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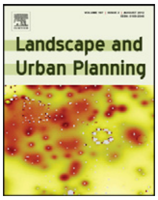

Multiple function benefit – Cost comparison of conservation buffer placement strategies

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HIGHLIGHTS

- ► Integrate multiple environmental benefits to compare six conservation buffer targeting strategies.
- ► Two riparian-focused buffer strategies have the lowest cost-effectiveness of 0.18.
- ► Soil survey-based strategy focusing on sediment movement has the highest cost-effectiveness of 0.31.
- ► Two topography-based strategies and soil survey-based strategy on water movement have cost-effectiveness around 0.22.
- ► The alternative buffer targeting strategies should be used when considering multiple environmental benefits and cost.

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ABSTRACT

Conservation buffers are considered to be effective practices for repairing impaired streams and restoring multiple ecosystem functions in degraded agricultural watersheds. Six different planning strategies for targeting their placement within watersheds were compared in terms of cost-effectiveness for environmental improvement in the 144 km^2 Neshanic River Watershed in New Jersey, USA. The strategies included two riparian-focused strategies, two soil survey-based strategies and two topography-based strategies that focus traditionally on water quality benefits. Each strategy was used to prioritize locations to install conservation buffers. An analytical methodology was employed to evaluate the level of multiple benefits (water quality improvement, erosion control, wildlife habitat improvement, and stormwater mitigation) and buffer establishment and maintenance costs provided by each strategy. The comparison results showed that the riparian-focused strategies were least cost-effective (their cost-effectiveness measure ranges from 0.17 to 0.18) compared to both soil survey-based and topography-based buffer targeting strategies (from 0.21 to 0.31). Although the riparian-focused strategies are popular and simple to administer, alternative placement strategies should be considered when riparian-focused strategies cannot meet the environmental goals, additional environmental concerns are involved and the program cost is of a great concern. The appropriate strategies to compare, the specific evaluation criteria, and the proper scoring system depend upon specific land characteristics and issues that are important in a given watershed. Specific comparative results may not be directly transferable to other watersheds or planning areas, but the methodological framework developed can be a useful tool for planners to compare alternative multiple-function buffer strategies.

1. Introduction

It has been one of great interest and importance in landscape planning and management to target conservation practices on the most critical sources area or “hot spots” in landscapes. The targeting approach helps enhance the efficacy of the conservation practices and improve the cost-effectiveness of their implementation for achieving specific environmental goals (Ribaudo, 1989). The targeting approach has been particularly recommended in agricultural landscape management for controlling agricultural nonpoint source pollution (Braden, Johnson, Bouzaher, & Miltz, 1989; Duda & Johnson, 1985; Prato & Wu, 1996; Srinivasan, Gérard-Marchant, Veith, Gburek, & Steenhuis, 2005; Walter et al., 2007). Studies on targeting range from identification of those “hot spots” based on their physical attributes (Heathwaite, Sharpley,

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& Gburek, 2000; Johnes & Heathwaite, 1997; Walter et al., 2000) to selection of spatially varying landscape management practices based on modeling systems that integrates geographic information systems, biophysical and economic/optimization models (Gitau, Veith, Gburek, & Jarrett, 2006; Qiu & Prato, 1999; Veith, Wolfe, & Heatwole, 2004). The targeting approach has been applied to study either the placement of a set of conservation practices or a single conservation practice such as conservation buffers (Khanna, Yang, Farnsworth, & Onal, 2003; Pritchard, Lee, & Engel, 1993; Qiu, 2009; Yang & Weersink, 2004; Yang, Khanna, Farnsworth, & Onal, 2003).

Conservation buffers are a structural mixture of vegetative strips consisting of selected trees, shrubs and grasses placed in landscape. Well established conservation buffers in landscape generally have multiple functions and benefits (Lovell & Sullivan, 2006). The basic functions well recognized include trapping sediments and reducing erosion-related pollution and improving water quality (Dosskey, 2001; Qiu, 2003; Schnepf & Cox, 2006; Voughta, Pinayb, Fuglsangc, & Rufflnonib, 1995). Conservation buffers can benefit wildlife habitat in direct and indirect ways. Conservation buffers exhibit high biodiversity because of their richer plant species, including trees, shrubs, and grasses (Boutin, Benoît, & Bélanger, 2003; Freemark, Boutin, & Keddy, 2002; Paine & Ribic, 2002). Conservation buffers also help to connect existing fragmented wildlife habitat and therefore serve as corridors for movement of wildlife (Schuller et al., 2000). Although conservation buffers are widely considered to be effective practices for repairing impaired streams and restoring multiple ecosystem functions in degraded agricultural watersheds, they have been increasingly used as best management practices to mitigate the negative impacts of urban sprawl and development because of their capacity in dispersing stormwater runoff caused by increases in impervious surface and filtering sediments and nutrients in stormwater runoff as well as their natural beauty (Borin, Passoni, Thiene, & Tempesta, 2010). Sullivan, Anderson, and Lovell (2004) found the benefits of conservation buffers in agricultural landscape are well recognized by non-farmer residents in most rural–urban fringes. The use of conservation buffers in landscape management is generally supported by broad stakeholders including landowners, planners and residents (Kenwick, Shammin, & Sullivan, 2009; Qiu, Prato, & Beohm, 2006).

Several strategies have been developed in targeting the placement of conservation buffers in landscapes. The riparian areas along streams are traditionally targeted for placing conservation buffers, which is popularly known as riparian buffers. Many existing state and regional riparian protection rules and municipal ordinances call for fixed-width riparian buffers, i.e., the areas with fixed width from both sides of stream are prioritized for buffer restoration. The model ordinance developed by US EPA recommended that the required width for all forest buffers (i.e., the base width) shall be a minimum of 100 feet, but the width chosen by a jurisdiction varies and usually depends on the sensitivity and characteristics of the resource being protected and the political environment in the community (Heraty, 1993). Some studies call for variable-width riparian buffers which involve designing riparian buffers with variable width along the streams based on the site-specific natural resource conditions to improve buffers' effectiveness (Basnyat, Teeter, Flynn, & Lockaby, 1999; Herron & Hairsine, 1998; Phillips, 1989; Xiang, 1993). Alternative conservation buffer strategies take the whole watershed or area approach and consider the topographic, soil and land use conditions within and beyond the riparian areas in watersheds to identify the potential sites for conservation buffers. Bren (2000) and Tomer, James, and Isenhart (2003) linked the location and size of buffers to the upland contributing areas. They used the hydrologic and pollutant loading in delineating landscape and the areas where the computed hydrologic loads exceed a threshold are prioritized for buffer placement. While Bren (2000) used two slope convergence parameters (i.e., specific area and slope index) as surrogate measures of hydrologic loading, Tomer et al. (2003) used a wetness index (Moore, Grayson, & Ladson, 1991) and an empirical erosion index. The parameters of these indices were derived from a digital elevation model (DEM) using terrain analysis. Dosskey, Helmers, and Eisenhauer (2006) developed two empirical indicators, sediment and water trapping efficiencies from soil survey attributes, to guide the placement of conservation buffers. Qiu (2009) used a modified topographic index that is consistent with the variable source area (VSA) hydrology (Walter et al., 2002) to determine the placement of conservation buffers. The modified topographic index is an extension of the wetness index by taking consideration of soil conditions. The potential sites for conservation buffers delineated with these alternative whole-area based buffer approaches often extend beyond the immediate riparian areas of existing streams. Although conservation buffers are multifunctional, the buffer placement strategies tend to use a single criterion to target their placement in landscapes. The riparian buffer approaches are primarily based on the proximity to streams while the whole-area approaches are based on hydrological loading or soil erodibility. Qiu (2010) develops a multiple attribute approach for targeting conservation buffer placement in landscape that takes into consideration of multiple environmental benefits of conservation buffers including reducing soil erosion, controlling runoff generation, enhancing wildlife habitat, and mitigating stormwater impacts.

Given the varieties of conservation buffer placement strategies available, the watershed managers and landscape planners have practical difficulty to determine a proper one to use in their resource management and landscape planning decisions. Dosskey and Qiu (2011) compared several mentioned buffer planning strategies in terms of the locations of the prioritized areas for buffer placement and concluded that each strategy associates the pollution risk and mitigation potential to a different part of the landscape and additional comparison is needed to assess their usefulness. This study expands the previous study to compare several different conservation buffer placement strategies by taking into consideration of multiple environmental benefits and buffer establishment costs to prioritize agricultural lands for conservation buffer placement in the Neshanic River Watershed with mixed land uses in a rural–urban fringe in Central New Jersey, USA. Specifically, these strategies will determine certain amount of agricultural lands in the watershed prioritized for conservation buffer placement and be compared using a multiple attribute cost-effectiveness index, which is a ratio of the aggregated value of multiple environmental benefits to the cost of establishing conservation buffers in the prioritized agricultural lands. The cost of conservation buffer establishment is the governmental program costs of establishing and maintaining conservation buffers in agricultural lands under the New Jersey Conservation Reserve Enhancement Program (NJCREP). The multiple environmental benefits considered include reducing soil erosion, controlling runoff generation, enhancing wildlife habitat, and mitigating stormwater impacts. The value of the multiple environmental benefits is aggregated in the similar manner as in Qiu (2010). Other benefits such as CO_2 immobilization and improvement of landscape beauty as noticed by Borin et al. (2010) are not included in the study because of the practical difficulty of quantifying them. The economic benefits of harvesting buffers are also ignored due to a couple of reasons. First, the economic gain from harvest in trees, shrubs and grasses within conservation buffers is a complicated topic by itself like an empirical study presented by Qiu, Prato, Godsey, and Benson (2002). Second, harvesting from the conservation buffers established under various programs such as NJCREP is rare and often discouraged except minimal maintenances.

Table 1
Land uses in 1986, 1995 and 2002 in the Neshanic River Watershed, New Jersey.

Land use type	1986		1995		2002	
	Hectares	Percent	Hectares	Percent	Hectares	Percent
Agriculture	7351	50.9	6465	44.8	5714	39.6
Barren land	116	0.8	31	0.2	178	1.2
Forest	3081	21.3	3241	22.5	3344	23.2
Urban	2157	14.9	2988	20.7	3523	24.4
Water	46	0.3	47	0.3	74	0.5
Wetlands	1682	11.7	1661	11.5	1601	11.1
Total	14,434	100.0	14,434	100.0	14,434	100.0

2. Study area

The study area is the 144 km^2 Neshanic River Watershed, a headwater watershed in the Raritan River Basin and is located across Hunterdon and Somerset Counties in central New Jersey, USA. The Neshanic River Watershed has experienced dramatic land use changes during the last two decades, notably a decrease in agricultural lands and an increase in urban lands (Table 1). While majority of urban development took place in the upper parts of the watershed, urban development also encroaches into the lower part of the watershed where are traditionally dominated by agriculture (Fig. 1).

Such land use changes significantly alter watershed hydrology and have direct impacts on both water quality and quantity in the watershed. The Neshanic River tributaries were listed as impaired for aquatic life, phosphorus, sediments and pathogens from non-point sources (NJDEP, 2008). Poor water quality has been linked to extensive urban development and agricultural land use. The Neshanic River Watershed is a priority watershed for installing water quality improvement practices including conservation buffers (NJWSA, 2002). The recently completed Neshanic River Watershed Restoration Plan recommends conservation buffers as one of the most important best management practices to be used in both agricultural lands and developed areas to restore watershed hydrology and improve water quality in the watershed (NJDEP, 2011). The Raritan Basin Watershed Management Plan developed by New Jersey Water Supply Authority (NJWSA, 2002) also recommended that maintaining productive but sustainable agricultural landscape is an essential part of the overall strategies to mitigate the negative impacts of urban sprawl in Raritan River Basin including this watershed.

In this study, we focused on establishing conservation buffers in the farmable agricultural land in the watershed. Agricultural land was identified by land use/cover data compiled from aerial photographs taken in spring 2002 and downloaded from the New Jersey Department of Environmental Protection (NJDEP) website. Farmable land (i.e., for cultivation) was identified by land capability classes 1 through 4 in the Soil Survey Geographic (SSURGO) soil database downloaded from the USDA-Natural Resources Conservation Service Soil Data Mart website. A total area of 5682 ha met both of these criteria. Conservation buffers in agricultural lands are expected to not only enhance the sustainable agricultural landscape by reducing the nonpoint source pollution and enhance wildlife habitat in the region, but also to diverse landscape and provide amenities to the growing non-farmer residential communities in the rural–urban interfaces in this watershed.

3. Methods

The assessment framework (Fig. 2) is used to compare six conservation buffer placement strategies by considering four

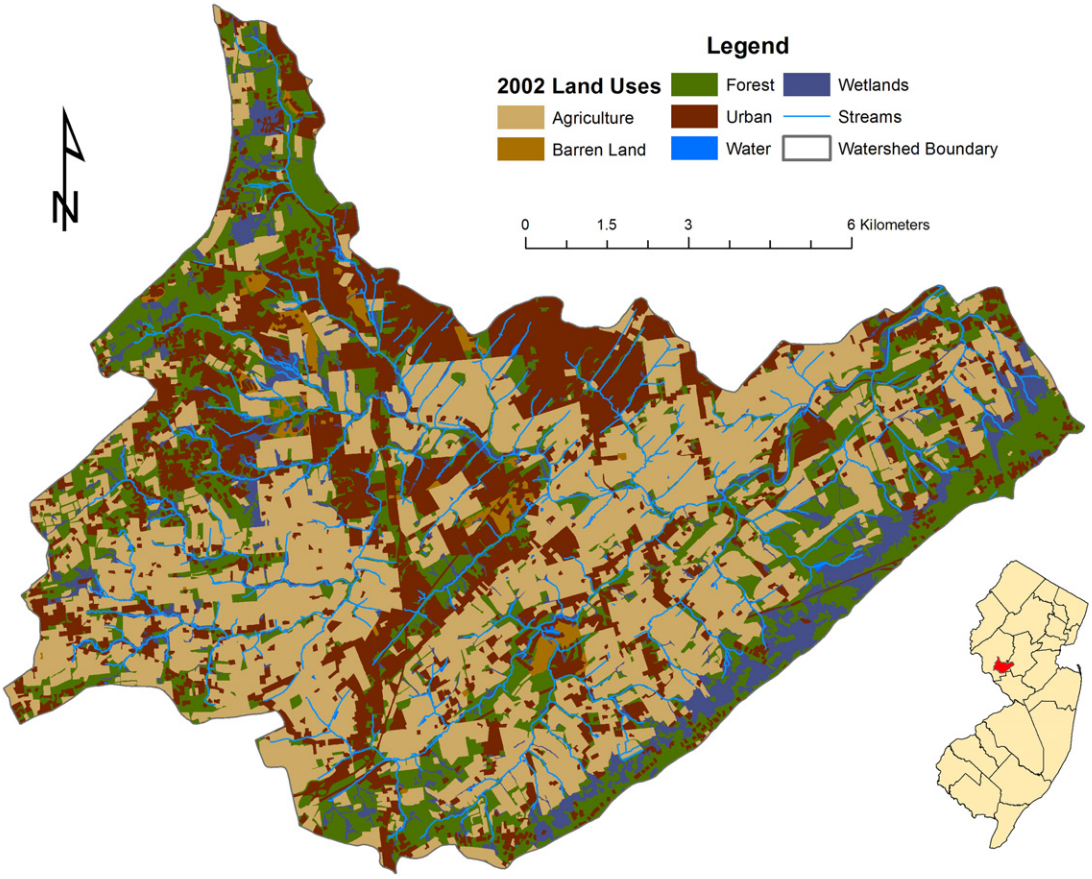


Fig. 1. The land use distribution in 2002 in Neshanic River Watershed, New Jersey.

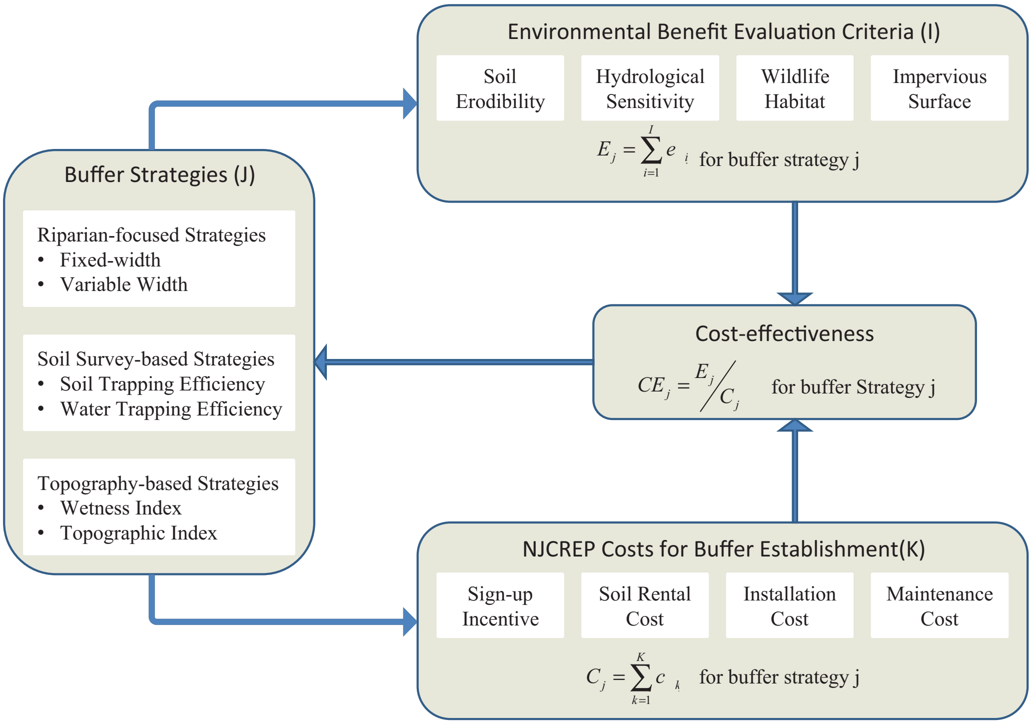


Fig. 2. The framework for assessing the alternative conservation buffer placement strategies.

environmental benefit criteria. The four environmental benefit criteria are soil erodibility, hydrological sensitivity, wildlife habitat, and impervious surface, which capture the conservation buffers' benefits in reducing soil erosion, controlling runoff generation, enhancing wildlife habitat, and mitigating stormwater impacts, respectively. In this application, the Neshanic River Watershed was divided into 10-m resolution grids based on the best available DEM maintained by NJDEP. Agricultural lands in the watershed were also converted into 10-m grids aligned to the DEM. Six alternative conservation buffer strategies applied to identify the 10-m agricultural grids for buffer placement in the watershed. Spatial data were collected from various sources to derive the values of the four criteria (i.e., soil erodibility, hydrological sensitivity, wildlife habitat, and impervious surface) for each grid in the watershed. Details of each element of the assessment framework are presented below.

3.1. Alternatives conservation buffer placement strategies

Six strategies for conservation buffer placement are assessed. They include two riparian-focused strategies, two soil survey-based strategies and two topography-based strategies. The first riparian-focused strategy is a regulatory fixed-width buffer that covers a 22.9 m-wide (75-ft) strip on both sides of streams following the New Jersey Flood Hazards Rule. The second riparian-focused placement strategy is the voluntary variable width riparian buffer strategy recommended in the Raritan Basin Watershed Restoration Plan for the Raritan River Basin including this watershed (NJWSA, 2002). NJWSA defined the riparian areas as the undeveloped areas adjacent to streams that are either within the 100-year floodplain, contain hydric soils, contain streamside wetlands and associated transition areas, or within a 45.7 or 91.4 m-wide (150 or 300 ft) wildlife passage corridor on both sides of a stream. The width of the riparian areas varies along the stream depending on site-specific conditions. Conservation buffers were placed in the agricultural lands located in the defined riparian areas for these two strategies. The total areas of the priority grids under the fixed-width and variable width riparian buffer placement strategies are 224 ha and 1135 ha, and represent 3.9% and 20.0%, respectively, of all farmable agricultural lands in the watershed (Table 2).

Two soil survey-based conservation buffer strategies are based on sediment trapping efficiency (STE) and water trapping efficiency (WTE; a surrogate for trapping pollutants dissolved in the water) by a buffer as defined by Dosskey et al. (2006). The calibrated STE is defined as

$$\text{STE} = 84.6(1.17 - e^{(-1320\,\text{Sediment index})}), \tag{1}$$

where the empirical sediment index in Eq. (1) is calculated by

$$\text{sediment index} = \frac{D_{50}}{RKLS}; \tag{2}$$

The calibrated WTE is defined by

$$\text{WTE} = 97(\text{Water index})^{0.26}, \tag{3}$$

where the water empirical index is calculated by

$$\text{water index} = \frac{K_s^2}{RLS}; \tag{4}$$

where D_{50} and K_s are median particle diameter and soil permeability, respectively, of the surface soil by texture class (Muñoz-Carpena & Parsons, 2011), and R, K, L and S are rainfall and runoff erosivity, soil erodibility, slope length, and slope steepness factors from RUSLE, respectively, in English units (Renard et al., 1997). Values for L and S are computed according to Renard et al. (1997) using the mean of the slope range given for the map unit in the soil survey. These equations were calibrated to describe overland runoff from tillage agriculture. STE ranged from 22 to 99 and WTE from 12 to 53 for the agricultural grids. Conservation buffers shall be installed in the agricultural lands with the STE values less or equal to 29 or WTE values greater or equal to 40 for these two strategies. These index thresholds amount to 273 ha and 207 ha, which are about 4.8% and 3.6%, respectively, of agricultural land in the study watershed (Dosskey & Qiu, 2011).

Two topography-based buffer strategies are based on a wetness index (WI) derived from a DEM as used by Tomer et al. (2003)

Table 2
Agricultural lands prioritized for conservation buffers by alternative buffer strategies in Neshanic River Watershed.

Conservation buffer strategies	Prioritization criterion	Prioritized area for buffers		Within NJWSA riparian area (Ha)
		Area (Ha)	Percentage (%)	
Riparian-focused				
Fixed width buffer[a]	75-ft buffer	224	3.9	224
Variable width buffer[b]	NJWSA riparian buffer	1135	20.0	1135
Soil survey-based				
Sediment trapping efficiency (STE)	$STE \le 29$	273	4.8	73
Water trapping efficiency (WTE)	$WTE \ge 40$	207	3.6	91
Topography-based				
Wetness index (WI)	$WI \ge 11$	246	4.3	142
Topographic index (TI)	$TI \ge 11$	367	6.5	199

[a] Based on New Jersey Stream Encroachment Rule and New Jersey Flood Hazards Rule.
[b] Based on Raritan Basin Watershed Restoration Plan developed by New Jersey Water Supply Authority (NJWSA).

and a modified topographic index (TI) derived from DEM and a soil database as used by Qiu (2009). The WI is defined as

$$WI = \ln\left(\frac{\alpha}{\tan\beta}\right), \tag{5}$$

where α is the upslope contributing area per unit contour length to a cell in a DEM and β is the local surface slope angle of the cell. The index measures the propensity of a given point in a watershed to accumulate runoff water, hence the name "wetness" (Beven & Kirkby, 1979). Walter et al. (2002) modified this index by using soil moisture deficit as the state variable to make it more applicable to describe shallow, interflow-driven runoff process common in watersheds in the northeastern US. The TI is defined as

$$TI = \ln\left(\frac{\alpha}{\tan\beta}\right) - \ln(K_sD), \tag{6}$$

where K_sD is the soil water storage capacity defined by the mean permeability K_s and depth D of the soil above a fragipan, bedrock, or other type of restrictive layer. The TI enumerates a relative likelihood that a rainfall event will saturate the soil and generate overland runoff from a grid cell. Higher TI values indicate greater likelihood of saturation and runoff. WI ranges from 3 to 26, and TI from 1 to 27 for farmable agricultural grids. Conservation buffers shall be installed in the agricultural lands with the WI or TI values greater than 11 for these two strategies. These index thresholds amount to 246 ha and 367 ha, which are about 4.3% and 6.5%, respectively, of agricultural land in the study watershed (Dosskey & Qiu, 2011).

The largest amount of agricultural area prioritized for conservation buffers (1135 ha) was identified by the variable-width riparian strategy. The NJWSA-defined riparian zone encompassed only a portion of the agricultural area prioritized by the soil survey- and topography-based indexes (Fig. 3). The agricultural lands located in the NJWSA-defined riparian zone and prioritized by STE, WTE, WI and TI are 73, 91, 142 and 199 ha, which make up 26.6%, 44%, 57.7% and 54.3% of the agricultural grids in the NJWSA-defined riparian zone, respectively (Table 2).

3.2. Multiple environmental benefit evaluation

Multiple environmental benefits are aggregated into a single environmental benefit measurement following the procedure developed in Qiu (2010). Specifically, the raw scores for each individual environmental benefit were first developed for all 10-m grids in the watershed. Then class scores are assigned to those grids according to the ranges of the raw criteria values defined by a classification scheme. Let e_{ij} be the average class score for the environment benefit i for the agricultural grids selected under the alternative buffer strategy j. A final aggregated environmental benefit score for the buffer strategy j (E_j) was calculated as follows:

$$E_j = \sum_{i=1}^{I} e_{ij}. \tag{7}$$

The aggregated scores were then used in calculating the cost-effectiveness to compare these alternative conservation buffer placement strategies. As argued by Qiu (2010), such aggregation procedure is consistent with the conventional multiple attribute decision making procedure that uses additive utility function and characterizes the decision makers' preferences using attribute weights. A classification scheme is usually based on decision makers' professional experiences and understanding of the relative importance of those benefits; therefore the class score (e_{ij}) in Eq. (7) reflects the combined impacts of the attribute weights and the attribute values. Eq. (7) is straightforward and easy to use for water resources management practitioners. The classification scheme can also be easily modified and adapted to reflect different preferences over and understanding of those environmental benefits in different conditions and regions.

In this application, the classification scheme and the aggregation process based on the benefit class scores were developed by an expert panel that consisted of representatives from universities, Natural Resources Conservation Service (NRCS), New Jersey Department of Agriculture, NJWSA, and the North Jersey Resource Conservation and Development Council (NJRCD), a local non-government environmental organization. The representatives include researchers, natural resource conservationists, watershed protection specialists, and agricultural extension specialists, who work around the study area and are familiar with conservation buffers, and various governmental buffer programs. The panel developed the classification schemes and the benefit aggregation process based on two assessment methods on riparian health and riparian restoration in the region. NJRCD (2002) assessed the existing riparian health in the Upper Delaware watershed, which is close to the study area, based on the sum of class scores on surface water quality designations, conditions of land use/land cover and habitat condition for wildlife and endangered species. Bergstrom, Cerucci, and Buckley (2004) prioritize the areas for riparian buffer restoration at a watershed scale based on the class scores on the stream visual assessment attributes, soil erodibility factors, slope, and land use conditions. The panel selected the potential environmental benefits that are relevant to the conservation buffers in agricultural lands in the region and determined the ways to approximately measure those benefits. After the benefit measurements were developed using the data from various sources, the results were presented to the panel to assess whether these measurements are accurate and reasonable in the region. The classification schemes

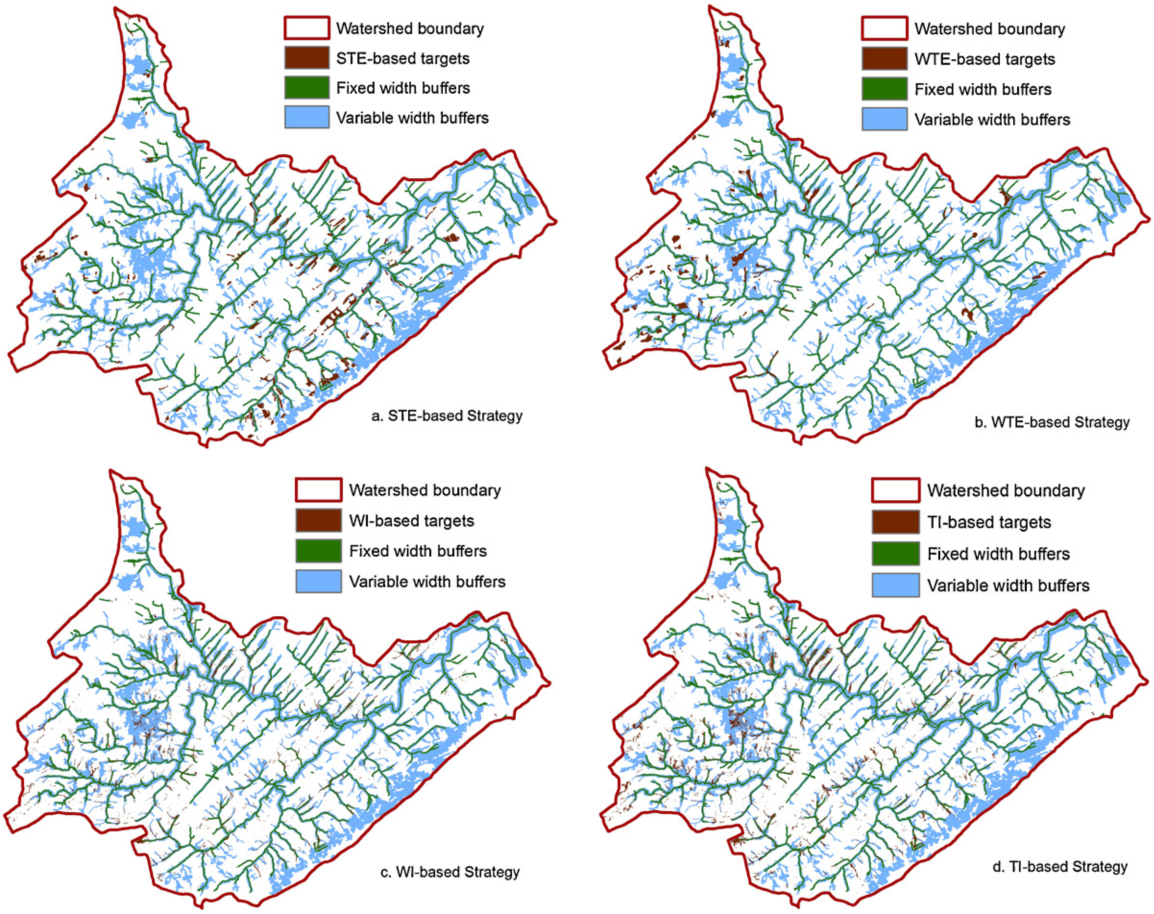


Fig. 3. The fixed and variable width buffers and the prioritized agricultural lands under alternative conservation buffer strategies.

for the environmental benefits were further refined through the panel discussion. The following subsections present the details of the selected environmental benefits, their measurements and classification schemes.

3.2.1. *Soil erodibility*

Soil erodibility measures the soil erosion potential of a specific site. Soil erosion not only results in less productive soil, but also is linked to many water quality problems, such as sediment loads and nutrients and pesticides attached to the soil particles transported to streams. NRCS soil erodibility index (EI) was used to approximate soil erodibility. EI provides the numerical expression of the potential for a soil to erode considering the physical and chemical properties of the soil and the climatic conditions where it is located. The higher the index, the more susceptible the soil is to erosion. EI equals the potential erodibility for the soil ($RKLS$) divided by the soil loss tolerance value (T) following Wischmeier and Smith (1978):

$$\mathrm{EI} = \frac{RKLS}{T}, \tag{8}$$

where T is the soil loss tolerance factor defined as the maximum amount of annual soil erosion that can occur without degrading the quality of a soil as a medium for plant growth. EI is usually estimated for each soil type in order to define the highly erodible lands (HELs) mapping units in the NRCS soil survey. The soils with an EI greater than 8 are considered to be highly erodible (USDA NRCS, 2008).

In this application, EI was estimated for each 10-m grid in Neshanic River Watershed. Since there are no T values for water and urban soils, a T value of 0.01 is assumed to ensure the completion of the calculation. Soil erodibility was classified into five classes based on the measured EI values (Table 3). Table 3 presents the distribution of soil erodibility class among the farmable agricultural lands in the watershed. The highly erodible class (class score 4) and extremely high erodible class (class score 5) are only 5.9 and 3.4% of all farmable agricultural lands.

3.2.2. *Hydrological sensitivity*

Hydrological sensitivity for an area indicates its potential for generating runoff during a storm event. Hydrological sensitivity is approximated by the TI in Eq. (6). The modified TI has been extensively evaluated for its ability to predict runoff and generate stream flow in the nearby Catskill Mountains of New York (Agnew, Walter, Lembo, Gérard-Marchant, & Steenhuis, 2006; de Alwis, Easton, Dahlke, Philpot, & Steenhuis, 2007; Lyon, Gérard-Marcant, Walter, & Steenhuis, 2004) which has similar hydrologic behavior as the study watershed (Qiu, 2009). The pattern of TI for Neshanic River Watershed was derived using the 10-m DEM data maintained by the NJDEP and the SSURGO soil database for Hunterdon and Somerset counties maintained by NRCS. In this application, the entire watershed was further divided into 5 zones of equal size based on the TI values. The zone of grids with the lowest TI values was assigned a class score of 1 and the zone of grids with the highest TI values was assigned a class score of 5. The farmable agricultural lands are roughly even distributed among hydrological sensitivity classes (Table 3).

3.2.3. *Wildlife habitat*

Existing wildlife habitat condition were evaluated using the results from the NJDEP Nongame and Endangered Species

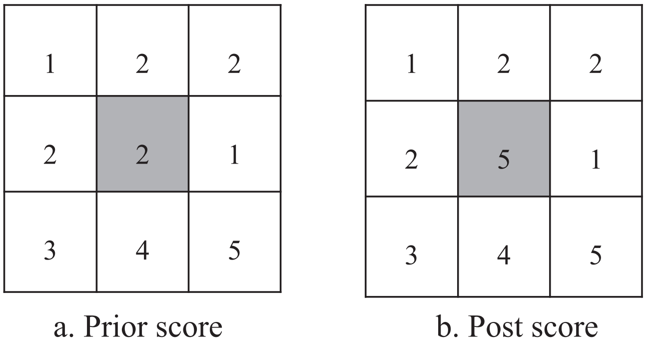
Table 3
Distribution of agricultural lands in different environmental benefit classes in Neshanic River Watershed.

Hydrological sensitivity				Soil erodibility			
Class	TI range	Area (ha)	Percentage	Class	EI range	Area (ha)	Percentage
1	≤6	1199.2	21.1	1	≤2	2582.3	45.4
2	6–7	1329.4	23.4	2	2–5	1865.0	32.8
3	7–8	1200.1	21.1	3	5–8	704.8	12.4
4	8–9.5	1049.9	18.5	4	8–12	334.4	5.9
5	>9.5	903.3	15.9	5	>12	195.4	3.4
Total		5681.8	100.0	Total		5681.8	100.0

Wildlife habitat				Impervious surface			
Class	Rank range	Area (ha)	Percentage	Class	Rate range	Area (ha)	Percentage
1	1	1824.1	32.1	1	0	5101.8	89.8
2	2	2011.8	35.4	3	5%	140.6	2.5
3	3	899.2	15.8	5	10%	182.6	3.2
4	4	517.6	9.1	7	15%	121.3	2.1
5	5–8	429.0	7.6	9	≥20%	135.6	2.4
Total		5681.8	100.0	Total		5681.8	100.0

Program's Landscape Project, which mapped out areas that have the potential for rare species based on a grouping of identified natural resources. Version 2.1 identified five general habitat types including forest, forested wetland, grassland, emergent wetland, and beach, as well as three specific habitat areas: bald eagle foraging areas; urban peregrine falcon nests; and wood turtle habitat. The Landscape Project's mapped areas were ranked from 1 (lowest priority) to 5 (highest priority) based upon the potential presence of species of concern. The forested wetland and emergent wetland related species (i.e., wood turtle and bald eagle) were considered to benefit from conservation buffers. In this application, the habitat maps for those species were first extracted for Raritan Basin from the New Jersey Landscape Project. Those polygon layers were then converted into 10-m raster layers based on the value in the field *rank* in those polygon layers. The habitat scores for all the species considered were measured by the sum of the ranks. The resulting habitat scores for individual grids ranged from 1 to 8. Since only a few areas have habitat scores greater than 5, any grid with a habitat score greater than 5 was re-assigned a habitat class score of 5. The remaining habitat class score is just the resulting summation of the ranks (Table 3).

Conservation buffers not only directly provide the wildlife habitats, but also indirectly enhance the habitat by connecting the fragmented habitats. To account for the indirect benefits of wildlife habitat, the expected wildlife benefits of conservation buffers in a given gird are measured by the maximum habitat class score in its 3 × 3 neighboring grids including itself (Fig. 4). In other words, if a grid is connected to a patch with high wildlife habitat, the grid itself will eventually provide the same level of wildlife habitats when converting to conservation buffers. For an example in Fig. 4, the benefits of the central grid would be 5, the highest in the 3 × 3 neighborhood. The expected wildlife benefits are derived from the wildlife habitat class score discussed above using the *Focus Statistics* function in the Spatial Analyst of ArcMap.



a. Prior score

b. Post score

Fig. 4. The change in class score in the central grid in a 3 × 3 neighborhood grids.

3.2.4. *Impervious surface*

Impervious surfaces such as rooftops, sidewalks, roads, and parking lots prevent precipitation and snowmelt from saturating and infiltrating soils. Increases in impervious surfaces often increase surface runoff, accelerate runoff velocity, and reduce groundwater recharge, which cause many environmental problems, such as flooding, water quality degradation, and loss of aquatic habitat (Paul & Meyer, 2001). Studies show that watersheds with 10–20% of their area in impervious surfaces have a high potential for physical, chemical, and biological impairments of water quality and other aquatic resources (Booth & Jackson, 1997; Booth, Hartley, & Jackson, 2002; Holland et al., 2004; Klein, 1979; Mallin, Williams, Esham, & Lowe, 2000; Roy, Rosemond, Paul, Leigh, & Wallace, 2003; Stepenuck, Crunkilton, & Wang, 2002; Wang, Lyons, Kanehl, Bannerman, & Emmons, 2000).

Land use/cover data provided by NJDEP not only identify land use type, but also estimate the percentage and area of impervious surface for each land use/cover polygon. Such estimates were made using aerial photography and were reported in 5% increments in the interval [0,100]. In this application, the existing condition of the impervious surface was extracted from the 2002 land use/cover data by converting it into a 10-m raster layer based on the impervious surface rate in the attribute table, which measures the percentage of the area of the impervious surface in each polygon. The converted raster for impervious surface rates in the watershed, which has values ranging from 0% to 100%. Since urban development and increases in imperious surface are a major source of water resource degradation in the watershed, a discontinuous 1–9 classification scale is used to give the imperious surface a greater impact on the final ranking (Table 3).

Carefully designed conservation buffers can mitigate the negative environmental impacts of impervious surface by dispersing runoff and filtering sediments and nutrients in runoff. In a manner similar to the wildlife habitat, the benefits of conservation buffers in mitigating the impacts of imperious surface for a given gird are measured by the maximum impervious surface class score in its 3 × 3 neighboring grids including itself. In other words, if a grid is connected to a gird with higher imperious surface rate, the conservation buffers in that grid would likely provide the higher benefits in mitigating the negative impacts of urban runoff. Such measurement may downplay the possible impacts of flow direction of stormwater runoff (i.e., the conservation buffer grids are not necessarily located below the grids with high impervious surface rate), but could add other benefits such as the look of natural landscape valued by non-farm residents (Sullivan et al., 2004).

3.3. Buffer establishment costs

The cost for establishing and maintaining buffers were based on the average costs of the buffer installation and maintenance costs in the agricultural lands enrolled NJCREP, which supports establishment of three conservation buffer practices CP8A (grass waterway), CP21 (filter strips), and CP22 (riparian buffers). For agricultural lands enrolled in NJCREP, USDA, NJ Department of Agriculture and other agencies offered a one-time sign-up incentive, 100% of the installation costs, and 15 years of buffer maintenance costs and soil rental costs. The one-time sign-up incentive is $247 per ha. The installation costs cover the equipments, materials and labor used to install the conservation buffers. The installation costs were based on the actual average costs of installing conservation buffers in agricultural lands enrolled in NJCREP during the period 2004–2007 (USDA FSA, 2007). The installation costs of three buffer practices were quite different. CP8A was the most expensive practice with an average installation cost of $40,402 per ha in New Jersey. CP21 was the cheapest buffer practice with an average installation cost of $974 per ha. Average installation costs for CP22 was $3430 per ha. The soil rental costs were the governmental payment to the land owners for the agricultural lands enrolled in NJCREP. The annual soil rental rate was calculated based on the soil types of the converted agricultural lands and the associated soil rental rate published by the USDA Farm Service Agency. The soil types of those agricultural lands were compiled from the NRCS soil SSURGO database. The average maintenance costs were $9.88 per ha for CP8A and CP21 and $14.83 per ha for CP22. The buffer establishment costs are estimated assuming the agricultural lands defined by the buffer strategies will be converted into CP22 if they are located within the variable riparian zone defined by NJWSA and into CP21 if located outside of the riparian zone.

3.4. Cost-effectiveness

This application assesses those buffer strategies based on a simple cost-effectiveness measure. Cost-effectiveness indicates the potential environmental benefits achieved by NJCREP costs of establishing the conservation buffers under each strategy. The cost-effectiveness of a buffer placement strategy was measured by the ratio of the potential aggregated benefits calculated by Eq. (7) to the average cost of establishing and maintaining the conservation buffers in the agricultural lands as defined by the buffer strategy.

4. Results

In the study watershed, there were 5682 ha farmable agricultural land use, which was then divided into 10-m grids based on DEM. Agricultural lands prioritized for conservation buffers under each buffer placement strategy were only a small subset of the total number of farmable agricultural grids. The average NJCREP program costs for installing and maintaining conservation buffers in the prioritized agricultural lands in the fixed and variable width riparian buffer placement strategies are $5237 and $5255 per ha. The discrepancy in their average program cost is due to the variations in soil rental rates accumulated in the 15-year program period. The average NJCREP program costs of establishing conservation buffers in the prioritized agricultural lands based on STE, WTE, WI and TI are $3369, $3876, $4219 and $4170, respectively (section A of Table 4). The differences in the average program costs are caused by the differences in soil rental rates and the different composition of buffer practices determined by the location of the prioritized agricultural lands. It is assumed that the agricultural lands will be converted into CP22 (riparian buffers) if they are located within the NJWSA-defined riparian zone and into CP21 (filter strips) if located outside of the riparian zone. The riparian-focused buffer strategies have the highest costs because the expensive buffer practice CP22 has to be installed in the agricultural lands in the riparian zones of the streams. The two topography-based buffer strategies incur very similar costs of establishing the buffers. The costs of establishing conservation buffers under the two topography-based buffer strategies are higher than the costs under the two soil survey-based buffer strategies because the two topography-based strategies prioritized higher percentage of agricultural lands in the riparian zone for conservation buffer than the two soil survey-based strategies.

The average benefits scores for each individual evaluation criterion – controlling pollutant generation, reducing soil erosion, enhancing wildlife habitat, and mitigating stormwater impacts – and the aggregated benefits are shown in section B of Table 4. The average hydrological sensitivity benefit ranges from 260 units per ha under the STE-based strategy to 500 units per ha under the TI-based strategy. The soil erodibility benefit ranges from 122 units per ha in the WI-based strategy to 287 units per ha under the STE-based strategy. The wildlife habitat benefit varies significantly across the buffer strategies. The WTE- and TI-based strategies generate the lowest wildlife benefit scores of 162 units per ha while the STE-based strategy generates of the highest wildlife benefit score of 338 units per ha. The average impervious surface benefit scores are relatively consistent across all assessed buffer strategies and have limited impacts on the ranking of the buffer placement strategies. The STE-based buffer strategy generates the highest average aggregated benefit score of 1032 units per ha primarily due to high benefits in controlling soil erosion and providing the wildlife benefits, followed by the fixed-width riparian buffer strategy (955 units per ha). The two topography-based strategies again have very similar aggregated benefit scores: 933 units per ha for the WI-based strategy and 930 units per ha for the TI-based strategy. The variable-width riparian buffer strategy has a low aggregated benefit score of 907 units per ha primarily due to its large prioritized areas for conservation buffers under this strategy. The WTE-based strategy generates the lowest aggregated benefit score of 799 units per ha.

Cost-effectiveness was obtained by dividing the average aggregated benefit scores by the average program costs (section C in Table 4). The STE-based strategy has the highest cost-effectiveness measure of 0.306 because of its high benefits and low cost. There are almost no differences between two topography-based buffer strategies in terms of their cost-effectiveness, which is around 0.22, because of their similarities in terms of costs and benefits. The WTE-based buffer strategy has the cost-effectiveness measure of 0.21, which is closer to the two topography-based strategies than the STE-based strategy, the other soil survey-based strategy. Such result is not surprising because all those three strategies focus on the water movements in landscapes when targeting the areas for conservation buffers. Both riparian-focused buffer strategies have the lowest cost-effectiveness: 0.18 for the fixed width riparian buffer strategy and 0.17 for the variable width riparian buffer strategy primarily because of their high costs for establishing and maintaining the conservation buffers.

5. Discussion

The methodology presented in this study provides a structured means for comparing benefits and costs of different conservation

Table 4
Comparison of the cost-effectiveness of alternative conservation buffer strategies in Neshanic River Watershed.

Parameter	Strategy					
	Riparian-focused		Soil survey-based		Topography-based	
	Fixed width	Variable width	STE	WTE	WI	TI
A. NJCREP program costs						
A1. Sign-up incentive ($/ha)	247	247	247	247	247	247
A2. Installation costs ($/ha)	3430	3430	1628	2055	2392	2307
A3. Soil rental costs ($/ha/year)	89	90	88	93	93	95
A4. Maintenance costs ($/ha/year)	15	15	11	12	13	13
A5. Average program costs ($/ha)[a]	5237	5255	3369	3876	4219	4170
B. Multiple environmental benefits						
B1. Hydrological sensitivity (units/ha)	378	335	260	361	498	500
B2. Soil erodibility (units/ha)	191	196	287	137	122	126
B3. Wildlife habitat (units/ha)	247	238	338	162	167	162
B4. Impervious surface (units/ha)	139	138	146	138	146	143
B5. Average benefit potential (units/ha)[b]	955	907	1032	799	933	930
C. Cost-effectiveness						
C1. Cost-effectiveness (B5/A5) (units/$)	0.182	0.173	0.306	0.206	0.221	0.223

[a] A5 = A1 + A2 + 15 * (A3 + A4).
[b] B5 = B1 + B2 + B3 + B4.

buffer targeting strategies for providing multiple ecological functions in watersheds. The specific results of this study are unique to this watershed and the particular set of benefits and criteria that were evaluated. Other watersheds or planning areas may produce different results because of landscape conditions and issues that are most important to planners may differ from one situation to another.

When conducting this kind of study, it is important to consider strategies that are consistent with the nature of the problems to be addressed in the watershed. For example, hydrology-related issues are better addressed by targeting strategies are consistent with the hydrology of the area, such as TI where VSA hydrology and saturation-excess overland flow are important processes, or, the STE and WTE indexes where the infiltration-excess overland flow process is a major factor in watershed degradation (Dosskey & Qiu, 2011). The WI index is a more generalized index that can have application in a broader range of watersheds, but it may be too general to provide satisfactory results in some planning situations. A mismatch between strategy and the nature of the problem could lead to prioritizing ineffective locations.

It is also important to choose appropriate evaluation criteria for a given situation. For example, the present study favored prioritization of areas with existing patches of high-quality habitat for species of concern that can be improved further by connecting them with buffer corridors. In other regions or for different species, however, a buffer may provide greater wildlife benefit by functioning as new habitat in areas where there is very little existing habitat. Local professionals need to be consulted to determine appropriate evaluation criteria. In a second example, the use of TI as the evaluation criterion for hydrological sensitivity for a strategy that uses TI for prioritization creates an obvious bias of the comparative results in favor of the TI strategy. A better approach would be to choose some other criterion instead of TI to lessen the problem of autocorrelation and to produce a less biased comparison of strategies.

The appropriate strategies to compare, the specific evaluation criteria, and the proper classification schemes depend upon specific land characteristics and issues that are important in a given watershed. Specific strategies and measures may not be directly transferrable to other watersheds or planning areas, but the methodological framework that is demonstrated in this study can be a powerful tool for planners to compare alternative multiple-function restoration strategies.

6. Summary and conclusions

A method is described for comparing the cost-effectiveness of different landscape management practices for providing multiple environmental benefits. The method was demonstrated for comparing the six different targeting strategies for placing conservation buffers in agricultural portions of a 144 km^2 urbanizing watershed in New Jersey, USA. The cost-effectiveness is measured by dividing the average benefit scores aggregated from multiple environmental benefit measurements by the average program cost of converting the prioritized agricultural lands into conservation buffers following the NJCREP program. The NJCREP costs include a one-time sign-up incentive, 100% of the installation costs, and 15 years of buffer maintenance costs and soil rental costs. These environmental measurements include soil erodibility, hydrological sensitivity, wildlife habitat, and impervious surface that are derived from different data sources and capture the conservation buffers' ecosystem services in reducing soil erosion, controlling runoff generation, enhancing wildlife habitat, and mitigating stormwater impacts, respectively. The environmental measurements are aggregated using a modified multiple criteria analysis tool based on a simple assumption of additive utility.

Both fixed and variable riparian buffer strategies are often chosen strategies by regulatory agencies and water resource professions to determine the spatial location for conservation buffers because of their intuitive simplicity, but in the Neshanic River Watershed in New Jersey they are least cost-effective. The alternative soil survey- and topography-based buffer placement strategies have been developed in recent years. Although they are initially based on single environmental criterion, they tend to be more cost-effective than the riparian placement strategies even when multiple environmental benefits are considered. Although the riparian placement strategies will continue to be used to improve environmental quality because of their popularity and simplicity, the alternative placement strategies should be considered especially when these riparian buffer strategies cannot meet the environmental objectives, additional environmental concerns are involved and the program cost is of a great concern.

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