Land Conservation, Restoration, and Stormwater Management Priorities for the Pretty Boy Reservoir Watershed, Maryland

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INTRODUCTION

This report summarizes the initial phase of mapping and modeling for the "Protecting the Source" project funded by the US EPA. It describes the (1) Pretty Boy Reservoir watershed (part of the city of Baltimore's water supply system) (2) compilation and adaptation of spatial data, (3) GIS-based overlay process used to identify key areas for source water protection, (4) preliminary findings, and (5) plans for additional analyses in support of the Stewardship Exchange and source water protection efforts.

THE WATERSHED

The Pretty Boy Reservoir impounds the Gunpowder River in the northwestern portion of Baltimore County, Maryland. The watershed extends west into Carroll County, Maryland, and north into York County, Pennsylvania (Figure 1). It has a total area of 205.7 km^2 (79.4 mi^2 or 50,830 acres). While most of the watershed lies on the Piedmont Plateau, the western headwaters reach the eastern periphery of the Blue Ridge. Most of the watershed has rolling terrain with steeply incised stream valleys. Steeper slopes occur in the ridge and valley section of the headwaters. Soils range in texture from clay and silt loams to gravelly sandy loams (USDA SCS 1969, 1976; USDA NRCS, n.d.). The climate is influenced by continental air masses, the proximity to Chesapeake Bay, and coastal storms. Precipitation averages about 40 inches (~1,000 mm) per year with one in ten year extremes of 34 to 48 inches. It is relatively uniform in temporal distribution. Dormant season precipitation is dominated by maritime tropical storms moving up the Atlantic coast. Thunderstorms are common during the summer. Severe weather events (i.e., tornadoes, hurricanes, blizzards) are relatively rare. Mean monthly temperatures in January and July are 33 and 75 °F, respectively. There are approximately 230 frost-free days (April to October) with a growing season of 170 to 200 days.

Current land cover and land use reflect more than three centuries of social, economic, and demographic change. At present, the watershed has about 15% developed land, 47% agricultural land (dominated by cropland at 37%), and 38% forests, wetlands, and water (dominated by forests at 34%) (Figure 2 and Table 1). The largest contiguous block of forest borders the Pretty Boy Reservoir (PBR); the remainder is fragmented into patches by agricultural and low density residential land use. It is far below the forest cover threshold─approximately 75% of the watershed─at which changes in water yield and quality are measurable relative to undisturbed conditions (Hornbeck et al., 1997). In addition to the direct effects of forest loss, conversion to agricultural land use typically increases soil erosion, sediment and nutrient inputs, and the potential for other agricultural chemicals (e.g., pesticide and herbicide residues) that reach streams, wetlands, and water supplies.

The proportion of the watershed in developed land, principally low density residential, with impervious surfaces and concentrated human activities introduces stormwater that can contain a wide range of pollutants into streams and groundwater. Notably, the fragmentation of the forest in the PBR watershed also extends into riparian areas. The Maryland DNR─Forest Service, U.S. Forest Service, US EPA, and other partners have been working to restore these critical gaps in riparian forest buffers as a primary means of reducing nutrient and sediment loading to Chesapeake Bay. Clearly, the Protecting the Source project should intensify earlier and on-going efforts in the region.

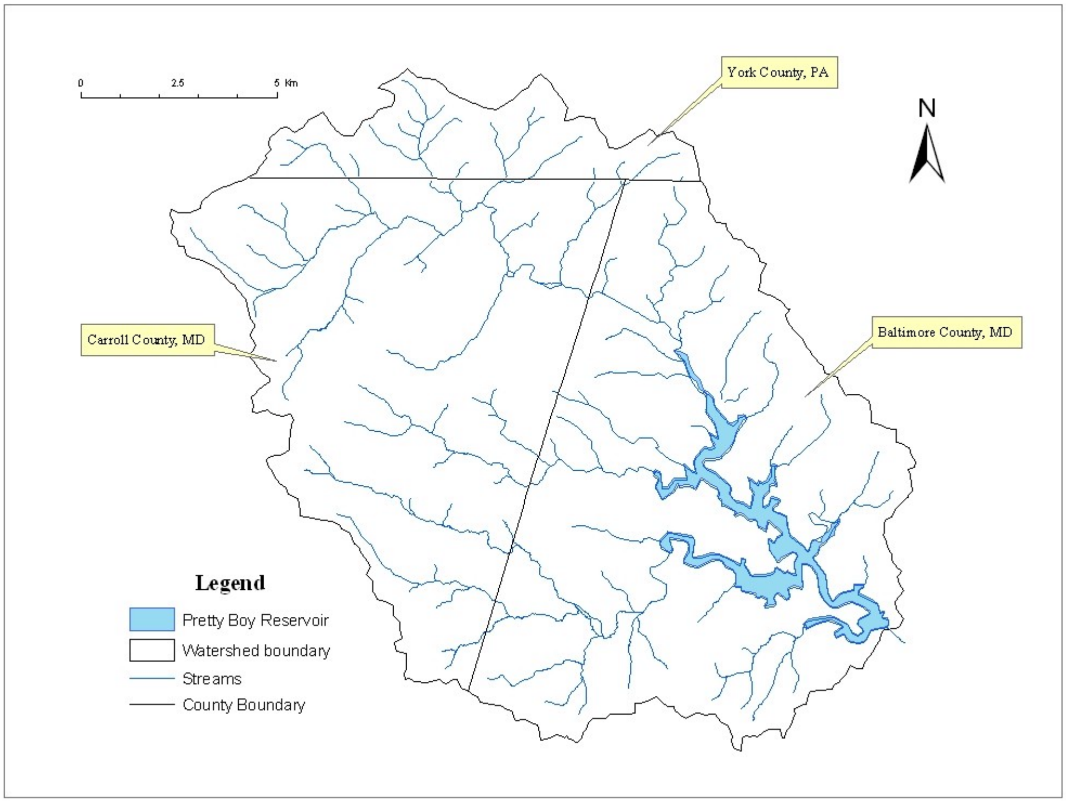

FIGURE 1 – Pretty Boy Reservoir Watershed, Maryland and Pennsylvania

SPATIAL DATA AVAILABILITY

The Geographic Information System (GIS) database for the PBR watershed was assembled from a variety of sources (Baltimore County, Maryland DNR, Pennsylvania Spatial Data Clearinghouse, USDA NRCS National Soils Database, USFWS National Wetlands Inventory, USGS, and the York County Planning Commission). Data gaps in one or more of the three political jurisdictions have limited the extent of the GIS database. For example, we had to "graft" Pennsylvannia land cover data originally developed for state-wide habitat classification (GAP Analysis Project) onto the Maryland Department of Planning land cover/land use layer. Because the Pennsylvania layer only contained plant canopy information we had to modify it with planning and zoning and tax parcel data showing the location and type of human use (in this case low density residential development). To complete the process, the Pennsylvania and classification system had to be cross-tabulated with the Maryland system and a 100 meter data gap along the Maryland state border that had to be filled. All of these operations, as well as the conversion from raster (grid cell) to vector (polygon) data in Pennsylvania, are the cause of the clear discontinuity at the state line. Nevertheless, we believe the LC/LU layer is adequate for preliminary assessment of the watershed system. The "gray" appearance of the Pennsylvania LC/LU fails to show the intact forest canopy over much of the area in low density residential use. In any case, we anticipate most conservation, restoration, and stormwater management efforts will occur in Maryland (91% of the PBR watershed).

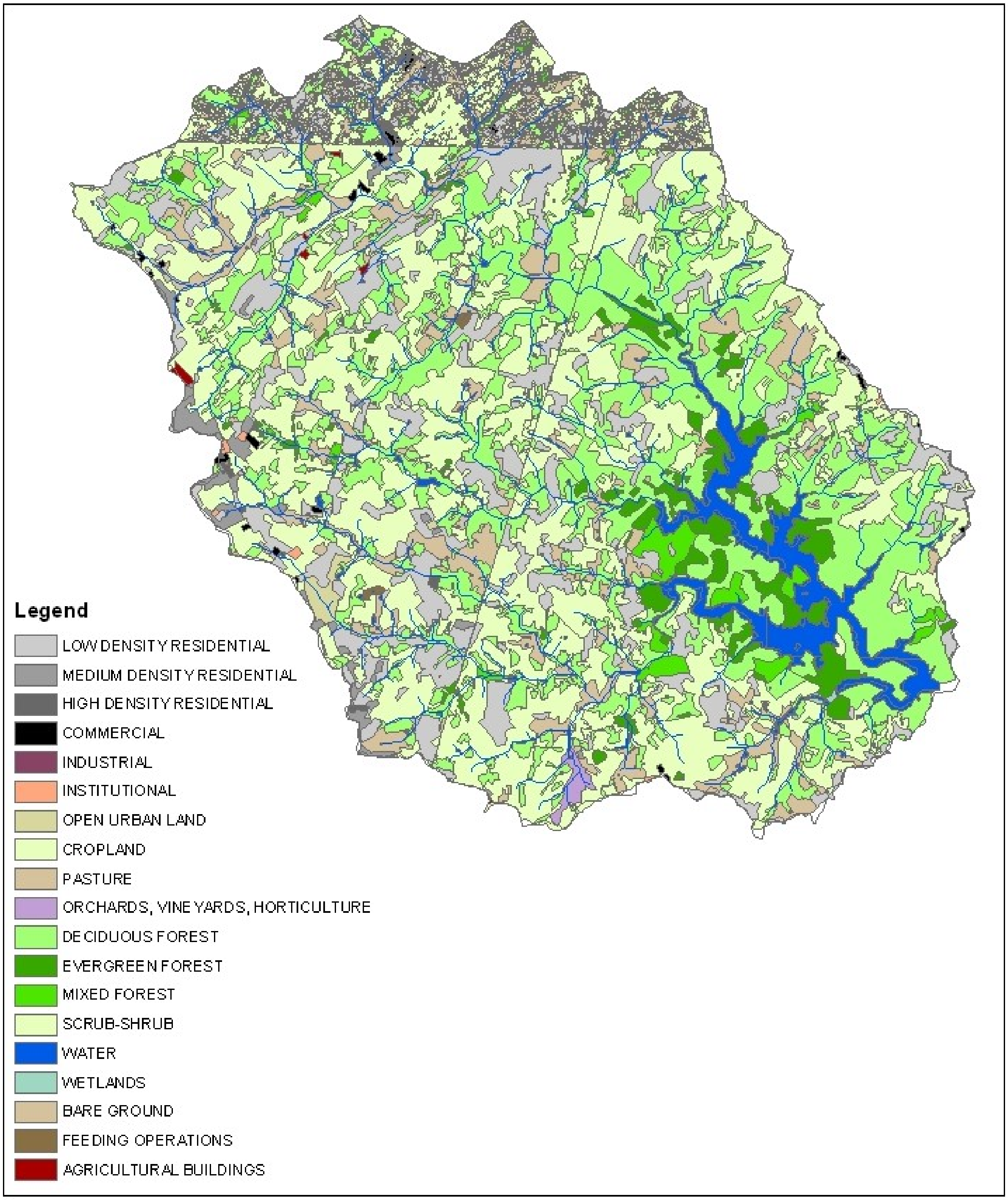

FIGURE 2 – Land cover and land use in the Pretty Boy Reservoir Watershed, Maryland and Pennsylvania. Data sources: Maryland Department of Natural Resources (2000), Pennsylvania Gap Analysis Project (1999), and York County Planning Commission.

TABLE 1 – Land cover and land use in the Pretty Boy Reservoir Watershed, Maryland and Pennsylvania. Data sources: Maryland Department of Natural Resources (2000), Pennsylvania Gap Analysis Project (1999), and York County Planning Commission (Figure 2). Area and proportion data are reported to 0.01 for accounting purposes; the accuracy of the estimates is probably lower than the implied precision.

Land Use	MD Land Use Code	Area (km^2)	Proportion of Watershed (%)
Low Density Residential	11	26.54	12.90
Medium Density Residential	12	2.17	1.06
High Density Residential	13	0.18	0.09
Commercial	14	0.66	0.32
Industrial	15	0.03	0.01
Institutional	16	0.18	0.09
Open Urban Land	18	0.64	0.31
Cropland	21	76.15	37.02
Pasture	22	18.63	9.06
Orchards, Vineyards, Horticulture	23	0.52	0.25
Deciduous Forest*	41	59.76	29.05
Evergreen Forest*	42	7.47	3.63
Mixed Forest*	43	3.33	1.62
Brush	44	1.91	0.93
Water	50	6.10	2.97
Wetlands	60	0.19	0.09
Bare Ground	73	0.91	0.44
Feeding Operations	241	0.15	0.07
Agricultural Buildings	242	0.18	0.09
TOTALS	-	205.70	100.00

* all forest = 70.56 km^2, 34.3% of the watershed

In sum, the availability of watershed-wide spatial data is somewhat limited. In addition to primary layers such as LC/LU and the digital elevation model (DEM), soils data at the mapping unit level (5 to 6 acre or ~150 meter resolution) comprised the most significant information resource for our preliminary analyses. Between the November 2002 meeting and the Stewardship Exchange in late-March 2003 we will be able to extend the database to include themes such as protected lands (already available for Maryland) and small community water systems (wells) for schools and small municipalities.

Analysis and Adaptation of Soils Data

Soil surveys and digital soils maps for Baltimore and Carroll County, Maryland and York County, Pennsylvania allowed us to derive two data layers for the GIS: (1) a permeability profile and (2) depth to seasonal water table. The former represents the likelihood that soil permeability, or the lack thereof, will lead to the generation of overland flow (Figure 3). When rainfall intensity [delivery rate] exceeds the infiltration capacity of a soil [rate at which water flows *through* the soil surface] overland flow is the obligate result. The permeability or saturated hydraulic conductivity of a soil is a conservative estimate of its infiltration capacity. We used mean permeability thresholds of ≤ 0.4, 0.4 to 2, and ≥ 2 inches/hour to assign scores of 3 (high), 2 (intermediate), and 1 (low), respectively, in the priority index calculations. We modified the classification (e.g., 2 → 3) if a shallow layer of intermediate permeability soil was underlain by a dense clay, fragipan, or other impeding horizon. Although, as expected, many soil series occur in all three counties, differences in the master profile descriptions and associated physical and hydraulic properties data meant we had to analyze and classify each of the 36 series separately. Relatively minor differences in the classification of same series can be noted in Table 2.

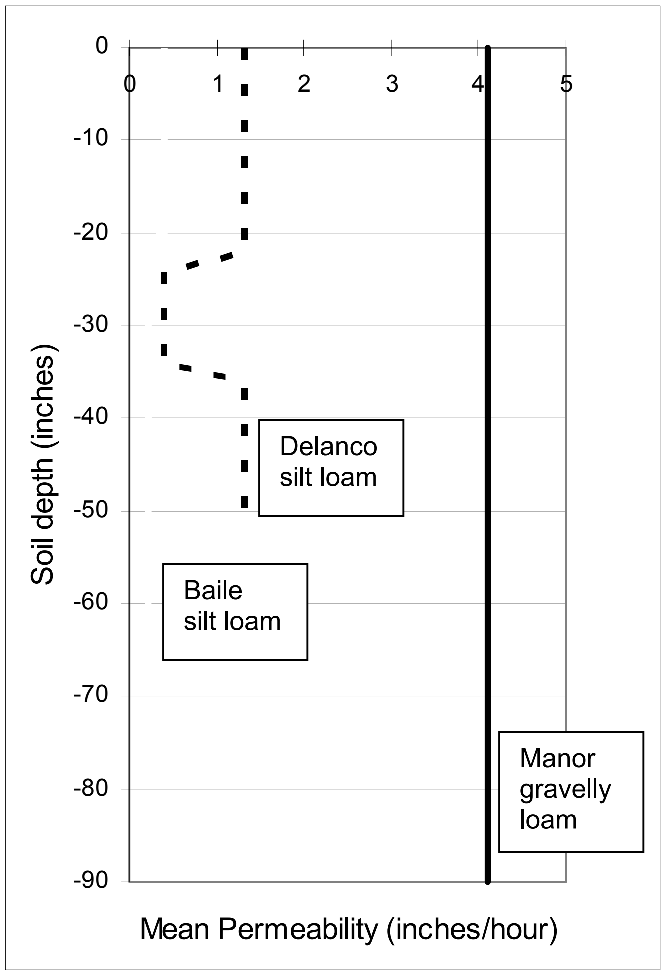

FIGURE 3 – Mean permeability versus depth for three Carroll County (MD) soils. The permeability profile classification for Baile, Delanco, and Manor series have priority indices of 3, 2, and 1, respectively.

The depth to seasonal high water table layer represents the likelihood that a soil will saturate from below and generate overland flow during the dormant season, hurricanes and tropical storms, or low frequency precipitation events. We used depth ranges of 0-1½, 1½-3, and >3 feet to assign scores of 3 (high), 2 (intermediate), and 1 (low), respectively, in the priority index calculations. During the dormant season when the high water table occurs, the unsaturated soil above it is typically moist or wet. A long-duration, low intensity rain can add enough water to cause the water table to reach the surface. Under these conditions, any additional rain or overland flow from upslope cannot enter the soil. In either case – whether infiltration or soil water storage capacity is limiting – overland flow can cause soil erosion and transport sediment, nutrients, and pathogens to streams, wetlands, and the Pretty Boy Reservoir.

CONSERVATION, RESTORATION, AND STORMWATER MANAGEMENT PRIORITY INDICES

Along with slope and proximity to streams, wetlands, or the reservoir, the soils data were organized as shown in Table 2. Land cover/land use classes are stratified into one of the three indices. In other words, each class is only used for the calculation of one index—*either* conservation, restoration, *or* stormwater management priority. Both the modeling overview and the Powerpoint presentation used during the Kickoff Meeting can be found on the Trust for Public Land web site.[2]

The layers were assembled into a computational model in ArcView (Figure 4). This flowchart details the sequence of vector to raster conversions (polygons to grid cells), assignment of 3-2-1 scores, and finally, the arithmetic overlay process that generates a priority index score for each of the more than 220,000 30 x 30 meter grid cells in the PBR watershed.

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[2] www.tpl.org …click on "Land & Water" …click on "Demonstration Projects."

TABLE 2 - Construction of Priority Indices for the Pretty Boy Reservoir watershed.

GIS Layer	Score									
	3 (high)			2 (intermediate)			1 (low)			0
Distance to water (m)	0 - 30			30 - 60			60 - 90			>90
Slope (%) Forest	>15			5 - 15			≤ 5			-
non-Forest	>8			3 - 8			≤ 3			-
Soil permeability profile (soil series)	Baltimore County, MD	Carroll County, MD	York County, PA	Baltimore County, MD	Carroll County, MD	York County, PA	Baltimore County, MD	Carroll County, MD	York County, PA	n/a
	Baile Captina Delanco Made-soil	Baile Birdsboro Cordorus Elioak Glenville Hatboro Linganore Urbana	Dump Glenville	Chester Cordorus Elioak Elsinboro Glenelg Glenville Hatboro Mt. Airy	Bucks Chester Comus Conestoga Delanco Elsinboro Glenelg Mt. Airy	Chester Cordorus Glenelg Mt. Airy Mt. Airy/ Manor	Manor Manor/ Brandy- wine	Manor	Baile	
Seasonal depth to water table (soil series)	Baltimore County, MD	Carroll County, MD	York County, PA	Baltimore County, MD	Carroll County, MD	York County, PA	Baltimore County, MD	Carroll County, MD	York County, PA	n/a
	Baile Glenville Hatboro Made-soil	Baile Cordorus Hatboro	Baile Cordorus Dump Glenville	Captina Cordorus Delanco	Comus Delanco Glenville Urbana		Chester Elioak Elsinboro Glenelg Manor Mt. Airy Manor/ Brandy- wine	Birdsboro Bucks Chester Conestoga Elioak Elsinboro Glenelg Linganore Manor Mt. Airy	Chester Glenelg Mt. Airy Mt. Airy/ Manor	

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______ Index	3	2	1	0
Conservation Priority	Deciduous Forest; Evergreen Forest; Mixed-Forest; Scrub-Shrub Vegetation	-	-	all other land uses
or				
Restoration Priority	Cropland; Bare Ground; Feeding Operations	Open Urban Land; Pasture; Orchards, Vineyards, Horticulture	-	all other land uses
or				
Stormwater Management Priority	High-Density Residential; Commercial; Industrial; Institutional; Agricultural Buildings	Medium-Density Residential	Low-Density Residential	all other land uses

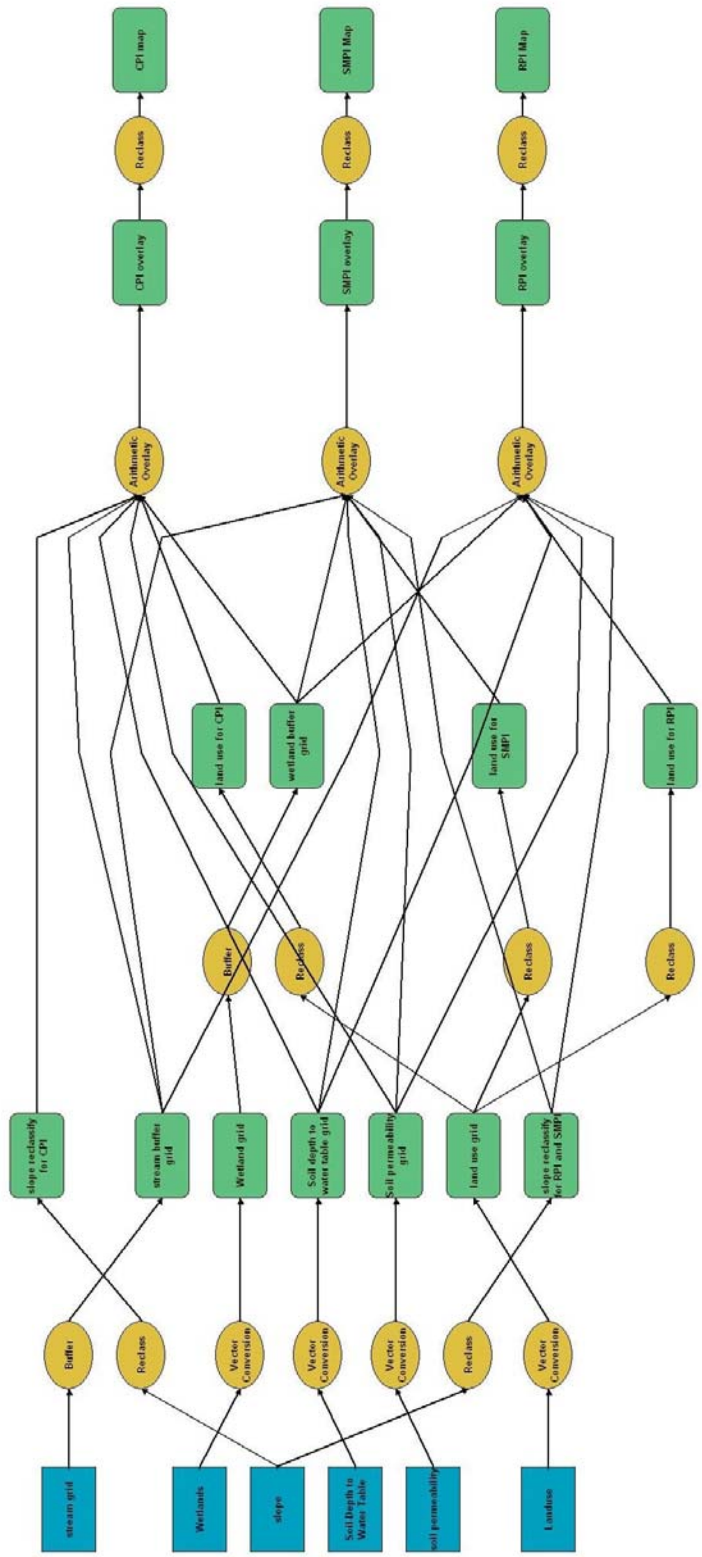

FIGURE 4 – Model schematic for Conservation (CPI), Restoration (RPI), and Stormwater Management (SMPI) Priority Indices for the Pretty Boy Reservoir watershed, Maryland and Pennsylvania. The model structure may change if additional data become available.

The results of the CPI overlay process highlight the importance of the forests along the Gunpowder River and other tributaries for the maintenance of water quality (Figure 5). As noted earlier, the gaps in riparian forests along many small streams may allow nonpoint (NPS) pollutants to enter the system at hundreds of sites. Once pollutants enter streams they may be assimilated or transformed into more benign forms or may simply flow right past intact riparian forests on their way to the Pretty Boy Reservoir.

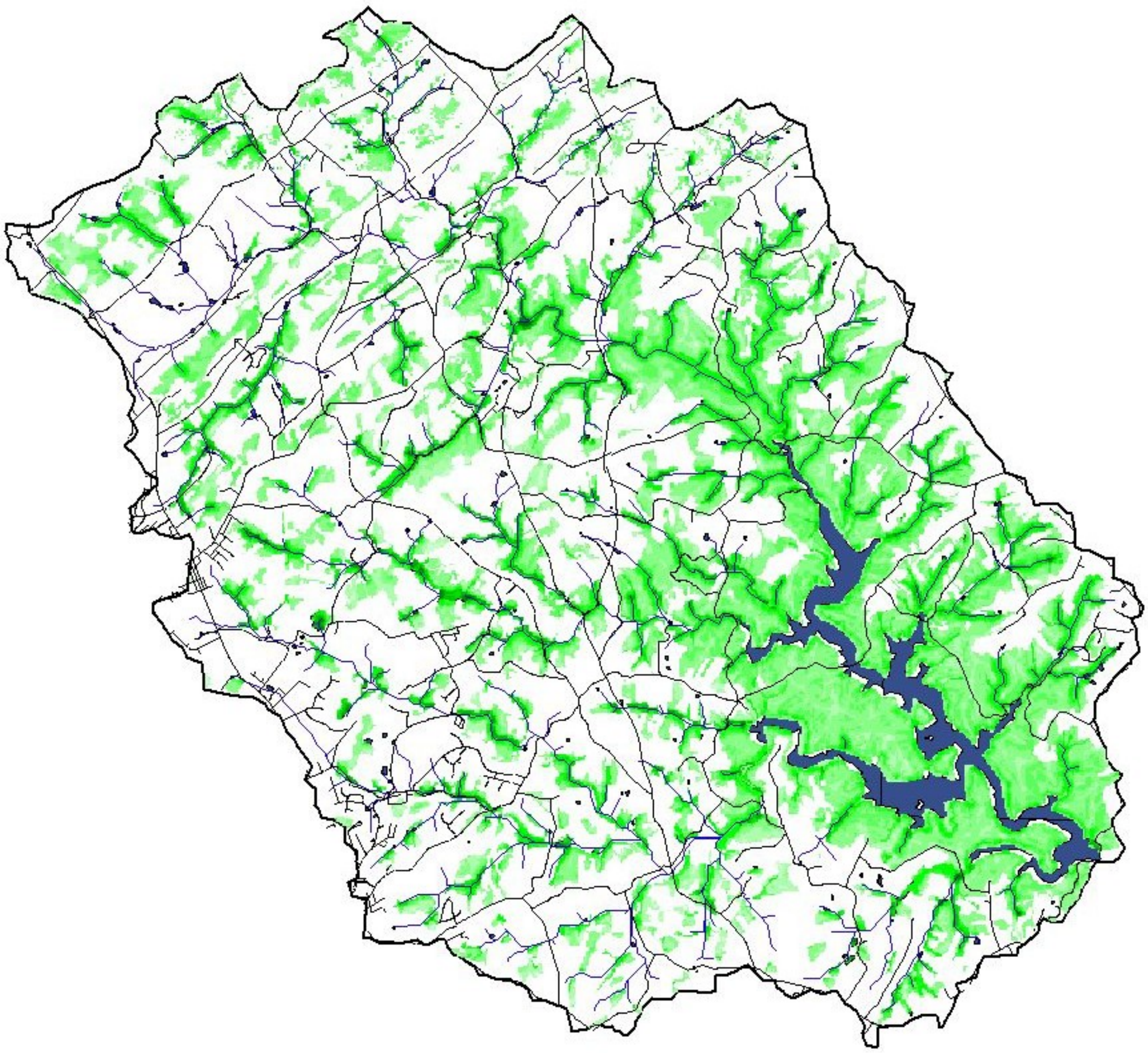

FIGURE 5 – Conservation Priority Index (CPI) for forests and wetlands in the Pretty Boy Reservoir watershed, MD and PA. The darkest hues indicate the highest priority land for conservation.

The overall landform of the PBR watershed—a plateau dissected with steep-sided stream valleys—has led to forest clearing at the headwaters of many small tributaries. This has produced an atypical pattern relative to many surface water supply systems in the northeastern U.S.—with forested headwaters, mixed land use of progressively higher density through the middle reaches, and urbanization in downstream areas. By contrast, the PBR is bordered by an island of forest that is, in turn, surrounded by a patchwork of farms and residential development, with some of the most densely populated areas around the periphery of the watershed (Figure 2). This pattern probably emerged because agricultural land use pre-dated the construction of the reservoir and, as usual, the road network preordained much of the post-1950 residential development. The results of the restoration priority index overlay for agricultural lands and other green space show the potential influence of areas that are distant from the PBR on water quality (Figure 6). This result is linked to the steeper topography of the northern portion of the watershed. Comparing Figures 5 and 6 highlights the juxtaposition of farms upstream of forests and the need to extend riparian buffers whenever possible.

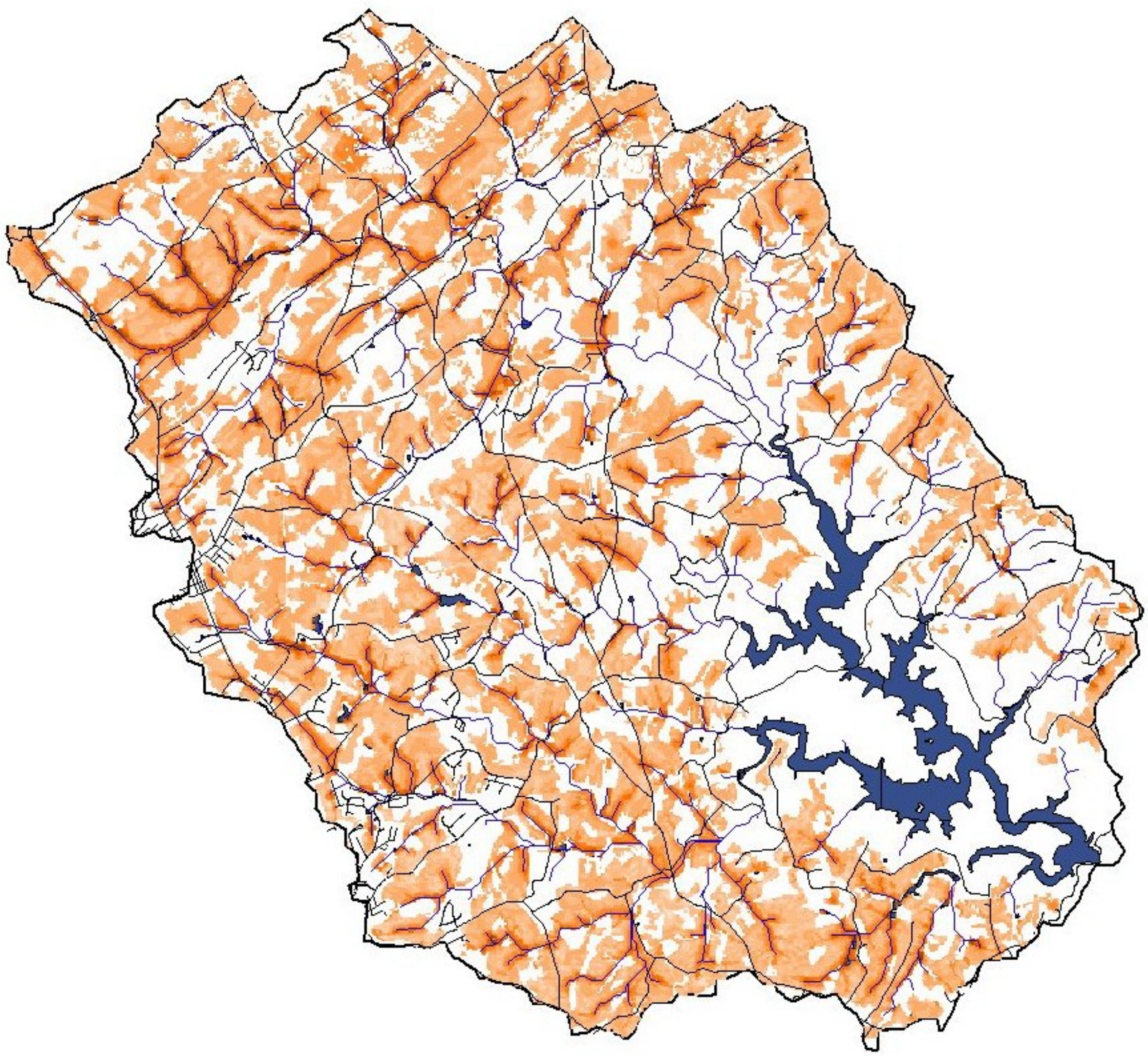

FIGURE 6 – Restoration Priority Index (RPI) for agricultural land in the Pretty Boy Reservoir watershed, MD and PA. The darkest hues indicate the highest priority land for restoration.

Because house lots require road frontage and reasonable access to secondary and primary roads for commuting, the road network often leads to adverse impacts on the quantity, timing, and quality of streamflow. In the PBR watershed—like most in rolling or mountainous terrain with human occupation dating from the Colonial period—roads follow, or at least parallel, streams. This brings 20th and 21st Century human activity in direct or proximate contact with receiving waters. The bright red areas scattered through the PBR watershed indicate parcels, subdivisions, or towns where stormwater management must meet very high performance standards in order to avoid contamination of source waters (Figure 7). The scattered spatial distribution may present an opportunity or a substantial challenge. It may be a cost-effective opportunity for water quality improvement if small-scale, low-tech Best Management Practices (BMPs) can prevent or mitigate urban stormwater impacts. Unfortunately, it may represent a substantial challenge if the space available for on-site mitigation (e.g., stormwater detention or diversion) does not permit enough time for settling and assimilation of suspended solids, nutrients, and other pollutants.

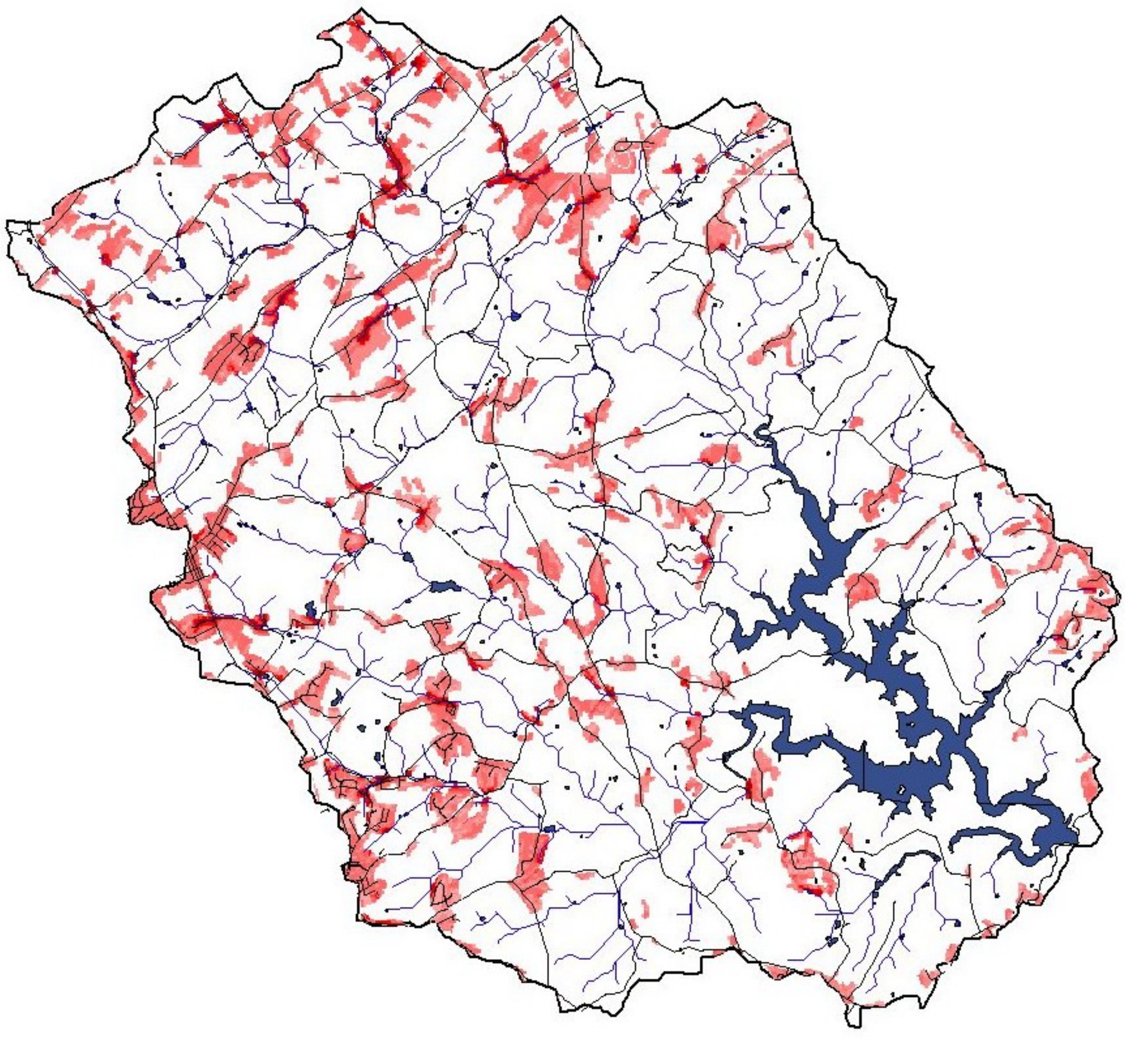

FIGURE 7 – Stormwater Management Priority Index (SMPI) for developed lands in the Pretty Boy Reservoir watershed, MD and PA. The darkest hues indicate the highest priority areas.

In addition to the detailed review of GIS layers, CPI, RPI, and SMPI scores also can be evaluated with basic statistical methods (Figure 8). As expected, the frequency distributions for the priority indices are negatively skewed – *many* ordinary values, *few* exceptional values. By design, the GIS overlay process highlights the sites with combined characteristics that warrant special attention. For example, a forested grid cell that is within 30 meters of a stream, with a slope greater than 15%, and poorly drained, fine-textured soil would yield a CPI score of 12; one of 216 grid cells out of 80,857 in the CPI calculation for the PB watershed. By contrast, there are 28,412 cells with a score of 4.

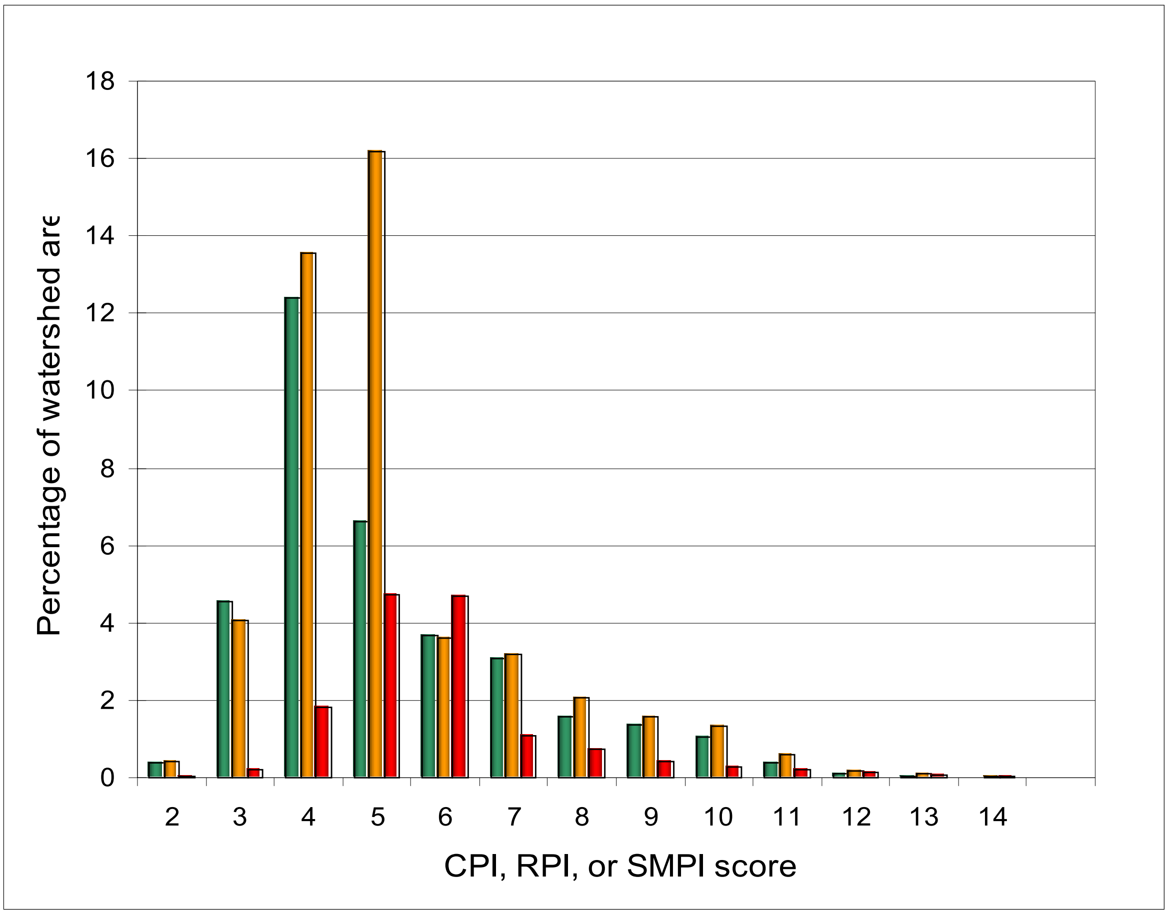

FIGURE 8 – Frequency distributions of Conservation (CPI, green), Restoration (RPI, orange), and Stormwater Management (SMPI, red) Priority Indices for the Pretty Boy Reservoir watershed, Maryland and Pennsylvania.

When plotted as cumulative frequency distributions, percentile ranks can be readily determined for all three indices (Figure 9). A cumulative frequency distribution is developed by beginning with the lowest score and adding the total number of grid cells in each successive class until reaching the highest score and 100th percentile (e.g., 14 for CPI). This is the same procedure used to report standardized test scores such as the SATs or as a reference for children's height and weight at annual physical examinations.

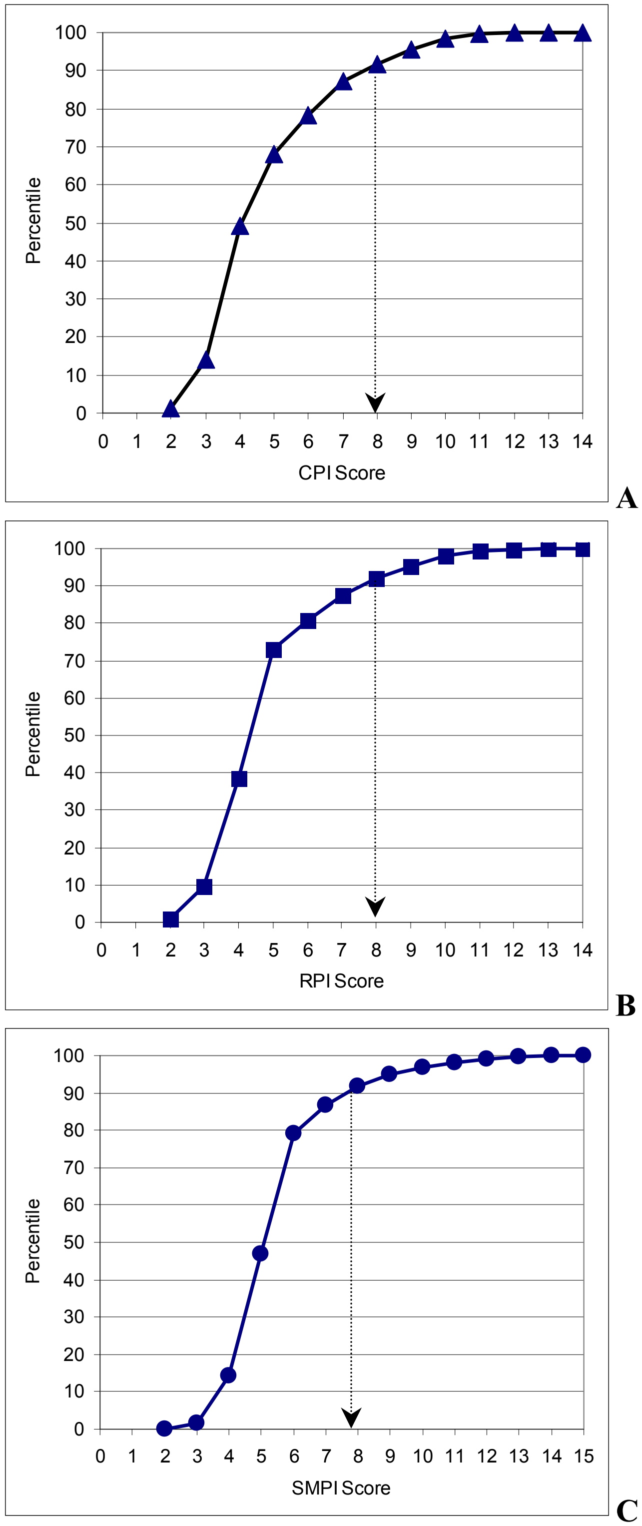

FIGURE 9 – Cumulative frequency distributions for Conservation (“A”), Restoration (“B”), and Stormwater Management (“C”) Priority Indices for the Pretty Boy Reservoir watershed, Maryland and Pennsylvania. As an example, the dashed line shows the 90th percentile score for each index as an initial threshold to guide field assessments, additional GIS analyses, outreach activities, and watershed management plans and programs.

The 90th percentile (the top 10% of CPI, RPI, and SMPI scores) can be used to focus land conservation, pollution prevention, and pollution mitigation efforts on areas that should generate the greatest return on investment. Interpreting and using both frequency distributions is directly analogous to the process by which teachers assign letter grades in relation to total numerical scores …90% and higher, A, 80 to 90%, B, 70 to 80%, C …and so forth. The GIS can be used to generate a customized map of the highest scores (e.g., 80th and 90th percentiles) in relation to streams, lakes, wetlands, and roads (Figures 10, 11, 12, and 13). This process can be incremented by different multiples and done separately or simultaneously for the three indices to enumerate and explore a range of management options.

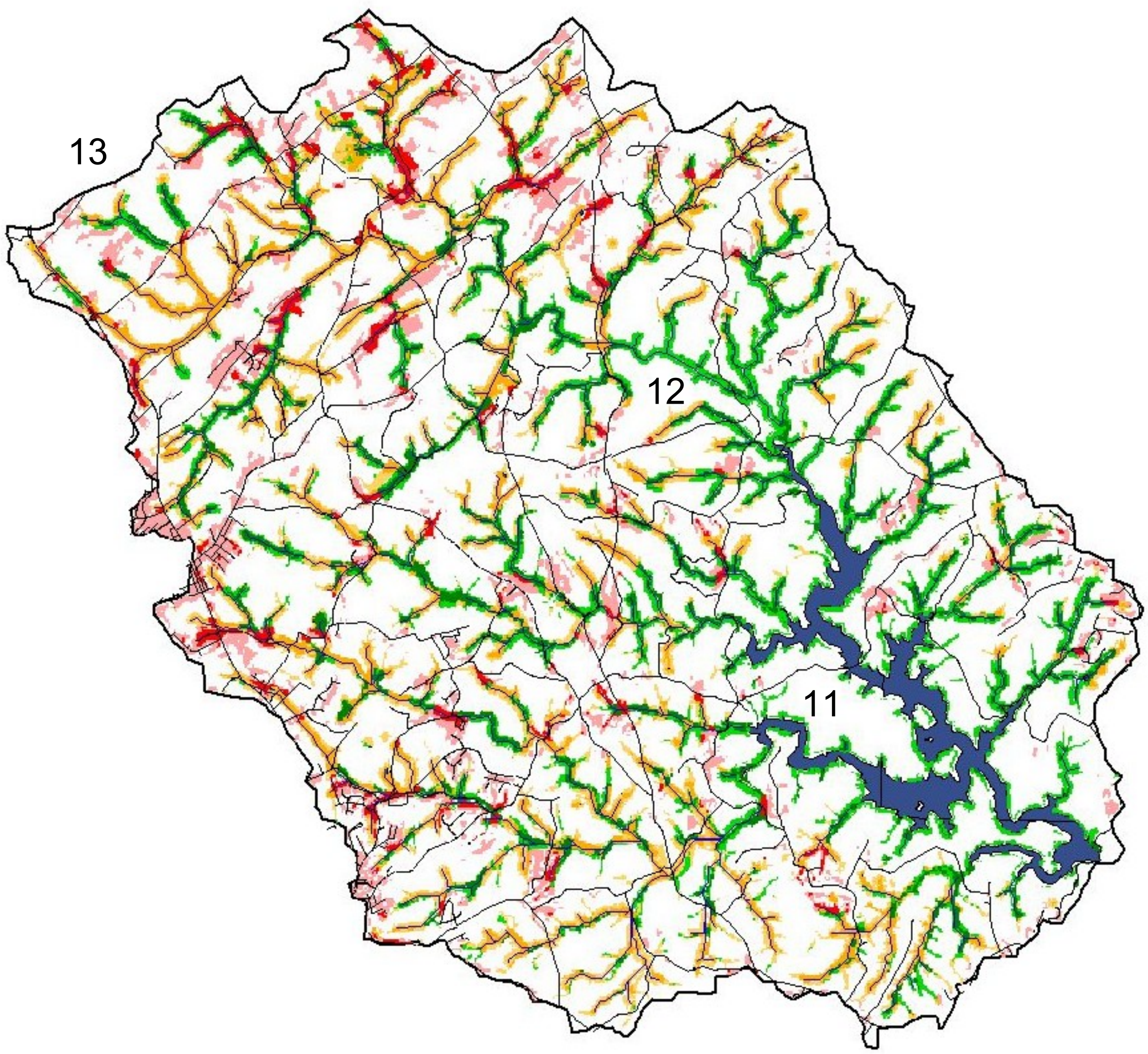

FIGURE 10 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the ≥ 80th or ≥ 90th percentile (light hues and dark hues, respectively) for the Pretty Boy Reservoir watershed, Maryland and Pennsylvania. Also shown are roads, streams, lakes, ponds, and wetlands. The numbers refer to enlargements in Figures 11, 12, and 13.

Scanning clockwise from the PBR dam and intake, several landscape-scale patterns are evident in Figure 10. Once outside the city of Baltimore landholdings on the south and west side of the reservoir, riparian forest buffers are fragmented or may be functionally non-existent. However, terrain and soil properties in this general area are less problematic than other parts of the watershed. Encroachment of residential and commercial development occurs along several major streams. Especially notable are breaks in the riparian forest in close proximity to the reservoir (labeled A-D in Figure 11). Here the short travel time for pollutants to the reservoir may amplify the net ecological effect relative to an equal mass of nutrients and sediment entering a headwater stream.

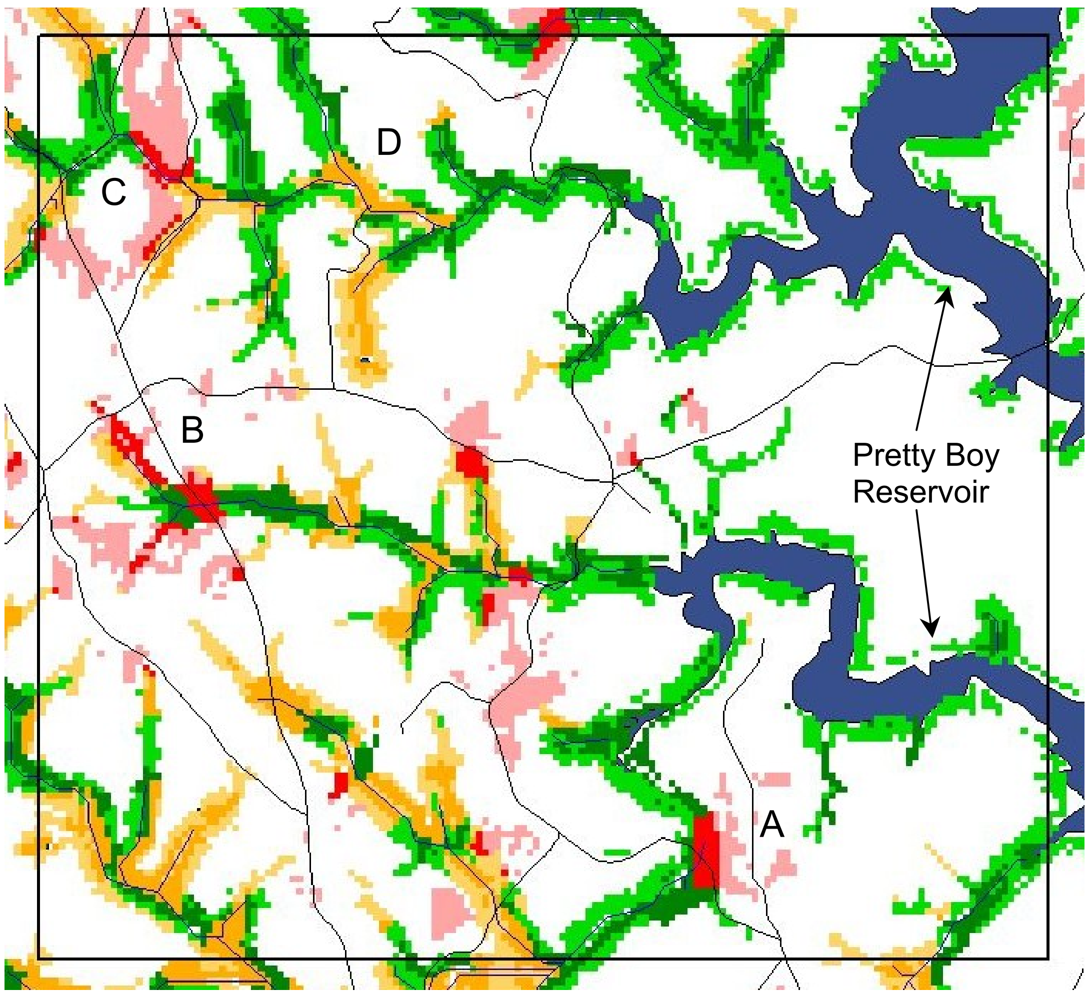

FIGURE 11 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the ≥ 80th or ≥ 90th percentile (light hues and dark hues, respectively) for a portion of the Pretty Boy Reservoir watershed, Maryland.

In the middle reaches of the PBR watershed the prevalence of unprotected headwater sections increases (Figure 12, E and F). In addition, the spatial extent of areas with high RPI and SMPI scores increases (figure 12, G).

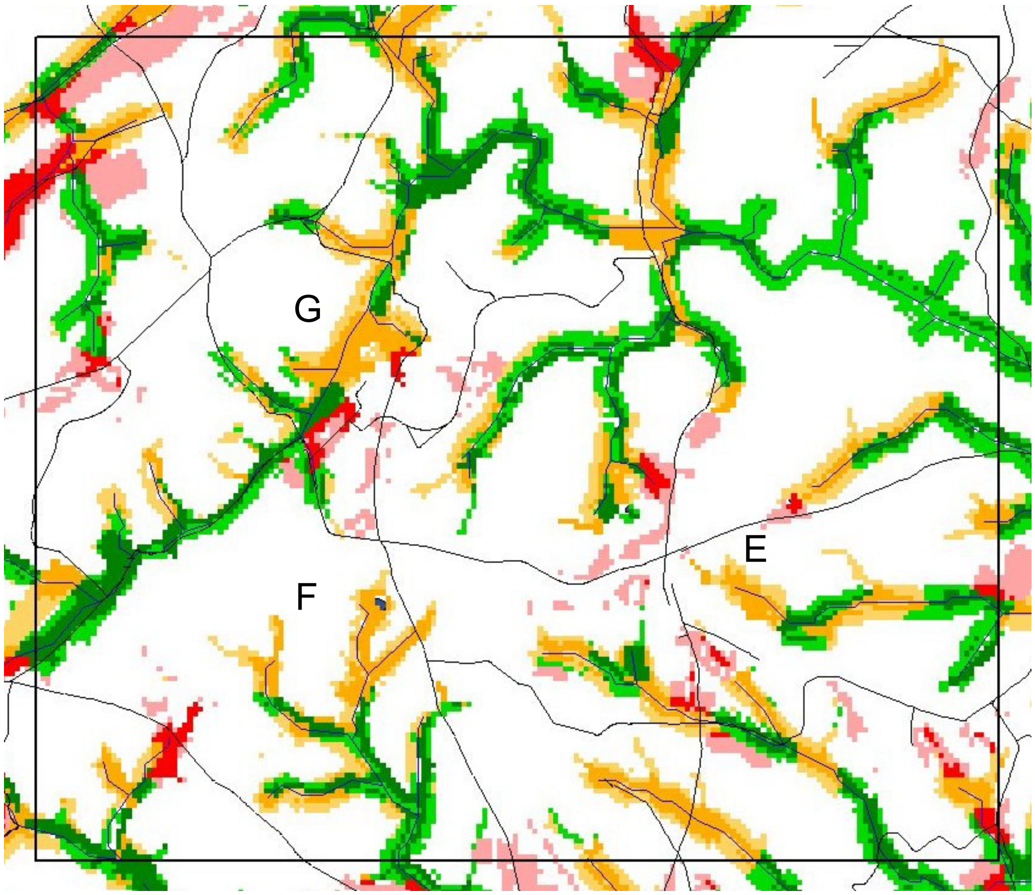

FIGURE 12 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the ≥ 80th or ≥ 90th percentile (light hues and dark hues, respectively) for a portion of the Pretty Boy Reservoir watershed, Maryland.

In the headwater region, steep slopes, soil conditions, and land use combine to yield some of the highest priority index values in the PBR watershed. Although we experimented with different line widths and colors to find the best way to display roads and streams, it is difficult to distinguish between them …and therein lies the watershed management problem (Figure 13, H and J). An area of pasture and cropland shows the largest concentrations of high RPI scores in the PBR watershed (Figure 13, I). This figure also shows that cumulative effects (either positive or negative) begin at or near the watershed boundary—so should watershed management plans and programs.

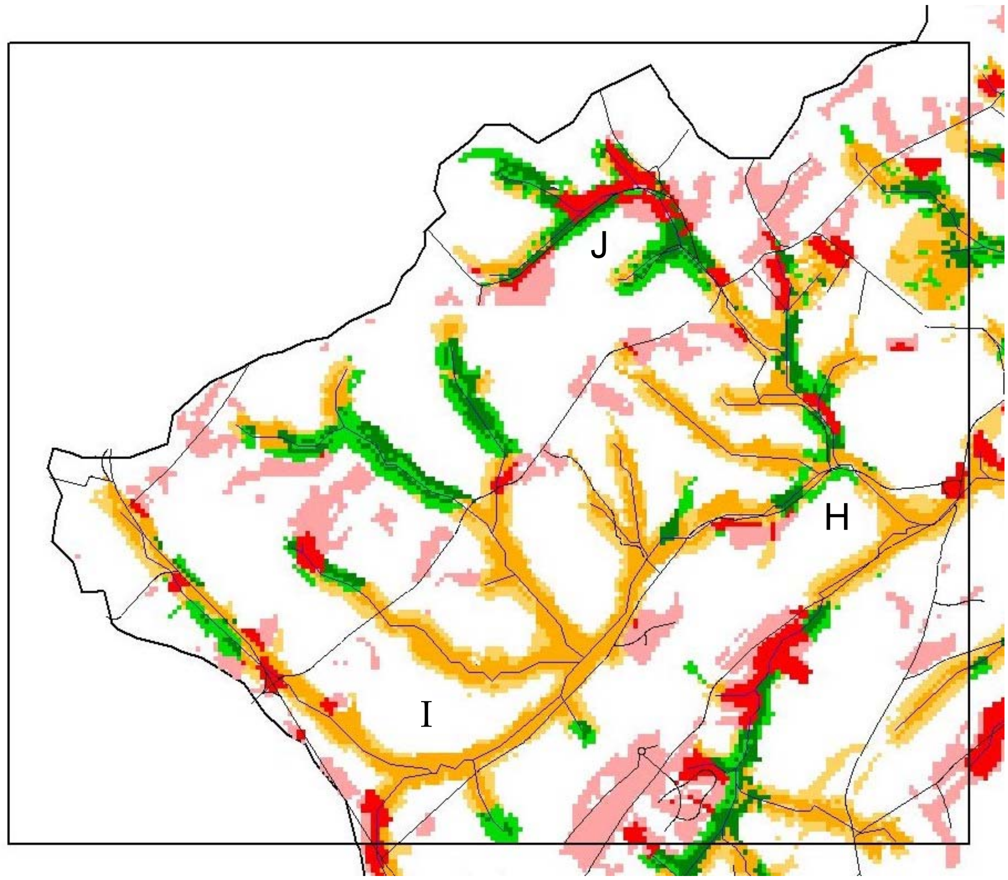

FIGURE 13 – Conservation, Restoration, and Stormwater Management Priority Indices (green, orange, and red, respectively) in the ≥ 80th or ≥ 90th percentile (light hues and dark hues, respectively) for a portion of the Pretty Boy Reservoir watershed, Maryland and Pennsylvania.

WATERSHED MANAGEMENT IMPLICATIONS

Our analyses highlight patterns, trends, and challenges well known to watershed managers in the region.

1. The forest surrounding the PBR watershed can not offset or mitigate NPS pollutant loading in the middle and headwater reaches. However, its conservation and stewardship are critically important to regional biotic integrity *and* public health in Baltimore.

2. Restoring the continuity of riparian forests throughout the watershed is critically important for the maintenance or improvement of water quality. Although the effectiveness of riparian forest buffers varies in relation to the type of pollutant (e.g., 80 to 95% removal of suspended sediment, 30 to 40% assimilation of nitrate, etc., Lowrance et al. 1995; NRC 2002), they generate a wide range of indirect and long-term benefits. These include the regulation of water temperature by shading,

stabilization of streams and floodplains by living vegetation and large woody debris, and the re-establishment of travel corridors for wildlife (NRC 2002).

3. If not already in place, a monitoring network that quantifies the proportional contributions of tributary streams and particular areas ("above and below" sampling) within subwatersheds is needed to clearly link land and resource use with water yield and quality. Coupled with GIS-based analyses, field data will help to identify, adapt, and implement watershed management strategies with the best return on investment. A strategically designed streamflow and water quality monitoring network also provides the opportunity to assess the performance of watershed management actions relative to baseline (pre-treatment) conditions (NRC 2000).

4. A cooperative approach involving the city of Baltimore, state and federal agencies, NGOs, and farmers and other landowners will be needed to maintain or improve water quality in the PBR watershed. While forests are the optimal land cover for source water protection, well-managed farms, orchards, nurseries, and other "green" components of a working landscape are preferable to residential use …with associated increases in commercial use, transportation systems, and other pollutant types and sources. The management of many large water supply systems in the densely populated Northeast is based on this premise (Barten et al., 1998, NRC 2000; Platt et al. 2000). It also reflects the long-term development and land use patterns in Europe—urban and rural areas in close proximity without 20 to 30 mile swath of sprawl and fragmentation surrounding every population center.

NEXT STEPS

The Watershed Issues meeting on November 6, 2002 and the Stewardship Exchange in March 2003 will provide venues for the review, discussion, and refinement of the preliminary analyses presented in this report. Both meetings will, no doubt, generate questions and ideas for additional analyses. For example, it may be possible to augment the PBR database with new layers. A "protected lands" layer could be included in the overlay process to identify opportunities to link and consolidate open space or conservation easements with new purchases. Parcel maps could be used to identify owners of key areas. Summing the priority index scores by parcel (polygon) would yield an objective way to compare properties of different sizes, shapes, and locations within the PBR watershed. Flowpath analyses could help to define and understand the connections between particular parcels or patches with streams and the PBR. Source protection is always a "work in progress" because the resource that must be conserved in perpetuity—water—is subject to constantly changing conditions.

ACKNOWLEDGMENTS

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