THE NATURE CONSERVANCY

Summary Report

Potomac Watershed Assessment Methodology

Keith Fisher
keith_fisher@tnc.org

Misty Downing
misty.downing@tnc.org

December 1, 2015

The following is a detailed description of the methodology used to complete the Potomac Watershed Assessment as part of the Agreement between the Chesapeake Bay Trust and The Nature Conservancy, March 26, 2015.

Summary Report of the Potomac Watershed Assessment Methodology

1.1.1 Planning Units

The assessment analysis was conducted at two spatial scales, beginning with planning units at the coarser scale of 12-digit USGS Hydrologic Unit Code (HUC) watersheds (referred to as HUC12 watersheds) nested within the HUC8 watershed. A HUC12 is a drainage area delineated by a spatial modeling technique using 24K scale hydrographic and topographic maps and data, to represent a 10,000-40,000 acre area that contributes source water to a single outlet point on a river or stream. It is identified by a 12-digit code indicating its position in the larger landscape, as well as a name corresponding to a significant hydrographic, cultural, or political feature within its boundaries (USGS 2009, NRCS 2012). A HUC12 may be composed of headwater streams, in which case it is self-contained, or it may include streams that originate in an upstream HUC12, in which case its water quality may be influenced by attributes of the upstream watershed.

A finer level of planning units consisted of NHDPlus catchments within the HUC8 watershed, a scale at which protection or restoration activities are more likely to take place. The NHDPlus catchments are elevation-derived drainage areas of individual stream segments produced by Horizon Systems Corporation, using a drainage enforcement technique that involved "burning-in" the 100K NHD flowlines and, when available, building "walls" using the national Watershed Boundary Dataset, primarily to achieve a compatible and hydrologically accurate catchment for each stream segment (USEPA and USGS 2005). Some NHDPlus catchments were modified to provide a more uniform planning unit size, by dividing very large catchments into smaller units or merging very small catchments with the larger adjacent catchment.

1.1.2 Landscape Classification

Watersheds were divided into three separate landscapes that were analyzed independently of each other, and for which separate sets of results at both levels of planning units (HUC12 watersheds and NHDPlus catchments) were calculated:

1.1.2.1 Streams/Riparian Areas

Streams considered in the assessment were defined using the USGS National Hydrography Dataset 24K (NHD24K) flowlines, plus an approximately 90-125 meter riparian buffer. The NHD24K dataset is known to be missing some headwater stream reaches, particularly intermittent streams, but several constraining factors, such as compatibility between datasets and amount of manual processing time required to generate auxiliary data for certain metrics, resulted in the NHD24K being the most detailed and reliable source of stream line data for the purposes of this project.

A riparian buffer was delineated using the northeast regional Active River Area (ARA) dataset generated by TNC’s Eastern Regional Office (Smith et al. 2008). The ARA is based on the concept that river health depends on a dynamic interaction between the water and the land through which it flows, thus incorporating both aquatic and riparian habitats. The ARA explicitly considers processes such as system hydrologic connectivity, floodplain hydrology, and sediment movement along the river corridor and delineates areas along a stream where such processes are likely to occur (Smith et al 2008). However, the ARA for this region was generated based on the NHD 100K flowlines dataset, a coarser-level dataset than the NHD24K dataset. Since a primary goal of the project was to analyze headwater streams within each HUC8, the greater detail of the NHD24K dataset was needed. Therefore, a 120-meter buffer was generated for any headwater streams that occurred within the 24K dataset, but were not covered within the Active River Area.

1.1.2.2 Wetlands

Wetlands considered in this assessment were defined using the US Fish and Wildlife Service's NWI dataset. The West Virginia NWI contains data collected over a large time period, from February 1971 to December 1992, and the statewide coverage was published in 1996. Therefore, the quality and accuracy of the wetland locations within the watershed are questionable, as the dataset is both old and largely based on interpretation of aerial photography and a variety of field survey techniques. The general NWI palustrine wetland types are listed in Table 1. To include the immediately surrounding wetland habitat into the analysis, a 50-meter wetland buffer was generated. A width of 50 meters was chosen based on a literature review and discussions with experts during workshops. Additionally, some metrics were calculated based on the catchment area for each wetland. These catchments were delineated by NHDPlus catchments, using flow direction grids to determine which NHDPlus catchments drained to a particular wetland, and manually selecting those catchments to create a wetland catchment layer that approximated the total drainage area for all mapped wetlands within a watershed.

Table 1. National Wetland Inventory Wetland Types in the Upper Guyandotte River Watershed (USFWS 2010)

NWI Code Prefix	NWI Wetland Type	Acres
PEM	Palustrine Emergent Wetland	47
PFO	Palustrine Forested Wetland	27
PSS	Palustrine Shrub-Scrub Wetland	65

1.1.2.3 Uplands

The purpose of including uplands as a separate landscape was two-fold: to characterize areas that are important for terrestrial species, and to quantify the potential impacts of upland habitat disturbance on water quality. We defined uplands as any areas not included in the riparian or wetland buffers; however, the material contribution zone of the Active River Area extended into the uplands. For the majority of metrics, we used the spatial datasets for the entire watershed instead of limiting the analysis to the riparian or wetland buffer as with the analysis of the previous two landscapes.

1.2 Priority Models

Three Priority Models were defined based on the three landscapes defined in the assessment:

- Streams/Riparian Areas
- Wetlands
- Uplands

Table 2. Watershed Characterization Priority Models and Indices

Priority Model	Index
Streams	Water Quality
	Water Quantity
	Hydrologic Connectivity
	Biodiversity
	Riparian Habitat
Wetlands	Water Quality
	Hydrology
	Biodiversity
	Wetland Habitat
Uplands	Habitat Connectivity
	Habitat Quality
	Biodiversity

Priority models were further divided into several indices to assess both the condition and function of the watershed (Table 2). Each index was defined by numerous metrics, derived from various datasets that were processed and analyzed for each planning unit (HUC12 and NHDPlus catchment). Condition and function include both *quality indicators* of the inherent physical features of the landscape (e.g., total miles of headwater streams), as well as any *stressors*, or anthropogenic/natural factors that may have a negative impact on the landscape (e.g., active surface mining). In many instances, a direct measurement or data source for a particular metric was unavailable or unreliable. In such cases, surrogate data were identified and used to estimate quality or stress (e.g., dam drainage area used to approximate the impacts of flow alteration from impoundments).

The objective was to identify and utilize datasets that characterize the following aspects of the watershed:

a. Riparian, wetland, and upland natural resources in the watershed

b. Functional values and ecological services provided by the natural resources in the watershed (surface water use, flood storage/abatement, groundwater use, sediment retention, pollutant assimilation, recreational benefits, etc.)

c. Freshwater connectivity within the watershed, and hydrologic connections upstream and downstream of the watershed (where appropriate), to determine how these affect watershed condition

d. Water quality impairments (including 303(d) stream listings, acid mine drainage (AMD) impaired, and TMDL streams) within the watershed, and issues affecting hydrology and environmental flows

e. The contribution of consumptive water use on aquatic resource quantity and function

f. Rare, unique and/or sensitive species (and their habitat requirements) and vegetative communities within the watershed

g. Existing conservation investments on the ground (local, state, federal, and private conservation lands; conservation easements; mitigation sites)

h. Identified government and private conservation priorities within the watershed (protection and/or restoration priorities identified by conservation organizations and government agencies)

i. Natural physical vulnerability of the watershed as indicated by factors such as slope, highly erodible soils, etc.

j. Land use practices in the watershed with the potential to negatively impact natural resource value and function (resource extraction activities such as mining, oil and gas well drilling, mineral operations; development, road construction, etc.)

k. Land use practices in the watershed with the potential to cause pollution of aquatic resources (point sources such as facilities that discharge to water, non-point sources such as impervious cover runoff, agriculture, landfills, etc.)

l. Sources of natural resource and/or function loss due to fragmentation (dams, transportation infrastructure, energy transmission, etc.)

1.2.1 Streams/Riparian Areas Model

The *Streams Water Quality* (SWQ) index attempted to evaluate the overall water quality of all streams within the watershed. Metrics for impaired streams included those that have been 303(d) listed, covered by a Total Maximum Daily Load (TMDL) requirement, or are known to be impacted by acid mine drainage (AMD). Many streams were monitored and sampled by the WVDEP Watershed Assessment Branch (WAB) for a variety of standard water quality parameters (e.g., pH, sulfates, heavy metals, specific conductivity), as well as biological and habitat indices, such as GLIMPSS (Genus Level Index of Most Probable Stream Status, a measure of macroinvertebrates) and RBP (Rapid Bioassessment Protocol, a measure of habitat quality) scores. However, as other factors may affect the water quality in a stream, and many stream segments lack a WAB sampling station, several surrogate metrics were added to this index. These included percent imperviousness and various anthropogenic land uses and potential stressors (e.g., surface and underground mining, roads and railroads, well locations, etc.).

The *Streams Water Quantity* (SWN) index attempted to evaluate the overall degree of flow alteration within a given planning unit. However, very little data were available as direct measurements of stream flow or of stream withdrawals or discharges, with the few known points of such activities (such as public water supply intakes or sewer treatment plants) having incomplete or possibly inaccurate attribute data regarding water volume. The USGS stream-gauging network, a principal source of streamflow data in West Virginia, is concentrated on large streams. Since flow characteristics of large and small streams are different, in some cases flow data from the main stem of a river could not be used to distinguish among the various HUC12s in the watershed (Messinger 2012). Therefore, surrogate metrics were developed to approximate the impact of water use within a planning unit and its potential alteration of flow, such as area of mining activities (surface and underground), percent of impervious surface, and dam drainage area (the total catchment area above a dam).

The *Streams Hydrologic Connectivity* (SHC) index attempted to evaluate the aquatic connectivity of the watershed in terms of network complexity and overall system integrity, with accompanying metrics such as miles of headwater streams, the mean local integrity of the planning unit, and total wetland area. The SHC index also addressed the more functional elements of hydrologic connectivity, focusing primarily on unimpeded flow and the ability of a stream segment to allow passage for aquatic species. Metrics generated for this purpose included the number of any potential structural impediments such as dams, roads/railroads in the riparian area (a surrogate for culverts and bridges), and conditions that may cause temperature changes that would affect passage of organisms (such as power plants whose discharges may raise overall stream temperatures or forested riparian area where the canopy may help maintain cooler temperatures).

The *Streams Biodiversity* (SBD) index attempted to capture the species diversity within the stream and riparian area, including metrics for the presence of rare or endangered species, the maximum number of invertebrate taxa found in stream samples, and known locations of non-native invasive species. Since species data for West Virginia do not distinguish between areas sampled with no species found and areas not sampled, additional metrics were included as an estimate of potential species presence (such as calcareous bedrock and number of terrestrial habitat types in the riparian area). Because of the lack of robust biodiversity data, this index received a weight of half compared to the other indices, and results should be used with caution.

The *Streams Riparian Habitat* (SRH) index attempted to characterize the habitat within the approximately 90-125 meter riparian buffer (the Active River Area), assuming that intact natural cover within this buffer will be most effective at stabilizing stream banks, moderating stream temperature, and providing habitat (such as native aquatic vegetation, rocks, and logs) for aquatic species. Corresponding metrics included various land uses and land cover within the riparian buffer (natural cover, mining, agriculture, grazing), percent impervious cover within the riparian area, RBP scores, and fragmenting features such as roads and wells.

1.2.2 Wetlands Model

The *Wetlands Water Quality* (WWQ) index attempted to identify the current water quality condition of existing wetlands, as well as approximate the functional value of each wetland in terms of pollutant filtration and sediment retention, two major functions related to wetland water quality. Thus, wetlands were evaluated based on their inherent ability to serve a designated function, as well as their potential for serving such function based on surrounding land uses and potential pollutants. WWQ metrics included type of wetland (e.g., forested headwater wetland) and stressors located within the wetland catchment (i.e., the drainage area of the wetland; with metrics including the amount of agriculture, grazing, or development; percent imperviousness; active surface mining; and wells). Since the WWQ metrics are dependent on the existence of a wetland, those planning units without an existing NWI wetland were excluded from this index.

The *Wetlands Hydrology* (WHY) index attempted to quantify the wetland extent within an area as well as assess the functional aspect of potential flood storage. Wetland extent was represented by total wetland area, while potential flood storage capacity metrics included the area of forested floodplain wetlands, total floodplain area, and hydric soils. These metrics also identified areas in the watershed with a greater potential for wetlands to develop under wet conditions, and which may have been areas of wetland loss in the past. It is due to these "potential wetlands" metrics (hydric soils and floodplain area) that the WHY index was calculated for all planning units (at both the HUC12 and NHDPlus catchment level), and not just those containing existing NWI wetlands. Any planning units with the potential wetlands metrics but no mapped NWI wetlands may be considered potential sites for wetland restoration.

The *Wetlands Biodiversity* (WBD) index attempted to capture the species diversity within the wetland buffer area, including metrics for the presence of rare or endangered species and known locations of non-native invasive species. Since species data for West Virginia do not distinguish between areas sampled with no species found and areas not sampled, additional metrics were included as an estimate of potential species presence (such as calcareous bedrock and number of terrestrial habitat types within the wetland buffer). Because of the lack of robust biodiversity data, this index received a weight of half compared to the other indices, and results should be used with caution.

The *Wetlands Wetland Habitat* (WWH) index attempted to quantify the habitat condition within the wetland buffer area. Habitat quality metrics included percent of natural cover and the mean size of unfragmented forest patches that intersected a given wetland buffer (connection with a larger forest patch is likely to create more desirable habitat within a wetland area). Habitat stressors included metrics that may indicate the amount of fragmentation within the wetland buffer, such as surface mining, wells, and road/railroad density.

1.2.3 Uplands Model

The *Uplands Habitat Connectivity* (UHC) index attempted to assess the ability of terrestrial organisms to reside and move within the landscape. It is generally agreed that blocks or corridors of native vegetation are most conducive to hosting native animal species. In West Virginia the natural cover is primarily forest. The amount of habitat required varies by taxon and species, but large forest blocks and blocks that are connected provide the optimal habitat for a variety of species to disperse, establish breeding territories, and migrate (Anderson et al. 2004). Habitat connectivity is positively affected by forest block size and local integrity, a metric developed by Compton et al. (2007) that quantifies the structural connections between ecosystems in a landscape. Fragmenting features (e.g., roads, energy transmission lines, and resource extraction) negatively affect habitat connectivity.

The *Uplands Habitat Quality* (UHQ) index attempted to quantify the degree to which a landscape has been altered from its original condition. Metrics included heterogeneity (a measure of landform variety) and the percent of the planning unit in natural cover (forest, grassland, wetlands). Conversion of forest to agriculture or pastureland is an example of degraded habitat quality. Some metrics that impact habitat connectivity also impact habitat quality, such as development and resource extraction.

The *Uplands Biodiversity* (UBD) index attempted to capture the species diversity within the uplands area, including metrics for the presence of rare or endangered species and known locations of non-native invasive species. Since species data for West Virginia do not distinguish between areas sampled with no species found and areas not sampled, additional metrics were included as an estimate of potential species presence (such as calcareous bedrock and number of terrestrial habitat types). Additional datasets were available from the US Forest Service (USFS) that provided information about predicted tree basal area loss to pests and pathogens within upland forests. Because of the lack of robust biodiversity data, this index received a weight of half compared to the other indices, and results should be used with caution.

1.3 Ranking Procedure

1.3.1 Objective Classification

The goal of the project was to prioritize the planning units for protection and restoration opportunities. To achieve this, it was necessary to develop a method of ranking planning units based on their current ecological condition and inherent overall quality. Therefore, individual metrics were evaluated using thresholds that assigned metric results to one of four quality categories, indicating the degree of deviation from a desirable ecological condition: Very Good, Good, Fair, and Poor (Table 3). These objective, or "categorized," rankings were determined at both the HUC12 and NHDPlus catchment scales of planning units.

The Good/Fair threshold is also referred to as the "restoration threshold," with any planning units in the Fair category requiring restoration to bring the planning unit into an acceptable ecological condition. Planning units in the Good category may require some restoration to increase the quality to ideal conditions and move the score into the Very Good category, and any planning units in the Very Good category should be considered as potential candidates for protection activities. Planning units in the Poor category may also be potential candidates for restoration, depending on the goals of the individual organization or restoration project.

Thresholds were used to define quantitatively, for each metric, the divisions among the four quality categories. Initially, research focused on identifying sources for threshold values from literature and previous studies (e.g., the percentage of surface mining that places the corresponding metric into a Poor category, or a specific conductivity level that places the metric into a Fair category). However, beyond a few land use classifications and impervious cover percentages, very few thresholds have been established in the scientific literature for landscapes comparable to those in West Virginia. Additional threshold values were solicited from experts, but there was still a notable lack of reliable, defensible

Table 3. Definition of Objective Method Categories (Foundations of Success 2009)

Category	Definition
Very Good	Planning unit is in ecologically desirable status; requires little intervention or maintenance.
Good	Planning unit is within acceptable range of variation; some intervention is required for maintenance.
Fair	Planning unit is outside of an acceptable range of variation; requires human intervention.
Poor	Restoration of the planning unit is increasingly difficult; may result in extirpation of target.

threshold values for most metrics. Therefore, an alternative approach was developed using WVDEP's reference and stressed streams to define the thresholds. The WVDEP has defined three levels (I, II, III) of reference (i.e., high quality) streams, which categorize a stream based on both water quality sampling data and field survey/visual inspections, such as Rapid Bioassessment Protocol (RBP) scores (Table 4). Level I reference streams are the highest quality, while Level II indicates slightly lower quality streams that still meet most criteria for reference stream designation, and Level III are considered the best representatives in geographic areas lacking true reference streams (WVDEP 2013). To ensure that only the highest quality streams were included in the analysis, the project used only Level I and II reference streams to determine threshold values.

The WVDEP has also identified criteria for water quality sampling and field survey data that indicate whether or not a particular stream reach is significantly impaired (Table 5). While the WVDEP defines stressed sites as meeting at least one of these criteria, this project used at least two criteria to minimize the potential for false positives.

Table 4. WVDEP Reference Stream Criteria (Pond et al. 2012)

Parameter	**Value**
Dissolved Oxygen	≥ 6.0 mg/l
pH	≥ 6.0 and ≤ 9.0
Conductivity	<500 µmhos/cm
Fecal coliform	<800 colonies/100 ml
RBP Epifaunal Substrate score	≥11
RBP Channel Alteration score	≥11
RBP Sediment Deposition score	≥11
RBP Bank Disruptive score	≥11
RBP Riparian Vegetation Zone Width score	≥6
RBP Total Habitat score	65% of maximum 200
No obvious sources of non-point source pollution	
Evaluation of anthropogenic activities and disturbances	
No known point discharges upstream of assessment site	

Table 5. WVDEP Stressed Stream Criteria (Pond et al. 2012)

Parameter	**Value**
Dissolved Oxygen	<4.0 mg/l
pH	< 4.0 or > 9.0
Conductivity	>1,000 µmhos/cm
Fecal coliform	>4,000 colonies/100 ml
RBP Epifaunal Substrate score	<7
RBP Channel Alteration score	<7
RBP Sediment Deposition score	<7
RBP Bank Disruptive score	<7
RBP Riparian Vegetation Zone Width score	<4
RBP Total Habitat score	<120

To establish thresholds, the contributing NHDPlus catchments for both reference and stressed streams were identified, resulting in 501 reference catchments and 583 stressed catchments statewide, with a relatively broad and inclusive geographic distribution (Figure 1). Applicable metrics were calculated for the 1,084 reference/stressed catchments for all three landscapes (Streams/Riparian, Wetlands, Uplands) and threshold values were derived from these calculated results.

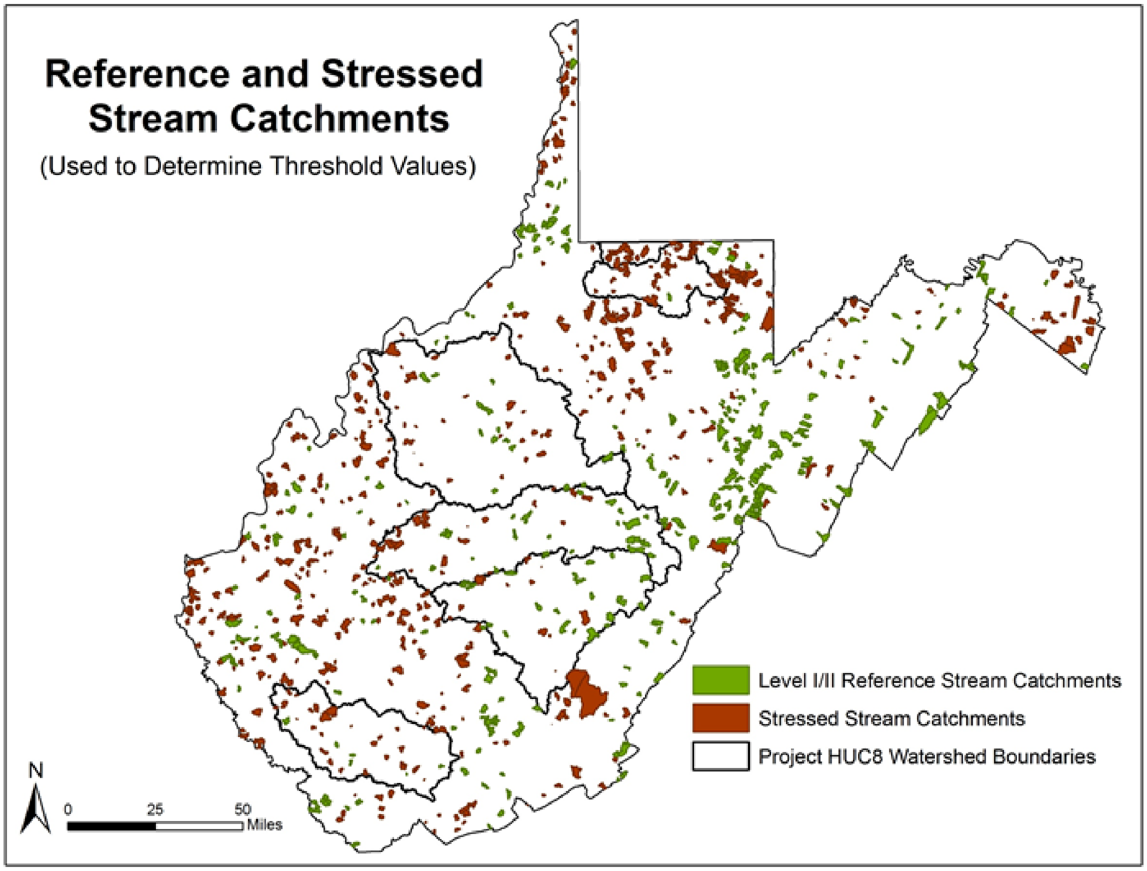

Figure 1. Reference and Stressed Stream Catchments

1.3.2 Objective Thresholds

To determine threshold values for each category, the distributions of the reference and stressed metric values were examined individually, and final analysis results were evaluated through an iterative process, using different percentiles as potential threshold values for all metrics. Different scenarios were run using different percentiles of the individual metrics as thresholds for all five pilot watersheds. Results were examined for consistency and validated by comparing the results of the various scenarios with known high-quality and impacted areas and by presenting the results to experts familiar with the condition of these areas at the expert workshops. For example, planning units in wilderness areas were expected to be in the Very Good category across most indices for all three models (Streams/Riparian Areas, Wetlands, and Uplands). Similarly, planning units with significant mining or development were expected to score predominantly in the Poor to Fair categories across most indices. It was determined during the expert workshops and project team discussions that the most consistent and reliable results were achieved when using the following percentiles: the Very Good/Good threshold was set as the 35% highest quality of reference catchment values, the Good/Fair threshold was set as the 75% highest quality of reference catchment values, and the Fair/Poor threshold was set as the 35% lowest quality of stressed catchment values (Figure 2). This methodology did not work well for some metrics with extremely skewed distributions, for example where both the 35th percentile and the median and 75th percentile were zero. Table 6 lists the percentiles for three different types of metrics: roads and railroads in the riparian area (a negative metric, with higher values indicating lower quality); percent forested riparian area (a positive metric, with higher values indicating higher quality); and percent surface mining (a metric for which this method of threshold selection did not work) in 5% increments for both stressed and reference catchments. Metrics for which the reference/stressed threshold determination were not suitable were either set as presence/absence metrics, resulting in a Good score if the metric was present for positive metrics or absent for negative metrics, or a Fair score if the metric was absent for positive metrics or present for negative metrics. A small subset of metrics (e.g., impervious cover and percent mining) had reliable threshold values in the literature, in which cases the values from the literature were used after consultation with and validation from experts at expert workshops. As water quality parameters were used by the WVDEP to define reference and stressed catchments, thresholds for water quality parameters were defined using the WVDEP's water quality standards.

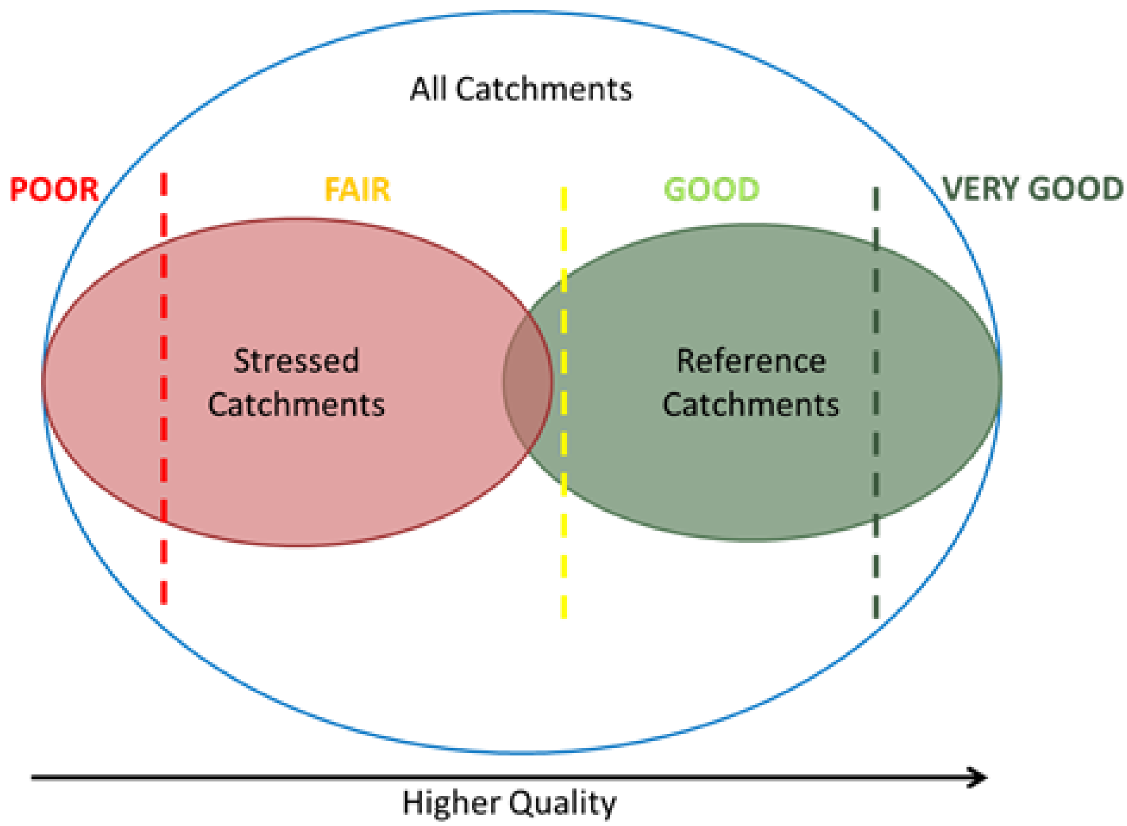

Figure 2. Threshold Definition Model

Table 6. Reference and Stressed Distribution Examples for Three Types of Metrics

Percentile[a]	**Reference Catchments**			**Stressed Catchments**		
	Negative Metric: Roads and Railroads in the Riparian Area (mi roads/sq mi planning unit)	Positive Metric: Percent Forested Riparian Area	Alternate Method[b]: Percent of Planning Unit with Surface Mines	Negative Metric: Roads and Railroads in the Riparian Area (mi roads/sq mi planning unit)	Positive Metric: Percent Forested Riparian Area	Alternate Method: Percent of Planning Unit with Surface Mines
Min/Max	0.00	102.7[c]	0.00	0.0	99.8	0.00
5th/95th	0.00	100.6	0.00	0.20	94.7	0.00
10th/90th	0.00	100.2	0.00	1.22	91.5	0.00
15th/85th	0.00	100.0	0.00	1.98	87.8	0.00
20th/80th	0.00	99.7	0.00	2.46	84.5	0.00
25th/75th	0.00	99.5	0.00	2.86	82.2	0.00
30th/70th	0.00	99.2	0.00	3.25	80.7	0.00
35th/65th	0.00	98.7[d]	0.00	3.62	78.0	0.00
40th/60th	0.00	98.5	0.00	3.93	75.2	0.00
45th/55th	0.13	98.0	0.00	4.29	63.8	0.00
Median	0.29	97.6	0.00	4.63	67.1	0.00
55th/45th	0.51	96.7	0.00	5.10	63.8	0.00
60th/40th	0.87	95.8	0.00	5.47	61.0	0.00
65th/35th	1.14	94.5	0.00	5.97	57.0[f]	0.24
70th/30th	1.69	93.2	0.00	6.34	53.4	0.80
75th/25th	2.46	91.6[e]	0.00	7.02	49.9	1.51
80th/20th	3.10	90.1	0.00	7.93	44.9	2.99
85th/15th	3.72	88.0	0.00	9.07	40.3	5.47
90th/10th	4.57	83.5	0.00	10.97	33.3	9.78
95th/5th	5.83	75.9	0.06	14.43	20.6	20.11
96th/4th	6.26	74.6	0.21	15.94	17.0	24.84
97th/3rd	6.49	72.3	0.54	16.87	14.5	27.72
98th/2nd	6.81	69.8	1.59	18.29	10.7	38.96
99th/1st	9.74	59.1	7.68	23.93	6.4	51.02
Max/Min	34.6	1.28	29.28	35.27	2.9	84.93

[a] Negative metrics used the first percentile (i.e., Minimum value if row is "Min/Max"), positive metrics used the second percentile (i.e., Maximum value if row is "Min/Max)

[b] Alternate method used for threshold selection

[c] Values are higher than 100% because of differences in the spatial properties of the geographic information system (GIS) datasets between the landcover dataset used for this metric and the planning units

[d] Selected as percentile for Very Good/Good threshold

[e] Selected as percentile for Good/Fair threshold

[f] Selected as percentile for Fair/Poor threshold

1.3.3 Critical Metrics

Discussions held during expert workshops suggested that some metrics, subsequently referred to as “critical metrics,” indicated an impairment or land use alteration of enough significance that these metrics should limit the final index category value, regardless of other metric values in that index. For instance, if a planning unit had a high enough percentage of impervious cover that placed the metric into the Fair category, the final index score for that planning unit could not be higher than Fair, regardless if other metrics ranked Good or Very Good. Since the Water Quality index in the Streams model had more critical metrics than the other indices, two of the critical metrics had to be Fair or Poor to cap the index at that category. Only a handful of metrics were considered critical (Table 7).

Table 7. Critical Metrics for Priority Model Analysis

Model	Index	Critical Metrics
Streams	Water Quality	Percent imperviousness
		Surface mining (active & legacy)
		Median pH values
		Median specific conductivity values
	Water Quantity	Percent imperviousness
	Hydrologic Connectivity	None
	Biodiversity	None
	Riparian Habitat	Percent imperviousness in riparian area
		Active surface mining in riparian area
Wetlands	Water Quality	None
	Hydrology	None
	Biodiversity	None
	Wetland Habitat	Development in wetland buffer
		Active surface mining in wetland buffer
Uplands	Habitat Connectivity	Development
		Active surface mining
	Habitat Quality	Development
		Active surface mining
	Biodiversity	None

1.3.4 Metrics Final Selection

Initially, the project team identified 214 metrics to characterize the three landscapes (listed in Appendix B: Metrics Description and GIS Process). The values for these metrics at the HUC12 level for all five HUC8 watersheds were subjected to a Pearson's Correlation analysis separately for each model, and if two metrics were highly correlated ($R > 0.90$), one of the metrics was eliminated. For metric pairs with correlation coefficients between 0.75-0.90, one of the metrics was eliminated if they were judged to be truly redundant. The full set of HUC12 metric values for the Streams priority model (which had the greatest number of metrics) was subjected to a Principal Components Analysis (PCA) to identify the most important metrics to retain in the assessment, i.e., those metrics that accounted for the greatest variation among the HUC12s. Three principal components together accounted for 45% of the variation among HUC12s (Table 8). The most influential component (eigenvalue 18.29, 25% of variation explained) described a gradient of anthropogenic disturbance, from high negative loadings on metrics such as forested riparian area and natural cover in headwater catchments, to high positive loadings on development metrics such as roads/railroads in riparian area. The second component (eigenvalue 9.34, 13% of variation explained) consisted of different mining and coal metrics, while the 3rd component consisted of oil and gas wells (eigenvalue 5.18, 7% of variation explained). Some of the metrics that were identified as important in the PCA were dropped from the assessment due to high correlation with other metrics, lack of data across watersheds, or other reasons. After the correlation and Principal Components Analyses, and discussions with experts at the expert workshops, the final current condition analysis dataset was reduced to 94 metrics.

Table 9 lists all metrics that were used in the final analysis with details on grouping of metrics into individual indices, thresholds, method of determining the thresholds, weight of the metrics in the final analysis, critical metrics, and if a metric was considered a positive or negative metric in the final analysis.

1.3.5 Metric Weights

Metrics were weighted to ensure that each metric contributed a value in its corresponding index relative to its significance in terms of affecting watershed condition. The weights were assigned to each metric based on literature where available, but more often on a synthesis of current knowledge provided by experts from TNC, state and federal agencies, universities, non-profit organizations, and local experts. Recommendations were provided and subsequently refined at several expert workshops and/or by follow-up correspondence with experts. Metric and index weights ranged from 0 to 3, with a weight of 0 assigned to those metrics initially considered but later removed from the analysis (see Appendix B for a full list of metrics originally considered in the analysis). Metrics with weights greater than 0 and considered in the final analysis are listed in Table 16.

Table 8. Principal Components Analysis of Streams Condition Metrics

Metric	**Factor Loading***
Component 1	
Forested riparian area	-0.8252
Natural cover in headwater catchments	-0.6871
Median GLIMPSS scores	-0.6836
Local integrity in headwater catchments	-0.6786
Median taxa richness	-0.6210
Large quantity users	0.5107
Wastewater treatment plants	0.5166
Biologically impaired streams	0.5272
Septic systems in riparian area	0.5464
Power plants	0.5780
Energy transmission lines in riparian area	0.6117
Bridges	0.6600
Septic systems	0.6730
Roads and railroad density in riparian area	0.7385
Percent imperviousness	0.7659
Buildings in riparian area	0.7799
NPDES permits	0.7866
Development in riparian area	0.8049
Road and railroad density	0.8056
Component 2	
Total coal production	0.6804
Legacy surface mining in riparian area	0.7279
Active surface mining in riparian area	0.7395
Active surface mining	0.7514
Legacy surface mining	0.7641
Coal NPDES permits	0.7889
Component 3	
Oil and gas wells in riparian area	-0.6943

*Only factors with loadings > |0.5| and loading on only one component are presented here.

Table 9. Metrics Included in the Current Condition Analysis

Model	Index	Metric Description (* "Critical Metric")	Weight	Units	Positive/ Negative Metric[a]	Threshold Method	Threshold: Very Good – Good	Threshold: Good – Fair	Threshold: Fair – Poor
STREAMS	*Water Quality (Weight: 1)*	AMD, TMDL, 303(d) impaired streams	2	% of total stream miles in planning unit	N	Reference/stressed	0	11.32	78.09
		Median pH values*[c]	2	Index[b]	P	Literature	350[b]	250	150
		Median sulfate values[d]	1	Index	P	Literature	350	250	150
		Median specific conductivity values*[e]	1.5	Index	P	Literature	350	250	150
		Median GLIMPSS scores[f]	2	Index	P	Literature	350	250	150
		Median sedimentation & embeddedness[g]	1	Index	P	Literature	350	250	150
		Percent imperviousness*	2	mean % imperviousness per planning unit	N	Literature	0	2	8
		All wells	1.5	#/sq mi planning unit	N	Reference/stressed	0	2.28	5.47
		Surface mining (active & legacy)*	2	% of planning unit	N	Literature/Expert opinion	2	10	20
		Underground mining	2	% of planning unit	N	Reference/ stressed	0	3.82	18.30
		Agriculture in riparian area	1	% of riparian area	N	Reference/ stressed	0	0.07	0.12
		Grazing/pasture in riparian area	1	% of planning unit	N	Reference/ stressed	0	1.67	10.31
		Development in riparian area	1	% of planning unit	N	Reference/ stressed	0	0.02	2.44
		Natural cover in riparian area	2	% of planning unit	P	Reference/ stressed	99.88	97.01	75.48
		All roads & rail	1.5	miles/sq mi planning unit	N	Reference/ stressed	0.13	1.66	2.79
	Water Quantity (Weight: 1)	Public water supply intakes	0.5	#/stream mi	N	Presence/ absence	-	0	-
		Large quantity users	2	#/stream mi	N	Presence/ absence	-	0	-
		Wastewater treatment plants	0.5	# customers served/sq mi planning unit	N	Presence/ absence	-	0	-
		Dam drainage area	1	% of planning unit	N	Presence/absence	-	0	-
		Percent imperviousness*	1.5	mean % imperviousness per planning unit	N	Literature	0	2	8
		Surface mining (active & legacy)	1	% of planning unit	N	Literature/Expert opinion	2	10	20
		Underground mining	1.5	% of planning unit	N	Reference/ stressed	0	3.82	18.30
	Hydrologic Connectivity	Headwater streams (size class 1a)	1.5	% of total stream miles in planning unit	P	Presence/ absence	-	0	-
		Local integrity score	1	mean score/planning unit	P	Reference/ stressed	44.43	30.35	20.72

Model	Index	Metric Description (* "Critical Metric")	Weight	Units	Positive/ Negative Metric[a]	Threshold Method	Threshold: Very Good – Good	Threshold: Good – Fair	Threshold: Fair – Poor
STREAMS	*Hydrologic Connectivity (Weight: 1)*	Total wetland area	1	% of planning unit	P	Presence/ absence	-	0	-
		Power plants	0.5	# / stream mi	N	Presence/ absence	-	0	-
		Forested riparian area	1.5	% of riparian area	P	Reference/ stressed	98.73	91.60	57.00
		Dams	1.5	#/ stream mi	N	Presence/absence	-	0	-
		All roads & rail in riparian area	2	mi/sq mi planning unit	N	Reference/ stressed	0	2.46	5.97
	Biodiversity (Weight: 0.5)	Rare species in riparian area	1.5	# species/riparian area	P	Presence/ absence	-	0	-
		Maximum taxa	1	maximum # taxa	P	Reference/ stressed	27	21	13
		Mussel streams	1	% of total stream miles in planning unit	P	Presence/ absence	-	0	-
		Northeast habitat types in riparian area	1	#/riparian area	P	Reference/ stressed	6	5	-
		Calcareous bedrock in riparian area	1	% of riparian area	P	Presence/ absence	-	0	-
		Non-native invasive species in riparian area	1.5	# species/riparian area	N	Presence/ absence	-	0	-
	Riparian Habitat (Weight: 1)	Median Rapid Bioassessment Protocol score[h]	1	Index	P	Literature	350	250	150
		Natural cover in riparian area	2	% of riparian area	P	Reference/ stressed	99.88	97.01	75.48
		Agriculture in riparian area	1	% of riparian area	N	Reference/ stressed	0	0.07	0.12
		Grazing/pasture in riparian area	1	% of riparian area	N	Reference/ stressed	0	1.67	10.31
		Percent imperviousness in riparian area*	2	% of riparian area	N	Reference/stressed	0	2	8
		Active surface mining in riparian area*	2	% of riparian area	N	Literature/Expert opinion	2	10	20
		Legacy surface mining in riparian area	1	% of riparian area	N	Literature/Expert opinion	2	10	20
		All wells in riparian area	1	#/sq mi riparian area	N	Reference/stressed	0	3.22	5.00
		All roads & rail in riparian area	1.5	miles/sq mi riparian area	N	Reference/stressed	0	2.46	5.97
WETLANDS	*Water Quality*	Forested headwater wetlands	2	% of planning unit	P	Presence/absence	-	0	-
		Agriculture in wetland catchment	1	% wetland catchment	N	Reference/stressed	0	0.01	0.37
		Grazing/pasture in wetland catchment	1	% wetland catchment	N	Presence/absence	-	0	-
		Development in wetland catchment	1	% wetland catchment	N	Reference/stressed	0	0.04	2.17

Model	Index	Metric Description (* "Critical Metric")	Weight	Units	Positive/ Negative Metric[a]	Threshold Method	Threshold: Very Good – Good	Threshold: Good – Fair	Threshold: Fair – Poor
WETLANDS	*Water Quality (Weight: 1)*	Natural cover in wetland catchment	3	% wetland catchment	P	Reference/stressed	98.78	92.97	72.82
		Percent imperviousness in wetland catchment	1	mean % imperviousness wetland catchment	N	Literature	0	2	8
		All roads & rail in wetland catchment	1	# miles/sq mi wetland catchment	N	Presence/absence	-	0	-
		Active surface mining in wetland catchment	2	% wetland catchment	N	Literature/Expert opinion	2	10	20
		All wells in wetland catchment	1	#/sq mi wetland catchment	N	Reference/stressed	0	0.60	3.90
	Hydrology (Weight: 1)	Total wetland area	2	% of planning unit	P	Presence/absence	-	0	-
		Forested headwater wetlands	1	% of planning unit	P	Presence/absence	-	0	-
		Floodplain, forested wetlands	1	sq mi/wetland buffer	P	Reference/stressed	-	0	-
		Floodplain area	1	% of planning unit	P	Presence/absence	-	0	-
		Hydric soils	1.5	% of planning unit with hydric soils	P	Presence/absence	-	0	-
	Biodiversity (Weight: 0.5)	Rare species in wetland buffer	1.5	# species/sq mi wetland buffer	P	Presence/absence	-	0	-
		Calcareous bedrock in wetland buffer	1	% of wetland buffer	P	Presence/absence	-	0	-
		Northeast habitat types in wetland buffer	1	# types in wet buffer/planning unit	P	Reference/stressed	5	3	-
		Non-native invasive species in wetland buffer	1.5	# species/sq mi wetland buffer	N	Presence/absence	-	0	-
	Wetland Habitat (Weight:1)	Natural cover in wetland buffer	2	% of wetland buffer	P	Reference/stressed	92.76	82.63	58.95
		Agriculture in wetland buffer	1	% of wetland buffer	N	Presence/absence	-	0	-
		Grazing/pasture in wetland buffer	1	% of wetland buffer	N	Reference/stressed	0	1.16	26.55
		Development in wetland buffer*	2	% of wetland buffer	N	Presence/absence	-	0	-
		Mean forest patch size within wetland buffer	1	mean sq mi forest block size in wetland buffer/planning unit	P	Reference/stressed	14.37	3.23	-
		All wells in wetland buffer	1.5	#/wetland buffer	N	Presence/absence	-	0	-
		Active surface mining in wetland buffer*	2	% of wetland buffer	N	Reference/stressed	2	10	20
		Legacy surface mining in wetland buffer	1	% of wetland buffer	N	Reference/stressed	2	10	20
		All roads & rail in wetland buffer	1	miles/sq mi in wetland buffer	N	Reference/stressed	0	0.93	5.99

Model	Index	Metric Description (* "Critical Metric")	Weight	Units	Positive/ Negative Metric[a]	Threshold Method	Threshold: Very Good – Good	Threshold: Good – Fair	Threshold: Fair – Poor
UPLANDS	*Habitat Connectivity (Weight: 1)*	Mean forest patch size	2	mean forest block size/planning unit	P	Reference/stressed	10.43	2.40	0.77
		Local integrity score	1.5	avg score/planning unit	P	Reference/stressed	44.43	30.35	20.72
		Development*	1.5	% of planning unit	N	Reference/stressed	0	0.11	1.55
		All roads & rail	1	miles/sq mi planning unit	N	Reference/stressed	0.13	1.66	2.79
		Energy transmission lines	0.5	miles/sq mi planning unit	N	Presence/absence	-	0	-
		Gas pipelines	0.5	miles/sq mi planning unit	N	Presence/absence	-	0	-
		Wind turbines	0.5	#/sq mi planning unit	N	Presence/absence	-	0	-
		All wells	1	#/sq mi planning unit	N	Reference/stressed	0	2.28	5.47
		Active surface mining*	1.5	% of planning unit	N	Literature/Expert opinion	2	10	20
		Timber harvesting operations	0.5	sq mi/planning unit	N	Presence/absence	-	0	-
	Habitat Quality (Weight:1)	Heterogeneity score	2	avg score/planning unit	P	Reference/stressed	38	36	33
		Natural cover (forest, grassland, wetland)	2	% of planning unit	P	Reference/stressed	98.59	94.00	79.96
		Active surface mining*	1.5	% of planning unit	N	Literature/Expert opinion	2	10	20
		Legacy surface mining	1	% of planning unit	N	Literature/Expert opinion	2	10	20
		Timber harvesting operations	1	sq mi/sq mi planning unit	N	Presence/absence	-	0	-
		Agriculture	1	% of planning unit	N	Reference/stressed	0	0.01	0.1
		Grazing/pasture	1	% of planning unit	N	Reference/stressed	0.06	4.14	9.76
		Development*	1.5	% of planning unit	N	Reference/ stressed	0	0.11	1.55
	Biodiversity (Weight: 0.5)	Rare species	1.5	#/sq mi planning unit	P	Presence/ absence	-	0	-
		Northeast habitat types	1	#/planning unit	P	Reference/ stressed	7	5	-
		Calcareous bedrock	1	% of planning unit	P	Presence/ absence	-	0	-
		Non-native invasive species	1.5	#/sq mi planning unit	N	Presence/ absence	-	0	-
		Percent tree basal area loss	2	% of planning unit	N	Reference/ stressed	3	15	30

[a] Positive metrics are characterized by higher values indicating higher quality, negative metrics are characterized by lower values indicating higher quality
[b] To enable comparison among different water quality parameters and among planning units, an index was calculated based on the WVDEP's water quality standards. Highest quality values were assigned the value 400, values higher than impairment level but not in the highest category were assigned the value 300, values considered impaired were assigned the value 200, and values considered severely impaired were assigned the value 100. The values 400, 300, 200, and 100 are analogous to the categories Very Good, Good, Fair, and Poor, respectively.
[c] Index values for pH values were assigned as follows: >10 or <5: 100, >9 or <6: 200, >8 or <6.5: 300, between 6.5 and 8 (inclusive): 400.
[d] Index values for sulfate values were assigned as follows: >250 mg/l: 100, >50 mg/l and <=250 mg/l: 200, >25 mg/l and <=50: 300, <=25 mg/l: 400.
[e] Index values for specific conductivity values were assigned as follows: >835 µmhos/cm: 100, >500 µmhos/cm and <=835 µmhos/cm : 200, >200 and <=500 µmhos/cm: 300, <=200 µmhos/cm: 400.
[f] Index values for GLIMPSS values were assigned as follows: <50: 100, <100 and >=50: 200, <125 and >=100: 300, >=125: 400. Based on percent threshold values of the modified GLIMPSS (CF), which excludes genus-level Chironimidae.
[g] Index values for an added Sedimentation/Embededdness score, two components of the RBP, assigned as follows: <11: 100, <21 and >=11: 200, <31 and >=21: 300, >=31: 400.
[h] Index values for the Total RBP score, assigned as follows: <60: 100, <110 and >=60: 200, <160 and >=110: 300, >=160: 400.

1.3.6 Metric Scores

Each metric received an objective score according to the thresholds developed in the objective classification, placing the metric into one of the four quality categories: Very Good, Good, Fair, or Poor. To be able to aggregate the metric scores to index scores and ultimately to model scores, objective categories were translated to a numerical rating for each metric, where the categories Very Good, Good, Fair, and Poor were assigned the values 4, 3, 2, and 1, respectively.

To compare planning units relative to each other, a relative score for each planning unit was calculated in addition to the objective score. Relative scores were defined by scaling the results for each metric on a scale from 0 to 1 (0 being defined as the lowest quality value and 1 being defined as the highest quality value for a particular metric over all planning units in the watershed). For example, to rank according to the amount of forested riparian area, a positive metric where a high value indicated a higher quality, the highest scoring planning unit's metric was set to a value of 1 and the lowest scoring planning unit was set to a value of 0, with all remaining scores distributed between 0 and 1. Conversely, to score for the amount of mining in a planning unit, a negative metric where a higher value indicated lower quality, the highest scoring planning unit's metric was set to a value of 0 and the lowest scoring planning unit was set to a value of 1. These scores were determined for both HUC12 and NHDPlus catchments.

Table 10 illustrates the value, relative score, objective category, and objective score for several catchments for three metrics: percent forested riparian area, percent of planning unit with surface mines, and roads and railroads in the riparian area.

1.3.7 Index Scores

Metric scores were aggregated, according to their assigned weights, to produce index scores. To compute the individual index scores (for example, Streams Water Quality) the following formula was used for each index:

Index objective score:

$$IOS = \frac{MOS_1 * MW_1 + MOS_2 * MW_2 + \cdots + MOS_n * MW_n}{MW_1 + MW_2 + \cdots + MW_n}$$

Where: IOS = index objective score
MOS_i = metric i objective score, where Very Good = 4, Good = 3, Fair = 2, Poor = 1
MW_i = metric i weight

These results were standardized by assigning them to the four objective categories according to the following definitions:

$$\begin{aligned} IOS &> 3.5 \rightarrow 4\ (Very\ Good) \\ 2.5 < IOS &\leq 3.5 \rightarrow 3\ (Good) \\ 1.5 < IOS &\leq 2.5 \rightarrow 2\ (Fair) \\ IOS &\leq 1.5 \rightarrow 1\ (Poor) \end{aligned}$$

Table 10. Example Values, Relative Scores, Objective Categories, and Objective Scores for Selected Catchments and Metrics

Metric	Catchment ID	Value	Relative Score	Objective Category	Objective Score
Percent Forested Riparian Area	C1167	100	1	Very Good	4
	C1277	98.79	0.9872	Very Good	4
	C932	98.50	0.9843	Good	3
	C622	91.88	0.9178	Good	3
	C995	82.71	0.8259	Fair	2
	C1336	61.43	0.6124	Fair	2
	C592	44.35	0.4409	Poor	1
	C662	10.17	0.0981	Poor	1
Percent of Planning Unit with Surface Mines	C998	0	1	Very Good	4
	C1018	1.71	0.9828	Very Good	4
	C874	3.12	0.9686	Good	3
	C359	6.93	0.9303	Good	3
	C999	10.51	0.8942	Fair	2
	C184	16.77	0.8313	Fair	2
	C210	23.61	0.7625	Poor	1
	C873	92.65	0.0680	Poor	1
Roads and Railroads in Riparian Area (mi roads/sq mi planning unit)	C998	0	1	Very Good	4
	C647	0	1	Very Good	4
	C1065	1.05	0.9514	Good	3
	C582	2.03	0.9061	Good	3
	C1055	2.56	0.8820	Fair	2
	C815	4.47	0.7936	Fair	2
	C387	6.41	0.7042	Poor	1
	C62	21.67	0.2422	Poor	1

Index relative score:

$$IRS = \frac{MRS_1 * MW_1 + MRS_2 * MW_2 + \cdots + MRS_n * MW_n}{MW_1 + MW_2 + \cdots + MW_n}$$

Where: IRS = index relative score
MRS_i = metric i relative score (between 0 and 1)
MW_i = metric i weight

A combined score was then calculated for every index for each planning unit, consisting of the objective category score added to the relative score, resulting in the possible values for each index ranging from the lowest possible score of 1 (a Poor catchment that also has the lowest possible value relative to the other catchments) to the highest possible score of 5 (a Very Good catchment that is also the highest relative quality compared to the other catchments). Table 11 gives examples of the Streams/Riparian Areas model indices and their corresponding objective, relative, and combined scores.

Table 11. Example Index Objective, Relative, and Combined Results for Selected Catchments for the Streams/Riparian Areas Model

	Index Objective Scores					**Index Objective Scores, standardized**				
Index	**Water Quality**	**Water Quantity**	**Habitat Connectivity**	**Biodiversity**	**Riparian Habitat**	**Water Quality**	**Water Quantity**	**Habitat Connectivity**	**Biodiversity**	**Riparian Habitat**
Index Weight	**1**	**1**	**1**	**0.5**	**1**	**1**	**1**	**1**	**0.5**	**1**
C1235	3.81	3.75	3.59	3.50	3.74	4	4	4	3	4
C721	3.78	3.56	3.53	2.93	3.70	4	4	4	3	4
C191	3.36	3.56	3.53	2.76	3.48	3	4	4	3	3
C920	3.25	3.44	3.34	2.26	3.30	3	3	3	2	3
C519	2.00	3.31	3.59	2.67	3.65	2	3	4	3	4
C954	3.11	2.00	2.75	2.50	2.00	3	2	3	3	2
C765	2.53	2.53	2.88	1.51	2.00	3	3	3	2	2
C27	2.00	2.00	1.85	2.67	1.00	2	2	2	3	1
C872	1.00	1.00	2.97	1.51	1.00	1	1	3	2	1
	Index Relative Scores					**Index Combined Scores**				
Index	**Water Quality**	**Water Quantity**	**Habitat Connectivity**	**Biodiversity**	**Riparian Habitat**	**Water Quality**	**Water Quantity**	**Habitat Connectivity**	**Biodiversity**	**Riparian Habitat**
Index Weight	**1**	**1**	**1**	**0.5**	**1**	**1**	**1**	**1**	**0.5**	**1**
C1235	1.00	1.00	0.94	0.91	1.00	5.00	5.00	4.94	3.91	5.00
C721	0.99	0.99	0.82	0.17	0.99	4.99	4.99	4.82	3.17	4.99
C191	0.90	1.00	0.93	0.50	0.97	3.90	5.00	4.93	3.50	3.97
C920	0.98	1.00	0.89	0.06	0.97	3.98	4.00	3.89	2.06	3.97
C519	0.76	0.98	0.89	0.13	0.99	2.76	3.98	4.89	3.13	4.99
C954	0.88	0.98	0.63	0.37	0.93	3.88	2.98	3.63	3.37	2.93
C765	0.88	0.90	0.78	0.00	0.92	3.88	3.90	3.78	2.00	2.92
C27	0.65	0.95	0.31	0.38	0.67	2.65	2.95	2.31	3.38	1.67
C872	0.71	0.78	0.74	0.00	0.66	1.71	1.78	3.74	2.00	1.66

Index combined score:

$$ICS = IOS + IRS$$

Where: ICS = index combined score

These results were again standardized to the four objective categories according to the following definitions:

$$\begin{aligned} ICS \geq 4 &\rightarrow 4\ (Very\ Good) \\ 3 \leq ICS < 4 &\rightarrow 3\ (Good) \\ 2 \leq ICS < 3 &\rightarrow 2\ (Fair) \\ ICS < 2 &\rightarrow 1\ (Poor) \end{aligned}$$

The combined score indicates the planning unit's relative ranking within the respective category compared to all other planning units in that HUC8 watershed. The objective and relative ranking methods convey different information about the planning unit, and provide an additional level of analysis to help an end user make decisions about conservation projects. For example, in Table 11, while both C1235 and C721 catchments are in the Very Good category for Water Quality, C1235 is slightly higher quality than C721 and may be considered a slightly higher priority for conservation, all other factors being equal. However, both are considered to be in the ideal ecological condition for water quality.

1.3.8 Model Scores

Index scores were aggregated to produce a score for each model: Streams/Riparian Areas, Wetlands, and Uplands. The aggregated model scores are referred to as "overall scores" to differentiate them from the individual index scores.

Model objective score:

$$ModOS = \frac{IOS_1 * IW_1 + IOS_2 * IW_2 + \cdots + IOS_n * IW_n}{IW_1 + IW_2 + \cdots + IW_n}$$

Where: IOS_i = index i objective score
IW_i = index i weight
ModOS = model objective score

These results were once again grouped into the four categories according to the same standardization as the index objective scores:

$$\begin{aligned} ModOS > 3.5 &\rightarrow 4\ (Very\ Good) \\ 2.5 < ModOS \leq 3.5 &\rightarrow 3\ (Good) \\ 1.5 < ModOS \leq 2.5 &\rightarrow 2\ (Fair) \\ ModOS \leq 1.5 &\rightarrow 1\ (Poor) \end{aligned}$$

Model relative score:

$$ModRS = \frac{IRS_1 * IW_1 + IRS_2 * IW_2 + \cdots + IRS_n * IW_n}{IW_1 + IW_2 + \cdots + IW_n}$$

Where: IRS_i = index i relative score
IW_i = index i weight
ModRS = model relative score

A combined overall model score was then calculated using the same method as for individual indices above, to produce an overall combined score for each model (Streams/Riparian Areas, Wetlands, and Uplands). Table 12 lists examples of the Streams/Riparian Areas model objective, relative, and combined results aggregated from the results for all Streams indices (Water Quality, Water Quantity, Hydrologic Connectivity, Biodiversity, and Riparian Habitat indices) selected catchments. For example, both C1235 and C721 catchments are in the Very Good category and are therefore considered to be in an ideal ecological condition and priorities for conservation, though C1235 is slightly higher quality than C721, and may be considered a slightly higher priority, all other factors being equal.

Model combined score:

$$ModCS = ModOS + ModRS$$

Where: ModCS = model combined score

The combined results were standardized to the four quality categories as follows:

$$\begin{aligned} ModCS \geq 4 &\rightarrow 4\ (Very\ Good) \\ 3 \leq ModCS < 4 &\rightarrow 3\ (Good) \\ 2 \leq ModCS < 3 &\rightarrow 2\ (Fair) \\ ModCS < 2 &\rightarrow 1\ (Poor) \end{aligned}$$

Table 12. Example Model Objective, Relative, and Combined Results for Selected Catchments for the Streams/Riparian Areas Model

Catchment ID	Objective Score	Standardized Objective Score	Objective Category	Relative Score	Combined Score
C1235	3.70	4	Very Good	0.98	4.98
C721	3.56	4	Very Good	0.86	4.86
C191	3.40	3	Good	0.90	3.90
C920	3.21	3	Good	0.86	3.86
C519	3.09	3	Good	0.82	3.82
C954	2.47	2	Fair	0.80	2.80
C765	2.38	2	Fair	0.77	2.77
C27	1.82	2	Fair	0.62	2.62
C872	1.49	1	Poor	0.64	1.64

The calculation of scores occurred at both planning unit levels, generated independently of each other:

1. a ranking of HUC12 watersheds in terms of their overall model combined scores for each priority model (Streams/Riparian Areas, Wetlands, and Uplands) and each index combined score (e.g., Water Quality, Biodiversity, Habitat Connectivity, etc.), and
2. a ranking of NHDPlus catchments based on overall model and index combined scores.

Through this process, three Priority Models were generated (Figures 3 - 5): a Streams/Riparian Areas Priority Model, a Wetlands Priority Model, and an Uplands Priority Model. These models remain separate, as they each identify a key landscape that was independently ranked. The analysis presents the final combined scores for each planning unit (HUC12 and NHDPlus catchment), with a high score indicating a higher conservation priority within that Priority Model.

1.3.9 Example Index and Model Scores Calculation

To illustrate the methodology outlined above, an example is presented to clarify how the relative, objective, and combined scores were produced for the Streams Water Quality index and Streams/Riparian Area model for one particular catchment, C1235. Table 13 shows the metric results for this catchment for the Streams Water Quality index. Applying the formulas from Section 3.3.6 and the metric values from Table 20, the Streams Water Quality (SWQ) index objective score was calculated as:

$$IOS = \frac{4*2+4*2+4*1.5+4*2+4*2+4*1+3*1+4+1+3*2+4*1.5}{2+2+1.5+2+2+1+1+1+2+1.5} = \frac{61}{16} = 3.81$$

which corresponds to the index objective score in Table 18. No water quality data were available for this planning unit and are therefore excluded from the analysis.

Similarly, the SWQ index relative score is:

$$IRS = \frac{1*2+0.985*2+1*1.5+1*2+1*2+1*1+1*1+1*1+0.988*2+1*1.5}{2+2+1.5+2+2+1+1+1+2+1.5}$$
$$= \frac{15.946}{16} = 0.997\ (rounded\ to\ 1.00)$$

which corresponds to the index relative score in Table 18.

To calculate the ICS, the IOS is standardized to 4 (as it is greater than 3.5), and the IRS added to it:

$$ICS = 4 + 1.00 = 5.00$$

which corresponds to the index combined score in Table 18, and is considered to be in the Very Good category.

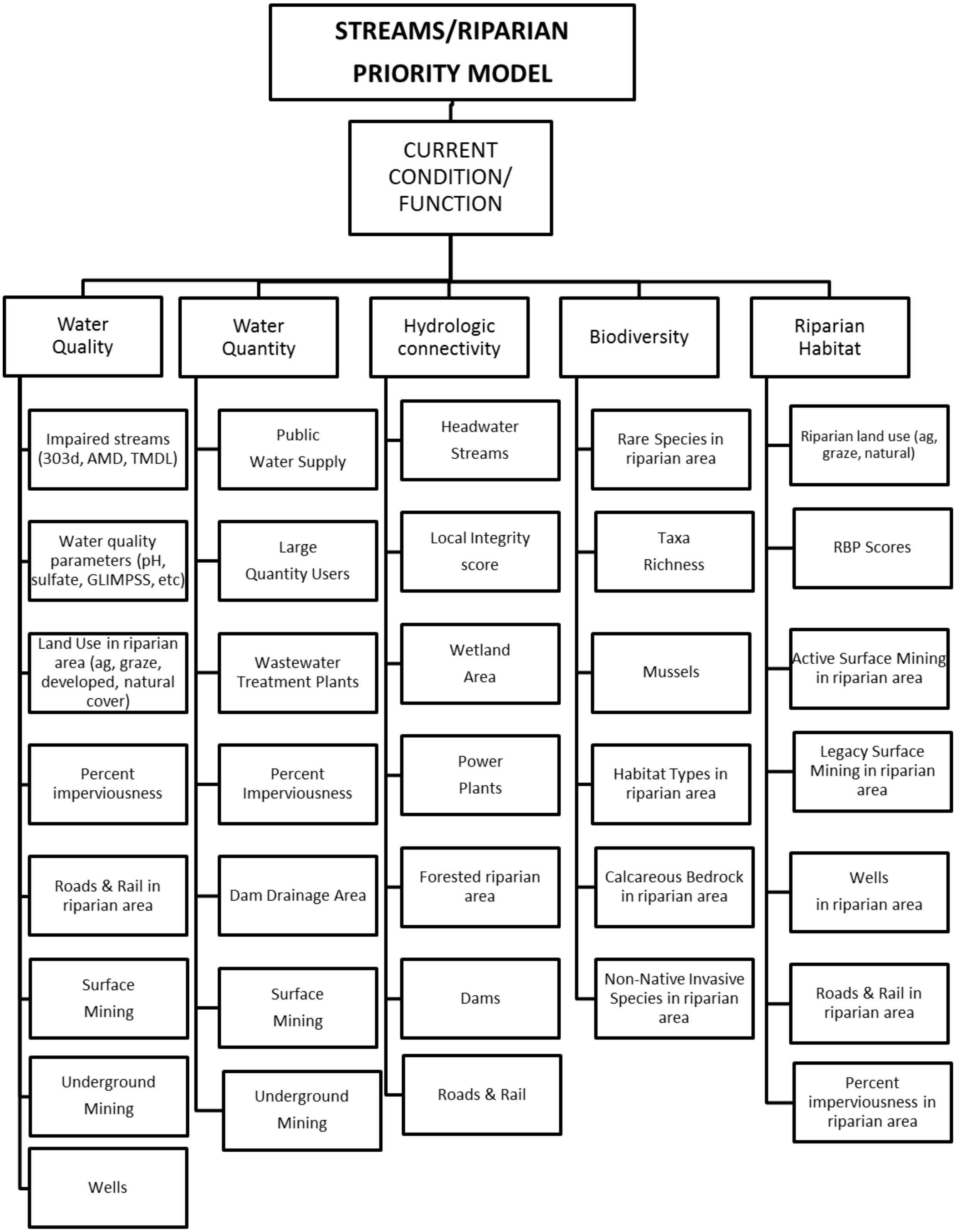

Figure 3. Streams/Riparian Areas Priority Model Flowchart

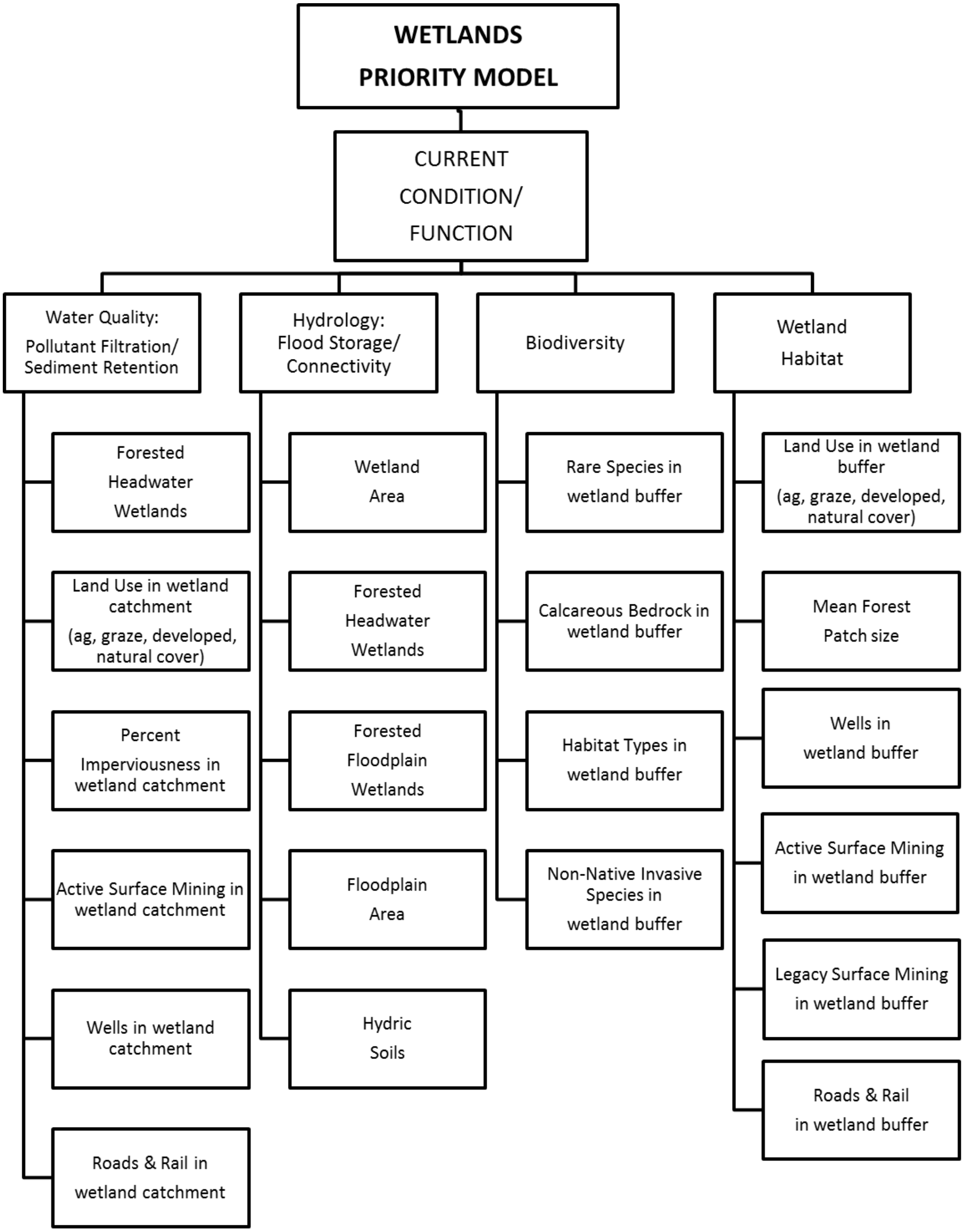

Figure 4. Wetlands Priority Model Flowchart

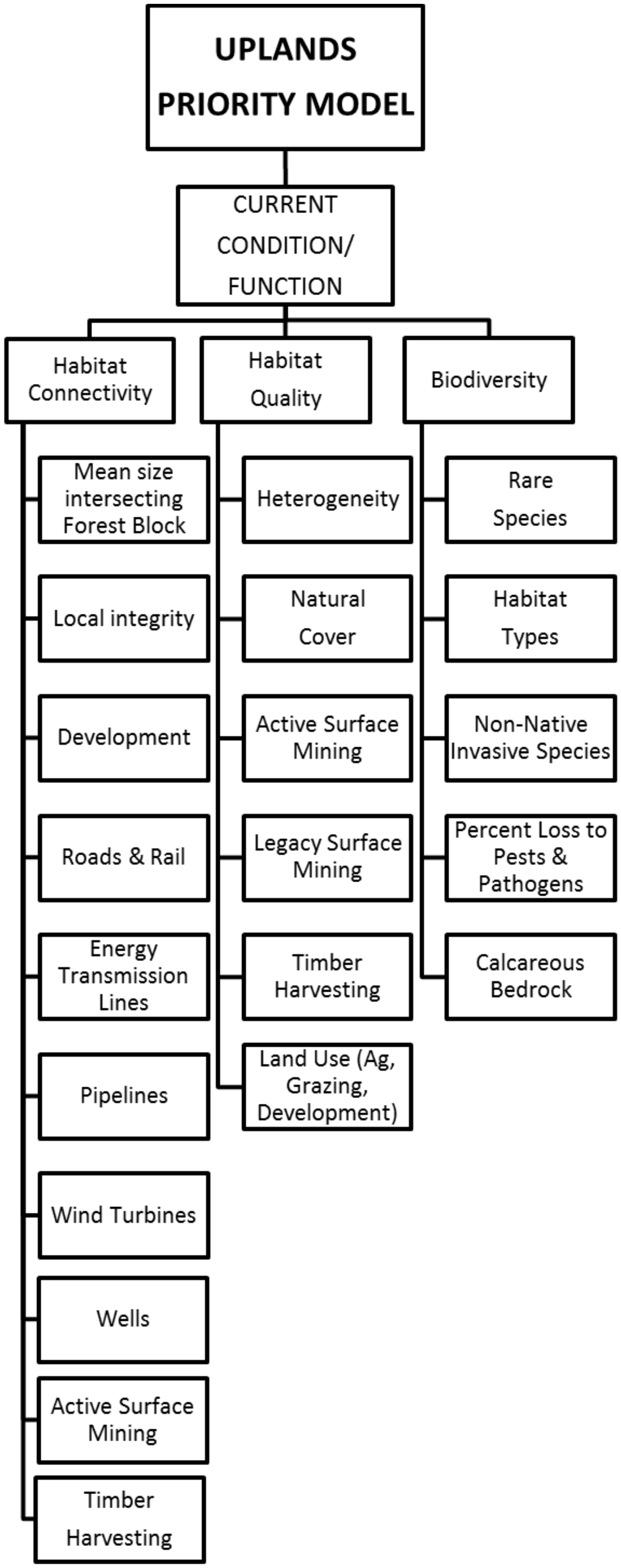

Figure 5. Uplands Priority Model Flowchart

To calculate the Streams/Riparian Areas Model objective and relative scores, all index scores in Table 18 are used:

$$ModOS = \frac{3.81 * 1 + 3.75 * 1 + 3.59 * 1 + 3.50 * 0.5 + 3.74 * 1}{1 + 1 + 1 + 0.5 + 1} = \frac{16.64}{4.5} = 3.70$$

which corresponds to the model objective score in Table 19, and places the index in the Very Good category.

$$ModRS = \frac{1.00 * 1 + 1.00 * 1 + 0.94 * 1 + 0.91 * 0.5 + 1.00 * 1}{1 + 1 + 1 + 0.5 + 1} = \frac{4.395}{4.5} = 0.98$$

which corresponds to the model relative score in Table 19.

The ModOS score is then standardized to 4 (as it is greater than 3.5), and the ModRS is added to it to produce the overall Streams/Riparian Area model combined score:

$$ModCS = 4 + 0.98 = 4.98$$

which corresponds to the model combined score in Table 19, and places the model into the Very Good category.

Table 13. Example Streams Water Quality Metrics for Catchment C1235 with Value, Objective Category, Objective Sco20re, and Relative Score for Each Metric

Metric (* critical metrics)	Weight	Value	Objective Category	Objective Score	Relative Score
AMD, TMDL, 303(d) impaired streams	2	0 %	Very Good	4	1
Median pH*	2	[a]	[a]	[a]	[a]
Median sulfate	1	[a]	[a]	[a]	[a]
Median specific conductivity*	1.5	[a]	[a]	[a]	[a]
Median GLIMPSS	2	[a]	[a]	[a]	[a]
Median sedimentation & embeddedness	1	[a]	[a]	[a]	[a]
Percent imperviousness*	2	0 %	Very Good	4	0.985
All wells	1.5	0 %	Very Good	4	1
Surface mining (active & legacy)*	2	0 %	Very Good	4	1
Underground mining	2	0 %	Very Good	4	1
Agriculture in riparian area	1	0 %	Very Good	4	1
Grazing/pasture in riparian area	1	1.13 %	Good	3	1
Development in riparian area	1	0 %	Very Good	4	1
Natural cover in riparian area	2	98.80 %	Good	3	0.988
All roads & rail	1.5	0 %	Very Good	4	1

[a] null value due to the absence of a WVDEP WAB water quality station in this catchment

1.4 Consolidated Analysis

The Consolidated Analysis consists of two main parts, a Future Threats assessment and an Opportunities assessment (Figure 6). It was originally envisioned to evaluate cumulative watershed effects, to analyze historical and possible future conditions where applicable data were available, to assess the impacts of past changes on the watershed, and to project future trends that might significantly impact the planning units over time (such as climate change or population growth). The objective was to incorporate the following into the consolidated analysis:

a. Impacts and stresses to natural resources, functions, and sensitive species (and their habitats) and vegetative communities in the watershed
b. Current and past land use changes in the watershed, evaluating their cumulative watershed effects on natural resource condition and function
c. The extent and location of riparian, wetland, and upland loss compared to historic conditions, including the loss of any species or vegetative communities
d. Natural resources, functions, and/or services that have been lost or degraded, where they are, and how significantly they have been impacted
e. Future threats analysis
f. Projected land use change with the potential to negatively impact natural resource value and function (population growth and urban expansion, planned energy projects)
g. Potential for increased resource extraction activities due to the presence of undeveloped natural resources (unmined coal, high wind or geothermal energy potential, Marcellus shale gas play)
h. Potential effects of climate change
i. Priority interest areas identifying portions of the landscape that are known priorities for protection by various federal, state, or non-governmental organizations

However, much of the data necessary for a comprehensive and thorough Consolidated Analysis was not consistently available for the five pilot HUC8 watersheds, and these datasets are listed in Section 5.3 as data gaps/needs identified for the state. For example, potential Marcellus shale development projections are not yet available from partner agencies, so the Marcellus shale thickness was used as a surrogate to estimate the probability of Marcellus shale development. Urban development projections were surprisingly lacking in West Virginia, except for the Morgantown area in the Monongahela watershed, and population projections were only available on a county-wide level. In contrast, the modeled resiliency and regional flow data, indicating potential response to climate change, are at a relatively fine scale. The latter two datasets are part of a larger analysis of the Northeast and Mid-Atlantic region conducted by The Nature Conservancy's Eastern Conservation Science program to identify geographic areas that are resilient in terms of providing species on the landscape the opportunity to adapt to a changing climate (Anderson et al. 2012). The concept of "resiliency" in this sense indicates that some areas may be able to buffer the effects of climate change by "offering a connected array of microclimates that allow species to persist." The analysis is based on two factors:

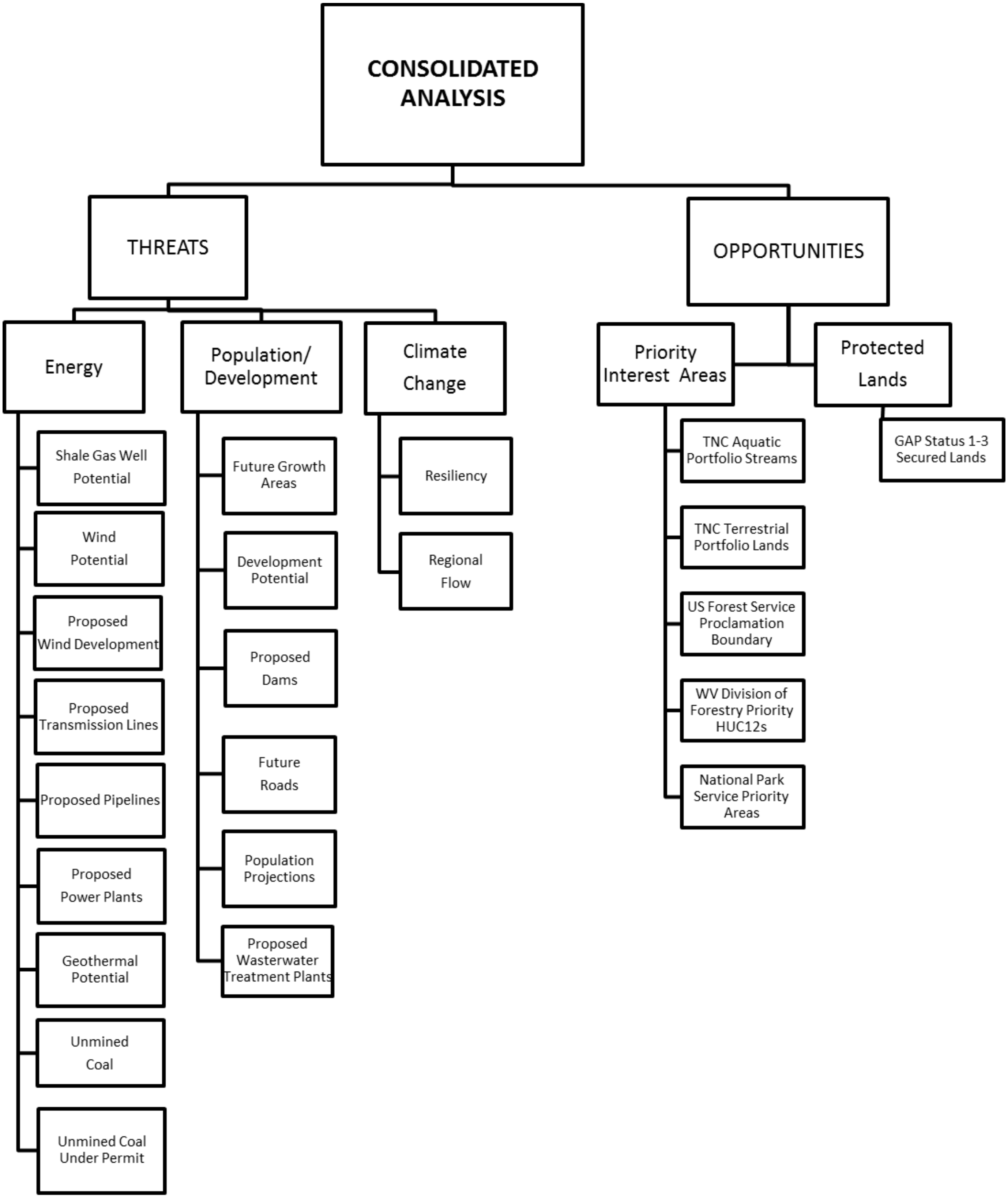

Figure 6. Consolidated Analysis Flowchart

landscape complexity (topography, elevation range, and wetland density) and landscape permeability (local connectedness and regional flow patterns, which are measures of landscape structure in terms of barriers, connected natural cover and land use patterns; Anderson et al. 2012). Detailed projections of temperature and precipitation changes are currently being developed for the Ohio River Basin by the USACE (Drum 2013) and may be incorporated into the Climate Change threats analysis when they become available.

Because of the inconsistent nature and variable scales of the different datasets, the Consolidated Analysis results were not calculated for the HUC12 or catchment-level planning units, but were instead calculated as gradients over the entire HUC8 watershed and are displayed as an informational layer rather than included in the model analysis results.

To display the cumulative known Future Threats to areas within the watershed, each metric was standardized from 0 to 100, with 100 indicating the lowest threat level for the metric in the HUC8 watershed, and 0 indicating the highest threat level. Metrics were weighted according to their significance in terms of affecting the overall future threat level of the watershed and summed to produce an overall index score. The indices were then combined using Esri's ArcGIS Spatial Analyst Raster Calculator tool to produce Threats Overall Results (a full list of metrics and assigned weights can be found in Table 14). This information was not included in the analysis results for each planning unit, but is meant to provide an additional set of information once the current condition of a planning unit has been determined.

The purpose of the second part of the Consolidated Analysis, the Opportunities assessment, was to provide information about currently protected areas, or areas that have been identified as priorities for protection by other organizations or regulatory agencies. This information may be helpful to entities planning protection or restoration activities in a given area by identifying potential partners or funding sources. Datasets included in the Opportunities assessment include permanently protected areas, The Nature Conservancy aquatic and terrestrial portfolios, West Virginia Division of Forestry priority areas, National Park Service priority areas, and National Forest proclamation boundaries.

Table 14. Metrics Included in the Consolidated Analysis

Model	Index	Metric Description	Weight	Units
FUTURE THREATS	Energy	Currently unmined area within permit boundary	2	% of planning unit
		Unmined area of mineable coal seams	2	% of planning unit
		Marcellus well potential, based on shale thickness	2	mean thickness/planning unit
		Modeled wind potential	2	% of planning unit
		Proposed wind turbine locations	1	#/sq mi planning unit
		Proposed energy transmission lines	1	mi/sq mi planning unit
		Proposed gas pipelines	1	mi/sq mi planning unit
		Proposed power plants	1	#/sq mi planning unit
		High geothermal potential (temp>150 degrees)	1	% of planning unit
	Population/ Development	Population projections	1	percent change, by county
		Areas designated for future development	1	% of planning unit
		Proposed dam locations	1	#/stream mile
		Proposed future roads	1	mi/sq mi planning unit
		Proposed wastewater treatment plants	1	#/planning unit
	Climate Change	Resiliency score	1	avg score/planning unit
		Current density score	1	avg score/planning unit
OPPORTUNITIES*	Priority Interest Areas	TNC aquatic portfolio streams	-	-
		TNC terrestrial portfolio lands	-	-
		US Forest Service proclamation boundary	-	-
		WV Division of Forestry priority areas	-	-
		National Park Service priority areas	-	-
	Protected Lands	GAP Status 1-3 secured lands	-	-

*The "Opportunities" metrics/datasets are considered informational and were not part of an analysis, but are presented to aid decision-making. Therefore, these datasets do not have assigned weights or normalized units of measurement.

1.5 Healthy Watersheds Analysis

Healthy watersheds were identified and presented using two methods, the objective method and the relative method. The analysis was completed at both the HUC12 and catchment scale. Each method presents a slightly different picture of healthy watersheds in the Potomac drainage, as described below.

The objective method represents a slightly modified version of the standard assessment methodology that utilizes 40 metrics to characterize a watershed rather than the 95 metrics used in the standard assessment methodology (Table 15). The intent was to remove duplication and focus the analysis on four main elements of a healthy watershed: water quality, hydrologic connectivity, habitat quality, and biodiversity. The data used in this analysis was the same as that used for the full watershed assessment; and weighting, normalization, and classification of the results remained the same. This method is independent of scale, and the analysis results remain the same when compared at the scale of an HUC8 watershed, or at the scale of multiple HUC8s combined.

The relative method utilizes the same data and methods as described above; however, the final results are represented utilizing only the normalized relative results across the entire Potomac drainage in West Virginia. This analysis reflects the same four focus elements (water quality, hydrologic connectivity, habitat quality, and biodiversity) without using the objective ranking method. The relative analysis method helps answer the question, within the Potomac region in West Virginia, which are the very best, and the very worst watersheds. The relative method is scale dependent, and results would change depending on the size of the area included within the analysis.

Table 15. Metrics included in the Healthy Watersheds analysis.

Metric Name (* "Critical")	**Metric Description**	**Normalization**
Impaired	AMD, TMDL, 303(d) impaired streams	miles impaired streams/total stream miles
MedpH*	Median pH values	Index for each planning unit
MedGLIMPSS	Median GLIMPSS scores	Index for each planning unit
Imperv1*	Percent imperviousness	mean % imperviousness per planning unit
SurfaceMine1*	Surface mining (active & legacy)	% of planning unit
UndrgrndMine1	Underground mining	% of planning unit
NatCoverRip1	Natural cover in riparian area	% of planning unit
MedSpecCond*	Median specific conductivity values	Index for each planning unit
AllWells	All wells	#/sq mi planning unit
AllRdRail	All roads & rail	miles/sq mi planning unit

MedSulfate	Median sulfate values	Index for each planning unit
MedS&E	Median sedimentation & embeddedness	median score/planning unit
AgRip1	Agriculture in riparian area	% of riparian area
GrazeRip1	Grazing/pasture in riparian area	% of planning unit
DevelopedRip1	Development in riparian area	% of planning unit
AllRdRailRip2	All roads & rail in riparian area	mi/sq mi planning unit
Hdwtrs	Headwater streams (size class 1a)	# headwater stream miles/total stream mi
Forestriparea	Forested riparian area	% of riparian area
Dams	Dams	#/ stream mi
LocInt	Local integrity score	avg score/planning unit
WetArea	Total wetland area	% of planning unit
PowPlants	Power plants	# / stream mi
WetArea	Total wetland area	% of planning unit
Hydricsoils	Hydric soils	% of planning unit with hydric soils
FloodArea	Floodplain area	% of planning unit
FldForestWet	Floodplain, forested wetlands	sq mi/wetland buffer
ForestHdwtrWet2	Forested headwater wetlands	% of planning unit
Hetero	Heterogeneity score	avg score/planning unit
NatCover	Natural cover (forest, grassland, wetland)	% of planning unit
ActiveSurface2*	Active surface mining	% of planning unit
Developed2*	Development	% of planning unit
LegacySurface	Legacy surface mining	% of planning unit
Timber2	Timber harvesting operations	sq mi/sq mi planning unit
Ag	Agriculture	% of planning unit
Graze	Grazing/pasture	% of planning unit
PctLoss	Percent tree basal area loss	% of planning unit
AllSGNCUp	Rare species	#/sq mi planning unit
NNIS	Non-native invasive species	#/sq mi planning unit

NEHab	Northeast habitat types	#/planning unit
CalcBed	Calcareous bedrock	% of planning unit

1.6 Data

3.6.1 Data Sources

Spatial data acquired for this study included:

- Surface water quality monitoring data
- Impaired streams (303(d), TMDL, AMD)
- Land use and land cover (LULC) data
- Surface and subsurface geology
- Soils
- Elevation (DEM)
- Stream network and drainage areas
- Wetlands location and type
- Species and habitat data
- Protected lands
- Infrastructure (roads, railroads, dams, energy transmission lines, pipelines)
- Mining, mineral extraction, oil and gas wells data
- Regulated sites (permitted discharge, landfills, toxic waste disposal, etc.)
- Demographics/population data
- Climate change models
- Political boundaries

Data were obtained from many sources including, but not limited to:

Federal agencies

- US Environmental Protection Agency
- US Geological Survey
- US Forest Service
- US Fish and Wildlife Service
- US Department of Agriculture
- US Department of Transportation
- US Census Bureau

State agencies

- WV Department of Environmental Protection
- WV Division of Natural Resources
- WV Division of Forestry
- WV Geological and Economic Survey
- WV Statewide Addressing and Mapping Board

Local agencies

- City/county/regional governments
- River or Watershed Associations

Non-profit organizations

- The Nature Conservancy

Universities

- West Virginia University
- WV GIS Technical Center

For a thorough reference to all data sources and intended uses please see Appendix A: Detailed Data Source Information.

1.6.2 Data Quality

Data were selected or rejected based on their relevance, completeness, accuracy, quality, and age. The most current data available were used, except in cases where using historical data for comparison or trend prediction was desirable. For example, species occurrence data older than 20 years were not used since they are unlikely to reflect current conditions. Particular factors that caused data to be rejected included: lack of appropriate or complete metadata; data that do not accurately reflect the current status of the watershed; data that appear incomplete or significantly conflict with known quality-assured data (thus casting doubt on data quality); and data that were deemed irrelevant or redundant during the analysis.

1.7 Works Cited

Anderson, M. G., S. Bernstein, F. Lowenstein, N. Smith, and S. Pickering. 2004. Determining the size of eastern forest reserves. The Nature Conservancy , Eastern Conservation Science Program, and Sweetwater Trust.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012. Resilient sites for terrestrial conservation in the northeast and mid-Atlantic region. The Nature Conservancy, Eastern Conservation Science, Boston, MA. http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/resilience/Pages/default.aspx

Compton, B. W., K. McGarigal, S. A. Cushman, and L. R. Gamble. 2007. A resistant-kernel model of connectivity for amphibians that breed in vernal pools. Conservation Biology 21:788-799.

Drum, G. 2013. Personal communication (expert workshop held 8-9 January 2013, regarding the USACE Institute of Water Resources Ohio River Basin Climate Change model for temperature and precipitation [in progress]).

Messinger, T. 2012. West Virginia USGS Stream gage coverage. Personal communication (email received 14 June 2012).

NRCS. 2012. Watershed Boundary Dataset (WBD) facts. Natural Resources Conservation Service www.ncgc.nrcs.usda.gov/products/datasets/watershed/facts.html. Accessed 26 April, 2012.

Smith, M.P., R. Schiff, A. Olivero and J. MacBroom. 2008. The Active River Area: A conservation framework for protecting rivers and streams. The Nature Conservancy Eastern U.S. Freshwater Program. Boston, USA.

U. S. Environmental Protection Agency and U.S. Geological Survey. 2005. National Hydrography Dataset Plus – NHDPlus, Edition 1.0.

U.S. Geological Survey. 2009. Federal guidelines, requirements, and procedures for the national Watershed Boundary Dataset: U.S. Geological Survey Techniques and Methods 11–A3. U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service.