial z_{ij}} = \lambda_{ij} \quad \forall i, j \qquad \text{(4A-2)}$$

$$\bar{z}_{ij} - z_{ij} = 0 \quad \forall i, j \qquad \text{(4A-3)}$$

Note that $\lambda_{ij} < 0$ for inputs that reduce runoff. Input use on the ith acre is determined by the simultaneous solution to $m + m'$ conditions in (4A-1)-(4A-3). Use of (unrestricted) input j will be a function of the standards for all restricted inputs, $y_{ij}(z_i)$, where $\bar{z}_i$ is an (m' x 1) vector whose jth element is $\bar{z}_{ij}$.

For simplicity, assume that producers hold no private information. Optimal input standards are determined by plugging the (unrestricted) input demand functions (i.e., $y_{ij}(\bar{z}_i)$) into the agency's objective function and choosing input standards to maximize expected net benefits, restricted on technology.

$$J(\bar{A}) = \underset{\bar{z}_{ij}, n}{Max} \left\{ \sum_{i=1}^{n} \pi_i(y_i(\bar{z}_i), \bar{z}_i)) - E\{D(a)\} \right\}$$

The first-order conditions are given by (2A-2) and

$$\begin{aligned} \frac{\partial J}{\partial \bar{z}_{iu}} &= \frac{\partial \pi_i}{\partial \bar{z}_{iu}} + \sum_{j=1}^{m-m'} [\frac{\partial \pi_i}{\partial y_{ij}}] \frac{\partial y_{ij}}{\partial \bar{z}_{iu}} \\ &- E\{D'(a) \frac{\partial \alpha}{\partial \rho_i} [\sum_{j=1}^{m-m'} \frac{\partial \rho_i}{\partial y_{ij}} \frac{\partial y_{ij}}{\partial \bar{z}_{iu}} + \frac{\partial \rho_i}{\partial \bar{z}_{iu}}]\} = 0 \quad \forall i, u \end{aligned}$$

Using (4A-1) and (4A-2), condition (4A-4) can be simplified to yield

$$\begin{aligned} \frac{\partial \pi_i}{\partial z_{iu}} = \lambda_{iu} &= E\{D'(a) \frac{\partial \alpha}{\partial \rho_i} \frac{\partial \rho_i}{\partial \bar{z}_{iu}}\} \\ &+ E\{D'(a) \frac{\partial \alpha}{\partial \rho_i} \sum_{j=1}^{m-m'} \frac{\partial \rho_i}{\partial y_{ij}} \frac{\partial y_{ij}}{\partial z_{iu}}\} \quad \forall i, u \end{aligned} \qquad \text{(4A-4)}$$

The optimal shadow value for the uth restricted input for the ith acre is equal to the marginal damage created by use of the uth restricted input on that acre, plus an adjustment term to account for the indirect effect on damages resulting from the effect of the standard on the use of other inputs.

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[6] The mathematical foundations for input standards, applied to a limited set of inputs, are developed in this appendix. Unless otherwise stated, the underlying model and assumptions are as developed in appendix 2A.