ECONOMIC AND ENVIRONMENTAL EVALUATION OF OFF-SITE MITIGATION OF STORMWATER IMPACTS

by

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ABSTRACT

While conventional stormwater management prioritized quick and consistent drainage using large infrastructure to prevent flooding, current practices have gradually shifted to be more in line with low-impact development strategies that emphasize mimicking pre-development hydrology. This transition has been challenging though, due to a regulatory structure that is centered around point sources and not easily adapted to fit stormwater runoff. This research aims to present an alternative management approach centered on markets for off-site mitigation of stormwater impacts. These markets, which would allow developers to offset their excess runoff by purchasing approved credits generated elsewhere, offer an opportunity to enhance stormwater management outcomes while providing developers greater flexibility.

INTRODUCTION

The effects of urbanization and development in the United States have had an unmistakable impact on the hydrology and water quality of streams of all sizes. From alterations in the volume, timing, and duration of flow, to changes in the chemical and biological characteristics of streams and rivers, stormwater from increased imperviousness throughout the landscape has degraded water bodies across the country. While the Clean Water Act (CWA) and other legislation designed to combat point source discharges into the nation's waters have been widely regarded as successful, stormwater has been much more challenging to manage efficiently and cost-effectively.

This lack of broad success in managing stormwater is in spite of overwhelming investment in resources, infrastructure, and legislation. Over the past several decades, stormwater management has been bolstered by a suite of regulatory actions that have made significant improvements in abating the impacts of stormwater. Nonetheless, most of these attempts were made within the same regulatory framework that was used under the CWA to manage wastewater and other direct discharges, a framework that does not easily adapt to the unique characteristics of stormwater, namely the diffuse and intermittent nature of urban runoff. Regulating a direct effluent source is straightforward, and simply involves permitting a single entity. On the other hand, regulating an entire municipality or watershed undergoing increasing urbanization is a much more challenging task. Establishing standards and goals is extremely difficult when there are hundreds and thousands of parcels generating stormwater across the landscape. Thus, most efforts to manage urban stormwater in the US over the last three decades have been frustrated by this inability of the current regulatory framework to target the actual source of stormwater problems: urban development.

An overwhelming focus on water quality impacts also limits the current regulatory structure from reaching success. Because the CWA was developed to address effluent from wastewater and industrial discharges, most resources have been devoted to improving overall water quality, primarily by reducing the input of nitrogen and phosphorus. The stormwater component of the CWA program has followed a similar path, with much of the focus placed on contaminants and nutrients that accumulate in runoff. While this is a major issue, the episodic nature of stormwater flows has implications not just for the biogeochemistry of streams, but also for the hydrology and geomorphology. Yet the CWA framework that has been applied to stormwater has focused almost exclusively on the water quality aspects of stormwater. With the exception of a handful of more progressive cities, such as Philadelphia and Minneapolis-St. Paul, most municipalities and states have benchmarked their stormwater management programs on water quality indicators, such as suspended sediment, nitrogen, and phosphorus. While these elements of stormwater do lead to water body degradation, they are difficult to trace back to a source, highlighting a key failing of current stormwater regulation: targeting the outfall and not the source of stormwater will inevitably lead to ineffective management.

Alternatively, a flow-based approach could offer a better connection between the source of runoff and the in-stream effects. At the moment, there is a lack of focus on volume, timing, and duration of stormwater flows, measurements of quantity that can easily serve as proxies for water quality. Stormwater management in the US can make a great deal of improvement by shifting away from a framework based strictly on water quality measures toward one focused on water quantity, where runoff sources must have technology in place to capture a quantifiable volume of precipitation before any runoff leaves the site. There is a current lack of focus on the impact that urban runoff has on the form and function of streams, particularly smaller urban streams that are heavily degraded during the higher magnitude flow events caused by increased runoff. Using flow or impervious surface area as standards provides quantifiable goals for dealing with runoff, and more definitively links this distributed pollution problem to its source on the landscape, making it far more efficient and easy to target.

Stormwater management is also hampered by inconsistent efforts within individual watersheds. Multiple political entities often regulate shared drainage areas, despite differences in goals, resources, and development patterns across the watershed. One community may implement a robust, well-supported stormwater management program with thorough monitoring and enforcement, while a neighboring community pursues minimal investment of time, resources, and energy into its stormwater program. When this occurs, the efforts of the proactive community are limited in their success by the lack of effort or resources of the latter community. This lack of unity on a watershed scale impedes the ability to have broad-based success in managing stormwater by diminishing the successes that do occur.

One of the more innovative and unproven ideas is the use of markets for stormwater management. The use of best management practices (BMPs) is often mandated with new development, whereby developers employ some technology or other feature on-site to mitigate the additional stormwater runoff created from the project. These BMPs can be as simple as basic detention basins, which capture precipitation, detain it for a given length of time, and then release it later at a slower rate. There are far more advanced and effective BMPs however, frequently called green infrastructure or low-impact development. These features attempt to mimic the pre-development hydrology by reconnecting the precipitation with the natural hydrologic cycle. Some examples of these technologies include rain gardens, bioswales, permeable pavements, and constructed wetlands. These projects and other approaches are typically designed to handle a "design storm," a precipitation event of a certain magnitude.

Under most stormwater management programs, developers are expected to implement SMCs on-site. For instance, if a developer paves a large parking lot that is anticipated to substantially increase the level of runoff generated by the site, most regulatory entities would require that the developer install some BMP on-site. Detention basins are extremely popular for this type of project, but are far from the only option available. Once a stormwater management plan has been developed and approved, the project can move forward.

In a market for stormwater impacts, this scenario would operate slightly differently, but with the same goal. If the developer cannot install a BMP on-site, for reasons such as space, cost, or environmental characteristics, then a market would permit the developer to find a stormwater management project off-site, and pay for any retention credits generated from the project. In the parking lot example, if there is not enough room for a BMP, the developer could hypothetically purchase a credit generated somewhere else in the service area. These credits could be generated by parcel-level retrofits, or by large stormwater retention banks. In the end, the goal is for the net stormwater impact to be negligible from a system-wide perspective, whether mitigation occurs off-site, on-site, or through a combination of the two.

While markets for water quality and other ecosystem services are far from new, the transition from these point source based markets to one focused solely on stormwater is unprecedented and untested. Some trading programs involve non-point sources, such as agriculture, in water quality exchanges, but these are typically included with high mitigation ratios that attempt to ensure that the runoff reduction is occurring. With regard to stormwater however, there is evidence to suggest that adopting a program where developers can find stormwater mitigation off-site holds a great deal of promise for stormwater management.

Combining this market structure with a watershed and quantity based approach offers the possibility of finding cost-effective outcomes where they might not have been available otherwise. This approach can also offer a new level of flexibility not found within the current system. Developers can be constrained by space, site characteristics, or simply cost when considering a BMP. A market for stormwater mitigation can enable not only better management of runoff by encouraging property owners to install BMPs on parcels that can most efficiently capture stormwater, but also by incentivizing the most cost-effective projects through a theoretically efficient market.

Despite the promising benefits that an exchange for off-site stormwater mitigation holds, it is not without potential pitfalls. The greatest trade-off that must be considered is the potential to lose hydrologic connectivity between impact and mitigation sites. Furthermore, without proper oversight and evaluation, an off-site trading program could fall victim to abuse and mismanagement. Potential issues include inadequate inspection and certification of BMPs used to generate credits, poor maintenance and upkeep of BMPs, credit stacking with other ecosystem service markets, and mitigation projects that do not adequately offset development impacts.

But the idea of enabling developers to seek mitigation for stormwater impacts away from the site of impact opens the door to some intriguing opportunities, and provides a great deal of flexibility that is often missing. By structuring the program in the right way, an in-kind off-site mitigation system can foster a more holistic watershed based management of stormwater impacts, and address the hydrologic impacts of excess runoff. Rather than delineating and regulating stormwater according to political boundaries, a marketplace for stormwater BMPs would ideally promote watershed cooperation. Additionally, the credits would be structured around flow and volume based metrics, such as total runoff retained during a storm event. This could offer significant improvements to current stormwater management outcomes with little overhaul to the existing regulatory framework.

While the demand and feasibility of this approach at the moment is at best nascent, the potential applications are extremely promising. In 2004, the Brookings Institution estimated that almost half of the built environment of 2030 in the US was yet to be built, representing a tremendous opportunity between now and then to implement sound stormwater management practices (Nelson, 2004). Although many projects will have ample space to adopt stormwater management controls (SMC) on-site, and have the necessary attributes on-site, such as soil and slope profile, off-site mitigation of impacts represents a cost-effective option for developers that encounter space constraints or other obstacles to effective management of increased runoff.

The current stormwater management framework has done a great deal to counter some of the most deleterious impacts of excess runoff and development. However, if it is to keep pace with the level of development that will occur over the coming century, it must adapt to a number of weaknesses that have limited the program to date. A market for stormwater mitigation is one tool that could be considered in some situations, bringing with it flexibility, cost-effectiveness, and ideally, improved environmental quality.

BACKGROUND ON STORMWATER IN THE US

URBANIZATION AND STORMWATER RUNOFF

With the rapid pace and scale of development throughout the United States over the past half-century, the growth of urban and suburban centers nationwide have added significantly to the pervasive effect of stormwater. With more than 80% of the population of the US residing in urban areas, the majority of the population growth has been concentrated in cities. The footprint of today's cities is compounding this population growth challenge; the percentage of suburban residents in the US has grown from 23% to 1950 to 47% today, meaning that, as cities are become more populous, they are also expanding their reach spatially (EPA, 2013).

All of this intensive urban growth has had significant implications for urban hydrology. An increase in impervious surface—the consequence of urban expansion—results in increased surface runoff during storm events. This increased runoff gathers from diffuse impervious sources throughout the watershed, and accumulates and enters streams at a far greater pace than if landscape was undisturbed. Precipitation that would typically enter the subsurface and slowly percolate through the groundwater system is instead routed directly to stream channels over impervious surfaces—or often through storm sewers and other engineered systems—where it picks up contaminants, nutrients, and sediment (Jennings & Jarnigan, 2002). As a result of this increased runoff, the discharge of urban streams dramatically spikes during storm events, as the lag time of runoff decreases and the total volume increases.

As urbanization increases throughout a watershed and, the receiving waterways suffer a decline in overall quality, based on factors such as biotic life, water clarity and sediment, nutrient and contaminant levels, and temperature. All of this development throughout the watershed ultimately has a negative impact on the health of streams and rivers. There is a well-researched positive correlation between the level of imperviousness as a percent of land cover throughout the draining watershed and the level of impairment in streams and other water bodies (Schueler, Fraley-McNeal, & Cappiella, 2009).

HISTORY OF STORMWATER REGULATION IN THE UNITED STATES

The Clean Water Act of 1972 has widely been regarded as one of the most successful pieces of environmental legislation in US history. While the CWA was not the first piece of legislation intended to address the nation's water quality concerns, it was unprecedented in its scope and the ambition of its goals. Furthermore, no prior regulatory framework for water had provided the same level of federal resources for implementation or enforcement (National Research Council, 2008).

The CWA acted by requiring all point sources of discharges to obtain a National Pollutant Discharge Elimination System (NPDES) permit. Initially, the law did not set standard benchmarks for specific contaminants, but rather required the use of the best available technology for treating wastewater effluent prior to discharge. Eventually, the EPA developed guidelines for discharges from specific industries, but the law initially enforced relatively strict and ambitious standards (National Research Council, 2008).

In time, the purview of the program expanded to include non-point sources as well. In 1987, amendments to the Clean Water Act included municipal stormwater discharges, as well as runoff generated by industrial and construction activities, under the umbrella of the EPA’s NPDES program. CWA section 402(p) now required these sectors to obtain a discharge permit and employ the best available technology to mitigate and abate stormwater runoff (National Research Council, 2008).

The new stormwater regulations from the EPA under the Clean Water Act were implemented over the course of five years from 1990 to 1995. In 1990, the EPA initiated the Phase I stormwater program, which required that large-scale industrial sites and construction sites spanning over five acres acquired a NPDES stormwater permit. Furthermore, and perhaps most significantly, the Phase I program required that medium to large municipal separate stormwater systems (MS4) serving 100,000 people or more obtained a permit as well. By including MS4s under the NPDES program, as well as the industrial and commercial sectors, the NPDES program attempted to account for stormwater runoff as a pseudo-point source (National Research Council, 2008).

Stormwater is incongruence with the traditional point source pollution control framework, however. While the NPDES program and the CWA very specifically target discharges of pollutants, it is less clear whether that definition of pollutants includes the volume and timing components that are unique to stormwater, in addition to traditional contaminants such as metals and nutrients. Traditionally, the interpretation of “pollutant” under the CWA has not included fluctuations in volume, timing, or other water quantity based factors, in spite of the tremendous impact that these factors have on stream health (National Research Council, 2008).

While there have been some efforts to integrate these attributes into stormwater management programs, on the whole, most efforts have been focused on water quality standards.

LIMITATIONS OF THE CURRENT FRAMEWORK

LITTLE FOCUS ON HYDROLOGIC IMPACTS

Stormwater management in the United States falls short of addressing urbanization impacts for a multitude of reasons, yet most of these reasons stem from a history of stormwater management that has focused on rapid and reliable conveyance of precipitation away from urban centers—streets, parking lots, and lawns, as a few examples—and into a receiving stream to transport this water. This goal had to be balanced with the consequences of delivering a great volume of water in an incredibly short period of time., This rapid influx of stormwater often resuled in flooding for downstream communities. As a result, engineering solutions became increasingly integral to stormwater management. Channel enlargement and hardening became standard practice, with disastrous consequences for aquatic life and stream health. Ultimately, municipalities slowly began implementing regulations in the 1970s that required developers to reduce the volume of runoff events on-site. This was frequently accomplished through the use of detention basins, large dry ponds that collect stormwater during precipitation events and release it at a later point in time. The detention basins that were used only delayed the runoff, and did not reconnect the post-development urban system with the pre-development hydrology (Ferguson, 1991; National Research Council, 2008). Nonetheless, because of their broad acceptance and popularity for developers, detention basins have remained one of the most widely used BMPs to address stormwater impacts. Overall however, detention basins have proven to be ineffective at managing runoff volume, and in some instances, traditional detention basins can actually exacerbate the peak flow effects of urbanization (Emerson, Welty, & Traver, 2005). As a result, there is a great need for stormwater mitigation approaches that more effectively abate the increased peak runoff from urbanization.

Attention to this issue of water quantity impacts has grown, and relatively recently, it has become a primary goal for some managers. Many communities adopted low-impact development (LID) strategies to adapt to this increasing impact of urbanization. The goal of LID is to maintain or replicate the natural hydrology of the pre-development site to the greatest extent possible. This is typically accomplished by techniques that encourage groundwater infiltration, among other pre-development hydrologic processes (Prince George's County, 1999). Over time, the focus of an increasing number of stormwater management programs has shifted away from the previous paradigm of managing and detaining the initial flash of runoff from a major precipitation, and toward an approach centered around LID principles.

Despite this gradual change in approach, there is still an immense amount of room for improving management programs and further implementing LID projects. Green infrastructure is still the exception and not the rule for stormwater planning. Because of the distributed nature of green infrastructure and the need for parcel level planning, as opposed to conventional large, centralized, engineered systems for stormwater capture, upfront costs and space constraints can serve as a roadblock to implementation. These challenges have slowed the pace at which communities have adopted LID.

LACK OF WATERSHED PLANNING AND PERMITTING

In 2008, the National Research Council conducted a comprehensive assessment of stormwater management in the United States. In that report, the NRC highlighted the need for more unified system design of stormwater management controls (SMC), and presented the drawbacks of having too many individual SMCs throughout a watershed with little to no coordination of installation or operation. When SMCs, particularly detention basins, are dispersed and unplanned, multiple problems arise (Ravazzani, Gianoli, Meucci, & Mancini, 2014). First, most of these controls are intended to reduce the flow of significant storms (> 10 year recurrence interval). As a result, the ability to offset the impact of smaller storms is minimal. Second, detention basins do address some issues related to runoff timing, but fail to also address the issue of total runoff volume. Detention basins only hold the runoff for a period of time, and do not significantly reduce the volume of runoff eventually released downstream. Third, a watershed full of uncoordinated SMCs is far less effective at managing runoff than a coordinated system of control measures. In fact, if not managed properly, multiple SMCs releasing detained runoff simultaneously can actually increase flooding throughout the watershed (Emerson et al., 2005; National Research Council, 2008).

With a stormwater management program centered on watershed planning and coordination, many of these problems can be avoided. The current framework frustrates success in many cases because of a lack of uniformity across a given watershed. As a hypothetical example, one community in the upper half of a small watershed could take very progressive steps to implement effective stormwater controls, while its downstream neighbors perform the bare minimum. As a result, the efforts of the upper community can be offset by excess runoff that is delivered from the downstream community. In the opposite scenario, where the proactive community is now in the downstream half of the watershed, and the upstream community does not make stormwater management a priority, the downstream community has two problems: first, it cannot effectively assess its performance because of the impacts being delivered from the upstream community; and second, because it cannot identify the success of its own program, it could be expending more resources than necessary to offset the other community's impacts. In this situation, a more unified watershed approach could assist both communities in limiting costs and improving stream health.

Given these challenges and limitations, there is a great deal of room for improvement. Flexibility is needed in many cases, and the focus should shift away from water quality metrics and toward volume based performance standards, such as runoff retained. Furthermore, until communities cooperate and regulate at a watershed scale, many proactive efforts will be negated by neighbors that do not "buy-in." While another regulatory approach is an obvious option, using an unconventional approach like a market for stormwater mitigation may be called for.

HOW MARKETS FOR STORMWATER MITIGATION CAN HELP

THEORY OF ENVIRONMENTAL MARKETS

The primary motivating force behind any environmental market is reducing cost and increasing efficiency. Rather than commanding that all parties meet a given environmental standard, such as a maximum acceptable level of pollutant emissions, the regulating entity sets a cap on the pollutant and issues permits to reach this maximum. Once these permits are issued, firms can buy and sell excess emissions until they share a marginal cost of abatement. This cap can be thought of as a mean discharge of the pollutant—some entities will emit more, and some will emit less, but across all firms, emissions will meet the standard (Tietenberg, 2010).

The draw of this approach is that it offers regulated firms both flexibility and the chance to find a lower cost abatement strategy, while still allowing the regulator to reach its environmental goals. When the marginal costs of abatement vary across firms, there is an opportunity to find an economically efficient outcome. In a hypothetical market scenario, firm A has a higher marginal cost of abatement compared with firm B. Under a traditional command and control approach, where both firms must meet a legislated standard, firms A and B must individually implement any necessary technologies or practices to reach the standard. Within a market, firm B can abate to meet its standard, and then abate an additional amount to the point that it covers firm A's excess discharge. Firm A then compensates firm B for this additional abatement, and both parties have met the same standard that was dictated under the command and control strategy (Tietenberg, 2010).

Markets for trading environmental impacts have emerged in a number of settings for a variety of factors, including air quality markets to address sulfur dioxide emissions, climate change markets that trade carbon dioxide emissions, water quality markets that trade nutrient discharges, and recently, more unconventional environmental goods such as trading biodiversity areas for protecting endangered species habitats. In all of these cases, mitigation costs varied a great deal between parties, and by opening a market, these costs could be lowered.

APPLYING MARKETS TO STORMWATER

A useful analogy for stormwater mitigation trading is the current practice of wetland and stream mitigation banking. While mitigation banking takes place over a much larger service area than stormwater trading would, and despite the fact that there are lingering questions about the effectiveness and oversight of mitigation banks and projects (Bernhardt et al., 2005; King & Herbert, 1997), the program is nonetheless a worthwhile analogy for how a market for stormwater mitigation could operate, and how it could avoid some of the problems that have plagued wetland and stream mitigation.

Under section 404 of the Clean Water Act, wetlands are protected from impacts under a policy of "no net loss"; according to this policy, there can be no loss in total area or function of the nation's wetlands. In the event that a developer, public or private, must impact an aquatic ecosystem, either through a loss of physical area or function, that party must apply for a permit with the US Army Corps of Engineers, and must take three steps: first, avoid impacts to wetlands and streams; second, minimize any impacts; and third, perform or pay for the necessary mitigation to offset the impacts. The Corps makes a determination as to whether the project will negatively impact aquatic ecosystems and what level of mitigation will be required. Aside from on-site restoration, developers can offset impacts through the purchase of approved credits. These credits are generated through wetland and stream restoration projects certified by the Corps. In many cases, these restoration projects are clustered into “banks” to take advantage of economies of scale and provide a large number of credits with the expectation that mitigation will be in demand in the future (BenDor et al., 2009).

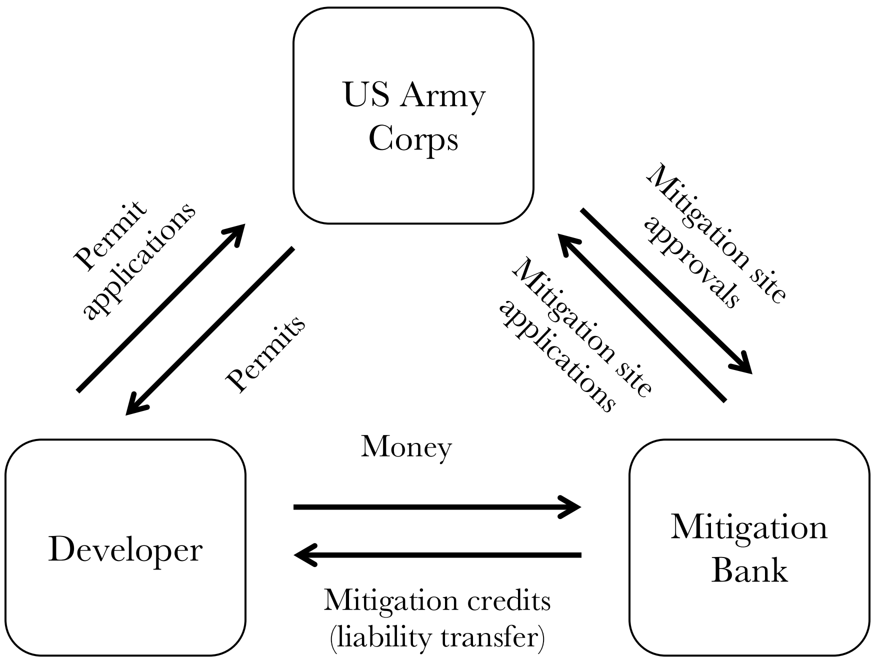

Figure 1: Flow diagram of the wetland and stream mitigation program. Adapted from BenDor, Sholtes, and Doyle (2009).

Figure 1 illustrates the flow of credits and compensation within the mitigation banking program. When a developer anticipates a significant impact to a stream or wetland, and has already taken steps to both avoid and minimize the impact, then a 404 permit application is filed with the regional Corps district. The Corps reviews the plan to see that impacts have been avoided and minimized, and in the event that a permit is issued, determines the level and type of mitigation necessary (BenDor et al., 2009).

The developer has three avenues to pursue mitigation: permittee-responsible mitigation, where the developer installs the mitigation project; in-lieu fee programs, typically paid to a public agency, which then fund restoration and enhancement projects; and finally, mitigation banking, which provides approved mitigation credits for purchase to offset impact. Mitigation banks are private firms that purchase degraded environments and attempt to restore them for the purpose of selling mitigation credits. In many cases, these are "banks" in every sense of the word: restoration projects can cover a truly vast amount of space to meet demand and provide as many credits as possible, take advantage of economies of scale, and provide more credits at a lower marginal cost (BenDor & Brozovic, 2007; EPA, 2003).

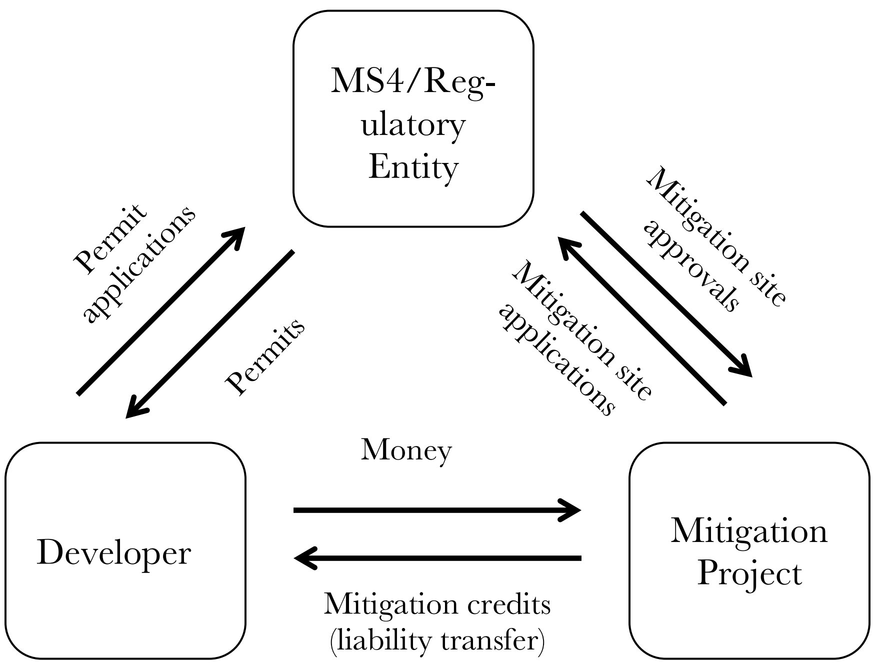

Figure 2: Adapted flow diagram of stormwater mitigation exchange program.

A mitigation market for stormwater would be structured in a very similar manner from a theoretical standpoint. When developers increase the level of runoff compared to the pre-development hydrology, mitigation must take place. Under the conventional stormwater management framework, this mitigation—through the installation of a stormwater control measure—would need to be placed on-site, in spite of space constraints, or other factors that could limit the feasibility of BMPs, such as soil type or slope.

By adapting the wetland mitigation banking framework, a stormwater mitigation market would function much the same, but on a much smaller scale. While wetland mitigation projects are frequently exchanged across great distances, with mitigation and impact occurring in separate watersheds in most exchanges, a stormwater market would take place at a much larger scale, due to the much smaller size of BMPs compared with restored wetlands, and the fact that the regulating entity would need to be the MS4 (BenDor & Brozovic, 2007).

Figure 2 depicts this adapted framework. In this new scenario, the US Army Corps is replaced with the stormwater utility or some other local entity that regulates stormwater. This piece of the diagram is responsible for setting the mitigation standard, reviewing BMPs, certifying and documenting credits, and ensuring that developers mitigate their impacts. Just as the Corps is responsible for ensuring no-net loss in the wetland mitigation program, the MS4 is responsible for setting and meeting its runoff abatement goals. When developers are unable to avoid impacts or

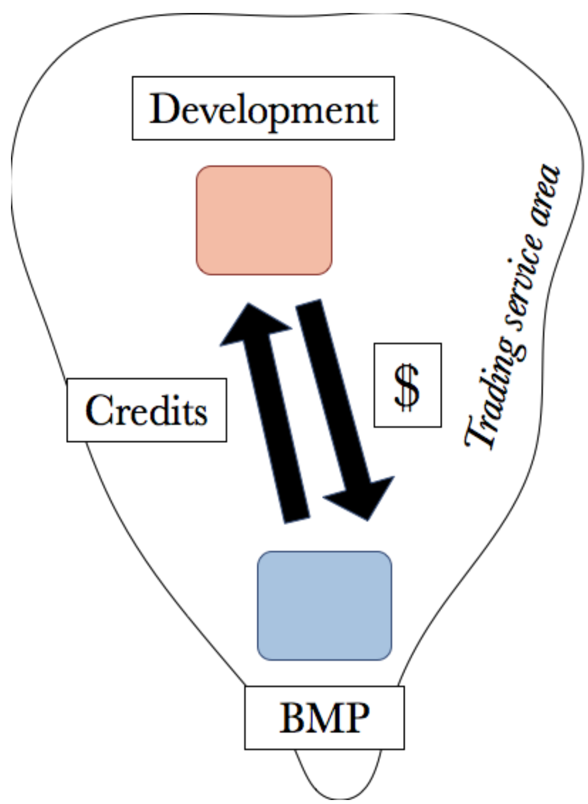

Figure 3: Conceptual diagram of market exchange.

mitigate on-site, they can go to a market that provides certified mitigation credits. Figure 3 offers a conceptual diagram of how this program would work geographically, with the flow of credits and compensation outlined.

HOW A MARKET CAN HELP

ADDRESSING HYDROLOGIC IMPACTS

While the CWA and its emphasis on improving water quality worked tremendously well for dealing with point source impacts, stormwater affects streams by very different mechanisms. Naturally, any regulatory framework should target stormwater using those different mechanisms as measures of performance.

Rather than dealing with the constituents and overall water quality, a stormwater market could use volume or other hydrologic factors as proxies to establish a currency. The benefit of this approach is that it targets the hydrologic impacts that are being overlooked currently, while still improving runoff water quality. If the total volume of runoff is reduced, then the contaminant load will similarly be reduced. This volume-based approach has the dual benefit of mitigating erosion and sedimentation both throughout the drainage area and within the stream channel itself, as the recurrence of high magnitude flows is decreased.

Years of monitoring on the chemical and biological composition of urban runoff provide sufficient knowledge and data to support the use of volume as a proxy performance standard. Due to over a decade of monitoring and modeling by various entities throughout the county, stormwater is well characterized and understood. Resources such as the National Stormwater Quality Database have kept track of MS4 stormwater monitoring in multiple regions and climates in the US, offering a solid picture of stormwater from a water quality standpoint. Aside from being better suited to the nature of stormwater, regulation based on flow is likely easier to implement. Building SMCs to address a specific volume flow is far more-straightforward than monitoring runoff for water quality (National Research Council, 2008).

The Potash Brook TMDL in Vermont offers an insight into the implementation of flow as a surrogate performance standard for dealing with stormwater. Challenged with biological impairments, a difficult issue to measure and mitigate, managers in Vermont decided to pursue a 16% reduction in the volume of the 1-year recurrence interval discharge. The targeted flow in this TMDL is generally recognized as a highly important discharge for determining stream form and function, making it a crucial event to target for reducing erosion, sediment loading, channel widening, and bank instability (EPA, 2006). In many ways, regulating flow is the best, most efficient avenue to reducing stormwater impacts.

A market for stormwater mitigation needs a tradable currency that can easily be certified and exchanged; using a flow volume that can be quantified is a natural means to that end. Not only can this be used effectively to address water quality concerns, it can mitigate and abate the impact of urban runoff on hydrology. With a decrease in excess runoff from the urban environment, contaminants, sediment, and erosion will naturally decrease in turn.

PROMOTING WATERSHED PLANNING

The National Research Council emphasized the need for a watershed based model for stormwater management, going as far as stating, "The course of action most likely to check and reverse degradation of the nation's aquatic resources would be to base all stormwater and other wastewater discharge permits on watershed boundaries instead of political boundaries. (National

Research Council, 2008).” Going this far would require significant legislative action however, a substantial task that may not be feasible.

A market for stormwater impacts is an alternative strategy to fostering this needed watershed cooperation. While the MS4 permits are currently issued at the municipal level based on political boundaries, a market would prioritize planning within watersheds or sub-watersheds. Depending on how the market is structured and managed, exchanges could be restricted to within the same sub-watershed as the impact. This would preserve a hydrologic linkage between impact and mitigation, and also foster development planning based on hydrologic boundaries as opposed to political ones.

LOGISTICAL CONSIDERATIONS

Following the increasing popularity of markets for water quality during the 1990s and early 2000s, the EPA issued policy guidance in 2003 on water quality trading structures. Within that policy, the EPA outlined seven common themes in successful trading programs. This list provides a starting point for establishing stormwater impact trading programs. EPA later added three additional elements and adapted others when it developed the total maximum daily load (TMDL) guidelines for the Chesapeake Bay states (Virginia, Maryland, Pennsylvania, West Virginia, New York, and the District of Columbia) in 2010. Because much of the Chesapeake Bay TMDL improvements will come through non-point source pollution management, these additions and adaptations made the water quality trading policy more applicable to stormwater trading, and are useful for outlining the logistics, structure, and mechanisms of an off-site stormwater mitigation marketplace. For a mitigation program that deals with stormwater alone, these guidelines can be consolidated and adapted to include the most pertinent elements. These steps are:

1. Defining the regulatory authority that permits the program.
2. Determining what sectors can participate and drawing marketplace boundaries.
3. Developing procedures and responsible for quantifying, inspecting, and certifying credit-generating projects.

A STEP-BY-STEP APPROACH TO IMPLEMENTATION

DEFINING REGULATORY AUTHORITY

Prior to permitting any off-site mitigation projects, the stormwater management entity needs to verify that it has the regulatory and legal authority to oversee mitigation projects off-site. Based on conversations with multiple stormwater managers on the East Coast, there are two primary paths that a city or state can take to achieve the authority for an off-site stormwater mitigation projects.

The first and most common of these methods is to implement an off-site permitting process through a NPDES MS4 permit, either at the city or state level. In most cases, the appropriate environmental regulating body at the state level issues these permits, with their authority provided by EPA. These permits are either Phase I or II. Under Phase I permits, medium and large MS4s are required to implement six minimum measures to reduce nutrient discharges to the “maximum extent practicable,” and have monitoring requirements (National Research Council, 2008). Phase II MS4s are covered under a general statewide permit, and are required to implement the same six measures, but monitoring is optional. Cities can either have off-site allowances included in their Phase I permits, or in their statewide general permits if they are a Phase II system. Multiple municipalities and states have taken this approach to allowing off-site mitigation to take place, and have regulated its practice using varying means.

Off-site mitigation programs can also be implemented through the use of a TMDL framework, or some other similar watershed based permitting approach. Under this arrangement, the ability to trade stormwater impacts can be applied over a much larger spatial area. Multiple MS4s within a watershed are included in the framework, and both developers and MS4s can find mitigation offsets throughout the TMDL watershed. Because the stormwater mitigation is exchanged based on the watershed and not the municipality, this approach has the advantage of fostering consistent and shared stormwater management goals over a broad area. Furthermore, depending on how the TMDL is structured, this approach has the advantage of bringing non-MS4 regions into the watershed-trading zone. Development that takes place outside of a Phase I or II community can participate in the exchange, bringing in areas that are currently not regulated for stormwater. The mitigation that takes place in these areas would likely not have occurred without the need for offset exchanges by MS4s.

Because TMDLs cover such a broad area, the trade-off here is that the exchanges can take place across sub-watersheds. Mitigation can be exported away from the watershed of impact, shifting the hydrologic connectivity to a much larger scale. One of the strengths of the TMDL approach—its emphasis on watershed planning—is also one of the weaknesses because these watersheds can be rather expansive and allow exchanges that cover quite large distances. Furthermore, the TMDL approach carries the risk of hotspot formation, despite overall improvements in water quality at the watershed scale. Hotspots form when pollutant loading is offset with mitigation elsewhere, and the original pollutant source remains. While the total pollutant input—in this case, stormwater—is reduced or maintained, the trading can create localized zones of poor water quality. This risk is greatest in situations when impacts are mitigated higher in the watershed than the site of the impact (mitigation upstream of the impact). Ultimately, this risk is minimal. Most water quality trading program guidelines specifically dictate that trading cannot result in a decline in water quality (EPA, 2004).

DRAWING THE MARKET BOUNDARIES

While the regulatory authority to enable trading for impacts is the foundation of the market, it does not create the market. That step requires targeting the appropriate buyers and sellers, and making the market economical attractive, while meeting community environmental goals. Serious consideration must be given to the participants in the market and their geographic reach. Environmental impacts can vary greatly in scale depending on the environmental quality in question. Some impacts are highly localized, such as wastewater treatment discharges, while climate change is global in scale. Therefore, the spatial extent of the impact must be measured, and then the exchange of impacts and mitigation can be appropriately exchanged.

Under citywide trading, developers can exchange projects anywhere within the boundaries of the municipality. There is no consideration of the hydrologic connectivity between the impact and the mitigation, and the mitigation does not need to take place within the same drainage area as the impact, limiting the offset capabilities of the mitigation project. Nevertheless, this arrangement provides the most flexibility to both developers and mitigation credit generators. Developers have the most geographic area available to find mitigation options, while creditors can find the most cost-effective projects. As a result, this schematic will encourage the greatest level of participation.

In order for a market for stormwater mitigation projects to be have the greatest benefit for stream health however, the mitigation needs to truly be in-kind, despite being off-site and geographically removed from the site of impact. In effect, there must be a hydrologic linkage between the site of impact and the mitigation site, or else the supposed mitigation will not truly offset the impact. In order to accomplish this, geographic boundaries should be set up in such a way that preserves this linkage. Markets that mimic political boundaries will be less effective because they bear little resemblance to hydrologic boundaries. Naturally then, watershed boundaries will likely be for more effective than citywide trading at keeping impacts and mitigation connected.

Watershed-based boundaries are likely to provide the greatest balance between ensuring the best environmental outcomes and granting the necessary flexibility to market participants. By limiting trades to take place within the same watershed as the impact, the program will keep the link between impact and mitigation intact. With that in mind, this approach is limited by the difficulty of choosing the size and extent of the watershed. The transferability of mitigation varies depending upon the nature of the watershed.

The question then becomes, how large should the scale of these watershed-marketplace boundaries be? This debate becomes a balancing act of sorts. If watershed boundaries are too restricted and geographically small, then no trades will take place because of a lack of mitigation projects within a reasonable distance from the impact site. The system needs to be large enough to give flexibility—which is the primary advantage of this system—to developers to go off-site and find appropriate mitigation. If the bounds are too small, then debitors will have difficulty finding suitable creditors. As the area of the market expands however, more and more credit providers will find the demand necessary to invest in BMPs, thus stimulating market participation (Doyle & Womble, 2012).

On the other hand, if the marketplace is too large, then the program runs the risk of disconnecting the linkage between the impact and the mitigation. This connectivity between the two sites is crucial for an off-site mitigation program to preserve the existing environmental condition. Without it, the mitigation is no longer in-kind and does not truly offset the development impact. As a result, the market needs to be restricted and small enough in scope so that it keeps the mitigation within an appreciable distance of the impact.

USGS hydrologic unit codes (HUC) are a convenient starting point for drawing the watershed boundaries. The HUC system covers multiple hydrologic scales in the United States, starting at the HUC-2 level (two-digit code), which covers the 21 major drainage basins of the country, and increases in resolution down to the HUC-12 level. The HUC-12—also titled the cataloging unit—is the smallest drainage delineation in the system, covering 2,264 individual hydrologic units. This level is an appropriate starting point for a municipality considering establishing off-site mitigation trading boundaries (USGS).

Ultimately, the process of drawing market boundaries will vary significantly between jurisdictions. One hydrologic unit that could be the perfect scale for one community will be virtually non-transferable for another based on characteristics such as development density, soil and slope, and the extent of the MS4 jurisdiction. Natural hydrologic boundaries may not be the only possibility for drawing the marketplace; communities with combined sewer systems can and should consider CSS catchment areas for trading zones. These "artificial" hydrologic boundaries more precisely target the impact of runoff in that community. With stormwater sewer systems redefining the hydrology of urban areas, these outfalls are equally important to consider when restricting trades. In these cases, trades should be constrained within the same sewer system areas.

QUANTIFYING, INSPECTING, AND CERTIFYING CREDITS

To allow trading to occur, stormwater mitigation must be converted to a quantifiable unit that can be bought and sold. For the program to work, mitigation projects must be measured against the same scale as impacts. Two broad approaches can be used for stormwater management: volumetric controls on runoff, and mitigation of impervious surface area. While many stormwater jurisdictions have adopted the first approach, few entities have taken the latter strategy, making it a more experimental yet effective measure.

Runoff volume abatement is frequently applied to development projects as a stormwater management target. For instance, Washington, DC, Philadelphia, and Los Angeles all have volume-based controls within their stormwater regulations (City of Los Angeles, 2011; District Department of the Environment, 2013; Valderrama et al., 2013). This is an especially practical benchmark for generating credits in an off-site stormwater mitigation market. If volume control is the selected method of creating credits, the next step is to determine what volume of precipitation. Aside from selecting an arbitrary number, such as the first 1-inch of runoff, another method is to start with a percentile storm, such as the 90^{th} percentile storm (precipitation event that is equaled or surpassed 10% of the time).

Once the recurrence interval and associated runoff volume are selected, that performance standard must be converted into a tradable credit. The simplest method is to convert the volume to a credit, such as 1-inch of runoff managed per unit surface area per year. If this method is selected, the unit surface area will have a significant impact on the market. Selecting a smaller surface area unit, such as 1-inch per square foot, has the advantage of opening the supply side of the market to many more properties, especially residential properties. In highly urbanized, densely developed areas where credit-generating sites are limited by space constraints, this could stimulate more credit-generating projects in the market. The disadvantage of this approach is that it could require buyers to purchase more credits from the smaller projects, which in turn could increase transaction fees and place more administrative burden on the certifying entity. Using more land area per unit runoff brings with it greater economies of scale, and the potential for greater hydrologic benefits due to the aggregation of mitigation projects over a larger contiguous surface area, but it does not incentivize small landowners to implement retrofit BMPs and generate credits to sell on the market (Valderrama et al., 2013).

Going one step further, adjusting for land use in mitigation projects presents a more nuanced method of developing credits. This adjustment would provide a uniform standard for ensuring that mitigation projects represent an actual improvement over the pre-mitigation condition. For instance, putting a rain garden in a tract of land that is already heavily forested and undeveloped brings with it no improvement to the watershed. This adjustment can be accomplished by applying an adjusted runoff treatment volume equation. The Runoff Reduction Method (RRM), developed by the Center for Watershed Protection and the Chesapeake Stormwater Network, is one method for estimating the runoff volume that must be treated. This equation adjusts the runoff volume for the percentage of land at the impacted site that can be characterized as forested, impervious, or turf/disturbed soil (Battiata, Collins, Hirschman, & Hoffman, 2010).

With these considerations in place, the responsibility for overseeing the market and credit-generating process needs be placed with the appropriate administrative entity. In many communities, the responsibility for stormwater management falls under the control of the local water utility or a stormwater utility in communities where one has been established. These offices and departments at the local level oversee the administrative duties related to NPDES MS4 program, whether it is Phase I or II. This is only considering the NPDES MS4 program and not the construction and industrial portions of the NPDES stormwater program. In many cases, these departments will already have review procedures in place for inspecting mitigation, and the process will likely not differ greatly for off-site projects.

CASE STUDY: WASHINGTON, DC STORMWATER CREDITS

BACKGROUND

In the summer of 2013, the District Department of the Environment (DDOE) in Washington, DC, released its final 2013 Stormwater Rules, which proposed an innovative and largely unparalleled off-site stormwater trading program. The trading program is based on stormwater retention credits (SRC), and allows development and redevelopment properties needing stormwater retention to buy SRCs from anywhere within the District of Columbia to meet their total retention volume requirement. The program does require that at least the first half of the stormwater retention volume requirement be met on-site, while the remaining half can be met with any combination of on-site treatment and SRCs. For development projects, the program requires retention of the 1.2-inch rainfall event, which is equivalent to the 90th percentile storm, and redevelopment projects are required to capture and retain runoff from the 0.8-inch rainfall event (District Department of the Environment, 2014).

ECONOMIC AND ENVIRONMENTAL BENEFITS AND COSTS

Environmental markets are popular based on the belief that they promote cost-effective environmental management, especially when traditional regulatory approaches are incapable of doing so. The theory holds that when the costs to install environmental controls vary significantly across firms, gains from trade can occur when they are allowed to share costs. Not only does this provide firms with the opportunity to match their marginal cost with that of the market, it finds a more economically efficient price when compared with a tax (Tietenberg, 2010). The District of

Columbia stormwater retention trading program is structured to take advantage of these potential cost-savings, and at the same time relieve the District of some of the administrative responsibilities and oversight involved with directly mitigating runoff.

While the rules were developed and announced in July 2013, development projects were not required to comply with the new regulations until January 15, 2014. As a result, there is not yet enough data to analyze the performance of this market. However, research on the economic and environmental benefits of the program conducted by the DDOE strongly suggests that the program will result in an overall improvement in stormwater management in DC.

Table 1: Comparison of on-site only and mixed mitigation projects under DC's new trading rules. Taken from Van Wye (2012).

	Scenario A: On-site only (0.1 hectare)	Scenario B: On-site and off-site	Difference
1.2" storm volume retained (gal.)	7,739	7,739	0
Annual volume retained (gal.)	280,280	440,605	57%
Estimated retention cost	$25,152	$15,087	-40%

From an environmental point of view, this analysis predicts that more BMPs dispersed across the landscape will capture far more runoff than if the retention occurred solely on-site. Table 1 outlines some of the projected retention and cost advantages of an off-site program of this kind. In scenario A, the quarter-acre development project meets its entire retention requirement on-site. This translates to 7,739 gallons of runoff during the 90^{th} percentile storm of 1.2." In scenario B, the development project splits its runoff retention in half between two sites, and as a result, increases the annual volume of runoff retained by 57%. Additionally, this decreases the overall cost of compliance for the developer by 40% (Van Wye, 2012).

Interestingly, DDOE has elected to allow trading between any properties within the District of Columbia. Trading based on political boundaries has the greatest potential for gains from trade, encourages the highest level of participation, and provides the most flexibility to developers when seeking mitigation. However, all of this flexibility comes at the risk of diminishing the hydrologic benefit of the mitigation projects by removing the linkage between the BMP and the impact. If the impact occurs in one small watershed, while the mitigation takes place in a watershed on the other side of DC, there is little to no immediate benefit for that stream.

Washington may present a special exception however, because of its role in the Chesapeake Bay TMDL. The entire District eventually drains to the Potomac River, with the Potomac forming the southwest boundary of the city, and the Anacostia River on the southeast draining into the Potomac just to the south in Virginia. The Potomac is a major tributary of the Chesapeake Bay, which has struggled for many years with water quality impacts. While DC comprises less than one half of one percent of the total land area in the Potomac watershed, it is home to approximately 11% of the total population living in the watershed. This incredibly dense concentration of the watershed's population is a large source of the Bay's urbanization impacts, but it also represents an opportunity to make tremendous improvements in the river's health while targeting a small geographic portion of the watershed (District Department of the Environment, 2010).

DC is thus posed with a trade-off: protect its urban streams and improve the overall health of small river systems within the District; or meet its TMDL targets and offset its significant impact on the water quality of the Chesapeake Bay estuary system. Based on the structure and oversight of this trading system, DC has chosen the latter, regulating at a local scale with regional policy goals in mind.

In spite of this seeming trade-off of environmental quality though, there may actually be a great deal of upside for small streams in DC as a result of this program. While trading outside of a sub-watershed removes the hydrologic benefits from the stream impacted, a proliferation of small, distributed BMPs may have a highly beneficial effect. Under a strictly on-site mitigation program, development projects would have to implement BMPs to capture the first 1.2” of runoff from each storm event. This design storm—the 90th percentile storm—would capture a large number of storms in their entirety. The new DC regulations would allow a split of this 1.2” between two properties, with a minimum of 50% on-site and the remainder off-site. At first glance, this greatly diminishes the number of storms captured. The 0.6” design storm is exceeded much more often than the 1.2” storm. However, there are now two BMPs capturing this volume, which doubles the number of sites capturing any storm smaller than 0.6” in magnitude. Under the on-site only scenario, more high-magnitude storms are captured, but still only one site is capturing the regular 1-year recurrence interval storms.

This additional capture potential resulting from two or more BMPs is highly beneficial to small urban streams from a hydrologic standpoint. Major channel shaping discharges are frequently estimated using metrics such as bankfull discharge or effective discharge, which are seen to govern the slope, size, and shape of streams. Past research has estimated that in many systems, these channel forming flows have a recurrence interval of approximately one to two years, meaning that the discharge with the greatest channel-shaping potential occurs on average every other year (Bray, 1975; Wolman & Miller, 1960). Urbanized streams see these channel forming flows at a much greater frequency, however. In some cases, these discharges can occur as frequently as four to eight times per year (Annable, Lounder, & Watson, 2011). Therefore, capturing these storms in more locations is more important in many cases than capturing as many storms as possible from one location. Due to the substantial increase in both the frequency and magnitude of high stream discharges stemming from increased runoff, this strategy of increasing the number of BMPs overall can result in a tremendous reduction in the number of storm events reaching small urban streams

DISCUSSION

Markets for environmental services are primarily motivated out of a belief that they can offer the flexibility and cost-effectiveness that regulation alone cannot provide. For instance, this is the argument behind cap and trade markets aimed at climate change mitigation or air quality. The hope is that, by permitting a set amount of pollution in conjunction with a reduction in pollution elsewhere, regulators can still reap the environmental benefits of stringent laws and standards, while spending less and offering additional flexibility. In order for this to work however, impact must be truly offset by mitigation. This is the bedrock of any environmental market where mitigation can be exported: looking at the system as a whole, no single impact can make a net negative change.

This framework is little different when applied to stormwater management. If a project results in a net increase in runoff when compared to the pre-development hydrology, that impact must be offset, and a market is a cost-effective mechanism to achieve that offset. Managers can struggle over decisions such as how to define what benchmarks must be met, or what menu of technology options to make available to offset impacts, but at the most fundamental level, this market works through an in-kind, like for like exchange of impact and mitigation, ideally creating an equilibrium for stormwater.

There are a number of potential pitfalls with this approach however, just as there are with every single market for environmental services. The room for abuse still exists. Rather than pursuing cost-effective environmental management, some could see this program as an opportunity to shirk environmental responsibilities. If not regulated rigorously, unscrupulous participants could take advantage of cheaper, ineffective mitigation projects. Instead of offsetting impacts and maintaining a baseline environmental quality, these lopsided exchanges could cause a decline in environmental quality. When mitigation projects do not represent a net improvement on the previous environmental quality, the impact is not offset by the mitigation and overall environmental quality suffers. This underscores the importance of rigorous inspection not just of the mitigation project, but also of the site condition prior to mitigation. If the site was an undisturbed, forested area prior to mitigation, then it’s virtually impossible that any BMP will actually improve the environmental quality of both the mitigation site and the system, and ultimately, it will not offset the impact.

This is of particular concern when geographic boundaries are drawn too large, and when land use varies considerably within the market. When the boundaries of the market are excessively broad, then mitigators may look to the lowest cost land to implement a BMP, which in many cases is unoccupied, unprotected, pristine land. There is a potential risk of this occurring within West Virginia’s MS4 off-site mitigation program. While not a market in the same sense as the program in Washington, DC, the West Virginia program allows developers to offset their impacts away from the development site. This program makes sense in a heavily urbanized area like DC, but in a state like West Virginia, where much of the land area is still untouched and environmentally undisturbed, it is difficult to envision scenarios where developers are sufficiently strapped for space that they would need to go off-site to install BMPs. As a result, there is a danger that unscrupulous developers and mitigators will “implement” BMPs off-site in regions that have no hydrologic disruptions in need of improvement. In the end, managers of these programs must develop carefully outlined procedures for approving mitigation projects, taking into account both the pre-mitigation and post-mitigation site condition. For this program to work, the site of the impact must not be the only location that comes under close scrutiny, or else mitigation projects could become avenues for developers to avoid their stormwater management responsibilities.

In addition to this issue of ineffective mitigation is the issue of "stacking." Stacking occurs when mitigation projects produce benefits that could potentially be used in multiple ecosystem service markets. For instance, some wetland mitigation projects can also potentially be used to generate credits in endangered species markets. The environmental benefits generated share the same site, and one would not occur without the other. Consequently, there is a great deal of discussion—and disagreement—over the virtue of decoupling these benefits and generating credits in two different, unrelated markets from one mitigation project (Robertson et al., 2014). There are numerous issues that arise when credits can be stacked, including the challenge of accounting for these shared credits, and whether the ecosystem functions can actually be untangled from a mitigation site. Consider an endangered species habitat that results from a wetland mitigation project: is this an additional benefit that can be detached from all of the other services performed by the wetland, and then commoditized and sold as a credit; or is that habitat inherent to the wetland ecosystem, and unable to be cleaved as a separate ecosystem service (Gardner & Fox, 2013)? Moreover, improper stacking may result in an overestimation of mitigation, and an underestimation of impacts. For instance, a small wetland mitigation project could conceivably serve as a stormwater BMP at the same time. While the project does serve both of these purposes, if it is used to offset both a stormwater impact and wetland impact, one of the original impacts is no longer offset. This raises the issue of additionality: credits should not be generated from benefits that would have occurred without any action of the credit generator (Robertson et al., 2014). The restored wetland would have served as a stormwater sink, regardless of the actions of the credit generator.

In the end, it is likely in the best interest of stormwater managers to avoid permitting stacking as an option for stormwater projects. Aside from the questionable ecosystem service accounting that would occur, this type of unbundling of services occurs at multiple regulatory scales that may be beyond the resources a local stormwater administrator. The level of coordination involved to properly account for these ecosystem services could potentially be too burdensome, and defeats the goal of flexibility that makes this market framework appealing.

CONCLUSION

Although stormwater management has made significant advancements in improving water quality and stream health over the last several decades, it has been limited by a lack of flexibility and has not adequately addressed the hydrologic impacts of urban runoff. These shortcomings are compounded by a dearth of cost-effective solutions and incentives for low-impact development. In light of these challenges, an environmental market is one possible option for communities looking for a way to overcome these obstacles. An exchange for stormwater mitigation would incentivize cost-effective options and more directly target and abate the hydrologic impacts of runoff.

This program is not without its trade-offs though. Careful attention must be paid to the efficacy of mitigation projects, and managers must give substantial consideration to the logistics of the market, most notably, the geographic size of the market, which will have a tremendous influence on the ability of this program to improve stream health and keep the hydrologic linkage between mitigation and impact. Once these steps are taken however, this program could provide both managers and developers with a new level flexibility.

There are still many questions and uncertainties regarding this approach, and the unfolding program in Washington, DC will hopefully provide some insight into its feasibility. If successful in DC, this framework could become a model for other cities across the country dealing with excess runoff and few cost-effective options for managing it. As that occurs, local regulators must be meticulous in developing these programs. While this approach could offer tremendous flexibility, too much flexibility could open the door to systematic abuse, and in the end, a degradation of environmental quality.

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