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The "Energy Balance" Method of Stormwater Management

BY MICHAEL S. ROLBAND AND FRANK R. GRAZIANO

It is a well-accepted and understood principle that changes in land use within a watershed, primarily related to the increase in impervious area resulting from land development, increase stormwater runoff. This increased flow degrades downstream receiving waters that are insufficient in size or do not have appropriate substrate to handle the change in flow regime. Almost half a century ago, negative impacts to receiving waters resulting from land development led to the implementation of the first stormwater management regulations. Since then, changes have been implemented as more knowledge has been gained, leading to the most widely accepted protocol that requires detention of stormwater runoff such that the post-development peak flow rate does not exceed the predevelopment peak flow rate for a given design storm (typically for a two-year and 10-year return period). However, despite the implementation of and adherence to these regulations for many years, degradation of downstream receiving waters has continued. The currently accepted explanation is that this continued degradation results from the increase in volume (which in effect increases the power supplied to the stream), even though the peak flow rate has not increased.

Ever-increasing sensitivity to the environmental quality of receiving waters—much of it driven by the desire to protect the Chesapeake Bay—has renewed interest in reducing the impacts from stormwater runoff. This overall concern, coupled with a local, high-profile, beneficial development project that was nearly stopped because of stormwater issues, prompted Wetland Studies and Solutions Inc. (WSSI) to develop the Energy Balance method of stormwater management. This method offers a means for reducing the deleterious effects of stormwater runoff without precluding economic development. WSSI has also been instrumental in obtaining approval of the Energy Balance method at both the local and state levels.

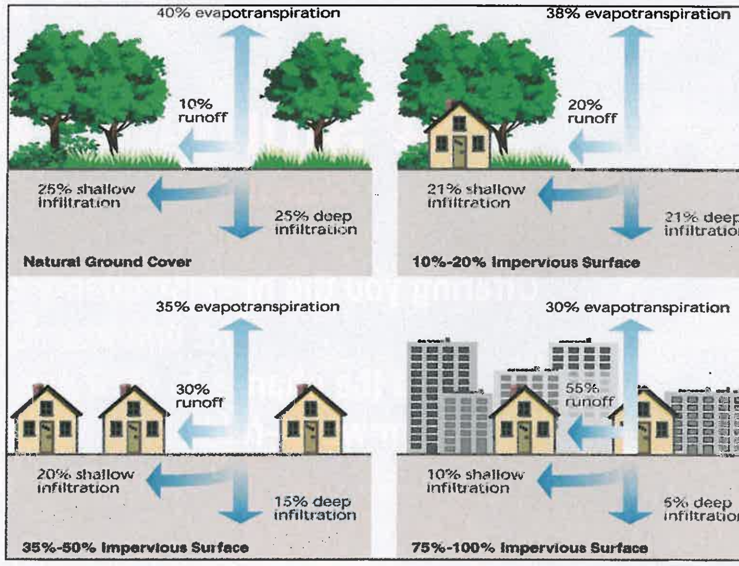

Figure 1. Increasing development and impervious area (Stream Corridor Restoration: Principles, Processes, and Practices. Federal Interagency Stream Restoration Working Group, October 1988)

Traditional Stormwater Management

As discussed above, traditional stormwater management practices control the peak flow rate in a pre- versus post- development condition. However, as the amount of impervious area increases, peak flow rate is not the only concern: The volume of runoff also increases as less water is able to infiltrate into the ground, as depicted in Figure 1.

Thus, approximately three to five times more water runs off of a developed landscape than a landscape in its natural state, increasing the peak rate as well as the runoff volume and frequency. The result is degradation of the receiving channels that progresses in a fairly predictable manner and generally adheres to the evolutionary process shown in Figure 2.

While the initial incision may occur quickly, many decades may pass before the channel adjusts to the increased flow

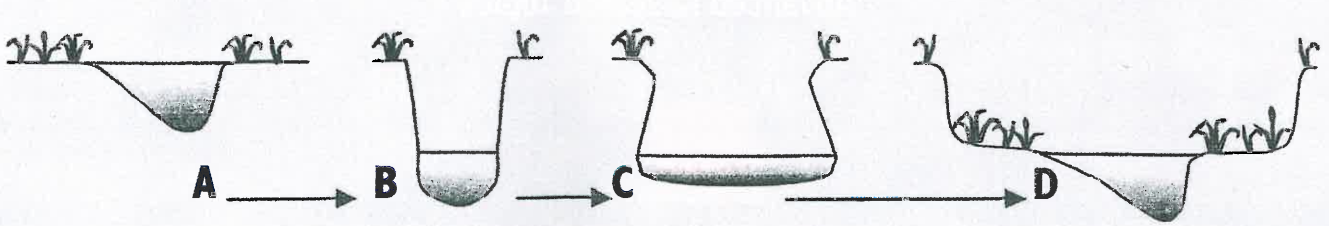

Figure 2. A: Stable channel connected to the floodplain; B: Channel begins to incise in response to the increased flow rate; C: Channel over-widens as the banks slump and material is washed away; D: Stream eventually stabilizes at a lower floodplain elevation. (Adapted from Dave Rosgen's *Wildland Hydrology*.)

rates to the point where stability is returned.

Again, this increase in runoff relates not only to peak flow, but also to the runoff volume. This additional amount of water volume is depicted in Figure 3, representing the pre- and post-development condition of a hypothetical 20-acre site with conventional two-year stormwater management controls. (Predevelopment site: forested, hydrologic soil group C, CN = 70. Developed site: townhouses, hydrologic soil group C, CN = 90.) Although the post-development peak flow rate is matched, flow rates of a particular magnitude will be experienced for a longer duration in the post-development condition. It is this power from the flow in the stream (resulting from this additional volume) that can lead to stream degradation, especially when the frequency of the bankfull events also increases as a watershed is developed. The net result is that significantly more energy is imparted on the stream channel, resulting in sometimes excessive erosion.

Energy Versus Power

Before describing the Energy Balance concept in more detail, a clarification on the term *energy* is warranted. *Energy* is defined as the ability to perform work, or force x distance. *Power* is defined as the rate at which force performs work, or work/time. Thus, the Energy Balance methodology is actually more of a "power balance," as it manages the flow rate (Q), which is in units of cubic feet per second. This nuance does not affect the derivation or application of the methodology, but it could lead to some confusion if not clarified.

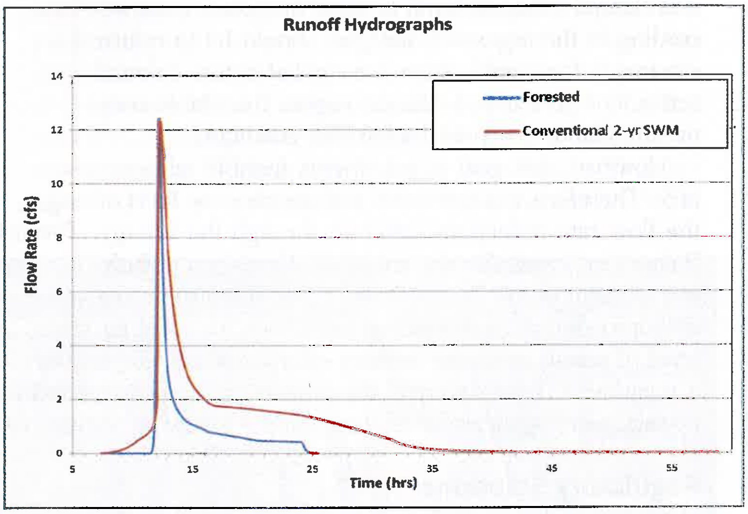

Figure 3. Runoff hydrographs for a hypothetical 20-acre site

Energy Balance—Fundamental Concept

In a perfect world, pre- and post-development hydrology would be matched, including both peak flow rate as well as runoff volume. In fact, Executive Order 13508 ("Chesapeake Bay Protection and Restoration") signed by President Barack Obama on May 12, 2009, requires that exact result from development activities associated with federal facilities located in the Chesapeake Bay watershed. In a guidance document it issued on March 15, 2010, in response to Section 502 of the executive order, the US Environmental Protection Agency includes the requirement for federal development projects to maintain or restore the predevelopment hydrology with respect to volume, flow rate, and temperature. To accomplish this goal, the additional runoff volume that results from the construction of impervious surfaces on undeveloped lands must be "eliminated," either through reuse, evapotranspiration, or infiltration.

However, all of these options have significant restrictions. For example, reuse of the additional volume requires that demand for the water exist at the site. This demand can take the form of irrigation, reuse for flushing toilets, or use in cooling towers. Of course, irrigation demand is seasonal in most parts of the United States, while use in toilets requires a high density of people versus impervious area to reduce runoff volumes significantly. Moreover, grey water use is subject to various federal, state, and local regulations. As for reuse in cooling towers, not all buildings are large enough to require such towers, nor do all facilities run them all year round. Meanwhile, evapotranspiration in such features as rain gardens and green roofs can account for some of the required volume reduction. However, like irrigation, evapotranspiration is seasonal in most parts of the country. As for infiltration of the excess runoff, this option is also limited for many sites that have insufficiently permeable soils, a high water table, or shallow depth to bedrock. For reasons such as these, requirements related to maintaining predevelopment hydrology are difficult to meet on most development sites.

In theory, managing the peak flow rate is fairly straightforward—additional storage volume is all that is needed. Of course, site constraints can complicate efforts to provide adequate storage for the increased volume. And without accounting for this increased volume, receiving waters will continue to be degraded. This fact drove the development of the Energy Balance method of stormwater management: We needed a way to mitigate for an increase in runoff volume for projects that had no practical means with which to reduce the runoff volume to predevelopment levels.

The basic principle of the methodology is that the product of the peak flow rate multiplied by the runoff volume in the predevelopment condition should be proportional to the same product in the post-development condition:

$$Q_{Pre} \times RV_{Pre} \approx Q_{Post} \times RV_{Post}$$

Where:

Q_{Pre} = Predevelopment peak flow rate (cfs)
RV_{Pre} = Predevelopment runoff volume (in.)
Q_{Post} = Post-development peak flow rate (cfs)
RV_{Post} = Post-development runoff volume (in.)

Implementation of this protocol protects receiving channels, even in instances where the additional runoff volume cannot be accounted for onsite (as is often the case). After all practicable volume reduction methods have been implemented, the factor that can be more easily controlled—peak flow rate—is reduced to balance the pre- and post-development conditions. Hydrographs representing the Energy Balance approach on the previously described hypothetical site are shown in Figure 4.

What is "Pre"?

In the example above, the "pre" condition was forested. Thus, the peak flow rate reduction derived using the Energy Balance method was applied to the peak flow rate in a forested condition. However, an argument can be made that regardless of the existing condition, the base from which the flow rates should be reduced should be a forested condition. The basis for this argument relates to the historical condition of watersheds within the mid-Atlantic region of the US where we primarily work: In most instances, degradation did not begin until land was cleared for agricultural or other purposes. Thus, according to the argument, the goal should be to return streams to their stable state that existed before colonial settlement. In the mid-Atlantic region, this stable state predominantly comprised a forested condition.

However, this goal is not always feasible or desirable. Therefore, it is necessary to determine the level of the flow rate reductions achieved through the Energy Balance approach for any given site. Goals can include not worsening the existing conditions, requiring some level of improvement over existing conditions, or meeting some level of runoff assuming existing conditions are forested (or a meadow). These different alternatives have been enacted by regulatory agencies, as discussed in the following sections.

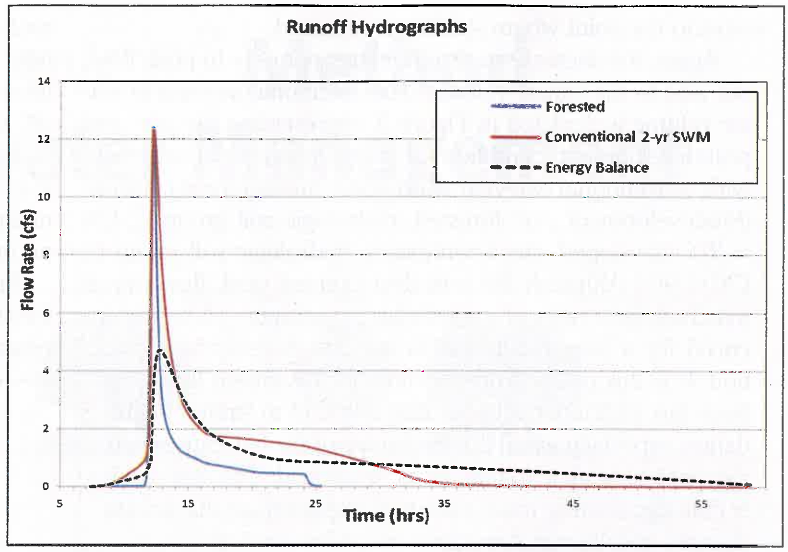

Figure 4. Runoff hydrographs for the hypothetical 20-acre site showing the Energy Balance approach

Regulatory Solutions

With the understanding that accounting for the additional runoff volume, in addition to the peak flow rate, is necessary to protect downstream receiving waters, the question becomes how to achieve this goal. One option would be to simply mandate that the hydrology in the pre- and post-construction condition match—that is, no increase in peak flow rate or runoff volume would be permitted. However, adoption of such a regulation would prevent many sites (if not most, in certain areas) from being developed without numerous subjective exceptions granted. This outcome would be particularly true for intensely developed sites located on soils that do not infiltrate (hydrologic soil groups C and D). Even for sites that do provide some level of infiltration (hydrologic soil groups A and B), there may not be enough capacity to eliminate the additional runoff volume that is generated for some land uses–for example, in an urban setting where the buildings occupy most of the site or where grading requirements eliminate use of the permeable portion of the soil profile. Because preventing site development would not be economically desirable, a system of waivers would have to be instituted on a case-by-case basis. This approach would add significant uncertainty and cost into the development process, as landowners would not know whether their property could be developed until significant funds had been expended.

As an alternative to the blanket mandate discussed above, a performance standard could be developed that encourages the goal of matching hydrology in the pre- and post-construction conditions without mandating that it be achieved. This approach allows site development to proceed in a more predictable manner, while providing real incentive to reducing impacts to downstream receiving waters.

The Energy Balance method achieves this goal. Recognizing that the pre- and post-construction product of runoff volume times peak flow rate must match, the more the runoff volume can be reduced, the less onsite storage volume that will be required. Because of the expense of storing the increased volume, this approach encourages the exploration of ways to reduce runoff volumes in the site planning process. This can include taking advantage of the portions of the site that have soils that can provide infiltration, if at all possible, or implementing low-impact-development (LID) techniques, such as the use of permeable paving materials, rain gardens, green roofs, or cisterns to capture rainfall to be used for onsite irrigation. In this way, the Energy Balance method provides incentives for reducing storage requirements for stormwater as a way to decrease stormwater management costs. The result is a methodology that quantifies the application of "practicality" instead of leaving its definition to the angst of a subjective regulatory process.

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The other benefit of this approach is that sites that are unable to reduce their runoff volumes sufficiently can still be developed through the provision of sufficient stormwater storage volume, but without the politics of an undefined waiver process. Thus the site can be developed and the stormwater management program can be planned early on in the process, as opposed to having to wait for a decision from a regulatory agency.

History of Regulatory Development

The regulatory history behind the development of the Energy Balance method of stormwater management has spanned many years, beginning at the local level and culminating in adoption for use throughout Virginia. The process by which this regulatory development occurred offers an example of how the Energy Balance method can be used to solve real-world stormwater management problems.

Fairfax County. The impetus behind the original development of the Energy Balance method to providing effective stormwater management was based on an issue that arose during the rezoning process for a major development project located in Fairfax County, VA, in 2005. The project called for redeveloping an aging community of single-family homes located immediately adjacent to a Washington DC Metrorail (subway) station. The plan was to develop the property around the station at a high density to take advantage of the proximity to mass transit. As with most urban areas, sprawl and the resulting traffic congestion are major problems–thus the rationale for this worthy "smart growth" project.

Given the high densities that were planned for the site, stormwater management clearly would be a significant factor. Specifically, state law required the presence of an "adequate outfall" in order to discharge stormwater. In other words, the receiving channel had to be adequate to handle the increased flow, both in terms of stability and capacity. These requirements are spelled out in the Virginia Department of Conservation and Recreation (DCR) manual titled the *Virginia Erosion and Sediment Control Handbook (VESCH), Minimum Standard 19* (as promulgated in 4VAC50-30-40). The *VESCH* also spells out the procedure by which the receiving channel is to be assessed for adequacy. The design and construction standards manual for Fairfax County (the *Public Facilities Manual, PFM*) cites the VESCH criteria to demonstrate adequacy.

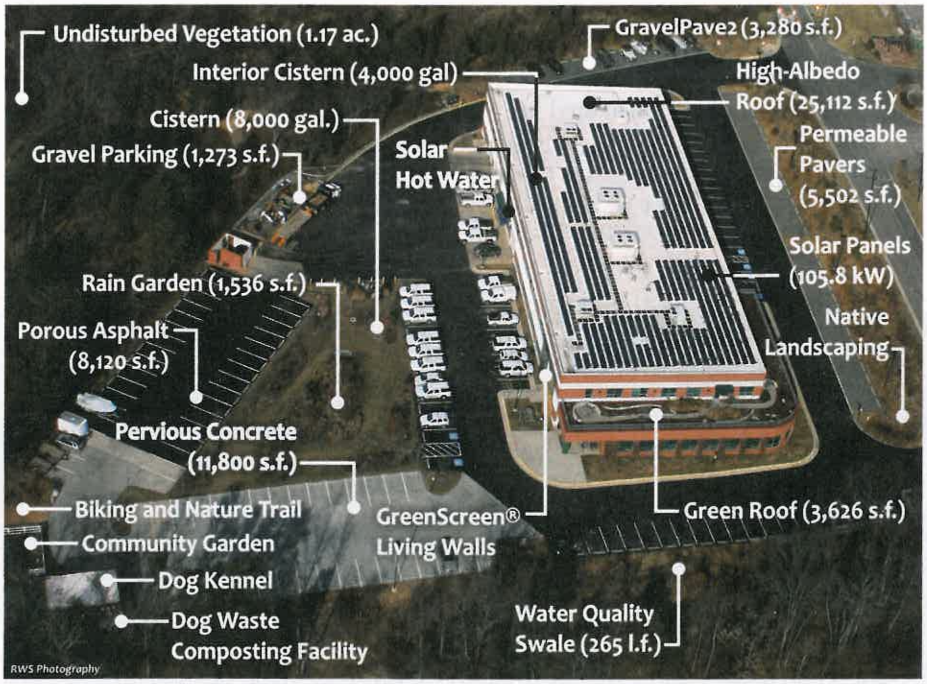

Figure 5. LID practices at WSSI office reduce stormwater runoff.

Although the requirement to provide "adequate outfall" had been in place many years before the commencement of this project, it was not rigorously enforced. However, given the high-profile nature of this project, adherence to the existing rules regarding adequate outfall was strict. Meanwhile, the receiving channels adjacent to the project were tested in accordance with the existing procedures and found to be eroding and unstable in their existing (predevelopment) condition, and thus they were not adequate even for existing flows. Therefore, the initial remedy was to restore the channels to make them capable of handling the additional stormwater expected from the project. The client in this case was willing to perform the restoration, despite the significant expense. All but about 50 feet of the channel was located on property owned by the Fairfax County Park Authority, with the remainder on private property owned by a homeowners association (HOA).

As the project moved through a very contentious public rezoning process, the HOA indicated that it would not be willing to grant an easement in order to allow the work to be performed on its property. The HOA's stance resulted from its opposition to high-density development at a Metro stop. Given the location of this section of the channel in the middle of the reach, the restoration could not be performed without access to the HOA property. As a result, the entire development project was in jeopardy: No adequate outfall existed, the stream could not be made adequate without the easement, and, strictly speaking, the regulation offered no remedy to overcome this circumstance.

With the renewed interest in issues related to adequate outfall, this situation was likely to become more prevalent and had the potential to prevent development projects from moving forward countywide. What was needed, then, was an onsite solution to adequate outfall. This need led to the development of the Energy Balance methodology. The first step was to change state law to provide for the option of an onsite remedy. Working with Delegate Tom Rust in Virginia's House of Delegates during the 2006 legislative session, WSSI drafted the following language for legislation (House Bill 684) that eventually was adopted into state law:

> Any land disturbing activity, as defined in § 10.1-560, that provides for stormwater management facilities that incorporate best management practices designed to (i) detain the water quality volume and to release it over 48 hours, (ii) detain and release over a 24-hour period the expected rainfall resulting from the 1-year, 24-hour storm; and (iii) reduce the allowable peak flow rate resulting from the 1.5, 2, and 10-year, 24-hour storms to a level that is less than or equal to the peak flow rate from the site assuming it was in a forested condition, achieved through multiplication of the forested peak flow rate by a reduction factor that is equal to the runoff volume from the site when it was in a forested condition

State Regulation (4VAC50-60)

3. Natural stormwater conveyance systems. When stormwater from a development is discharged to a natural stormwater conveyance system, the maximum peak flow rate from the one-year 24-hour storm following the land-disturbing activity shall be calculated either:

a. In accordance with the following methodology:

$$Q_{Developed} \leq I.F. * (Q_{Pre\text{-}developed} * RV_{Pre\text{-}Developed}) / RV_{Developed}$$

Under no condition shall $Q_{Developed}$ be greater than $Q_{Pre\text{-}Developed}$ nor shall $Q_{Developed}$ be required to be less than that calculated in the equation $(Q_{Forest} * RV_{Forest}) / RV_{Developed}$

Where:

IF (Improvement Factor) = 0.8 for sites > 1 acre or 0.9 for sites ≤ 1acre.

$Q_{Developed}$ = The allowable peak flow rate of runoff from the developed site.

$RV_{Developed}$ = The volume of runoff from the site in the developed condition.

$Q_{Pre\text{-}Developed}$ = The peak flow rate of runoff from the site in the pre- developed condition.

$RV_{Pre\text{-}Developed}$ = The volume of runoff from the site in pre-developed condition.

Q_{Forest} = The peak flow rate of runoff from the site in a forested condition.

RV_{Forest} = The volume of runoff from the site in a forested condition;

or

b. In accordance with another methodology that is demonstrated by the local stormwater management program to achieve equivalent results and is approved by the board.

divided by the runoff volume from the site in its proposed condition, shall be deemed to satisfy this subsection, and shall be exempt from any flow rate capacity and velocity requirements for natural or manmade channels as defined in any regulations promulgated pursuant to this section, section 10.1-562, or section 10.1-570.

In summary, HB 684 provided landowners with the option of an onsite solution to the adequate outfall problem, while respecting downstream property owners' rights, by incorporating a design standard that lowers stormwater flows to less than or equal to the flows from a forest in good condition.

At the same time the large development project was moving through the rezoning process, Fairfax County convened a committee of county staff and private-sector engineers, including WSSI, to review requirements in the county's *PFM* related to adequate outfall and stormwater management. While its work was not initiated in response to this one specific development project, the committee could have prevented the project from moving forward. Our involvement on the committee allowed us the opportunity to present the Energy Balance method as a solution to the adequate outfall issue.

Fairfax County staff recognized the possible benefit of allowing the Energy Balance approach, and incorporated its use as an alternative method to meeting adequate outfall requirements into the County's *PFM* (Section 6-0200, "Policy and Requirements for Adequate Drainage"). Once adopted (effective February 7, 2006), the Energy Balance method allowed the smart growth project at the Metro station to move forward by providing onsite stormwater management that reduced outflows from the project to levels below those seen in a forested condition. In this case, the goals of the Energy Balance method were primarily accomplished by providing underground detention vaults coupled with some LID features. Although very expensive, the vaults provided a solution that would have otherwise not been available.

Statewide Stormwater Regulations. On a different track, and before the changes were implemented at the county level, the Commonwealth of Virginia began taking steps to improve the regulation of stormwater. The process formally began in 2004 with the passage of House Bill 1177 (patron: L. Preston Bryant Jr.), which created the Virginia Stormwater Management Program (VSMP). Subsequent to the passage of this legislation, DCR began the process of revising parts I, II, and III of the permit regulations of the VSMP in order to develop and strengthen the technical requirements (related to both water quality and water quantity), as well as to improve the administration of the program. These revised regulations would apply to localities with municipal separate storm sewer systems, localities covered by the Chesapeake Bay Preservation Act (required for localities in Virginia that have tidally influenced water bodies), and localities requesting to operate or "opt in" the VSMP.

To assist in the revision process, DCR convened a regulatory advisory panel (RAP) comprising stakeholders and DCR staff. Mike Rolband of WSSI was an active participant, chairing the water quantity subcommittee. This participation, along with the prior work by WSSI to develop and implement a form of the Energy Balance method at both the state and local levels as an option to provide stormwater management, led to the consideration of the Energy Balance approach by the RAP. Following a series of meetings held by the committee, as well as public meetings held throughout the state spanning several years, the Soil and Water Conservation Board approved a proposed regulation on May 24, 2011, with an implementation date of July 1, 2014. A main component of the new stormwater regulations is the Energy Balance principle, which was slightly modified from the version that was adopted in the Fairfax County *PFM*. The pertinent text from the state regulation (4VAC50-60) is provided in the sidebar.

One of the changes between the requirements of HB 684, Fairfax County's *PFM*, and the resulting state regulation concerns the comparison that must be made regarding site conditions. In the Fairfax County and state legislative versions, the "pre" condition was assumed always to be a forest in good condition.

In the recently adopted state regulation, however, the Energy Balance is applied to whatever the existing conditions of the site may be. Thus, the new regulation will provide for a reduction in peak flow rate that is inversely proportional to the increase in runoff volume, coupled with the further reduction represented by an improvement factor—an achievable outcome that will provide real protection for downstream receiving waters. The new regulation also stipulates that provision of the Energy Balance methodology will, by definition, result in an "adequate" downstream channel. In this way, the new regulation eliminates problems (with issues unrelated to stormwater flow) that often arise from having to obtain easements from downstream property owners.

Another important modification relates to the design storms that must be considered. Previously, the Energy Balance had to be applied to the 1.5-, two-, and 10-year, 24-hour storms. (The 1.5-year storm was included to accommodate LEED certification requirements.) The newly adopted regulation limits the application of the Energy Balance to the one-year, 24-hour storm. This was done in recognition of the fact that the smaller, more frequent storms contribute most to stream erosion. Thus, streams are protected without the unnecessarily large detention volumes that result from requiring the Energy Balance approach on infrequent storms like the 10-year storm.

Preliminary assessments have been conducted on a hypothetical site that represents varying levels of development and soil types. Results of these assessments suggest that pond sizes can be expected to vary up to ±20%, depending on the specific factors of the development scenario, when compared to current regulations that require control of peak flow rates for the two- and 10-year, 24-hour storm events. However, any nominal increase in required pond size could be offset by providing LID practices that include infiltration or by conducting reuse. Thus, another added benefit of adopting the Energy Balance methodology is its built-in incentive to reduce the volume of stormwater runoff.

Conclusion

Regulations at the federal, state, and local levels are becoming increasingly more stringent in terms of the control of stormwater runoff, and this trend is likely to continue. Balancing this regulatory reality and desire to protect the environment with the many benefits that come from a robust development sector is a significant challenge that must be met. The Energy Balance method provides a workable solution to the problem of providing effective stormwater management in a manner that is both economically and technically achievable and that provides real protection of downstream receiving waters. ♦

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