NC STATE UNIVERSITY

AN EVALUATION OF COST AND BENEFITS OF

# Structural Stormwater Best Management Practices

IN NORTH CAROLINA

*Two structural stormwater BMPs: a sand filter at NC State University (top) and a nearly full bioretention/raingarden in Chapel Hill.*

## Introduction

Clearing land, laying pavement, and constructing buildings increase the volume and speed of stormwater runoff. These actions contribute to flooding and may damage property and habitat, with the damage known as stormwater quantity impacts. Clearing and construction also contribute to lowering of water quality by increasing the flow of human pollutants (such as oil, fertilizers, and pesticides) and natural elements (such as nitrogen, phosphorus, and sediment). When these substances get into the water, they create stormwater quality impacts. Degradation of lakes, streams, and wetlands by urban stormwater runoff reduces property values, raises bills from public water utilities, and reduces tourism and related business income.

Urban stormwater runoff can be controlled by the use of various best management practices (BMPs). BMPs are either nonstructural, such as reduced road widths and elimination of sidewalks, or structural, varying from small, site-specific practices to large-scale regional practices. Research results outlined here focus on which structural BMPs work best at removing selected pollutants and their relative costs for North Carolina conditions. This information offers decision-makers an *economic* tool to aid them in choosing the *best* BMP for a particular location and pollutant type.

## Structural stormwater BMPs

An urban stormwater BMP is believed to be a "best" way of treating or limiting pollutants in stormwater runoff. The stormwater treatment practices investigated here include wet ponds, stormwater wetlands, sand filters, and bioretention areas.

**Wet ponds,** also called wet detention ponds, have been used in North Carolina longer than any other stormwater BMP. Wet ponds are runoff-holding facilities that have standing water in them constantly. Storm flows are held in the ponds temporarily and then released to minimize large-scale flooding. The primary pollutant-removal mechanism is settling (sedimentation), while stormwater runoff resides in the pool. Nutrient uptake also occurs through biological activity. Wet ponds can be designed to look like natural lakes to enhance the value of surrounding property. They have been and can be used for commercial sites as small as 1 acre and for watersheds as large as 100 acres or more. The example on the cover is at a construction site at NC State University in Raleigh.

**Stormwater wetlands,** also called constructed wetlands, are comparable to wet ponds but are much shallower and more heavily vegetated with wetland plants. They serve as a natural filter for urban runoff, help to slow the flow of water to receiving waters, and replenish groundwater. As stormwater runoff flows through the wetlands, sedimentation, adsorption, and biological processes achieve pollutant removal. In North Carolina, constructed stormwater wetlands have been located on watersheds as small as 4 to 5 acres, but they are more commonly used for larger drainage areas and typically serve watersheds ranging from 15 acres to more than 100 acres. Thanks to the vegetative cover, wetland effluent is typically cooler than that of wet ponds, minimizing the impact of thermal pollution. Wetlands consume a relatively large amount of space and thus have limited applicability in highly urbanized settings.

**Sand filters** are usually two-chambered stormwater treatment practices. Water enters the first chamber, where debris settles out, and then moves to a second chamber, where a filter bed filled with sand or another filtering medium removes other forms of pollution. At the bottom of the sand layer, an underdrain pipe typically connects the treated water with the existing drainage network. Sand

**Table 1. Structural stormwater BMPs by relative size of commercial/residential drainage area.**

| *BMP* | *Relative size of commercial/residential drainage area* | |
|---|---|---|
| | *Large* | *Small* |
| Wet pond | X | X |
| Stormwater wetland | X | |
| Sand filter* | | X |
| Bioretention/raingarden** | | X |

** Only effective with a significant drop in elevation (for perimeter sand filter, at least 2 feet).*
*** In clay soils, a significant drop in elevation (4 feet) is typically required.*

filters are particularly well-suited for treating stormwater runoff in ultra-urban areas because they can be designed to be walked over or driven on, thus preserving expensive land. Typically, the sand filter will treat a drainage catchment of only a few acres. This practice is designed for impervious watersheds in particular.

**Bioretention/raingardens** in many respects are landscaped and vegetated filters for stormwater runoff. Surface runoff is directed into shallow, landscaped depressions. Trees and shrubs are planted in bedding material consisting of a high percentage of sand and lesser amounts of silt, clay, and/or organic matter. During rain events, stormwater pools above the mulch and soil in the system. The remaining runoff filters through the mulch and prepared soil mix. Typically, the filtered runoff is collected in a perforated underdrain and is returned to the storm drain system. Bioretention systems are ideally suited to many ultra-urban areas as they will fit existing parking lot islands or other landscaped areas. Because bioretention potentially can fulfill two purposes—water quality control and landscaping requirements—their use is expected to increase. Bioretention areas typically serve very small watersheds, such as (portions of) parking lots or residential runoff areas.

Table 1 summarizes the four structural stormwater BMPs discussed above, keying on the relative size of the associated drainage area. A more extensive summary of these and other stormwater practices can be found in *Urban Stormwater Structural BMPs*, AG-588-1.

## Land opportunity costs

Construction of BMPs may reduce the availability or the size of a (re-)development site, and this is a frequent concern of real-estate interests. Land opportunity costs must take into account any lost opportunity to use the land for other commitments. In highly urbanized areas, dedicating land to stormwater BMPs involves a loss of development profit, and this loss is likely to be the most important cost of a BMP.

Land requirements vary by type of BMP and are also dependent on watershed composition and precipitation. An important indicator is runoff, which is determined by precipitation and curve number (CN). CN reflects the ability of a watershed to store water through initial storage and subsequent infiltration. A high CN suggests a very impervious area with limited storage capacity. The lower part of Table 2 summarizes the general sizing rules for BMPs, which were developed by the Department of Biological and Agricultural Engineering at North Carolina State University (see *Designing Stormwater Wetlands for Small Watersheds*, AG-588-2, for an explanation of these rules). They are location-specific. Note that a specific practice for a specific development may require more or less land, depending on site-specific conditions. The sizing rules in Table 2 were used in the cost calculations.

**Table 2. Summary of construction cost curves, maintenance cost curves, and required surface area for stormwater BMPs in North Carolina.**

| | *Wet ponds* | *Stormwater wetlands* | *Sand filters* | *Bioretention in clay soils* | *Bioretention in sandy soils* |
|---|---|---|---|---|---|
| Construction cost | $C=13{,}909X^{0.672}$ | $C=3{,}852X^{0.484}$ | $C=47{,}888X^{0.882}$ | $C=10{,}162X^{1.088}$ | $C=2{,}861X^{0.438}$ |
| 20-year maintenance cost | $C=9{,}202X^{0.269}$ | $C=4{,}502X^{0.153}$ | $C=10{,}556X^{0.534}$ | $C=3{,}437X^{0.152}$ | $C=3{,}437X^{0.152}$ |
| Required surface area of BMP in acres | | | | | |
| Residential development | | | | | |
| • Piedmont (CN 80-90) | SA=0.015X | SA=0.02X | | SA=0.025X | SA=0.025X |
| • Coastal Plain (CN 65-75) | SA=0.0075X | SA=0.01X | | SA=0.015X | SA=0.015X |
| Highly impervious area with CN 80 | SA=0.02X | SA=0.03 | | SA=0.03X | SA=0.03X |
| 100% impervious areas (CN 100) | SA=0.05X | SA=0.065X | SA=0.017X | SA=0.07X | SA=0.07X |

C=cost in $; X=size of watershed in acres; SA=surface area of BMP in acres

*Source: Wossink and Hunt (2003)*

Prices of land vary to a large extent, and three situations were distinguished in the evaluation of the cost of stormwater BMPs:

- Undeveloped land for commercial use with an average opportunity cost of $5 per square foot ($217,800 per acre).
- Undeveloped land for residential use with an average opportunity cost of $50,000 per acre.
- Undeveloped land with zero opportunity cost because of the requirement for open space.

## Construction, maintenance, and inspection costs

Construction and maintenance costs were collected for more than 40 stormwater BMPs, principally from North Carolina. From this data, cost equations were formulated, relating costs to watershed size. Table 2 summarizes these equations.

Statistical analysis indicated that the relationship between the size of the watershed and the construction cost as presented in Table 2 is not that strong. There are other factors that affect construction cost, such as watershed composition, required excavation depths, and many other engineering aspects that were not included in the construction cost curves. Note that bioretention construction costs were significantly different with regard to soil types: clayey or sandy.

## Total annual costs

The total cost of a stormwater BMP is made up of the following three components: construction costs + maintenance and inspection costs + land opportunity costs. When comparing stormwater BMPs and deciding which practice to install, consider the long-term maintenance cost. By accounting for the value of future expenditures, the net total cost of each stormwater BMP can be calculated. A discount rate of 10 percent for the private developer was used in these calculations. This rate includes the risks associated with the specific industry. The net total cost value of a BMP is then to be converted to annualized costs per acre treated and annualized costs per percent of pollutant removed. Thus, BMPs of different duration, treatment area, and removal effectiveness can be compared.

Developers may be able to use the costs of structural stormwater BMPs as a deduction for tax purposes. Operating costs generally are fully deductible as expenses in the year incurred. Capital investments associated with compliance generally must be depreciated over some number of years. Tax advantages are highly dependent on the marginal tax rate and were not accounted for in the calculations.

## Removal effectiveness

Data were collected from 60 BMPs in the Southeast and Mid-Atlantic states on removal of total suspended solids (TSS), total phosphorus (TP), nitrate ($NO_3^-$), total nitrogen (TN), and zinc (Zn). Based on a statistical analysis of these data, each practice was assigned a single removal rate (the median removal efficiency) in the cost-effectiveness analysis. That is, it can be assumed that the practice will work comparably well whether it serves a small or a large watershed. The median pollutant removal efficiencies for each of the practices are reported in Table 3. The negative and low removal efficiencies for nitrate-nitrogen when using a sand filter and bioretention area are due in great part to the design configuration. These BMPs are designed to drain freely, and the lack of an anaerobic zone is responsible for the low to negative removal rates of nitrate-nitrogen (Davis *et al.*, 2001).

## An example: Cost comparison for a 10-acre watershed (CN 80).

For a 10-acre watershed with CN 80, we compare the installation of a wet pond, a stormwater wetland, and a bioretention area on the basis of the cost per acre treated and the cost per percent TSS and TN removed. A sandfilter is not an option: such a practice is applicable only to areas that are 100 percent impervious (see Table 2).

Table 4 shows that a bioretention area would be the least expensive BMP if this practice could be installed in sandy soil. Both the cost per acre treated and the cost per percent TN removed are less for this practice than if a wet pond or a wetland were used. A comparison based on the cost per percent TSS is not possible because data on TSS removal effectiveness was not available for bioretention areas. A stormwater wetland would be the least expensive solution if clay soil were to prevail. In that situation, bioretention in sandy soils is no longer an option. Of the three remaining BMPs, a wetland has the lowest annualized cost per acre of watershed.

**Table 3. Median removal effectiveness and number of sites analyzed for 4 BMPs from studies in the Southeast and Mid-Atlantic.**

| BMP type | *TSS* | | *TP* | | *$NO_3^-$* | | *TN* | | *Zn* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Rmvl. Effic. (%)* | *No. Sites* | *Rmvl. Effic. (%)* | *No. Sites* | *Rmvl. Effic. (%)* | *No. Sites* | *Rmvl. Effic. (%)* | *No. Sites* | *Rmvl. Effic. (%)* | *No. Sites* |
| Wet ponds | 65 | 27 | 46 | 28 | 42.5 | 16 | 28 | 27 | 51 | 24 |
| Stormwater wetlands | 61 | 14 | 32.5 | 14 | 55 | 8 | 22 | 14 | 49 | 6 |
| Sand filters | 79 | 12 | 59 | 11 | (56.5) | 11 | 41 | 12 | 64 | 11 |
| Bioretention areas | N/A | — | 71 | 5 | 16 | 4 | 45 | 4 | 89 | 4 |

*Source: Wossink and Hunt (2003)*

**Table 4. Cost comparison of 4 BMPs for a 10-acre watershed (CN 80)**

| *Practice* | *Wet pond* | *Wetland* | *Bioretention in clay soils* | *Bioretention in sandy soils* |
|---|---|---|---|---|
| Construction cost | 65,357 | 11,740 | 124,445 | 7,843 |
| Annual maintenance cost | 4,411 | 752 | 583 | 583 |
| Opportunity cost of land ($217,800/acre) | 43,560 | 65,340 | 65,340 | 65,340 |
| Present value of total cost | 146,474 | 83,486 | 194,751 | 78,137 |
| Annualized cost per acre watershed | 1,721 | 981 | 2,288 | 918 |
| Annualized cost per percent pollutant removed | | | | |
| • TSS | 26 | 15 | N/A | N/A |
| • TN | 61 | 45 | 51 | 20 |

## Conclusion

The economic decision-making tool described here will help people dealing with stormwater runoff make an informed choice about which BMP will be most effective for the different conditions that exist in watersheds across North Carolina.

The size of the watershed, the soil type, the imperviousness of the watershed as described by CN range, the pollutant of main concern, and the amount and price of land for the structure all influence the selection of a BMP. The complexity of these factors makes it impossible to summarize in a few sentences just which BMP is to be preferred from an economic perspective in each situation. A full research report (Wossink and Hunt, 2003) is available that includes the results of systematic applications of this economic decision-making tool to the various N.C. conditions (Report Number 344 of the Water Resources Research Institute of the University of North Carolina; also available on the Internet at http://www.ag-econ.ncsu.edu/faculty/wossink/outreach.html).

However, the information presented in Tables 2 and 3 offers some general findings with respect to cost, pollution removal efficiency, and watershed management, namely:

- There are large differences in the total-cost-per-acre-treated among the BMPs analyzed.
- All BMPs, except for bioretention not in sandy soil, display economies of scale within the practice—the construction cost and the maintenance cost-per-acre-treated decrease as the size of the watershed increases.
- The effectiveness of wet ponds and stormwater wetlands with regard to removing the pollutants TSS, TP, and $NO_3^-$ was found to be comparable. In North Carolina before this study, it generally had been assumed that wetlands work better.
- For the four BMPs analyzed, no significant relationship was found between pollution-removal efficiency and watershed size.
- All BMPs need to be maintained, and money should be set aside up-front for this purpose. Approximate amounts for each type of BMP can be estimated from Table 2.

This small bioretention/raingarden in Chapel Hill has filtered and drained most of its stormwater.

A stormwater wetland in Alexander County, heavily vegetated with wetland plants to filter rain runoff, is also an educational site.

## References


Davis, A. P., M. Shokouhian, H. Sharma, and C. Minami. 2001. "Laboratory study of biological retention for urban stormwater management." *Water Environment Research* 73(1): 5-14.

Wossink, Ada, and Bill Hunt. 2003. *The Economics of Structural Stormwater BMPs in North Carolina*, WRRI Research Report Number 344. Also available at http://www.ag-econ.ncsu.edu/faculty/wossink/outreach.html.

**Funding for this economic analysis of stormwater BMPs was provided through the Water Resources Research Institute of the University of North Carolina.**

*Prepared by*
Ada Wossink, Associate Professor and Extension Specialist,
Department of Agricultural and Resource Economics, North Carolina State University
and
Bill Hunt, Assistant Professor and Extension Specialist,
Department of Biological and Agricultural Engineering, North Carolina State University

**Published by**
**North Carolina Cooperative Extension Service**



11/03—2M—JL/DC AG-642
E04-43938