Appendix D. Ecological Land Units

This appendix describes supplementary metadata for the ELU30 raster data developed by the Eastern Resource Office of The Nature Conservancy. BioMap2 *used these data to inform the analysis of Wetland Cores. The Wetland Core analysis used Elevation and Geology components of the ELU data layer, but did not employ the Landform component since nearly all wetlands fall within the "wetflat" landform type, and therefore these data do not assist in further categorizing MA wetlands.*

Background

An understanding of patterns of environmental variation and biological diversity is fundamental to conservation planning at any scale—regional, landscape level, or local. This dataset was developed as a tool for assessing the biophysical character of landscapes, and for mapping the distribution and composition of community assemblages across those landscapes. Informed decisions on where to focus conservation efforts require such tools.

Data on biological distributions are very often inadequate to a large-scale analysis of biodiversity. The close relationship of the physical environment to ecological process and biotic distributions underpins the ecological sciences, and in the absence of suitable biological datasets, conservation science has recognized that physical diversity could be an acceptable surrogate for biological diversity. Research has repeatedly demonstrated especially strong links between ecosystem pattern and process and climate, bedrock, soils, and topography. This recognition led to the development of the ecological land unit, or ELU.

The ELU is a composite of several layers of abiotic information: elevation, bedrock geology, distribution of deep glacial sediments that mask bedrock's geochemical effects, moisture availability, and landform. An ELU grid of 30 meter cells was developed for the Lower New England-Northern Piedmont (LNE) and North Atlantic Coast (NAC) ecoregions. The ELU dataset describes the "ecological potential" of the landscape. A second dataset (a "systems" grid) was developed that informs ELUs with landcover data, bringing them to earth by telling us what is actually on the ground in a region where human alterations to the landscape have everywhere affected the natural vegetation. The ELU dataset itself carries no information about actual landuse or landcover, however. A brief discussion of each of the layers of information built into the ELUs follows.

Dataset content and development

<u>Elevation classes</u>

Elevation has been shown to be a powerful predictor of the distribution of forest communities in the Northeast. Temperature, precipitation, and exposure commonly vary with changing altitude. We broke continuous elevation data for the LNE and NAC ecoregions (from the National Elevation Dataset of the USGS) into discrete elevation classes with relevance to the distribution of forest types region-wide. Meaningful biotic zones would be defined with quite different elevation cut-offs in the northern and southern parts of the region, so class ranges necessarily approximate critical ecological values.

Appendix Table 1. Ranges for elevation classes.

Elevzone	*M (ft)*	*Characteristic forest type*
1000/2000	0-6 & 6-234 (0-20 & 20-800)	Oak, pine-oak, pine-hemlock, maritime spruce, floodplain forest
3000	234-533 (800-1700)	Hemlock-N. hardwoods, N. hardwoods, lowland spruce-fir
4000	533-762 (1700-2500)	Northern hardwoods, spruce-hardwoods
5000	762-1158 (2500-4000)	Krummholz, montane spruce-fir, alpine communities

Bedrock geology and deep sediments

Bedrock geology strongly influences area soil and water chemistry. Even in glaciated landscapes, studies suggest that soil parent material is commonly of local origin, rarely being ice-transported more than a few miles from its source. Bedrock types also differ in how they weather and in the physical characteristics of the residual soil type. Because of this, local lithology is usually the principle determinant of soil chemistry, texture, and nutrient availability. Many ecological community types are closely related to the chemistry and drainage of the soils or are associated with particular bedrock exposures.

We grouped bedrock units on the bedrock geology maps of ME, NH, VT, MA, CT, RI, NY, PA, NJ, and MD into seven general classes designed to have particular relevance to vegetation distributions (Appendix Table 2). We based our scheme on broad classification schemes developed by other investigators which emphasize chemistry and texture, and on bedrock settings that are important to many ecological communities, particularly to their herbaceous components. Please refer to another file accompanying this metadata, bedgeo_src.doc, for information on bedrock geology source materials.

In some settings deep sediments of glacial origin mantle the bedrock. The consolidated bedrock of valleys of pro-glacial lakes, for example, may lie under many meters of fine lacustrine sediments, and deep coarse deltaic or outwash deposits often overlay the bedrock in pine barrens and sand plains in the northeast. In these settings it is the nature of the sediments—their texture, compactness, and moisture-holding capacity, their nutrient availability, their ability to anchor overstory trees in a wind disturbance--that is ecologically relevant, and not the nature of the underlying bedrock. We used a USGS dataset of sediments of the glaciated northeast to identify such places. The USGS map was compiled at a coarse scale (1:1,000,000), but we made the data a little "smarter" by informing it with our landform map (please see the document on landforms that accompanies this metadata). Our landform layer was compiled at a much finer scale (the scale of the digital elevation models from which they were constructed, 1:24,000), and we allowed the deep coarse or fine sediments of the USGS dataset to be mapped only on those landforms on which they would naturally be expected to occur. In the case of sandy, coarse sediments, this would be in broad basin and valley/toe slope settings; in the case of fine clayey lacustrine or marine sediments, in these same settings, plus low hills and lower sideslopes. The seven bedrock classes were numbered 100 through 700 (Appendix Table 2), and the coarse and fine sediments classes were numbered 800 and 900, respectively.

Appendix Table 2. Bedrock geology classes.

Geology class	*Lithotypes*	*Meta-equivalents*	*Comments*	*Some characteristic communities*
100: ACIDIC SEDIMENTARY / METASEDIMENTARY: fine- to coarse-grained, acidic sed/metased rock	Mudstone, claystone, siltstone, non-fissile shale, sandstone, conglomerate, breccia, greywacke, arenites	(Low grade:) slates, phyllites, pelites; (Mod grade:) schists, pelitic schists, granofels	Low to moderately resistant rocks typical of valleys and lowlands with subdued topography; pure sandstone and meta-sediments are more resistant and may form low to moderate hills or ridges	Many: low- and mid-elevation matrix forests, floodplains, oak-pine forest, deciduous swamps and marshes
200: ACIDIC SHALE: Fine-grained acidic sedimentary rock with fissile texture	Fissile shales		Low resistance; produces unstable slopes of fine talus	Shale cliff and talus, shale barrens
300: CALCAREOUS SEDIMENTARY / META-SEDIMENTARY: basic/alkaline, soft sed/metased rock with high calcium content	Limestone, dolomite, dolostone, other carbonate-rich clastic rocks	Marble	Lowlands and depressions, stream/river channels, ponds/lakes, groundwater discharge areas; soils are thin alkaline clays, high calcium, low potassium; rock is very susceptible to chemical weathering; often underlies prime agricultural areas	Rich fens and wetlands, rich woodlands, rich cove forests, cedar swamps, alkaline cliffs
400: MODERATELY CALCAREOUS SEDIMENTARY / METASED: Neutral to basic, moderately soft sed/metased rock with some calcium but less so than above	Calc shales, calc pelites and siltstones, calc sandstones	Lightly to mod. metamorphosed calc pelites and quartzites, calc schists and phyllites, calc-silicate granofels	Variable group depending on lithology but generally susceptible to chemical weathering; soft shales often underlie agricultural areas	Rich coves, intermediate fens
500: ACIDIC GRANITIC: Quartz-rich, resistant acidic igneous and high grade meta-sedimentary rock; weathers to thin coarse soils	Granite, granodiorite, rhyolite, felsite, pegmatite	Granitic gneiss, charnockites, migmatites, quartzose gneiss, quartzite, quartz granofels	Resistant, quartz-rich rock, underlies mts and poorly drained depressions; uplands & highlands may have little internal relief and steep slopes along borders; generally sandy nutrient-poor soils	Many: matrix forest, high elevation types, bogs and peatlands

600: MAFIC / INTERMEDIATE GRANITIC: quartz-poor alkaline to slightly acidic rock, weathers to clays	(Ultrabasic:) anorthosite (Basic:) gabbro, diabase, basalt (Intermediate, quartz-poor:) diorite/ andesite, syenite/ trachyte	Greenstone, amphibolites, epidiorite, granulite, bostonite, essexite	Moderately resistant; thin, rocky, clay soils, sl acidic to sl basic, high in magnesium, low in potassium; moderate hills or rolling topography, uplands and lowlands, depending on adjacent lithologies; quartz- poor plutonic rocks weather to thin clay soils with topographic expressions more like granite	Traprock ridges, greenstone glades, alpine areas in Adirondacks
700: ULTRAMAFIC: magnesium-rich alkaline rock	Serpentine, soapstone, pyroxenites, dunites, peridotites, talc schists		Thin rocky iron-rich soils may be toxic to many species, high magnesium to calcium ratios often contain endemic flora favoring high magnesium, low potassium, alkaline soils; upland hills, knobs or ridges	Serpentine barrens

Landforms

Stanley Rowe called landform "the anchor and control of terrestrial ecosystems." It breaks up broad landscapes into local topographic units, and in doing so provides for meso- and microclimatic expression of macroclimatic character. It is largely responsible for local variation in solar radiation, soil development, moisture availability, and susceptibility to wind and other disturbance. As one of the five "genetic influences" in the process of soil formation, it is tightly tied to rates of erosion and deposition, and therefore to soil depth, texture, and nutrient availability. These are, with moisture, the primary edaphic controllers of plant productivity and species distributions. If the other four influences on soil formation (climate, time, parent material, and biota) are constant over a given space, it is variation in landform that drives variation in the distribution and composition of natural communities.

Of the environmental variables discussed here, it is landform that most resists quantification. Landform is a compound measure, which can be decomposed into the primary terrain attributes of elevation, slope, aspect, surface curvature, and upslope catchment area. The wide availability and improving quality of digital elevation data has made the quantification of primary terrain attributes a simple matter. Compound topographic indices have been derived from these primary attributes to model various ecological processes. We adopted the Fels and Matson (1997) approach to landform modeling. They described a metric that combines information on slope and landscape position to define topographic units such as ridges, sideslopes, coves, and flats on the landscape. That approach is described here: feel free to skip over the details, to the set of defined landforms that emerges from the process (Appendix Figure 1 and Appendix Table 3 below).

The parent dataset for the two grids used to construct the landforms is the 30 meter National Elevation Dataset digital elevation model (DEM) of the USGS. Step one was to derive a grid of discrete slope classes relevant to the Northern Appalachian landscape. We remapped slopes to

create classes of 0-2˚ (0.0-3.5%), 2-6˚ (3.5–10.5%), 6-24˚ (10.5–44.5%), 24-35˚ (44.5-70.0%), and >35˚ (>70.0%) (vertical axes of Figure1). Ground checks have shown that, because the NED dataset averages slopes over 30 meter intervals, raster cells in the 2 steepest elevation classes contain actual terrain slopes of from about 35 to 60 degrees (in the 24-35˚ class) and 60 to 90 degrees (in the steepest class).

The next step was the calculation of a landscape position index (LPI), a unitless measure of the position of a point on the landscape surface in relation to its surroundings. It is calculated, for each elevation model point, as a distance-weighted mean of the elevation differences between that point and all other elevation model points within a user-specified radius:

$$LPI_o = \left[\sum_{1,n} (z_i - z_o) / d_i \right] / n,$$

where z_O = elevation of the focal point whose LPI is being calculated,
z_i = elevation of point i of n model points within the specified search radius of the focal point,
d_i = horizontal distance between the focal point and point i, and
n = the total number of model points within the specified search distance.

If the point being evaluated is in a valley, surrounding model points will be mostly higher than the focal point and the index will have a positive value. Negative values indicate that the focal point is close to a ridge top or summit, and values approaching zero indicate low relief or a mid-slope position (Appendix Figure 1).

The specified search distance, sometimes referred to as the "fractal dimension" of the landscape, is half of the average ridge-to-stream distance. We used two methods to fix this distance for each subsection within the region, one digital and one analog. The "curvature" function of the ArcInfo Grid module uses the DEM to calculate change in slope ("slope of the slope") in the landscape. This grid, when displayed as a stretched grayscale image, highlights valley and ridge structure, the "bones" of the landscape, and ridge-to-stream distances can be sampled on-screen. For our analog approach we used 7.5' USGS topographic quadsheets. In each case, we averaged several measurements of ridge-to-stream distances, in landscapes representative of the subsection, to obtain the fractal dimension. This dimension can vary considerably from one subsection to another.

There is a third approach to fixing the landscape fractal dimension. A semivariogram of a clip of the DEM for a typical portion of the regional landscape can be constructed— it quantifies the spatial autocorrelation of the digital elevation points by calculating the squared difference in elevation between each and every pair of points in the landscape, then plotting half that squared difference (the “semivariance”) against the distance of separation. A model is then fitted to the empirical semiovariogram “cloud of points.” (This model is used to guide the prediction of unknown points in a kriging interpolation.) The form of the model is typically an asymptotic curve that rises fairly steeply and evenly near the origin (high spatial autocorrelation for points near one another) and flattens out at a semivariance “sill” value, beyond which distance there is little or no correlation between points. Though the sill distance, in the subsections where we tried this approach, was 2 or 3 times the “fractal distance” as measured with the first 2 methods,

the relationship between the two was fairly consistent. With a little more experimentation, the DEM semivariogram could prove to be a useful landscape analysis tool.

The next step was to divide the grid of continuous LPI values into discrete classes of high, moderately high, moderately low, and low landscape position. Histograms of the landscape position grid values were examined, a first set of break values selected, and the resulting classes visualized and evaluated. We did this for several different types of landscapes (rolling hills, steeply cut mountainsides, kame complexes in a primarily wet landscape, broad valleys), in areas of familiar geomorphology. The process was repeated many times, until we felt that the class breaks accurately caught the structure of the land, in each of the different landscape types. Success was measured by how well the four index classes represented the following landscape features:

High landscape position (very convex): sharp ridges, summits, knobs

Moderately high landscape position: upper side slopes, rounded summits and ridges, low hills and kamic convexities

Moderately low landscape position: lower sideslopes and toe slopes, gentle valleys and draws, broad flats

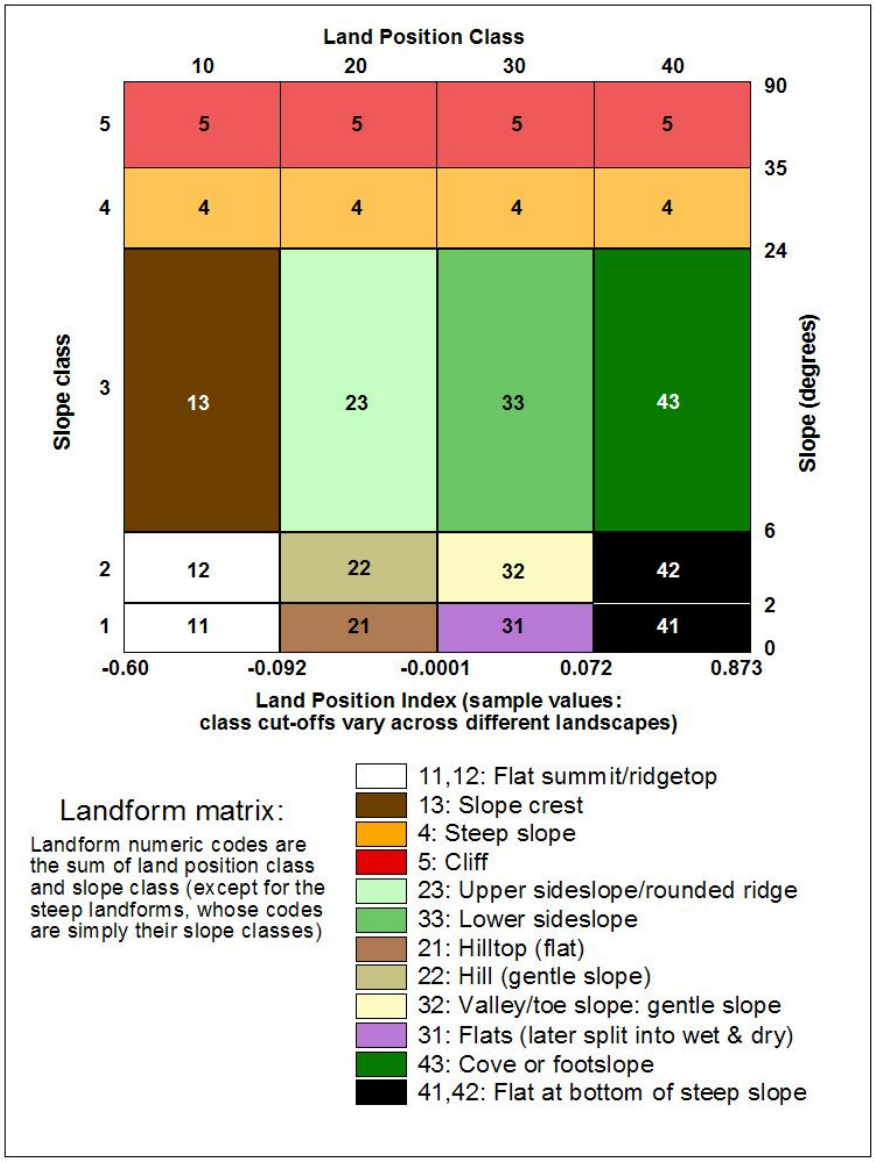
Low landscape position (very concave): steeply cut stream beds and coves, and flats at the foot of steep slopes

We assigned values 1-5 to the five slope classes, and 10, 20, 30, and 40 to the four LPI classes. Following Fels and Matson (1997), we summed the grids to produce a matrix of values (Appendix Figure 1), and gave descriptive names to landforms that corresponded to matrix values. We collapsed all units in slope classes 4 and 5 into "steep" and "cliff" units, respectively. The ecological significance of these units, which are generally small and thinly distributed, lies in their very steepness, regardless of where they occur on the landscape.

Recognizing the ecological importance of separating occurrences of “flats” (0-2˚ slope) into primarily dry areas and areas of higher moisture availability, we calculated a simple topographic moisture index that maps variation in moisture accumulation and soil residence time. We used National Wetlands Inventory datasets to calibrate the index and set a wet/dry threshold, then applied it to the flats landform to make the split. The formula for the moisture index is:

$$\text{Moist_index} = \ln [(\text{flow_accumulation} + 1) / (\text{slope} + 1)]$$

Grids for both flow accumulation and slope were derived from the DEM by ArcInfo Grid functions of the same names.

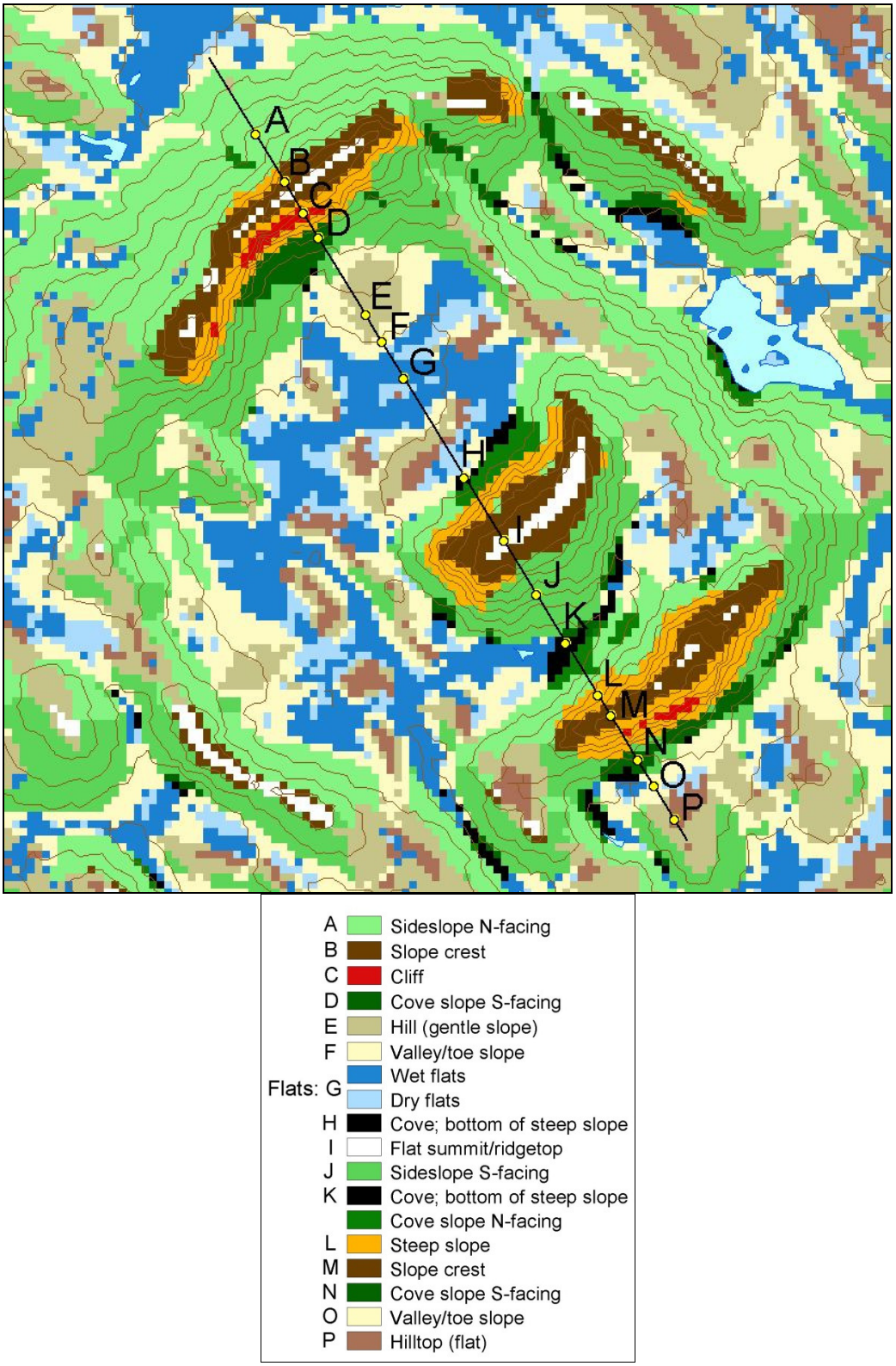


Appendix Figure 1: Formulation of landform models from land position and slope classes.

For the ecoregional ELU dataset, upper and lower sideslopes are combined, and a simple ecologically relevant aspect split is embedded in the sideslope and cove slope landforms (Appendix Figure 2 and Appendix Table 3).

Last, waterbodies from the National Hydrography Dataset (NHD), which was compiled at a scale of 1:100,000 and is available for the whole region, were incorporated into the landform layer with codes 51 (broader river reaches represented as polygons) and 52 (lakes, ponds, and reservoirs). Single-line stream and river arcs from the NHD were not burned into the landforms-- only those river reaches that are mapped as polygons.

Landform units for an area of varied topography in southeastern New Hampshire are shown in map view in Appendix Figure 2.



Appendix Figure 2: Landforms in Pawtuckaway State Park, NH

The ELU grid

With the elevation, substrate, and landform layers, all the elements for assembling ecological land units, or ELUs, are in place. ELU code values for each cell in the region-wide grid are simply the summed class values for elevation zone, substrate, and landform for that cell (Appendix Table 3). For example, a cell in a wet flat (landform 31) at 1400 feet (elevation class 2000) on granitic bedrock (substrate class 500) would be coded 2531.

Appendix Table 3: How the 4-digit ELU code is calculated.

Elevation class (ft)	+	**Substrate class**	+	**Landform**
1000 (0-800)		100 acidic sed/metased		4 steep slope
2000 (800-1700)		200 acidic shale		5 cliff
3000 (1700-2500)		300 calc sed/metased		11 flat summit/ridgetop
4000 (2500-4000)		400 mod. calc sed/metased		13 slope crest
5000 (> 4000)		500 acidic granitic		21 Hilltop (flat)
		600 mafic/intermed granitic		22 Hill (gentle slope)
		700 ultramafic		23 NW-facing sideslope
		800 coarse sediments		24 SE-facing sideslope
		900 fine sediments		30 Dry flat
				31 Wet flat
				32 Valley/toe slope
				41 Flat at bottom of steep slope
				43 NW-facing cove/draw
				44 SE-facing cove/draw
				51 Polygonal rivers from NHD
				52 NHD lakes/ponds/reservoirs

Waterbodies from the National Hydrography Dataset (NHD), which was compiled at a scale of 1:100,000 and is available for the whole region, were incorporated into the landform layer (landform codes 51 and 52). Single-line stream and river arcs from the NHD were not burned into the landforms-- only those river reaches that are mapped as polygons.

The ELU grid for the Lower New England/Northern Piedmont and North Atlantic Coast Ecoregions comprises 503 unique combinations of elevation zone, substrate type, and landform. We added an "ELU_color" item to the attribute table, and used it to construct a coding scheme that assigns ELU values to groups of a particular ecological character. Symbolizing on the ELU_color item creates a simplified display of the complex ELU dataset (see "Displaying the data" below). A fragment of the attribute table for the two-ecoregion ELU grid is reproduced in Appendix Table 4.

Appendix Table 4. Sample set of three ecological land unit codes ("value" item) from the ELU value attribute table for the LNE and NAC ecoregions.

VALUE	5113	3424	1831
COUNT	15655	339325	3606930
ELEVZONE	5000	3000	1000
ELEVZONE_DESC	2500-4000ft	1700-2500ft	0-20ft
SUBSTRATE	100	400	800
SUBSTR_DESC	acidic sedimentary/ metasedimentary	moderately calcareous sed/metased	coarse sediments
LANDFORM30	13	24	31
LF30_DESC	Slope crest	Sideslope S-facing	Wet flats
ELU_COLOR	12	22	32
ELUCOLOR_DESC	Slope crest	Sideslope S-facing	Wet flats on deep coarse sediments