Appendix F

Savannah River Basin Landscape Analysis

By
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Landscape Analysis

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INTRODUCTION

Scientists from the U.S. Environmental Protection Agency (EPA), Region 4, Science and Ecosystem Support Division, enlisted the assistance of the landscape ecology group of U.S. EPA, Office of Research and Development (ORD), National Exposure Research Laboratory, Environmental Sciences Division (ESD), in conducting a landscape assessment of the Savannah River Basin (Figure 1) as part of their ongoing Regional Environmental Monitoring and Assessment Program (REMAP) demonstration project. In the Scope of Work provided by Region 4, the goal was stated as “provide technical/scientific assistance ...to EPA Region 4 in assessing current wadeable stream conditions in the Savannah River Basin with landscape factors that may be contributing to these conditions or gradients.” Three specific objectives were presented in the form of questions. These were:

> Are both the proportions of land uses and the spatial pattern of land uses important for characterizing and modeling stream condition in watersheds/ecoregions of different areas?
>
> Can land uses near the streams better account for the variability in ecological condition than land use for the entire watershed/ecoregion?
>
> Does the size of the watershed/ecoregion influence statistical relationships between landscape characteristics and ecological condition?

In addition, an assessment of landscape change was to be conducted as part of continuing ESD research in application of change detection techniques.

The data analysis plan developed to address the objectives given above called for calculation of a specific suite of landscape indicators for all nine United States Geological Survey (USGS) 8-digit hydrological unit codes (HUC; USGS, 1982), a selected subset of the 94 Georgia and South Carolina subbasins, and the riparian corridors in the HUCs and selected subbasins. The subbasins are generally equivalent in area to USGS 11-digit HUCs. The riparian corridor was defined as 100 meters on either side of stream arcs; this size was selected from a review of state laws and literature available on the Internet (e.g., Santa Cruz County, 1998; U.S. EPA, 1998; South Carolina Department of Natural Resources, 1998). The suite of indicators included: landcover types, u-index, agriculture on slopes greater than 3 percent, agriculture on highly erodible soils, agriculture on moderately erodible soils, agriculture on highly erodible soils with slopes greater than 3 percent, number of occurrences of roads crossing streams, and number of impoundments. Landscape indicator statistics were also computed for the drainage areas and associated riparian corridors of a selected set of sites sampled by Region 4 using REMAP protocols. Region 4 provided an ARC/INFO coverage of the sampling locations and Quattro Pro spreadsheets of the water quality and biotic measurements.

METHODS

The selected landscape indicators are identical to, or based on, indicators used in the mid-Atlantic atlas (Jones et al, 1997). In the atlas, the indicators were calculated only for 8-digit HUCs; in this study, indicators are additionally calculated for smaller spatial units. The basic methodology is the same, however. In general, calculation of the landscape indicators involves ARC/INFO techniques of extracting or “cookie cutting” the desired area from a spatial data set. The data are formatted in an ARC/INFO grid of uniform cell size. In this study, a 30-m cell size is used for all grids. For indicators which are produced from more than one data set (e.g., roads crossing streams), ARC/INFO overlay and intersection techniques are used. A few indicators, used only on the drainage areas of the individual sampling sites, are produced from an in-house custom statistics program. These are indicators of fragmentation, i.e., the degree to which landcover types are present in patches rather than in continuous, homogenous blocks. The landscape change indicator is produced from comparison of satellite imagery from two dates. This is the only indicator which does not use ARC/INFO as the primary data analysis software. Landscape change assessment employs ENVI, an image processing software package available for PC or Unix systems.

Data Sets Used

The spatial data sets used are obtained from a variety of sources. The primary data sets used in this landscape assessment include: Multi Resolution Land Characteristics (MRLC) Interagency Consortium land cover/land use (Bara, 1994), State Soil Geographic data base(STATSGO)soils (Natural Resources Conservation Service, 1996), RF3 streams (U.S. EPA, 1997), USGS 8-digit HUCs, Georgia and South Carolina subbasins, Region 4 sampling site locational and sampling data, 30-m and 100-m digital elevation models (DEM; USGS, 1990), digital line graph (DLG) roads (USGS, 1989), and National Inventory of Dams impoundments (U.S. Army Corps of Engineers, 1997). Landscape change assessment used North American Land Characterization (NALC) imagery from the 1970s and 1990s (U.S. EPA, 1993). Data sets were subset to the area of interest using the basin boundary coverage.

Sampling Site Ranking, Selection, and Drainage Area Creation

A simple, unweighted scoring system was used to rank the sampling sites, shown in Figure 2, by their results. Water quality variables (pH, dissolved oxygen, conductivity) and biota [algal growth potential test (AGPT); Ephemeroptera, Plecoptera, and Trichoptera index (EPT); fish index of biological integrity (fish_ibi), macroinvertebrate habitat, and macroinvertebrate richness] were scored separately. The frequency distributions for each variable was examined. Most indicated a bimodal distribution, with reduced frequencies near the lower and upper ends of the variable’s range. Measurement values corresponding to the inflection points of the curve were selected to divide the range into three classes. A score value was ascribed to the measurement value, 1 for bad, 2 for fair, 3 for good, and 0 for missing data. Although these are labeled as good, fair, and bad, these terms apply to the measurement value compared to the range of measurement values, not to any applicable water quality standards or other measurement system. The scores were summed and recorded. The number of measurements used in the summation was also recorded; this was necessary because of the large number of sites missing results for one or more variables. The measurement data and scoring data were then associated with the site location coverage. Map compositions were prepared for each HUC, presented here as figures 3 through 11. The figures were useful in characterizing relative conditions across the basin and making preliminary decisions about areas for further investigation.

The sampling locations had been selected by the Region using the EMAP site selection protocol. Several discussions and correspondences were conducted with a lead EMAP Statistician, Dr. Tony Olson, about the spatial area represented by the sampling sites. It was determined that it would be necessary to develop the specific drainage area of each sampling location and to treat the water quality and biota information as point data. Accurate drainage area computation requires DEMs of 30-m intervals or better; at the time of analysis, these were available for only portions of the Savannah River Basin, primarily the north end and part of the central area.

The process used to delineate the drainage areas employs hydrological analyses tools contained in the Grid module of ARC/INFO. First sinks in the DEMs are identified and filled. Flow direction is computed as the direction from each 30-m cell towards its steepest downslope neighbor. From the flow direction grid, a flow accumulation grid is created by calculation of the number of cells which flow into each downslope cell; this grid resembles the existing stream network. The sampling station locations are input as pour points. In some cases, the sampling point coordinates did not fall directly on a flow accumulation path; in these instances, the pour point was placed on the flow accumulation in the cell nearest to the given station coordinates.

In the selection of the subset of sites for landscape indicator assessment, efforts were made to select sites that met the following criteria: 1. Full suite of measurement variables, 2. Located in the areas indicated to be of greatest interest to the Region, 3. 30-m DEM data available to use in drainage area determination, 4. Representation of the full range of measurement values, and 5. Representation of first through third stream order classes. Using these criteria, sixteen sites were selected.

The selection of subbasins for presentation of landscape indicators was made after selection of the sampling sites. The selected subbasins are all in HUC 3060103 and each includes one or more of the sampling site subset. This provides the nested hierarchy of spatial units in the assessment. An arbitrary number was assigned to each subbasin after merging the separate Georgia and South Carolina coverages. The subbasins are shown in Figure 12.

LANDSCAPE ASSESSMENT

HUC Indicators

The Savannah River Basin is arrowhead-shaped, trending generally northwest to southeast. The basin is comprised of nine USGS 8-digit HUCs (numbered 3060101 through 3060109, hereafter referred simply by the last digit), spanning three ecoregions: Blue Ridge, Piedmont and Coastal Plains. As shown in Figure 13, HUCs 1 and 2 are primarily in the Blue Ridge ecoregion, HUCs 3, 4, 5, and 7 lie in the Piedmont, and the majority of HUCs 6, 8, and 9 are in the Coastal Plain. As shown in Table 1, the size of the HUCs varies from 200,987.55 ha (HUC 7) to 488,842.20 ha (HUC 6). Associated riparian areas vary from 31,324.14 ha (HUC 7) to 88,651.85 ha (HUC 3), based on a 100-m corridor on either side of all RF3 stream arcs.

Landcover types are derived from MRLC data, nominal base year 1992. Differences among the three ecoregions are evident in the forest landcover statistics for the HUCs, Table 2. Deciduous and evergreen forests predominant in HUCs 1 through 5 and 7, the HUCs comprising the Blue Ridge and Piedmont ecoregions; all forest types account for 64.7 to 83.49% of the total land cover. Forest landcover accounts for 37.20 to 53.35% of the landcover in the Coastal Plain HUCs, with evergreen forests the predominant forest type. Wetland landcover types are found primarily in the Coastal Plain HUCs, accounting for 11.10 to 35.93% of the total landcover, most of it in woody wetlands. Wetlands comprise less than one percent of the landcover in the HUCs outside the Coastal Plains.

Agricultural landcover types, Table 3, comprise 9.91 to 32.47% of the total landcover in each HUC. Pasture/hay is the dominant agricultural land use in the upper part of the basin, while row crops are the largest agricultural land use in the lower basin. Urban landcover types, Table 4, account for between 0.85 to 5.33% of the total land use in all HUCs. There is no ecoregion-related pattern to the distribution of urban landcover. Barren landcover types, Table 5, comprise less than one percent of the total landcover in HUCs 1 and 2, and approximately 2 to 10 percent of the landcover of the Piedmont and Coastal Plains HUCs.

The patterns of landcover/land use within the riparian corridors, Table 6, are not substantially different than those for the HUCs overall, with the exception that water is an appreciable percentage of the landcover within riparian corridors in most HUCs. Agricultural land use within the riparian corridor ranges from 4.63% to 12.78% and urban land use ranges from 0.33% to

3.51%. Barren landcover ranges from less than 1% to a little more than 6%. The predominant landcover types in the HUC riparian corridors are forest and wetlands in the Coastal Plains and forest in the other ecoregions.

While there is some variation in landcover types among the three ecoregions, overall the HUCs are relatively homogeneous in landcover/land use pattern. In all HUCs, natural landcover types comprise greater than 50% of the total landcover. Urban land uses account for only a small percent of the total landcover and agricultural uses account for 1/10 to approximately 1/3 of the total land cover/land use. These results contrast greatly with the results obtained for 8-digit HUCs in the mid-Atlantic region (Jones et al, 1997), where large differences were evident at this scale. The broad-scale patterns evident in the mid-Atlantic (e.g., intensive urbanization of the Coastal Plains, concentrated agricultural land uses in valleys, and isolation of forests to highland areas) are not in evidence in the Savannah River Basin.

Agriculture on slopes greater than 3% grade has been developed as a landscape indicator because the potential for erosion increases significantly at this grade. Similarly, agriculture practiced on highly or moderately erodible soils has a higher potential for erosion. These indicators are developed from overlays of DEMs, MRLC land cover/land use, and erodibility factors contained in the STATSGO soils data base. Results for all of these indicators are generally low, as shown in Table 7. Only HUCs 3 and 4 showed greater than 20% total land area for any of the agriculture-soil-slope indicators, that being agriculture on moderately erodible soils, most of it in pasture/hay. Results for these indicators within the riparian corridors are lower, ranging from nonexistent to less than 12% agriculture on moderately erodible soil in HUC 4, as shown in Table 8.

Roads frequently cause increased runoff to streams and contribute pollutants washed off the road surfaces. This phenomenon is represented by the roads-crossing-streams indicator, computed from intersecting digital line graph roads with RF3 stream arcs. As shown in Table 9, values for this indicator range from 362 in HUC 5 to 1,914 in HUC 6. Normalizing these values to the number of road crossings per stream kilometer, also shown in Table 9, shows the greatest frequency of roads crossings per stream kilometer is in HUC 6 with more than one road crossing per kilometer of stream length. The lowest frequency is in HUC 7 with approximately one road crossing for every 8 kilometers of stream length. The remaining HUCs have frequencies in the range of one road crossing for every 2.5 to 5 kilometers of stream length.

Information for dams was obtained from the National Inventory of Dams which tracks all dams greater than 6 feet in height for inspection purposes. As shown in Table 9, the fewest number of dams in any HUC is 31 in HUC 9 while the greatest number is 191 in HUC 6. Normalizing by the total stream length within each HUC shows the greatest frequency of dams is also in HUC 6, with one dam for every 9 kilometers of stream length. The lowest frequencies of dams are in HUC 9 and HUC 7, with roughly one dam for every 80 kilometers of stream length. The locations of dams are depicted in Figure 1.

Subbasin Indicators

As discussed above, the landscape indicators at the HUC level show some variation among HUCs attributable to natural landcover variation at the ecoregion level. However, the patterns of land use are generally consistent across ecoregions and among HUCs. This section focuses on the next scale, the subbasin. Landscape indicators are presented for several subbasins of HUC 3. These particular subbasins were selected because they each contain one or more of the sampling sites selected for analysis. The landscape indicators produced for the subbasins are the same as those produced for the HUCs.

Physical dimensions of the selected subbasins are shown in Table 10. The total land area in each subbasin ranges from 17,195.76 ha in #32 to 68,295.33 ha in #53. The associated riparian corridors range from 4,311.00 to 12,800.34 ha.

The landcover statistics for HUC 3 overall are 64.70% forest (approximately 28% evergreen, 25% deciduous and 11% mixed forest), 22.29% agriculture (approximately 13% pasture/hay and 9% row crops), 2.59% urban, 6.60% water, approximately 3% barren, and less than one percent wetlands. Among the subbasins, the forest landcover classes vary from 40.26% in #32 to 73.66% in #53. As shown in Table 11, evergreen forests are the largest forest class in #26, #36, and #53; deciduous is the largest class in #20 and #32. Agricultural land use in #26 is about the same as in the HUC overall (23.65% of which approximately 16% is in pasture/hay). Greater agricultural land use is evident in #20 (34.07% with about 20% in pasture/hay) and #32 (32.45% of which almost 18% is pasture/hay). Less landcover is in agricultural land uses in #36 (15.16%, with more than 8% pasture/hay) and #53 (11.58%, with row crops slightly exceeding pasture/hay). Urban land use is lowest in #53 at less than one percent and highest in #20 at 8.05%. The remaining three subbasins have urban land use in slightly higher percentages than for the HUC overall, ranging 3.05% in #36 to 4.81% in #32.

In the riparian corridors, forest comprises 53.02 to 85.52% of the total cover, with deciduous the most dominant forest cover type, as shown in Table 12. Agricultural land use within the riparian corridor ranges from 4.41% in #53 to 15.92% in #32 and urban land use comprises from 0.39% to 4.99% of the total riparian land cover. Wetlands account for approximately 3% or less of the riparian land cover types.

The agriculture-soil-slope indicator results for HUC 3 are 2% agriculture on slopes greater than 3%, approximately 21% agriculture on moderately erodible soils, approximately 1% agriculture on highly erodible soils, and less than 0.1% agriculture on slopes greater than 3% in highly erodible soils. Among the subbasins, #20, #26, and #32 have more agriculture on slopes greater than 3% and more agriculture on moderately erodible soil than for the HUC overall; the remaining two subbasins are substantially lower than the HUC overall for both these indicators, as shown in Table 13. Only #53 has any agriculture on highly erodible soil (about 7%) and agriculture on slopes greater than 3% and highly erodible soils (0.35%). Results for these indicators are lower for the riparian corridors, with only subbasins #20, #26, and #32 having more than 10% riparian land cover in agriculture on moderately erodible soils.

Table 14 provides results for the number and frequency of roads crossing streams and dams; these indicators are depicted in Figure 14. Roads crossing streams ranges from 56 in #32 to 299 in #20. There are no dams in #32, but 19 dams in #20. The frequency of roads crossing streams is highest in #20 with approximately one road crossing for every 1.6 kilometers of stream length; the lowest frequency is in #53 with one road crossing per approximately 9 kilometers of stream length. The frequency of roads crossing streams for the HUC overall is approximately one crossing per 3 kilometers of stream length. The frequency of impoundments for the HUC overall is approximately one dam for every 50 stream kilometers. The frequency of dams is lower than for the HUC overall in #32 with no dams and in #53 with approximately one dam for every 167 kilometers of stream length. The greatest frequency of dams among the subbasins is in #20 with one dam per approximately 25 stream kilometers.

At this scale, patterns which may impact water quality begin to be evident. In Figure 5, the sampling stations in #53 are indicated as fair to good (as compared to the overall data range). This subbasin has the highest proportion of landcover in forest among the subbasins, the lowest proportion of agriculture and urban land uses, and a low proportion of agriculture on slopes greater than 3%. Among the selected subbasins, it has the lowest frequency of roads crossing streams. Although is the largest of the subbasins in total area, this subbasin has only 4 dams. However, #53 is the only subbasin among those examined with agriculture on highly erodible soils and agriculture on slopes greater than 3% and highly erodible soils.

In contrast, the sampling sites in #32 and #20 rank as fair to bad compared to the overall data ranges. These two subbasins contain the greatest proportion of agriculture among the subbasins, 28 to 33% agriculture on moderately erodible soils, and 3 to 4% agriculture on slopes greater than 3%. In addition, #20 has the highest proportion of urban land use, the highest normalized roads crossing streams value, and the greatest frequency of dams among the selected subbasins.

Sampling Site Drainage Landscape Indicators

As described above, landscape analysis at the subbasin scale may be adequate to provide a generalized characterization of the Savannah River Basin. One of the objectives of this project, however, is to try to establish relationships among landscape indicators and water quality/aquatic biota indicators. The water quality data were collected at specific sampling sites. To investigate relationships with landscape indicators, it is necessary to delineate the drainage area to the individual sampling site. This was done for a subset of 16 sampling sites. The selection process was described earlier, as was the methodology for delineating the drainage areas.

The drainage areas for the sampling sites range from 122.58 to 10,665.18 ha, as shown in Table 15. In delineating the drainage areas, the locations for the sampling sites frequently did not lie on a stream arc, necessitating a best guess, based on the indicated stream order and proximity to stream arc, as to the point on the arc to use as the pour point. In addition to the landscape indicators calculated for the HUCs and subbasins, indicators of fragmentation were generated using a custom, in-house software program. For the fragmentation indicators, the 15 landcover/land use classes of the MRLC data were aggregated to six classes: water, urban, forest, agriculture, wetlands, and barren, as shown in Table 16 for the overall drainage area and in Table 17 for the riparian corridors. In these aggregated land cover types, other grasses are included in agriculture and woody wetlands are included in the wetlands cover type.

Results for agriculture-related indicators over the entire drainage area and the riparian corridor are presented in Table

18. The number of road crossing streams and dams are shown in Table 19. Ten of the 16 sampling site drainages contain no dams; however, where dams are present, they are generally greater in frequency than in the HUC or subbasins overall. The frequency of roads crossing streams ranges from approximately one road crossing per 5.5 kilometers of stream length to a maximum of one road crossing for every stream kilometer.

Results for each indicator were encoded into ARC/INFO Grids. A Grid stack was generated and used to develop a correlation matrix. A separate Grid stack was generated for the riparian corridors contained in the drainage areas for the sixteen sampling sites. With an n of 16, the correlation coefficients are significant at values greater than 0.666 for $\alpha = 0.005$, at values greater than 0.601 for $\alpha = 0.01$, at values greater than 0.507 for $\alpha = 0.025$, and at values greater than 0.425 for $\alpha = 0.05$. Using these values, a number of significant correlations between water quality/aquatic biology indicators and landscape indicators were indicated, as shown in Table 20. In general, correlations were the same or less for the riparian corridor than for landscape indicators over the whole drainage area. The primary exception is dissolved oxygen, which exhibited significant correlation only with total anthropogenic cover (U-index, comprised of an aggregation of urban and agriculture land cover types) in the riparian corridor. It should be noted that this analysis is preliminary and is based only on the nonrandomly selected subset of sixteen sampling locations. The data set size was insufficient to perform a cluster analysis. The strongest correlations were between landscape indicators; this is not surprising as several of the landscape indicators contain similar information. The redundancy is needed at this point in the research until the strongest and most sensitive relationships with aquatic indicators can be established.

Figures 15 through 20 depict six of the sampling station drainage areas. Sites S68, S113, and S195 are ranked as good data sites, based on the relative rankings of the data measurements. Site S68 is a small forested drainage located in HUC 2. Site 113 is also relatively small and is located in HUC 6; although agriculture and urban areas are evident within the drainage, they are fragmented as compared to the forest landcover; much of the riparian corridor is wetlands. Site S195 is a larger drainage and higher order stream located in HUC 2. All of the landcovertypes are present, as are a number of roads and a few dams. The predominant landcover, however, is unfragmented forest.

The remaining three figures are indicative of sites with fair to bad relative rankings. Site S22, located in HUC 3, subbasin #39 has extensive agriculture, much of it in large blocks while the forest landcover types are fragmented. Site S80 is a large drainage area located in HUC 3 subbasin #36; the sampling site is located in an area of unfragmented forest, but the upper reaches of the drainage, including the headwaters of most of the streams are dominated by urban and agricultural landcovers and extensive road networks. Site S149 is a fairly small drainage located in HUC 3, subbasin #20. There is extensive agriculture and urban land use; the forest landcover is highly fragmented. The headwaters of one of the two streams in the drainage is found in an area of high intensity commercial/industrial land use.

Landscape Change

Two mosaics were developed from the NALC data base for the 1970s (Figure 21) and the 1990s (Figure 22) Savannah River Basin study area. The mosaics were matched to provide analysis across similar areas of the two mosaics. Both mosaics were processed into normalized difference vegetation index (NDVI) images and the values in the 70s mosaic was subtracted from the 90s. Positive numbers indicate gains in vegetation and negative numbers equate to losses in vegetation; in Figure 23 vegetation gains are shown in green while vegetation losses are shown in red. A standard deviation was calculated using n–1, for the entire change NDVI image. The Arc/Info grid coverages depicting the various areas of interest were then converted to image files (hereafter referred to as masks), and the UTM coordinates for each were recorded. The resolution for each mask was converted to 60 meters to match the resolution of the change NDVI image. The change NDVI image was repeatedly sub-sampled to select the matching areas of each mask. Each sub-sampled change NDVI image and its corresponding mask were then used as inputs to a custom in-house software program which calculates the amount of cells (pixels) that are inside the mask and groups them into 4 categories. They are: cells which are greater than or equal to 4 standard deviations of loss in vegetation, those cells which are greater than or equal to 2 standard deviations of loss in vegetation, and the corresponding numbers of cells for gains in vegetation. In the following tables the losses and gains have been grouped together and shown as either a negative number for percent of loss or a positive number for percent of gain.

An additional column is used to represent the cells removed from the study area, which contain negative NDVI indices in either the70s or 90s NDVI image. Negative NDVI indices are generated by clouds, water and other non-vegetation. This also helps to remove erratic NDVI values caused by differences in solar illumination. However, sometimes these values are meaningful, as in the case where an impoundment may have been installed after the 70s image and before the 90s. An example of this is shown in Figure 24.

Table 21 depicts change in selected subbasins of HUC 3. Subbasin #26 reflects greater than 3% negative change, because an impoundment was installed between the 70s and the 90s image. Subbasin #26 is the white-shaded area shown in Figure 25.

Subbasin #32, differences in the water surface (solar glare) produced a positive change in vegetation which offset the loss in that area. When the water areas (negative NDVI numbers) were removed the overall sub-watershed had a loss of greater than 6%.

Table 22 shows the NDVI change in the drainage areas of the selected sixteen sampling sites.

SUMMARY

The three questions posed as objectives by the Region can now be addressed:

Are both the proportions of land uses and the spatial pattern of land uses important for characterizing and modeling stream condition in watersheds/ecoregions of different areas?

As shown in this landscape assessment, both the proportion and the patterns of land use are important in assessing impacts on streams. In the correlation analysis conducted on the sampling site drainages, both total landcover types (%forest, U-index) and pattern indicators (fragmentation indicators including average patch size, forest and agriculture edges) were found to correlate with aquatic indicators. A third important element is the scale at which analysis is done. As demonstrated here, landscape indicators at the HUC level were too coarse to provide any indications of water quality. In the analysis of selected subbasins, patterns of land use began to emerge; this scale may be sufficient to provide a generalized characterization of the basin.

Can land uses near the streams better account for the variability in ecological condition than land use for the entire watershed/ecoregion?

In this particular assessment, landscape indicators for the riparian corridors did not provide stronger correlation with aquatic indicators, with the exception of dissolved oxygen. It should be remembered, though, that this is one analysis of a small spatial area in one region with a particular suite of indicators. In other situations the riparian corridor may be of greater importance than the overall watershed. Even in this region, the southern portion of the basin has riparian corridors dominated by wetlands. Only one site from this area was used in the analysis and the entire sampling data set contains only a few sites in this ecoregion. A separate analysis of wetlands-dominated systems is probably worthwhile.

Does the size of the watershed/ecoregion influence statistical relationships between landscape characteristics and ecological condition?

There was no indication in this analysis of any relationship with the spatial extent of the drainage areas. This includes the landscape indicators developed for the HUCs and subbasins. In the sampling site analysis, one of the selection criteria was to include streams of varying order; by doing so, both small and large drainage areas were included. Drainage area was included in the correlation analysis; no correlation was shown with any of the aquatic indicators.

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