

Application of market mechanisms and incentives to reduce stormwater runoff[☆] An integrated hydrologic, economic and legal approach

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Abstract

Increased stormwater flows are a direct result of urbanization and the consequent increase in the proportion of land area under impervious surface. Due to its contribution to abnormally high stream flows and its role as a carrier of pollutants that degrade water quality, excess stormwater runoff has negative impacts on both terrestrial and aquatic ecosystems. In response to the increased magnitude and frequency of stormwater runoff events, municipalities and local governments seek cost-effective strategies to manage the risks associated with these stormwater flows. The goal of a proposed interdisciplinary approach involves providing incentives for the construction of small-scale best management practices throughout a small urban watershed, leading to a cost-effective means to control stormwater runoff, and partially restoring a more natural hydrologic regime to a watershed area. Market mechanisms and other incentives have been suggested as plausible approaches to the reduction of stormwater runoff. Development and implementation of market mechanisms and incentives to reduce stormwater runoff, however, involves interdisciplinary considerations and issues. This paper develops an interdisciplinary view of the stormwater runoff issue, beginning with a brief description of stormwater runoff management from a hydrologic perspective. We then present a background on types of market instruments and their related incentives as possible approaches to reducing the risks associated with both the magnitude and frequency of recurrence for excess stormwater runoff flows. This is followed by an analysis of how the federal Clean Water Act and state water laws have dealt with stormwater issues. These perspectives and methods are synthesized to develop several stormwater management scenarios that include stormwater user fees, stormwater runoff charges, allowance markets, and voluntary offset programs. Each of these programs would likely incorporate stormwater best management practices at the watershed level, yet in different ways, and we discuss the opportunities and limitations borne out of our analysis of the legal, economic, and hydrologic considerations.

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1. Introduction

Communities nationwide in the USA are becoming more aware of the damage to the environment and personal

property that stormwater runoff causes. This is due in part to the recognition that urban sprawl and increased impervious surface cause increased runoff, and in part because many previously unregulated communities are subject to the United States Environmental Protection Agency's recently promulgated National Pollutant Discharge Elimination System stormwater measures.² Controlling excess stormwater runoff poses some challenging issues: stormwater

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² National Pollutant Discharge Elimination System – Regulations for Revision of the Water Pollution Control Program Addressing Storm Water Discharges; Final Rule, 64 Fed. Reg. 68,722 (8 December 1999).

runoff is not defined as a pollutant, nor is the source of runoff well defined. The stated objectives of excess stormwater management typically are to provide for drainage from upland communities, to minimize downstream impacts of upstream development, and to balance the environmental and social impacts of the drainage infrastructure. Yet, these objectives clash more often than not.

It has been suggested that market mechanisms similar to pollutant trading could be used to encourage the use of distributed (i.e., as opposed to centralized) stormwater control measures. The proposed management approach involves providing incentives for the construction of small-scale best management practices (BMPs; e.g., infiltration trenches, small detention ponds) throughout a small watershed, leading to a cost-effective means to control stormwater runoff, and partially restoring a more natural hydrologic regime to a watershed area. Recognizing that a uniform, generalized solution is seldom effective (Booth and Jackson, 1997), we look at a range of possible management scenarios from the hydrologic, economic, and legal standpoints. The multi-faceted nature of the problem calls for the kind of interdisciplinary approach we take in this research. Section 2 provides some background on the hydrology of stormwater runoff, the economic aspects of proposed solutions for dealing with the runoff, and the legal responsibilities and recourse communities have in dealing with stormwater runoff. The Section 3 presents four implementation scenarios and discusses their relative attractiveness from each discipline's perspective. Section 4 synthesizes these perspectives and concludes our paper.

2. Background: stormwater runoff

2.1. Hydrologic aspects

There are two basic runoff formation processes: pervious surfaces that infiltrate water eventually become saturated and the excess precipitation runs off; or pervious surface is replaced with impervious surface that does not allow the infiltration of water. Therefore, precipitation is more completely converted to runoff, which also initiates within a shorter time frame. In urbanized areas, the increase in stormwater runoff is a direct result of the proliferation of impervious surface and a concomitant decline in natural sinks for storm flows (Hey, 2001). All properties within a watershed contribute stormwater runoff to some extent. Each parcel contains different combinations and arrangements of types of impervious surfaces, which affects the amount of runoff produced and the time at which it is delivered to other parts of the catchment.

The intensity and duration of a precipitation event is the major determinant of runoff volume (Church et al., 1999). The stormwater infrastructure has historically provided the capacity to handle stormwater from small storm events (i.e., 2–10-year events) and large events (i.e., 50–100-year events)

and these systems are known as convenience and emergency systems, respectively (Walesh, 1989). The convenience system collects stormwater from downspouts, street inlets, and other portals, which is then conveyed to treatment plants; more generally, these flows are piped to streams and their tributaries. The emergency system attempts to address larger flows that result from the more infrequent, yet higher volume stormwater runoff events, and relies on streets, roadways, and low-lying areas to act as open-channel conveyances and temporary detention basins, respectively. The terminal receptor for these flows is also typically a stream. These urbanized conditions route stormwater to streams in less time and in greater quantities, causing higher peak flows that lead to stream degradation and habitat alteration. Excess stormwater runoff has historically had a degrading impact on both terrestrial (Putnam, 1972; Johnson and Sayre, 1973; Cairns, 1995; Jauregui and Romales, 1996; Carlson and Arthur, 2000) and aquatic (Klein, 1979; Neller, 1988; Booth and Jackson, 1997; Swanson et al., 1998) ecosystems.

2.2. Economic aspects

Traditional “command-and-control” regulations set uniform standards for all sources, with the most common being technology- and performance-based standards. Technology-based standards dictate the manner in which individuals must comply with the regulation. A performance standard sets a uniform control target for all sources that allows for some flexibility in the choice of abatement technology utilized. Rather than requiring individuals to meet uniform control targets, market-based instruments persuade individuals to expend equal marginal control costs. When the cost of controlling emissions or runoff differs across individuals, equalizing marginal control costs ensures that the overall target is attained at the lowest aggregate cost. A larger portion of the abatement burden is allocated to individuals with relatively lower abatement costs.

The interested reader can refer to [Appendix A](#) for more detail and graphical illustration of this and subsequent control mechanisms.

Allocating the abatement burden among sources to achieve the lowest overall control costs can be accomplished through either a Pigouvian tax or through an allowance market. A Pigouvian tax is a price-based instrument that is a charge collected by a regulatory agent and that is levied on each unit of runoff from an individual's parcel. An allowance market is a quantity-based instrument that restricts allowable levels of runoff but permits the transfer of these allowances through free trade. The application is shown graphically in [Appendix A](#).

Allowance markets can also achieve the lowest cost allocation of abatement among individuals, but without the same abatement cost information requirement. Under this quantity-based approach, each individual is required to have an allowance for the runoff that leaves his or her property.

Each allowance defines the quantity of runoff that the individual is allowed to have exit his or her parcel. This is no different from saying that each allowance defines the amount of abatement that each individual is required to provide. The total number of allowances issued by the control agency must equal the total allowable level of runoff for the watershed. Finally, the individuals are allowed to buy and sell allowances to other individuals within the market. This permits the allowances to be reallocated to the individuals with the highest abatement costs, which results in the equalizing of marginal abatement costs and the low cost allocation of the abatement burden.

The use of market mechanisms for pollution control is attractive from a theoretical standpoint, and boasts measurable successes in air pollution trading markets. Less widespread, but gaining credence is the use of markets to create incentives for water quality improvements. Using markets to control excess stormwater runoff, a water *quantity* issue, is a novel approach that has, as we detail in this paper, potential for successful application. Market-based instruments place an economic value on reducing excess stormwater runoff, and provide financial incentives for individuals to identify and adopt lower cost control technologies. As with all potential applications, transfer from theory to application requires attention to details of “real-world” obstacles for effective implementation.

In practice, allowance markets have been gaining acceptance in a wide variety of applications. Perhaps the best known of these is the SO₂ market. Traded in the USA on the Chicago Board of Trade, the market in sulfur dioxide emissions has been a success in meeting overall emissions reductions targets at lower than expected attainment costs. While a large degree of the markets’ success can be attributed to its remaining faithful to theoretical design, this can also be criticized as its weakness. An underlying assumption of emissions trading theory is that the pollutant is uniformly mixing and that the point of discharge does not affect the degree of environmental impact. In reality spatial characteristics of discharge do have an effect on environmental impact. For example, Midwest emissions tend to concentrate in the Northeast causing environmental damages in that region (U.S. GAO, 2000; New York State Department of Environmental Conservation, 2004; Green Nature, 2002).

The use of trading markets for the control of water pollution is currently being encouraged, with 37 programs in the development or implementation stage in the United States (U.S. EPA, 1996; *Environomics*, 1999). Including nonpoint pollution within these markets necessitated several key modifications in the design of allowance markets due to its diffuse nature. Monitoring individual contributions can be prohibitively costly, loadings are in large part driven by random weather events, and uncertainty exists regarding the effectiveness of pollution abatement controls (Tomasi et al., 1994). Nonpoint sources of water pollution have not been directly regulated under the NPDES

program of the Clean Water Act partly because of the difficulty of identifying individual contributions.³ As a result, existing allowance markets have deviated from traditional design by (i) including nonpoint sources on a voluntary basis and (ii) monitoring trades based on the adoption of abatement technology (e.g., best management practices) rather than observed performance. The latter modification has led to the expanded use of trading ratios, which we will define and discuss in the next section. Within these markets the trading ratio deals not only with differential spatial impacts of emissions, but also the uncertainty of the relationship between the estimated reductions from individual best management practices and actual emissions.

The use of market mechanisms, such as allowance markets, will require further modification to the traditional design of these instruments. For example, like nonpoint sources the disperse nature of stormwater runoff introduces questions of how to monitor and enforce trade within allowance markets. Stormwater runoff also adds the additional concern of not being a regulated pollutant, introducing new concerns regarding the ability to create appropriate legally enforceable incentives.

2.3. *Legal aspects*

While all properties within a watershed contribute to stormwater runoff, the property owner’s rights and obligations associated with stormwater runoff vary depending on property type (commercial, residential, governmental), location (urban or rural), and controlling Federal and/or state law. Here, we focus on the Federal Clean Water Act’s programs to reduce pollutants carried by stormwater, state water law as it relates to drainage and the right to dispose of excess water, and differences between trading to increase versus decrease water quantity.

Stormwater is addressed by the Federal Clean Water Act (CWA) under Section 402, which requires point source dischargers of pollutants to obtain a [National Pollutant Discharge Elimination System, 1999](#) (NPDES) permit. While stormwater itself is not a pollutant as defined by the CWA, it often contains pollutants and so several sources of stormwater are considered point sources subject to the CWA. Those sources include certain industrial sectors, such as construction, publicly owned treatment works

³ The Clean Water Act’s NPDES program focuses on permits for discharges of pollutants. 33 U.S.C. §1342(a) (2001). “Discharge of a pollutant” is defined in the Clean Water Act as “any addition of any pollutant to navigable waters from any point source.” 33 U.S.C. §1362(12) (2001). “Point source” is defined as any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.” 33 U.S.C. §1362(14) (2001). Nonpoint sources, by nature, are not easily discernible nor do they flow from a confined or discrete conveyance and are therefore not subject to the NPDES program.

(POTWs), and municipal separate storm sewer systems (MS4s).

Stormwater presents a particular problem in older cities with combined sewer and sanitary systems (CSS). Combined systems are designed to collect and treat wastewater and stormwater together. When large storm events occur, many systems do not have the capacity to handle the excess stormwater and are forced to discharge this mix of stormwater and untreated wastewater directly into rivers or streams. When this occurs, the POTW is frequently forced to violate its NPDES permit because the permit does not allow wastewater to be discharged into waterways without treatment.

In addition to pollution law, relevant state water law deals directly with the drainage of diffused surface water (which includes stormwater). Water law is very complex and state-specific, but three general rules determine liability for damages caused by changes made to the natural flow of diffused surface waters. The majority of states follow the “common enemy” rule, which allows a landowner to protect his or her property from diffused water without regard to the consequences. The “natural servitude rule” (also called the “natural flow” or “civil law” rule) requires the lower landowner to accept the natural flow of water from the upper land, but prevents the upper landowner from changing the natural drainage flow such that it increases the burden on the lower land. There are exceptions to both, but some states use a third rule, which is “reasonable use”. The reasonable use rule allows landowners to divert or change drainage water in any way that does not unreasonably injure others (Dellapenna, 1991).

In areas where water is scarce, trading in water quantity has occurred in the context of trading or selling one’s right to capture and use waters of the state. An example is the Deschutes Water Exchange (DWE) in Oregon. The DWE Annual Water Leasing Program was established in 1998 as a cooperative effort with local irrigation districts and water-right holders to restore stream flows for environmental benefit. In that program, right holders are paid to not withdraw their rightful allocation of in-stream waters. The lease constitutes exercise of their water right so that it is not forfeited (in Oregon, a water right is forfeited if it is not exercised every 5 years), but the water that would otherwise be withdrawn is allowed to remain in stream (The Deschutes Resources Conservancy, 2003).

However, trading in this case is to *increase* flows. We are not aware of any trading systems aimed at *reducing* the flow of water. Excess water is seen as a liability, not a desired asset to which rights and value attach. In this regard, water quantity trading to increase flows is fundamentally different from trading to decrease flows. With some important distinctions, to be discussed in a later section, trading to decrease stormwater flows is more analogous to pollutant trading where the value attaches to the right to discharge the item (i.e. pollutant), not to the item itself.

3. Implementation scenarios

In the following sections, we present an interdisciplinary analysis of potential market-based instruments. Although these instruments can be employed in a variety of ways, for our purposes it is convenient to frame them in terms of price and quantity instruments. The instruments are examined from the perspective of hydrology, law, and economics. From the hydrology perspective, the instruments are compared on the basis of their relative potential to address the reduction of stormwater runoff. The legal analysis evaluates the alternative market-based instruments based on the legal complexity associated with implementation, which includes such considerations as: (i) authority needed to implement the scenario; (ii) potential constitutional issues; (iii) conflicts with existing law; (iv) jurisdictional issues; and (v) other potential objections. Finally, the economics analysis focuses on the cost-effectiveness of the alternative approaches. Cost-effectiveness analysis identifies the instrument that can achieve a stated regulatory goal with the lowest compliance costs.

A few caveats need to be mentioned. Generalizing market-based instruments into the four price and quantity scenarios discussed below provides only a limited representation of potential market-based approaches. The hydrologic, legal, and economic analyses are far from exhaustive, and do not consider all dimensions of the stormwater control problem. Instead, the purpose of this article is to discuss the opportunities along with some of the more onerous obstacles to creating market-based approaches for stormwater control. This focus on identifying the interdisciplinary complements and conflicts that may arise in implementing such options enables us to undertake this more narrowly defined analysis.

3.1. Price Instruments

Price instruments place a charge (either a fee or tax)⁴ on the amount of stormwater runoff that a parcel generates,

⁴ The distinction between a fee and a tax varies from state to state, but in general, tax revenue can be used to fund legitimate government functions. The function need not be related to specific applications or purposes, but revenues are rarely earmarked for specific purposes and taxes must be applied uniformly to all taxpayers. In contrast, fees must bear a substantial relationship to the cost of providing the specified services and/or facilities and they must be apportioned in a fair and reasonable manner in order to be constitutionally valid. Traditionally, municipal stormwater systems were funded by tax revenue, but creating fee-based stormwater management programs is becoming more popular. There are several likely reasons for this trend (Lindsey and Doll, 1999; Lehner et al., 1999): (1) not all local governments have authority granted by the state constitution to collect taxes, but most, if not all can charge fees; (2) some state constitutions (such as Missouri and Michigan) require taxes (but not fees) to be subject to voter approval; (3) fees are perceived as more fair because the typical basis for determining the fee (impervious surface) is an objective measurement, and because the fee reflects actual use of the system; (3) tax revenue is always subject to competing needs and changing priorities; and (4) unlike fees, taxes do not reflect the actual contribution of stormwater runoff.

providing some incentive to reduce runoff to the point where the marginal control cost equals the runoff charge. To achieve the desired level of runoff control at the lowest cost, the stormwater runoff charge should be set equal to the marginal benefit from the desired level of reduced runoff. However, in practice this is not the case. In the following section, the use of user fees and runoff charges are compared as price instruments for stormwater runoff control.

3.1.1. Scenario #1: stormwater user fee

Stavins (2001) argues that most applications of price instruments have failed to have the incentive effects promised in theory, either because of the structure of the systems or because of the low levels at which charges have been set. Existing stormwater user fees may serve as an example of this phenomenon. As with any constitutionally valid fee, stormwater fees must be fair, equitable, and based on the cost of the service provided as measured directly or by some approximation of use or benefit. Stormwater fees are generally calculated by some measure of the approximate quantity of runoff that leaves a parcel of land, with the square footage of impervious surface being a broadly accepted metric. To provide incentives for the adoption of on-site source reduction BMPs, many stormwater utilities offer credits or fee reductions for landowners who implement BMPs to reduce runoff from their parcel. A table reproduced from Doll et al. (1999) containing examples of these credits is given in Appendix B.

Although user fees are directly related to excess stormwater runoff levels and have their revenues earmarked for the provision of closely related environmental services (i.e., construction and/or operation and maintenance of the stormwater sewer system), in practice they do not encourage desired behavior. Doll and Lindsey (1999) argue that existing user fee/credit systems, where available, have failed to encourage widespread adoption of on-site source reduction BMPs. From an economic standpoint, stormwater user fees are set too low to induce the appropriate level of BMP adoption on private property, and, therefore, are not a cost-effective means of stormwater runoff control.

There are several hydrologic issues relating to the efficacy of using stormwater fees predicated on the extent of impervious surface. Although setting an areal unit impervious surface equivalent to a certain volume of excess stormwater runoff is a step in the right direction, there are critical shortfalls in this method of estimation. Generalized notions of impervious surface may be reasonable estimates of the two-dimensional extent of impervious surface, yet these values give no information on whether the impervious surface is connected to conveyances (i.e., connected impervious surface) to take stormwater away from the site, or otherwise allowed to flow onto the property. Furthermore, not all impervious surface is created alike. There are a very large number of combinations of impervious surfaces, which is complicated by differences in geometry (e.g., slope, curvature), which affects the timing and concentration of

flows; and connectivity or proximity to pervious or other impervious surfaces, and distance to drains or other conveyances. These factors contribute to the production of tremendous variation in observed runoff volumes, and we speculate that these factors would become more important with a reduced parcel size. It seems that a more informed method of estimation would be required when considering runoff production in residential neighborhoods, or where land use patterns are relatively heterogeneous.

Additional hydrologic concerns pertain to the use of stormwater user fees to influence appropriate BMP adoption. They include the limited range of sources that are subject to user fees, as well as the accuracy of the models used to predict stormwater contributions. Thus, landowners whose properties are served by a combined sanitary sewer system, as well as rural property owners, may be exempt from the user fee. This limits the potential range of stormwater runoff reduction and the areas that can be targeted for BMP adoption. In addition, fee reductions through credit provisions usually are limited to non-residential properties, resulting in the exclusion of the expanding residential proportion of the total acreage within the watershed. These likely impair the ability of the stormwater fee system to reach the desired ecological target. The primary benefit of reliance on a stormwater user fee/credit system is that it has proven to be a legally acceptable price instrument in most jurisdictions.

3.1.2. Scenario #2: stormwater runoff charge

To overcome the hydrologic and economic shortcomings of existing stormwater user fee/credit systems addressed above, the stormwater utility needs to incorporate more accurate hydrologic models, apply the price instrument to all landowners, and raise the price to reflect the marginal costs of reducing the desired level of runoff. This would convert the existing stormwater user fee into an incentive-based “stormwater runoff charge”, where the charge would provide a more realistic “price signal” increasing its ability to influence private landowner behavior and coordinate that behavior across landowners.

To calculate an improved hydrologic status with a stormwater charge on runoff or impervious area, the hydrologic model underlying the price mechanism must focus not only on the amount of impervious surface, but also an evaluation of landscape factors, extant development, existing stormwater and sewer infrastructure, and inventory of pipe breaks and other losses, and other information to better understand how the watershed drains. It is also important to incorporate the effect of spatial and trans-boundary relationships between adjacent parcels on stormwater runoff. For example, runoff may compound across many adjacent parcels, with implications for larger cumulative flows at the bottom of the slope. This is not a straightforward modeling effort. A model calibrated to local conditions and rainfall patterns can be parameterized to account for all of these factors, though routing these flows is

beyond the scope of a lumped parameter model. A continuous, spatially distributed rainfall-runoff model could provide a reasonable approximation of the effect of stormwater runoff control on the hydrologic status of the watershed. Model assessments can then calculate an average peak runoff from storm events within a 1–10-year return period. From the modeling exercise, one may identify conditions leading to the desired level of reduction in the average peak runoff.

From an economic standpoint, two sets of information are required for the implementation of a cost-effective stormwater runoff charge. First, the desired level of runoff reduction must be identified for a given recurrence interval. Second, the aggregate cost of stormwater runoff abatement from the landowners in the watershed needs to be determined. To influence behavior in a cost-effective manner the stormwater runoff charge must be set equal to the marginal aggregate cost of runoff control in the watershed. This provides the proper incentive for each landowner to provide the appropriate level of control to ensure the target is met. For this reason, price instruments are always difficult to implement effectively in practice. The costs of stormwater BMP installation, as well as the costs of operation and maintenance, are relatively well known. However, the private opportunity costs of individual landowners are not known and can be a substantial proportion of total costs. These costs include the foregone opportunity and use of the land that is devoted to BMPs. While this information can be estimated, the penalty for not getting the price right can be substantial. When the price is set below the actual marginal cost, too little abatement will be provided. When the price is set above the actual marginal costs, the control standard is set too stringently. While this problem can be overcome by starting with a reliable estimate of total costs and revising the charge based on observed compliance, it could take a considerable amount of time to adjust to the appropriate charge level.

Legally, implementing a stormwater runoff charge poses considerable difficulty. If the price instrument was a tax, it would have to be applied uniformly (not based on actual use) and the proceeds would be available for any legitimate governmental purpose. In order to be a constitutionally valid fee, the charge must bear a substantial relationship to the cost of providing the specified services and/or facilities and it must be apportioned in a fair and reasonable manner. In some states, the cost of providing the service can include a consideration of related activities, allowing some increase in the fee such that it might provide incentives for changes in behavior, but the fee must still be substantially related to those activities. As an example, Ohio law⁵ authorizes a local government to levy a fee on solid waste disposal for the purposes of defraying the added costs of maintaining roads, providing emergency services, paying for the costs of administering and enforcing the laws pertaining to solid

wastes, etc. Stavins (2001) reports that the unit charge system used in the financing of household solid waste collection is most analogous to a Pigouvian tax. Furthermore, these incremental unit charges have been shown to reduce the generation of household waste (Stavins, 2001). Increasing the stormwater user fee to reflect the costs of retrofitting the stormwater sewer system to handle excess input could provide a solid incentive for BMP adoption. Actual implementation would depend on the specific laws of the state. In some states, user fees can fund only operation and maintenance and tax revenue is required for capital improvements. In others, fees are defined such that they can be used directly for capital improvements in the system. Other localities take an indirect approach by using the fee revenue to back loans or revenue bonds sold to finance the improvement (Keller, 2003).

The required connection between the fee and the cost of service and related activities applies to new development as well. Several states and localities now charge developers “impact fees” to cover the cost of new infrastructure and services needed to accommodate the added burden on the system. The rationale is that the current residents have already paid for the infrastructure that serves them (i.e. either through taxes or fees) and they should not have to pay for additional services to meet the new development’s demands (Kolo and Dicker, 1993). Again, states vary in how they interpret and enforce these concepts and one could argue that current rate payers have not sufficiently “paid their way” if the existing infrastructure is not adequate to protect public health and the environment (i.e. as in the case of combined sewer systems).

3.2. *Quantity instruments*

Quantity instruments can achieve the same cost-effective allocation of the control burden as a price system, with the added advantage of avoiding the problem of having to “get the price right”. Under a quantity instrument, i.e., a trading system, an allowable overall level of stormwater runoff is established and allocated among individuals in the form of allowances. Landowners that keep their runoff levels below their allotted level may sell their surplus allowances to others. We explore two forms of quantity instrument. The first is a traditional allowance market and the second is a modification that allows for the voluntary participation of individual landowners.

3.2.1. *Scenario #3: “cap and trade” stormwater runoff allowance market*

Allowance markets work in three stages: setting a cap, dividing the allowable runoff among parcel owners, and finally encouraging the trading of allowances. In terms of stormwater runoff, the cap is determined, if possible by a specific ecological constraint, such as stream flow capacity, or the cap might be determined by the capacity of the existing sewer system or other conveyances. The allowable

⁵ Ohio IO Rev. Code Ann. §3734.57(C) (2003).

runoff is then allocated among the individual sources in the market. These allowances grant permission to release a specified amount of runoff at the parcel level and could be based on the differential in stormwater runoff caused by development on the parcel. For example, any stormwater runoff from a 2-year storm event that would have occurred naturally (considering soil type, slope, and so on) when the property was in its pre-development state would not have allowances associated with it. Allowances would only be needed, for instances, where runoff exceeds the predevelopment level (e.g., for eastern states, this would be a forested condition). This system allows parcel owners to trade allowances, which creates incentives for individuals who can reduce runoff at lower costs to take on a larger share of the burden. For example, property owners could retain or detain stormwater, thus freeing allowances that could be traded with other property owners.

From the hydrologic perspective, an allowance market is desirable because an enforceable limit is placed on the allowable runoff within the watershed. It also encompasses all current development within the watershed as well as any future development. Each landowner having either existing or new development would limit the post-development runoff from his or her parcel either directly or through trading.

Economically, the allowance market overcomes the informational requirements of the price instrument, while promising the same level of cost-effectiveness. Trading can be accomplished through free-exchange, bilateral negotiation, or a clearinghouse arrangement. The choice of exchange mechanism is based on the tradeoff between administrative and transaction costs associated with each. The dispersed nature of stormwater runoff is difficult to observe at the individual parcel level. Resulting allowance markets, as in the case of existing water quality trading markets, may promote a monitoring exchange, based on the successful adoption and implementation of best management practices. To deal with the uncertainty of using an imperfect proxy for actual abatement these markets trading ratios will also be incorporated.

In existing water quality trading markets, trading ratios have been introduced to allow for the exchange of heterogeneous goods within an allowance market. The trading ratio specifies the number of units of nonpoint pollution reduction, estimated by modeling the effectiveness of chosen best management practice, that must be exchanged for a single unit increase in point source pollution. A trading ratio greater than 1 provides a safety margin for the environment, as deviations from expected abatement performance of best management practices are less likely to result in violations of the regulatory standard. However, setting high trading ratios also reduces the benefits of trade and can lead to the collapse of the market altogether (Randall and Taylor, 2000). Stormwater allowance markets will face the same challenges. The ability of an allowance market to provide adequate protection of the overall quantity

target, while also encouraging trading and its associated cost-savings, is an empirical question that must be determined on a case-by-case basis.

The stormwater runoff allowance market faces several legal challenges, particularly on properties with existing development. Property rights are viewed as “a bundle of rights”. Examples include the drainage rights discussed above and the rights to possess, use, modify, lease, sell, or develop the land for residential, commercial, or industrial purposes (Daubenmire and Blaine, 2003). A state or its authorized political subdivision, such as a municipality may use its “police power” to restrict these rights if it is necessary to promote the public health, safety, and welfare; however, the power is limited by the Fifth and Fourteenth Amendments to the U.S. Constitution and also by many state constitutions. The Fifth Amendment prohibits the government from taking private property without just compensation. The Fourteenth Amendment prohibits states from taking property without due process of law. In this context, due process means the government regulation must have a legitimate goal and the method used to achieve that goal must be rationally related to the goal (Burgin, 1991). The prohibition on “takings” means the government cannot force “some people alone to bear public burdens which, in all fairness and justice, should be borne by the public as a whole” by taking their property without paying a fair price for it.⁶

Protecting the downstream environment from excessive flows could be considered a legitimate goal, but the question would be whether limiting a landowner’s right to release diffused stormwater (by allowing less than current levels of runoff) is a rational way to meet that goal. In states using the “reasonable use” approach to drainage, the actions of the landowner and nature of the harm could affect the answer. Where the “natural flow” rule is followed, hydrologic parameters could factor into the decision. In states following a strict “common enemy” doctrine, a limit on stormwater releases might be viewed as an unacceptable means of achieving the goal.

Whether the property is currently developed or undeveloped could also affect the outcome. Several options exist for limiting stormwater runoff from new development or redevelopment including limiting the amount of impervious surface permitted on a property through zoning, encouraging or requiring the use of low impact designs, and installing BMPs as part of the development (Livingston et al., 1997). Another approach is to avoid development altogether by purchasing or transferring the development rights associated with the property (Daubenmire and Blaine, 2003).

Limiting stormwater runoff from currently developed properties may be more problematic. Aside from possible political objections, it might be challenged as a retroactive law that unconstitutionally changes the legal status of a vested right. Ohio’s constitution, for example, prohibits the

⁶ *Armstrong versus United States*, 364 U.S. 40, 49 (1960).

passage of laws that affect substantive rights or impose new or additional burdens, duties, obligations, or liabilities as to a past transaction.⁷ Depending on the nature of the limit, a property owner could argue that it interfered with the development rights that were vested in the property at the time the improvements were made. On the other hand, if a strong enough case can be made for the need to limit runoff to protect human health and welfare, the restriction on existing development might be seen as a legitimate exercise of the police power. In that regard, any potential nuisance or health issues associated with the BMP would have to be considered as well.

If a regulation constitutes a permanent physical occupation of land without compensation (e.g., using private property for a public drainway without paying for it), it would be a taking regardless of the interference with the owner's use or the importance of the government's interest.⁸ In any event, the specific facts of each case would have to be examined by a court to determine if the regulation was valid or if a taking occurred.

3.2.2. Scenario #4: voluntary offset program

A voluntary offset program using the existing NPDES permit program as an incentive for government participation would provide economic incentives for private landowners to reduce their stormwater runoff. Both publicly owned treatment works (POTWs) and municipal separate storm sewer systems (MS4s) are subject to NPDES permits. In the case of POTWs, the permits set effluent limitations and treatment requirements. Stormwater runoff plays a contributing factor in POTW control in the presence of combined sewer systems (CSSs). In the presence of CSSs, a POTW will have the incentive to purchase runoff-reducing BMPs that reduce runoff from landowners such that these reductions avoid the need for more costly sewer system upgrades by reducing the incident of CSS overflows. For MS4s, their permits simply require that they limit the amount of pollutants entering the sewer system. In some cases, this may be accomplished at lowest cost by reducing the amount of sediment and pollutant bearing runoff entering the system at the parcel level. This trading program allows regulated POTWs and MS4s to meet their existing regulatory obligations by financing the adoption of BMPs by private landowners. This scenario is analogous to the Deschutes Water Exchange in which the government pays the water-right holder to not exercise his or her right to withdraw water from the stream. In this case, the government is paying the landowner to not exercise her right to release all of her stormwater to the POTW or MS4.

MS4s do not have as stringent regulatory obligations as do POTWs since they are not subject to particular effluent

standards or treatment standards.⁹ MS4s may be able to easily meet their NPDES requirements without the need to reduce the amount of runoff entering their system. MS4s are not regulated on the amount of runoff in their systems but on their practices of limiting pollutants from entering stormwater runoff. MS4s may not find a great benefit in this type of trading scenario. POTWs with CSSs, though, would greatly benefit from the reduction of stormwater runoff entering their system because the amount of stormwater is the cause of the combined sewer overflows during storm events (U.S. EPA, 2004).

From a legal perspective, because the offset program incorporates landowner participation on a voluntary basis, many of the constitutional issues presented in an allowance trading market are avoided. One issue that needs to be considered is that revenue, be it from taxes or fees, must be applied to a legitimate government purpose. Thus, paying landowners to reduce their stormwater runoff would have to be considered a legitimate government purpose for constitutional purposes. This should not be difficult to demonstrate, particularly in the case of the POTW with a CSS since a reduction in flows would address a significant public health issue. However, the applicability of this type of trading scenario is most likely limited to landowners within the reaches of a POTW, MS4, or both systems. A POTW or MS4 may be limited to using fee revenue to benefit only those who have contributed to these funds, i.e., landowners within the system. Few limitations would apply to tax revenue (but the local authority may not have the power to tax). If the POTW or MS4 or some other governmental entity has authority to pay landowners outside of the utility system, then the system could benefit from reductions in stormwater runoff at other locations within the watershed.

This program would be most accurately described as a combination price/quantity mechanism. If the POTW or the MS4 receive a substantial portion of their operating budget, including the funds to pay for landowner BMP adoption, through tax revenue that is collected by the municipality and allocated to the utility, the adoption of this offset program (i.e. quantity instrument) could result in increased taxes (i.e. a price instrument). However, for simplicity we are assuming that the tax pool is large enough that the increase in individual tax payments to pay for the offset program is relatively small and will not have any effect on individual behavior. It is important to note that in the case where the

⁷ Ohio Const. §28, Art. II (2003).

⁸ *Loretto versus Teleprompter Manhattan CATV Corp.*, 458 U.S. 419 (1982).

⁹ While an MS4 also has an NPDES permit for releases of pollutants introduced into the system, its requirements are limited to implementing six control measures under its NPDES permit: (1) public education and outreach on stormwater impacts; (2) public involvement/participation; (3) illicit discharge detection and elimination; (4) construction site stormwater runoff control; (5) post-construction stormwater management in new development and redevelopment; and (6) pollution prevention/good housekeeping for municipal operations. National Pollutant Discharge Elimination System – Regulations for Revision of the Water Pollution Control Program Addressing Storm Water Discharges, 64 Fed. Reg. 68722, 68736 (8 December 1999).

increase in the tax payments of landowners is noticeably affected by the adoption of the offset program, important synergies between the two would have to be examined.

From the perspective of economic theory, the switch to voluntary participation should not change the outcome of the quantity instrument, as long as transaction costs are low and the full right to release, or the obligation to detain, stormwater is exchanged. However, it is not likely that either of these assumptions holds true in implementation. The utility would enter into a private agreement with each landowner specifying the amount of compensation for the amount of stormwater reduction, but the liability of compliance with the CWA will remain with the utility. Recourse for breach of contract would have to be sought through the court system, adding the costs of verifiable monitoring and enforcement of BMP adoption and performance to the POTW or MS4s transaction costs.

From a hydrologic standpoint, the voluntary offset program is preferable to the price instruments because it identifies an ambient quality standard that must be met, and it avoids the uncertainty of setting the appropriate price. Yet, this does not directly pertain to controls on quantity of stormwater or its direct effects on quality. This implementation may not be appropriate for smaller municipalities, based on the lack of connected septic sewers, absence of an even moderately-sized POTW, and the variability in the specific arrangement of hydraulic conveyances.

This implementation also is inferior to the allowance market, because the “cap and trade” component is lost. Landowners retain the right to unlimited release of stormwater runoff from their parcel. Therefore, changes to impervious surface are neither prevented nor discouraged through this program, and this threatens the ability of maintaining the overall standard through this type of trading arrangement. The only option for maintaining the overall

standard, in the presence of increased impervious surface on existing properties, is to require the POTW or MS4 to control an increasing amount of stormwater runoff through their NPDES permits.

4. Synthesis and conclusion

As expected, no clear cross-disciplinary consensus emerges in the choice of a market-based approach to control stormwater runoff. The selection of an appropriate management instrument requires complicated tradeoffs between the important goals of all three disciplines and their preferred implementation scenarios. In practice, these tradeoffs are dependent upon the unique physical characteristics of the watershed, as well as the existing legal structure, and social institutions of the community. Table 1 provides a brief summary of the disciplinary concerns associated with each of the scenarios discussed above.

Providing even a simple rank order based on the disciplinary criteria for each of the scenarios proves to be difficult. We provide a general ranking, while acknowledging that the ordering will not hold in all cases. As mentioned above, the hydrologic rankings are based on their potential to address environmental quality goals, the economic rankings are based on the cost-effectiveness of the alternative approaches, and the legal rankings are based on the legal complexity associated with implementation. These various factors contribute to the difficulty in making definite rankings and therefore some rankings are somewhat interchangeable. Moreover, no clear choice of implementation scenario is apparent from these rankings. This shows that not one scenario is the solution to the stormwater runoff problem.

We applied this interdisciplinary approach to the stormwater runoff problem to create several stormwater manage-

Table 1
Summary of rankings from disciplinary perspectives for different stormwater management approaches

	Price instruments		Quantity instruments	
	Scenario #1: stormwater user fee	Scenario #2: stormwater runoff charge	Scenario #3: allowance market	Scenario #4: voluntary offset program
Economic concerns	Improperly priced incentive results in too little investment in BMPs	Cost-effective when fee is set equal to marginal cost of desired runoff reduction; extensive private cost information required	Cost-effective; reduced information requirement	Voluntary participation by landowners reduces incentive effects
Ranking	4	2 or 3	1	2 or 3
Hydrologic concerns	May not include all parcels; error-prone accounting for impervious surface	May not include all parcels; complex modeling effort required with at least some initial monitoring	Includes all parcels; difficult to determine a “cap” on allowable total runoff; monitoring required	May not include all parcels; no “cap” on impervious surface or total allowable runoff; quality vs. quantity issues; monitoring required
Ranking	4	2 or 3	1	2 or 3
Legal concerns	Program currently exists	No constitutional authority to charge incentive-based fees	Constitutional issues, particularly on existing development	Voluntary; authority may currently exist
Ranking	1	4	3	2

ment scenarios. Based on these rankings, our next step is to pursue further research on a voluntary offset program. Although it is not the first choice of any discipline, it best addresses the concerns of all the disciplines involved. The voluntary offset program will prove to be a challenging application of this interdisciplinary approach and hopefully will provide beneficial results for state and local governments to apply to the reduction of stormwater runoff in their watersheds.

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Appendix A

The marginal abatement costs for two individuals are illustrated in Fig. A.1. The marginal cost of abatement represents the additional outlay that is required to reduce one additional unit of output (i.e., runoff). The area under the marginal abatement curve gives the total costs of abatement. Thus, in Fig. A.1, Mr. A has lower abatement costs relative to Ms. B. Suppose that the regulator desires a total of 14 units of abatement from these individuals. Under a command-and-control approach both Mr. A and Ms. B are given uniform standards requiring each to abate seven units. As shown in Fig. A.1, this will result in different marginal costs of abatement and, therefore, is not the lowest cost allocation.

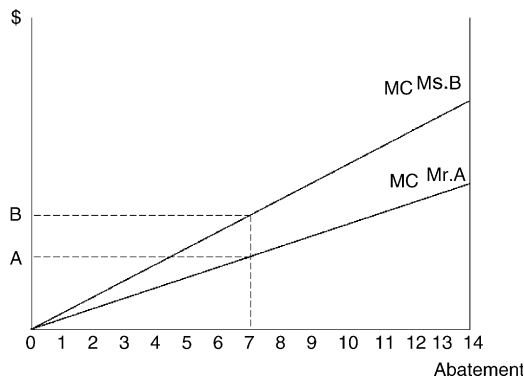


Fig. A.1. Command and control.

Again, we assume the regulator is interested in achieving 14 units of total abatement, but this time at the lowest possible abatement costs. Fig. A.2 illustrates how a price-based instrument ensures the lowest cost allocation of the abatement burden. Faced with a per unit charge of T, both Mr. A and Mr. B will choose to provide some level of abatement. In particular, both they will choose to provide abatement as long as it is less costly than the per unit tax. In Fig. A.2, setting the tax at price T will result in Mr. A choosing to abate nine units and Ms. B choosing to abate 5 units, for a total of 14 units of abatement. It is important to note that setting the tax at the appropriate price is essential to achieving the desired level of total abatement. It is easy to see in Fig. A.2, if T were set higher than its current level each individual would provide more than the required level of abatement. This results in unnecessary abatement costs. Similarly, if T were set lower than in Fig. A.2, each individual would provide less abatement resulting in less than the desired level of total reductions. This requires either the regulator to have detailed information regarding individual abatement costs, or the use of an iterative system of tax setting. The iterative process updates the tax level at the end of each year, based on the observed level of total abatement.

Fig. A.3 illustrates an allowance market where the desired level of total abatement is 14 units. Assume the

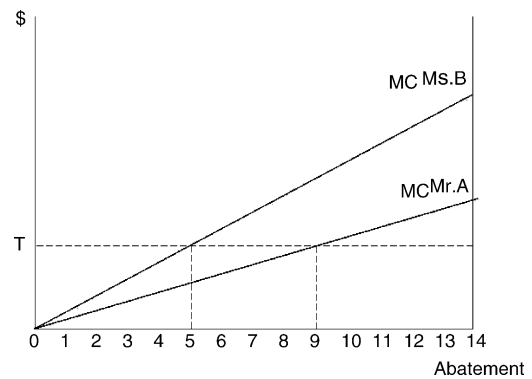


Fig. A.2. Price instrument (Pigouvian tax).

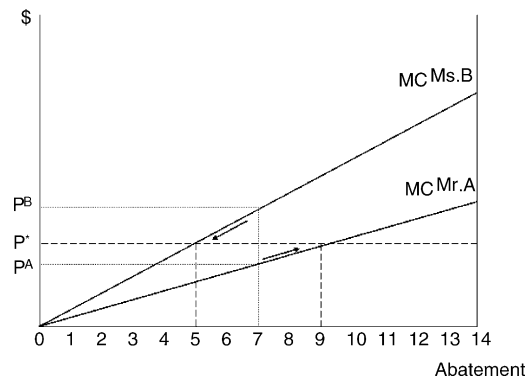


Fig. A.3. Quantity instrument (allowance market).

control agency has initially distributed allowances to Mr. A and Ms. B such that each is required to abate seven units of runoff. Note that this is the same allocation as under the command-and-control example in Fig. A.1. However, both individuals have an incentive to reallocate the abatement responsibility. Ms. B will be willing to pay any price less than P^B for each unit of abatement that Mr. A is willing to provide, because this will reduce her total cost of

abatement. Mr. A is willing to provide additional abatement at any price greater than P^A , as this will provide him with profit. The equilibrium price will be P^* , where the marginal costs of abatement of Mr. A and Ms. B are equal and no further benefits of trade exist. This also results in the low cost allocation of the abatement, where Mr. A abates nine units of runoff and Ms. B abates 5 units.

Appendix B. Summary of credit options^a

Utility	Eligible users	Basis for credit	Design storm	Maximum credit	Typical credit
Gainesville, FL	Nonresidential properties	Volume of onsite detention	25-year, 24-h	100% of base fee	15–35%
Orlando, FL	Commercial and multifamily residential	Onsite retention or detention	NA	42%	42%
Wichita, KS	Properties less than or equal to 50 ERUs	Two credits: volume of detention or retention	1. 100-year 2. Complete retention	1. 40% 2. 80%	Currently no applications
Louisville-Jefferson County KY	Commercial properties	Onsite detention of peak flows	2-year, 10-year and 100-year predevelopment runoff	82%	Varies with degree of control
St. Paul, MN	Nonresidential properties	Onsite detention of peak flows; acreage, peak flows	5-year and 100-year release limited to (1.64 ft ³ /ac/s)	10% (5-year) 25% (100-year)	Varies with degree of control
Charlotte, NC	Commercial, industrial, institutional, multifamily, residential, and homeowner associations	1. Peak discharge 2. Total runoff volume 3. Annual pollutant loading reduction	1. 10-year, 6-h 2. 2-year, 6-h 3. Reduction in loading	1. 50% 2. 25% 3. 25% Up to 100%	Varies with degree of control
Durham, NC	Nonresidential properties	Pollution credits for water quality and quantity controls	State standards for facility design; estimated pollutant runoff efficiency	25%	Few applications received
Cincinnati OH	Commercial properties	Onsite retention	Limited discharge to predevelopment runoff	50%	Credit never used
Tulsa, OK	Privately maintained facilities	50% or greater detention; maintenance costs of onsite facilities	NA	60%	Varies
Austin, TX	Commercial properties	Onsite detention; inspection	NA	50%	50%
Bellevue, WA	All properties	Onsite detention; intensity of development	NA	Reduction of one rate (intensity of development) class	Varies
King County, WA	Commercial properties	Private maintenance	NA	Reduction of one rate class	Varies
Indianapolis, IN	Nonresidential properties	Discharge to specified streams; onsite retention or detention watershed size	Tier two: 2-, 10-, 25-, 50-, 100-year events	Tier one: 24%; ≤\$50 Tier two: 35%; <\$250	(proposed)

^aDoll, A., Scodari, P.F., Lindsey, G. (1999).

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