A GIS Site Selection Tool for Stormwater Best Management Practices

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Introduction

Water is commonly accepted as one of life's necessities. It sustains Earth's plant and animal kingdoms that make this such a diverse and resilient planet. Humans, it seems, have an intrinsic connection to the soothing sights and sounds of water.

The past century substantially changed the way society valued water. Development patterns evolved into a form that necessitated rainwater removal for the sake of public health. A new engineered approach to rainwater removal became prominent. The modern 'stormwater management' method required systems to be designed to remove precipitation from specific 'storm events.' This engineered approach no longer treated rainwater as a resource; *rainwater* became *stormwater*, an element from bad storm events that gathers on urban surfaces, and needs to be removed quickly and efficiently. In a simplified way, that which was good and beneficial for the earth and for humans became bad.

Over time, the stormwater management paradigm shifted from treating water quantity to sequestrating pollutants (Debo and Reese 2003). It has recently shifted towards replicating natural hydrologic processes. Stormwater best management practices (BMPs) are an essential for the replication of natural hydrology. BMPs are structural and non-structural solutions to water quantity and water quality issues (Images 2-7).

Image 1. Traditional stormwater management method.

Image 2, 3. Evolving filtration stormwater BMPs along roadsides
Image source: Stuart Echols

Image 4. Stormwater wetland park
Image source: Stuart Echols

Image 5. Cistern and filtration
Image source: Stuart Echols

Image 6. Filtration channel
Image source: Stuart Echols

Image 7. Green roof
Image source: Robert Berghage

Objectives

The objectives of this research included the following:

1) Understand the current site selection criteria being used for stormwater BMP retrofits.
2) Determine additional criteria to include in the site selection process.
3) Conceptualize these criteria spatially in ArcGIS, a Geographic Information Systems software package.
4) Assemble the criteria into a multi-criteria analysis
5) Analyze the implications of these additional criteria on the sites selected

Significance of the Research

It is essential to recognize the value and importance of the existing urbanized environment, its unresolved problems, and its opportunities. As Ferguson (1994, p.5) notes, "Urban communities, once built, tend to stay in place, occupied and functioning in one way or another, for many human generations." The Brookings Institution also suggests that up to half of the development in the next 30 years may be redevelopment of underutilized existing urban areas (Nelson 2004). Strategies are needed to assist in the reintegration of stormwater into the existing urban environment as a valuable socio-cultural resource, rather than a hazard. This could simultaneously increase the ecological functions within the urban environment.

Image 8. 1934 Sanborn Fire insurance map. Image 9. 2002 Google Earth Aerial Imagery. These two images of the same location in Lexington, KY illustrate the minimal change of urban areas over 70 years.

An ecologically functional environment provides a multitude of benefits, including:

- clean air and water
- natural heating and cooling mechanisms
- increased happiness of humans
- recreational opportunities through greenway networks,
- encourage more healthy lifestyles
- increased biodiversity
- resilience to biological diseases and disasters

It is critical to redirect existing urban communities towards a more sustainable future and maintain their potential to stay in place and function for many human generations. This thesis provides one method for advancing towards that end.

While this tool was developed in detail for a specific watershed, it is adaptable to other cities. The same framework is applicable to regional scales for the selection of communities which would benefit from stormwater BMPs. The multi-criteria analysis provides opportunities for adaptation to varied economic, socio-cultural, infrastructural and environmental conditions. It will be useful to guide specific policy decisions of local governments, such as stormwater retrofit programs and future land development approaches to stormwater management.

Image 10. Stormwater wetland park enhances biodiversity, cleans water, and offers recreational opportunities

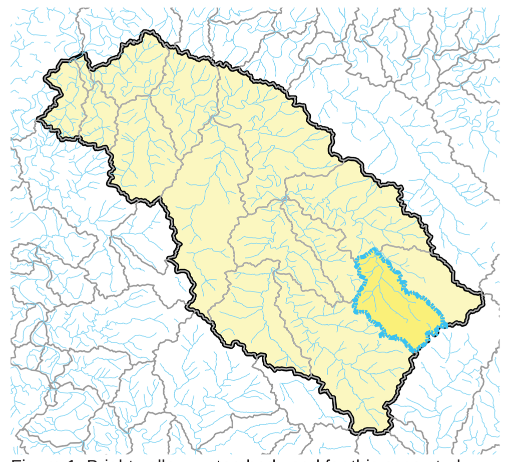


Figure 1. Bright yellow watershed used for this case study. This tool is applicable to similarly-sized watersheds, or the larger watershed, outlined in dark black.

Methods

Literature review focused on prior stormwater BMP site selection tools and models. For this research, a *model* is a method for organizing and automating workflows in ArcGIS (Environmental Systems Research Institute 2010). Literature review also examined research and theory of additional stormwater BMP considerations.

Following the literature review, Wolf Run watershed in Lexington, Kentucky, was selected as a case study location. This location was selected due to data availability, stormwater issues in the specific watershed and city, and a need for an overarching strategy to implement stormwater BMP retrofits. Appropriate spatial datasets were retrieved for the watershed, and were analyzed for relevancy to the model. The literature review and case study informed the conceptual development of the model.

ModelBuilder is an application in ArcGIS which allows a user to create, edit, and manage models. ModelBuilder was used to create and manage the three overlay assessments in this research. The model included attributes that were derived from existing literature, including stormwater BMP selection methods, watershed planning, landscape aesthetics, and GIS modeling. These attributes are shown below as map images, under each overlay assessment. The model construction process utilized a GIS method called "geoprocessing," which is the transformation of original datasets into new datasets. Geoprocessing was used to give values to the different attributes in the model.

The overlay process, shown in Figure 3, represents a simple addition process, wherein each attribute is overlaid on top of one another. Each individual attribute is unique and adds a particular value to the composite overlay. The composite overlays (Environmental, Socio-Cultural, and Infrastructural) and their associated attributes are displayed below. The color gradient for the maps is consistent, and transitions from low value (light blue) to high value (dark blue). The values for each composite overlay are impacted by the attributes values.

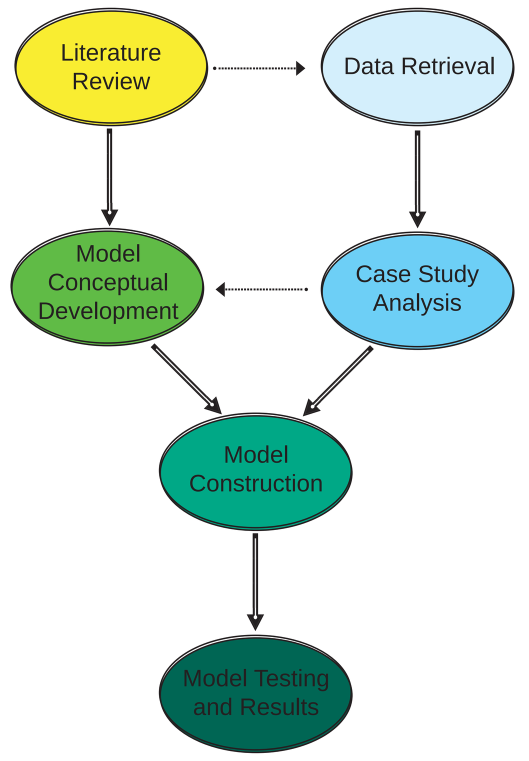


Figure 1. Research process

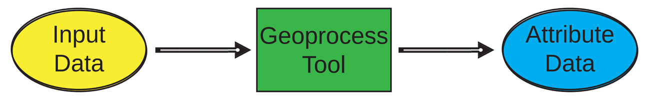


Figure 2. Model construction: geoprocessing workflow.

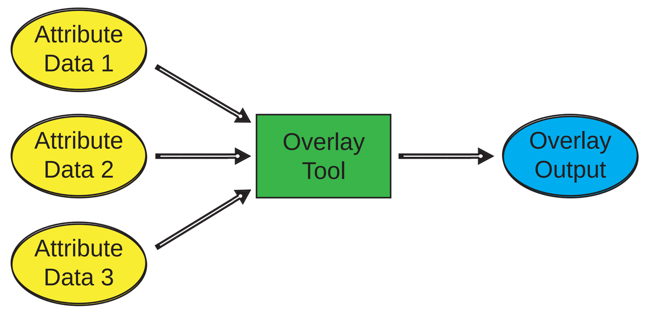
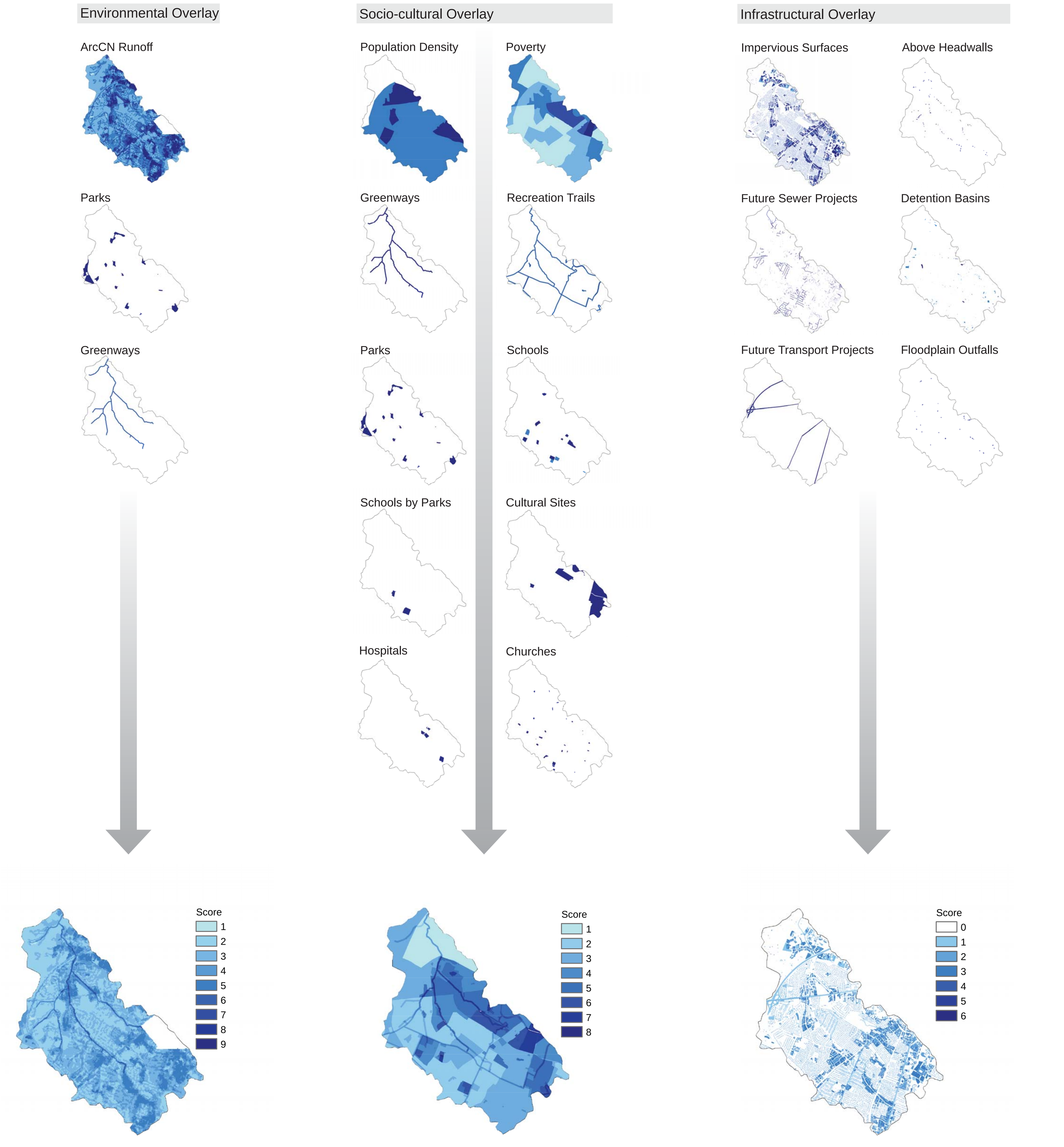


Figure 3. Model construction: the overlay process.

Figure 4. Model Overlays and Attributes



Results/Findings

The final overlay represents the combination of the Environmental, Socio-Cultural, and Infrastructural Overlays (see Figure 6). The final overlay provides an evaluation of the watershed for potential of stormwater BMP retrofits. The locations of low retrofit potential are shown as light blue and areas of high retrofit potential are shown as dark blue.

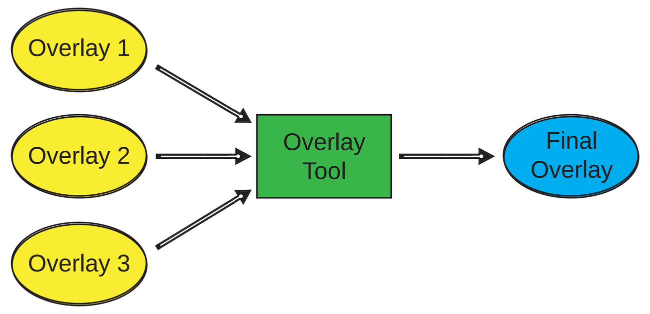


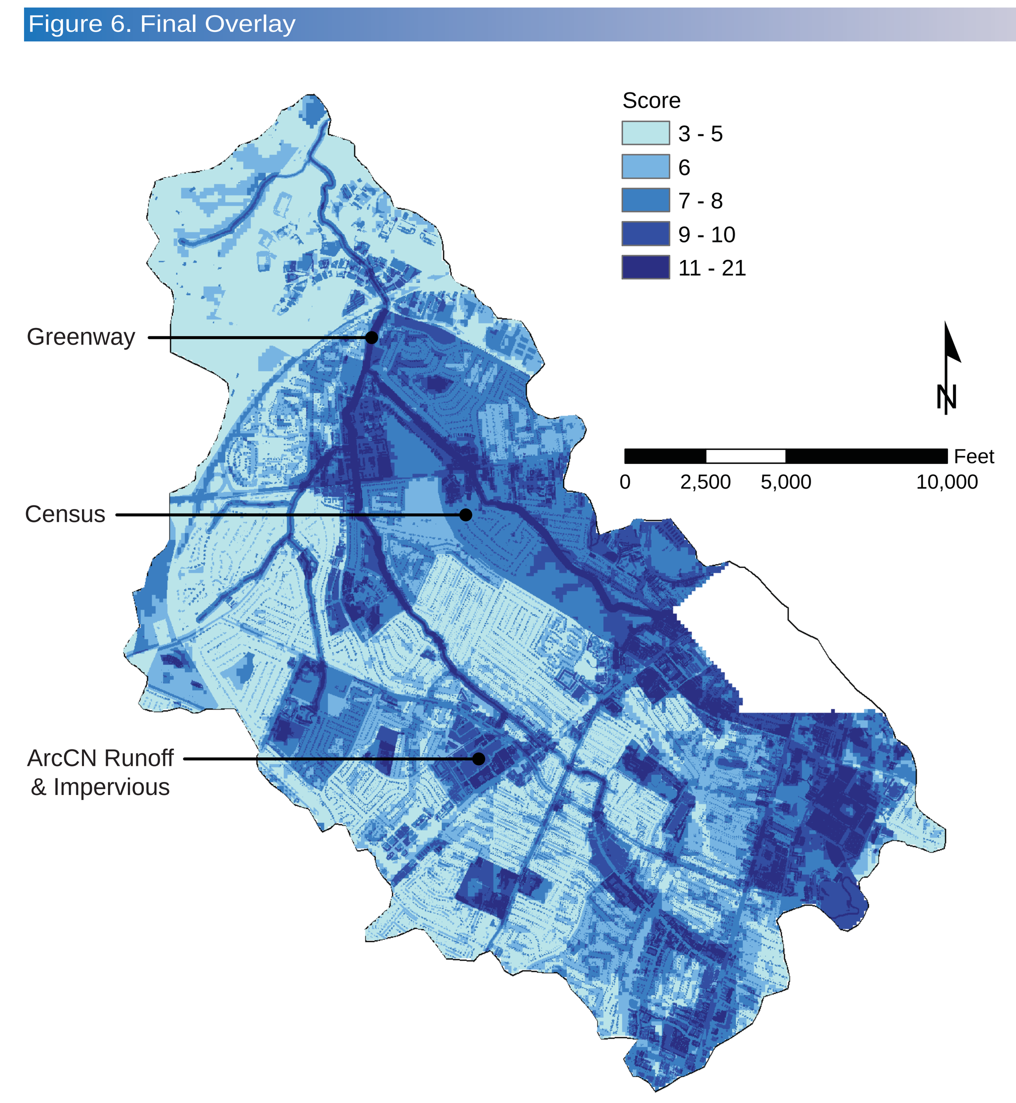
Figure 5. Model construction: the overlay process.

The results somewhat contradict the expections. First, it was expected that the multi-criteria analysis would reveal two sets of information. The first set was expected to be sites that overlap with those from the environmental overlay. Other sites were expected to differ sharply between the environmental overlay and final overlay.

In contrast, the results indicate the strong presence of the greenway corridors, and the impact of the clearly defined lines of census block groups. The influence of the environmental assessment is still apparent in the clusters of high value areas. These three main results are noted in Figure 6 to the right.

The final overlay also indicates that the areas in the center and southwest edge of the watershed have the least potential for stormwater BMP retrofits. These areas have lower population density and lower poverty levels.

Figure 6. Final Overlay



Interpretation of Results and Conclusions

The results directly suggest potential for stormwater BMP retrofits, but also indirectly imply strategies for approaching the retrofits. Specifically, a three-pronged strategy for approaching stormwater BMP retrofits seems apparent. First, the results suggest that greenways along streams should be a significant focus of stormwater BMPs. These could be both structural approaches, such biofiltration, or non-structural, such as establishing and maintaining sufficient riparian buffers. Second, the results suggest a need to decrease or more sufficiently treat impervious surfaces, particularly those areas of highly concentrated impervious surfaces. This is not surprising, given the well-known impact of impervious surfaces on stormwater runoff. Finally, the impervious surfaces and/or socio-culturally signficant areas in the census block groups of higher value should be targets for retrofits.

Equally important is that the results suggest that lower density residential areas, which maintain more dispersed impervious surfaces (roofs, driveways, sidewalks), have less potential for retrofits. More dispersed impervious surfaces are inherently better than masses of highly concentrated impervious surfaces, such as strip malls and parking lots. The green spaces and canopy between the impervious surfaces on a residential property allow some of the rainwater from storms to naturally infiltrate. Highly concentrated impervious surfaces prevent this natural hydrologic mechanism from working properly. Thus, this suggests that development should always incorporate a proper ratio and distribution of pervious and impervious surfaces. It also reinforces the need to incorporate BMPs, such as green roofs, into highly impervious areas.

In conclusion, the result of this research is an ArcGIS Model that acts as a decision-support tool for determining potential locations for stormwater BMP retrofits in urbanized areas. The methods utilized in the model were drawn from a host of existing literature, including stormwater BMP selection methods, watershed planning, landscape aesthetics, and GIS modeling. It is important to emphasize that the model was not developed in one fell swoop. It required adding, modifying, and removing attributes based upon the resolution of the model, and data conflicts. The initial test results also required some reprocessing of data to achieve more reliable and error-free results.

Directions for Future Research

This research does not claim to be complete. Future research is needed for the specific attributes included, and the value schemes utilized for them. Additional attributes or modifications in the value schemes may be necessary to make the model more complete and accurate. In addition, stormwater BMP retrofits represent a finite scale, and current land cover datasets are completed at a resolution larger than some retrofits. A higher resolution of land cover datasets would improve accuracy, and better inform different types of retrofits for highly specific areas. To that end, it will be important to research the use of this model in conjunction with other tools, such as EPA's new SUSTAIN tool, which assists in the selection and implementation of BMPs on the basis of cost and effectiveness for acheiving water quality goals for specific sites (Shoemaker et al 2009).

References

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