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TOPOGRAPHICALLY-BASED LANDSCAPE-SCALE

ECOLOGICAL MAPPING IN PENNSYLVANIA

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Ecology

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Ningning Kong

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The thesis of Ningning Kong was reviewed and approved* by the following:

Wayne L. Myers
Professor of Forest Biometrics
Thesis Adviser
Chair of Committee

Denice H. Wardrop
Associate Professor of Geography and Ecology

Charles Andrew Cole
Assistant Professor of Landscape Architecture

Rick Day
Associate Professor of Soil Science and Environmental Information Systems

David A. Mortensen
Professor of Weed Ecology
Chair of the IGDP in Ecology

*Signatures are on file in the Graduate School

Abstract

With emphasis on sustainable ecosystem management, ecological mapping at landscape scale provides basic information about the nature and distribution of ecosystems for natural resources management, planning, monitoring and assessment. Landtype association (LTA) and ecological landtype (ELT) are two landscape scales of ecological units in a hierarchical ecological classification system developed by the USDA-Forest Service for use in ecosystem management. LTA is a complex of complementary landscape components (ecological landtypes) that combine through spatial adjacency to create ecological contrasts across regions. ELT is a subdivision of LTA unit based on similarities in landform, soils, geomorphic processes, and plant associations. The goal of this study is to develop, describe and verify a scientifically based system of map units for Pennsylvania that incorporates ecological principles and processes across landtype association and ecological landtype scales.

At the LTA level, the influences of topography and terrain topology on ecosystem distributions motivated an ecological mapping approach with the concern for ecological, hydrologic and environmental aspects of the area that separates LTA units into three major categories, as highland habitat (HH), transitional terrace (TT), and dual drainage (DD). Highland habitat is designated as being primarily headwater stream areas composed of mounding or arching to level upper land surfaces. Dual drainage is designated to be areas having both large streams and small tributary streams. Transitional terrace is intermediate level elevated terrain unit that is otherwise similar to highland habitat, but also receives some hydrologic influx from adjacent upland along partial margin. A GIS-assisted, top-down classification method was adopted in the mapping procedure, and produced 10,782 LTA units delineated across the state with size ranging from 100 to 5,000 acres.

These units were classified into eighteen subtypes according to their topographic and hydrologic characteristics.

At the ELT level, considered as unique combinations of topography and soil characteristics, the mapping units were generated by aggregating adjacent soil SSURGO polygons with same soil series, aspect and similar slopes. There were 699,336 ELT units mapped for sixty-four counties in the state where soil data are available with the size ranging from 10 to 100 acres.

Relationships between the resulting ecological units and other spatial information were analyzed. The results indicate that physiographic characteristics, stream node and drainage densities, land cover patterns, and vertebrate species habitat distributions have substantial differences between different types of ecological units.

In general, the highland habitats and transitional terraces have larger size, higher average elevation and relief, and steeper slope compared to the dual drainage units. The ELT units in highland habitats and transitional terraces also tend to have larger size and steeper slope.

The hydrologic characteristics of LTA units indicate that in most of the physiographic subsections the first-order stream node density is much higher in the highland habitats and transitional terraces, whereas higher order stream node densities are higher in the dual drainages. Drainage densities are higher in dual drainages for all stream orders. In different LTA subtypes, the stream node and drainage density patterns also have definite differences. This establishes that the LTA mapping in this study can effectively separate headwater areas from downstream drainage areas, and also that the LTA subtype classification can separate different hydrologic characteristics in each subtype.

Land cover has different patterns in different landtype associations. There are more intensive human land use areas located in the dual drainage units, whereas forests are more likely to be extensive in the highland habitats and transitional terraces. It is shown that the LTA unit types reflect the preference of human activities, thus determining the distribution patterns of forest and wildlife habitats.

Most of the vertebrate species also have significantly different potential habitat distributions between the HH/TT and DD types of LTA units in each physiographic component. Some key species can be identified having strong affinity for certain kinds of LTA units. Highland habitats and transitional terraces are favorable for species associated with headwater streams, exposed environment and forest land cover types. Dual drainages are favorable for species associated with moist environments and large streams. The results confirm that LTA units can separate different habitats at the landscape level.

Table of Contents

List of Tables

List of Figures

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Chapter 1

Introduction

The goal of ecosystem management is to conserve, restore, and maintain the health, integrity, sustainability, and biological diversity of ecosystems (Grumbine, 1994; Interagency Ecosystem Management Task Force, 1995). Ecosystem management attempts to maintain the complex processes, pathways and interdependencies of ecosystems and keep them functioning well over long periods of time, in order to provide resilience to short-term stress and adaptation to long-term changes (Risser, 1999; Gunderson, 2000).

To implement sustainable ecosystem management, we need basic information about the nature and distribution of ecosystems (Cleland, 1997). Management should be applied within a geographic framework defined primarily by ecological boundaries. Even though spatial organization of ecosystems tends toward gradations, there is some order of pattern to these systems that should be considered in the inventory and stewardship of natural resources (Gleason, 1926; Shipley and Keddy, 1987; Küchler, 1988).

Ecological mapping provides an environmentally relevant system for classifying landscapes and conducting monitoring. It is a method of designating units of land with uniform climate, physiography, topography, soil or vegetation characteristics at different research and management scales (Devlin et al., 2001; Zastrow, 2001). It offers an effective way to collect and convey complex information about ecosystems and biodiversity and it facilitates understanding of landscape organizations in terms of ecological implications for resource management. Ecological mapping is independent of political boundaries, which allows for shared resources, data and criteria; and it provides a logical classification of sites for the establishment of reference conditions. Land ownership is not a consideration when delineating ecological units; but propensity toward urbanization and agricultural land uses does figure in the determination (Myers, 2000).

ECOMAP for Pennsylvania has endorsed and adapted the concepts of the U.S. Forest Service *National Hierarchical Framework of Ecological Units* (ECOMAP, 1993), which entails ecological classification at eight different scales based on concepts and terminology developed by numerous scientists and resource managers. From broad scale to fine, these eight types of ecological units are:

1. Domain
2. Division
3. Province
4. Section
5. Subsection
6. Landtype association
7. Ecological landtype
8. Landtype phase

The Forest Service, in cooperation with the Pennsylvania Bureau of Forestry, coordinated cooperative delineation of ecological units within the Commonwealth and across state boundaries of Pennsylvania through the first five levels of the hierarchy.

The first three levels of ecological units, adapted from Bailey (1980), are considered at continental to regional scales, and recognized by differences in global, continental, and regional climatic regimes and gross physiography based on the assumption that climate governs energy and moisture gradients, thereby acting as the primary control over more localized ecosystems (ECOMAP, 1993).

Section and subsection units for Pennsylvania were configured for compatibility with the long-standing and widely recognized physiographic features of Pennsylvania (Sevon, 2000). At these levels, the hierarchy delineates ecological units based on environmental and biotic factors including geomorphology, lithology and stratigraphy, potential natural vegetation, fauna, climate, hydrology, natural disturbance regimes, land use and other aspects of cultural ecology (ECOMAP, 1993). Further work is needed in refining these designations to produce detailed layers and delineate zones at the landscape scale as *landtype association* (LTA) and *ecological landtype* (ELT) levels.

This research focuses on the delineation of landtype associations and ecological landtypes. LTAs are complexes of complementary landscape features that combine through spatial adjacency to create ecological contrasts across regions (Myers, 2000). They can be presented as landscape level potential ecosystems, made up of clusters of interacting finer-scaled patches (Crow, 1991). At this scale, general topography, potential natural community patterns and local climate are important determining factors in defining ecological units (Forman and Godron, 1986). These factors affect biotic distributions, hydrologic function, natural disturbance regimes and general land uses. An LTA is individualistic to some degree, since the effect created by the combination of landscape elements and geographic setting may not occur elsewhere (Myers, 2000). As a landscape level unit, landtype association represents a scale at which natural resource management plans and operations become more specific. As defined by the hierarchical framework (ECOMAP, 1993), the general polygon size of LTA will be hundreds to thousands of acres. However, this size standard may change in different states according to their specific ecological settings, different kinds of mapping strategies, and the designed mapping purposes. For example, in landtype association mapping of the national forest land in the northern region, LTA unit size ranges approximately from 23,000 to 9,000,000 acres (9,300 to 3,642,000 hectares), which is much bigger than the hierarchy design, but fits their management purposes.

ELTs are subdivisions of LTAs based on similarities in soils, landform, geomorphic processes, and plant associations (ECOMAP, 1993). They are instances of a specific landscape setting. ELTs are influenced by a suite of interrelated local environmental factors such as solar insolation, drainage, and wind. Topographic factors are the strongest considerations for delineating ELTs (Shao, 1999). Differences in soil and geology should be expressed in this level of delineation as well. ELTs are most relevant to ecological analysis, understanding, and manipulation at site level. As designed by the national hierarchical framework, the general size range of ELTs is ten to hundreds acres.

Research Objectives

The goal of this study is to develop and describe a scientifically based system of map units for Pennsylvania that incorporates ecological principles and processes across landtype association and ecological landtype scales. This study uses information regarding topography and terrain topology derived from digital elevation models and other data sources including watersheds, soils, streams and remote sensing images, to map landtype associations and ecological landtypes within Pennsylvania. The specific objectives of this study are as follows:

1. To delineate landscape units at landtype association (LTA) scale for Pennsylvania using topographic and terrain topological information.
2. To map ecological landtypes (ELTs) for Pennsylvania using topographic and soil information.
3. To verify and describe the ecological units with respect to their physiographic, hydrologic, ecological and land cover characteristics.

The landtype association classification approach is based on topological features of terrain from a hydrologic and habitat perspective, considering that topography and terrain topology organize and express ecological influences at the landscape scale, especially in Pennsylvania where terrain has substantial variability in elevation and steep slopes. The ecological landtype mapping is based on topographic and soil information considering that the combination of these two factors determines water and nutrient availability for plant communities. After the mapping processes, topographic and soil properties of the result mapping units are described, and effectiveness of mapping methods is examined by comparing hydrologic, land cover, and ecological differences between different kinds of mapping units.

The ecological mapping in this study requires that the resulting units should be applicable at local scales. This point is extremely important to our objectives. LTAs and ELTs must be recognized on the ground as well as on a map. The boundaries should be appropriate in the real research and management activities.

Major Motivations

In this study, the landtype association classification is developed based on topographic analysis of landscapes with the concern for ecological, hydrologic and environmental aspects of the area. As defined by the National Hierarchical Framework (ECOMAP, 1993), the goal of ecological mapping is to classify particular study areas into landscape level components with particular ecological potentials. From this perspective, ecological interpretability becomes the most important consideration in the LTA mapping designation. The mapping framework should be effective for segregating different ecological conditions. The framework should be useful for ecological resource assessment, research, inventory, monitoring and management. Also, ecosystems are places where life forms and environment interact, and are composed of multiple abiotic and biotic factors. The moisture regimes and environmental differences should also be reflected in this classification.

The concept of landscape is itself a multi-scale construct, and is strongly tied to vicinity and surroundings. We also seek to operationalize the somewhat nebulous concepts of landscapes in terms of LTA units. To this end, we consider a particular LTA polygon to be a zero-order landscape. An order-one landscape emerges when this is augmented by all neighboring LTA polygons that make contact on a boundary. Similarly, an order-two landscape comes from augmenting with neighbors of neighbors. Higher-order landscapes can be obtained in like manner. With this approach, ecological contrasts can be revealed at landscape levels among different mapping units.

At the landtype association level, general topography and the terrain topology exert strong control over environmental conditions through complex interactions. Major factors among these include erosion, exposure, stream types, disturbance regimes, etc. Rowe (1961) defined an ecosystem as “a topographic unit”. Viedma (1999) verified this definition by examining the relationships between the topographic units and vegetation developments, and concluded that the environmental constraints within a particular terrain unit exert a strong and persistent effect on vegetation composition within the unit and strengthen the association between current vegetation and topographic characteristics. With the landscape definition in this study, we consider contexts of sites, settings and surroundings where regional and relative relief has evident expression over the scope of visible vicinity.

With topographic and terrain topology information as the primary data source, the LTA mapping in this study is based on the following hypotheses. First, the information is supposed to be able to reveal surficial hydrologic influences. The upland areas tend to have headwater streams and drier conditions, whereas lowland areas concentrate moisture. Second, the terrain units are assumed to reflect propensity for different disturbance regimes. Gentle terrain and low elevation favor human activities, thus bringing more disturbances to the ecosystems, whereas steep slopes and highlands tend to have naturalistic and intact habitats. Third, different terrain characteristics are associated with different habitat types. Highland areas favor species associated with drought conditions and exposed environment, whereas lowland areas favor species requiring moisture and nutrient-rich habitats.

At the ecological landtype level, the site level conditions will be reflected for resource management. At this finer scale, water, plant, animals, soils, and topography interact to form ecosystems (Cleland, 1997). As defined by ECOMAP (1993), ecological units at this scale should be designed and mapped based on properties of local topography, rock types, soils, and vegetation, because these factors influence the structure and composition of plant communities, hydrologic function, and basic land capability. In this study, ELTs are defined by combinations of topographic information and soil characteristics, with the goal of capturing differences in water and nutrient availability for natural communities at specific positions in the landscape. With the soil information included in this level of mapping, geological substrate characteristics will be captured indirectly.

GIS-assisted mapping methods have been developed in this study for both LTA and ELT mappings. At the LTA level, the terrain units are classified across upper level ecological boundaries in the state through combinations of GIS assisted mapping and human interpretation method. These methods should be adaptable to other areas having similar degree of topographic expression as Pennsylvania, while allowing us to profile LTA units in terms of environmental, ecological and hydrologic characteristics. At the ELT level, an automated GIS mapping method was developed to generate ELT units where detailed soil surveys are available.

GIS is used in this mapping study based on the following considerations. First, GIS offers convenient ways to calculate local topographic parameters. Based on a digital elevation model, slopes, aspects, curvatures, and flow characteristics can be calculated readily with GIS software, which greatly facilitates the topographically based ecological mapping. Second, as more and more thematic digital maps become available, GIS helps to overlay all kinds of data sources for the mapping purpose. Although digital elevation data were our primary reference, a variety of coverages including soils, streams, and remote sensing images helped to make the determinations where terrain distinctions are subtle.

Potential Use of the Mapping Units

LTA and ELT levels of ecological units bear directly on natural resource management and planning. Ecological unit maps at these levels may be used for activities such as delineating ecosystems, assessing resources, conducting environmental analyses, establishing desired future conditions, and managing and monitoring natural resources (ECOMAP, 1993).

LTA and ELT units provide spatial framework inventories of potential ecosystem conditions. Combined with existing conditions such as current vegetation, wildlife, water quality, etc., these ecological units provide the basis for inference regarding ecosystems. To assess and manage resources, the LTA and ELT level ecological units can be used to identify areas with propensities toward similar natural disturbance regimes, assess site conditions and stratify distributions of terrestrial and aquatic biota, forest growth, succession and health, and various physical conditions, thus helping to establish management objectives to meet conservation, restoration and human needs. For comparative environmental analyses, these ecological units facilitate studying the feasibility and effects of management alternatives.

Chapter 2

Previous Work

Broad Scale Ecological Mapping in Pennsylvania

The first three levels of ecological units (domain, division and province) are adapted from Bailey's ecoregion classification (1980). Pennsylvania encompasses warm continental and hot continental divisions of the humid temperate domain. The division and province levels of ecological units in Pennsylvania are shown in Figure 2.1. Most of northern Pennsylvania lies in the *Laurentian Mixed Forest Province* of the warm continental division. The bulk of central and southern Pennsylvania lies in the *Eastern Broadleaf Forest Oceanic Province* of the hot continental division with the more mountainous areas called *Central Appalachian Broadleaf Forest – Coniferous Forest – Meadow Province*. The Lake Erie shore area lies in the *Eastern Broadleaf Forest Continental Province* of the hot continental division.

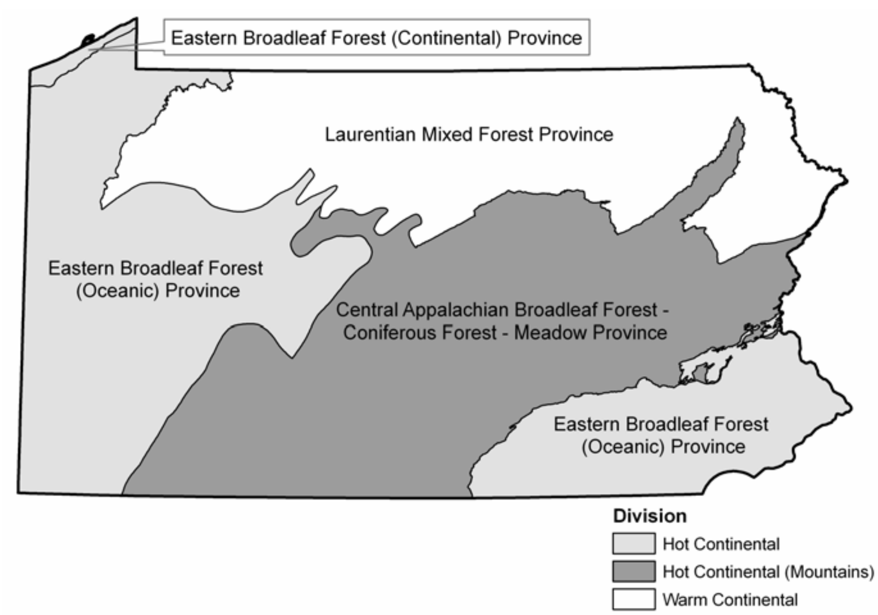


Figure 2.1 Ecological divisions and provinces in Pennsylvania.

Section and subsection levels of ecological mapping have been done in Pennsylvania, and they were configured for compatibility with the physiographic features of Pennsylvania (Sevon, 2000). The section level ecological units in Pennsylvania, which correspond to a different classification of physiographic units, are shown in Figure 2.2. There are three primary and three minor physiographic components across the extent of the state. The three primary physiographic components are Appalachian Plateaus, Ridge and Valley, and Piedmont. They can be considered in a progression of decreasing size beginning in the northwest then moving south and east.

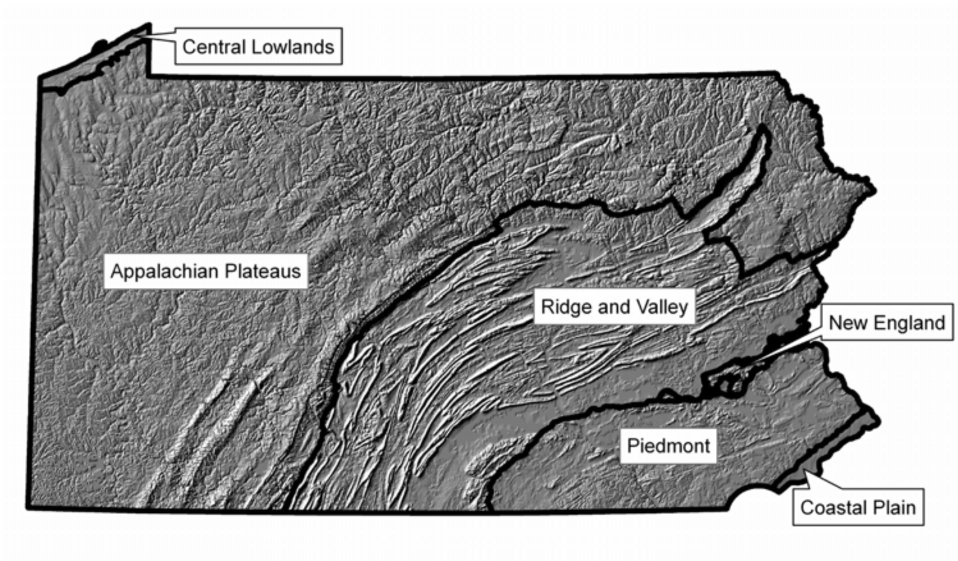


Figure 2.2 Physiographic areas of Pennsylvania.

The Appalachian Plateaus cover most of northern and western Pennsylvania. A thick horizontal and relatively unfolded layer of resistant sandstone is the major formative element of the region (Loomis, 1937). The sandstone weathered slowly resulting in shallow, infertile soils that are more suited to forests than to agriculture. The sandstones of these plateaus contain inter-bedded shales that are more easily eroded, giving rise to differential dissections in the form of steep river valleys.

The Ridge and Valley is a belt of sinuous ridges and interconnecting valleys with a general northeast-southwest orientation. The ridges are primarily resistant shale and sandstone and the valley floors are primarily made up of soft and eroded limestone (Loomis, 1937). The forested ridges are rocky with thin infertile soils. Soil fertility increases as one moves into the valleys, particularly where limestone parent material is found.

Landscapes of the Piedmont Plateau are generally undulating to gently rolling hills on a very old worn down surface of deeply weathered igneous and metamorphic bedrock (Cuff, 1989). Chemical weathering is extensive, and true soils, lacking residual rock structures, are generally 2-6 feet thick (DCNR, 2004). Agriculture and urbanized development are the primary land uses. Remaining forests are restricted mostly to the more rugged topography where relatively resistant parent materials produce shallower soils.

Three minor physiographic components include a narrow strip of Central Lowlands along the shore of Lake Erie, a narrow strip of Coastal Plain along the Delaware Bay, and a Reading Prong of a New England formation in eastern Pennsylvania. Both Central Lowland and Coastal Plain have relatively low elevation compared to adjacent components. The Central Lowland includes a series of northwest-sloping, lake-parallel, low-relief ridges. The Coastal Plain consists of a flat upper terrace surface that is cut by numerous short streams. The New England component has relatively higher elevation compared to its neighbors. It consists of circular to linear, rounded low hills or ridges that project upward in significant contrast to the surrounding lowlands (DCNR, 2004).

At subsection level, the three major physiographic components were further divided as shown in Figure 2.3.

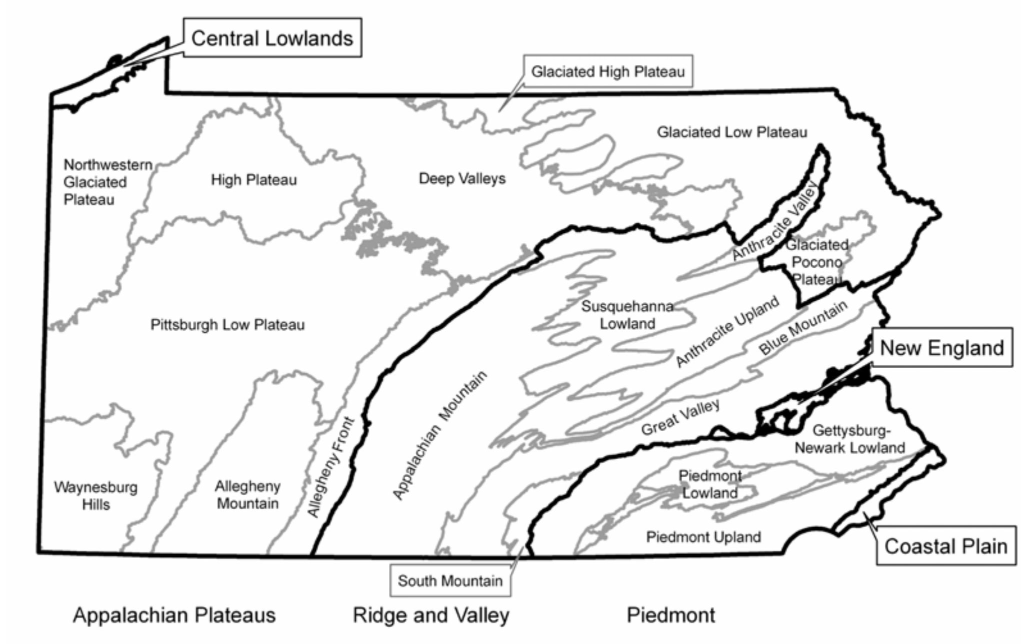


Figure 2.3 Physiographic subsections of Pennsylvania.

The Appalachian Plateaus are subdivided into ten parts (Sevon, 2000). The northwestern and northeastern portions were glaciated, which further contributed to differentiation of this region, and formed Northwestern Glaciated Plateau, Glaciated Low Plateau on the northeast corner of the state, Glaciated Pocono Plateau on northeast, and several small pieces of Glaciated High Plateau. These glaciated parts consist of many broad to narrow, rounded or elongate uplands cut by long, linear valleys with steep slopes or well defined escarpments. Deep Valleys occur in the north central portion consisting of many narrow, flat to sloping uplands separated by deep, steep-sloped valleys. The high plateau occurs between the Northwestern Glaciated Plateau and the Deep Valleys. This area is characterized by broad, rounded to flat uplands cut by deep angular valleys. Moving down to the south, the Pittsburgh Low Plateau covers most of western and southwestern Pennsylvania. It consists of a smooth undulating upland surface cut by numerous, narrow, relatively shallow valleys. Valley sides are usually moderately steep except in the upper reaches of streams where the side slopes are fairly gentle. The eastern edge of the Appalachian Plateaus is sharply demarcated by the east-facing scarp, which forms the Allegheny Front. This provides an abrupt transition between the Ridge and Valley and the Appalachian Plateaus. The Allegheny Mountains occur west of the Allegheny Front. They consist of broad, rounded ridges separated by relatively broad valleys. The ridges decrease in elevation from south to north. The Waynesburg Hills occur in the southwest corner of the state, and are characterized by very narrow hilltops and steep-sloped, narrow valleys.

The Ridge and Valley can be further divided into seven components (Sevon, 2000). The Appalachian Mountains occur next to the Allegheny Front. This is a strongly folded area, consisting of numerous, long, narrow mountain ridges separated by narrow to wide valleys. Very hard sandstones occur at the crests of the ridges and relatively soft shales and siltstones occur in most of the valleys. Some of the valleys here are also underlain by limestone and dolomite. The Susquehanna Lowland occurs in east-central Pennsylvania, and consists of low to moderately high, linear ridges and linear valleys, and the Susquehanna River valley. The local relief in this part is much less than for the Appalachian Mountains to the west. The Anthracite Valley is a canoe-shaped valley enclosed by a steep-sloped mountain rim, occurring in the northeast corner of the Ridge and Valley. The overall structure of this valley is a broad, doubly plunging syncline with smaller folds. The Anthracite Upland occurs east to the Susquehanna Lowland, and consists of an upland surrounded by an escarpment, a valley, and a mountain rim. This upland has low, linear to rounded hills. The Blue Mountain occurs in east-central Pennsylvania as a narrow strip. It is a linear ridge to the south, where it is a south limb of a broad fold with a valley to the north. The valley widens eastward and includes low linear ridges and shallow valleys. The Great Valley lies on the eastern side of the Ridge and Valley, and consists of a very broad lowland that has gently undulating hills eroded into shales and siltstones on the north side of the valley and a lower elevation flatter landscape developed on the south side. South Mountain occurs in the south central Pennsylvania, and it is an area of ridges partly dissected by deep valleys.

The Piedmont Plateau can also be broken into three sections including Gettysburg-Newark Lowland, Piedmont Upland, and Piedmont Lowland (Sevon, 2000). The Gettysburg-Newark Lowland is located on the northern portion of the Piedmont, and consists mainly of rolling low hills and valleys developed on red sedimentary rock. The slopes are gentle, and the relief in this area is generally subdued, ranging from 30 to 70 meters. The Piedmont Upland occurs in the south. It consists of broad, gently rolling hills and valleys. The continuous sloping surface is dissected by the valleys eroded into it. The local relief is usually less than 100 meters. The Piedmont Lowland occurs between these two. It consists of broad low hills separated by broad, moderately dissected valleys. Karst topography is common in this area and the local relief in this section is generally less than 30 meters.

These larger levels of ecological units are well defined, described, and organized in hierarchy. Section and subsection levels of mappings are defined according to these physiographic characteristics within Pennsylvania, and divide the state into different ecological settings. They provide valuable references for ecological research that extends across the state, and they are also helpful to finer level ecological mapping studies such as LTA and ELT mapping in this study.

Landscape Level Ecological Mappings

Some classification work has been conducted or is in progress at the landscape level in North America. These efforts have covered different sizes of areas and used different criteria according to their research purposes. Some of these works focused on habitat classification and/or forest site evaluation such as habitat type mapping in northern Idaho (Deitschman, 1973), forest habitat type classification in Montana (Pfister et al., 1977), and forest site classification for the interior uplands of the eastern United States (Smalley, 1984). Although their purposes are somewhat different from the ecological mapping as mentioned in the first chapter, they provide some important references for ecological mapping studies. Some works have directly dealt with ecological mapping according to the National Hierarchical Framework (ECOMAP, 1993) such as LTAs classification in the Northern region (Ford etc., 1997), delineations of LTAs for northwest Wyoming (Reiners, 1999), landscape classification for the Hudson Valley Section of New Jersey (MacFarlane, et al., 2000), and ecological landscape mapping in Wisconsin (WDNR, 2005).

Some of these classifications have been based mainly on vegetation, like Pfister's (1977) research on forest habitat type classification in Montana using indicator species as the diagnostic key for field identification. The objective was to develop a classification system based upon potential natural vegetation, which according to Küchler (1967) is the vegetation which exists in landscapes unaffected by man. In the Montana work, actual vegetation was used because the vegetation in that area developed over a long period of time without disturbance and was felt to reflect the overall condition. In many cases, however, man has become very active in destroying natural plant communities, changing them or replacing them with others. Potential natural vegetation cannot be determined simply by observing actual vegetation on ground. There exists the closest relationship between the various phytocenoses of the potential natural vegetation and the sites on which they occur. Küchler (1967) formulated the terminology of *biotopes,* whereby a biotope is an area of relatively uniform physical features (climate, topography, soil, etc.) and is therefore occupied by one particular phytocenose of the potential natural vegetation. He stated that “a given kind of biotope and a given phytocenose of the potential natural vegetation always go together.” Hence, potential natural vegetation related mappings can be produced based on biotope classifications.

In most of the ecological mapping works, abiotic factors provide the most important classification criteria. Westveld (1952) pointed out in his research on evaluating forest site quality that soil and climate are two very important factors in forest site classification. Identifying the soil conditions for forest sites will be very helpful in forest management practice.

Gysel and Arend’s (1953) oak sites classification in southern Michigan revealed a fairly consistent relationship between the growth of trees and the texture of the general topography, subsoil layers, slope positions, and the position of moist layers. They concluded that a majority of their research area could be classified by observing certain characteristics of the general topography, soil, and position on the slope. From these site classes it is possible to predict the potential growth of oak.

In recent research on LTAs and ELTs, topography and soil were the most frequently used factors. At the LTA level, topography, terrain topology, and soil information are the most often used factors in classifying ecosystems. Ford et al. (1997) developed landtype association maps for national forest land throughout northern Idaho, Montana, and North Dakota. Landforms and geologic materials were used as mapping criteria, based on the assumption that these are features that can be mapped consistently at landscape level and that they closely predict significant differences in watershed, stream, and riparian properties.

In landscape classification for the Hudson Valley Section of New Jersey, MacFarlane et al. (2000) delineated land type associations (LTAs) based only on soil information. They derived LTAs from digital soil series maps. Soil series map units were aggregated into broad-scale groups that reflect similar parent material from which they were derived. Parent material groups were aggregated to form LTAs, which were believed to reflect both parent material and landscape topography.

Some other investigators have argued that topography is the dominant factor at the landscape level, which can greatly affect ecosystem distributions. In habitat type mapping research in northern Idaho, Deitschman (1973) discussed the environmental effects on habitat types. He argued that geographic location and landform are two major environmental factors which influence habitat occurrence. Topographic factors including elevation, aspect, slope configuration (curvature), and adjacent land features are four of the major characteristics that exercise strong control over environmental conditions through complex interactions. They influence precipitation, infiltration, evapotranspiration, growing season, and wind exposure in the particular region. Geographic location influences the temperature, precipitation and evapotranspiration at a larger scale to some degree.

The work of Bowersox (1972) verified that topographic factors do have a strong effect on forest ecosystems. In his work, a site index prediction equation for oak stands was developed from data of 39 permanent sample plots in southcentral Pennsylvania. He found that the prediction equation accounted for 79 percent of the variation in site index. Among the multiple predictors, slope position is a very important factor for the prediction of site quality.

Based on these facts, some investigators use topography or landform as a single source in their ecological mapping research. Smalley (1984) applied a forest site classification system to the interior uplands of the eastern United States based on consideration of the landforms. He found that in rugged terrain, landforms have as much as or even greater significance than soils in site classification, because soils are closely related to landforms and topography.

Some ecological mapping efforts found that using topographic information as a single classification criterion is even better than multiple criteria, such as in the

LTAs classification in northwest Wyoming (Reiners et al., 1999). They believed that the different variables used in those multivariate classification systems vary at different scales and therefore are not likely to bound at the same places or to lead to definition of integral systems. Such methods probably tend to "smooth over" prominent differentiating features in local cases, so incorporating multiple variables leads to compromises in polygon boundaries.

In mapping at the ecological landtype (ELT) level, topography and soil especially become major considerations as stated in the National Hierarchical Framework, “ecological landtype units are designed and mapped based on properties of local topography, rock types, soils and vegetation” (ECOMAP, 1993). Moriarity (1996) mapped ecological landtypes on the Allegheny National Forest in Pennsylvania. He described ecological landtypes based on slope position, steepness, soil properties, bedrock information, streams, etc.

Shao et al. (1999) identified the ecological landtypes (ELTs) of the Brown County Hills ecological subsection in Indiana based on local topographic characteristics. They designed the keys for the ecological classification according to information about slope position, steepness and aspect. These keys can be used for classification in the field and also can be incorporated into automated or semi-automated ecological classification with the use of geographic information systems.

MacFarlane et al. (2000) mapped the ecological landtypes for Hudson Valley Section of New Jersey based on combinations of soil characteristics and topographic information, with the goal of mapping water and nutrient availability for forested plant communities at specific points in the landscape. They found that soil and topographic information are very good information source in this mapping process.

Based on all of these investigations, we can conclude that topographic factors captured from a digital terrain model should be able to provide sufficient information in ecological mapping at the landtype association level. And local topographic and soil properties can also serve as good classification criteria at the ecological landtype level to meet our goal for ecosystem management.

Considering the importance of topographic and terrain topologic characteristics in shaping ecosystems, Myers (2000) described ELT and LTA families for Pennsylvania forests. He introduced terms of *caplands* and *cuplands* in LTA classification. Caplands are dome-like upper land surfaces, which are usually headwater areas. Cuplands are concave to level areas which receive hydrologic inputs from caplands. He also grouped ELTs for Pennsylvania forests into seven families, including crests, uplands, slopes, terraces and plains, valleys, hills, wetlands and water. With these rules, Pennsylvania forests LTA classification mapped a series of LTA units for state forests. These guidelines became the basic tools for LTA mapping in this study, and the state forest LTA work also provides helpful references for the delineation here.

Mapping Methods

Human interpreters often play a role in producing natural resource related maps. With the development of commercial GIS and spatial databases, there has been considerable interest in extracting terrain parameters and ecosystem characteristics from digital elevation data, soil maps, and other digital data sources by computers (Dikau, 1989; Dikau, 1993; Moore, 1993). Especially in classifying terrain features or hydrologic units, automated classification systems can help to capture the slope, aspect, curvature, and flow topology for each point in the study area, which not only increases the mapping accuracy but also saves time and labor compared to manual interpretation. Collins (1975) discussed different algorithms that could be used for identifying features such as tops of hills, bottoms of depressions, watersheds or slopes and aspects. However, automated mapping is still a developing technique and has some limitations. For example, lacking human intelligence and empirical knowledge, a computer has difficulties in recognizing the topographic patterns at various scales. A computer also might not be able to provide practical final boundaries for map units due to lack of experiential judgment. In many of the ecological mapping works, both human interpretation and computer automated methods are used in order to obtain consistent and practical results and save time.

Human interpretation is still considered to be an effective mapping procedure. In landtype association mapping in the Northern Region (Ford, 1997), delineations were drafted by several forest soil scientists on 1:100,000 scale contour maps and then scanned, merged and geo-referenced into a digital file. This mapping method can help to produce fully human-controlled map units. The resulting map is more interpretable in an ecological sense, and also has more practical utility in natural resource management activities. However, manual delineation is both time-consuming and dependent on the expert's interpretation of a more or less qualitative set of rules. This method also lacks ability to overlay different spatial information layers interactively, so judgment can only be based on a single factor. Another problem is that mapping on several adjacent maps may lose consistency and requires some technique to match edges between maps.

More and more researchers are looking for automatic mapping methods for classifying terrain features in the fields of geomorphology and hydrology, which might provide some insights for our ecological mapping with topographic information. There are several possible approaches. Each of them is in a process of development, and there are still some limitations to be overcome in the future. One approach is based on Hammond's (1964) landform classification system. Hammond identified landform types for the United States by manually moving a square window and calculating the percentage of flat or gentle area, relative relief, and profile type within each window. He then grouped the resulting values into four classes of percentage of flat area, six classes of relative relief and four classes of profile type, and then used the unique combinations of these three attributes to form the landform sub-classes. Dikau et al. (1991) developed automated processes that computationally simulated Hammond's manual methods and tested them in New Mexico using a 200m cell size DEM. The results have a good resemblance to those of manual methods and were believed to be a significant development in automatic landform classification. However, progressive zonation is one major problem associated with this mapping scheme. In the transition zone of plain to mountains, the system will produce a series of classes going from plains, to plains with low hills, to plains with high hills, to low mountains. This reflects a progressive change in relative relief as you get closer to mountain areas and is not a particularly desirable result (Brabyn, 1998). The effects of scale and generalization also need special attention in this method. So there are still needs for improvement before this method can be used in an actual ecological mapping based on topographic data.

Some other investigators have tried to use statistical models in topographic classification. Niemann and Howes (1991) used slope, profile, profile curvature, plan curvature, and upstream contributing area to build a statistical model in clustering the landscape into a number of morphologically uniform facets. However, the result of iterative cluster analysis is often a set of classes with a marked lack of coherence in geographical space. The scattering of classes occurs because there is an authentic overlap between different classes in both attribute and geographical space (Romstad, 2001). This suggests that other procedures should be used for relief extraction before the clustering in order to take the class overlap into account. Irvin (1997) and Burrough (2000) describe the use of continuous classification (fuzzy set) methods. In these methods, individual cells are assigned an affinity to each cluster rather than an absolute membership. They can easily be integrated in a cluster analysis, but the result of a fuzzy classification is hard to visualize and assessment requires a comprehensive understanding of how the algorithms work and the nature of the data. Friedrich (1996) coupled the cluster analysis with a preliminary spatial-neighborhood analysis. He generalized the data based on the proximity distance vector in multivariate space between neighboring cells in the terrain, and then applied iterative cluster analysis on the generalized dataset. The result showed that this method delivered a spatially correlated and relatively accurate classification for the geomorphologic analysis. However, the optimal number of classes for the cluster analysis is a major question in this study (Romstad, 2001). Furthermore, such multivariate approaches to classification depend on the assumption that ecosystem properties are co-located in landscapes. This assumption might not always be true in the field.

Deterministic modeling is another major approach in automatically classifying landscapes. Li and Dapper (1996) fitted a f(x,y,z) surface function to each 3 by 3 neighborhood on the DEM. Then, they identified points of summits, lines of saddle backs, stream lines, and ridge lines, and areas of nine slope facet types after removing the sinks from the digital elevation data. However, a salt-pepper effect problem exists, or in other words, the resulting map includes a lot of isolated pixels belonging to different categories because the neighborhood function is sensitive to small scale variation. They performed a majority filter to cope with this problem on the derived slope facet map to get more general patterns. This method can provide scientific evidence for classifying the landscape, but the scale problem is still something to be conquered in the classification. Maps can't be produced at a designable size for the actual application since it recognized the ridges and valleys as lines instead of polygons.

In order to take advantage of GIS convenience, and at the same time have some control over the mapping delineation, some investigators try to combine both human interpretation and computer-assisted mapping in making their maps. In delineation of LTAs for northwest Wyoming and the Buffalo Resource Area, Reiners et al. (1999) adopted the automated mapping methods derived from Hammond's (1964) classification system first, and then they digitized the outlines by hand while taking into account other GIS coverages including shaded relief, hydrology and geology information. Thus, their final maps not only benefited from the GIS techniques by increasing the precision and consistency across the regions and saving time and labor, but are also fully controlled by the human in order to produce practical ecological units for management.

In view of these precedents, this current research couples GIS assisted mapping and human interpretation methods, trying to obtain the advantages of both methods while avoiding the limitations.

Chapter 3

Landtype Association Classification

Mapping Considerations

Landtype associations (LTAs) represent landscape scale ecological units in the ECOMAP hierarchy. They are groupings of Landtypes or subdivisions of Subsections based upon similarities in geomorphic process, geologic rock types, stream types, lakes, wetlands, soil complexes, subseries or plant association vegetation complexes (ECOMAP, 1993). LTA is a level of the Hierarchy that was developed primarily for use in area-wide forest planning and analyses. It also has applications in assessment and analyses at broader and finer scales, and is useful to natural resource managers.

Ecosystems are made up of multiple factors, and at a specific level of spatial-scale, there is only one or a few ecological factors dominating ecosystem structure or function. LTA mapping should design differentiating criteria with respect to the dominant controlling or mediating factors operating at landscape scale that allow us to conceptually separate ecological units (Jordan, 2001). Delineation decisions will be made on where the dominant factor or combination of these ecological factors changes in a way significant to management. LTA boundaries are then placed at the approximate locations where these changes occur.

Since LTAs are landscape ecosystems, made up of clusters of interacting finer scaled patches (Crow, 1991), they should have emergent properties which are not discernable by observing the function of an individual patch, but are apparent at the broader spatial scale (Salt, 1979). According to this view, LTA mapping should also be able to design differentiating criteria that are recognizable at a large scale, and divide land into smaller units.

Map Unit Design

At the landscape level, the ecological units are defined by general topography, geomorphic process, surficial geology, potential natural community patterns and local climate, because these factors affect biotic distributions, hydrologic function, natural disturbance regimes and general land use (Forman and Gordan, 1986). Pennsylvania encompasses various topographic settings across regions, such as undulating plateaus and sinuous valleys in the Appalachian Plateaus, interlaced ridges and valleys in the Ridge and Valley, and gently rolling hills in the Piedmont Plateau. The considerable topographic relief, often with steep slopes, makes the general topography and terrain topology (juxtaposition) more apparent as influences on ecosystem distributions compared to other environmental factors. Within each physiographic subsection, these complex topographic characters and their spatial relationships not only reflect different geologic foundations modified by the processes of weathering and sediment transport, but also influence stream types and control stream patterns formed by topographic fluctuation. Topography is also a determinant of local microclimate for the ecosystem. It exerts strong controls over environmental conditions, such as evapotranspiration, infiltration, erosion, wind exposure, and disturbance regimes. The topological juxtaposition of terrain elements aids this LTA classification by providing information about the spatial relationships of terrain units. These relationships between different terrain units help to differentiate LTA units at the landscape scale and subdivide them into more detailed categories. Given these considerations, this study uses topography and terrain topology as primary information in classifying LTA units. Other information is also referenced in the delineation, including stream network, land use characters, soil groups, etc.

The next concern is how topography and terrain topology information can be used in designing LTA units. The landscapes should be sensibly delineated without losing sight of important ecological linkages. Moisture regimes and hydrology influence many ecosystem processes either directly or indirectly. They tend to play prominent parts in conditions conducive to competition among communities of organisms (Myers, 2005). Areas that are substantially elevated and irregularly mounded or dome-like will have tendency toward rapid runoff of precipitation and experience erosion. These upland terrain components such as mountains, ridges and hills can be characterized as *caplands* (Myers, 2000). They have a degree of ecological integrity that is largely ignored by the watershed perspective. These caplands have community consistency with regard to headwater hydrology, often with many of the flow paths being of an intermittent nature along with narrow riparian areas of low-order streams. These kinds of terrain units are usually somewhat xeric zones, and support plant communities having appropriate adaptations.

At the places where slopes steepness decreases, the runoff rate is reduced and causes a shift from erosion to deposition with regard to suspension of sediment. This is also a juncture where habitats change with regard to species that tolerate dryer conditions versus more moisture dependent species. After the determination of caplands, the subordinate valley areas can be generalized as *cuplands* (Myers, 2000). These caplands and cuplands can distinguish ecosystems well by their hydrologic properties and topographic settings without losing the ecological linkages. The drainage network of streams in the cuplands has a different character from that in the caplands. Whereas low-order headwater streams are predominant in the caplands, the cuplands have both low-order and high-order streams.

In this LTA classification study, there are two kinds of LTA units designed as capland components, including *Highland Habitat* (HH) and *Transitional Terrace* (TT). The **Highland Habitats** are defined from a headwater stream habitat point of view. They are mounding or arching to level upper landscape surfaces that receive precipitation and direct it downward as runoff to small intermittent or headwater flowpaths. Caplands usually extend from crests and uplands down to the beginning of footslopes flanking valleys. In addition to being source areas for water, caplands are also non-point sources of sediment due to their vulnerability to erosion. They often have more wind exposure and dry to moderate moisture conditions. Due to their higher elevations and slopes, they tend to have less human disturbances and relatively intact ecosystems. Species that accommodate exposed environments and dry conditions are usually associated with these areas. The **Transitional Terraces** arise in upland terrain units having subordinate projections with constricted attachments. They are extensions of highlands where a limited hydrologic input is received from above but the overall character is otherwise like highlands. This landscape position enhances their moisture status somewhat. Their extent and topographic placement affects how water is apportioned between overland flow and channelized flow affecting stream size and sediment accumulation.

The cuplands in this study are named as *Dual Drainage* (DD) LTA units. **Dual Drainages** are drainage areas with both large streams and headwater streams that form tributaries to large streams. They are cupping to level or undulating valley areas that concentrate moisture as channelized flow and near-surface groundwater. Hydrology is a major factor in these ecosystems. Species that require moist and nutrient-rich or downstream habitats will reside here. These areas are often subject to human disturbance because of their moist, fertile soil and more gentle topography which is suitable for agriculture.

The designation of these three landtype association categories gives process rationale for LTA separation. Using these criteria, this study recognizes three sets of polygons with comparable size and similar identity of HH, TT or DD, that repeat across the landscape. Their occurrence is driven by predictable landscape patterns of topography, terrain topology and other relevant ecological factors. Within each HH, TT or DD category, properties of units might also vary according to different topographic characters. For example, highland habitats not only can be in the form of undulating plateaus, but also can be elongated ridges. Dual drainages can occur as broad basins, but also can occur in deep valleys. Further classifications within capland and cupland LTA units are characterized and described in a second stage of mapping.

Delineation Strategy

DeMeo et al. (2001) in their discussion of national landtype association data standards recommended two mapping strategies, top down (regionalization) and bottom up (aggregation) strategies. The top down approach conceptually separates broader ecological regions into LTAs using a series of delineation criteria, whereas the bottom-up approach aggregates existing finer-scale units into landtype associations.

In this study, the top down approach to LTA mapping was adopted for the following reasons. First, LTAs are combinations of different landtypes, and they have emergent properties. These properties might not be recognized by just observing the function of an individual landtype, but are evident if the observers have a broader view. The top down approach ensures that synoptic features are recognized. Second, the primary information used for present purposes of delineation is topography and terrain topology. Topographic characteristics are expressed as complex landscape patterns which can only be perceived by observing combination characteristics of various slope facets at a broad scale. These patterns can not be captured easily by merging similar kinds of smaller units. Terrain topology as assemblages of elements also requires that the classification be conducted at a broader scale. A top down approach enables recognition of these complex landscape patterns and their spatial relationships that may be less obvious at a finer scale. Third, there is no salient candidate approach for aggregating finer level ecological units in a bottom up manner. Although site level ecological units are addressed in this research, they are produced by combining soil and topographic information which might not reflect emergent properties of LTA units. Finally, top down methods have the advantage of relatively quick development and inexpensive cost (DeMeo et al., 2001). Therefore, HH, TT and DD types of LTA units are first recognized at the larger scale, and then these large units are subdivided into smaller ones until the unit size falls within the desired range.

Geographic information systems aid this process by displaying data interactively, calculating topographic parameters, generating boundaries, and overlaying different spatial layers. Application of GIS can greatly improve mapping efficiency and help to ensure that uniform mapping judgments can be made across regions. Human interpretation is also applied in the mapping process to control map unit size and shape because a computer system can not guarantee unit boundaries appropriate for management and research purposes.

Data Sources

Since the map units are designated according to their topographic characteristics and terrain topology, the primary data source used in this mapping process is topography. In addition to this information, other spatial layers, such as watershed boundaries, stream network, landform, soil, and remote sensing images also aid in delineation when major factors are not obvious for boundary determination in some situations.

Topographic Data

A Digital Elevation Model (DEM) is a raster grid of elevation values at regularly spaced intervals. It provides spatial elevation information in GIS, facilitates topographic related research, resource monitoring, terrain modeling and analysis, mapping, and visualization applications. Accordingly, DEM became a basic tool for this mapping purpose. The DEM layer used in this study was assembled by the Pennsylvania GAP Analysis project (1999). The elevation data were originally acquired from the National Elevation Dataset (NED) developed by U.S. Geological Survey (USGS). The GAP Analysis project clipped the dataset to Pennsylvania boundaries, reprojected, and generalized it to 90-meter grid cells. The 90-meter resolution was used here instead of 30-meter or less because the coarse resolution DEM can help to smooth out local elevation fluctuations and recognize terrain units from a general sense. Furthermore, a DEM for the whole state is a large data file. Coarser resolution reduces the file size and saves screen display time in GIS, which can also greatly improve mapping speed because the classification system requires loading elevation data frequently. In this study, the acquired elevation data were smoothed twice using a 3 by 3 moving window with Inverse Distance Weighted (IDW) method to remove noise in the data caused by the production methods of DEMs or other artifacts. Based on the DEM layer, maps of slope, aspect, and contours for the whole state were generated to assist in the mapping process.

Auxiliary Datasets

There are several auxiliary datasets used in the delineation process to help make the decisions for unit boundary locations. Watershed boundaries derived according to water courses and topography provide references for delineating ecosystems occurring in valley areas. At the large level of LTA mapping, USGS 14-digit hydrologic unit codes (HUC) boundaries were used in this study as the major reference for cupland delineation. A HUC is the code used to represent an area designated by the USGS as belonging to a certain watershed. The 14-digit HUC units are minor sub-watersheds nested within each 11-digit HUC unit (major sub-watersheds) and 8-digit HUC unit (cataloging unit) and maintain a typical size of 10,000 to 40,000 acres (approximately 4,000 to 16,000 hectares). This level of HUC was selected because it is the smallest set of hydrologic unit boundaries within the hierarchy and provides detailed information about watershed delineations, although the average polygon size in this layer is still larger than our desired LTA units.

At the fine scale of cupland mapping, Pennsylvania small watersheds boundaries were referenced to provide more local hydrological information. This layer was published by Pennsylvania Department of Environmental Protection, and incorporates more than 9,000 small watersheds in Pennsylvania indicated in the Pennsylvania gazeteer of streams. It provides the most comprehensive watershed delineation information within the state. These boundaries enclose catchment areas for named streams officially recognized by the Board on Geographic Names and other unofficially named streams that flow through named hollows.

For the finest level of LTA delineation, the mapping system is designed to map LTA units within a size range of 100 to 5,000 acres (40 to 2,000 hectares). But in some cases, the topographic differences are not apparent enough to divide the large LTA units into smaller ones within the preferred size range. These situations occur often in plateaus or coastal plain areas where elevations do not change much and watersheds are not compact. In these cases, more supportive data need to be overlaid in GIS with the existing information to help make decisions. The advantages of human interpretation in this part became especially clear because it allows researchers to synthesize all of these complex ecological factors, analyze the major ones based on empirical experience, and make decisions based on the most important components.

Stream network is one of the most important auxiliary datasets used in the LTA mapping process. The digital stream network was edited and verified by the

Environmental Resources Research Institute (ERRI) at Penn State University. The connected networks of streams and waterways are indicated as single lines in this dataset with stream order information in an attribute table. Stream flowpaths can indicate subtle terrain fluctuations in gentle slope areas where terrain characters are difficult to observe from 90-meter DEM. Stream patterns can also be used as delineation criteria.

The draft map of landforms in Pennsylvania compiled by the Pennsylvania Geological Survey also aided in LTA delineation. It provides some detailed landform information in Pennsylvania, especially in Ridge and Valley and Deep Valleys areas.

Spatial soil data served as auxiliary information in mapping decisions because of the importance of soil in ecosystem development. Furthermore, soil properties also revealed some of the geological substrate information. At the LTA landscape level, the State Soil Geographic (STATSGO) database from Natural Resource Conservation Service (NRCS) was used because this level of soil mapping is designed to be used for broad planning and management purposes covering state, regional, and multi-state areas and can provide more general soil distribution information compared to detailed soil survey data.

Finally, remote sensing images were also used to provide land cover information. These images include both Terrabyte images from PASDA (1998) with 30-meter resolution and SPOT images with 10-meter resolution. The land use differences indicate different ecological regimes and also help in making delineation decisions.

Mapping Process

In this study, there are three levels of delineations involved in the LTA mapping process. From the largest level to small, they are α-level delineation,

β-level delineation, and γ-level delineation, respectively. The objective of α-level delineation is to differentiate the basic units of highland habitats, transitional terraces, and dual drainages based on their topographic definition. After that, β-level delineation refines α-level HH, TT, or DD units into smaller-size components according to apparent topographic differences within the α-level LTA unit scale. Finally, γ-level delineation breaks these β-level units down still further in order to control the size of final mapping units under 5,000 acres (approximately 2,000 hectares) by more subtle criteria.

α - Level Delineation

This level of LTA mapping is designed to differentiate the HH, TT and DD associations from the landscape. The mapping criteria in this level are the basic topographic differences between HH, TT and DD. After practicing with different DEM-derived topographic layers in GIS, the contour map was selected as the major tool in this process because a contour map not only presents topographic information via the line attributes, shapes and densities, but also provides linear boundaries as mapping references. Highland habitats generally have closed contour lines with higher elevation in the middle, and can be easily determined from the contour maps as a first step. Transitional terraces are sloping to level terrain units extending from the highlands. From a contour map, we can pick up those outstretched contours from highlands and close them manually as this level of TT units. Lastly, the remaining part of the state comprising the landscape matrix contains the dual drainages.

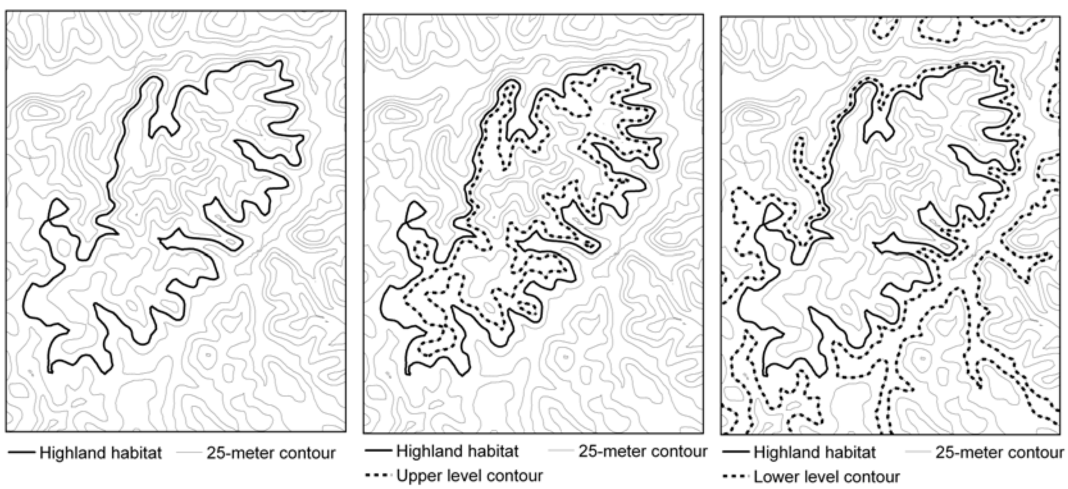
Contours were generated in this application based on DEM. Several choices of contour intervals were tried, and the 25-meter was selected as the final one. In the beginning, the 50-meter contour interval was tried, but the contour map generated with this setting missed a lot of useful information. Especially in the gentle terrain areas, small local hills with low elevation differences can be totally lost in a 50-meter interval contour map. In addition, 20-meter and even 10-meter interval contours were also generated in gentle slope areas to verify that 25-meter interval can provide enough details to capture all those highland habitats. The results show that most of the increased contour lines in finer-interval maps are concordant to the existing lines, and the shapes of those increased lines are very similar to 25-meter ones. Accordingly, these small-interval contours do not give an obvious improvement in recognizing highland habitats. Small-interval contours are dense and take more time to be displayed in GIS. Thus, 25-meter interval was finally adopted.

Highland habitats are arching or mounding to level uplands that receive precipitation and direct it downward to channellizing areas. In a contour map, such units are expressed as a series of contour loops with one nested in the other and having concordant shapes. In the middle of the nested contour series, contour lines have higher elevations compared to the surrounding contours. As the contour lines go down to lower elevation, they might still be concordant with the higher ones, but at some level, this shape breaks down. At this elevation of terrain transition, the contours are not concordant any more because of incisions by streams flowing out into the lowlands. The highland habitat boundary in this research was defined at this place where the change occurs. Consequently, the boundary of a highland habitat unit will occur at a particular base level.

The concept of "last concordant capping contour" provides a practical way for mapping highland habitat LTAs in this study. The "capping contours" are defined as nested contour loops having elevation level decreasing as the loops in the nest expand. This guaranteed that all of the selected closed-contours are dome-like or mounding surfaces at the landtype association unit scale. The "concordant" capping contour means that the nested set of contour loops exhibit an approximately parallel pattern of progressively decreasing elevations. And the "last" concordant contour means that the next lower (outer) contour line is not concordant with the current one. This assured that the selected areas include highland habitat areas until the terrain changes to dual drainages or transitional terraces. The transition from capland to cupland is marked by a pronounced increase in the irregularity of contour lines as they weave into and out of drainages and around the varying slopes of valleys (Myers, 2005). This zigzag zone of shifting slopes also lends strong support to the segregation of caplands and cuplands.

In this mapping procedure, scale is an important factor in defining highland habitats. Both the "capping" and "concordant" properties of contour loops are defined at the LTA unit scale. It is possible that the terrain units captured by "capping" contours include local depressions, but judging at the LTA unit scale, these units have a general dome-like or mounding character and the small scale cupping can be ignored. The definition of "concordant" here is also scale dependant. The α-level highland habitat could be systematically pursued in greater detail. Dome domains (Myers, 2005) have been introduced for this purpose. A dome domain is conceived as a monotone increasing or decreasing set of nested contour lines wherein each larger (longer) line has only one smaller (shorter) line as an immediate neighbor. Thus, a new dome domain begins with a loop that either reverses the direction of change or encompasses more than one interior line as an immediate neighbor. The "concordant" definition here applies to those dome domains at the LTA unit scale. At this scale, the last "concordant" contour line is defined at the transition zone from capland to cupland where the line irregularity increases because of the drainage influence.

In practice, this phase of the mapping was accomplished interpretively in a computer-assisted interactive mode using the GIS to selectively highlight and/or delete particular contours. Starting at a local summit and going downward and outward, if the next lower contour had capping coherence, then the current contour was deleted from the digital display. This activity entails some interpretive judgment regarding degree of parallelism for contour lines, but this has generally not been an issue that would substantially alter the structural outcome. Figure 3.1 is an example showing this delineation context. Figure 3.1(a) shows the contour line which was picked out as highland habitat from the contour map. It was considered to be an HH unit, because 1) all the contours contained inside of this one have higher elevations. As Figure 3.1(b) shows, the higher contour loops are also concordant with this selected one, that is, they exhibit an approximately parallel pattern of progressively decreasing elevations outward from center. 2) the nearest lower contour (Figure 3.1(c)) is not concordant with the selected one, being highly irregular due to outflowing streams.



(a) Highland habitat *(b) Upper level contour* *(c) Lower level contour*

Figure 3.1 Delineation rule for highland habitats.

At some places where terrain does not fluctuate markedly, highland habitat can also be just a single circle in a contour map with higher elevation compared to surrounding areas. This kind of HH unit was also picked out when the size of the hill is larger than designed minimum LTA unit size which is 100 acres (40 hectares).

With these “last concordant capping” contours or single contour circles, the α-level highland habitat units were established (Figure 3.2). There are 670 α-level HH units identified across the state with size ranging from 42 hectares to 840,573 hectares. The total area of these HH units is about 5,675,715 hectares, which occupies 48.85% of the whole state. The α-level HH units turned out to be large in the Appalachian Plateaus due to connected high plateaus. In the Ridge and Valley, these units are relatively small and linear, representing the linear ridges and local hills. They have middle size in the Piedmont because of the gentle terrain undulations and rolling hills there. There is no highland habitat occurrence in the Central Lowland and Coastal Plain.

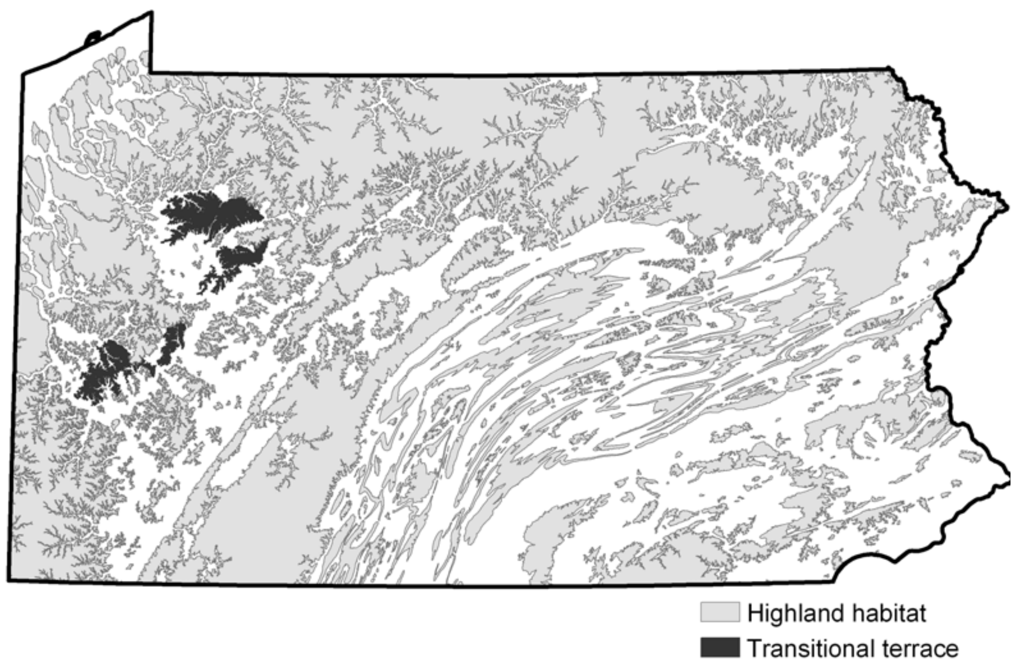


Figure 3.2 Distribution of α-level highland habitats and transitional terraces in Pennsylvania.

Transitional terraces are intermediate elevation capland surfaces that receive some hydrologic inputs from adjacent highlands along partial margins. The contours are not closed at the place where they receive hydrologic inputs from their neighbors. They can be partially defined by contour shapes at the place where transitional terraces change to dual drainages, because they have similar hydrologic process as highland habitats when the streams flow down to dual drainage areas. Transitional terraces can be delineated by identifying outstretched contour lines from highland habitats, and manually closing them. Figure 3.3 shows an example of transitional terrace delineation. In this step, a DEM was displayed as background to help in making the decisions. The left panel in Figure 3.3 shows the lower contour line around uplands. This line is open to higher elevations, and also does not have concordant shape with the boundaries of enclosed highland habitats. However, this contour encompasses intermediate elevation upland which is apparently higher than surrounding landscapes. This surface is lower than the defined highland habitats, which means it receives some hydrologic inputs from the adjacent HH unit, and is distinct from the surrounding drainage areas by the higher elevation. Therefore, this outstretched part of the lower elevation contour was selected, and manually closed at the place where it connects to highland habitat to make a transitional terrace unit.

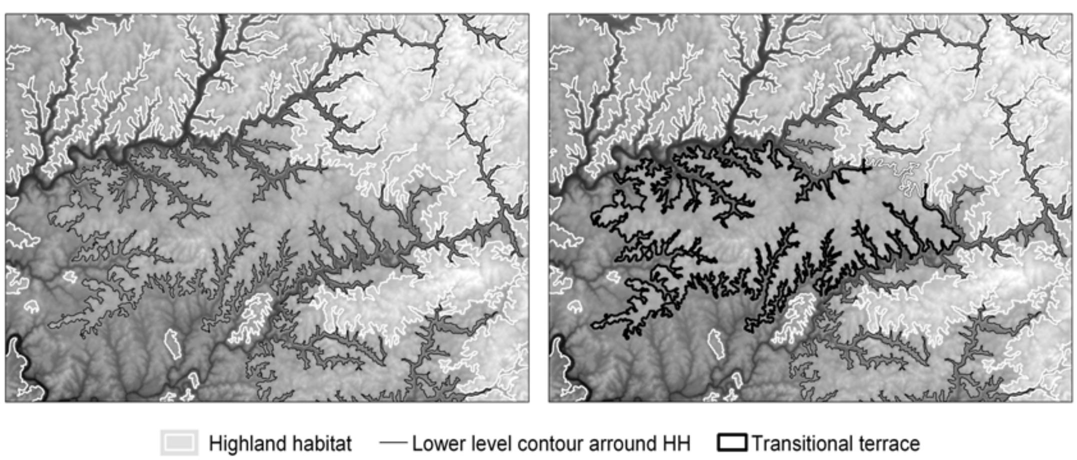


Figure 3.3 Delineation rule for transitional terraces.

At this scale, there are only four α-level transitional terraces identified in the state as shown in Figure 3.2. All of these four TT units are situated within the Appalachian Plateaus as middle elevation land surfaces attached to upper plateaus. They have size averaging around 30,000 hectares, and occupy 1.12% of the state area (around 130,000 hectares).

After delineation of highland habitats and transitional terraces, all the remaining parts of the state are dual drainages. Dual drainage units are sloping to nearly level valleys that concentrate moisture as stream flows or near-surface groundwater. Water courses have great influence in determining dual drainage unit boundaries. Accordingly, HUC units were used here to delineate α-level dual drainages. Three levels of HUC polygons (8-digit HUC, 11-digit HUC, and 14-digit HUC) were intersected with this landscape matrix. After comparing the three resulting maps, 14-digit HUC boundary was selected for the delineations, because this set of polygons can help to divide the large dual drainage areas into relatively even size units, and also, this layer can provide most detailed information about hydrologic units. In delineation practice, 14-digit HUC units were intersected with the remaining parts of the state after delineation of HH and TT units. Thereafter, small polygons with size less than 100 acres (40 hectares) were merged with their adjacent dual drainage units, which guaranteed that all of the LTA units are greater than 40 hectares. Figure 3.4 shows the layout of α-level dual drainages in Pennsylvania. There are 1381 DD units identified at this level. Together, they occupy about 5,818,650 hectares, which accounts for 50.03% of the whole state area. The size of these DD units ranges from 41 hectares to 16,278 hectares. Small size units are mainly situated within the Appalachian Plateaus as narrow valleys, while large units are distributed across the state wherever dual drainage matrix covers most of the existing 14-digit HUC units. Although the average size of α-level DD units is relatively smaller than HH or TT units, they provided appropriate information for further delineation work. Since α-level LTA units are subdivided into smaller pieces in the final result anyway, the size of DD units at this level need not match closely with HH and TT units.

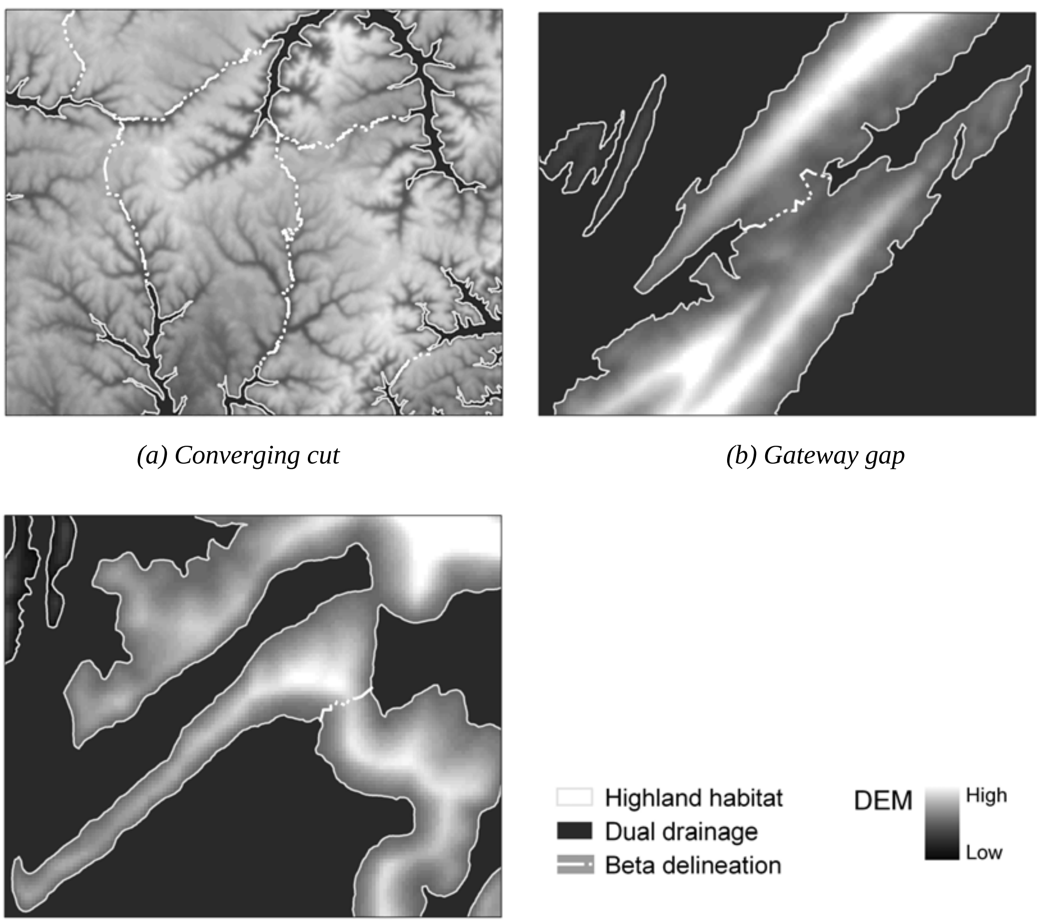
After α-level delineation, highland habitat, transitional terrace and dual drainage areas are well separated. However, most of them have large unit sizes at this level, and are not practical for management or research activities. These large units need to be further divided into smaller pieces in the following two steps.

Figure 3.4 α-level dual drainages in Pennsylvania.

β - Level Delineation

The sizes of α-level LTA units are essentially determined by the inherent topographic trends along with some relatively minor restriction from the DEM and contouring. From a practical perspective, it is necessary to subdivide these initial units. The target of β-level LTA mapping is to refine large α-level LTA units into smaller units based on major topographic differences that are observable at the α-level LTA unit scale.

For highland habitat units, since they were defined as arching or mounding to level land surfaces, all of their subdivisions at β-level should also have this key character. The delineation should be around these mounded or dome-like surfaces, and occur at the places where elevations are relatively lower. Accordngly, the expressions of erosion were employed as the major subdivision criteria. These expressions of erosion are converging cuts, gateway gaps and saddle sections (Figure 3.5).



(a) Converging cut

(b) Gateway gap

(c) Saddle section

Figure 3.5 β-level delineation rules for highland habitats and transitional terraces.

Figure 3.5(a) shows an example of an α-level HH unit where converging cuts occur. Converging cuts are areas where two narrow valleys cut the highland at opposing directions. Tops of the two valleys have the trend to be converging toward each other over eons of erosional process. In this β-level highland delineation, we cut HH units along these narrow valleys, and connect the top of them according to the geomorphic developing trend. This kind of topographic setting is very common in Appalachian Plateaus. In these areas, highland habitats occupy most of the land surfaces, and dual drainages appear as small valleys and only occupy a small part of the landscape. The converging cut rule helps to cut those extensive plateau highlands into several smaller sectors.

Gateway gaps are lower-elevation passageways through the highlands (Figure 3.5(b)). With upper-level contours, the gateway gap can be easily recognized as the break between two higher parts of the highland. Most of gateway gaps occur within the Ridge and Valley, and some of them occur in the Piedmont. They are usually the lower "gateways" or "passes" between different ridges or mountains when these ridges or mountains were picked out within the same α-level highland habitat. In these cases, gateway gaps provide a direct and reasonable rule to subdivide these ridges (mountains).

Figure 3.5(c) shows an example of the saddle section rule in β-level highland habitat delineation. Saddle sections are sagging parts of ridge tops. Recognized from DEM, they are lower sections between ridges, which provide slight evidence to refine large, continuous HH units into smaller sectors. These characters occur often in the Ridge and Valley and the Piedmont, but can also be found in small plateau α-level highland habitats, such as the HH units in the Pittsburgh Low Plateau.

For transitional terrace units, the same rules were applied in their β-level delineation as highland habitats, because they are also capland units and they are similar to highland habitats in the way of forming stream flows and directing them down to dual drainages. The three criteria used in refining highland habitat should also work in this context since they delineate land units around their lower elevation boundaries.

With this further delineation, there are 1,245 highland habitats and 14 transitional terraces delineated at β-level for the whole state (Figure 3.6). Their sizes range from 42 hectares to 62,100 hectares, with the average at 4,600 hectares. These are intermediate elevation LTA units and can be applied in some ecological management or research situations at this scale.

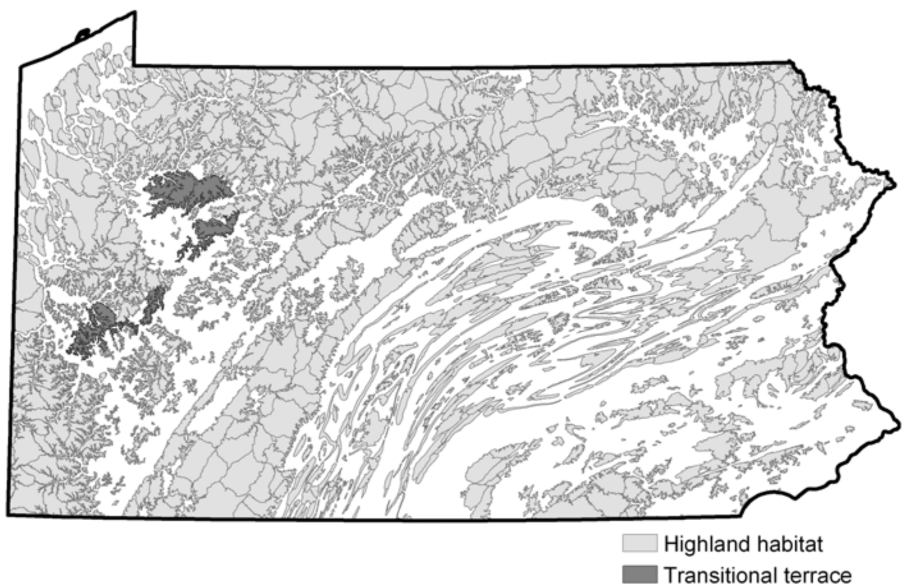


Figure 3.6 β-level highland habitats and transitional terraces in Pennsylvania.

The objective of β-level dual drainage delineation is to reveal the major topographic differences within α-level DD units which were not identified by 14-digit HUC units. These differences were mainly represented as the differences between narrow valleys and broad basins. As introduced earlier, 14-digit HUC watershed boundaries are pre-defined. After cutting out highland habitats and transitional terraces from these watersheds, however, the remaining dual drainage areas might be narrow V-shaped valleys with high slopes and dendritic stream networks, or broad basins with gentle slopes and wide valley floors. These two types of dual drainages can occur within the same HUC unit; for example, the narrow valley occurs around the lower order streams while broad basin occurs in the down stream area. Thus, the β-level dual drainage delineation focused on these differences in order to segregate the two types.

Figure 3.7 gives an example of this delineation. DEM and the unit shape served as major references in the delineation, and stream networks were also considered. The unit in Figure 3.7 was divided into two pieces because one branch of the streams was generated from the high plateau area and formed narrow valleys by erosion, while the other part of the unit occurs in lowland areas where dual drainage units dominate the landscape and the large river within it makes extensive flood plains. The delineation separated this difference by cutting the unit at the place where the stream branch from a narrow valley joins into the broader valley.

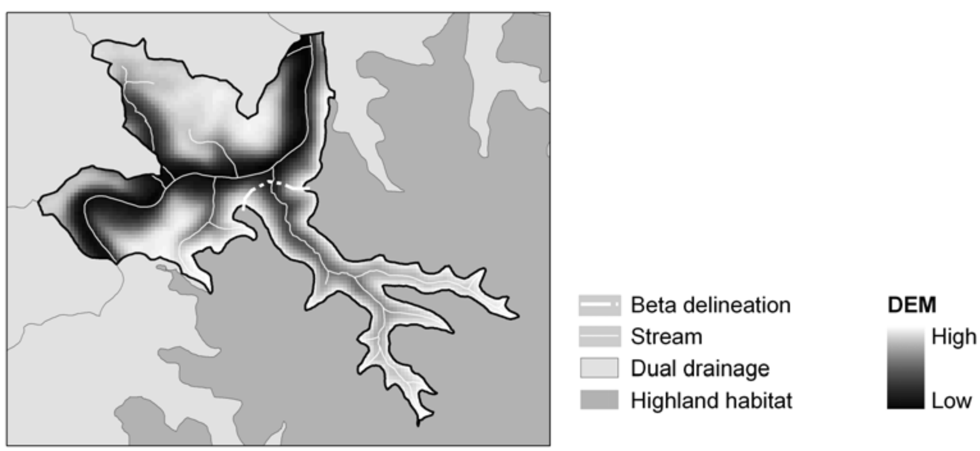


Figure 3.7 β-level delineation rule for dual drainages.

With β-level delineation, all of the narrow valleys were separated from broad basins if the size of the small valley is greater than our LTA criteria (100 acres or 40 hectares). After the delineation, the number of dual drainage units more than doubled from 1,381 at α-level to 3,568 at β-level (Figure 3.8). The sizes of these units range from 40 hectares to 16,280 hectares, with more than 60% of the units having size less than 1,500 hectares. Most of the additional small units are narrow valleys, but large units remain where slopes are gentle.

Figure 3.8 β-level dual drainages in Pennsylvania.

γ - Level Delineation

The final LTA unit sizes should be limited within a certain range. As defined by ECOMAP (1993), general polygon size of LTA will be hundreds to thousands of acres. However, this standard varies for different study areas and for different research objectives, such as the LTA mapping of national forest land in northern regions where their final LTA units have sizes ranging from 23,000 to 9,000,000 acres (9,300 to 3,642,000 hectares). In the present study, the lower LTA size limit was set as 100 acres (40 hectares). For the upper limit, we considered the topographic character of Pennsylvania, and used the 5,000 acre maximum set by the Bureau of Forestry (approximately 2,000 hectares).

The objective of γ-level LTA delineation is to control the size of all final LTA units within 100 to 5,000 acres (40 to 2,000 hectares). In this level of LTA mapping, the main task is to subdivide larger LTA units (greater than 5,000 acres) into smaller segments with size less than 5,000 acres using all possible topographic differences or evidences from other auxiliary spatial information.

Cuts, gaps and saddles occur in a gradation of sizes. The more prominent ones determine β-level capland components. Smaller ones come into play for capland determinations at the γ-level where targets for unit sizes are 5,000 acres or less. Additional evidence is also used when cuts, gaps and saddles are not sufficient. Topographic difference between high elevation and low elevation within HH unit is one of these indicators. As Figure 3.9 shows, some large HH units have no distinct valley or lowland passing through the unit, but there may be apparent elevation steps. In these cases, partitions were made according to elevation differences as well as constrictions in the shapes of units. There are also some other indicators used in the γ-level of HH and TT delineation, where topographic differences are not obvious. These indicators include differences on satellite images which reflect different land use types, different soil properties from the STATSGO dataset, and different stream network patterns.

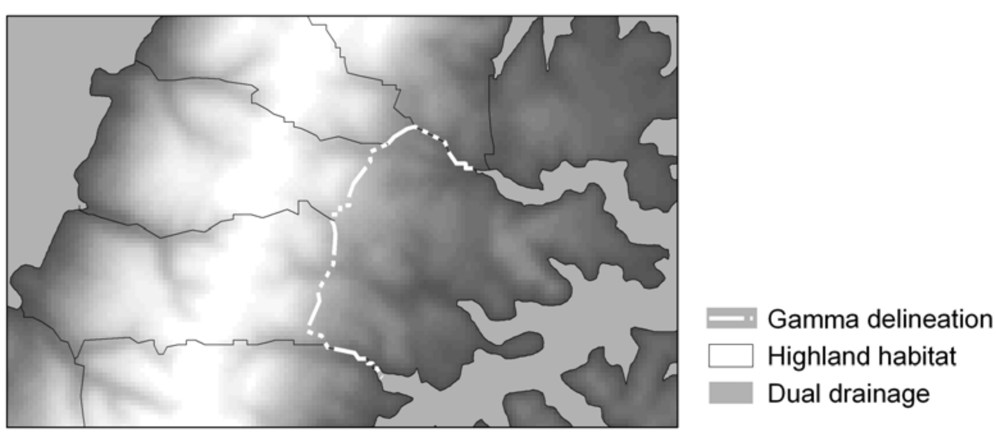


Figure 3.9 High elevation vs. low elevation areas in γ-level HH delineation.

With these additional delineations, 4,896 HH units and 106 TT units across the state were mapped as final γ-level LTA units (Figure 3.10). These units have sizes ranging from 100 to 5,000 acres with average at 2,868 acres (1,160 hectares).

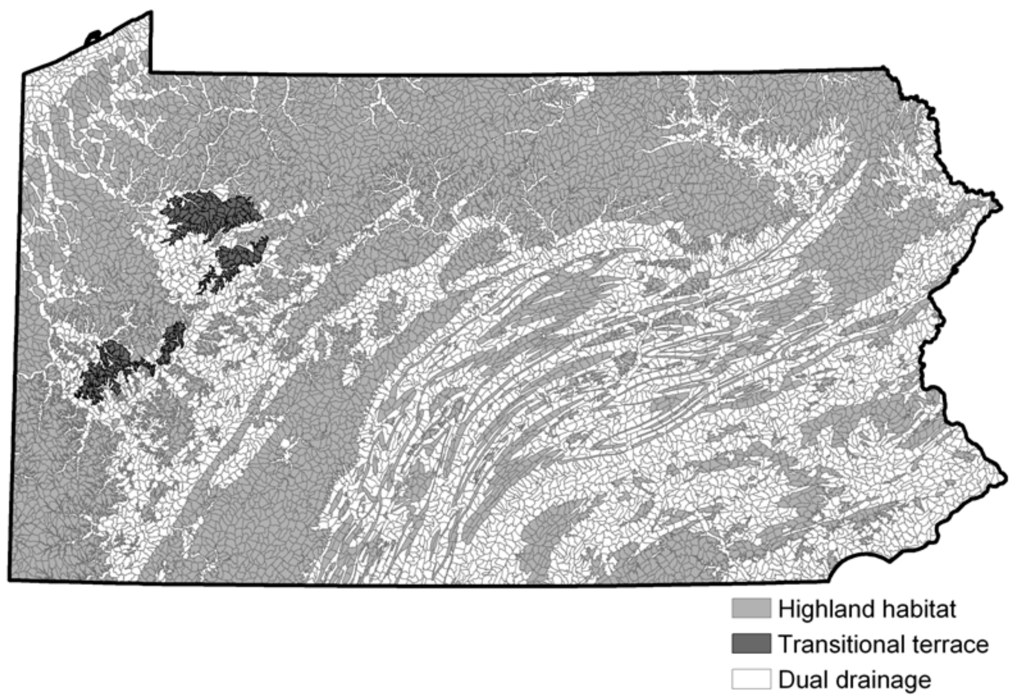


Figure 3.10 γ-level landtype associations in Pennsylvania.

For dual drainages, since hydrologic processes greatly influence ecosystems in these areas, watershed boundaries are still the major basis for delineation in γ-level DD mapping. Pennsylvania small watersheds became the most important reference in this delineation because they provide the most comprehensive and detailed information about watersheds available in Pennsylvania. This layer also has limitations for the present mapping purpose. Although it incorporates more than 9,000 small watersheds in Pennsylvania indicated in the Pennsylvania gazetteer of streams, it does not necessarily cover all of the small streams in state, and the sizes of these smallsheds are not as evenly distributed as HUC units, because this layer was generated according to existing stream names.

There are some very small watersheds with size less than 100 acres, and there are also some large watersheds that encompass several small streams within one unit. Accordingly, this level of DD delineation requires interpretive analysis at local scale with mapping judgments for each unit separately, instead of simply intersecting the layer with β-level DD units. In γ-level DD mapping practice, if the smallshed boundary could satisfy our mapping objective and help to subdivide DD units into pieces less than 5,000 acres, then the boundary was adopted. Otherwise, boundaries of partitions were adjusted manually according to watershed delineation criteria, topographic differences, or other indicators from the satellite images, STATSGO soil properties, and stream network patterns.

After γ-level delineation, there are 5,780 dual drainage units identified for the state (Figure 3.10). The sizes of these units range from 100 to 5,000 acres with average unit size being 2,485 acres (1,005 hectares).

Coding γ-Level LTA Units

Although the γ-level LTA units can be differentiated by attributes, each of them also needs a unique identification code for reference in applications. The sizes of these units are too small for naming them according to their associated county names or existing geographic names. Therefore, longitude and latitude are used to assign unique codes for these γ-level LTA units. Figure 3.11 shows longitude and latitude grids projected upon LTA units. These grids have 0.1 degree spacing. GIS was used to generate a centroid for each LTA polygon and ensure that every centroid falls in its LTA unit. X and Y coordinates for the centroid were then recorded in decimal degrees. Keeping three decimal digits in both longitude and latitude values is sufficient to differentiate all the γ-level LTAs. With the two integer digits on X and Y coordinates, a 10-digit code was assigned for each of the LTA units in the form of “XXXXXYYYYY”. The first five “X”s are

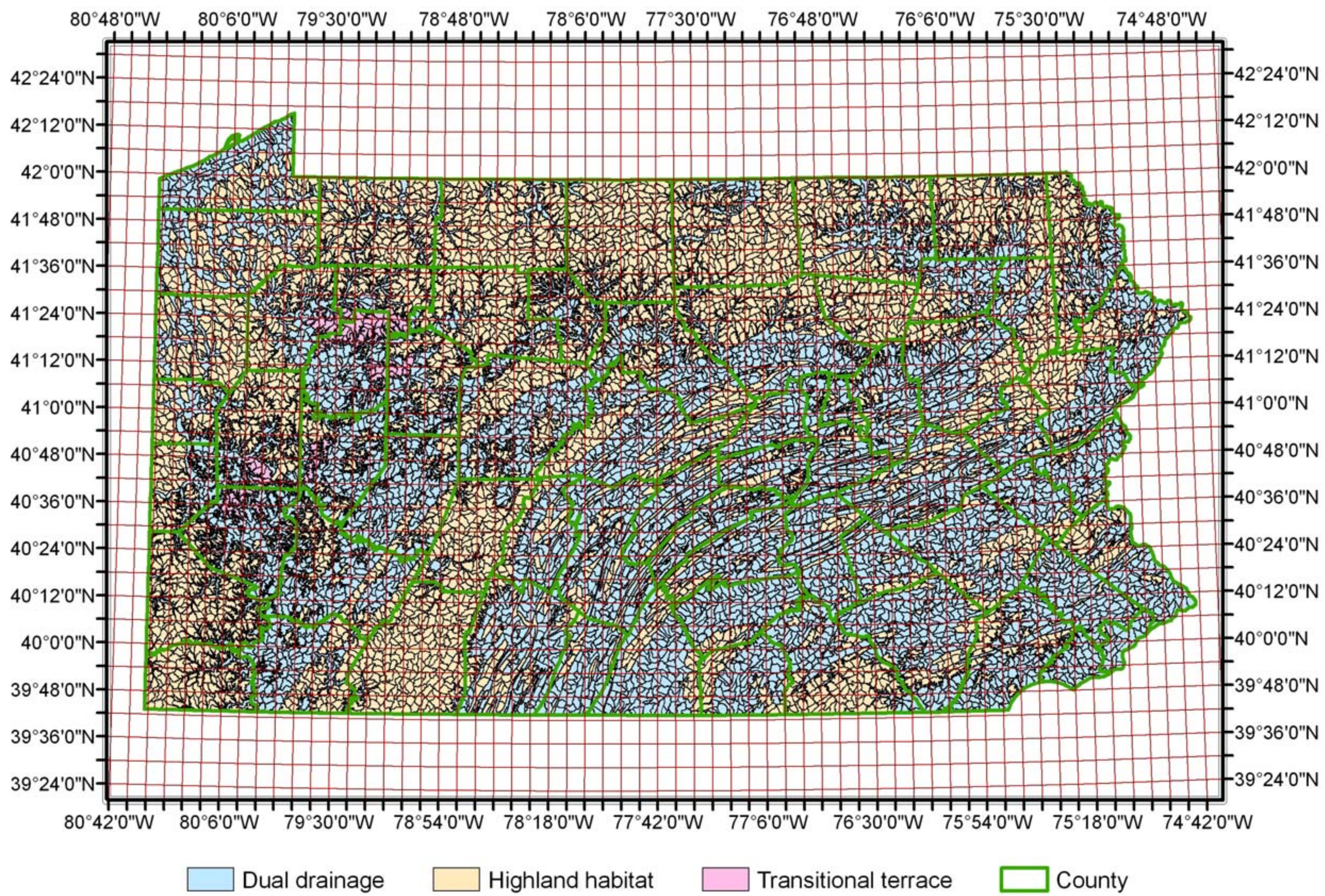


Figure 3.11 Coding γ-level LTA units with longitude and latitude.

longitude values of the LTA centroid, with the first two “X”s indicating integer digits and last three “X”s indicating decimal digits. The five “Y”s in the code are latitude values of LTA centroids, with the first two “Y”s indicating integer digits and last three “Y”s indicating decimal digits. For example, the code “7554341982” represents the LTA unit with its centroid having longitude of 75.543 degree and latitude of 41.982 degree. Thus, each of the HH, TT or DD types of LTA units has a unique identification code for reference in applications.

Discussions

In Pennsylvania, general topography and terrain topology can provide basic information for landtype association classification by separating capland and cupland terrain units, based on the consideration that the topographic and hydrologic influences are important factors in shaping ecosystems. The concept of “last concordant capping contour” provides an efficient way to delineate the highland habitat LTA units from their surrounding landtype associations. And the contours extending as lobes from HH units help to separate the transitional terraces from dual drainage areas. Finer topographic differences can also help to refine the large LTA units into smaller ones for practical purpose.

However, in this LTA classification, there are several points that need to be noticed. First, scale is an important factor in defining LTA units. With the last concordant capping contour definition, all the capping contours that are concordant with the higher elevation ones, but having irregular lower neighbor contours are picked out as the α-level highland habitats. In the south central part of the state, Chestnut Ridge was recognized as an almost separated linear ridge unit at this scale, but Laurel Ridge was incorporated into the Allegheny Mountain as one large plateau HH unit instead of being separated as a ridge unit (Figure 3.12). The contour used to define this large HH unit is a 500-meter contour line which is considered as the last concordant capping contour in this area. As indicated in Figure 3.12, Laurel Ridge and Allegheny Mountain can be recognized as two separated units at the 675-meter contour level. But under 675 meters, the lower contour lines above 500 meters still have concordant shapes with the higher ones, and are not broken down by stream incisions, which indicates that these areas are still above the transition zone between highland habitats and dual drainages. Accordingly, the areas between 675-meter and 500-meter contour lines here can still be defined as highland habitat, and the 675-meter contour is not the "last" concordant capping contour for defining α-level HH boundary. According to the concept of dome domain introduced earlier, this large HH unit is the parent dome domain of the Laurel Ridge and Allegheny Mountain dome domains. Both the Laurel Ridge and Allegheny Mountain can be recognized as separate units at the 675-meter contour level, but in the current α-level LTA classification these two terrain units are too close to be separated and make up a large HH unit.

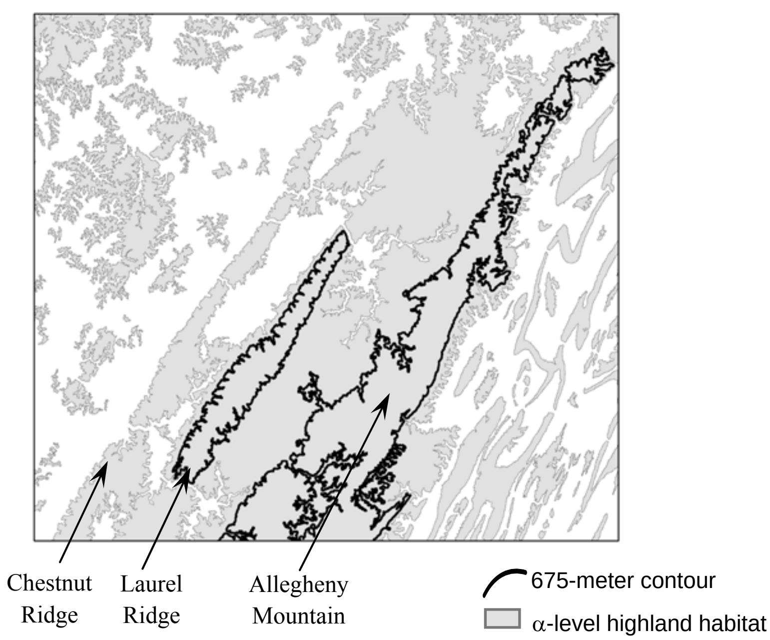


Figure 3.12 Chestnut Ridge, Laurel Ridge and Allegheny Mountain in south central Pennsylvania.

Second, in the fine level of LTA delineation, all the γ-level LTA units' sizes are limited to be less than 5,000 acres. The Laurel Ridge is a very broad ridge unit, and there are not a lot of obvious converging cuts occurring on the top of the ridge, but the different elevation steps are apparent along its two sides. So the γ-level LTA delineation mainly used the criteria of elevation differences, and divided the broad ridge into undulating ridge top units which are similar to plateau units at this scale, plateau edge units, and relatively lower-elevation plateau units. Consequently, the ridge characteristics of Laurel Ridge are not obvious at the γ-level landtype associations in this area.

Although there is expression of the Laurel Ridge from DEM, with both the α-level and γ-level mapping scales in this study the Laurel Ridge was not recognized as a distinct ridge unit. For studies particularly interested in this ridge area, the dome domain concept can be used to separate the Laurel Ridge dome domain from the large α-level HH unit.

In the γ-level dual drainage mapping, watershed delineation rules were adopted in most of the cases, but there are a few DD boundaries across streams at the places close to the stream confluence points. Considering that this study covers a large area and includes more than ten thousand LTA units, it is possible to have some minor errors. In addition, the watershed boundaries used in this study including the small watershed boundaries and 14-digit HUC boundaries also have these minor problems. Since these minor errors won't seriously influence the ecosystem classification results, this study did not attempt to rectify such boundary locations, although errors of this nature can be corrected in the future mapping enhancements.

Chapter 4

Types of γ - Level LTA Units

After three levels of LTA delineations, γ-level landtype association units were generated with sizes ranging from 100 to 5,000 acres (40 to 2,000 hectares), and belonging to one of the three major LTA categories, including highland habitat, transitional terrace, and dual drainage. Pennsylvania encompasses various topographic settings in different physiographic formations. Although these three categories generalize the capping or cupping characteristics and terrain topology information of the LTA units, they have broad definitions and can not provide sufficiently detailed descriptions for the fine scale LTA units. For instance, the dual drainage units can be narrow valleys developed by deep stream erosion between high plateaus, and they can also be broad basins located between sparsely distributed hills. Highland habitats can include linear ridges or small hills. In order to further describe the topographic characteristics among and within the three major LTA categories, more rules are needed for classifying the capland and cupland LTA units into more specific subtypes.

After considering topographic and terrain topologic characteristics of these 10,782 γ-level LTA units, both the capland and cupland LTA units were classified into nine subtypes respectively. For the capland LTA units, including highland habitats and transitional terraces, the nine subtypes include **c**onvoluted **c**omponent (**cc**), **e**levated **e**xposure (**ee**), **h**ermit **h**eight (**hh**), **m**ulti-**m**ount (**mm**), **p**eripheral **p**lateau (**pp**), **r**egional **r**idge (**rr**), **s**ide **s**tep (**ss**), **t**rough **t**errain (**tt**), and **u**ndulating **u**pland (**uu**). The nine subtypes of dual drainage units are **a**xial **a**queduct (**aa**), **b**ranching **b**asin (**bb**), **f**luvial **f**acet (**ff**), **g**eneral **g**radient (**gg**), **i**nclined **i**nflow (**ii**), **l**ocal **l**owland (**ll**), **o**riginal **o**utflow (**oo**), **v**eining **v**alley (**vv**), and **w**ater/**w**etland (**ww**).

Types of Highland Habitats and Transitional Terraces

Highland habitat and transitional terrace units are considered together for designation of subtypes, because they are all capland LTA units and shared the same β- and γ-level delineation criteria. The γ-level LTA subclasses for HH and TT are based on the dominant topographic characteristics within each unit and terrain topologic relations between the units. Topographic properties are used for classifying these upland units because they reflect exposure and flow path, and can also indicate geologic composition to some degree in different physiographic formations, all of which are considered important in ecological communities. There are 5,002 γ-scale capland units in the whole state, which include 4,896 highland habitats and 106 transitional terraces derived from 670 α-scale HH units and 4 α-scale TT units.

Figure 4.1 shows the classification rules and subtypes for highland habitats and transitional terraces. At the first step, a program searched out all the HH and TT units which are considerably lower than their adjacent HH or TT units. These units are delineated in the γ-scale LTA mapping process according to the criterion of high elevation versus low elevation. Some of these units are connected to DD units, so that water coming from their higher neighbors passes through these units and continues to flow into the lower DD units. Such units in this case are classified as **s**ide **s**teps (**ss**). In other cases, these lower units are just part of the low caplands surrounded by other higher HH/TT units. Accordingly, the latter are designated as **t**rough **t**errain (**tt**).

If the HH/TT unit has complex boundaries shared with dual drainages, which indicates major influences of small stream dissections, the unit is considered as a **c**onvoluted **c**omponent (**cc**). If the HH units are isolated local hills that arise directly from α-scale delineation, they are designated as **h**ermit **h**eights (**hh**). If the HH units are connected to each other and constitute continuous elongated high

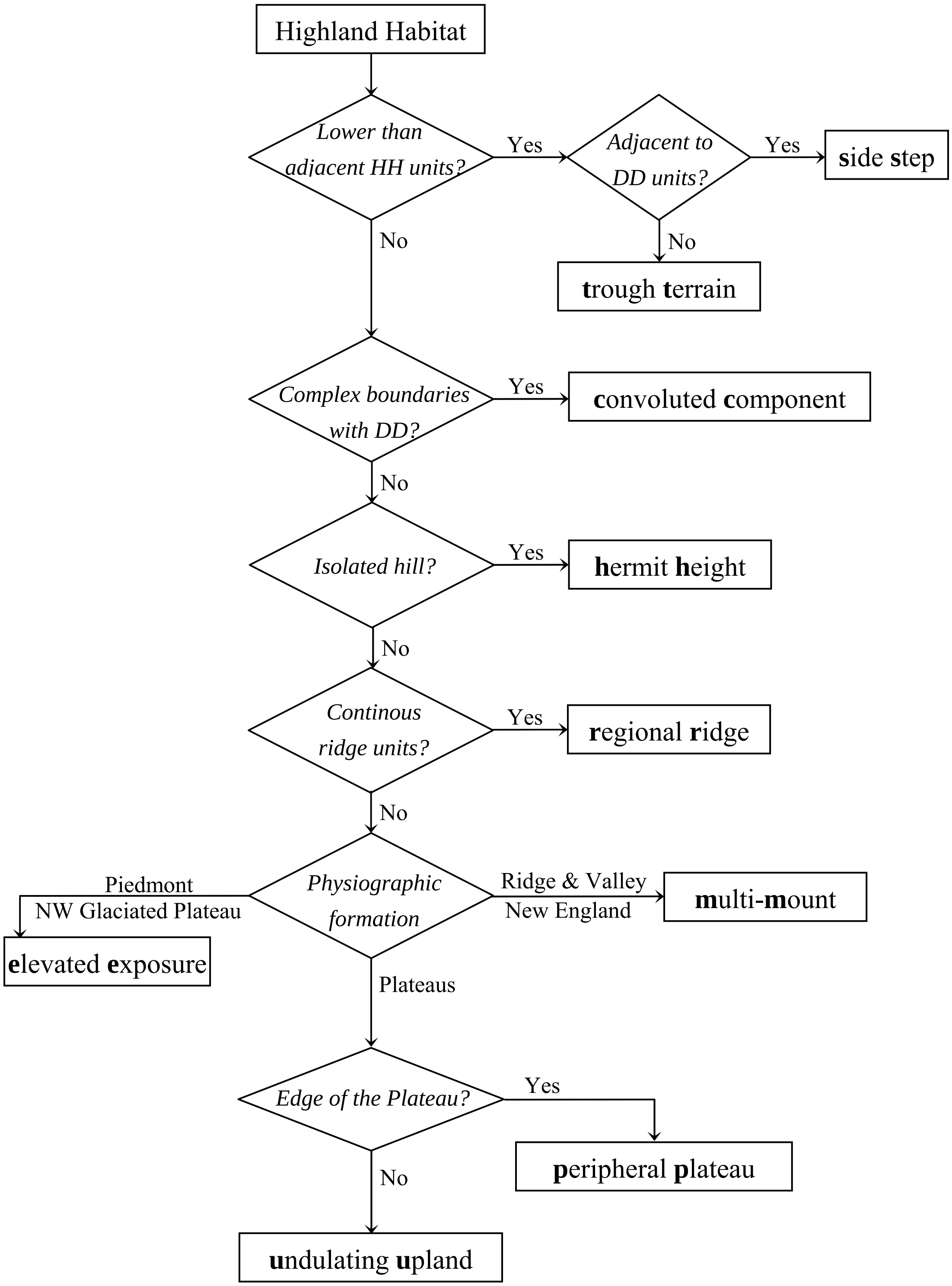


Figure 4.1 Classification rules and subtypes of highland habitats and transitional terraces.

features across regions with consistent elevation relief, these HH units are designated as **r**egional **r**idges (**rr**).

Although the remaining HH and TT units are also classified based on the consideration of topographic and terrain topologic differences, these subtypes are practically separated in this study by the physiographic settings of different LTA units. The reason is that these subtypes are differentiated by the combination of different topographic characteristics, including elevation relief, slope profile type, aspect distribution, etc. To develop general topographic indicators describing these units and define thresholds separating them are relatively complex and difficult. However, the different physiographic settings can help to classify these units well because the topographic characteristics are highly related to the geologic compositions and geomorphic processes occurring in different physiographic sections. In the Piedmont and Northwestern Glaciated Plateau, capland units having low elevation ranges and gentle slopes are classified as **e**levated **e**xposures (**ee**). In the Ridge and Valley and New England physiography, the remaining HH units are more or less connected mountains, and are designated as **m**ulti-**m**ounts (**mm**). In the remaining part of Appalachian Plateaus, if the units are on the edge of large plateaus and dominated by a single kind of aspect, they are designated as **p**eripheral **p**lateaus (**pp**). Units in the middle of extensive plateaus are designated as **u**ndulating **u**plands (**uu**).

Figure 4.2 shows the distribution of these nine capland subtypes in Pennsylvania. The following are brief descriptions of HH/TT LTA units mapped in each of the subtypes.

Side Step (ss)

Side **s**teps are subordinate HH or TT units located between adjacent higher HH units and lower DD units, as shown in Figure 4.3. Side steps receive hydrologic inputs from their neighbor highlands, and pass them to lower dual

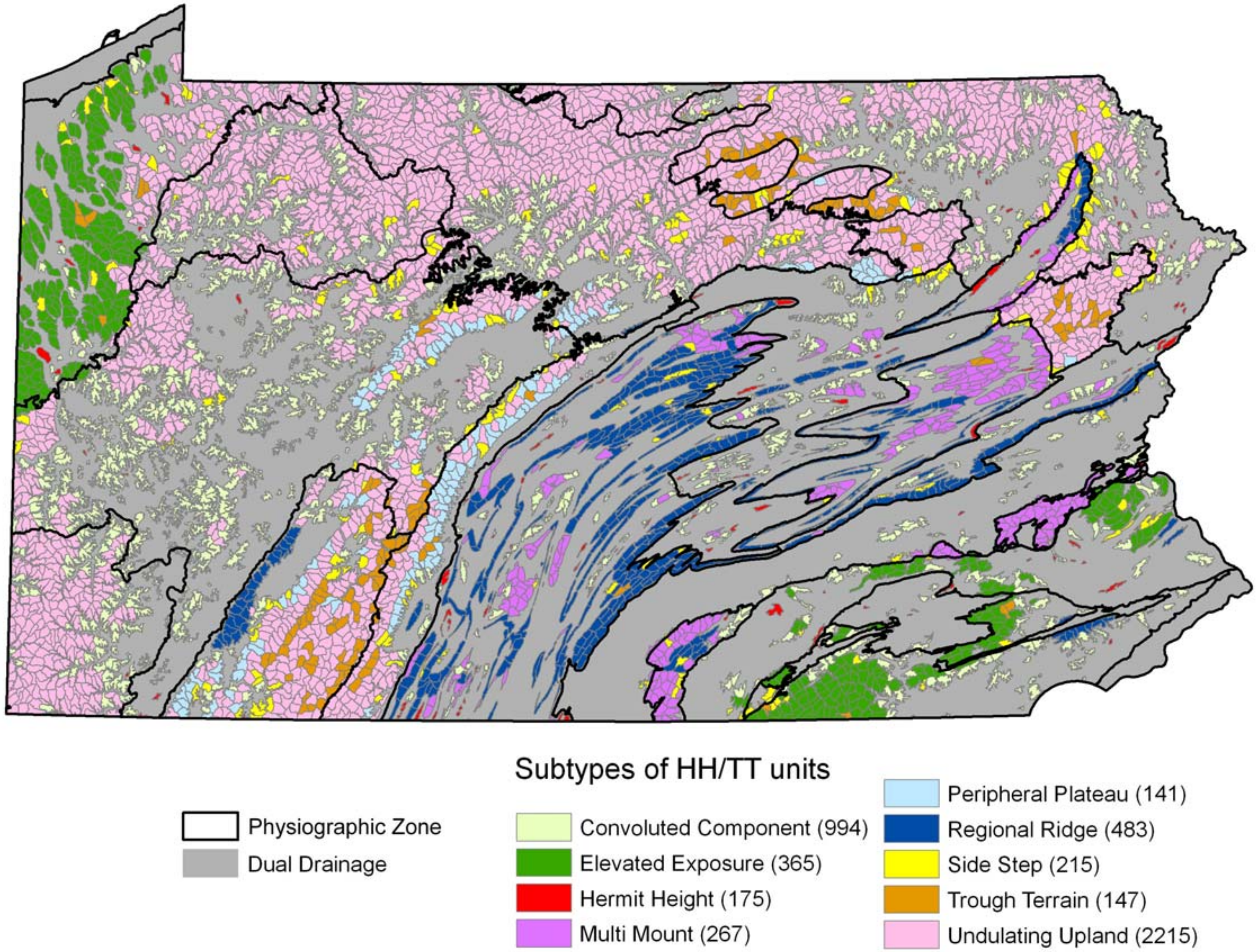


Figure 4.2 Subtypes of highland habitats and transitional terraces in Pennsylvania. (The numbers in brackets indicate number of units within the particular categories in the whole state.)

drainage units. This landscape position helps to enhance their moisture status, and shapes ecosystems within these units somewhat differently than for other HH units.

There are 215 LTA units classified as side steps in the state. Figure 4.2 shows the distribution of these units. Most of the side steps are located in the Appalachian Plateaus. They have sizes ranging from 40 to 2,000 hectares, and they have elevation relief within units of about 100 meters.

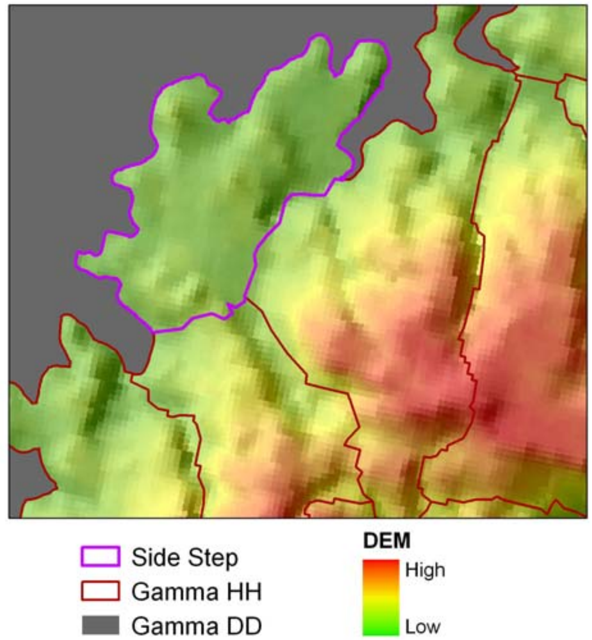


Figure 4.3 Side step units of the HH/TT LTAs.

Trough Terrain (tt)

Trough **t**errain types are subordinate γ-scale HH units which have lower elevations relative to their adjacent HH unit, but are surrounded only by other HH units. Figure 4.4 shows examples of trough terrain units. At α-scale of LTA delineation, the extensive plateaus were recognized as highland habitats, but at smaller scale, there are some local areas on these plateaus with relatively low elevation. These are delineated as separate LTAs, and grouped into this subtype. Also different from dual drainages, these units are still hill-forms with the topographic characters of highland habitat. Trough terrain units collect hydrologic inputs from their neighboring superior HH units and form headwater stream flows. With this topographic position, these units have good moisture conditions relative to other highland habitats.

There are 147 trough terrain units in the state (Figure 4.2). Most of these units are located within the Appalachian Plateaus and distributed in several small groups. One major group of trough terrain units occurs in the Allegheny Mountain and Allegheny Front physiographic settings along Laurel Ridge, Negro Mountain, and Meadow Mountain. They comprise subordinate HH units between these parallel high mountains or ridges. Another major group of trough terrain units is situated along the boundary of the Glaciated Low Plateau, adjacent to the highlands of the Glaciated High Plateau. There is also a small group of trough terrain units in the Pocono Plateau. Trough terrain units are relatively large, with average size around 1,215 hectares. These units usually occur in the extensive plateau surface area, where distinct dissections are mostly lacking.

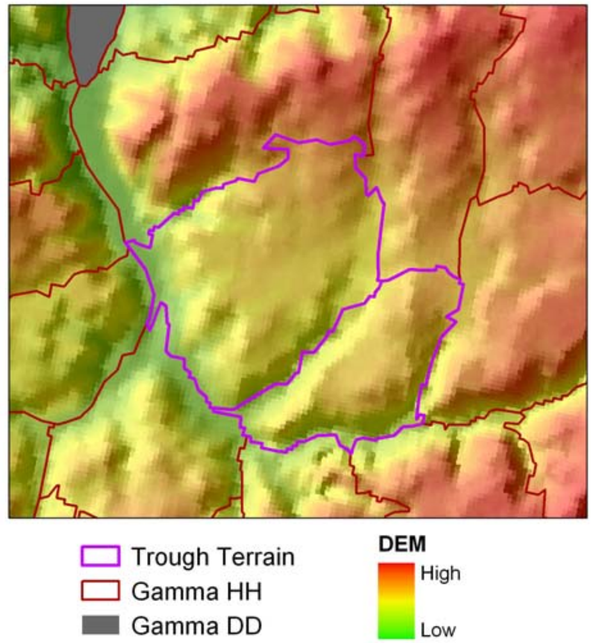


Figure 4.4 Trough terrain units of the HH/TT LTAs.

Convoluted Component (cc)

The **c**onvoluted **c**omponent subtype is designed to represent a group of HH/TT LTA units that is characterized by small stream dissections. Due to the stream erosion, they have complex boundaries with surrounding dual drainages. As shown in Figure 4.5, they are generally comprised of a series of relatively small capping components forming the top of a crest. The elevation fluctuations are usually not great within these units, with an average value around 98 meters. These topographic features have drier environments on the top of the small crest parts, with better moisture conditions in the dissections. Forest composition also varies due to these changes within a convoluted component.

There are 994 convoluted components identified for the whole state. They are spread across the three major physiographic settings as shown in Figure 4.2. They appear most frequently in the Pittsburgh Low Plateau and Waynesburg Hill areas as edge LTA units around large plateaus or separated capland units. Being situated between the major plateaus and dual drainages, or totally surrounded by dual drainages, these LTAs are highly influenced by streams passing through them. Convoluted components can also be found often in the Susquehanna Lowland area of the Ridge and Valley, and in the Piedmont areas where terrain is mainly composed of relatively shallow valleys and narrow hilltops.

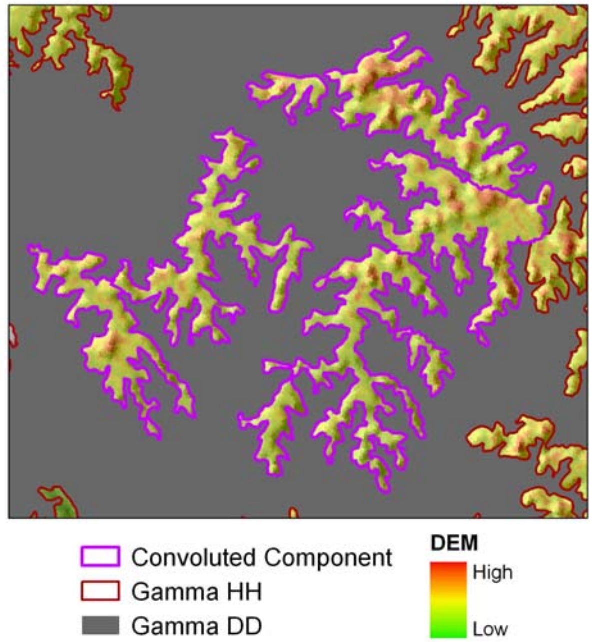


Figure 4.5 Convoluted component units of the HH/TT LTAs.

Hermit Height (hh)

Hermit **h**eights are isolated hills surrounded by dual drainages. These units directly come from α-scale HH units and were picked out as the last concordant capping contours or single contour circles in the α-scale delineation. As showing in Figure 4.6, they are mostly small, low to moderate relief capping units standing upon the surrounding dual drainage background. They are different from other subtypes of HH/TT units in two ways. Firstly, they are entirely enclosed by dual drainages. Secondly, they are simple hills, often with low relief.

The average size of these units is only 273 hectares, and the average relief is 79 meters. These units are remnant results of stream dissection of deeply weathered surfaces.

There are 175 highland habitats classified as hermit heights in the state (Figure 4.2). They are spread all over the state, and are especially common in the Ridge and Valley as small, discontinuous local ridge units. There are also some hermit heights situated in the Piedmont, Glaciated Low Plateau, and Northwestern Glaciated Plateau.

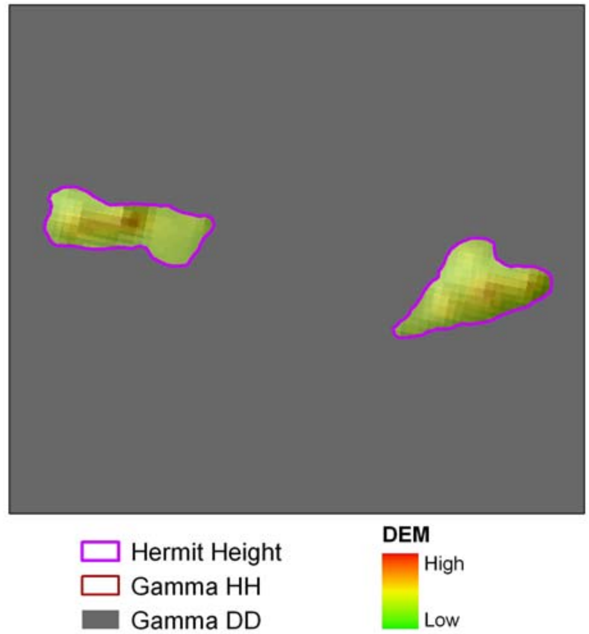


Figure 4.6 Hermit height units of the HH/TT LTAs.

Regional Ridge (rr)

Regional **r**idges are ridge units occurring primarily in the Ridge and Valley. As shown in Figure 4.7, a large ridge unit was subdivided into γ-scale LTA units, and each of the small portions became a member of the regional ridge type. The primary landforms of this group are composed of ridge tops and sideslopes. The ridge tops are continuous, crests, and the

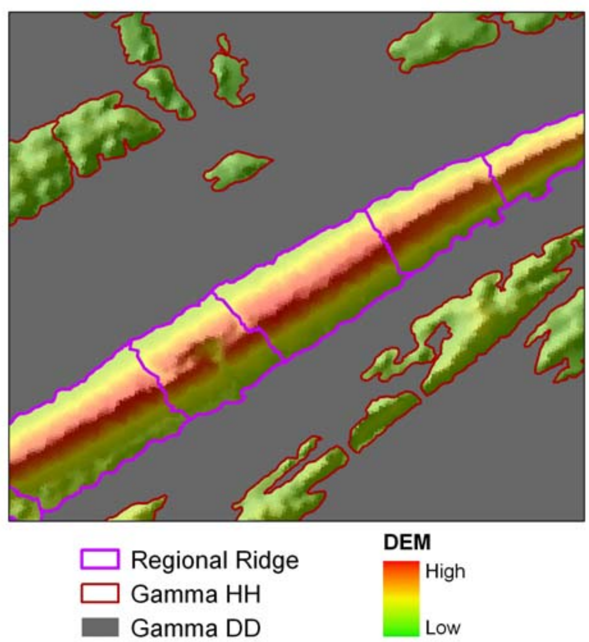


Figure 4.7 Regional ridge units of the HH/TT LTAs.

sideslopes are predominantly straight. Slope gradients for the sideslopes generally range from 20 to 45 percent, but for some broad ridges with asymmetric sides they can also include relatively gentle slope areas ranging about 10 to 20 percent. Because of the high slope, the average elevation range is also large within these units, and the relief is about 242 meters. The topographic setting for ridges entails exposure to wind and generally rapid drainage. Soils also tend to be thin and rocky due to prolonged gradual erosion.

There are 483 units classified as regional ridges in the state, and most of them are in the Ridge and Valley as shown in Figure 4.2. There are also some such units located along Chestnut Ridge in the Allegheny Mountains. Several small and low relief units also occur in the Piedmont.

Elevated Exposure (ee)

Elevated **e**xposures are broad, gently rolling hills dissected by valleys eroded into them. As shown in Figure 4.8, these units are characterized by small elevation ranges and relatively gentle slopes. The size of these units is generally larger than the average of HH/TT units, with the average area being about 1,322 hectares. The mean elevation relief within each unit is only 92 meters, which is much less than the average for all HH/TT units.

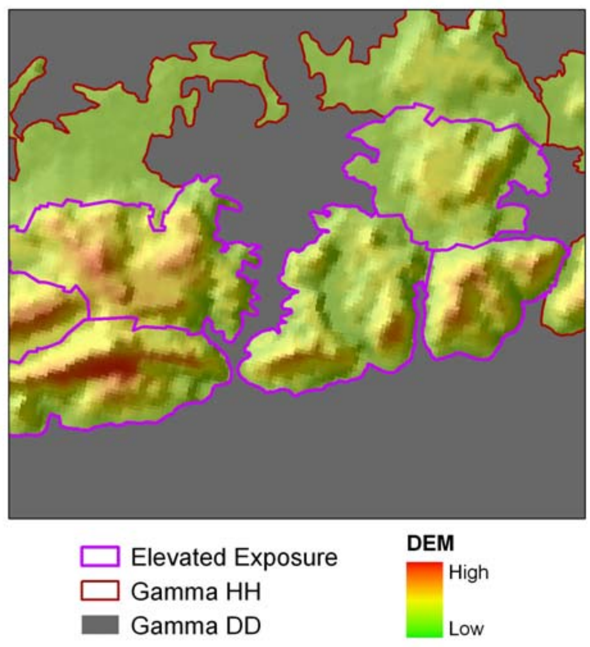


Figure 4.8 Elevated exposure units of the HH/TT LTAs.

There are 365 elevated exposures identified within the state. They are distributed in two major groups as defined in the subtype classification (Figure 4.2). One group is located in the Piedmont, especially the Piedmont Upland area. The other group is in the Northwestern Glaciated Plateau. The physiographic setting was used as a criterion here in defining this subtype because some HH/TT units on the top of broad plateaus can also have low elevation relief and gentle slopes. However, those plateau units are different from units in this subtype by having more extensive summit areas, different geological substrate and subject to different geomorphic processes.

Multi-Mount (mm)

Multi-**m**ounts are clustered mountain units. As shown in Figure 4.9, they are a series of mountains that occur together at a regional scale, and dissected by saddles. They are usually composed of capping mountain summits and sideslopes. Different from the regional ridges, they do not have elongated ridge lines. Unlike the plateau upland units, they do not have expansive summit areas. And also different from the elevated exposures, these units usually have large elevation relief. The sideslopes are relatively steep in these units, and the percent slope is generally greater than 15. In some areas, the slope can even reach more than 40 percent. The elevation relief is also large with the average elevation range being about 191 meters.

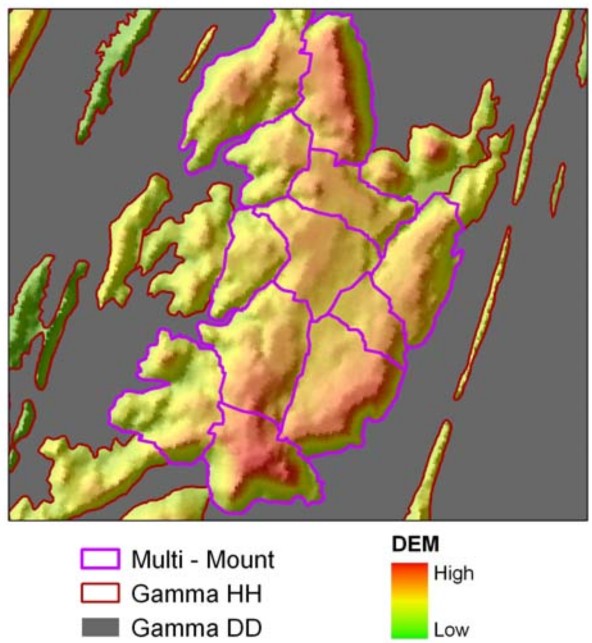


Figure 4.9 Multi-mount units of the HH/TT LTAs.

There are 267 highland habitats classified as multi-mount units in the state, and they are distributed in the Ridge and Valley and the New England physiography (Figure 4.2). They account for all highland habitat units in the New England physiography. In the Ridge and Valley, they occur as grouped mountains in the places where ridge characteristics are not obvious.

Undulating Upland (uu)

Undulating **u**pland units are mature eroded surfaces developed on a stratum or beds of geological materials having greater durability than underlying components where more active streams have cut on the margins, perhaps through fractures. Figure 4.10 shows the typical layout of undulating uplands. They have extensive summit areas. These summit areas are usually horizontally oriented with local slopes less than 10 percent. The peripheral slopes can be relatively steep slopes or cliffs due to the intensive erosion process. In this case, these units have high elevation relief with steep surrounding slopes of 25 to 45 or even greater than 50 percent. Otherwise, the surrounding slopes can also be relatively gentle in some areas where the topography was mainly modified by the glacial erosion. In these areas, the units have little elevation relief, and the side slopes are usually 15 to 20 percent. Undulating uplands are the most typical HH units in the Appalachian Plateaus region.

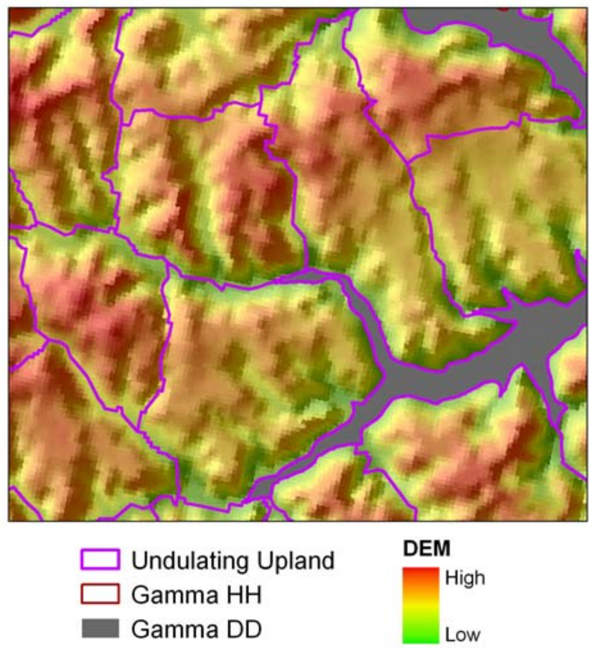


Figure 4.10 Undulating upland units of the HH/TT LTAs.

There are 2,215 HH/TT units recognized as undulating uplands in the state, and they are all situated in the Appalachian Plateaus (Figure 4.2). They account for 44% of the total HH/TT units, because Appalachian Plateaus occupy much of the state. The elevation range, slopes, and summit extension vary in different physiographic settings. The high relief ones are usually distributed in the High Plateau and Deep Valleys, whereas the low relief ones are common in the Glaciated Low Plateau in the northeastern part of the state.

Peripheral Plateau (pp)

Peripheral **p**lateaus are HH/TT units situated along the edges of large plateaus. As shown in Figure 4.11, these units have high elevations on the side which is close to the major plateau area, and lower elevations where they are close to dual drainage areas. They are the transitional units between undulating uplands on large plateaus and the dual drainage units. There is generally one kind of aspect dominating the entire unit. They usually have large elevation changes, and steep slopes. On average, the elevation range within peripheral plateaus is 261 meters, which is much more than other HH/TT subtypes. The slopes can reach over 35 percent in some areas. The vegetation in these units is greatly influenced by the slope and aspect effects, and erosion also occurs in these units as a common phenomena.

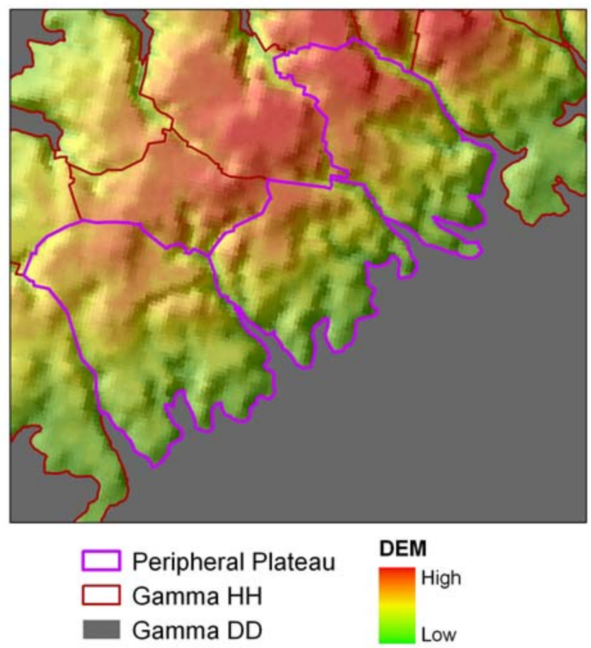


Figure 4.11 Peripheral plateau units of the HH/TT LTAs

There are 141 peripheral plateaus identified in the state, and they are all situated in Appalachian Plateaus around the margin, especially along the eastern margin (Figure 4.2).

Types of Dual Drainages

The γ-scale dual drainage units were delineated from the landscape matrix of HHs and TTs according to 14-digit HUC units, differences between deep valleys and broad basins, small watershed boundaries etc. In total, there are 5,780 DD units delineated for Pennsylvania with sizes ranging from 100 acres to 5,000 acres (40 to 2,000 hectares). These dual drainages have different appearances and properties due to the topographic and hydrologic differences. The criteria for classifying γ-scale dual drainages are based on topographic, hydrologic and terrain topologic characteristics of these units. Based on the properties of DD LTAs, nine classes were created in the subdivision.

Figure 4.12 shows the classification rules and subtypes of dual drainage units. At the first step, **w**ater/**w**etland (**ww**) units were distinguished from the other units by overlaying a wetland and water body map with the DD units. If the water/wetland occupies more than 25% of the total area, the unit is classified as water/wetland. Secondly, **v**eining **v**alleys (**vv**) are differentiated by their special shapes and topographic positions. If the unit is small, elongated, and has complex boundaries with its adjacent HH units, it can be considered as veining valleys. The remaining units that are small and adjacent to HH units are recognized as **l**ocal **l**owlands (**ll**). After that, the remaining dual drainage units are classified into two broad categories according to their hydrologic properties. In the first category, the units do not receive drainage from any other DD units. In the second category, the units receive flow from upstream DD units. For the first group, if the DD unit is composed of gentle slopes, it is classified as **o**riginal **o**utflow (**oo**); otherwise, the

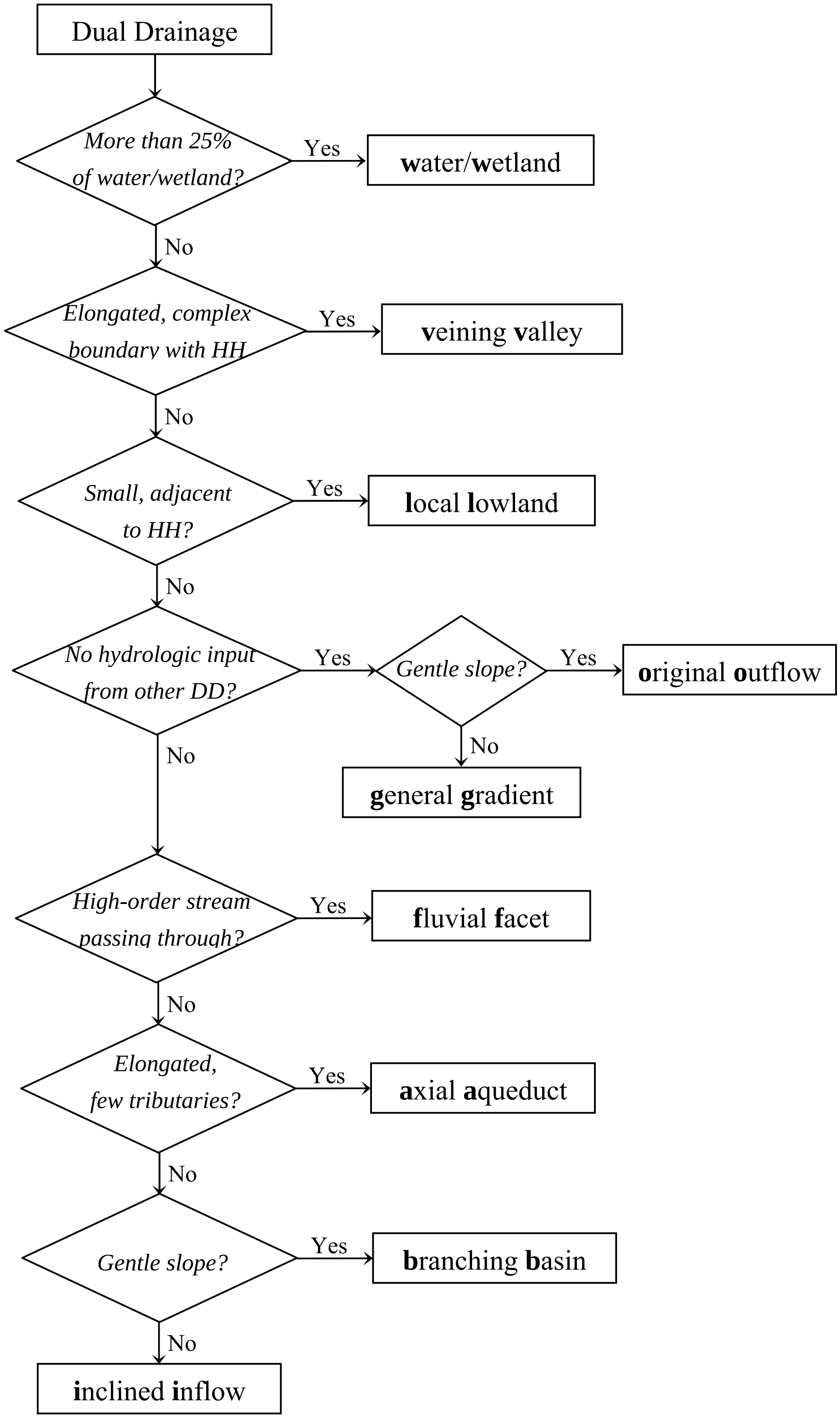


Figure 4.12 Classification rules and subtypes of dual drainages.

unit is grouped as **g**eneral **g**radient (**gg**). In the second category, if the DD unit is highly influenced by large streams (stream order greater than 4), the unit designation is **f**luvial **f**acet (**ff**). If the unit is a narrow valley with only infrequent tributaries, it is designated as **a**xial **a**queduct (**aa**). After that, the remaining parts in the second category were divided into two subtypes according to their slopes. The gentle slope group was called **b**ranching **b**asin (**bb**), and the steep slope group was called **i**nclined **i**nflow (**ii**).

Figure 4.13 shows the distribution of these nine subtypes of dual drainage units in Pennsylvania. The followings are brief descriptions of DD units mapped in each subtype.

Water/Wetland (ww)

Water/**w**etland units are dual drainages dominated by water bodies or various types of wetlands. The ecosystems in these units are greatly influenced by the water or wetland conditions. The 2005 National Wetlands Inventory (NWI) dataset was used in this classification. This dataset covered the whole study area, and mapped wetlands locations and classifications as developed by the U.S. Fish and Wildlife Service. All DD units with more than 25 percent of area in wetlands or water are included in this group, as shown in Figure 4.14. These units not only include areas with big river stems or water bodies, but also contain areas with vegetated palustrine wetlands.

There are 120 water/wetlands units identified within the state. Figure 4.13 shows the distribution of these units. About 30 of these units are distributed along the main stem of Susquehanna River. There are also some water/wetland units separately spread within or around the Northwestern Glaciated Plateau. Some of them may cover part of water bodies, such as Pymatuning Reservior, Shenango River, Allegheny Reservoir, Lake Arthur, etc; and some of them may include palustrine forest wetlands. In the Ridge and Valley, Raystown Lake occupies

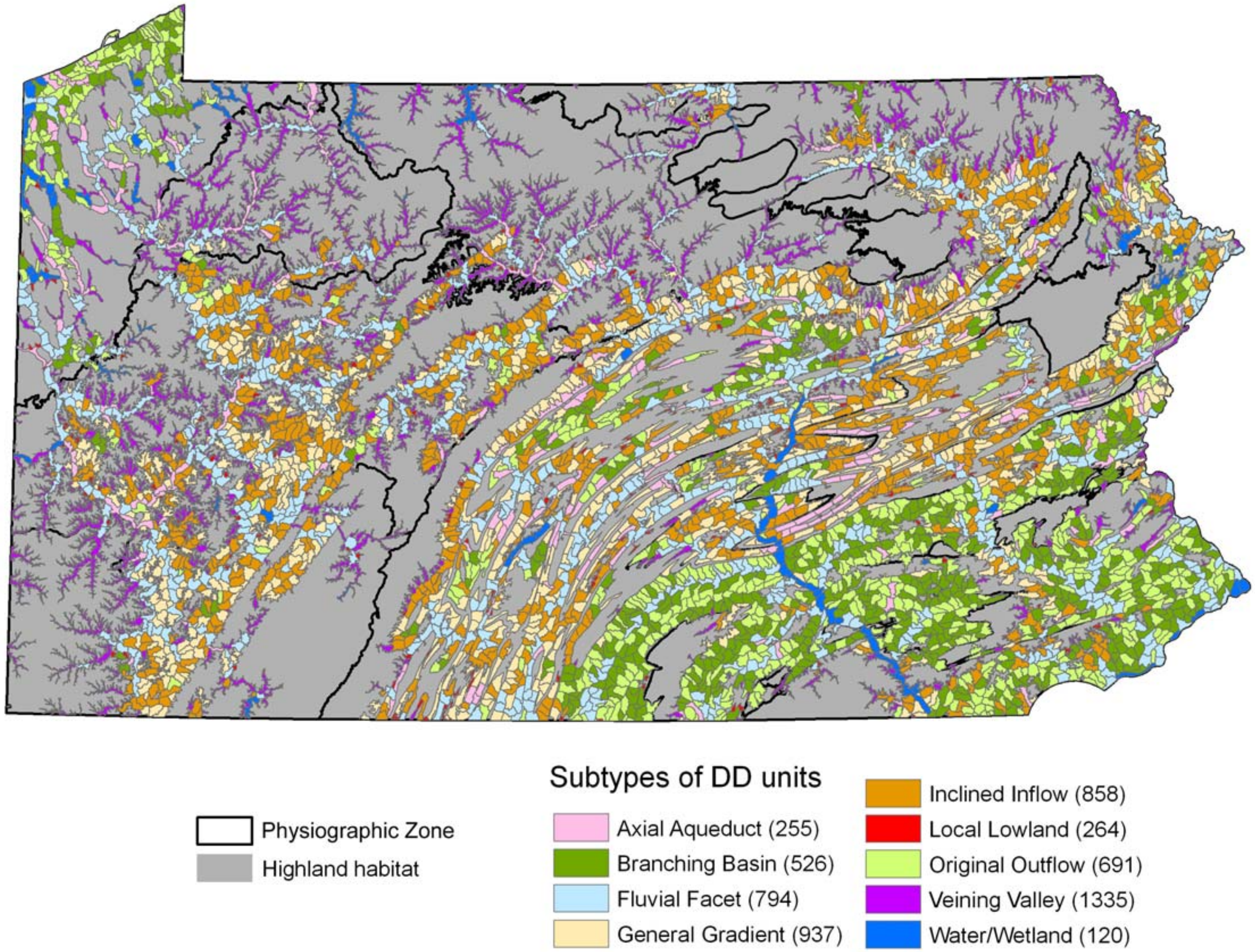


Figure 4.13 Subtypes of dual drainages in Pennsylvania. (The numbers in brackets indicate number of units within the particular categories in the whole state.)

several water/wetland units. In the northeastern part of the state, a small group of water/wetland units occurs in conjunction with Lake Wallenpaupack, and other lakes or wetlands.

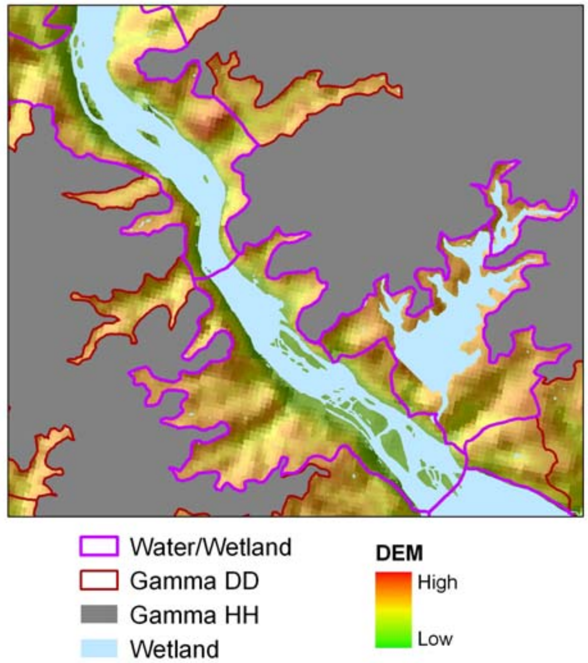


Figure 4.14 Water/wetland units of the DD LTAs.

Veining Valley (vv)

Veining **v**alleys are deep, narrow, steep-sloped valleys generally formed by entrenched streams. They are horizontally sinuous and do not have expansive valley floors. At the head of these valleys, they usually merge with the uplands with small elevation differences. These terrain units were usually formed as the result of stream erosion – they are surrounded by more durable geological materials and deeply cut by active streams. Figure 4.15 shows some examples of veining valley units. They were formed by streams cutting into the edge of the highland habitats and they are characterized by steep slopes. Except for the stream channels, most of the slopes in these units are over 20 percent, and some areas even reach 50 percent.

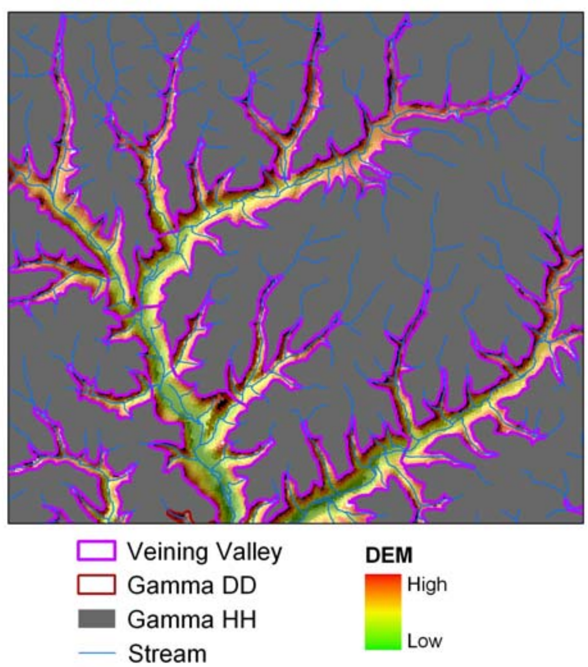


Figure 4.15 Veining valley units of the DD LTAs.

In total, there are 1,335

dual drainages identified as veining valleys in the state. Figure 4.13 shows the distribution of these units. They are most often found in the plateaus as the narrow valleys between undulating uplands. There are also some veining valleys distributed in the Ridge and Valley and the Piedmont. These are usually small valleys notched into their neighboring ridges, uplands, or hills. Although this group has large numbers of components, it does not occupy large areas because all the veining valleys have small sizes. Their sizes range from 40 to 1,000 hectares with an average at 505 hectares.

Local Lowland (ll)

Local **l**owlands are small DD units surrounded by adjacent HH or TT units. They are usually small gaps between highland habitats or transitional terraces. And they only receive hydrologic inputs from the higher HH or TT units. Figure 4.16 shows examples of local lowland units. These units generally do not have expansive valley floors and elongated shapes. They are the local cupping components next to highlands. They concentrate moisture within the unit, form wetlands or distribute the water to other adjacent DD units. This kind of DD unit has good moisture conditions, and often forms palustrine ecosystems.

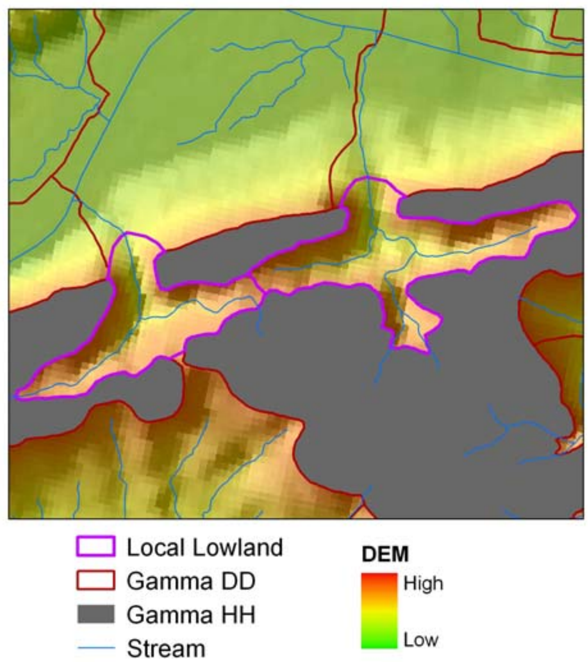


Figure 4.16 Local lowland units of the DD LTAs.

There are 264 DD units classified as local lowland in the state. Figure 4.13 shows the distribution of these units. Most of them are distributed in the

Ridge and Valley as small lowlands around hills or notched into the large ridge units. There are also some local lowlands separately situated in the Pittsburgh Low Plateau around the smooth undulating uplands as shallow, local valleys. The average unit size of local lowlands is about 500 hectares. The elevation range is small, with the average being around 80 meters because of the small unit size.

Original Outflow (oo)

Original **o**utflows are dual drainage units that do not receive hydrologic inputs from any other dual drainage areas, and have more than 50 percent of the unit area with gentle slopes less than 5 percent. The valley profile is commonly U-shaped. As shown in Figure 4.17, they are generally composed of expansive, nearly flat valley floors with side slopes that are generally straight to concave. The slopes are quite gentle, and range from 0 to 15 percent. These DD units usually only contain first and second order streams. Some of them are small planar watershed units, while others receive hydrologic inputs from adjacent highland habitats through first order streams or occasionally second order streams.

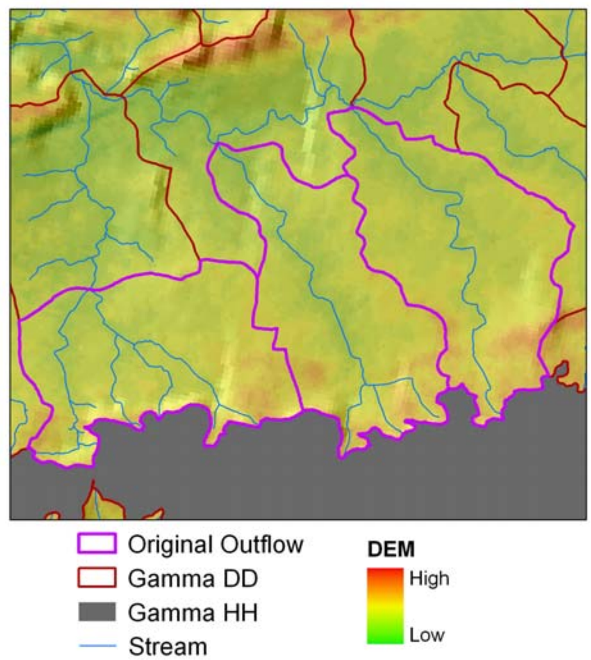


Figure 4.17 Original outflow units of the DD LTAs.

There are 691 original outflows identified within the state. Their distribution is shown in Figure 4.13. Most of them are situated in the Piedmont, Great Valley, or northwestern corner of the state where lowlands have gentle slopes. They usually have large sizes ranging from 600 to 2,000 hectares with an average size of 1,190 hectares. Their local relief is small, ranging from 30 to 120 meters with an average less than 90 meters. Large relief does exist in some units because there may be small hills extending on the edge of these nearly flat areas, which are not large enough to be recognized as a hermit height unit in highland habitat category.

General Gradient (gg)

These units are called general gradients because they include more than 50 percent of the unit area having slopes more than 5 percent. They do not receive hydrologic inputs from other DD units, but they do have the possibility of getting stream flows from adjacent HH/TT units. As shown in Figure 4.18, they are usually V-shaped valleys without expansive valley floors. Stream patterns in these units are usually complex with irregular branches. The relatively steep slopes promote erosion.

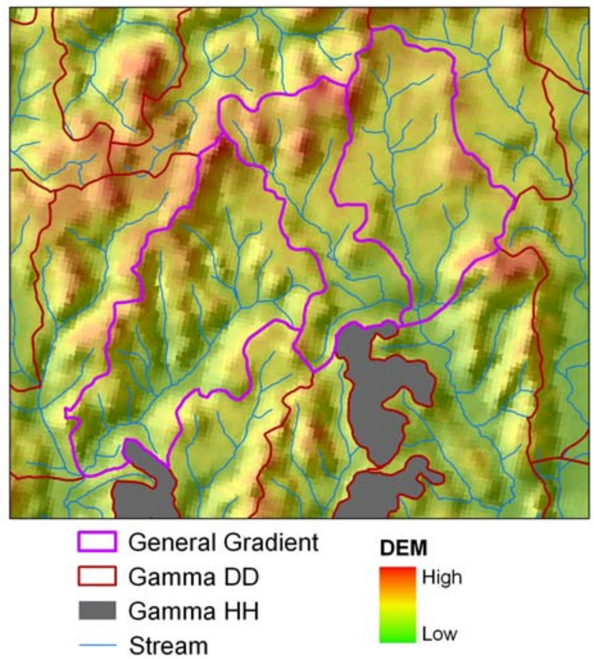


Figure 4.18 General gradient units of the DD LTAs.

There are 937 general gradients classified for the whole state, and their distribution is shown in Figure 4.13. Most of them are located in the Ridge and Valley, and in the Pittsburgh Low Plateau. Although the percentage of flat areas in this group ranges from 0 to 50, most of these units have only 12 to 25 percent of valley floor. The gentle-slope areas are concentrated along the stream channels, and the sideslopes can reach up to 30 percent. Some facets may even have slope of 40 percent. They also have large relief, which ranges from 60 to 210 meters with an average around 150 meters. Their sizes range from 100 to 2,000 hectares.

Fluvial Facet (ff)

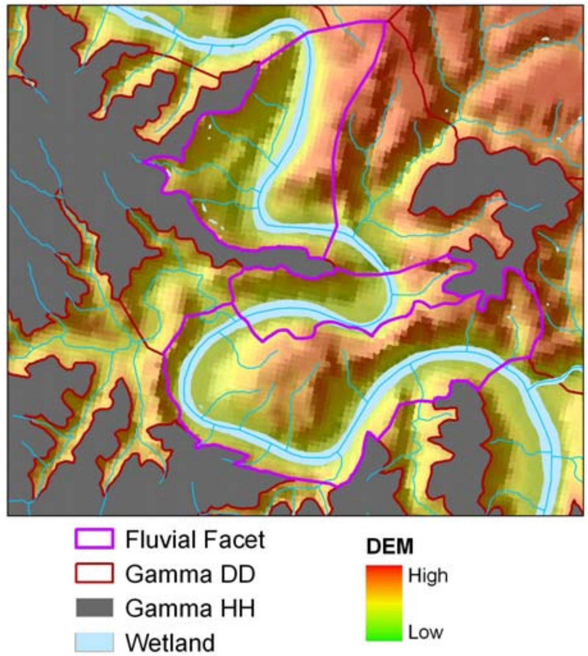


Figure 4.19 Fluvial facet units of the DD LTAs.

Fluvial **f**acets are DD units that are heavily influenced by high-order streams passing through them. The general layout of this kind of unit is that there is one major river flowing through the middle of the unit along its elongation axis. They are usually U-shaped valleys with broad valley floor and gentle to steep side slopes. Some of them have a large percentage of area covered by wetlands or water bodies. Figure 4.19 shows part of the fluvial facet group. They can contain some first or second order tributary streams within the units, but the dominant hydrologic influence is from a large stream.

In the classification, large-order streams are defined as streams with 5 or higher Strahler orders. All of the units containing large-order streams belong to this group. In order to ensure that these major rivers do flow through these units instead of just touching the boundaries, another criterion, the length of the highest order stream, is also used. If the stream length is more than half of the unit diameter, then the unit is considered as fluvial facet.

There are 794 dual drainage units classified into the fluvial facet type. These units do not have consistent topographic characteristics. The percentage of floor area in these units varies from 3 to 90 percent, and they also have a wide range of relief varying from 60 to 250 meters. Their sizes tend to be large because of the river's influence, ranging from 800 to 2,000 hectares with mean of 1,323 hectares.

Figure 4.13 shows the distribution of fluvial facet units in Pennsylvania. They are all situated along high-order streams, including the Allegheny River, Delaware River and their branches and the branches of the Susquehanna River.

Axial Aqueduct (aa)

Axial **a**queducts are long and narrow DD units that receive stream flow from the upper DD units and conduct it down to the lower ones. Figure 4.20 shows the typical layouts of axial aqueduct units. They are valleys with a distinct and relatively straight river channel along the long axis. They usually do not have other tributary streams except for occasional short first or second order tributaries. These units are generally linear V-shaped valleys with sideslopes ranging from 15 to 30 percent. Their sizes are generally small with an average of 1,105 hectares, and the average elevation relief is around 153 meters.

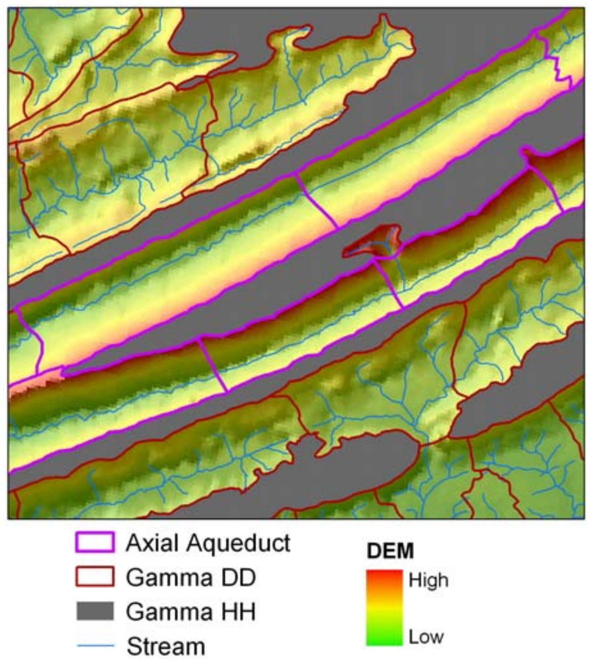


Figure 4.20 Axial aqueduct units of the DD LTAs.

There are 255 DD units in Pennsylvania identified as axial aqueducts. Figure 4.13 shows their distribution in the state. Most of them are situated in the Ridge and Valley as linear valleys between two parallel ridges. There are also some axial aqueducts in the Appalachian Plateaus and the Piedmont. These are usually narrow valleys between two highland habitat units having parallel edges, or valleys connected to the veining valley units.

Branching Basin (bb)

Branching **b**asins are gently-sloped DD units that receive hydrologic input from their adjacent DD units, and direct it down to still lower DD units such as inclined inflows, fluvial facets, water/wetlands or other branching basins. More than 50 percent of the unit area is in gentle slopes of less than 5 percent. Figure 4.21 shows examples of branching basins. They have nearly flat valley floors, with major streams meandering through the middle of the units. They are so-called "branching" because they collect many first or second order stream inputs within the units. Higher order stream input is not normal because the valley is so flat that the stream patterns are usually simple.

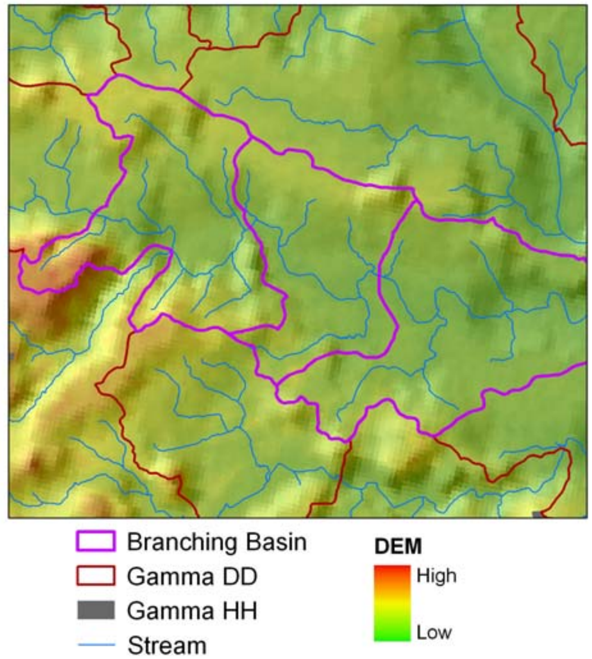


Figure 4.21 Branching basin units of the DD LTAs.

There are 526 DD units classified into this group. Most of the areas in these units are relatively flat with gradients less than 10 percent, while some small areas may have slopes ranging from 10 to 20 percent. The local relief is also small within these units, ranging from 20 to 100 meters. Like the original outflows, they also tend to have large sizes and occur in relatively flat areas. Their sizes range from 800 to 2,000 hectares with the average being 1,336 hectares.

Figure 4.13 shows the distribution of branching basins in Pennsylvania. Similar to the original outflows, most of these units are located in the Piedmont, in the Great Valley and in the northwestern corner of the state.

Inclined Inflow (ii)

Inclined **i**nflows are sloping DD units with less than 50 percent of the unit area being gentle slopes (less than 5%) that collect hydrologic inputs from other DD units and direct them down to other inclined inflows, branching basins, water/wetlands or fluvial facets. Figure 4.22 shows two examples of inclined inflows. Compared to the branching basins, they have more complicated topographic settings. The undulating valley floor makes stream patterns more complex in these units. The general layout is that a major stream passes through the unit in the middle, with several first or second order tributary streams.

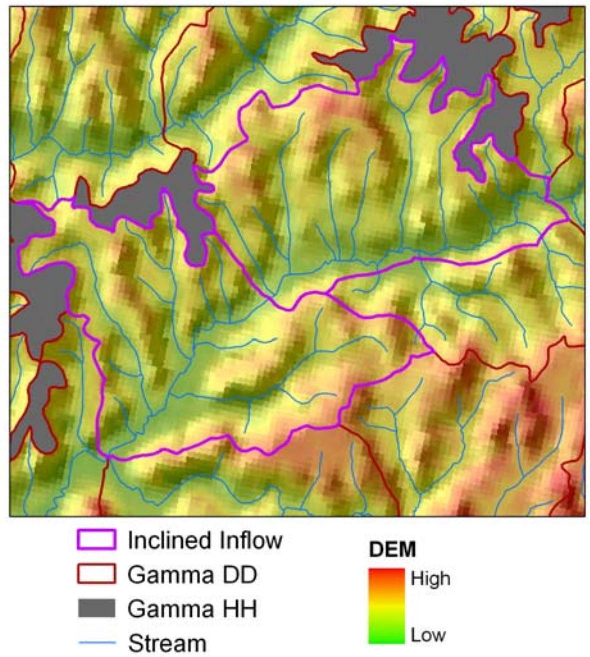


Figure 4.22 Inclined inflow units of the DD LTAs.

There are 858 DD units grouped into this category for the state as a whole. The local relief ranges from 80 to 250 meters, which reflects the fluctuating terrain settings of these units. They also tend to be large with sizes ranging from 600 to 2,000 hectares. Their distribution is shown in Figure 4.13. Most of these units are in the Ridge and Valley or the Pittsburgh Low Plateau, which is very similar to the distribution pattern of general gradients. These two types of dual drainage units often occur together in sloping terrain, with general gradients collecting headwaters and inclined inflows conveying the stream flows.

Chapter 5

Mapping Ecological Landtypes (ELTs)

Mapping Considerations

As the site-level primary land unit in the ECOMAP hierarchy, Ecological Landtype (ELT) was designed for site specific management and project-level planning. They are subdivisions of landtype associations or groupings of landtype phases based on similarities in soils, landform, rock type, geomorphic process and plant associations (ECOMAP, 1993). As defined by USDA Forest Service, Ecological Landtype is an area of land with a distinct combination of natural, physical, chemical, and biological properties that cause it to respond in a predictable and relatively uniform manner to the application of given management practices. In a relatively undisturbed state and/or at a given stage (sere) of plant succession, a predictable and relatively uniform plant community usually should occupy an ELT. They are specific portions of landscapes, whose physiographic characteristics should have a strong influence on the ecological communities found there. The typical size of ELT is generally about ten to hundreds of acres as defined by ECOMAP (1993).

Map Units Design

In this mapping study, both soil and topographic information were used to define Ecological Landtypes because the combination of these two factors determines water and nutrient availability for plant communities, with water and nutrients being the two most important variables in evaluating site conditions. In this case, Ecological Landtypes were considered as unique combinations of soil characteristics and topography. Soil maps provide detailed information about soil component features, soil chemical and physical properties, potential forestland or rangeland productivity and site index, which are key factors in evaluating natural communities at site level. Topographic characteristics such as slope and aspect together with soil texture determine local hydrologic properties. With the combination of soil, slope and aspect, the major physical characteristics of an ecological community can be well described in a specific portion of landscape.

Considering the potential uses of Ecological Landtypes, size of ELTs in this study was designed to range from 10 to 100 acres (4 to 40 hectares). In some areas such as the Piedmont, however, where soil properties are very uniform and topography does not change much, the combinations of soil and topography define uniform local areas with sizes greater than 100 acres.

For the goal of site specific management and project-level planning, the final units should be regular polygons with reasonable boundary shapes. The boundaries of Ecological Landtype units should make sense on the ground in actual management and research practices.

Delineation Strategy

Since the map units are considered as unique combinations of soil characteristics and topography, these became the two major data sources in the mapping process. Soil maps were selected as the primary data source, supplemented by topographic information.

Topographic information such as slope and aspect is usually obtained from a DEM, which is a raster grid of elevations for which accuracy is limited by the grid resolution. Currently, the finest resolution of available DEM data in the study area is 10-meter. But for generating site-level ELT unit boundaries, this raster data would still give jagged shapes of resulting map units due to the rectangular cell edges. Digital soil maps produced by digitizing soil survey maps are usually recorded in vector data format containing smooth-boundary polygons. Thus, soil maps can provide regular and reasonable boundaries to construct Ecological Landtype units.

Topographic information can be evaluated for each soil unit by calculating statistics of the DTM grid values within each polygon of the vector soil layer.

With soil maps as the primary data source, a bottom-up approach is used in this mapping process. Adjacent fine-scale soil polygons are aggregated based on similar topographic characteristics. This method was adopted because of the following considerations.

Firstly, fine-scale soil survey maps already exist for most parts of the state. The Soil Survey Geographic (SSURGO) Database provides nation-wide the most detailed soil maps by the Natural Resources Conservation Service (NRCS). They consist of small soil survey polygons, with the average polygon size being much less than the desired size of Ecological Landtypes. At the time of the present work, SSURGO data are available for all of the counties in Pennsylvania except Erie, Fayette, and Potter.

Secondly, the bottom-up strategy allows us to construct ELT boundaries consistently. All of the ELT boundaries generated in this mapping conform to soil polygons, so the shapes of these ELTs are consistent across regions. If we had used a top-down strategy and subdivided STATSGO soil units with topographic rules, the topographic information would not only give jagged delineation boundaries, but also require that delineation rules vary in different kinds of soil polygons. Since ELT is designed to be transferable among regions, the mapping criteria should be uniform across the state. By aggregating fine soil polygons with similar topographic characteristics, we can ensure the same ELT mapping criteria and also best use the soil information and its smooth boundaries.

Thirdly, it is logical to aggregate small soil polygons based on similar topographic factors. The detailed soil survey carefully considered slope effects and divided the fine scale survey units according to their slopes as a factor. Thus each small polygon in these soil maps should have similar topographic characters within the unit. The raster topographic layers made it possible to summarize slope and aspect characters for these small units. The average slope and dominant aspect can be calculated from the grid values within each polygon. The programmable ArcObjects makes it possible to write routines in ArcGIS to combine the adjacent soil polygons if they have similar topographic characteristics.

Finally, the bottom-up approach makes the composition of the ELTs known in substantial detail. By aggregating the finer-scale units, the combinations of soil properties and topographic characters of ELT units are well understood.

Data Sources

As mentioned above, two major data sources, digital soil maps and topographic datasets, were used in generating Ecological Landtype units in this study.

Soil Data

The Soil Survey Geographic (SSURGO) data base was selected in this study as our primary soil data input. It is a digital soil survey and generally is the most detailed level of soil geographic data developed by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS). It was designed primarily for natural resource planning and management. Components of map units in the data base are generally phases of soil series that enable the most precise interpretation (SSURGO data base, 1995).

This data set consists of georeferenced digital map data and computerized attribute data. The map data are saved in a soil survey area extent format and were mapped at a scale ranging from 1:12,000 to 1:63,360 (SSURGO data base, 1995). The maps were recorded in a vector format, and map units are linked to attributes in the National Soil Information System database, which gives the proportionate extent of the component soils and the properties for each soil. The database contains both estimated and measured data on the physical and chemical soil properties and soil interpretations for engineering, water management, recreation, woodland, range, agronomic, and wildlife uses of the soil.

At the time of the present work, 51 of the 61 survey areas were officially SSURGO certified, and are available in the Soil Data Mart from NRCS website. Another seven survey areas, including Allegheny, Chester, Crawford, Mercer, Northampton, Beaver-Lawrence, and Juniata-Mifflin survey areas, were also finished by the Pennsylvania Map Complication and Digitizing Center and can be downloaded from their website. Data from three survey areas remained unavailable. They are Erie, Fayette, and Potter survey areas. These counties were at the stage of being updated in the field currently. In this ELT mapping, we only generated ELT units in the 58 available soil survey areas. However, the mapping method has been developed with unique criteria for all of the state, and the computer program was also built and applicable for all the survey areas (see Appendix A). Thus, the three remaining counties can be mapped as soon as the soil data become available.

Topographic Data

The topographic information used in this mapping was generated from 30-meter resolution DEM. Two major terrain layers derived from this DEM, slope and aspect, were used in this study as supplemental topographic data inputs.

The 30-meter resolution DEM was selected because this resolution can provide enough terrain information within each SSURGO map unit, and also remains an operable file size for the whole state. Although 10-meter resolution DEM is also available, this file is too large to be calculated for the whole study area. Since this study is more interested in the average slope and general aspect information within each soil polygon, the 30-meter resolution DEM can be effective enough to provide these general topographic characters. These 30-meter elevation data were acquired from National Elevation Dataset (NED) assembled by the U.S. Geological Survey (USGS). In order to reduce the noise in the DEM caused by the production methods or other artifacts, these elevation data were smoothed twice using a 3 by 3 moving window with Inverse Distance Weighting (IDW).

Based on this DEM layer, the slope and aspect raster grids were generated in a GIS for the whole state. Considering that aspects in degrees are difficult to compare with statistical methods between different map units, this layer was further reclassified into 9 general categories. These aspect categories include flat (0), North (0-22.5, 337.5-360), Northeast (22.5-67.5), East (67.5-112.5), Southeast (112.5-157.5), South (157.5-202.5), Southwest (202.5-247.5), West (247.5-292.5), and Northwest (292.5-337.5). This classification scheme was used because most of the mountains and ridges in Pennsylvania have a northeast-southwest orientation.

Mapping Procedure

In this Ecological Landtype mapping, adjacent soil units with same soil series and having similar slope and aspect were merged together to create an ELT unit with size ranging from 10 to 100 acres, or above 100 acres in some areas where soil and topographic properties do not have obvious variations. Because the soil maps were acquired by soil survey areas and some of these areas do not have the edge-match step done yet, this mapping doesn't merge the 58 available soil survey areas together. The ELT units were generated for each of these survey areas individually.

There are two steps involved in this mapping process, with the first step being data preparation. In this step, the soil maps were first overlaid with existing landtype association boundaries to ensure that all the produced ELTs will be nested in their upper level ecological units. Then the GIS system assigned the related soil and topographic parameters through soil data base and the slope and aspect grids for all these small intersected soil polygons. The second step is to aggregate adjacent polygons with similar properties, and to generate the final ELT units. A Visual

Basic for Applications (VBA) command was written in ArcGIS software to automate this process for each soil survey area.

Data Preparation

In this step, the main objective is to overlay existing LTA boundaries with the soil maps and get the associated soil and topographic characters for each soil polygon after the intersection, so that they can be used directly as input datasets for the aggregation command in ArcGIS in the second step.

First, all the soil maps from different soil survey areas were overlaid with the existing γ-level landtype association boundaries. Each of the resulting small polygons was assigned the unique LTA id to which it belongs. This step guaranteed that all the generated ecological landtype units will be nested in their upper level LTA units.

Then, the soil series name was assigned to each of these small polygons. The corresponding soil information system data bases were joined to the attribute tables of spatial soil maps, and the soil properties were extracted for each of these polygons. A new field of soil series was created for each of these soil maps.

Next, the GIS system obtained topographic properties for each of the small soil polygons within different LTA units. Here, the topographic properties include both percent slope and slope aspect. For percent slope, each of these polygons was assigned the average slope value of cells which fall in the polygon. For the purpose of comparison, the standard deviation of slope values for each of these small polygons and the number of cells in topographic raster maps which fall in each soil polygon were also calculated. But for slope aspect, since the aspect degrees are difficult to be compared by statistical methods, the aspect raster grid was reclassified into 9 general categories as mentioned before. Each soil polygon was assigned the dominant aspect class property among the cells which fall in the polygon.

Finally, areas of soil polygons were calculated in GIS, because area is one of the major criteria in judging if the polygons meet our ELT design. If the polygon's area is above 10 acres, it has the possibility to be a separate ELT unit.

Aggregation Process

After the input datasets were ready, a VBA command in ArcGIS read the spatial and attribute-table information from the shape file of each soil survey area, merged adjacent similar polygons, and generated ELT units. Figure 5.1 shows the flow chart of this program.

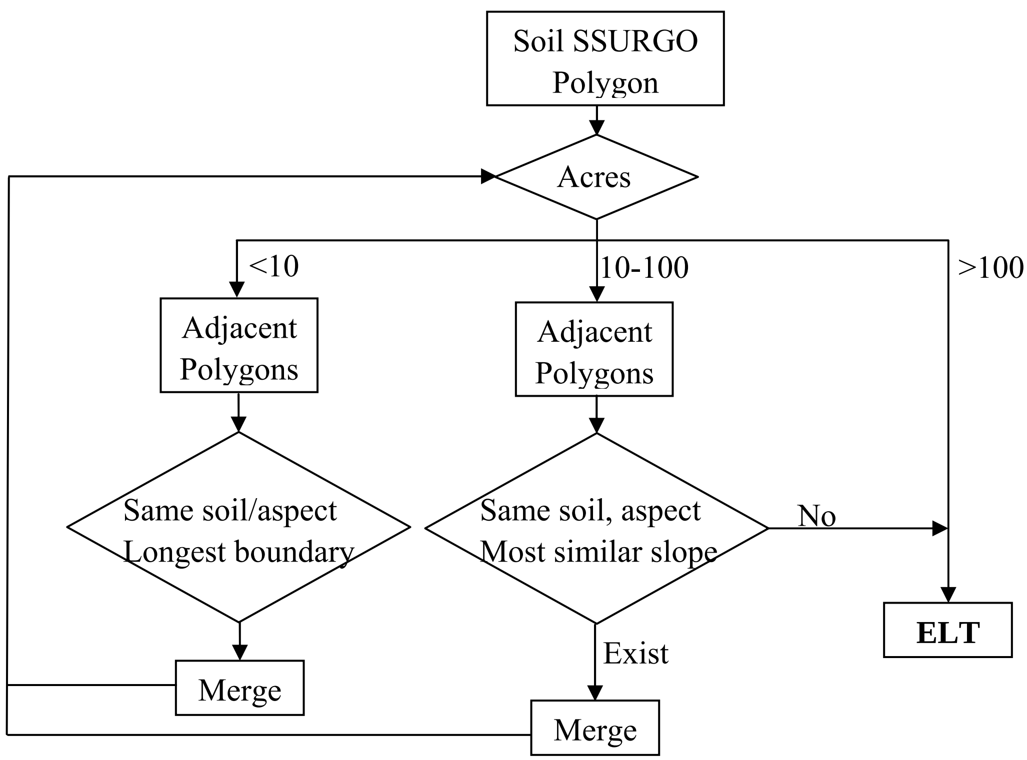


Figure 5.1 Flow chart of ELT generator program.

In this ELT generator command, the program conducts a loop and repeatedly deals with every existing polygon in the shape file. In each turn, the program searches for all of existing polygons in the shape file, and determines if they need to be merged with other polygons. If one polygon needs to be merged, the program will find out the most similar polygon adjacent to the current one, and merge these two features into one new polygon. Otherwise, if the polygon is already qualified to be an ELT unit without merging, it will be marked as ELT by the program. The program stops when all of the polygons in the shape file are marked as ELT units.

The criteria for merging or not are as followings. If the polygon area is greater than 100 acres, the polygon can be considered as an ELT unit and won't be checked by the program again. This kind of polygon comes from the original soil maps directly. Although our designed ELT size ranges from 10 to 100 acres, in some areas the soil properties are so uniform that the basic soil survey units are even bigger than this upper limit. In this case, these large polygons themselves make up an ELT unit at a manageable size, and need not be merged with adjacent polygons. If the polygon area is less than 100 acres and greater than 10 acres, it will be merged with the most similar polygon which is adjacent to the current one, or it will be marked as an ELT unit if there is no similar neighboring polygon. Polygons in this size range can be considered as a separate ELT unit, and can also be aggregated with adjacent similar polygons if available, and if the aggregated new polygons are less than 100 acres. These polygons can be original polygons from soil maps, and can also be new polygons generated in the program by merging two or more small soil polygons together. The most similar polygon here was considered as a polygon that has same soil series and aspect class as the current one, and the percent slope is most similar to the current one. In the ELT generator command, the program first searches for all the adjacent polygons. If an adjacent polygon is in the same LTA unit with the current one, has same soil series, same aspect classification, and total area of adjacent polygon and the current one is less than 100 acres, the program proceeds to compare average percent slopes between these two polygons.

Two slope means are compared with Student's t-test. The statistic t is calculated as:

$$t = \frac{x_1 - x_2}{\sqrt{S^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

x_1 and x_2 are two slope means, n_1 and n_2 are number of cells in two soil polygons, and S is the pooled estimate of standard deviation. S^2 is calculated as:

$$S^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

s_1 and s_2 are two corresponding standard deviations of slope cells in two polygons. Then, the corresponding p-value was calculated for t with the given degrees of freedom N ($N = n_1 + n_2 - 2$). This program used a loose criterion, and considered polygons with p-value greater than 0.3 (statistic t value is approximately 1) to have similar slopes. With all these p-values calculated for each adjacent polygon with same LTA id, soil series, and aspect class, the one with highest p-value was considered as the most similar polygon around the current one. The program then merged these two polygons together, and generated a new polygon. In the new feature's attribute, it keeps all the LTA id, soil series, and aspect class characters from the two original ones. It adds up the acreage and count of cells from the two original ones, and re-calculates the average slope and slope standard deviation.

If the polygon size is less than 10 acres in the input shape file, it needs to be aggregated with other polygons within the same LTA unit because this size is smaller than our designed ELT unit. Polygons in this size range can be those polygons which directly come from soil maps, and can also be new polygons generated by merging small soil polygons together. Since the program only selects one adjacent polygon and merges with the current one at each time, there are some priorities involved in deciding which adjacent polygon should be selected. Within the same LTA unit, the program first searches for adjacent polygons with same soil series and aspect class as the current one. If there are several such polygons existing, the one having the longest common boundary with the current polygon will be selected.

Otherwise, the program only searches for adjacent polygons with same soil series, and selects the one that has the longest common boundary with the current polygon. If there is no adjacent polygon of same soil series, the adjacent polygon which has the same aspect class and longest common boundary will be selected. If there is no polygon satisfying the criteria above, the adjacent polygon with longest common boundary is selected. Then, the program merges the current and selected polygons, and assigns corresponding attributes for the newly generated polygon.

With these rules, the program searches every polygon in the shape file, merges it with one adjacent polygon, or marks it as an ELT unit. The program then searches again from the beginning of the adjusted file for polygons that are not marked as ELT units, and merges or marks them until all of the polygons in the shape file have been marked as ELT units.

Output Units

The generated ELT units are all nested in the upper level landtype associations. Most of them have sizes ranging from 10 to 100 acres, and occasionally, some of these ELTs have sizes above 100 acres. They are saved as vector files with the properties of soil series, major aspect, average slope, and acreage associated in the attribute tables.

The ELT units for the whole state are saved separately according to different soil survey areas because of the following two reasons. First, ecological landtypes are relatively small units, if we put them together for the whole state, the file size will be very large, and it will be extremely slow for display or analysis. Second, our soil maps came from different sources. Some of the soil maps are edge matched between different survey areas, while some are not. There will be some inconsistency existing if we put all the spatial files together.

Discussions

The bottom-up strategy used in this chapter helps to aggregate small soil polygons with same soil series and similar topographic characteristics. This approach produces the ELT units nested in the γ-level LTA units and designated to be the unique combinations of soil characteristics and topography with the sizes in the range of 10 to 100 acres. This method includes the following advantages. Firstly, it is efficient. The VBA command developed in ArcGIS accomplishes the aggregation step automatically, which saves time and labor, and makes the site-level mapping possible for such a large study area. Secondly, this mapping method can be transferable to other areas with similar ELT designation. Once the spatial data of small scale soil survey and DTM information are available, the ELT units can be generated for the study area. Thirdly, this aggregation method ensures that the ELT mapping criteria are consistent across different areas. With the automated mapping system, the ELT units are generated without subjective judgments. Finally, this method is also flexible. The criteria for judging if two polygons have similar topographic characteristics or not can be modified in the program according to different mapping designation, and other soil properties can also be used to aggregate soil polygons.

However, there is also limitation in this ELT mapping study. There are some small soil polygons which are less than 10 acres that do not have any neighboring polygon with same soil series. They were merged with other polygons of different soil series to generate the ELT units larger than 10 acres. For these ELT units, the soil properties are not uniform. To group soil polygons based on other more general soil properties with specific site-level consideration, such as soil hydrologic group, soil depth, and surface runoff might help to reduce this problem and make the resulting ELT units with more specific soil functional considerations.

Chapter 6

General Characteristics of Mapping Units

Characteristics of LTA Units

After three scales of delineation, there are 10,782 landtype association units mapped for Pennsylvania including 4,896 highland habitats, 106 transitional terraces, and 5,780 dual drainages, which were divided from 2,055 α-scale LTA units, or 4,827 β-scale LTAs. Table 6.1 shows the numbers of these three scales of LTA units in the state as a whole. For highland habitats and transitional terraces, the average unit size was reduced from 8,614 hectares at α-scale to 4,611 hectares at β-scale, and 1,160 hectares at γ-scale. For dual drainages, the average unit size was decreased from 4,208 hectares at α-scale, to 1,629 hectares at β-scale, and 1,005 hectares at γ-scale. The highland habitats occupy 48.85% of the area of the state; transitional terraces occupy 1.12% of the state; and dual drainages occupy 50.03% of the state.

Table 6.1 Numbers LTA units for three scales of delineation in Pennsylvania

	Highland Habitats	Transitional Terraces	Dual Drainages	Total
α-scale	670	4	1,381	2,055
β-scale	1,245	14	3,568	4,827
γ-scale	4,896	106	5,780	10,782

The numbers, average sizes, and area percentages of LTA units in different subtypes at the γ-scale are listed in Table 6.2. Among all the subtypes, undulating upland and veining valley are most numerous, because these two types of units are common LTAs in plateaus, and Appalachian Plateaus are the most extensive physiographic context in the state. In HH and TT categories, the convoluted component subtype has the second greatest frequency, occurring all over the state where uplands are strongly influenced by stream flows. Regional ridge and multi-mount together constitute another large HH group, occurring primarily in the Ridge and Valley which is the second most extensive physiographic context in the state. Elevated exposure subtype is the next in order of frequency for the HH category, occurring most often in the Piedmont and in the northwestern part of the state. All other HH and TT subtypes have relatively small numbers and widespread distribution. In the DD category, general gradient and inclined inflow are the second most common subtypes that represent drainage units having relatively steep slopes. Fluvial facet is another frequent subtype occurring along large rivers. Next in order of frequency are original outflow and branching basin subtypes that have relatively gentle slopes. All other DD subtypes have relatively low frequency and somewhat restricted distribution.

Table 6.2 Numbers, sizes and areas of different subtypes of LTA units in Pennsylvania

	Subtype	Number of Units	Average Size (hectares)	Area Percentage
HH and TT	Undulating Upland	2,215	1,281.4	24.43
	Convoluted Component	994	993.6	8.50
	Regional Ridge	483	1,124.8	4.68
	Elevated Exposure	365	1,322.8	4.16
	Multi-Mount	267	1,144.8	2.63
	Side Step	215	1,059.2	1.96
	Peripheral Plateaus	141	1,375.7	1.67
	Trough Terrain	147	1,215.4	1.54
	Hermit Height	175	273.0	0.41
DD	Inclined Inflow	858	1,241.5	9.17
	Fluvial Facet	794	1,322.7	9.04
	General Gradient	937	1,102.2	8.89
	Original Outflow	691	1,189.9	7.08
	Branching Basin	526	1,336.0	6.05
	Veining Valley	1,335	505.6	5.81
	Axial Aqueduct	255	1,105.5	2.43
	Water/Wetland	120	1,078.1	1.11
	Local Lowland	264	202.0	0.46
Overall	**--**	**10,782**	**1,077.6**	**100.00**

The overall average size of LTA units is 1,077.6 hectares (2,662.8 acres). In HH and TT categories, the LTA units occurring in the Appalachian Plateaus and the Piedmont tend to have larger sizes, particularly for peripheral plateau, undulating upland, and elevated exposure subtypes. Convoluted component and hermit height subtypes have small sizes, because these kinds of units are bordered by dual drainages and highly dissected by stream channels. Fluvial facet, branching basin, and inclined inflow subtypes of dual drainages tend to be larger than most other subtypes, while receiving stream flows from upstream drainage units and being more influenced by higher-order streams. Veining valley and local lowland units are of small relative size to other DD subtypes. The veining valleys are small because they are narrow, steep-sloped valleys formed by entrenched streams; whereas the size of local lowlands is limited by the "localness" of their definition.

Caplands (HH and TT) and cuplands (DD) each occupy about 50% of the whole state. In the capland group, undulating uplands occupy most of the highland areas, accounting for 24.43% of the state, because they are the most common LTA units distributed in the Appalachian Plateaus that constitute the largest physiographic context in the state. This HH and TT subtype is both large in size and in number of occurrences. Convoluted components also occupy a substantial area percentage (8.50%), because they spread across the three major physiographic components as caplands that are strongly influenced by shallow stream dissections. As dominant HH units in the Ridge and Valley and the Piedmont, regional ridge, multi-mount and elevated exposure types also occupy relatively large area percentages. As special landscape settings of HH/TT, peripheral plateau, side step and trough terrain only occupy 1% to 2% of the state area. Hermit heights only account for 0.41% of the state area. In the cupland group, general gradient, inclined inflow and fluvial facet subtypes account for most of the DD areas, together covering more than 27% of the state. These are common DD subtypes in the Appalachian Plateaus and the Ridge and Valley. As representative DD subtypes in gentle terrain, original outflow and branching basin subtypes account for 7% and 6% of the area respectively. The most typical drainage units in the Appalachian Plateaus are veining valleys which occupy 5.8% of the state area. Although this subtype of DD unit is numerous, individual instances are not large. As DD types of special settings, water/wetland, axial aqueduct and local lowland subtypes only occupy small areas in the state.

The following paragraphs summarize size, mean elevation, elevation range, and slope characteristics for LTAs, and their occurrence in different physiographic components.

Size Distributions of LTA Units

As mentioned before, all of the γ-scale LTA units have sizes in the range of 100 to 5,000 acres (40 to 2,000 hectares), with the average being 2,662.8 acres (1,077.6 hectares). Figure 6.1 shows the frequency distribution patterns of HH/TT and DD types of LTA units. On average, DD units are smaller than HH and TT units with the average size of 2,485 acres (1,006 hectares), compared to the average size of HH/TT at 2,868 acres (1,161 hectares). The dual drainage group has many more LTA units distributed in the range of 40 to 800 hectares, whereas highland habitat and transitional terrace are more often in the range of 800 to 1,400 hectares. For large LTA units greater than 1400 hectares, the size distribution patterns in caplands and cuplands are similar.

In the dual drainage group, there are many narrow valleys and small lowlands situated between caplands. These small drainage areas are distinguished from their surrounding cuplands by different topographic settings and drainage characteristics. Accordingly, there are many more small units in the cuplands and these small units are mainly comprised of veining valleys and local lowlands. In the caplands, however, small HH or TT units mainly occur as small hermit heights or small lobes attached to other capland units. These hermit heights and small lobes do not occur often in the state, thus there are few capland units having size less than 800 hectares.

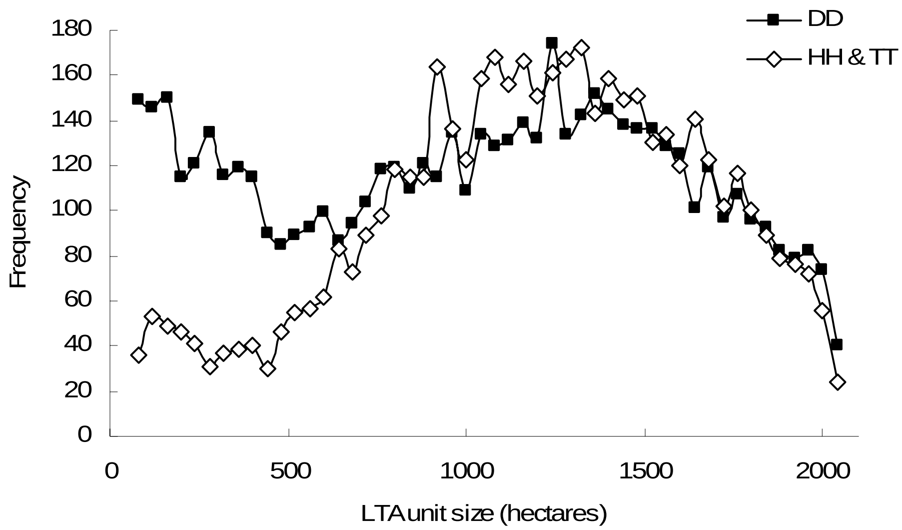


Figure 6.1 Size frequency distribution of γ-scale LTA units.

Small LTA polygons may not merit separate attention in some ecological management activities. In recognition of this, a database table is provided for dissolving small LTA units having size less than 500 acres (200 hectares). There are 759 LTA units including 570 dual drainages and 189 highland habitats having sizes less than 500 acres. Among the 570 small DD units, more than 90% are veining valleys or local lowlands. Sixty-two (10.9%) of these small DD units arise directly from α-scale DD delineation, according to 14-digit HUC boundaries, and 504 (88.4%) arise from β-scale DD delineations separating narrow valleys from broad basins. Among the 189 small HH units, most of them are hermit heights or convoluted components. These two subtypes are more influenced by stream flows, and tend to have smaller sizes. Of these small HH units, 170 (90.0%) arise directly from α-scale LTA mapping that picked out the last coherent capping contours or single contour circles as highland habitats. The other 10.0% of the small HH units arise from β- or γ-scale HH mapping as obvious small lobes attached to other HH units.

The size distributions of HH/TT and DD units can be better understood by comparing the distribution patterns between different subtypes of LTAs. Figure 6.2 shows the size frequency distributions of different HH/TT subtypes. Figure 6.2 (a) and (c) show distributions of regional ridges and multi-mounts, the two major HH subtypes in the Ridge and Valley. These two subtypes have some small LTA units distributed in the small size range of 40 to 500 hectares. Their peaks occur around 1,200 hectares which represent most of the middle-size mountains and ridges. There are also some large units distributed in the size range above 1,500 hectares in these two subtypes.

Figure 6.2 (b) shows size distribution of elevated exposures which are the major LTA units in the Piedmont and in the northwestern part of the state. Because of the gentle terrain in these regions, this kind of unit tends to be large. There are few units having sizes less than 500 hectares, and most of the units in this subtype are distributed between 1,000 to 2,000 hectares with the peak around 1,500 hectares.

Side steps are distributed across most of the size ranges. This subtype is intermediate elevation land surfaces between higher HH/TT units and lower DD units, and their sizes are not constrained by this topographic setting and not limited within certain ranges.

Convoluted components are also distributed across most of the size ranges. They can be either small units or large units depending on the degree of streamflow influence. They can be small units if the stream totally dissects them from their surroundings; but they can also be large if the relatively small convex components produced by stream dissections are still connected to each other in some degree.

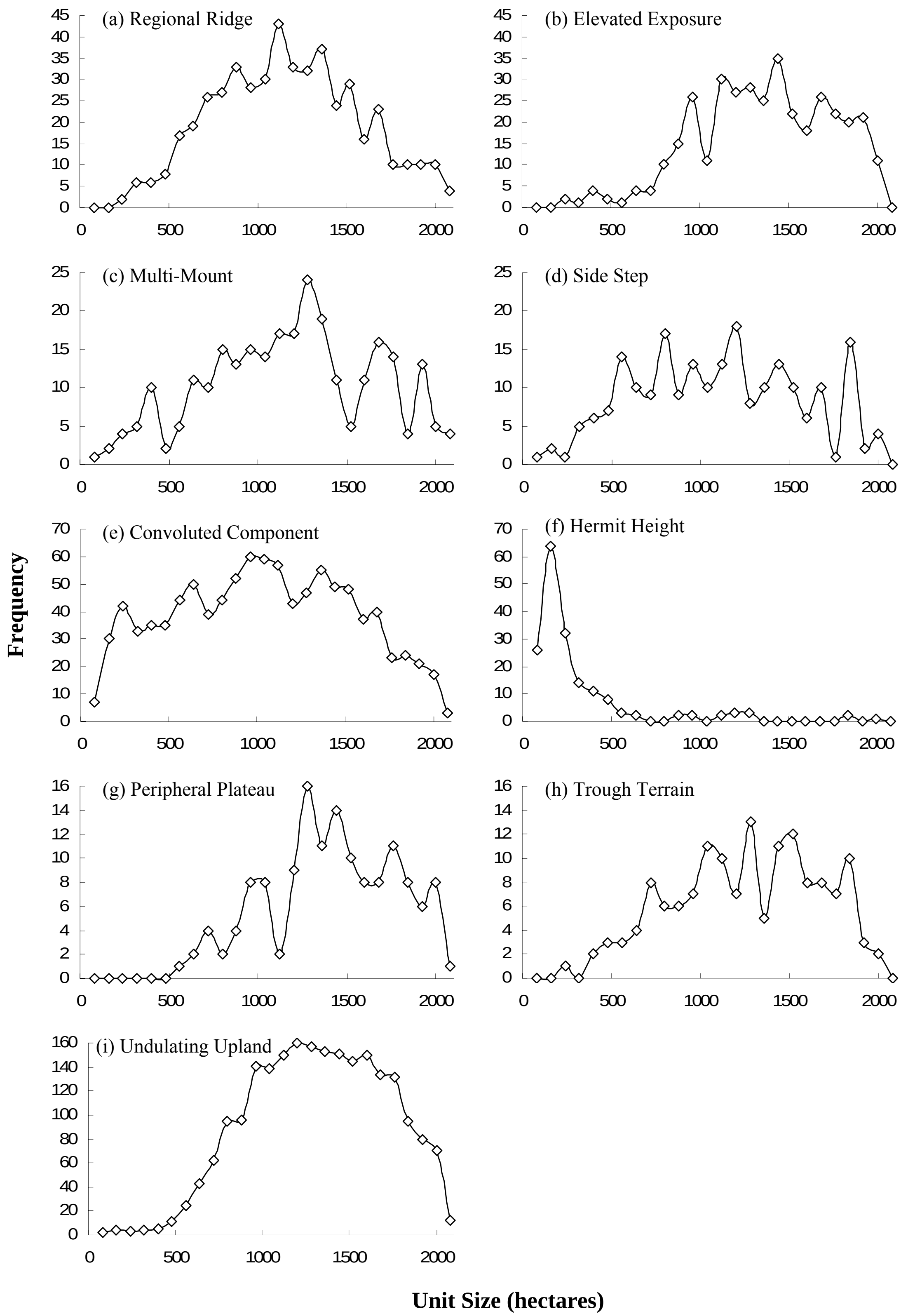


Figure 6.2 Size frequency distribution of different subtypes of HH and TT units.

Hermit heights have a totally different size distribution pattern compared to other HH/TT subtypes. They only exist in the small size range around 40 to 500 hectares because they are small hills arising directly from α-scale highland habitat delineation.

Figure 6.2 (g) and (i) are size distributions of peripheral plateaus and undulating uplands. These two subtypes of HH/TT units are the most common units found in the Appalachian Plateaus. Because of the plateau topographic settings, these units tend to be large. The cases are concentrated in the large size range with almost none in 40 to 500 hectares size range.

Trough terrain units also occur mostly in the Plateaus and these units also tend to have large sizes. Most of the cases are distributed in the range of 800 to 1,800 hectares. However, there are some small trough terrain units below 500 hectares. These small units are usually constrained by the local topography.

Figure 6.3 shows the size frequency distributions of different DD subtypes. Figure 6.3 (a) and (b) are size distribution patterns of branching basins and original outflows, which are DD subtypes characterized by relatively gentle slopes. Because of the gentle terrain, these two kinds of units tend to have large areas, with few in the size range of 40 to 500 hectares. The distribution peaks occur around 1,500 hectares, and there are still some units between 1,500 to 2,000 hectares. This distribution pattern can also be found in the fluvial facet subtype in Figure 6.3 (e), because fluvial facets are highly influenced by high order streams that have wide valley bottoms.

Figure 6.3 (c) and (d) show size distributions of inclined inflows and general gradients, which are two DD subtypes with stronger slopes. Compared to more gentle slope subtypes, inclined inflow and general gradient have more units in the small size range of 40 to 500 hectares, and their size distribution peaks also have smaller values.

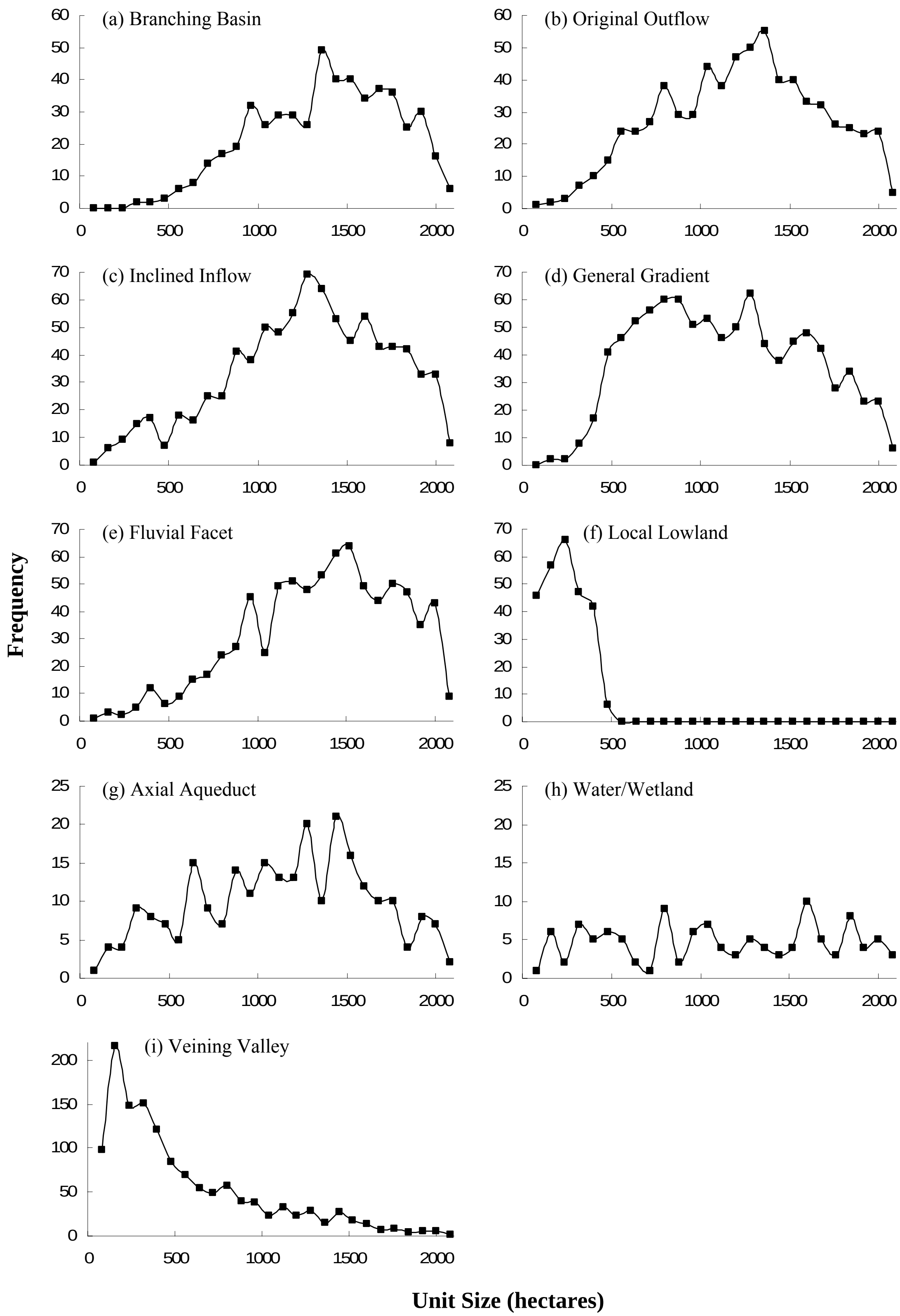


Figure 6.3 Size frequency distribution of different subtypes of DD units.

Local lowlands have a distinctive size distribution pattern compared to the previous DD subtypes. Most instances are smaller than 500 hectares, because they occur as small gaps located between highland habitat or transitional terrace units.

Figure 6.3 (g) and (h) are axial aqueduct and water/wetland, which have irregular size distribution patterns. Axial aqueduct units are defined by their shapes and stream patterns, whereas water/wetlands are defined by existing water bodies and wetlands within the units. These two attributes have little relationship to unit sizes, so they have units across all size ranges.

Veining valley subtype has most of the units in small size ranges, and the number of units decreases sharply as unit size increases because veining valley units are composed of steep side slopes and narrow valley floors. Since there are many veining valley units in Pennsylvania plateaus, they account for most of the small DD units under 800 hectares, and make the DD size distribution pattern obviously different from the HH/TT in the small size range.

Distributions of Average Elevation for LTA Units

By definition, the average elevation for HH and TT units should be higher than DD units. At the γ-scale, the average elevation of HH and TT units is 467 meters, and the average elevation for DD units is 300 meters. This difference reveals the dramatic contrast in topographic positions between these two major LTA categories. Figure 6.4 shows the frequency distribution of mean elevation for HH/TT, and DD units. In comparing these two elevation distribution patterns, two things are noteworthy. First, the range of mean elevation for DD units is much lower than for HH and TT units. The average elevation for DD units ranges from 2 to 535 meters, whereas the average elevation for HH and TT units ranges from 84 to 910 meters. Second, both have three peaks, although the third peak for DD is relatively low and not obvious. Comparing the locations of units within each peak, the LTAs in same peak are located in similar regions. The first distribution peak occurs between 2 to 280 meters for DD units and 80 to 300 meters for HH and TT units with most of the LTA units in this range being distributed in the Piedmont, Great Valley and Susquehanna Lowland. The second peak occurs between 280 to 400 meters for DD units and 300 to 440 meters for HH and TT units with most of these units being located in the western portion of the state, including Waynesburg Hills, Northwest Glaciated Plateau, west side of Pittsburgh Low Plateau, or in the Glaciated Low Plateau. These first two peaks have higher frequency in the dual drainage category than in the caplands because in these LTA distribution areas, especially in the LTAs distribution areas of the first peak, dual drainages have more occurrences than the highlands. The third peak is a subtle one for DD units that occurs between 400 to 520 meters, but it occupies a wide range in HH/TT distribution curve from 440 to 700 meters. Most of these units are located in the higher part of the Appalachian Plateaus, including High Plateau, Deep Valleys, Glaciated High Plateau, Allegheny Mountain, Allegheny Front, and Glaciated Pocono Plateau. Because of the plateau topographic settings, HH and TT units dominate the landscape, so this peak for DD units is not obvious on the graph.

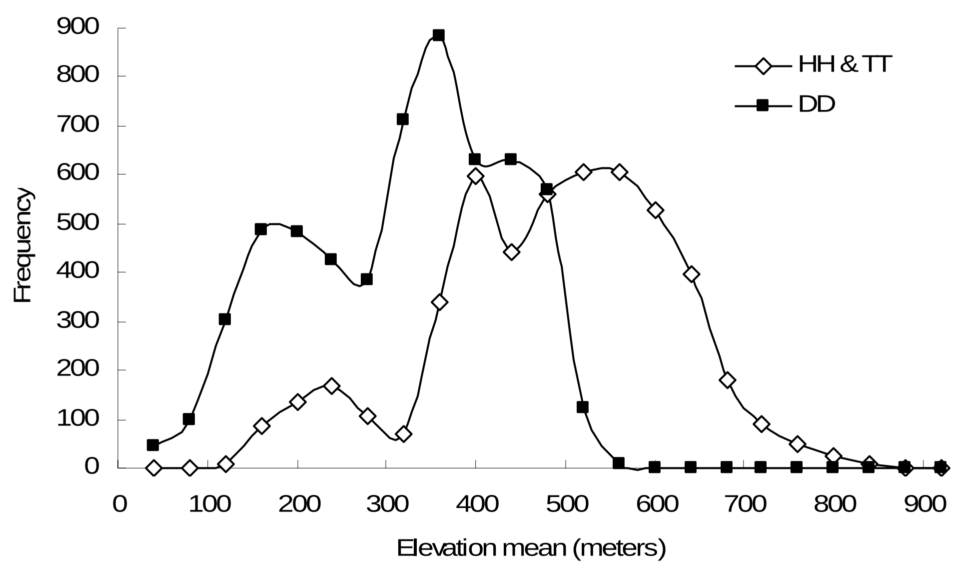


Figure 6.4 Average elevation frequency distribution of γ-scale LTA units.

The average LTA elevation characteristics can be better understood by looking at the elevation distribution patterns for each subtype. Figure 6.5 shows the average elevation distribution of different HH/TT subtypes. Figure 6.5 (a) is elevation distribution of elevated exposures (**ee**). In general, the elevation mean for this subtype is relatively lower than other subtypes of HH/TT. There are almost no **ee** units above 500 meters because this type only occurs in low elevation regions such as the Piedmont and Northwestern Glaciated Plateau. The curve also shows two obvious high peaks due to different **ee** locations. The first peak represents most of the elevated exposures in the Piedmont, which have elevation mean ranging from 40 to 320 meters; while the second peak is mainly formed by the elevated exposures in Northwestern Glaciated Plateau, which have average elevations above 320 meters.

Figure 6.5 (b) shows average elevation distribution of regional ridge units. There are some regional ridges distributed in the low elevation range. These units are mainly located in low elevation areas such as Susquehanna Lowland along with some small ridges in Blue Mountain and other parts of the Appalachian Mountains. Most of the regional ridges have mean elevations ranging from 300 to 700 meters with the peak around 500 meters, which represent most of the ridges in the Appalachian Mountains along with the Chestnut Ridge in the Allegheny Mountains.

The convoluted components have several distribution peaks along elevation ranges, because this subtype occurs all over the state. In general, this subtype has relatively low elevations because these units are close to dual drainages and are highly influenced by stream flows. There are almost no **cc** units above 600 meters. Convoluted components in the Piedmont and lower part of the Ridge and Valley have mean elevations less than 280 meters, which form a small peak on the distribution curve. Most of the convoluted components in Waynesburg Hills, Pittsburgh Low Plateau, and Glaciated Low Plateau have average elevations ranging

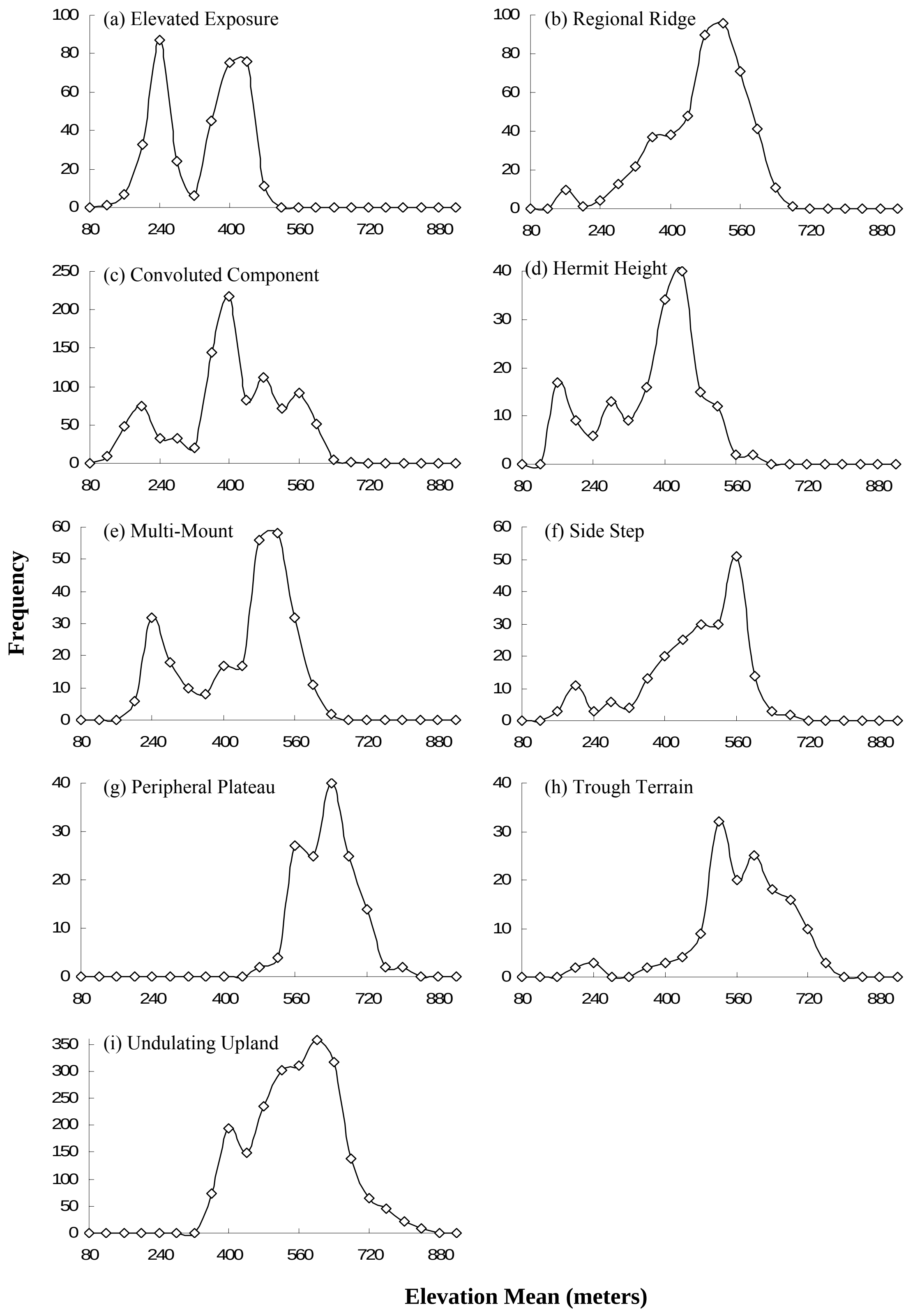


Figure 6.5 Average elevation frequency distribution of different subtypes of HH and TT units.

from 280 to 440 meters, and make the second peak on the curve. Because there are many convoluted components located in these settings, this peak is much higher. The other two small peaks on the curve represent a few **cc** units in High Plateau and Deep Valley areas, respectively.

For the hermit height subtype, its elevation distribution also has several peaks along the elevation ranges because these hills can occur all over the state at all elevation ranges. But they are most often located in the Ridge and Valley as hills, so the average elevation is not high compared to other HH/TT subtypes.

The multi-mount subtype in Figure 6.5 (e) has two peaks in the elevation distribution curve. The first peak is mainly composed of HH units located in New England physiography, and the higher units are mountains in the Ridge and Valley.

Side steps and trough terrain are both lower HH/TT units compared to their neighbor LTAs and both are mainly distributed in the Appalachian Plateaus, but they have very different elevation distributions. Side steps are those units adjacent to dual drainages, while trough terrain units are surrounded by other HH units. So side steps are usually lower than trough terrain units on average. There are also a few side step units distributed in low elevation range. These are units located in the Piedmont.

The remaining two subtypes, peripheral plateau and undulating upland have similar elevation distribution patterns, because these are all common units in the Appalachian Plateaus. Although these two subtypes have very different numbers of LTAs, they are distributed in the high elevation range with the distribution peaks around 600 meters. There is no unit in these two subtypes with the average elevation below 360 meters, and there are still some LTA units higher than 700 meters, which is not common for other HH/TT subtypes.

Figure 6.6 is the average elevation frequency distribution of different DD subtypes. Figure 6.6 (a) and (b) show elevation distributions of branching basin and original outflow, which are subtypes with gentle slopes. Since these two subtypes are spatially distributed close to each other, they also have similar elevation distribution patterns in two ways. First, these units tend to be lower than other DD units, because they most often occur in the low elevation portions of the state having gentle terrain. Second, both of these two subtypes have high distribution peaks between 40 to 280 meters, and small rises above 280 meters. The high peaks represent most of the DD units located in the Piedmont, and the small raises on the higher elevation range are from small numbers of units distributed in the wide valleys of the Ridge and Valley and in the Northwestern Glaciated Plateau.

Figure 6.6 (c) and (d) are distribution patterns of inclined inflow and general gradient, two DD subtypes which have some slope. They are also similar to some degree because they are distributed in similar regions. In general, these two subtypes have relatively high elevation means with the distribution peaks around 350 meters. There are not many of these units distributed in the low elevation range, and most of them have average elevations above 200 meters. This is because most of these units are located in the Ridge and Valley and the Appalachian Plateaus, where the elevations are relatively high.

Fluvial facets have units distributed in all elevation ranges with two obvious peaks on the distribution curve. These two peaks correspond to the elevation differences in different physiographic components. The first peak occurs between 40 to 200 meters, which includes most of the fluvial facet units in the Piedmont and the Ridge and Valley; and the second peak occurs between 240 to 500 meters including all the fluvial facets in the Appalachian Plateaus.

Both local lowland and water/wetland units have distributions along all elevation ranges. Their occurrence very much depends on the local topography or hydrologic conditions.

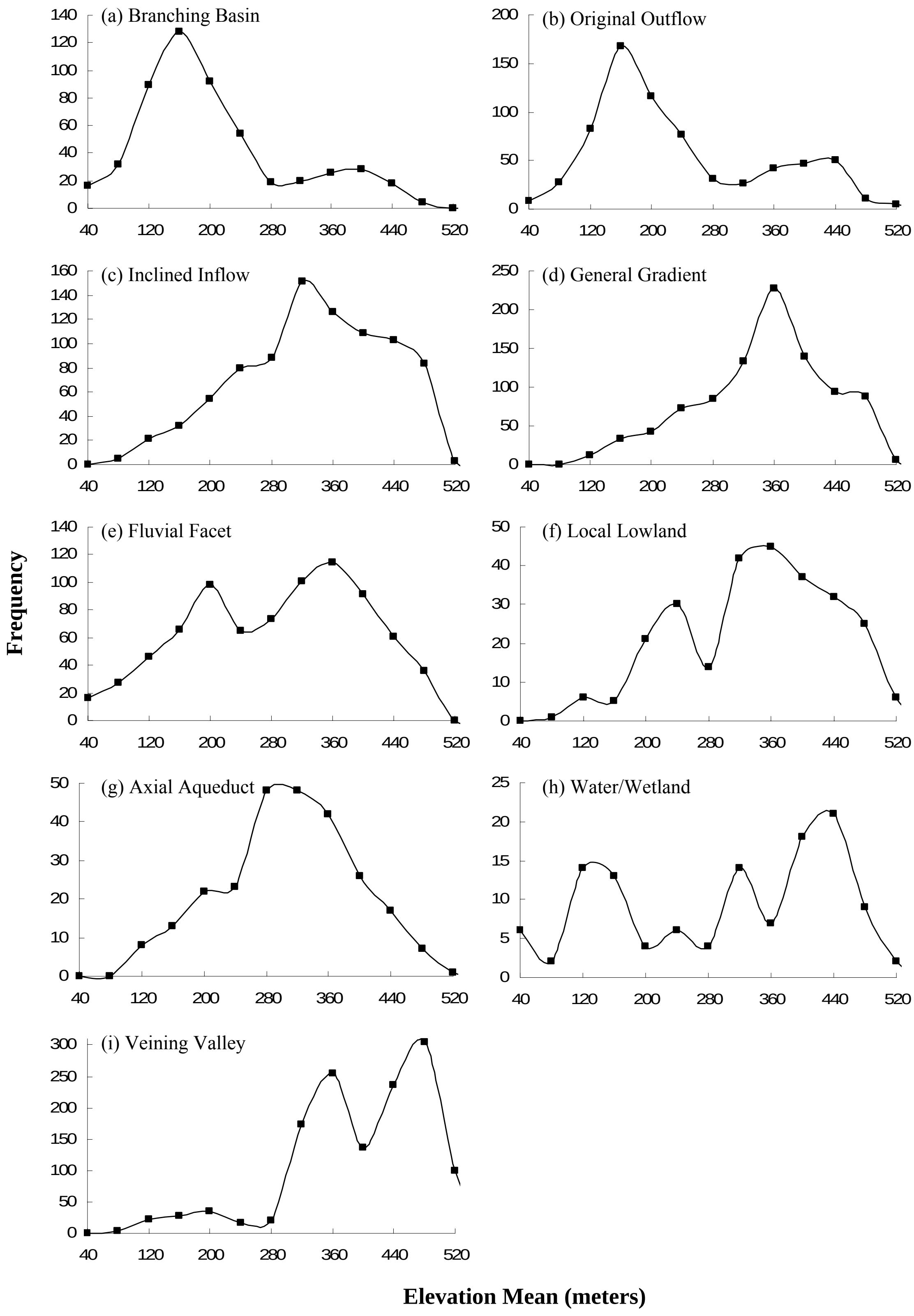


Figure 6.6 Average elevation frequency distribution of different subtypes of DD units.

The elevation distribution of axial aqueducts in Figure 6.6 (g) shows that this subtype has relatively high elevations compared to other DD subtypes, with a peak around 300 meters because most of them occurring in the Ridge and Valley or the Appalachian Plateaus between the highland habitat units.

Figure 6.6 (i) is elevation distribution of veining valley units. This subtype of DD units has obviously higher average elevation compared to all the other DD subtypes. There are only a few units distributed in the elevation range below 280 meters, and these are mainly those small narrow valleys notched in elevated exposures located in the Piedmont. There are two distribution peaks above 280-meter elevation for veining valley units. The first peak is between 280 to 400 meters, which represents the veining valleys in the lower part of the Appalachian Plateaus including Northwestern Glaciated Plateau, Waynesburg Hills, Glaciated Low Plateau and west part of Pittsburgh Low Plateau. The second peak occurs between 400 to 520 meters, which includes all the veining valleys in the higher part of the Appalachian Plateaus including the units in High Plateau, Allegheny Mountains, Allegheny Front and Deep Valleys.

Distributions of Elevation Range (Relief) for LTA Units

Elevation range (or relief) of a particular LTA unit describes the elevation change within the unit, and is an important topographic character in studying the LTA units. Elevation range was defined as the elevation difference between the highest and lowest points in each individual unit. In general, LTA units with steep slopes and/or large sizes tend to have high elevation ranges. At γ-scale, the average elevation range for HH and TT units is about 158 meters, and the average elevation range for DD units is 118 meters. There are several possible reasons for this difference. First, highland habitats and transitional terraces have larger unit sizes. The more area the unit encompassed, the more elevation changes may occur within the unit range. Second, some dual drainages may have wide valley bottoms that are almost flat. Figure 6.7 shows the frequency distribution of elevation range for HH/TT and DD units. Both of the two curves have distribution peaks around 100 meters, with long tails on the high elevation range side extending to 300 to 400 meters. This indicates that most of the LTA units have small relief, and there are only a few LTAs having large elevation variations. Comparing the shapes of these two distribution curves, there are more DD units distributed below the elevation range of 200 meters, and more HH/TT units above 200 meters. The LTA units with elevation ranges above 200 meters mainly occur in Deep Valleys, part of the Ridge and Valley, and part of the Allegheny Mountain areas where the local elevation changes dramatically. In these areas, highland habitats dominate the landscapes, and have more units than dual drainages. These highland habitats include a large proportion of undulating uplands, some regional ridges, multi-mounts, and some peripheral plateaus; while these dual drainage units include inclined inflows, general gradients, and some veining valleys.

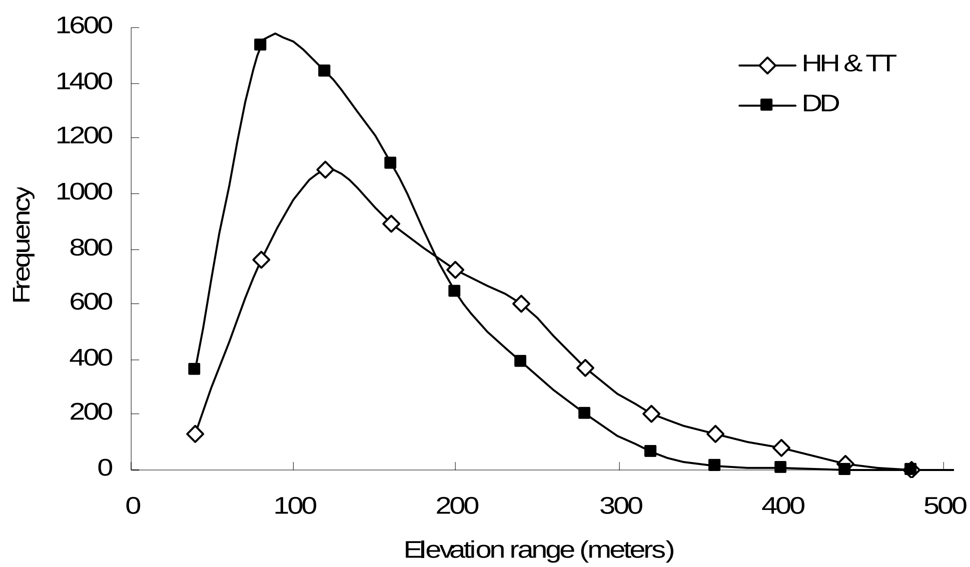


Figure 6.7 Elevation range frequency distribution of γ-scale LTA units.

The elevation range distribution for each subtype of LTA units was also analyzed to compare the differences between these types. Figure 6.8 is the elevation range distribution for different subtypes of HH and TT units. Figure 6.8 (a) and (c) are elevation range distributions for elevated exposures and convoluted components. They have very similar distribution patterns although these two subtypes have different numbers of LTA units. They both have elevation relief in the low range of 40 to 280 meters with a peak around 100 meters, and they do not have any units distributed in the high ranges. Elevated exposures are gently rolling hills located in the Piedmont and the Northwestern Glaciated Plateau, and low elevation range is one of the most important characteristics for this group of units. Convoluted components are greatly influenced by stream dissections and are comprised of series of small capping components. It is impossible to have dramatic elevation changes within such kind of units.

Figure 6.8 (b) shows elevation range distribution of regional ridges. This subtype of LTA units has obvious high relief compared to other HH/TT subtypes with a sharp distribution peak occurring at 280 meters. These units do not have expansive crests and are mainly formed by steep side slopes, so the elevation changes substantially within each unit. The elevation range is especially large for the units located on wide ridges because of the longer side slopes.

The elevation range distribution curve for hermit heights in Figure 6.8 (d) shows that this subtype tends to have small relief within units. The distribution peak only occurs around 60 meters, and there are no units distributed above 240 meters. This is because hermit heights are all isolated hills with very small areas, and elevation typically does not change much within such a small area.

The relief for multi-mount units is frequently in the range of 150 to 250 meters, which is large relative to most of other subtypes. The multi-mount units in large mountain clusters tend to have more elevation changes because these units are

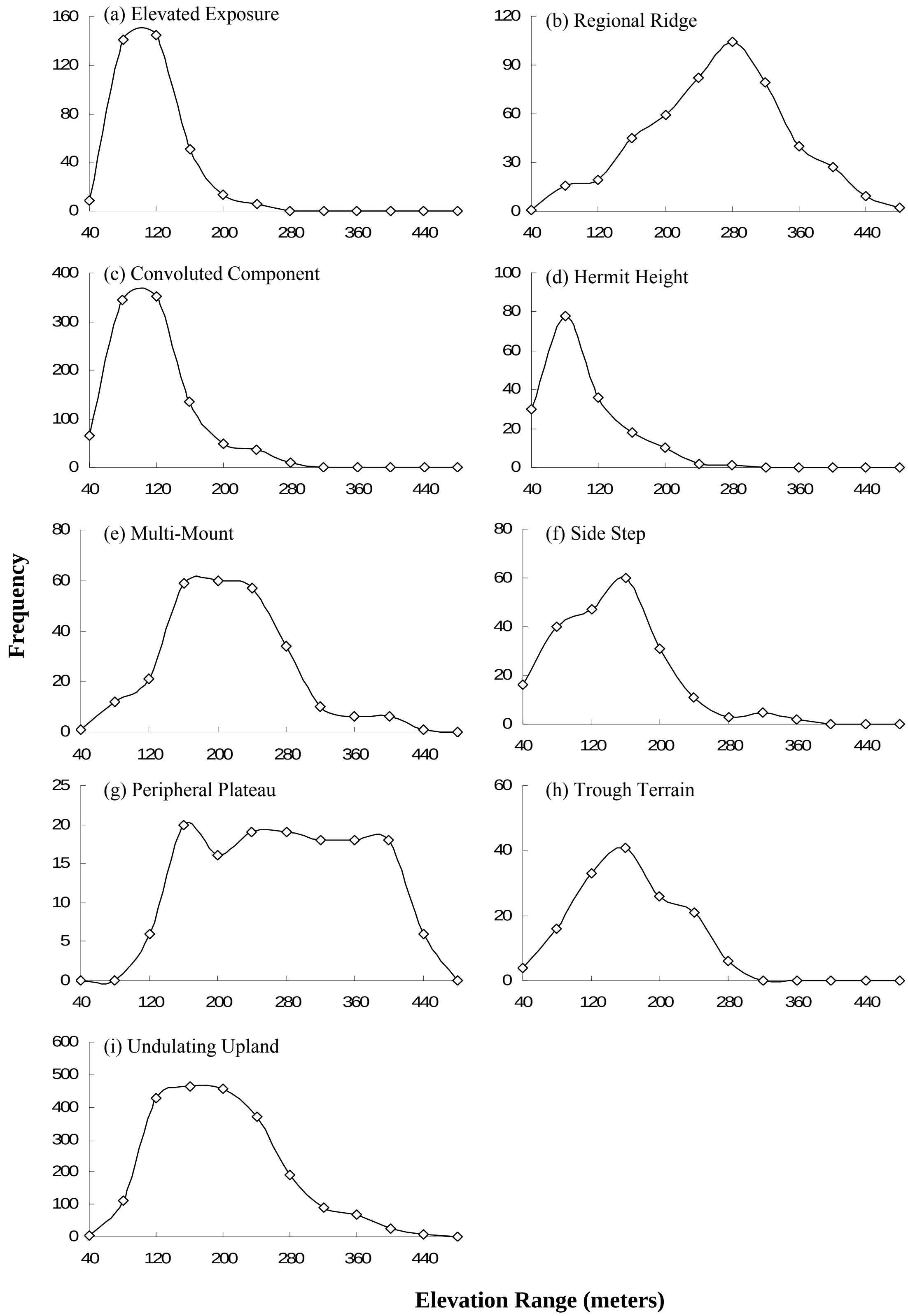


Figure 6.8 Elevation range frequency distribution of different subtypes of HH and TT units.

usually high and the saddles between mountains can be deep. The multi-mounts in Anthracite Upland, however, have relatively small relief because the upland in this area is not dissected by deep cuts or saddles.

Most of the side steps have small relief less than 200 meters, but some of them have large elevation changes. The units with high relief occur in plateaus, especially in Allegheny Mountains and Deep Valleys because these areas have dramatic terrain fluctuations.

Compared with side steps, trough terrain units have fewer cases distributed in the small relief range because these units often occur in expansive plateaus with relatively deep cuts, and elevation changes more within units.

Peripheral plateaus have wide elevation range distribution from 120 to 440 meters. The units with small relief are mainly distributed around the Pittsburgh Low Plateau, and the units with large relief are along the Allegheny Front and on the edge of the Allegheny Mountains.

Figure 6.8 (i) is the elevation range distribution for undulating uplands. Most undulating uplands have elevation ranges from 120 to 280 meters. The units having small relief mainly occur on low plateaus, such as the Pittsburgh Low Plateau, and on large expansive plateaus lacking deep cuts, such as some areas in High Plateaus and Glaciated Pocono Plateau.

Figure 6.9 shows the elevation range distributions of different subtypes of DD units. Figure 6.9 (a) and (b) are elevation range distributions for branching basins and original outflows. These two subtypes have similar distribution curves. They both have small relief with most of the units distributed below 150 meters and peaks occurring around 80 meters. Due to gentle slopes, these units can not have high elevation changes.

Figure 6.9 (c) and (d) show elevation range distributions for inclined inflows and general gradients. These two subtypes also have similar curves.

They both have large relief compared to other DD subtypes, with the distribution peaks occurring between 120 to 200 meters. Since these two subtypes are DD units with some slopes and large sizes, they can have large elevation changes within units.

Fluvial facets and axial aqueducts have similar elevation range distribution patterns in Figure 6.9 (e) and (g), although these two subtypes have different physiographic and hydrologic characteristics and different number of LTA units. They have dense distributions in the range of 80 to 240 meters with a tail toward large relief range. For both fluvial facet and axial aqueduct, those small relief units with elevation range less than 120 meters are mainly distributed in the Piedmont and in the northwestern corner of the state. For large relief units with elevation change greater than 200 meters, the fluvial facets mainly occur in the Deep Valleys, and the axial aqueducts concentrate in the Anthracite Upland. There are not many of such units existing in these areas, however, so the distribution curves are low in this range.

Local lowlands have low relief because these units are small and the elevation change is quite limited in such small areas.

Water/wetland units also have low elevation relief because most of the water bodies or wetlands have gentle slopes. The high relief **ww** units occur along the Susquehanna River and Raystown Lake because of the elevation change along river stem or steep slopes surrounding the water.

Figure 6.9 (i) is elevation range distribution for veining valleys, and shows that this subtype of DD units has relatively small elevation changes with most of the units having relief of 40 to 160 meters. Although this type of unit has steep slopes, the sizes are small and the elevation can not change very much within the small areas. High relief **vv** units only occur in those areas where elevation changes dramatically such as the Deep Valleys.

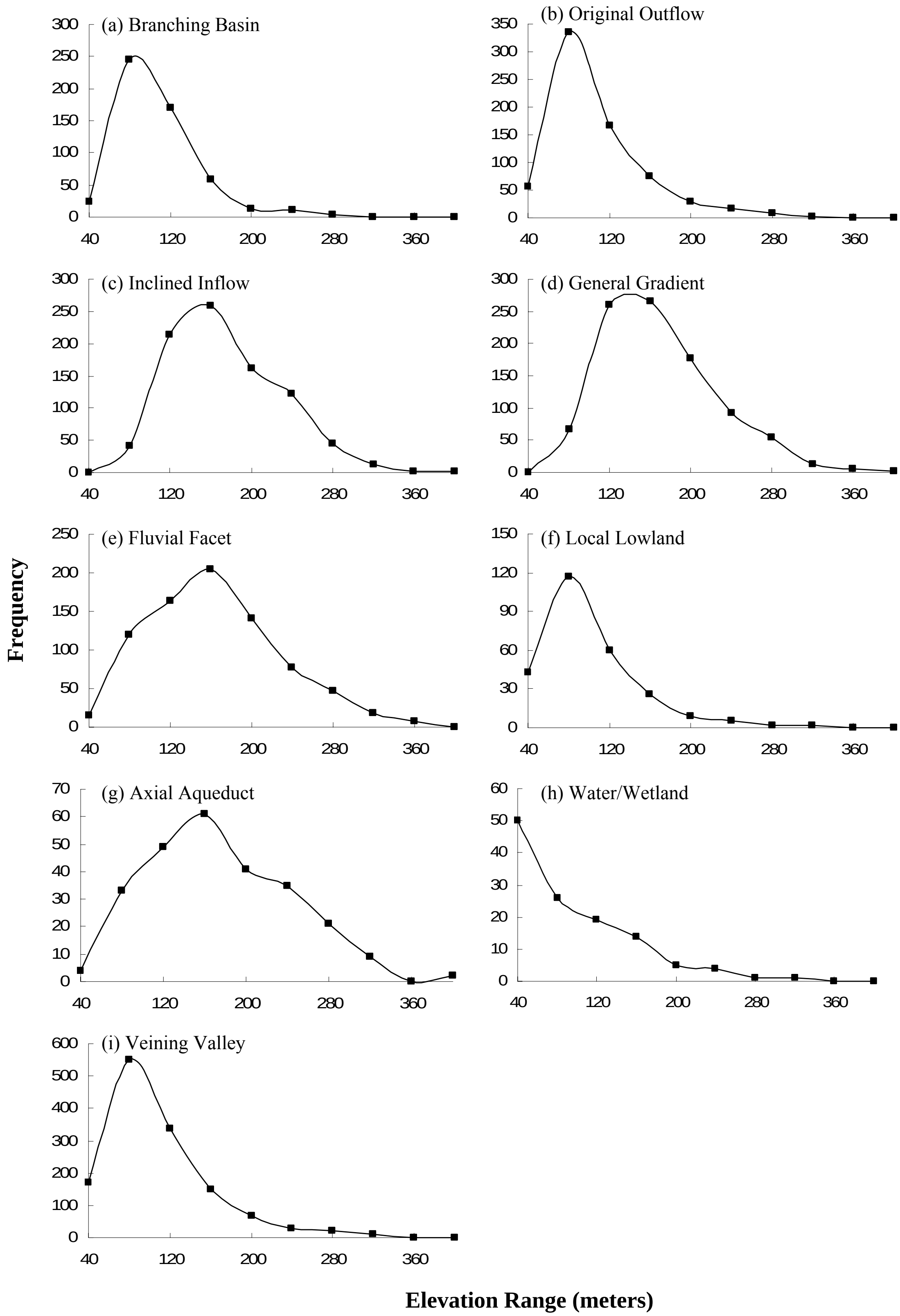


Figure 6.9 Elevation range frequency distribution of different subtypes of DD units.

Average Slope Distributions of LTA Units

Average slope is another important characteristic to describe LTA units. The value was calculated by averaging all cells in the slope grid that fall in the particular LTA unit. The γ-scale HH and TT units have average slope of 12.4 percent, and DD units have 10.7 percent. Figure 6.10 shows slope frequency distributions of the LTA units for these two major categories. Both HH/TT and DD units have slope distribution peaks around 10 percent with long tails toward the high slope range up to 45 percent. Comparing the two curves, dual drainages have more units distributed below 18 percent slope, and highland habitats and transitional terraces have more units above 18 percent. LTA units with average slopes greater than 18 percent are mostly situated in the Deep Valleys and on some linear ridges in the Appalachian Mountains. There are more HH units distributed in these high slope areas than DD units. In the Deep Valleys, however, the veining valley units can have extremely steep slopes that are greater than 35 percent. Thus the number of DD units is slightly larger than HH/TT units in the slope range above 35 percent.

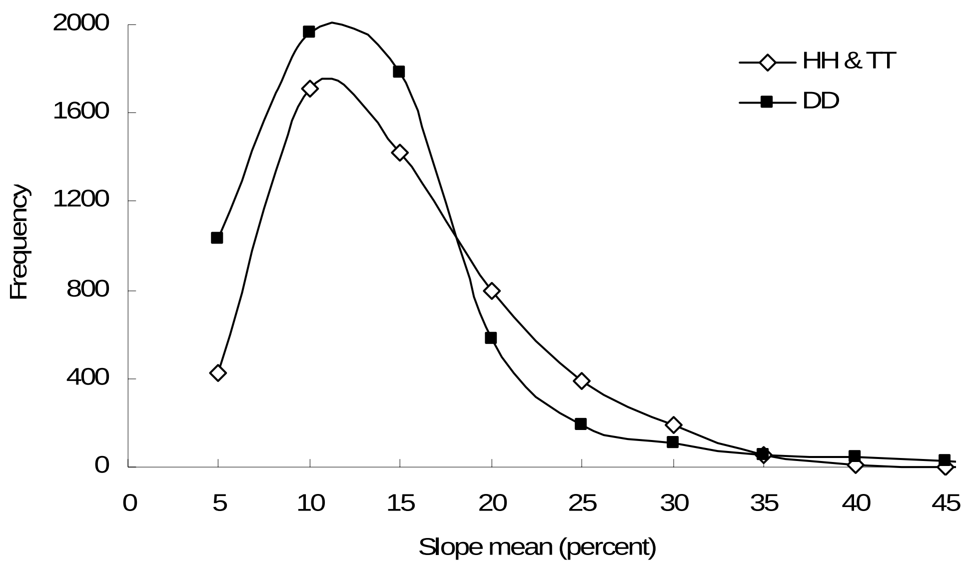


Figure 6.10 Average slope frequency distribution of γ-scale LTA units.

The slope distribution curves for different subtypes of LTA units provide more detailed information about the slope characteristics of LTA units. Figure 6.11 shows the slope distributions for different subtypes of HH/TT units. Figure 6.11 (a) shows the distribution curve for elevated exposures. Most of these units have average slopes less than 5 or 10 percent because they are all situated in the Piedmont and in the northwestern corner of the state, where the terrain is gentle.

Regional ridges have steepest slopes compared to all the other HH/TT subtypes, with most of the units having 15 to 35 percent slopes. These units are generally comprised of sideslopes and small areas of ridge tops, so the average slopes are high due to relatively steep sideslopes.

Convoluted components have relatively low slopes with the distribution peak occurring at 10 percent. The small stream dissections do not carve out steep slopes and keep this type of unit having gentle slopes.

Hermit heights also have relatively gentle slopes but are slightly steeper compared to the convoluted components. These isolated small hills occur as remnants of stream dissections on deeply weathered surfaces. In such settings, they usually do not have steep slopes.

As the other major HH type in the Ridge and Valley, multi-mounts do not have steep slopes relative to regional ridges, and most multi-mounts are distributed in the slope range of 10 to 20 percent. This is because multi-mounts have expansive summit areas compared to ridge units along with gentle fluctuations on the mountain tops. Also, many of these units are located in the Anthracite Upland where terrain is relatively gentle compared to other parts of the Ridge and Valley.

Both side step and trough terrain units have similar slope distribution patterns, as well as similar topographic positions. Their slopes are relatively gentle with the distribution peaks occurring around 10 percent. These two types are both relatively lower HH units compared to their neighboring HH units. They were

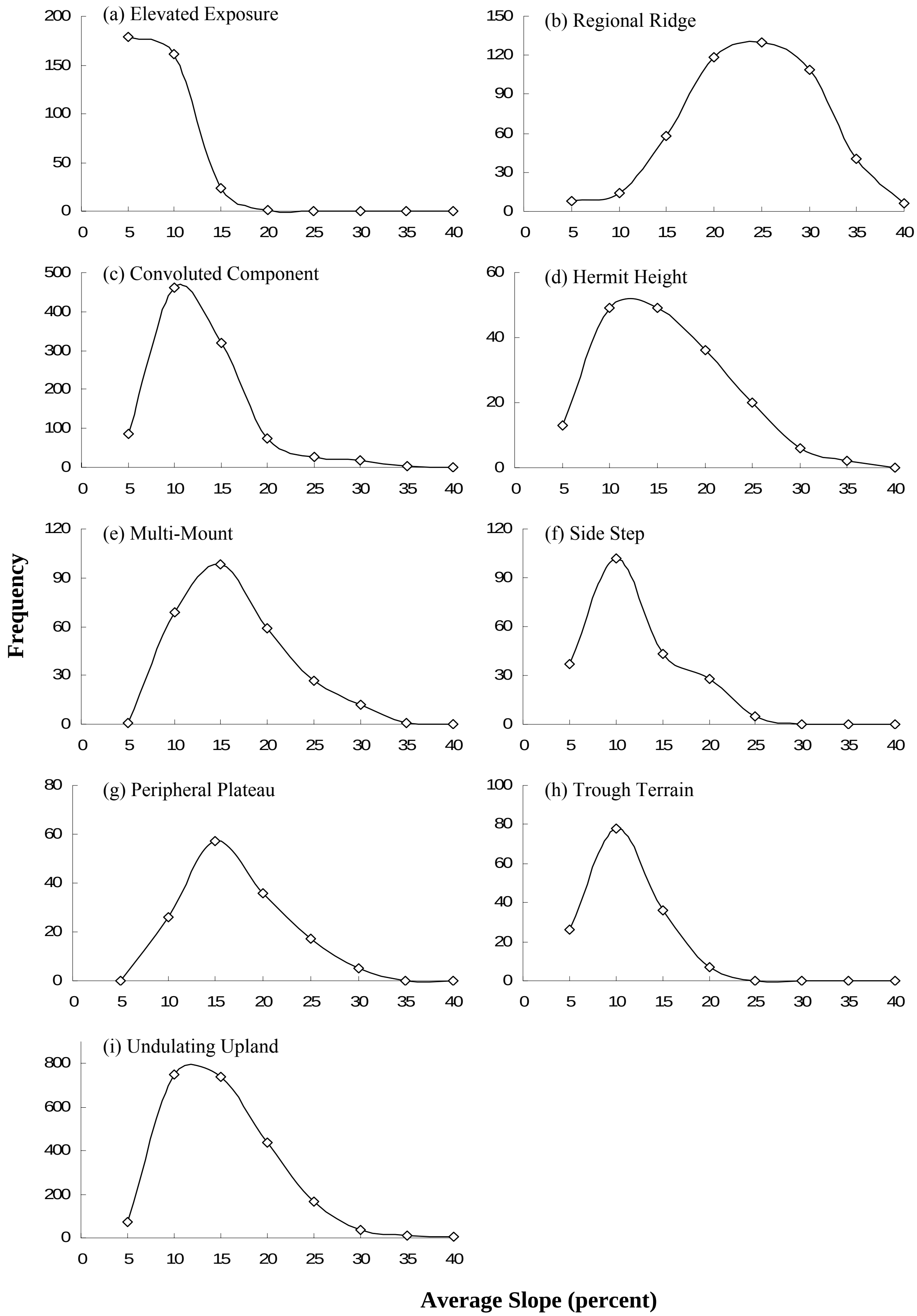


Figure 6.11 Average slope frequency distribution of different subtypes of HH and TT units.

delineated at the γ-scale according to the topographic differences between high and low elevations. This criterion was used most often on the units occurring in expansive plateaus where there is no distinct valley or lowland passing through, so the slopes in these two types are relatively gentle.

Peripheral plateaus have relatively high average slopes because of their topographic positions. As the transitional units distributed along plateau edges, they usually have slopes with one kind of aspect dominating. The average slope is especially high in the peripheral plateau units of the Allegheny Front. There are peripheral plateaus having more gentle slopes in the Pittsburgh Low Plateau area where elevation fluctuation is not dramatic.

As the major HH type in the Appalachian Plateaus, undulating uplands have relatively gentle average slopes mostly below 20 percent. The undulating upland units usually developed on geological materials having great durability where streams are difficult to cut through, so the surfaces of these units are generally rolling. Steep slopes mostly occur on the edge of these units where erosion is most active. Thus, the average slope is not steep for most units in this type. Steep slope undulating uplands are located in the Deep Valleys where the stream cuts are pronounced.

Figure 6.12 shows the LTA distributions along slope ranges for different subtypes of DD units. Figure 6.12 (a) and (b) show slope distributions for the two DD types having gentle slopes, which are branching basin and original outflow. They have similar slope distribution patterns. As designated in the subtype classification, these two types of units have low average slopes with all the units having average slopes less than 15 percent.

Figure 6.12 (c) and (d) are slope distribution curves for inclined inflow and general gradient, the two DD types with less than 50 percent of unit area being gentle slopes. Judging from the graphs, their slopes are higher than the two LTA

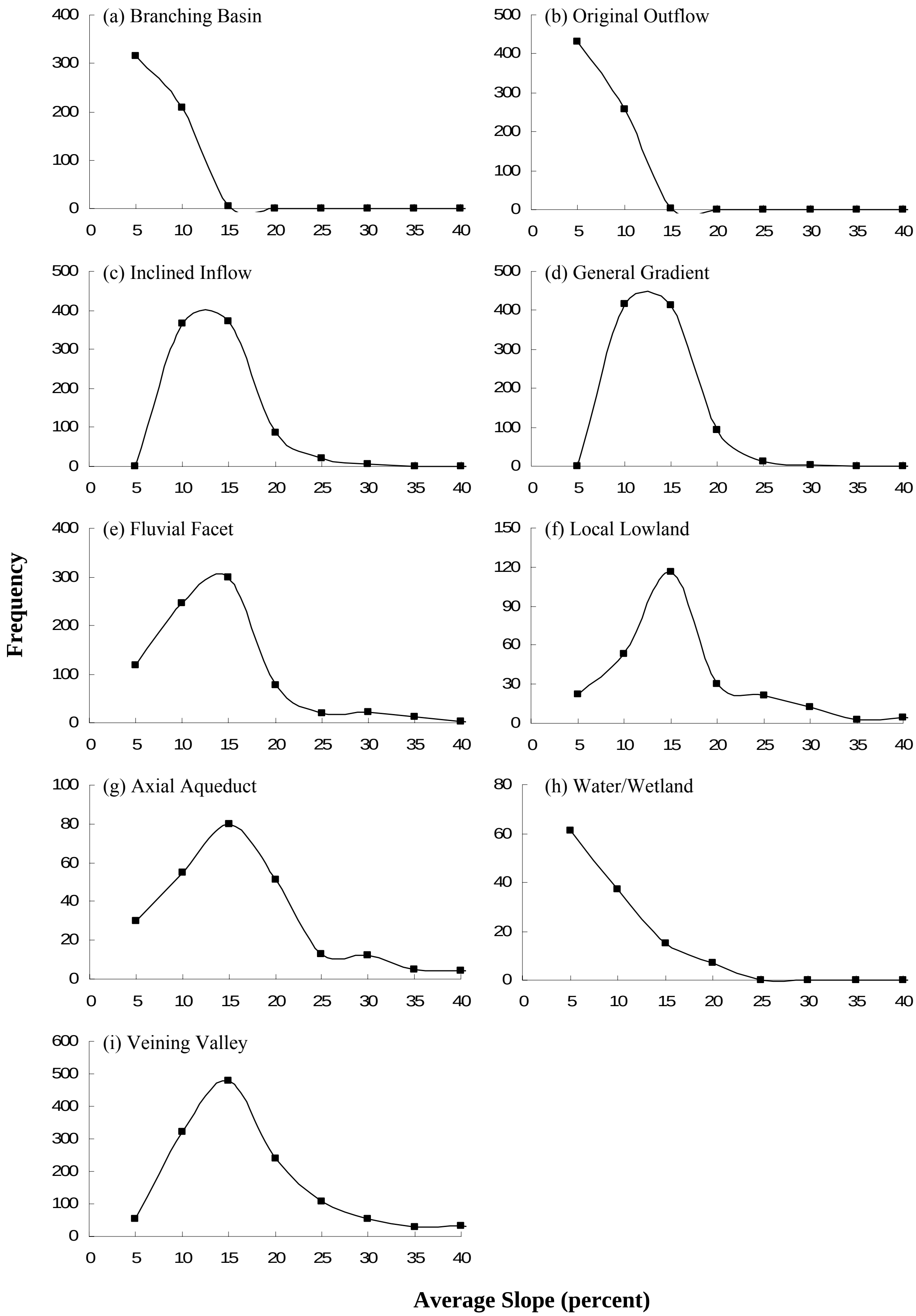


Figure 6.12 Average slope frequency distribution of different subtypes of DD units.

subtypes above, but are not as high as veining valleys and local lowlands. The two curves have similar shapes with the distribution peaks occurring between 10 to 15 percent. The stream erosion within these units creates some slopes, but the surrounding geological materials in these two types are not as durable as those for veining valleys, so although general gradients and inclined inflows are areas with elevation fluctuation, their average slopes are not very high.

Most of the fluvial facets have slopes between 10 to 15 percent with the distribution peak of 15 percent. Although these units have broad valley bottoms with the influence of high order streams, most of them are surrounded by steep side slopes and fluctuating terrain around river stems because of the high-order stream erosion, which makes this type of DD unit relatively steep in average slope.

Local lowlands also have relatively steep average slope with distribution peak of 15 percent. Terrain in these units is very limited by their surrounding HH units. They do not have expansive valley floors and the side slopes are usually steep because these slopes are close to the transitions between HH and DD. Especially in some areas of the Ridge and Valley, the local lowlands are surrounded by ridges which are very close to each other, so these local lowland units have steep average slopes that give the distribution curve a slightly convex shape in the slope range of 20 to 30 percent.

Most of the axial aqueducts have relatively steep average slopes, and are distributed in the 10 to 20 percent slope range with peak of 15 percent. These units have V-shaped valleys with moderate sideslopes. Low-slope units occur in the Piedmont and in the northwestern corner of the state, and steep-slope axial aqueducts occur in the Plateaus or in the Ridge and Valley areas.

Water/wetlands have gentle average slopes because of the water bodies or wetlands they encompass. Although some of these units can have large elevation ranges, the elevation fluctuations only occur in small scale and do not influence the average slopes within unit in a dramatic way.

Veining valleys have the steepest slopes among all DD subtypes because they are V-shaped deep, steeply sloped valleys formed by active stream erosions. The veining valley units have extremely steep slopes in the Deep Valleys and High Plateau areas. There are also some veining valley units having relatively gentle slopes situated in the remaining parts of the Appalachian Plateaus.

Soil Properties of LTA Units

Soil associations vary in caplands and cuplands, and in different LTA subtypes. In this study, the compositions of different soil series were generalized for each LTA subtype. For each soil series, the area percentages within LTA subtypes were calculated, and the soil series which have large area percentages and occupy more than 50 percent of the overall LTA subtype area were considered as the major soil series in the subtype. The followings are general descriptions of the soil properties in each LTA subtype.

For LTA subtypes in HH/TT category, they usually include fewer soil series than those in DD category. The soil associations in convoluted components include Gilpin, Hazleton, Dormont, Cookport, Wharton, Weikert, Berks and Hartleton soil series. The soils in this LTA subtype are usually moderately deep or deep and very deep, well to moderately well drained soils formed in residuum of interbedded shale, siltsone and sandstone on uplands with fine-loamy or loamy-skeletal textures. Some of these soils on gentler slopes have been cleared for farming or pasture, and the areas on moderately steep and steep slopes are generally in mixed hardwoods, including oaks, maple and cherry.

The soil associations in elevated exposures are Ravenna, Frenchtown, Chester, Venango, Canfield and Mt. Airy series. The soils here have fine-loamy or loamy-skeletal textures. These are very deep, somewhat poorly drained or moderately well drained soils formed in Wisconsinan, loamy Wisconsinan or low-lime Wisconsinan age till on till plains. Most of these soils are in cropland with corn, wheat, oats, soybeans and mixed hay as principal crops. Some areas are used for pasture and a few are wooded with the native vegetation of mixed deciduous hardwoods.

Hermit heights include the soil series of Hazleton, Oquaga, Dekalb, Elliber, Berks, Benson, Ravenna, Opequon, Morrison and Neshaminy. These are moderately deep or deep and very deep, somewhat excessively drained or well drained soils with loamy-skeletal and fine-loamy textures. These soils are formed from sandstone on uplands or in residuum weathered from shale, siltstone on uplands. Most of the soils here are in forests of mixed oaks, maple, and occasional conifers, but some of these areas have been cleared for pasture and cropland.

The multi-mount subtype includes Hazleton, Gladstone, Dekalb, Buchanan, Laidig, Highfield and Oquaga soil series. These soils have loamy-skeletal, fine-loamy, or coarse-loamy textures. They are deep and very deep, well to excessively drained soils formed in residuum of sandstone or from granitic gneiss on upland. Most of these areas are in woodland of mixed oaks, maple, cherry and some white pine and hemlock. Smaller areas here have been cleared for cultivation and pasture.

The soil series in peripheral plateaus include Hazleton, Clymer, Laidig, Cookport, Meckesville and Wharton. These are deep and very deep, well drained soils with loamy-skeletal, coarse-loamy and fine-loamy textures. The soils are formed in residuum from sandstone but include some materials from shale and siltstone. Soil permeability is moderate or moderately rapid to rapid. Most of these soil areas are forested with mixed oaks, maple, cherry and some conifers. A relatively small acreage is cleared and used for cropland or pasture.

Regional ridges only have three major soil series including Hazleton, Laidig and Dekalb. They have loamy-skeletal or fine-loamy textures. These are deep and very deep or moderately deep, well drained or excessively drained soils formed from sandstone or siltstone and some shale on uplands. Permeability is moderate or moderately rapid. Most soil areas are in forests of mixed oaks, maple, cherry, or occasional conifers. Smaller areas have been cleared for cultivation and pasture.

Side steps occur all over the state and include many different soil series. The soil associations here include Oquaga, Hazleton, Wellsboro, Morrison, Wharton, Rayne, Gilpin, Cookport, Volusia, Clymer and Leck Kill. These soils include moderately deep or deep and very deep, somewhat excessively drained or well drained to moderately well drained or even somewhat poorly drained soils with loamy-skeletal, fine-loamy or coarse-loamy textures. Most of the soils in these areas are in woodland of mixed oaks, maple, cherry or some pines. Many areas here have been cleared and are used for general farming and pasture.

The soil associations in trough terrain units include Rayne, Morrison, Wellsboro, Oquaga, Wharton, Cookport, Cavode and Leck Kill. These are deep and very deep, well drained soils with fine-loamy, coarse-loamy and loamy-skeletal textures. Permeability is moderate to moderately rapid. About half of the soils here are cleared and used for general farm crops, hay and pasture. Wooded areas contain oaks, maple, beech and some pines.

Undulating uplands include the soil series of Hazleton, Cookport, Oquaga, Dormont, Volusia, Lordstown, Wellsboro and Hartleton. These are mainly deep and very deep or moderately deep, well to moderately well drained soils formed in residuum of sandstone but include some materials from shale and siltstone on uplands. They have loamy-skeletal, fine-loamy or coarse-loamy textures. Most of the soil areas are forested of oaks, maple, cherry or occasional conifers. Some of these areas are cleared for farming and pasture.

The LTA subtypes in dual drainages usually have more soil series than HH/TT subtypes. The soil associations in axial aqueduct include soil series of Laidig, Hazleton, Berks, Dekalb, Buchanan, Weikert, Gilpin, Calvin, Leck Kill, Holly, Oquaga and Hagerstown. Urban land and water also account for about 10 percent of the unit areas in this subtype. The soils here are deep and very deep to moderately deep, well drained soils formed from sandstone, siltstone and some shale. They have fine-loamy and loamy-skeletal textures. Most of the soil areas here are forested and mixed oaks are the most common trees with maple, cherry, and occasional conifers. Some areas are in cropland and pasture.

The soil associations in broad basins and original outflows are similar with the soil series of Hagerstown, Berks, Duffield, Penn, Weikert, Glenelg, Manor, Bedington and Readington dominating. There are also about seven percent of these unit areas classified as urban land in the soil survey. These soils are very deep and deep to moderately deep, well drained soils formed in residuum of limestone, or shale, siltsone and sandstone. They have fine, fine-loamy and loamy-skeletal textures. Most of the soil areas in these two subtypes are cleared and used for general crops, pastures, orchards and truck crops. The remainder are in woodland or other uses. Native vegetation is mixed deciduous hardwood forest.

Fluvial facets include Weikert, Gilpin, Berks, Hazleton, Ernest, Oquaga, Klinesville, Monongahela, Calvin, Dekalb, Penn, Laidig and Buchanan soil series besides the occupancy of urban land and water areas. These are moderately deep or shallow, well drained or somewhat excessively drained soils with loamy-skeletal and fine-loamy textures. Permeability is moderately rapid to rapid. Most of these soil areas are cleared and used for cropland and pasture. Forested areas are mixed deciduous hardwoods, mainly oaks.

The soil associations in general gradients and inclined inflows are also very similar, including Berks, Gilpin, Weikert, Hazleton, Ernest, Oquaga, Dekalb, Calvin, Leck kill, Buchanan, Laidig and Morrison. These are moderately deep, or very deep, or shallow, well drained soils with loamy-skeletal and fine-loamy textures. Permeability is moderate or moderately rapid. Some of these soil areas are in cropland and pasture, and the remainder are in woodland or other uses.

The local lowland subtype includes soil series of Weikert, Hazleton, Gilpin, Berks, Ernest, Leck Kill, Buchanan, Laidig and Dekalb. They include shallow, or moderately deep, or deep and very deep, well drained soils with loamy-skeletal and fine-loamy textures. The land uses here are combinations of cropand and pasture and woodland of mixed oaks, maple, and cherry.

The soil associations in veining valleys include Hazleton, Gilpin, Ernest, Oquaga, Dormont, Buchanan, Volusia, Atkins, Hartleton, Philo and Dekalb. These are deep and very deep or moderately deep, well or moderately well drained soils with loamy-skeletal and fine-loamy textures. Most of these soil areas are forested, but some areas are used for cropland and pasture.

In the water/wetland subtype, more than 30 percent of the areas are covered by water, and about 5 percent of the areas are classified as urban land in the soil survey. For the remaining parts of this LTA subtype, dominating soil series include Atkins, Holly, Weikert, Berks, Carlisle and Calvin. They have fine-loamy or loamy-skeletal textures.

LTA Units in Different Physiographic Components

Each of the six physiographic components has different LTA distribution patterns according to its specific topographic characteristics. Table 6.3 shows the area percentages of HH/TT and DD units in the six physiographic settings. In the Appalachian Plateaus, there are more areas occupied by HH or TT units than DD units, because the resistant sandstone layer in this region occupied most of the areas and formed upland surfaces. The dual drainages only occur where inter-bedded shales were eroded by stream activities. In the Ridge and Valley, however, there are more DD units than HH units. The linear ridges, mountains, or hills are resistant shale or sandstone projecting upward on the background of narrow to wide valleys. Moving down to the Piedmont, dual drainages also dominate the landscape, because the extensive weathering produced much more broad basins compared to the remaining gently rolling hills. For the three minor physiographic components, dual drainages occupy the whole areas of Central Lowland and Coastal Plain, while highland habitats are the major landtype associations in the New England physiographic component. The Central Lowland and Coastal Plain are relatively gentle terrain areas with low elevations compared to their adjacent components, so all of the areas are defined as dual drainages. The New England formation is composed of rounded hills with significant contrast to surrounding lowlands, so more than ninety percent of the area is defined as highland habitat.

Table 6.3 Area percentages of HH/TT and DD in different physiographic areas

	DD	HH and TT
Appalachian Plateaus	37%	63%
Central Lowland	100%	0%
Coastal Plain	100%	0%
New England	9%	91%
Piedmont	70%	30%
Ridge and Valley	70%	30%

These physiographic components not only have different area percentages of HH/TT and DD units, but their LTA subtype compositions are also different as well. Table 6.4 gives the area percentages of different subtypes of LTA units in each physiographic setting. The three primary physiographic components contain almost all LTA subtypes.

In the Appalachian Plateaus, where HH units occupy a large proportion of the landscape, undulating upland is the predominant LTA subtype and occupies 40 percent of the whole area. Convoluted components also have a relatively large area percentage in this setting. They occur often in the Pittsburgh Low Plateau, or they can be the transitional units between undulating uplands and dual drainages. Most of the dual drainages in this area are veining valleys although this subtype doesn't occupy a large area percentage because of the small sizes. They are the most common DD units that occur between prevalent undulating upland LTA units. Fluvial facets also occupy some dual drainage areas in the Appalachian Plateaus as DD units cut by the Allegheny River and its major branches. The remaining dual drainage areas in this physiographic component are mainly comprised of general gradients and inclined inflows.

Table 6.4 Area percentages of different LTA subtypes in different physiographic settings (%)

	Subtype	Appalachian Plateaus	Central Lowland	Coastal Plain	New England	Piedmont	Ridge & Valley
HH and TT	Convoluted Component	10.41	--	--	7.79	9.03	4.45
	Elevated Exposure	3.91	--	--	2.34	17.56	0.02
	Hermit Height	0.21	--	--	0.90	0.54	0.81
	Multi-Mount	0.06	--	--	80.11	0.10	7.89
	Peripheral Plateaus	2.72	--	--	--	--	0.06
	Regional Ridge	0.53	--	--	--	1.11	15.36
	Side Step	2.45	--	--	--	1.40	1.20
	Trough Terrain	2.41	--	--	--	0.39	0.12
	Undulating Upland	40.11	--	--	--	--	0.17
DD	Axial Aqueduct	1.65	11.22	--	0.60	1.25	4.46
	Branching Basin	1.30	29.48	34.01	0.97	22.87	9.53
	Fluvial Facet	7.62	3.14	31.73	1.11	9.20	11.93
	General Gradient	6.80	--	--	1.45	3.11	16.05
	Inclined Inflow	7.79	--	--	0.96	4.86	14.26
	Local Lowland	0.33	--	--	0.14	0.28	0.83
	Original Outflow	1.96	49.81	21.76	1.91	24.20	11.10
	Veining Valley	8.78	0.41	--	1.73	2.29	0.84
	Water/Wetland	0.95	5.95	12.50	--	1.81	0.93

In the Ridge and Valley, there are more dual drainages than highland habitats although there is no single type of DD unit occupying a large percentage of the area. The dual drainages in this region are mostly composed of general gradients, inclined inflows, fluvial facets, original outflows, and branching basins with similar area percentages in the valleys between ridges and mountains. There are also some axial aqueducts present where the ridges are close and parallel to each other. The highland habitats in the Ridge and Valley are mainly composed of regional ridges and some multi-mount units. Convoluted components also account for some area, occurring as small units of ridges or mountains that are dissected by shallow streams.

In the Piedmont, where dual drainages dominate the landscape, original outflows and branching basins together become the most common LTA subtypes and occupy almost half of the whole area, characterized by gently topography. The fluvial facets also account for some of the dual drainages here as the river units around the major branches of Susquehanna River and Delaware River. Most of the highland habitats in the Piedmont are in the form of low-elevation, gentle rolling hills, and were classified as elevated exposures. There are also some convoluted components in this area when the hills are dissected by small stream erosions.

The three minor physiographic components only contain certain LTA subtypes. Both Central Lowland and Coastal Plain areas lack highland habitats. As gentle lowland along the shore of Lake Erie, Central Lowland is dominated by original outflows and branching basins. With the Delaware River, Coastal Plain not only includes these two DD subtypes, but also has a large area percentage occupied by fluvial facets. The New England physiography is mainly occupied by highland habitats, especially the multi-mount units that account for 80 percent of the total area.

The average elevation distributions of HH/TT and DD units in different physiographic components can help to understand the elevation differences between the highland habitats (or transitional terraces) and dual drainages. Figure 6.13 shows these elevation distribution curves for the three major physiographic components. As designated in LTA mapping, the HH and TT units always have relatively higher elevations compared to DD units in each of the physiographic areas. Since the Appalachian Plateaus have highest elevation, the LTAs in this area have higher elevations compared to the other two areas. In the Appalachian Plateaus, both elevation distributions for HH/TT and DD units have two peaks, representing the two elevation levels in this region. The first peak for DD units occurs around 350 meters, and the first peak for HH/TT units occurs 50-meter higher than DD's. All the LTA units in these two first-peaks are spatially distributed in the western part of the state and mostly in the Glaciated Low Plateau. In these areas, the plateau elevations are relatively low and the elevation differences between highlands and valleys are not large. The second peak for DD units occurs around 450 meters, and the second peak for HH/TT units occurs around 600 meters. All LTA units in these two peaks are distributed in the relatively higher parts of the Plateaus including the Deep Valleys, High Plateau, Allegheny Mountains, Allegheny Front and the eastern part of the Pittsburgh Low Plateau. In these areas, the plateaus are high and valleys are deep, so the elevation differences between highlands or terraces and drainages are large with the two distribution peaks having 150 meters difference.

In the Ridge and Valley, elevation differences between highland habitats and dual drainages are obvious. The distribution peak for DD units occurs around 200 to 250 meters, and the peak for HH units occurs at 500 meters. The large elevation difference between those two peaks indicates that the Ridge and Valley is the area with most distinct differences between highlands and valleys. Since the elevations in the Piedmont are relatively low, both HH and DD units are distributed in very low elevation ranges. Comparing the shapes of these two curves, the elevations of HH units are only slightly higher than DD units, with the peak occurring 50 meters higher than for DD's.

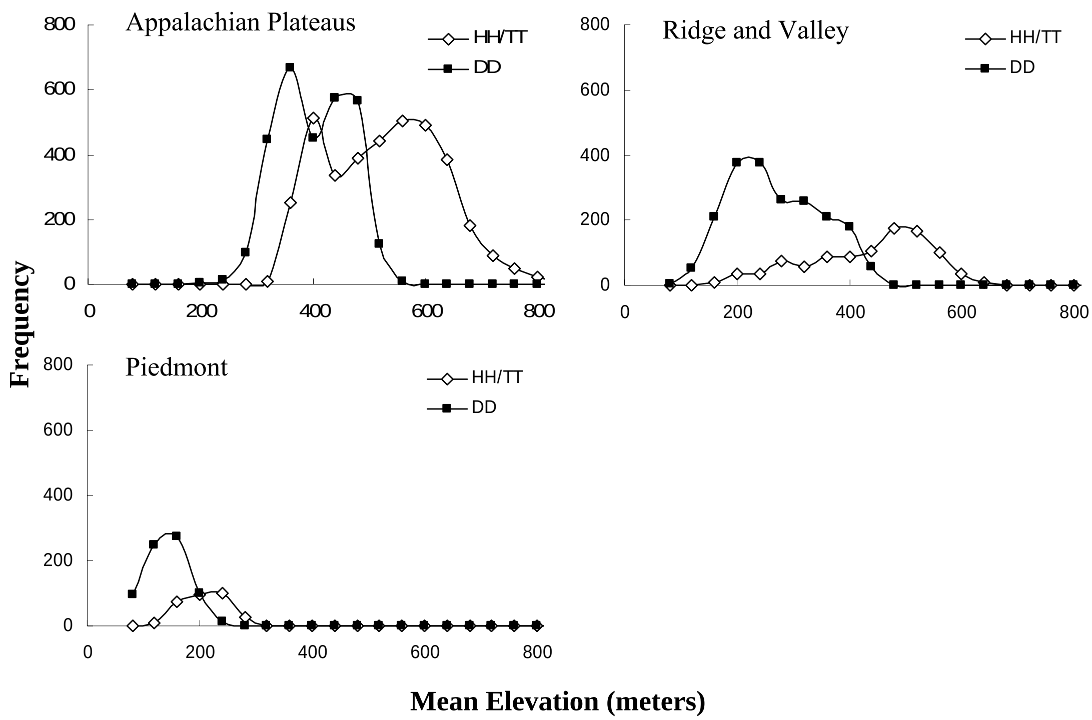


Figure 6.13 Elevation distributions of HH/TT and DD in three major physiographic components.

The elevation ranges of LTA units also differ in different physiographic components. Figure 6.14 shows the average elevation range of HH/TT and DD LTA units in all of the six physiographic components in Pennsylvania. For highland habitats, the LTAs have the highest average relief in the Ridge and Valley area because of the large elevation changes in regional ridge and multi-mount units. The New England component also has high HH relief due to the dominance of multi-mount units. The HH/TT units in the Appalachian Plateaus have relatively smaller average elevation changes because there are some undulating uplands with low relief occurring on low plateaus or expansive plateaus that lack deep cuts. The HH units in the Piedmont have the smallest average relief in Figure 6.14, indicating that elevated exposures which dominate this area have subtle elevation changes within units. For dual drainages, the average relief in the Ridge and Valley and the Appalachian Plateaus are the largest. The valleys in these two regions have fluctuating terrain, and the high-relief DD subtypes, such as general gradient, inclined inflow and fluvial facet, occur mostly in these two regions. Dual drainages in the Piedmont have small relief because the valleys in this area often have gentle slopes. The DD units here belong to small-relief subtypes, and are mainly composed of original outflows, branching basins and some gentle fluvial facet units. The DD units in the two minor physiographic components have very different relief characteristics although both of them are primarily composed of branching basins and original outflows. The Central Lowland consists of a series of low-relief beach lines, so the elevation changes within units are relatively large. However, the Coastal Plain is basically a flat surface cut by short streams, so the average LTA relief in this area is the lowest among all the regions. Comparing the relief of HH/TT units and DD units in the same regions, dual drainages always have

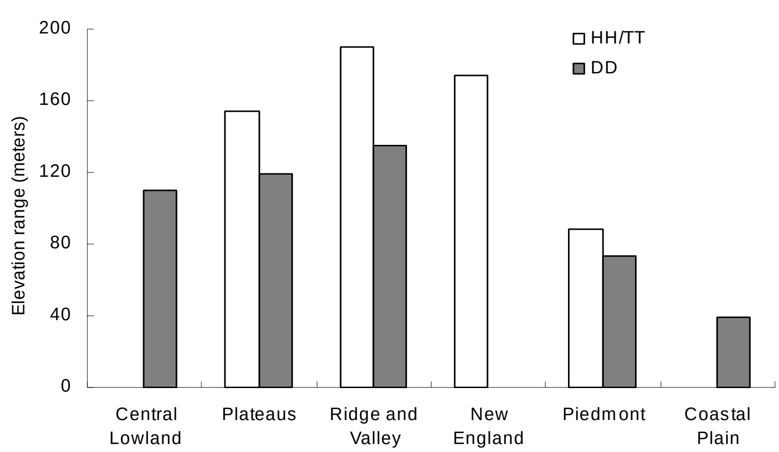


Figure 6.14 Average relief of HH/TT and DD in different physiographic components.

lower elevation changes than highland habitats or transitional terraces. This difference is especially large in the Ridge and Valley, where highlands and lowlands have very different topographic characteristics.

The average LTA slopes in different physiographic components give another important description of the differences for HH/TT and DD units between/within these settings. Figure 6.15 shows the average slopes of HH/TT and DD categories in the six physiographic settings. In the Appalachian Plateaus, the highlands have relatively small slope percent, because the undulating upland units have gentle summit areas. However, the dual drainages here have the steepest slope compared to all the other regions, and they are steeper than the HH units in the same area because the stream erosion produced deep and steep-sloped valleys in the plateaus. In the Ridge and Valley, highland habitats have steepest slopes due to the high occupancy of regional ridges and multi-mounts in this area. The dual drainages in the Ridge and Valley also have relatively steep slopes in the form of general gradients, inclined inflows and fluvial facets, but these slopes are much smaller than the highland habitats in the same region. In the Piedmont, both

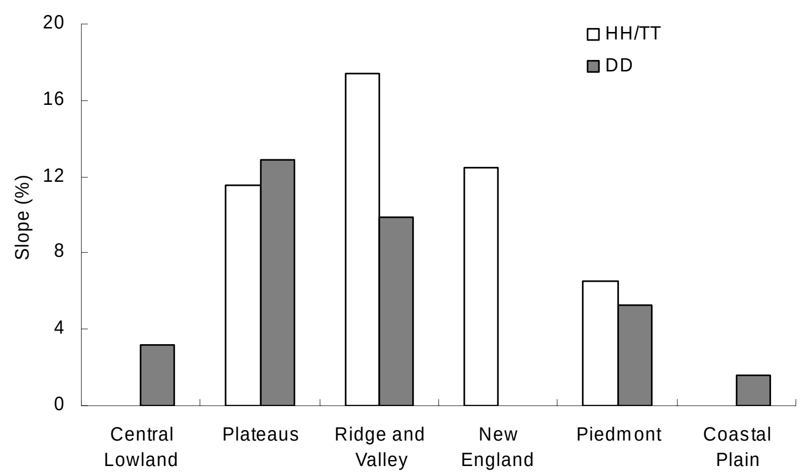


Figure 6.15 Average slopes of HH/TT and DD in different physiographic components.

HH and DD units have gentle slopes, and the slopes in dual drainages are lower than highland habitats because these valleys have very broad bottoms. The highland habitats in New England physiography have steep slopes because of the dominance of multi-mount units in this area. In the Central Lowland and Costal Plain areas, the dual drainages are mainly branching basins and original outflows with gentle slopes. Although the LTA unit relief in the Central Lowland is relatively high, those elevation fluctuations do not occur in a large area, so the average LTA slope in this area is still very gentle.

Characteristics of ELT Units

The Ecological Landtype units were generated for all the counties in Pennsylvania, except for Erie, Fayette, and Potter counties. There are 699,336 ELT units mapped in this study area. Among these units, there are 373,361 ELTs located in the dual drainage areas, and 325,975 of them are situated in the highland habitats or transitional terraces. The following are some general descriptions of the characteristics of these ELT units.

Size of ELT Units

As designated in the ELT mapping rules, most of the ELT units have sizes in the range of 10 to 100 acres (4 to 40 hectares). There are also some ELT units (about 6% of the total) having sizes greater than 100 acres. The average size of all the Ecological Landtype units is about 39 acres. Figure 6.16 shows the size distributions of ELT units in DD and HH/TT landtype associations. In both kinds of LTAs, ELT units have highest frequency around the size of 15 acres, and about one third of the total ELT units fall in this size range. As the ELT size increases, the number of ELT units decreases sharply for both LTA groups. Although the shapes of the two curves in Figure 6.16 are similar, the average ELT unit sizes show differences in the two LTA categories. The ELT units in dual drainages have average size of 37 acres, whereas the ELT units in highland habitats and transitional terraces are somewhat larger with an average unit size of 41 acres. The generated ELT unit sizes are dependent on the input soil polygon sizes.

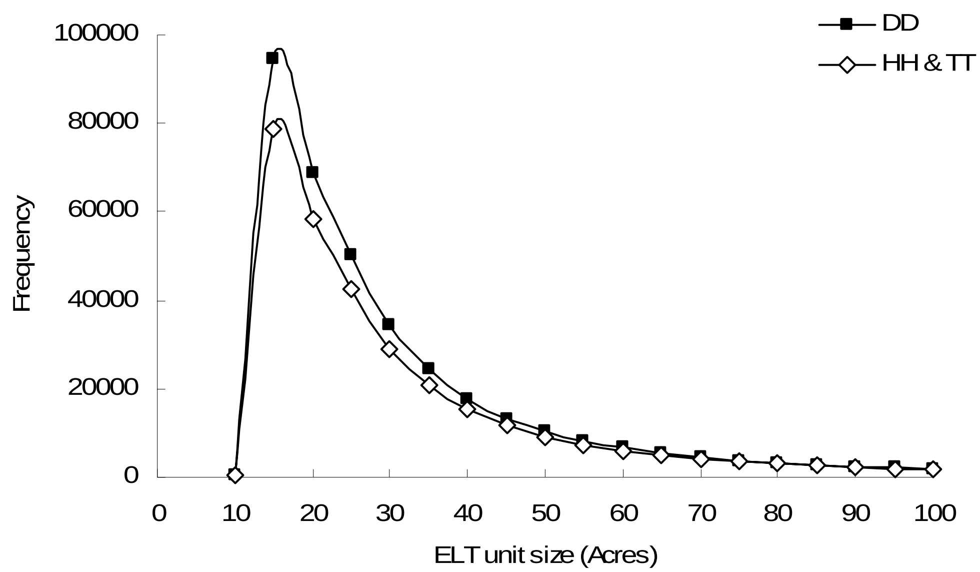


Figure 6.16 Size distributions of ELT units in DD and HH/TT landtype associations.

The average ELT sizes in different LTA subtypes can help explain the ELT size differences between DD and HH/TT areas. Table 6.5 shows these average ELT sizes. The average ELT size for the whole study area is 39 acres. Highland habitats and transitional terraces have more LTA subtypes with average ELT sizes greater than this overall average compared to the subtypes in dual drainages. The average ELT size has the largest value in the regional ridge LTA subtype, which means that the input soil polygons are relatively large in these areas or small soil polygons are more likely to be combined with their adjacent ones due to similar topographic characteristics in regional ridge units. In these areas, the sideslopes are generally straight with similar slopes and aspects and the soil properties tend to be similar in these areas along the axis of ridge elongation. Water/wetlands also have large-size ELT units. In most of these units, the land surfaces are covered by water, so the soil polygons are relatively large. This subtype also includes some LTA units composed of many small wetland patches such as palustrine forests. Since the soil properties vary in different wetlands, the ELT sizes are small in such LTA units. The average ELT sizes are also large in multi-mount, peripheral plateau, and elevated exposure subtypes of HH units because the soil properties do not vary dramatically in these areas, or because similar slopes and aspects help to aggregate more small size soil polygons togethe. In dual drainages, the ELTs are relatively large in the axial aqueduct subtype, because these units are parallel-sided valleys and the properties of soil and topography can remain similar in a large area along the axis of valley elongation.

Table 6.5 Average ELT unit size in different subtypes of LTA units

	LTA Subtype	Average ELT Size (acres)
HH and TT	Convoluted Component	34.2
	Elevated Exposure	44.8
	Hermit Height	42.8
	Multi-Mount	51.0
	Peripheral Plateaus	45.8
	Regional Ridge	66.0
	Side Step	36.8
	Trough Terrain	33.5
	Undulating Upland	40.8
DD	Axial Aqueduct	43.7
	Branching Basin	38.2
	Fluvial Facet	37.9
	General Gradient	34.9
	Inclined Inflow	34.4
	Local Lowland	33.5
	Original Outflow	37.7
	Veining Valley	36.6
	Water/Wetland	63.8
Overall	**--**	**39.0**

Slope of ELT Units

The slopes of ELT units in the study area vary from 0 to 60 percent with the average around 11 percent. Figure 6.17 shows the slope distributions for all ELT units that occur in DD and HH/TT areas. About twenty percent of the ELT units have slopes less than 5 percent, and most of the ELTs (about one third) have slopes between 5 to 10 percent, which form peaks on the two distribution curves. As the percent slope increases, the number of ELT units decreases sharply. Although the two curves for ELT units in DD and HH/TT areas have similar shapes in Figure 6.17, the average ELT slopes show differences in these two kinds of LTA units. The average ELT slope in HH/TT units is around 11.7 percent, which is a little higher than that in dual drainages (10.6%). This is consistent with the slope characteristics of LTAs described earlier in this chapter.

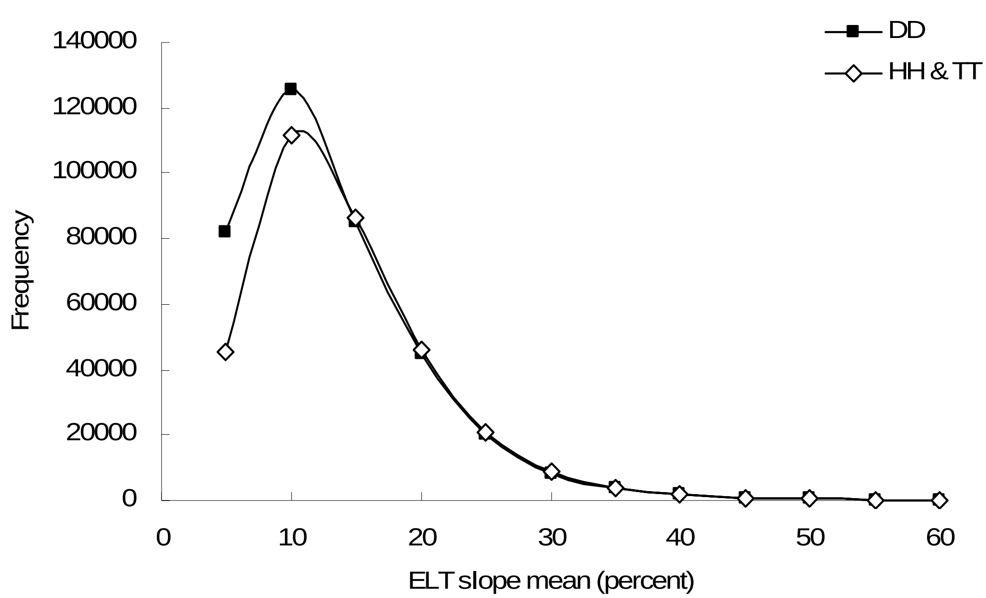


Figure 6.17 Slope distributions of ELT units in DD and HH/TT landtype associations.

The average ELT slopes have large differences in different subtypes of LTA units. Table 6.6 shows the average ELT slope values in each type of LTA. Consistent with the slope distributions of different types of LTA units, ELT units in regional ridges have the highest slope. In highland habitat and transitional terrace areas, ELT slopes in hermit heights and peripheral plateaus also have relatively high values. In dual drainage areas, ELT units have high slopes in veining valleys and local lowlands.

Table 6.6 Average ELT slope and slope standard deviation in different subtypes of LTA units

	LTA Subtype	Average ELT Slope (percent)	ELT Slope Std.
HH and TT	Convoluted Component	11.7	4.81
	Elevated Exposure	6.9	3.20
	Hermit Height	13.6	5.23
	Multi-Mount	12.9	6.69
	Peripheral Plateaus	13.2	7.42
	Regional Ridge	17.6	8.78
	Side Step	10.1	4.79
	Trough Terrain	9.6	4.44
	Undulating Upland	11.7	5.64
DD	Axial Aqueduct	12.2	7.82
	Branching Basin	6.2	3.39
	Fluvial Facet	11.1	6.69
	General Gradient	12.0	5.44
	Inclined Inflow	12.1	5.99
	Local Lowland	14.0	5.58
	Original Outflow	5.7	2.98
	Veining Valley	14.1	6.53
	Water/Wetland	9.4	6.00
Overall	--	**11.1**	**5.61**

Table 6.6 also lists the average slope standard deviation between ELT units in different LTA subtypes. The slope standard deviation between ELT units within an LTA unit indicates topographic variations within the particular landtype association area. Higher standard deviation of ELT slopes means more slope changes and thus greater complexity in the LTA unit. Table 6.6 shows that ELT slopes have the highest standard deviation in regional ridge units, which indicates that regional ridges are composed of ELT units with very different slopes. This

characteristic increases the difficulty of environmental management in these units. In HH/TT types of LTA units, peripheral plateau and multi-mount subtypes also have relatively high standard deviations, showing the complex slope changes within these units. In dual drainage category, axial aqueduct, fluvial facet and veining valley subtypes are those with high ELT slope standard deviations. There are also some types of LTAs having low ELT slope standard deviations. For HH/TT LTAs, these types include elevated exposure, trough terrain, side step and convoluted component. For DD LTAs, these types include original outflow and branching basin. The ELT slopes do not change much within these landtype association units. They have gentle and relatively uniform terrain within unit areas.

Aspect of ELT Units

In this ELT mapping, the aspect of ELT units was classified into nine groups including north, northeast, east, southeast, south, southwest, west, northwest, and flat. The numbers of ELT units in different aspect groups within a particular LTA indicate general orientation of the landtype association. Figure 6.18 shows the ELT aspect distributions on different subtypes of HH/TT LTA units. Figure 6.18 (a), (b) and (c) are HH/TT subtypes that usually occur in the Appalachian Plateaus. Undulating upland, peripheral plateau, and trough terrain all have similar number of ELT units distributed on all aspect directions, and their distribution curves are almost round in the graphs. This means that the HH/TT LTA units in the Appalachian Plateaus do not have a particular orientation and they can occur in any direction. Figure 6.18 (d), (e) and (f) show the HH/TT LTA subtypes that mainly occur in the Ridge and Valley. All of these three LTA types include more ELTs in the directions of northwest and southeast and less ELTs in the directions of southwest and northeast, which indicates that the LTA units in these types have a general orientation of northeast-southwest. Most of the regional ridges occur in a northeast-southwest direction. The multi-mount units also occur in this general orientation although they are not as obvious as those of ridges, so the shape of the aspect distribution curve in multi-mount is a little wider than that for the regional ridge type. Although hermit height units can occur all over the state, they are most common in the Ridge and Valley as disconnected local ridge units, and these small units also have a northeast-southwest direction. The hermit heights in other areas

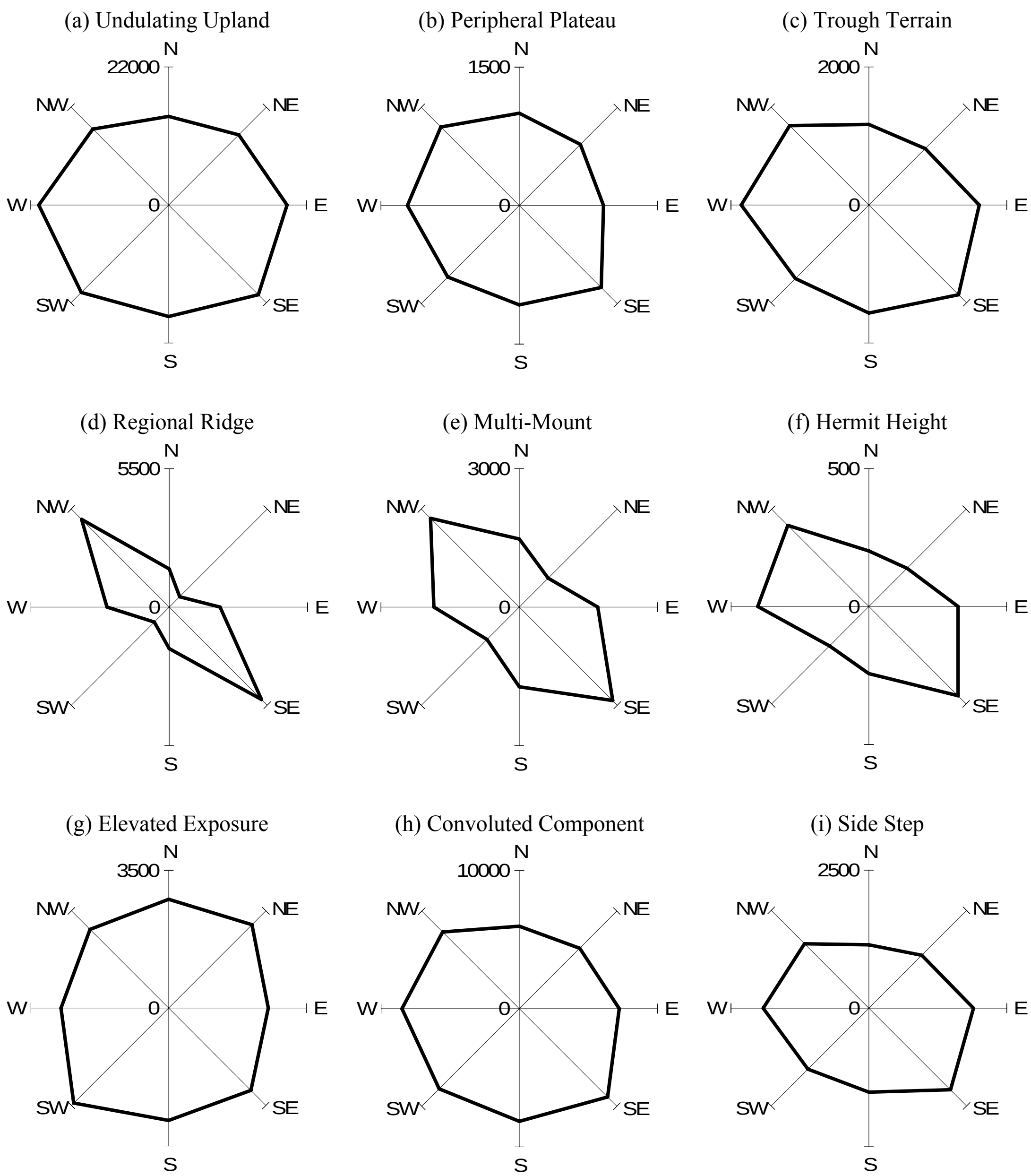


Figure 6.18 Aspect distributions of ELT units in different subtypes of HH/TT LTAs.

averaged this character, so the distribution curve for this subtype is wider than the other two common HH subtypes in the Ridge and Valley. The elevated exposures have almost the same number of ELT units distributed in all aspect groups. They are round rolling hills without any particular orientation. The convoluted components and side steps can possibly occur all over the state in every physiographic area, and the stream erosions can occur within the units in all possible directions, so they also do not have any particular orientations within units, and their ELT aspect distribution curves are almost round with similar number of ELT units occurring in all aspect groups.

Figure 6.19 shows the ELT aspect distributions in different DD subtypes. Figure 6.19 (a) and (b) are curves for general gradient and inclined inflow. These two subtypes mostly occur in the Ridge and Valley and some areas of the Pittsburgh Low Plateau. In the Ridge and Valley, these units are distributed in the northeast-southwest oriented valleys between the ridges. In the Pittsburgh Low Plateau, these drainage units are also influenced somewhat by the northeast-southwest oriented streams. Thus, these units have more ELTs distributed in the northwest and southeast aspect groups and less ELTs in the southwest and northeast directions. Axial aqueducts also have the major distribution area in the Ridge and Valley as the straight valleys between parallel ridges. Being influenced by the general northeast-southwest orientation in this physiography, units in this subtype also include more ELTs in northwest and southeast directions. Figure 6.19 (d) and (e) are two DD types with gentle slopes (original outflow and branching basin) that are mostly distributed in the Piedmont and Great Valley. Being influenced by several northeast-southwest oriented major rivers, these two subtypes of LTA units also show the obvious aspect distribution patterns with more ELTs in the northwest and southeast aspects. The shape of ELT aspect distribution curve in fluvial facets is almost round with somewhat more ELTs in northwest and southeast aspects because there are several occurrences of fluvial facets in the Ridge and Valley where the northeast-southwest terrain orientation is obvious. Local lowlands also have some of this trait because they are mainly located in the Ridge and Valley. Veining valley and water/wetland LTA subtypes have almost same number of ELTs distributed in all aspect groups, indicating that these two subtypes do not have apparent orientation characteristics.

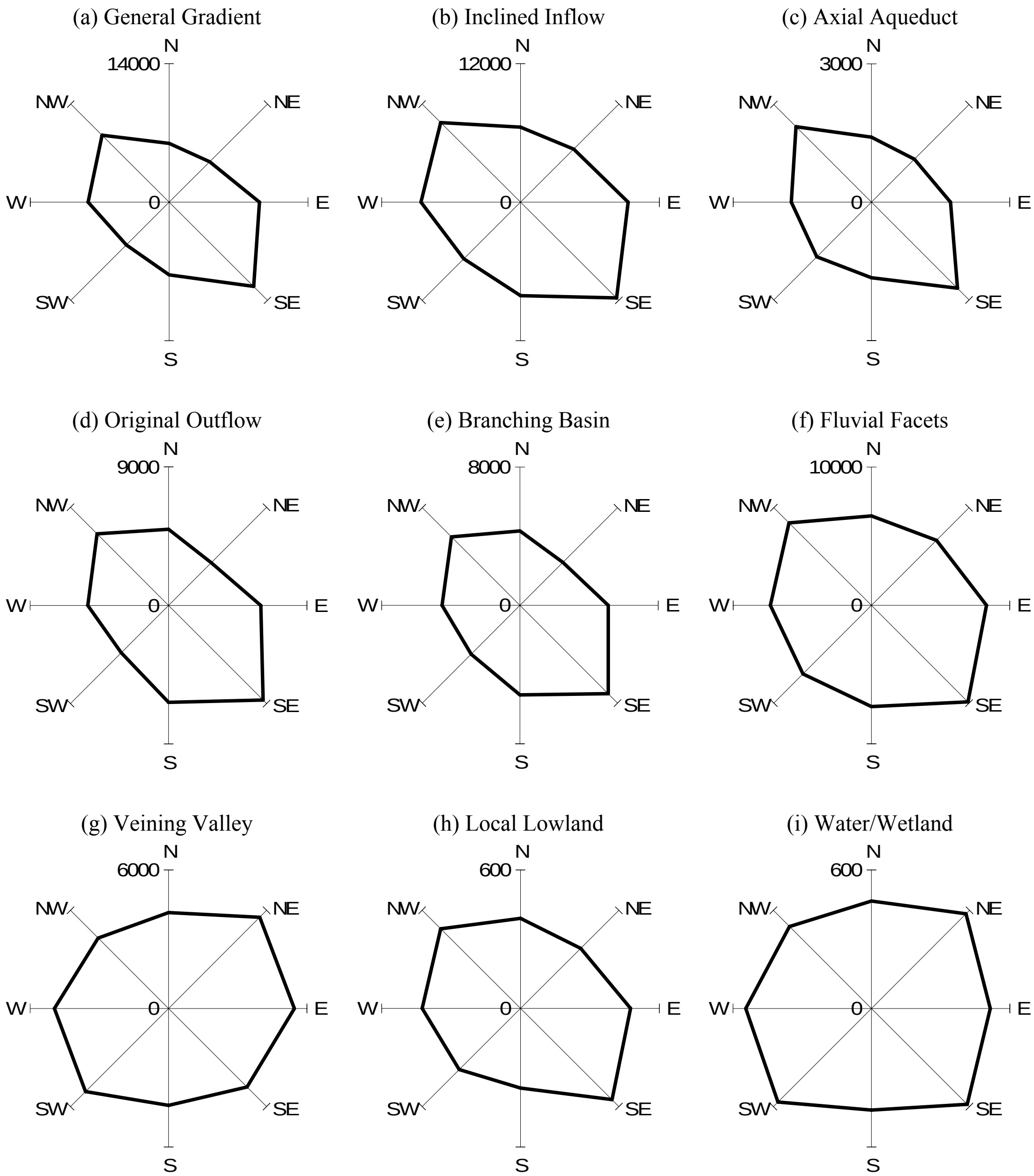


Figure 6.19 Aspect distributions of ELT units in different subtypes of DD LTAs.

Chapter 7

Hydrologic Characteristics of the Ecological Units

Introduction

The LTA units in this mapping were designated to be in one of the three major categories of highland habitat (HH), transitional terrace (TT) or dual drainage (DD), based on consideration of ecological differences between headwater areas and downstream drainage areas. Highland habitats were designated as being primarily headwater stream areas. Dual drainages were designated to be areas having both large streams and small tributary streams. Transitional terraces are intermediate level elevated terrain units that are otherwise similar to highland habitats, but also receive some hydrologic influx from adjacent uplands along partial margins. According to these designations, topography and terrain topology information was used as the primary criteria to map the landtype associations for Pennsylvania. This mapping method was adopted based on the following hydrologic hypothesis:

H_0 (null hypothesis): There is no stream drainage network structure difference between different kinds of landtype associations.

H_a (alternative hypothesis): The LTA mapping method makes distinctions with regard to structure of stream network.

In this chapter, the structure of drainage network within LTA units is examined in terms of stream node densities and stream drainage densities of different Strahler (1952) order streams. The Strahler stream order system is a simple method of classifying stream segments based on the complexity of tributaries upstream. A stream with no tributaries (headwater stream) is considered a first order stream, and a segment downstream of the confluence of two first order streams is a second order stream. Thus, an n^{th} order stream is the downstream channel of the confluence for two $(n-1)^{th}$ order streams. Nodes are the origins or confluence pints for streams.

With these concepts, upland areas should have a substantially higher proportion of low-order-stream nodes than dual drainage areas. Accordingly, in this mapping system, if the first order stream node density is significantly higher in highland habitats and transitional terraces and lower in dual drainages, we can consider that the mapping method used in this study is effective in separating different hydrologic characteristics in different kinds of mapping units, and the hydrologic hypothesis can thus be confirmed.

Drainage density is average stream length per unit area. The drainage densities might also have different characteristics in different kinds of LTA units. The dual drainage areas include both large and small streams, so all the streams with different orders should have high density values in these units. However, the highland habitat and transitional terrace areas only cover the headwater portion of the hydrologic system. The HH/TT units might have high first or second order stream densities, but they should not have high density values for large streams. If the drainage densities have different patterns in different LTA categories, this can also be supportive evidence to reject the null hypothesis in this chapter.

Methods

Data Sources

The stream network data file was acquired from the Pennsylvania Spatial Data Access (PASDA) website. This network file was edited and verified by the Environmental Resources Research Institute (ERRI) at Penn State University. The connected networks of streams and waterways are indicated as single lines in this coverage, and the Strahler stream order information is included in the attribute table. The stream nodes were generated from this stream network file as the start points of the stream lines. Then, these starting points were assigned the Strahler stream order number according to the corresponding stream lines. That is, the first order stream nodes are originating points of first order streams. Second order stream nodes are the confluence points of two first order streams where first order streams join to form second order streams. And the n^{th} order stream nodes are the confluence points of two $(n-1)^{th}$ order streams or points where lower order streams join to form the n^{th} order streams.

Data Analysis

The stream node and drainage densities in LTA units were calculated in ArcView. The stream node densities were calculated as the number of nodes per square kilometer, and the drainage densities were calculated as the length of stream (meter) per square kilometer. Square kilometer was used here as the basic area unit because it can help to keep the density values as relatively large numbers for the comparison and statistical analysis purposes.

The node densities and drainage densities in HH/TT and DD types of LTA units were averaged by physiographic components for comparison. The physiographic subsections are upper level ecological units in the ECOMAP hierarchy. This step makes the comparisons of hydrologic characteristics between HH/TT and DD units nested within the subsection units, which define similar surficial geology and geomorphic processes. The highland habitats and transitional terraces were considered in one combined category because both of them are capland units with similar headwater habitat characteristics, except that transitional terraces receive part of the hydrologic inputs from their neighboring uplands. Also because transitional terraces only occur in Pennsylvania in a small portion in the Appalachian Plateaus, grouping these two kinds of LTA units together can help to make the comparisons uniform for all physiographic subsections. Paired t-tests were then used to compare the stream node and drainage densities between the

HH/TT and DD units in each physiographic subsection and to test if these densities are significantly different between different kinds of LTAs.

The stream node and drainage densities of LTA units were also averaged by the LTA subtypes in this study to describe and compare the hydrologic characters in different LTA subtypes. Cluster analysis with Ward's linkage was then conducted for all the LTA subtypes based on the density information to group the LTA subtypes and to compare the differences between these groups.

Results

Stream Node Densities in LTA Units

The node densities for different stream orders are important indicators for describing hydrologic characters in a particular area. They can indicate whether an area is dominated by headwater influences or more affected by confluences of higher order streams. LTA units with higher first order stream node densities and lower densities of other stream nodes are areas of headwater stream habitats. LTA units with more second and higher order stream nodes are areas where stream confluences occur frequently and waters are channelized in these areas.

The different order stream node densities were calculated for HH/TT and DD types of LTA units within each physiographic subsection. Figure 7.1 shows the average first order stream node density for HH/TT and DD types of LTAs in these subsections in Pennsylvania. In most of the subsections, the first order stream node density is apparently higher in the highland habitat or transitional terrace areas compared to the density in dual drainage areas. The exceptions occur in the Central Lowland, Coastal Plain, Great Valley and Blue Mountain areas where there are no HH/TT LTA units or the HH/TT types of LTAs only occupy a very small proportion of area in the subsection. In general, considering the entire state, highland habitats and transitional terraces have much higher first order stream node density compared to the dual drainages.

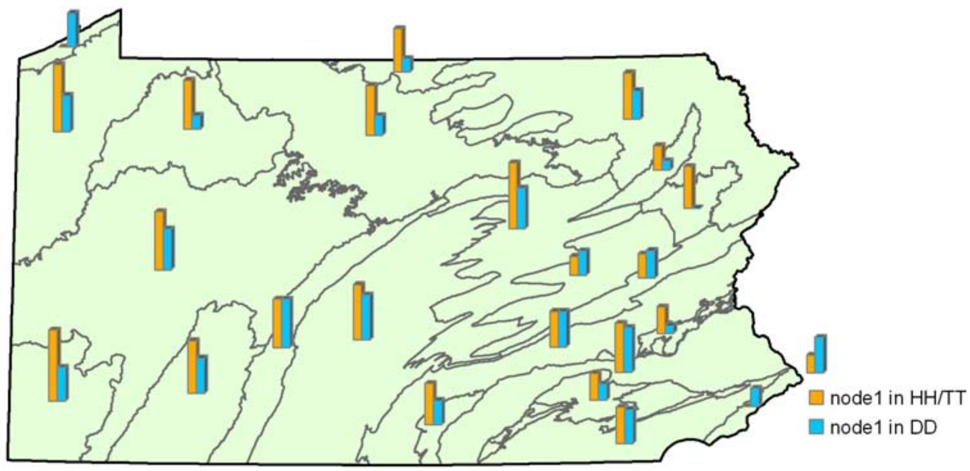


Figure 7.1 First order stream node densities in HH/TT and DD types of LTA units in different physiographic subsections in Pennsylvania.

The paired t-test also verifies this significant difference between the two LTA groups. The t-test result shows that the highland habitats and transitional terraces have significantly higher first order stream node density (0.548±0.040) than the density in dual drainages (0.375±0.036) (p-value < 0.001). This result indicates that most of the first order streams originate in the HH/TT LTA units. Therefore, highland habitats and transitional terraces in this mapping are shown to be headwater stream habitats.

The second, third and fourth order stream node densities in HH/TT and DD areas for different physiographic subsections are shown in Figure 7.2. In almost all subsections, these stream node densities are much higher in the dual drainage areas compared to those in the highland habitat and transitional terrace areas. Exceptions occur in the Glaciated Pocono Plateau and Glaciated High Plateau areas where the undulating uplands occupy almost all the subsection area with a few small veining valleys notching into the edges. The stream node densities calculated in these small dual drainage areas are not representative for comparison purposes at large scale.

The paired t-tests for second, third and fourth order stream node densities also show that these stream node densities have significantly higher values in dual drainage areas than in highland habitats and transitional terraces. The p-values in these tests are < 0.001, < 0.001 and 0.012. At the significance level of 0.05, we can conclude that these three orders of stream node densities are much higher in the DD type of LTA units. This shows conclusively that stream confluences occur more often in the dual drainage areas than in the HH/TT units.

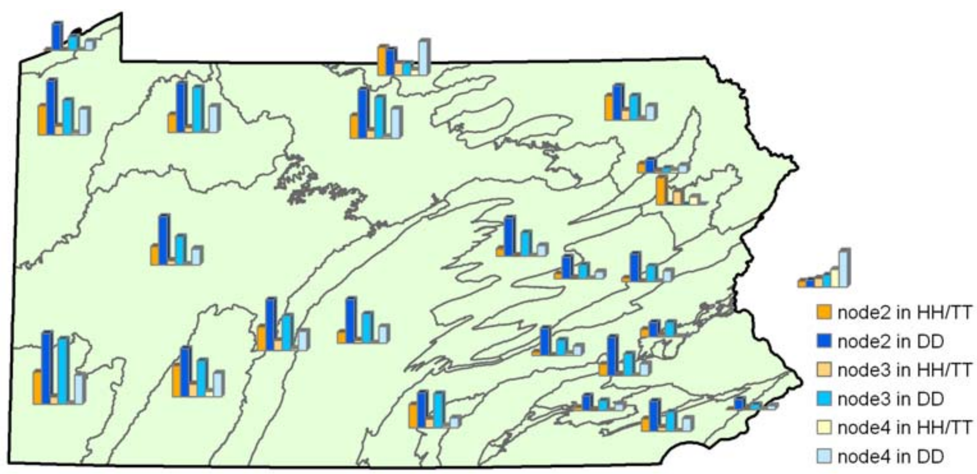


Figure 7.2 Second and higher order stream node densities in HH/TT and DD types of LTA units in different physiographic subsections in Pennsylvania.

There are only a few of the fifth and higher order stream nodes existing in HH/TT areas in very infrequent cases, and most nodes of these orders occur in the dual drainage areas. These stream node densities were not compared statistically between HH/TT and DD units in this study because the differences are quite obvious.

The comparisons above provide justification for rejecting the hydrologic null hypothesis in this chapter, and establish that the LTA mapping method in this study can effectively separate headwater areas from the downstream drainages. The first order stream nodes concentrate in the highland habitat or transitional terrace areas, whereas the higher order stream node densities have greater values in the dual drainages.

The stream node densities in different LTA subtypes were also calculated and compared in this study in order to determine whether LTA subtype classification can effectively separate LTA units with different hydrologic characters. The average stream node densities for first, second, third and higher order streams in different LTA subtypes are shown in Figure 7.3. In general, comparing the two major LTA categories, the first order stream node density is higher in the HH/TT subtypes than in the DD subtypes. The second and higher order stream node densities are usually higher in the DD subtypes.

In the HH/TT category, convoluted component (**cc**) has the highest first order stream node density, consistent with being designated as having strong stream dissections. There are relatively few second and higher order stream nodes in this type of unit.

The node densities in hermit heights (**hh**) have similar patterns with those in convoluted components, although the first and second order stream node densities here are lower than those in the convoluted components. Hermit height is also an HH/TT subtype that is greatly influenced by stream dissections, so the first order stream node density in this subtype is high. The less complex dissections give fewer higher order stream nodes.

The first order stream node densities are similar in the remaining HH/TT subtypes except for the multi-mount (**mm**) subtype, which includes certain units with very gentle mountain tops having low flow accumulation. The second and

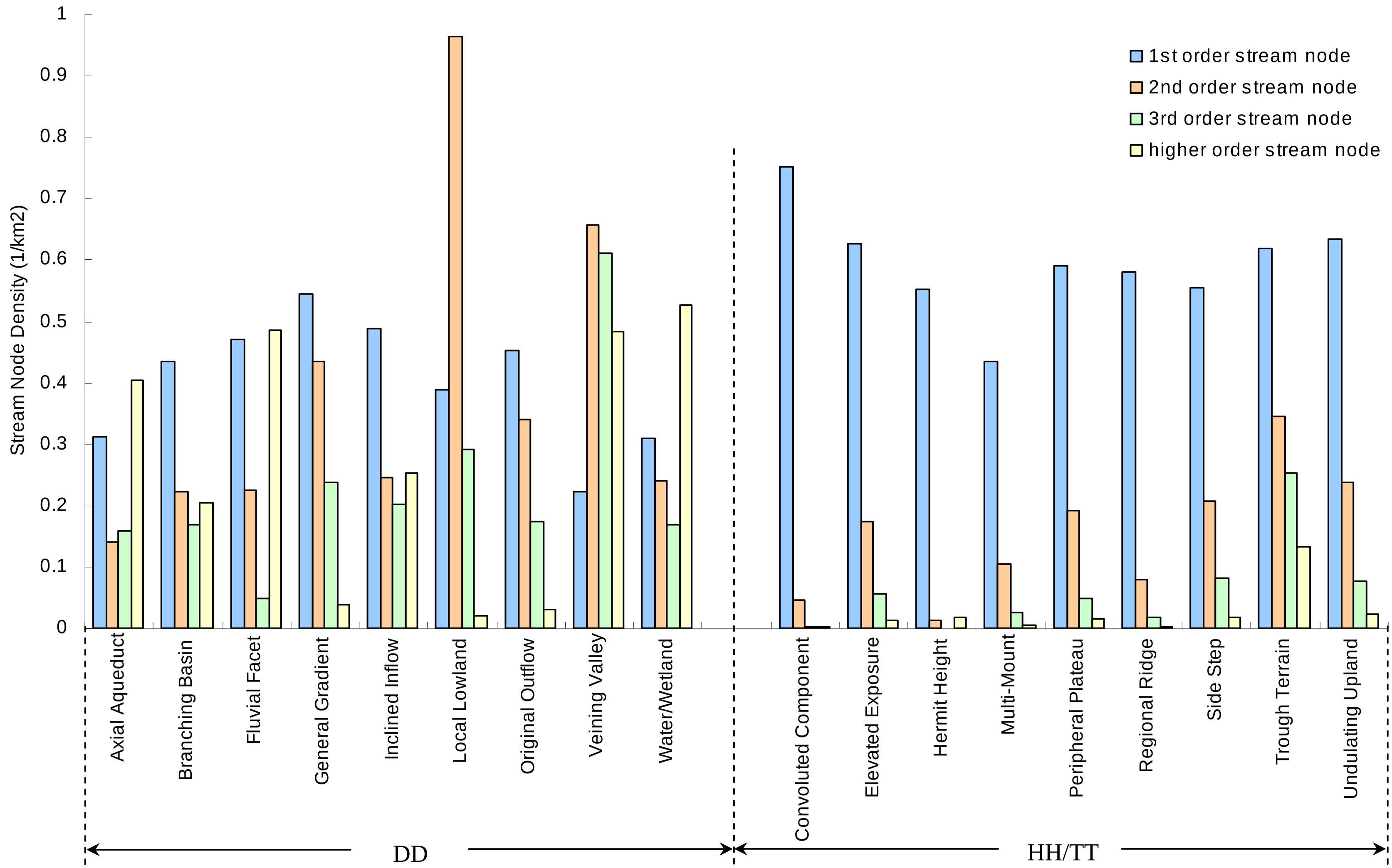


Figure 7.3 Average first, second, third and higher order stream node densities in different LTA subtypes.

higher order stream node densities are relatively lower in regional ridge (**rr**) with patterns similar to convoluted component and hermit height. Because the linear ridge units have almost straight sideslopes, the first order streams flow down these slopes in parallel patterns and confluences do not occur often. In trough terrain (**tt**), however, the second and higher stream node densities are relatively higher than other HH/TT subtypes because these are lower elevation units surrounded by higher HH/TT LTAs and the streams tend to converge in these low areas. The remaining five HH/TT subtypes of elevated exposure (**ee**), multi-mount (**mm**), peripheral plateau (**pp**), side step (**ss**) and undulating upland (**uu**), have similar stream node density distribution patterns. They all have high first order stream node densities with much lower second order stream node densities that are about one-fourth to one-third of the first order stream node densities, and then lower third and higher order stream node densities in an almost geometrically decreasing progression.

The stream node density patterns are diverse in the DD category. The two DD subtypes that do not receive hydrologic inflow from other DD units, general gradient (**gg**) and original outflow (**oo**), have similar node density patterns. They both have higher first order stream node density, slightly lower second order stream node density, relatively low third order stream node density, and very low higher order stream node density. As they are defined, their high first order stream node density is due to the fact that many first order streams originate in these upstream DD units. These first order streams often converge with each other in these areas to form second order streams, so second order stream node density is also relatively high here compared to other DD subtypes except the two extreme cases, local lowland (**ll**) and veining valley (**vv**). Some second order streams in these units converge to form third order stream nodes. Because of the upstream locations, higher order stream nodes are unusual in these subtypes.

Local lowland is also a DD subtype that is close to highland habitats and usually does not receive hydrologic inflow from other DD units. Therefore, this type should be similar to the above two with respect to higher order stream node density. This subtype has extremely high second order stream node density and relatively low first node density. This unusual pattern has several causes. First, these units are surrounded by highland habitats where most of the first order streams originate, so the first order stream node density here is not high. Second, these first order streams originated in the neighboring highlands tend to converge with each other in these lower LTAs and form frequent second order stream nodes here. Also because these units have small sizes, the second order node density is extremely high in local lowland. Furthermore, these second order streams can also converge at some points within these units because of the relatively steep slopes here, which makes the third order stream node density high in this subtype.

Veining valley has some similar characteristics with local lowland in the way that they are both surrounded by highland habitats and they both have small unit sizes. Thus the first and second order stream node densities have similar pattern in these two DD subtypes. Since these valleys are mainly formed by stream entrenchment, there are more stream branches occurring in these units and the drainage networks are more complex here. Consequently, the third and higher order stream node densities are also very high in this subtype.

As the two DD subtypes which receive hydrologic inflow from other DD units, branching basin (**bb**) and inclined inflow (**ii**) have similar stream node density patterns. They both have high first order stream node density and low second order stream density. The first and second order stream nodes here usually come from the contributing streams in these units. Because the first order streams usually contribute to the major streams in these units directly, the second order stream node densities are not as high as those in general gradients and original outflows. The third order stream node density for these two subtypes is slightly lower than the second order. Large density values for higher order stream nodes are caused by the downstream locations of these two subtypes.

Axial aqueduct (**aa**) is a DD subtype that is similar to branching basin and inclined inflow because the units in this subtype also receive hydrologic inflow from other DD units. Thus, the stream node density pattern in this subtype is also similar to **bb** and **ii**, but the axial aqueducts usually do not have many branch streams, so the first and second order stream node densities are relatively low in these units.

The fluvial facet (**ff**) subtype has very large node density value for the higher order streams because these units constitute dual drainage areas with high order streams. The first, second and third order stream nodes in these units generally come from the contributing small streams around the major river stems, and these small streams usually occur on the relatively high elevation areas such as small hills around the major river. Therefore, the node density pattern for these three orders of streams is very similar to those in HH/TT LTA units, decreasing in a sequence of nearly geometric progression.

Water/wetland (**ww**) subtype has very high value for the higher order stream node density because most of these units occur on the big river stems. This subtype also has some first, second and third order stream nodes. These stream nodes can be either contributing stream nodes for large river stem units, or small streams around wetlands or lakes.

Based on the eight orders of stream node densities, the eighteen LTA subtypes were grouped with cluster analysis to compare the stream node characteristics among these subtypes. The dendrogram from cluster analysis is presented in Figure 7.4. As described above, all of the HH/TT subtypes except for trough terrain (**tt**) are similar to each other and were grouped into one cluster with high similarity. Within this HH/TT cluster, **cc**, **hh** and **rr** are more similar to each other because of the low third and higher order stream node densities, whereas **ee**, **mm**, **pp**, **ss** and **uu** belong to the other subgroup. The DD subtypes have very diverse node density patterns. Axial aqueduct, branching basin and inclined inflow were clustered into one group because these are all DD units which receive hydrologic inputs from other DD units. General gradient and original outflow were grouped together with high similarity because they do not receive any hydrologic inputs from other DD units. Trough terrain was also clustered into this group. The trough terrain type consists of relatively low HH/TT units that do not have any other DD neighbors, so the stream node densities in those units are somewhat similar to those upstream DD units. Water/wetland was also grouped with these three subtypes because of the similar patterns on first, second and third order stream node densities. Because of the high densities on higher order stream nodes and low second order stream node densities, fluvial facet was considered as a unique subtype. It was considered more similar to the HH/TT cluster judging from the first three orders of stream node densities. Finally, local lowland and veining valleys were considered as another special group because they both have much higher second order stream node densities than the first order nodes due to their special locations and small sizes.

The result of this cluster analysis shows that the LTA subtypes effectively organized the LTA units with different characteristics of stream node densities. Each group in the cluster analysis shows its special stream node density pattern, and the LTA subtypes with similar topographic positions or similar hydrologic characteristics in the subtype classification designation were clustered into the same groups.

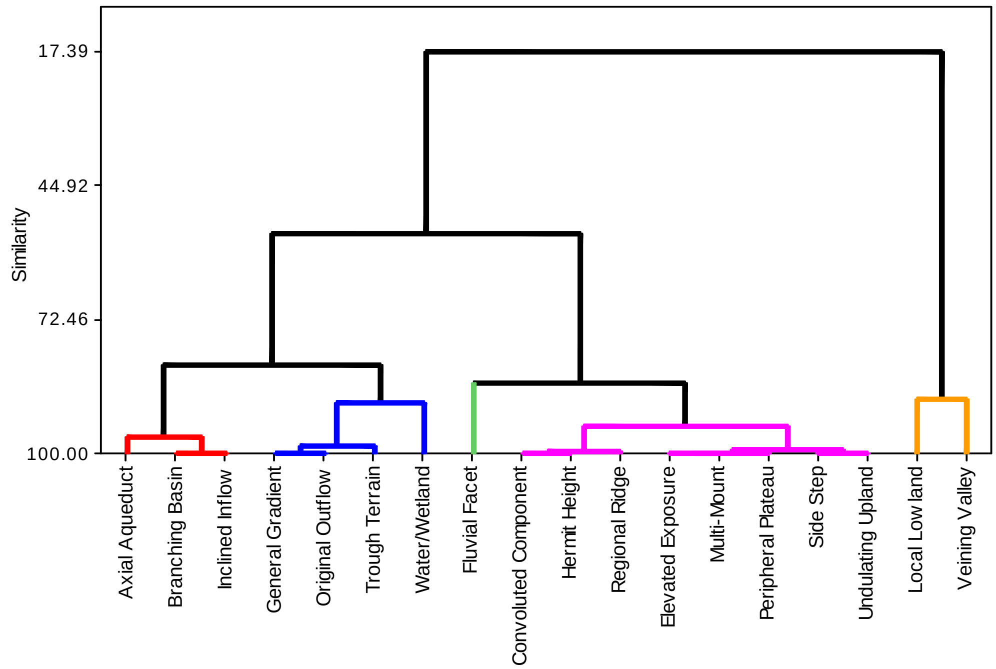


Figure 7.4 Dendrogram of stream node density cluster analysis for LTA subtypes based on Ward's linkage.

Drainage Densities in LTA Units

Since the LTA units in this study cross streams at the points where caplands change to cuplands, average stream length information within LTA units can not serve as a good indicator to compare the hydrologic characteristics between LTA types. However, stream drainage densities can capture the drainage length characters by calculating the stream length per unit area within LTA. The characteristics of stream drainage densities can be different from the stream node densities in LTA units, because drainage densities concern stream length characteristics, whereas the stream node densities concern stream convergences or the first order stream origins. Figure 7.5 presents the first, second, third and fourth order stream drainage densities in HH/TT and DD types of LTA units in different physiographic subsections in Pennsylvania. In all of these subsections, the stream drainage densities are all higher in dual drainage areas than in highland habitats and transitional terraces. Although the first order stream node densities are higher in HH/TT units, the first order streams have shorter length in these units. The paired t-tests also show that the DD LTA units have significantly higher drainage densities for all of these four orders of streams than the HH/TT units (p-value < 0.001 for the first three orders, and p-value = 0.001 for the fourth order stream). These results indicate that drainage densities are also significantly different in the two major LTA categories. Thus, it is further established that the LTA mapping method in this study can effectively separate LTA units with different hydrologic characteristics.

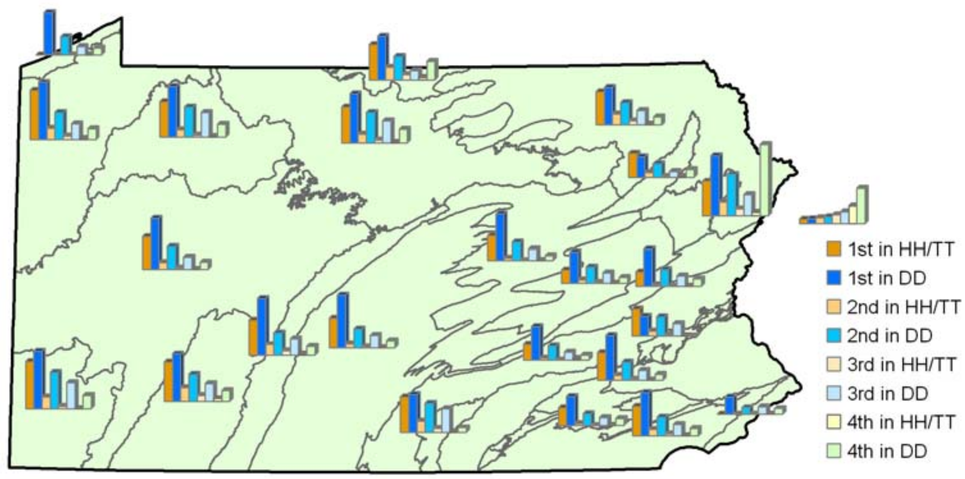


Figure 7.5 Drainage densities in HH/TT and DD LTAs in different physiographic subsections.

There are almost no fifth or higher order streams flowing through the HH/TT units, and these streams are all located in the dual drainage areas. The differences for these streams between HH/TT and DD types of LTAs are obvious, and do not require statistical detection.

The drainage densities in each of the LTA subtypes were also calculated and compared in Figure 7.6. Comparing the two major LTA groups in general, DD subtypes tend to have higher drainage densities for all orders of streams. For each LTA subtype, the first order stream density is always higher than the second or higher order stream densities. In the HH/TT group, almost all the LTA subtypes

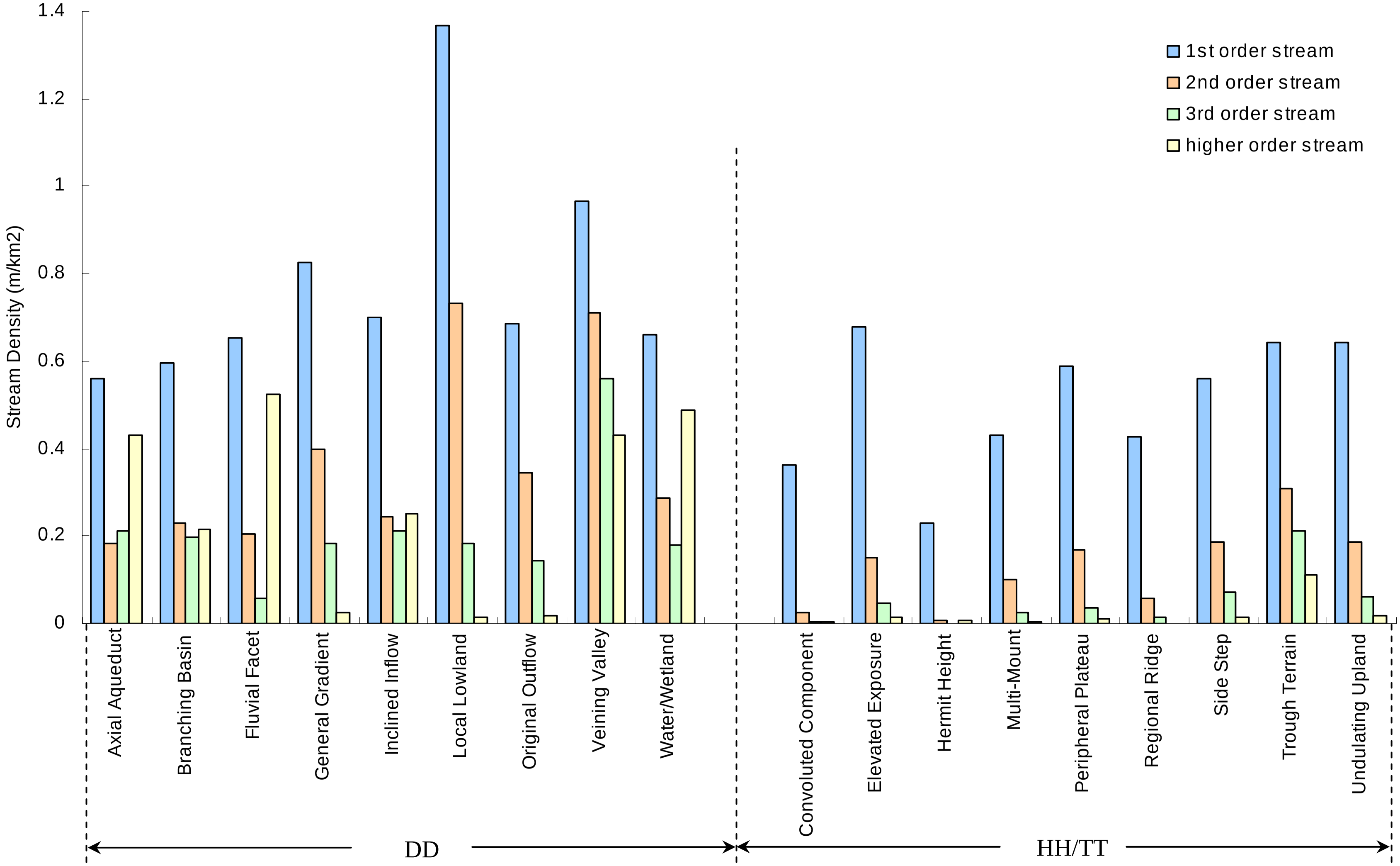


Figure 7.6 Average first, second, third and higher order stream drainage densities in different LTA subtypes.

are dominated by first order streams. Especially in convoluted component (**cc**), hermit height (**hh**) and regional ridge (**rr**) subtypes, the second and higher order streams are rare. This character corresponds with the stream node densities in these subtypes, because there are also not many second and higher order stream nodes in these units. Although the convoluted components and hermit heights have high first order stream node densities, their first order stream drainage densities are very low. The first order streams originating in these low-relief units have short pathways within units and flow down to the surrounding dual drainage areas. As for the stream node characteristics, elevated exposure (**ee**), multi-mount (**mm**), peripheral plateau (**pp**), undulating upland (**uu**) and side step (**ss**) subtypes also have similar drainage density distribution patterns. They all have high first order stream drainage densities, relatively low second order stream drainage densities which are only about one fourth to one third of the first order stream drainage densities, and very low third and higher order stream drainage densities in an almost geometrically decreasing progression. Trough terrain (**tt**) again becomes a unique HH/TT subtype because it not only has high first order stream drainage density, but also has relatively high second, third and higher order stream drainage densities. This unique character was determined by its special topographic position. In the large HH areas lacking dual drainages, these relatively lower land surfaces concentrate flow into more second and higher order streams.

For the DD subtypes, the drainage density patterns are more diverse. The two DD subtypes that do not receive hydrologic inputs from other DD units, general gradient (**gg**) and original outflow (**oo**), have very similar drainage density patterns. Stream drainage densities decrease as the stream orders increase, which is very similar to the pattern for trough terrain in the HH/TT group because of the upstream positions of these two subtypes. Local lowland (**ll**) also has this character, but the first and second order stream drainage densities are extremely high in this subtype.

The local lowlands are DD units that are located between highlands, so they contain many first and second order streams that originate in the upland areas. Also because these units are small, the first and second order stream drainage densities are very high in these units.

The drainage densities in veining valleys (**vv**)also have the decreasing trend as stream orders increase, but the decrease is not as dramatic as the above three subtypes. Although these units are located in an upstream position, they have some high order streams because stream confluences occur frequently in these units due to the complex topography within this subtype.

Branching basin (**bb**) and inclined inflow (**ii**) are two DD subtypes that receive hydrologic inputs from other DD units. These two subtypes also have similar drainage density patterns. The first order streams have high drainage densities in these units, and the second, third and higher order streams have similar drainage densities that are about one-third to one-half of that for first order streams. Axial aqueduct (**aa**) has a drainage density pattern close to these two subtypes but it has more higher order streams.

The remaining two DD subtypes, fluvial facet (**ff**) and water/wetland (**ww**), both have more higher order streams compared to other DD subtypes because of their downstream positions. Although they have high first order stream drainage densities, the densities for second and third order streams are not as high as other subtypes, which indicates that most of the contributing small streams in these units are first order streams.

Cluster analysis was conducted for the LTA subtypes based on drainage densities to compare stream characteristics between these subtypes. The dendrogram from this cluster analysis is shown in Figure 7.7. Convoluted component, hermit height and regional ridge in the HH/TT category were grouped together because they all have very low third and higher order stream drainage densities. Elevated exposure, multi-mount, peripheral plateau, undulating upland and side step were grouped together as another major HH/TT cluster in the cluster analysis. Water/wetland was also grouped with this cluster at a lower similarity level because this DD subtype has similar drainage density patterns to HH/TT units on the first, second and third order streams. Although water/wetland has large values on the higher order streams, these density values are relatively small compared to those for lower order streams. As described above, branching basin, inclined inflow and axial aqueduct have similar drainage density patterns because of their downstream locations, and were grouped into one cluster. General gradient, original outflow and local lowland also have similar patterns because of their upstream locations, and were grouped into one cluster as well. Although trough terrain units belong to the highland habitat category, they have similar drainage density properties to the upstream DD units because of their lower elevations, and were grouped into this upstream DD cluster. Veining valleys have same stream density characteristics as the upstream DD cluster, and can be grouped with these subtypes at a lower similarity level. However, veining valleys have much higher second and third order stream drainage densities than these subtypes. Finally, fluvial facet is a unique LTA subtype, and can only be grouped with other subtypes at very low similarity level. This subtype has high first order stream drainage density, low second and third order stream drainage densities, but very high drainage densities of higher order streams.

The result of cluster analysis indicates that most of HH/TT subtypes have similar drainage density characteristics, and DD subtypes can be roughly classified into two groups based on drainage densities as upstream DD units and downstream DD units. Fluvial facet is a DD subtype with special drainage density characteristics. The water/wetland subtype was grouped in an anomalous manner based on these stream drainage density values.

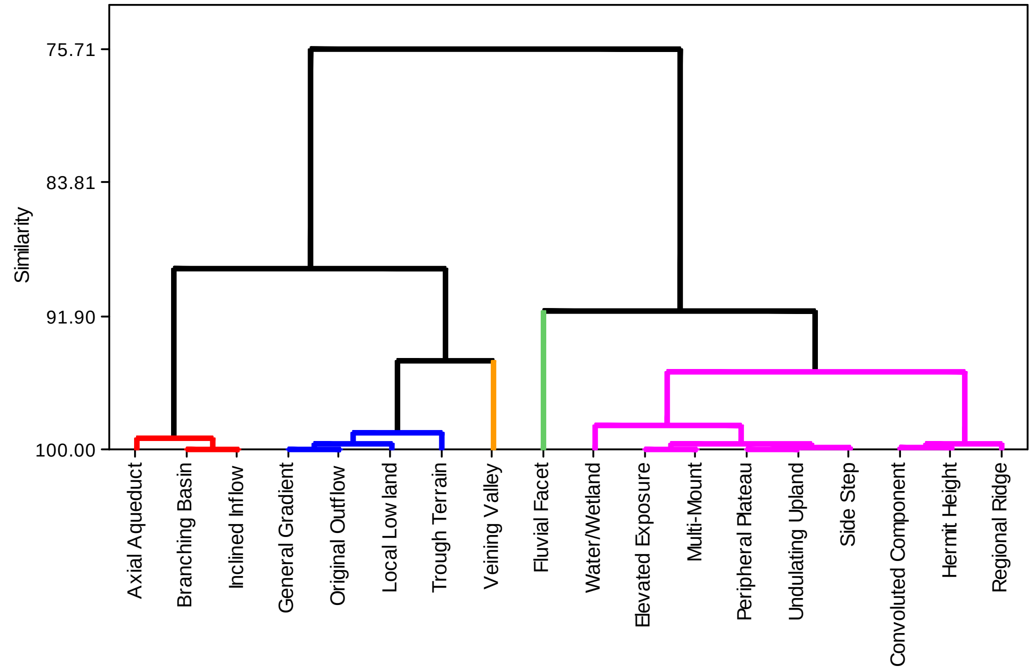


Figure 7.7 Dendrogram of drainage density cluster analysis for LTA subtypes based on Ward's linkage.

Based on both the stream node densities and drainage densities for all the eight order streams, cluster analysis was used again for the LTA subtypes to compare the synthesized stream network structures between these subtypes. The resulting dendrogram is shown in Figure 7.8. All the HH/TT subtypes except trough terrain were grouped into one cluster, indicating that these capland subtypes have similar patterns of stream network structures. Within this cluster, **cc**, **hh** and **rr** were considered more similar to each other because of lacking the third and higher order streams. Like the results from the other two cluster analyses, the remaining HH/TT subtypes, **ee**, **mm**, **pp**, **ss** and **uu**, were grouped together again. Fluvial facet was grouped with these capland subtypes at a low similarity level. This DD subtype has a unique stream network structure because it concentrates high order streams, and has similar first, second and third order stream structures to upland terrain units. All the remaining seven DD subtypes together with trough terrain were grouped into another large cluster in this analysis. As with the results from previous cluster analyses, axial aqueduct, branching basin and inclined inflow were considered more similar to each other within this large cluster because they are all downstream DD types. The upstream DD types, general gradient and original outflow, and lower HH/TT type, trough terrain, were considered similar to each other in this analysis. Local lowland and water/wetland are somewhat special DD types, and were grouped with this cluster at lower similarity level. Finally, veining valley was considered as a unique DD type because it has more second and third order streams, and relatively low first order stream node density.

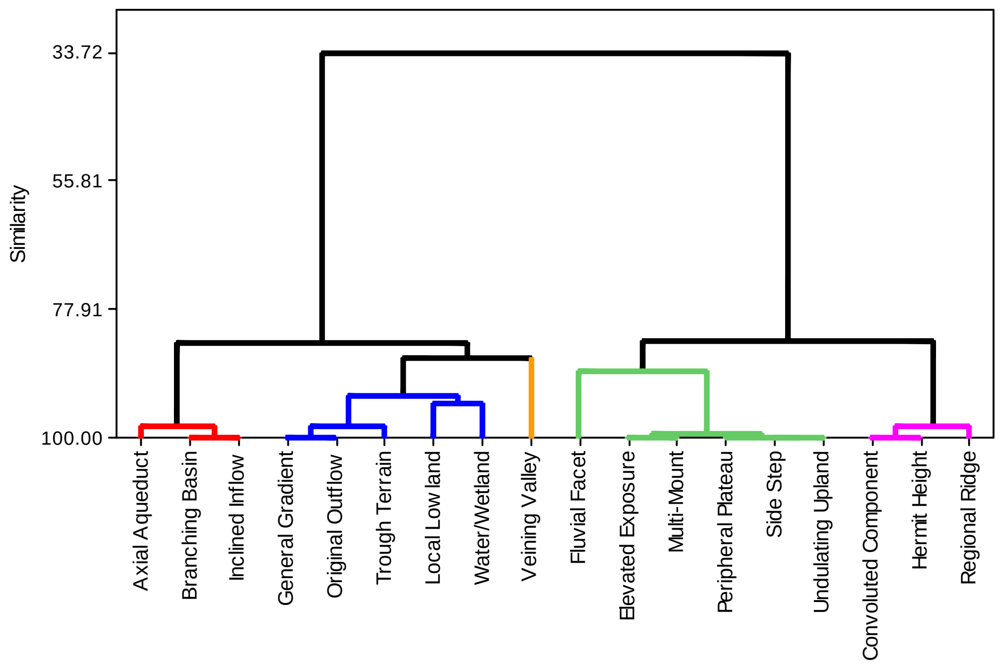


Figure 7.8 Dendrogram of stream node density and drainage density cluster analysis for LTA subtypes based on Ward's linkage.

This cluster analysis has both the stream node and drainage densities as input variables, and the result suggests that the capland and cupland mapping method used in this study can segregate different stream network structures in different LTA categories quite well. The stream structures can also be distinguished by the subtype classifications within capland and cupland categories.

For highland habitats and transitional terraces, **cc**, **hh** and **rr** have similar drainage structures characterized by the dominance of first order streams. **Ee**, **mm**, **pp**, **ss** and **uu** are similar to each other because they not only include dominant first order streams, but also have some second and third order streams. The lower HH/TT subtype, trough terrain, is a unique type and has similar drainage structure with the upstream DD units. The dual drainage subtypes can be divided into downstream cluster including **aa**, **bb** and **ii**, and upstream cluster including **gg** and **oo**. The **ll**, **ww**, **vv** and **ff** have their special stream structure characters and can not be grouped with other LTA types at high similarity level.

Summary

The results above indicate that the stream networks have different structures in different kinds of LTA units. The HH/TT units have higher concentrations of first order stream nodes, whereas DD units have more second and higher order stream nodes. The comparisons for drainage density show that DD units have higher density values for all orders of streams than HH/TT units. These results suggest that the HH/TT units in this mapping can be defined as the headwater stream habitats because they are the areas where headwater streams originate, whereas DD units accumulate flow with more streams. It is established that the mapping method used in this study can effectively separate headwater areas from the dual drainage areas, which supports the alternative hydrologic hypothesis in this chapter.

The stream node and drainage density comparisons between different LTA subtypes also show that different LTA subtypes have different stream structures. Through cluster analysis, these stream structure differences were found to correspond with different topographic and hydrologic positions of each LTA subtype. These results show that the LTA subtype classification can also effectively separate different hydrologic characteristics in each subtype.

The hydrologic differences between different LTA types influence the ecosystems and habitat types in each LTA group. The LTA mapping in this study can separate different drainage network structures, thus separate different landscape level ecosystems in some degree.

In further study, other hydrologic information, if available, can also be used to compare the hydrologic differences between LTA types. For example, the stream gradient, sinuosity, flood plain, hydrologic soil groups and curve numbers may provide more information about the hydrologic characters in LTA units.

Chapter 8

Land Cover Characteristics of the Ecological Units

Introduction

The land cover characteristics reveal different disturbance regimes for ecosystems. Distinguishing these disturbance regimes through LTAs can be helpful for decision making in ecosystem management. The mapping criteria and resulting units in this study were intended to reflect land cover differences by segregating terrain units according to topographic and terrain topology characteristics. Hydrologic processes change at the interface between capland and cupland from being dominated by runoff and erosion to favoring infiltration and deposition. These changes induce land cover changes between the LTA units. Usually, the lowland areas are more likely to be used for agricultural purposes because of more abundant moisture and less difficult terrain. Developed areas, such as high-density urban and low-density urban, are more likely to occur in the areas with low elevation and gentle terrain or places where major rivers pass through, because these areas have convenient transportation and the topography favors construction. Headwater areas, however, tend to have more naturalistic and intact habitats with muted human influence. Therefore, transitions between highlands and lowlands are also junctures where land cover patterns change. With these considerations, the LTA mapping in this study includes the following developmental hypothesis:

H_0 (null hypothesis): There is no difference in land cover characteristics among various landtype associations.

H_a (alternative hypothesis): The land cover patterns are different in different types of landtype associations.

In this chapter, the land cover patterns in different groups of LTA units are examined. The land cover differences between HH/TT and DD LTA units are analyzed in three major physiographic settings in Pennsylvania to help test this hypothesis. If different land cover types, as for example strongly human influenced types versus naturalistic types, have different distributions in different LTA categories, it will suggest that these ecological units can separate different land cover patterns. Land cover in each of the LTA subtypes is also examined in this chapter. The LTA subtypes represent different detailed local topographic and hydrologic characteristics, which can also affect land cover distribution patterns. If the land cover patterns in different LTA subtypes have evident differences, it suggests that the LTA subtype classification can also effectively separate the different land cover impacts on ecosystems and habitat distributions.

Methods

Data Sources

The statewide land cover map used in this chapter was generated from a combination of satellite and vector ancillary data with 30-meter resolution by the Office for Remote Sensing of Earth Resources in Penn State University. Imagery from Enhanced Thematic Mapper (ETM) instrument during 1999 to 2001 served as the primary data source for the land cover interpretation. In this dataset, the land cover was classified into the following types: water, high-density urban, low-density urban, hay/pasture, row crops, conifer forest, mixed forest, deciduous forest, beach, and transitional (mixed vegetation).

In this study, the high-density urban and low-density urban are combined into one urban category for the comparisons between LTA units. Beach and transitional land cover types are not analyzed because each of these two land cover types only occupies about one percent of the whole state area, and the beach only occurs in the Central Lowland.

Data Analysis

First, the area percentages of each land cover type in DD and HH/TT areas are compared within each of the three major physiographic components. In these comparisons, we only consider the three major physiographic components because there are no caplands in the Central Lowland and Coastal Plain components and there is only a small area of dual drainages in the New England component. The area percentages are used in these comparisons rather than the total area because DD and HH/TT LTA units have different area distributions in different physiographic settings.

Then, two sample t-tests are used to test whether there are significant differences between the HH/TT and DD LTA groups with respect to area percentages of urban, agriculture and forest land cover types. In these tests, the row crops and hay/pasture land cover types are grouped into an agricultural land cover type. The conifer forest, mixed forest and deciduous forest are combined into one forest category. Water is not compared in this step. The area percentages of urbanized, agriculture and forest cover types are calculated for every LTA unit in capland and cupland. The two sample t-tests are then used to compare the means of these area percentages between the DD and HH/TT LTA groups for each of these three major land cover types.

Finally, the area percentages of each land cover type are also calculated by different LTA subtypes in order to describe and compare the land cover differences between different LTA subtypes.

Results

Land Cover of LTAs in Physiographic Components

Each land cover type occupies a different percentage of area in dual drainages and highland habitats (including transitional terraces) in the three major physiographic components. Figure 8.1 presents the area percentages of different land cover types in DD and HH/TT areas in the Appalachian Plateaus, the Ridge and Valley, and the Piedmont. In general, intensive human use cover types of urban and agriculture have higher area percentages in the dual drainage areas, and low intensity land use cover types of forests have higher area percentages in the highland habitats and transitional terraces.

Urbanization occupies much more area in the DD cuplands than in the HH and TT caplands for every physiographic component because the development activities prefer lower elevations in regard to construction and transportation. The major cities or towns in Pennsylvania, including Philadelphia, Pittsburgh, Harrisburg, Allentown/Bethlehem, Scranton/Wilkes-Barre, Lancaster, York, Altoona, etc., all have their centers located in the dual drainage areas. In the Appalachian Plateaus, the HH/TT LTA units only include some low-density urban areas which are usually in the vicinities of the major cities. The suburban areas of Pittsburgh contribute to most of these urban areas in the HH/TT in Appalachian Plateaus. Because the valleys in this physiographic component are usually narrow, the urbanization process has expanded toward the nearby highlands; and these urbanized highland areas usually occur on those low-slope convoluted components distributed in the relatively low elevation areas in the Pittsburgh Low Plateaus and Waynesburg Hills. In the Ridge and Valley, the urban distribution differences between HH/TT and DD LTAs are even more obvious. The highlands in this section are characterized by high elevation relief and steep slopes, and there are almost no urban areas existing in these HH units. Most of the urban areas in the

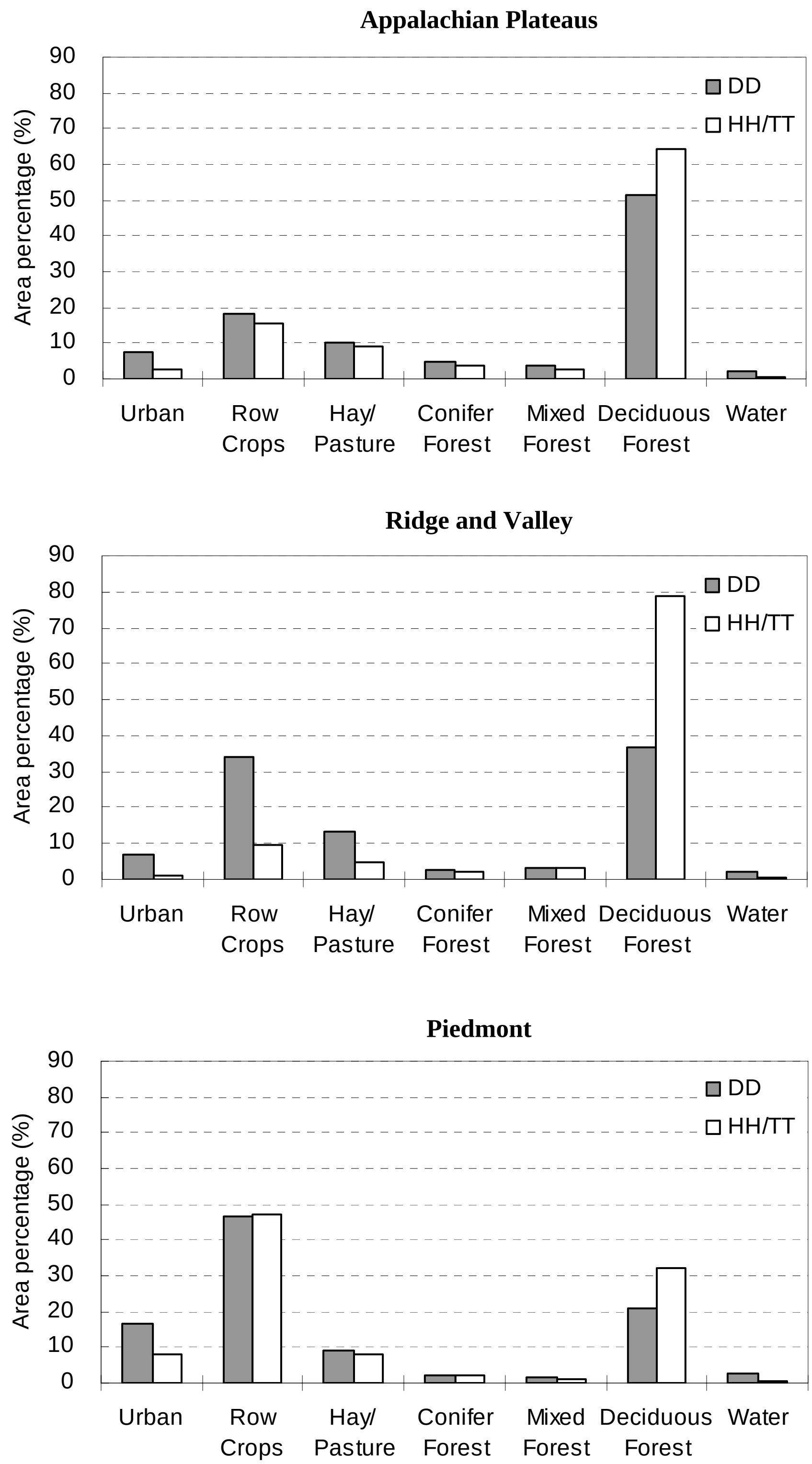


Figure 8.1 Area percentages of different land cover types in DD and HH/TT areas in three major physiographic components in Pennsylvania.

Ridge and Valley, such as Harrisburg, Scranton/Wilkes-Barre and Allentown, are located in the dual drainages. Also because these urban areas occur in broad valleys, they do not expand into highlands. In the Piedmont, urban areas including Philadelphia, Lancaster and York occupy a large percentage of the landscape. Although the centers of these cities are located in the dual drainages, the gentle terrain in this section does not impose strong restrictions on the pattern of urban sprawls, and many urban areas have expanded to their neighboring low-relief elevated exposure units. Especially in the Philadelphia vicinity, there are substantial urban areas occupying the low-elevation elevated exposures. Consequently, in this physiographic component, both DD and HH/TT LTAs include extensive urban areas even though the urban area percentage in DD is much higher than that in HH/TT units.

The agricultural land cover of row crops and hay/pasture is more likely to occur in the dual drainage areas than in the HH/TT units. In the Appalachian Plateaus, agriculture does not occupy large areas because of the infertile soils, but row crops and hay/pasture have slightly more area percentages in the DD areas. In the dual drainages of this physiography, the agricultural land is mainly distributed in the Pittsburgh Low Plateau, Northwestern Glaciated Plateau and Glaciated Low Plateau where the valleys are relatively broad compared to other DD areas in this section. These agricultural DD units are mainly composed of fluvial facets, general gradients and inclined inflows. In the highland habitats and transitional terraces of this physiography, agricultural areas are mainly distributed in low elevation areas such as the elevated exposures in the Northwestern Glaciated Plateau, the trough terrain in the Glaciated Low Plateau and Allegheny Mountain and some of the convoluted components in the Pittsburgh Low Plateau. In the Ridge and Valley, agricultural areas occupy much more of the landscapes compared to the Appalachian Plateaus, and distribution differences between DD and HH are very distinct. There is only 14 percent of the highlands occupied by row crops or hay/pasture, and these highlands are mainly composed of convoluted components having low relief and are strongly influenced by streams. Rocky ridges have thin and infertile soils and are not suitable for agriculture. Soil fertility increases as one moves into the valleys, so there is abundant agriculture in the dual drainages in this area that accounts for 47 percent of the combined DD areas. Especially in the broad basin and original outflow units in the Great Valley and in some areas of the Susquehanna Lowland and Appalachian Mountains, the flat terrain and fertile soils favor agricultural activities to the extent that row crops and hay/pasture occupy most of the DD units. In the Piedmont, agricultural row crops and hay/pasture dominate the landscape and occupy more than half of the total area, but their distributions are similar in HH and DD according to the area percentages. The extensive weathering in this region made the soils thick and fertile and the highlands here have gentle slopes, so agriculture is not restricted to dual drainage areas. In DD units, these agricultural areas are distributed throughout the gentle-slope branching basins and original outflows in the Piedmont Lowland and most parts of the Gettysburg-Newark Lowland and Piedmont Upland. In the HH area, the agricultural occurs on the gentle terrain of elevated exposures in the Piedmont Upland.

Forest land cover types preferentially occur on highland habitats and transitional terraces in general, especially for the deciduous forests. The conifer and mixed forests do not occupy large areas in any of the three physiographic components, and they have similar area percentages in both HH/TT and DD areas. In some physiographic components, they even have more concentration in the dual drainages, because the abundant moisture in the DD areas facilitates the growth of hemlock and spruces. Especially in the areas with infertile soils such as the Appalachian Plateaus, conifer and mixed forests can be favored to occur more in lowlands. Deciduous forests, however, have obvious concentration in the highlands rather than in dual drainages in all of the three major physiographic components. In the Appalachian Plateaus, deciduous forests occupy more than half of the landscape and are distributed in the undulating uplands of the Deep Valleys, High Plateau, Allegheny Front and Allegheny Mountain with large patch sizes. They are also distributed in the undulating uplands of the high elevation areas of Pittsburgh Low Plateau and Waynesburg Hills subsections. In dual drainages of the Appalachian Plateaus, deciduous forests are mainly located in the steep-sloped DD units which occur between the forested undulating uplands, such as for the veining valleys, general gradients and inclined inflows. In the Ridge and Valley, the deciduous forest distribution differences between highlands and drainages are very apparent. The deciduous forests occupy 79 percent of the highlands but only account for 37 percent of the dual drainages. The rocky ridges and mountains in this area are mainly occupied by deciduous forest. In the dual drainages, these forests only occur in the relatively steep-sloped LTA units such as general gradients, inclined inflows, axial aqueducts and local lowlands. In the Piedmont, forests only take up a small area percentage of the landscape, and they are restricted to the more rugged topography where relatively resistant parent materials produce shallower soils such as some of the elevated exposures in the Gettysburg-Newark Lowland. Therefore, deciduous forests also have a higher area percentage in the HH units than in DD units in this physiography. The forests in dual drainages in the Piedmont only occur in some uncommon and relatively steep DD units, such as the general gradients and inclined inflows in the Gettysburg-Newark Lowland and Piedmont Upland.

Water only occupies dual drainages in the Appalachian Plateaus and the Ridge and Valley physiographic components. In the Piedmont, water is also mainly distributed in the dual drainages but there is a small percentage of highlands occupied by water bodies in this physiography. These are usually very small water bodies located on the lower-elevation elevated exposures or convoluted components.

Concluding from the foregoing evidence, the three major land cover types (urban, agriculture and forest) have obviously different distribution characters in HH/TT and DD LTAs in all of the three major physiographic components. In order to test the significance of these differences statistically, the average area percentages of these three land cover types in HH/TT and DD units were compared with t-tests in each physiographic component. The mean, standard error and t-test results are shown in Figure 8.2. Both urban and forest have significant distribution differences in all of the three physiographic components. Urban areas tend toward dual drainage LTAs, whereas forests are more abundant in the highland habitats or transitional terraces. Agriculture lands have significantly different area distributions between HH/TT and DD LTAs in the Ridge and Valley. Although the means of agricultural land cover percentage in DD are slightly higher than the means in HH/TT in the Appalachian Plateaus and Piedmont, these differences are not significant at 0.05 level. In the Appalachian Plateaus, soils tend to be infertile throughout. In the Piedmont, HH units are mainly composed of gentle terrain elevated exposures, and agricultural land types can be distributed on these gentle highlands if they have fertile soils.

With the comparisons above, intensive human-use land cover types are typical of the dual drainage LTAs, and naturalistic cover is typical in the highland habitats and transitional terraces. This conclusion supports the alternative hypothesis in this chapter that the major LTA category designation and LTA mapping method can serve to separate different land cover patterns.

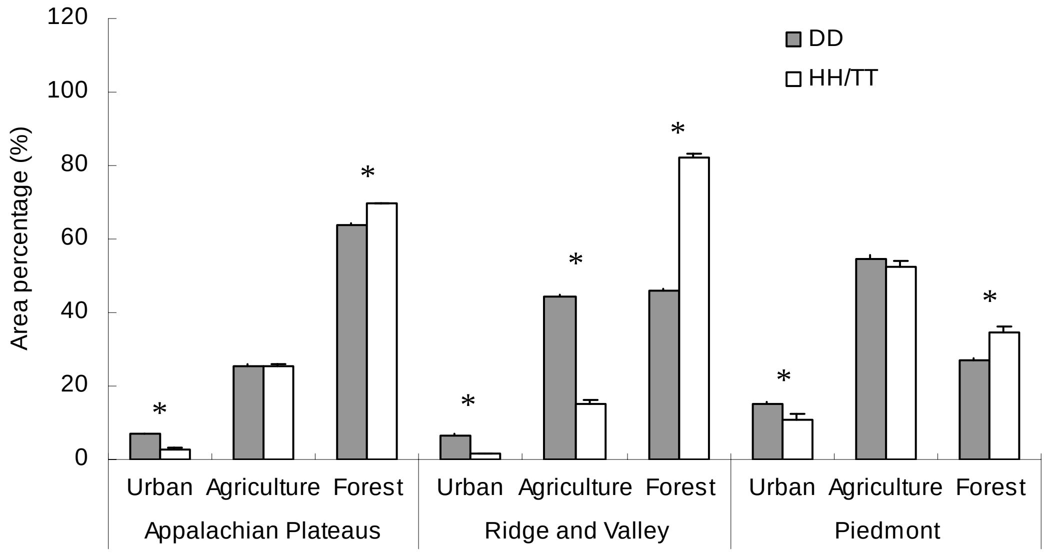


*Figure 8.2 Mean and standard error of area percentage of three major land cover types in LTA units in the Appalachian Plateaus, Ridge and Valley and Piedmont. * means the area percentage differences between DD units and HH/TT units are significant (p<0.05).*

Land Cover in Different Subtypes of LTAs

The area percentages of different land cover types were also compared by each of the LTA subtypes. Figure 8.3 presents the land cover percentages in different subtypes of HH/TT LTA units. For all the HH/TT subtypes except elevated exposure, the deciduous forests dominate these highlands or terraces. Row crops and hay/pasture are the second and third most extensive land cover types, and occupy different percent of areas in the LTA subtypes according to their specific topography and soil characteristics.

The regional ridges have the largest percentage of areas covered by deciduous forest, which account for more than 85% of the collective **rr** areas because of the thin infertile soils on the ridges. Other land cover types only occur here with small areas in very occasional cases. In this same physiography with similar slope and soil properties, the multi-mount units also have this land cover distribution pattern, although the deciduous forest gives way to some small areas of

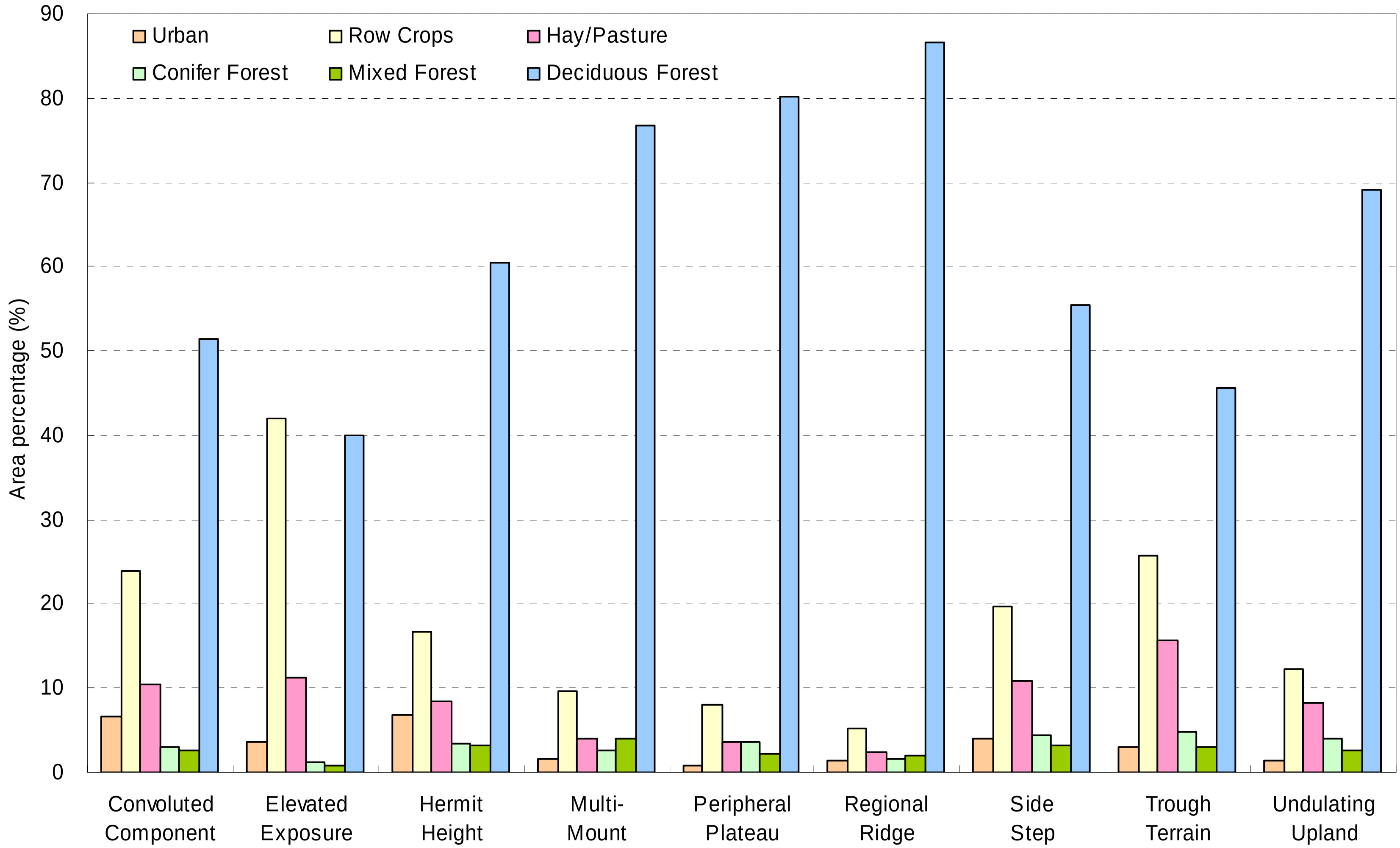


Figure 8.3 Area percentages of different land cover types in different HH/TT subtypes.

other land cover types in this LTA subtype. Although hermit heights are also mainly distributed in the Ridge and Valley, the deciduous forest in this subtype is not as high as the other two subtypes, and there are more urban, row crops and hay/pasture areas existing in these isolated hills. Because the units in this subtype usually have small sizes and low relief and are all surrounded by the dual drainages, they can be more influenced by the land covers in surrounding DD units and have more intensive human land use.

The two major HH/TT subtypes in the Appalachian Plateaus, undulating upland and peripheral plateau, also have large area percentages of forests with the deciduous forest covering about 70 percent because the infertile soils here are more suited to forests than to agriculture. However, there is still 20 percent of the undulating upland areas occupied by agricultural land cover types. These agriculture areas mainly occur at the Glaciated Low Plateau.

The two HH/TT subtypes that have relatively lower elevation than their neighboring HH units, side step and trough terrain, have relatively less areas occupied by forests and more areas occupied by agriculture and urban due to their lower positions and better moisture conditions. In the trough terrain, row crops and hay/pasture even account for more than 40 percent of the total area.

In convoluted component units, urban takes up a relatively large area percentage along with row crops and hay/pasture because these LTA units usually have low relief and are more influenced by streams. The urban areas in these units include the Pittsburgh and Philadelphia vicinities. The agriculture mainly occurs in the Piedmont, some units in the Ridge and Valley, Glaciated Low Plateau and lower part of Pittsburgh Low Plateau. Most of the convoluted components in the Deep Valleys and High Plateau are fully covered by forest.

The land cover pattern in elevated exposures is very different from other HH/TT subtypes in the way that row crops even occupy more areas than deciduous forest. There are also high percentages of hay/pasture and urban areas in these units. This is because these elevated exposures have properties which favor intensive human activities. They are mostly distributed in the low elevation parts of the state with suitable soils as in the Piedmont and Northwestern Glaciated Plateau, and these units have low relief and gentle terrain. Forest is relegated to rugged areas with thin soils in these units.

The land cover in different DD LTA subtypes is shown in Figure 8.4. In comparison to the LTAs in highland habitats and transitional terraces, urban and row crops occupy more areas in these DD subtypes, but deciduous forest has less area. In the two relatively level DD subtypes, branching basin and original outflow, gentle slopes facilitate human activities. Row crop cover in these units dominates the landscape with almost 50 percent of the total area, whereas forests only occupy about 20 percent. Urban and hay/pasture also have larger area percentages here compared to all other DD subtypes.

Under the influence of high order streams passing through, fluvial facets have relatively high area percentages of intensive human land use and low forest cover. Due to the major rivers, water also occupies some areas in this DD subtype.

General gradient and inclined inflow are two DD subtypes with more slopes, although their slopes are not as steep as those in veining valley, local lowland or axial aqueduct. The forest area in these units increases to more than 50 percent, but there is still considerable area here occupied by the row crops, hay/pasture and urban land covers.

Both veining valley and local lowland DD units have high slopes. In these units the agricultural land cover and urbanization do not occupy as much area as for other DD subtypes, and their area percentages are even smaller than some HH/TT units. Intensive human land use only occurs on some valley bottoms, and most of the slope areas are covered by forests, especially deciduous forest.

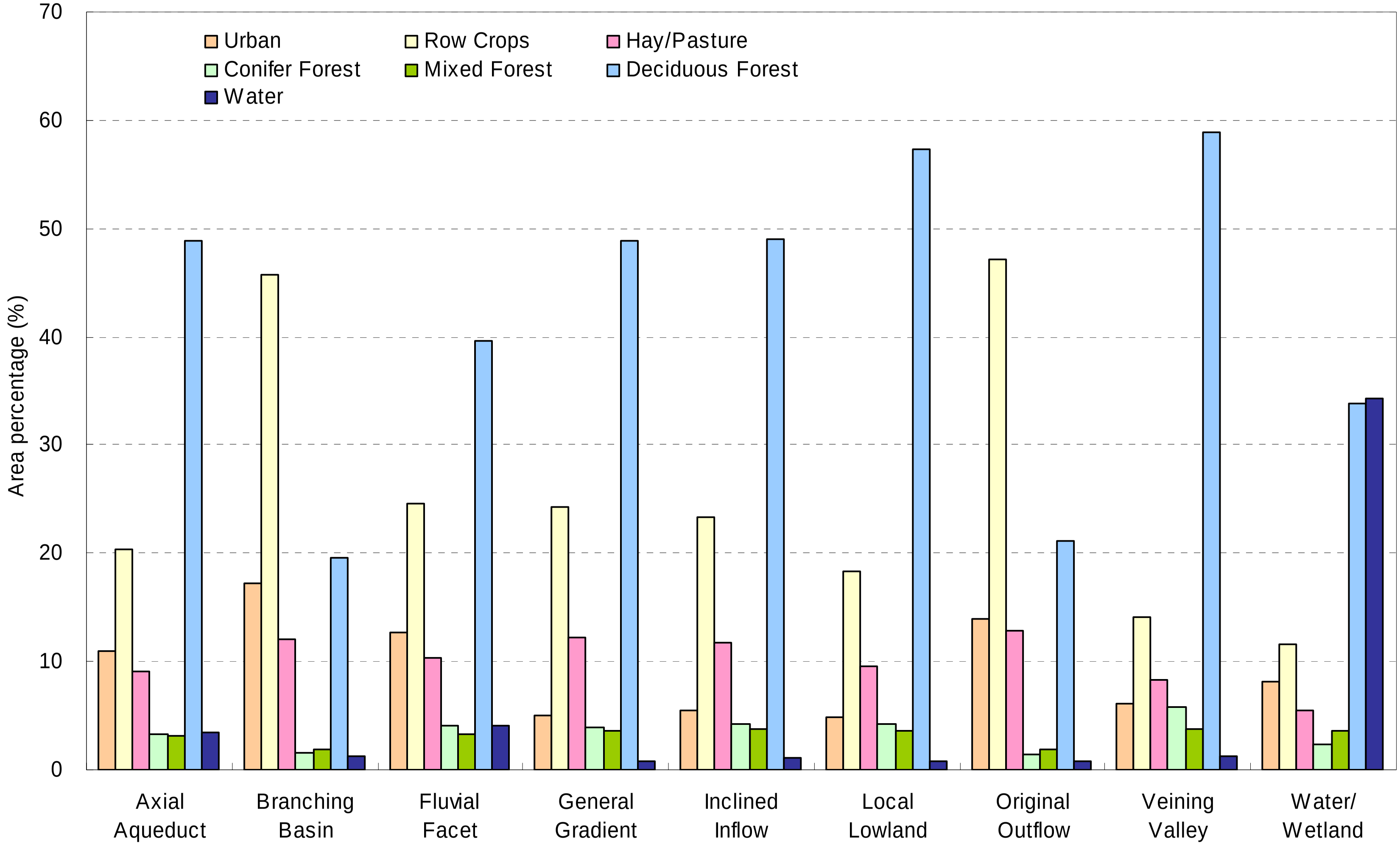


Figure 8.4 Area percentages of different land cover types in different DD subtypes.

Similarly, axial aqueducts also have steep side slopes, so the forests in these units occupy large areas whereas other land cover types are relatively small. There are, however, some axial aqueduct units distributed in the Pittsburgh Low Plateau and Northwestern Glaciated Plateau where slopes are gentle that accommodate more agriculture and urban areas.

The water/wetland subtype includes 35 percent of the area as water. There are also some forests, urban and agriculture lands in these units situated along the river stems or wetland areas. Forests can also occur in the wetland ecosystems in these units.

With the comparisons above, we can conclude that the HH/TT LTA subtypes have very different land cover patterns from the DD subtypes, and that each subtype in HH/TT or DD category also has its special land cover pattern according to the physiographic characters. The LTA subtype classification can thus separate different land cover characters to some degree.

Summary

The results above indicate that the land cover patterns are different in different kinds of LTA units. In each of the three major physiographic components, the composition of different land cover types varies in cupland areas and capland areas. In general, there are more developed urban areas located in the dual drainage units, whereas the forests are more likely to be distributed in the highland habitats and transitional terraces. Although the agricultural lands occupy more areas in the dual drainage units and this high occupancy is very obvious in the Ridge and Valley, the agricultural land cover differences between caplands and cuplands are not statistically significant in the Appalachian Plateaus and the Piedmont because of the special topographies and soils in these two physiographic settings. With these evidences, we can conclude that the LTA unit properties (capland or cupland) can influence the preference of human activities, thus determining the distribution patterns of forest and wildlife habitats. In the highland habitats or transitional terraces, human disturbances of ecosystems are usually muted, and the natural communities can be kept relatively intact. In the dual drainages, the development and agricultural activities are more common and exert strong influences on the ecosystems there.

At LTA subtype level, different LTA subtypes within the capland or cupland category also have different land cover compositions, although these differences between subtypes are not as much as the differences between capland and cupland. In the capland LTA subtypes, deciduous forest dominates the landscape in all subtypes with gentle slope units tending to include more urban and agriculture lands. In the cupland subtypes, both row crops and forests have high area percentages and their composition within each subtype is related to the slopes and rivers within the units. This suggests that the LTA subtype classification based on topography and hydrologic characters can reveal land cover differences between different LTA subtypes. Therefore, the ecosystems in different subtypes are prone to different patterns of influence.

In addition to area compositions of different land cover types, landscape structures such as the patch size, connectivity, and spatial contagion can also have great influences on ecosystems. Landscape structure analysis for LTA units remains a subject for further study.

Chapter 9

Habitat Distributions in LTA Units

Introduction

One of the most important considerations in this landtype association mapping is to delineate different habitat types at the landscape scale. The designation of major LTA categories in this study, highland habitat, transitional terrace and dual drainage, includes habitat considerations with the following hypothesis:

> **H_0 (null hypothesis):** There is no habitat distribution difference between different kinds of landtype associations.
>
> **H_a (alternative hypothesis):** The LTA units can separate different habitat types.

The highland habitats are source areas for water and composed of hilly to level land surfaces. They often have more wind exposure and dry to medium moisture conditions. Species that favor headwater streams, exposed environments or dry conditions are usually associated with these areas. Due to the higher elevation and slopes, highland habitats also tend to have less human disturbances and relatively intact ecosystems, which provide more forest habitat. Dual drainages, however, are cupping to level valley areas which include both large streams and small tributary streams. These areas favor infiltration and deposition. Species which require moist and nutrient-rich or downstream habitat will reside here. In addition, these areas are subject to human disturbances because of their moist, fertile soils and gentle topography which is suitable for agriculture and development. Species which depend on or have high tolerance for human disturbances also tend to distribute in these areas. Transitional terraces are hilly land surfaces like highland habitats. They also include primarily headwater streams within their unit ranges and the hydrologic processes here are dominated by runoff and erosions. Therefore, the habitat distributions in this LTA category should be very similar to the highland habitats. However, there are some species which do not have strong habitat favoritism on one kind of LTA unit. These are usually wide-spread species or some species whose habitat distributions are more influenced by other larger scale factors, such as climate, or smaller scale factors, such as certain slope conditions.

In this chapter, vertebrate species habitats from Pennsylvania Gap Analysis project (Myers et al., 2000) are used to test the habitat distribution hypothesis in LTA mapping, and to describe the habitat distribution differences between caplands and cuplands for species that exhibit habitat preference at landtype association level. In each of the three major physiographic components, the percentages of capland and cupland in every species habitat range has been calculated for every species in the GAP dataset. Species that favor highland habitats (or transitional terraces) should have larger habitat proportions in the HH/TT LTA category, and species favoring dual drainages should have larger habitat proportions in the DD category. Otherwise, the species that are widely spread throughout the state or are influenced by other factors will not have strong distribution differences between the caplands and cuplands. Proportion tests are used to identify the species that favor HH/TT or DD LTA units. If there are such species, it would suggest that the highland habitats and dual drainages in this LTA mapping can separate different habitat types. Proportion tests with more stringent criteria are also conducted to screen out species that have strong favoritism with respect to HH/TT or DD LTA units. These species might serve as indicator key species for the highland habitats or dual drainages.

Methods

Data Sources

The habitat data used in this chapter were obtained from the Pennsylvania Gap Analysis Project (Myers et al., 2000). This project mapped the statewide potential habitat (predicted distribution) for all vertebrate species considered to breed consistently in Pennsylvania. There are 470 vertebrate species considered in the project, and they were separated into six major taxonomic groups including amphibians, birds, fish, mammals, turtles, and snakes/lizards. The habitat models for each of the species in these six groups were provided by this project with habitat variables and their rating of relevance to particular species. Habitat models for amphibians, birds, mammals, and reptiles are generally similar. They are based primarily on species affinity for land cover types supplemented with modifications for aquatic ecosystems, landscape position regarding elevation, urban density and stream order. The fish habitat modeling was conducted according to physiographic units, major river basins, stream size class, median slope, and extent of disturbance. In this dataset, the entire state was partitioned into a network of 1-kilometer square cells, with related tabular databases for different taxa showing whether or not habitat models indicate any potential habitat in the cell for each species.

Data Analysis

In this chapter, the species that favor highland habitats (or transitional terraces) and species that favor dual drainage habitats are identified. Because the habitat distributions are influenced by physiographic settings, the analyses in this chapter are conducted separately for each of the three major physiographic components. Within each physiographic component, the area percentages of capland and cupland in the potential habitat of each species are calculated for comparisons. These area percentages are strongly related to the capland and cupland areas in the particular study area. For example, if there are more dual drainage areas in the physiographic component, then the habitat will have more possibility to distribute in the dual drainage units. So in this study, the areas of capland and cupland in each species habitat are weighted by the total capland or cupland areas in the particular physiographic component for the area percentage calculations. For instance, the weighted HH/TT area percentage in each species habitat is calculated as:

$$P_{Hw} = \frac{n_H / r_H}{n_D / r_D + n_H / r_H} \times 100\%$$

where P_{Hw} is the weighted area percentage of habitat which is classified as HH/TT, n_D and n_H are number of 1-km square cells which are habitat and distributed in the DD or HH/TT areas (as shown in Figure 9.1), r_D and r_H are the area ratios of DD and HH/TT in the study area (for example, $r_H = N_H / (N_D + N_H)$, where N_D and N_H are total number of 1-km square cells which are classified as DD or HH/TT in the particular physiographic component).

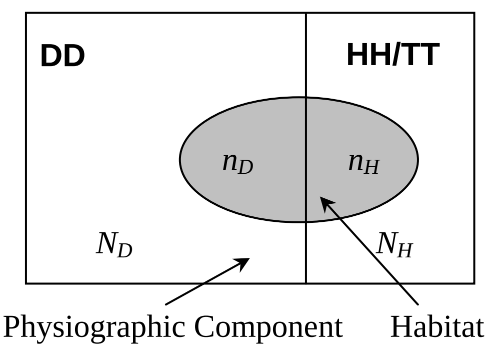


Figure 9.1 Illustration of habitat distribution in DD and HH/TT areas in the physiographic component.

The species in each of the six groups are then sorted according to their P_{Hw} value. The species that favor cuplands have low P_{Hw} values (less than 50%), because their habitats only have small chances to distribute in the HH/TT area. Whereas the species that favor caplands will have high P_{Hw} values (greater than 50%). For those species that do not have obvious favoritism between caplands and cuplands, their P_{Hw} value should be very close to 50%.

The next step is to distinguish the capland species and cupland species in the six species groups. Proportion tests are used in this study to help identify these species. The hypothesis in the proportion test is:

H_0: $p = p_0$

H_a: $p \neq p_0$

where p is the proportion of HH/TT areas in the species habitat ($p = n_H / (n_H + n_D)$), and p_0 is the proportion of HH/TT areas in the particular study area ($p_0 = N_H / (N_H + N_D)$).

The null hypothesis here means that the species habitat has equal chances to occur in both caplands and cuplands. If the null hypothesis is rejected, it suggests that the habitat for this species has a higher tendency to occur in either caplands or cuplands. In this study, the significance level of 0.01 is used in the statistical test to limit the number of species in the result list.

After identifying the species with either HH/TT or DD habitat favoritism, these species are sorted again according to their P_{Hw} value. The species with P_{Hw} value less than 50% are considered as species that favor dual drainage habitats, and the species with P_{Hw} value greater than 50% are considered as species that favor highland habitats or transitional terraces.

The result of the test above indicates species that favor caplands or cuplands even this favoritism is only slightly above 50%. In order to identify the key species that have stronger affinity in caplands or cuplands, another proportion test with more stringent criteria in the hypothesis is conducted. With this test, a shorter list of species having 60% or more chance to distribute in one LTA category is obtained. This proportion test is conducted separately for highland habitat species and dual drainage species. The hypothesis in the test is:

H_0: $p = p_0$

H_a: $p > p_0$

For the highland habitat species, p is the proportion of HH/TT areas in the species habitat ($p = n_H / (n_H + n_D)$), and p_0 is the proportion of HH/TT areas in the whole study area multiplied by factor 1.2 ($p_0 = 1.2 \times N_H / (N_H + N_D)$). The multiplier 1.2 is used here because the distribution favoritism is increased from 50% to 60%. Similarly, for the dual drainage species, p is the proportion of DD areas in the species habitat, and p_0 is the proportion of DD areas in the whole study area multiplied by factor 1.2. If the null hypothesis is rejected in this test, it indicates that this particular species has more than 60% chance of distributing in the caplands (or cuplands). Again, significance level of 0.01 is used in this test.

With this test, the key species in highland habitats (or transitional terraces) and dual drainages can be identified. The habitat relationship models for these species provided by the Pennsylvania Gap Analysis project is referenced to describe the key habitat features and help verify these habitat distribution tendencies.

Results

Habitat Affinity of Species in the Appalachian Plateaus

Amphibian species habitat distributions:

Among the 35 amphibian species analyzed in the Pennsylvania Gap Analysis Project, there are 32 species distributed in the Appalachian Plateaus. With the proportion test, 3 species were considered to favor highland habitats or transitional terraces, and 17 species were considered to favor dual drainage habitats (Appendix B1). With the higher-criteria proportion test, species that have 60% or more of suitable habitat in one kind of LTA unit are listed in Table 9.1.

Among these key amphibian species, there is only one (northern cricket frog) identified as highland habitat species, and eight species considered as dual drainage species. The northern cricket frog only has a small habitat area (321 km^2) distributed in the Appalachian Plateaus. Although it favors habitat related to medium or large streams, palustrine herbaceous wetlands and open water, it can also use the deciduous and mixed forest. In Appalachian Plateaus, all of its habitats are distributed on the undulating uplands of Glaciated Pocono Plateau where streams are dense and deciduous forest and mixed forest dominate the landscape.

Table 9.1 Key capland and cupland amphibian species in the Appalachian Plateaus

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Acris crepitans*	Northern cricket frog	0.0	100.0	<0.001
DD	*Ambystoma opacum*	Marbled salamander	68.3	31.7	<0.001
DD	*Necturus maculosus*	Mudpuppy salamander	67.4	32.6	<0.001
DD	*Desmognathus monticola*	Appalachian seal	65.2	34.8	<0.001
DD	*Plethodon hoffmani*	Valley & ridge salamander	65.1	34.9	<0.001
DD	*Cryptobranchus alleganiensis*	Eastern hellbender	63.9	36.1	<0.001
DD	*Bufo woodhousii*	Fowlers toad	63.7	36.3	<0.001
DD	*Pseudacris brachyphona*	Mountain chorus frog	63.0	37.0	<0.001
DD	*Aneides aeneus*	Green salamander	61.2	38.8	<0.001

The dual drainages only occupy a small area proportion of the Appalachian Plateaus, and most of the DD areas here occur in the Pittsburgh Low Plateau and Glaciated Low Plateau. Thus the eight dual drainage species most often occur in these two subsections. The DD areas in the Appalachian Plateaus contain higher percentage of forest areas compared to the other two physiographic components, so the dual drainages here favor the DD species that require forest areas. The marbled salamander, mudpuppy salamander and eastern hellbender require valley bottom habitats, so they most often occur in the dual drainage units in the Pittsburgh Low Plateau or Glaciated Low Plateau. The Appalachian seal salamander requires habitat close to first or second order streams covered by deciduous or mixed forests, and this habitat is mainly in the general gradients or inclined inflows in the Pittsburgh Low Plateau. The green salamander needs riparian areas along with forest cover, and occurs in the dual drainage units in the Pittsburgh Low Plateau. Having deciduous and mixed forest or some palustrine communities as habitat, the fowler toad, the mountain chorus frog and the valley and ridge salamander mainly occur in the dual drainage units of the Pittsburgh Low Plateau area and some areas in the Glaciated Low Plateau.

Bird species habitat distributions:

Among the 181 bird species that range into the Appalachian Plateaus, 38 of them were identified as capland species, and 66 of them were considered to favor cupland habitats (Appendix B2). The key species among these that have more than 60% of habitat distributed in one kind of LTA unit are listed in Table 9.2. There are 10 bird species with strong favoritism for highland habitats or transitional terraces, and 11 bird species for the dual drainages.

Table 9.2 Key capland and cupland bird species in the Appalachian Plateaus

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Empidonax flaviventris*	Yellow-bellied flycatcher	0.0	100.0	<0.001
HH	*Dendroica striata*	Blackpoll warbler	0.6	99.4	<0.001
HH	*Troglodytes troglodytes*	Winter wren	10.1	89.9	<0.001
HH	*Junco hyemalis*	Dark-eyed junco	16.9	83.1	<0.001
HH	*Vireo flavifrons*	Yellow-throated vireo	17.2	82.8	<0.001
HH	*Seiurus noveboracensis*	Northern waterthrush	19.1	80.9	<0.001
HH	*Catharus ustulatus*	Swainson's thrush	25.0	75.0	<0.001
HH	*Contopus borealis*	Olive-sided flycatcher	28.3	71.7	<0.001
HH	*Catharus guttatus*	Hermit thrush	35.9	64.1	<0.001
HH	*Dendroica magnolia*	Magnolia warbler	36.6	63.4	<0.001
DD	*Guiraca caerulea*	Blue grosbeak	100.0	0.0	<0.001
DD	*Corvus ossifragus*	Fish crow	87.5	12.5	<0.001
DD	*Asio flammeus*	Short-eared owl	79.3	20.7	<0.001
DD	*Chlidonias niger*	Black tern	74.6	25.4	<0.001
DD	*Caprimulgus carolinensis*	Chuck will's widow	69.4	30.6	<0.001
DD	*Sturnella neglecta*	Western meadowlark	68.1	31.9	<0.001
DD	*Spizella pallida*	Clay-colored sparrow	67.9	32.1	<0.001
DD	*Vermivora pinus*	Blue-winged warbler	65.8	34.2	<0.001
DD	*Falco peregrinus*	Peregrine falcon	65.7	34.3	<0.001
DD	*Cistothorus palustris*	Marsh wren	62.2	37.8	<0.001
DD	*Cistothorus platensis*	Sedge wren	60.2	39.8	<0.001

All of the 10 highland bird species in Table 9.2 have elevation requirements in their habitat distribution models. They all use habitats higher than 460-600 meters elevation. In addition, they tend to avoid urban and herbaceous open areas, which occur often in the dual drainage LTAs. The dark-eyed junco, yellow-throated vireo, hermit thrush and Swainson's thrush favor habitats in deciduous forest, mixed forest or conifers; whereas the winter wren, yellow-bellied flycatcher, blackpoll warbler, northern waterthrush, olive-sided flycatcher and magnolia warbler occupy conifer forest, mixed forest or palustrine woody wetlands.

Among the 11 key DD species, the fish crow, blue-winged warbler and blue grosbeak utilize habitats lower than 300 or 400 meters. In the Appalachian Plateaus, most of the HH or TT units are higher than this elevation, so these species are largely relegated to the dual drainages. The Peregrine falcon has been introduced to urban areas and inhabits areas along second or higher order streams, which are found predominantly in dual drainage units. Chuck will's widow is more likely to occur in the forests, especially mixed forest in the dual drainages. The remaining six DD bird species favor different kinds of herbaceous cover. The dual drainages encompass more herbaceous areas compared to the highlands, so these species have the habitat affinities for dual drainage areas.

Fish species habitat distributions:

There are 140 fish species distributed in the Appalachian Plateaus. Thirty-one of them were tested as favoring highland habitats or transitional terraces, and 95 species were identified as having affinity for dual drainages (Appendix B3). With the higher 60% criterion in proportion tests, the key fish species in caplands and cuplands were identified and listed in Table 9.3. Only 6 species were considered as key capland species, and all of the remaining 49 species were designated as having more affinity for dual drainage areas.

Since fish distribution models are related to the physiographic subsections and drainage basins, the habitat affinities of fish species in capland or cupland are influenced by the HH/TT and DD LTA compositions in the particular physiographic section. All of the six highland species occur only in the Deep Valleys, High Plateau, Glaciated High Plateau and Allegheny Mountain subsections. In these areas, undulating uplands dominate the landscape, and dual drainages only occur in small areas in the form of veining valleys.

Table 9.3 Key capland and cupland fish species in the Appalachian Plateaus

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Catostomus catostomus*	Longnose sucker	19.3	80.7	<0.00
HH	*Amia calva*	Bowfin	20.8	79.2	<0.00
HH	*Nocomis biguttatus*	Hornyhead chub	22.3	77.7	<0.00
HH	*Clinostomus funduloides*	Rosyside dace	22.9	77.1	<0.00
HH	*Notropis dorsalis*	Bigmouth shiner	30.7	69.3	<0.00
HH	*Lampetra appendix*	American brook lamprey	36.4	63.6	0.008
DD	*Ictiobus cyprinellus*	Bigmouth buffalo	100.0	0.0	0.007
DD	*Etheostoma exile*	Iowa darter	90.3	9.7	<0.00
DD	*Hiodon tergisus*	Mooneye	89.3	10.7	<0.00
DD	*Alosa sapidissima*	American shad	88.4	11.6	<0.00
DD	*Alosa chrysocloris*	Skipjack herring	87.0	13.0	<0.00
DD	*Oncorhynchus nerka*	Sockeye salmon	79.9	20.1	<0.00
DD	*Oncorhynchus tshawytscha*	Chinook salmon	79.9	20.1	<0.00
DD	*Ichthyomyzon unicuspis*	Silver lamprey	79.8	20.2	<0.00
DD	*Micropterus punctulatus*	Spotted bass	79.0	21.0	<0.00
DD	*Osmerus mordax*	Rainbow smelt	78.5	21.5	<0.00
DD	*Ictiobus bubalus*	Smallmouth buffalo	78.4	21.6	<0.00
DD	*Aplodinotus grunniens*	Freshwater drum	78.1	21.9	<0.00
DD	*Stizostedion canadense*	Sauger	78.1	21.9	<0.00
DD	*Lepisosteus osseus*	Longnose gar	77.4	22.6	<0.00
DD	*Notropis buchanani*	Ghost shiner	77.4	22.6	<0.00
DD	*Hiodon alosoides*	Goldeye	76.3	23.7	<0.00
DD	*Moxostoma macrolepidotum*	Shorthead redhorse	75.2	24.8	<0.00
DD	*Ictalurus punctatus*	Channel catfish	73.5	26.5	<0.00
DD	*Morone chrysops*	White bass	73.5	26.5	<0.00
DD	*Carpoides cyprinus*	Quillback	71.8	28.2	<0.00
DD	*Erimystax dissimilis*	Streamline chub	71.4	28.6	<0.00
DD	*Stizostedion vitreum vitreum*	Walleye	71.4	28.6	<0.00
DD	*Oncorhynchus mykiss*	Steelhead trout	71.0	29.0	<0.00
DD	*Macrhybopsis storeriana*	Silver chub	70.7	29.3	<0.00
DD	*Coregonus artedi*	Cisco	70.3	29.7	<0.00
DD	*Notropis atherinoides*	Emerald shiner	69.8	30.2	<0.00
DD	*Ameiurus catus*	White catfish	66.8	33.2	<0.00
DD	*Etheostoma blennioides*	Greenside darter	65.9	34.1	<0.00
DD	*Petromyzon marinus*	Sea lamprey	65.8	34.2	<0.00

(Table 9.3 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Notropis amoenus*	Comely shiner	65.0	35.0	<0.00
DD	*Oncorhynchus kisutch*	Coho salmon	65.0	35.0	<0.00
DD	*Noturus miurus*	Brindled madtom	64.7	35.3	<0.00
DD	*Etheostoma maculatum*	Spotted darter	64.0	36.0	<0.00
DD	*Pylodictis olivaris*	Flathead catfish	63.8	36.2	<0.00
DD	*Noturus stigmosus*	Northern madtom	63.8	36.2	<0.00
DD	*Ammocrypta pellucida*	Eastern sand darter	63.8	36.2	<0.00
DD	*Ichthyomyzon fossor*	Northern brook lamprey	63.3	36.7	<0.00
DD	*Labidesthes sicculus*	Brook silverside	63.3	36.7	<0.00
DD	*Noturus eleutherus*	Mountain madtom	63.1	36.9	<0.00
DD	*Etheostoma tippecanoe*	Tippecanoe darter	63.1	36.9	<0.00
DD	*Lampetra aepyptera*	Least brook lamprey	61.9	38.1	<0.00
DD	*Fundulus diaphanus*	Banded killifish	61.3	38.7	<0.00
DD	*Lepisosteus oculatus*	Spotted gar	61.1	38.9	<0.00
DD	*Etheostoma camurum*	Bluebreast darter	60.2	39.8	0.002
DD	*Noturus gyrinus*	Tadpole madtom	60.1	39.9	0.004
DD	*Luxilus spiloptera*	Spotfin shiner	59.8	40.2	<0.00
DD	*Percina evides*	Gilt darter	59.7	40.3	<0.00
DD	*Ameiurus natalis*	Yellow bullhead	59.6	40.4	<0.00
DD	*Percopsis omiscomaycus*	Trout-perch	59.2	40.8	0.005

Most of the 49 dual drainage fish species require large (fifth and higher order) streams as their primary habitats, so they tend to occupy the dual drainage units with large streams passing through. There are also some species in this key DD fish species list that accommodate medium level human disturbances. In this case, dual drainage units with more agriculture and development areas can also provide suitable habitats for these species compared to the highlands.

Mammal species habitat distributions:

Among the 61 mammal species distributed in the Appalachian Plateaus, 15 of them were identified as species that favor caplands and 10 of them that favor cuplands (Appendix B4). The 60% proportion test yielded 5 species with stronger affinity for highland habitats, but none for dual drainage areas (Table 9.4).

All of these five key species in the caplands require forest cover, and avoid urban and herbaceous areas. These habitat affinities make them more likely to occur in highland habitat areas. In addition, the eastern spotted skunk and Appalachian cottontail also require ridge top topography in their habitat models, which determines that they must occur primarily in the highland habitat LTA units. However, the eastern spotted skunk has not been recorded in the state since the 1960s, and may be extirpated from Pennsylvania. The Indiana myotis and northern water shrew live around small or medium size streams with forest cover, and more often occur in higher areas where these forested streams are abundant.

Table 9.4 Key capland mammal species in the Appalachian Plateaus

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Spilogale putorius*	Eastern spotted skunk	26.3	73.7	0.005
HH	*Microtus chrotorrhinus*	Rock vole	27.8	72.2	<0.001
HH	*Mytotis sodalis*	Indiana myotis	30.4	69.6	<0.001
HH	*Sylvilagus obscurus*	Appalachian cottontail	34.3	65.7	<0.001
HH	*Sorex palustris*	Northern water shrew	35.4	64.6	<0.001

Snake and lizard species habitat distributions:

There are 23 snake and lizard species distributed in the Appalachian Plateaus. With the proportion test, 6 of them were identified as species that favor highland habitats or transitional terraces, and 14 species were considered as dual drainage species (Appendix B5). Table 9.5 contains the list of key capland and cupland snake and lizard species in this physiographic component.

Table 9.5 Key capland and cupland snake and lizard species in the Appalachian Plateaus

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Opheodrys aestivus*	Rough green snake	26.0	74.0	<0.001
DD	*Agkistrodon contortrix*	Northern copperhead snake	68.3	31.7	<0.001
DD	*Sistrurus catenatus*	Eastern massasauga	67.0	33.0	<0.001
DD	*Clonophis kirtlandii*	Kirtland's snake	66.8	33.2	<0.001
DD	*Regina septemvittata*	Queen snake	64.6	35.4	<0.001
DD	*Carphophis amoenus*	Eastern worm snake	61.2	38.8	<0.001
DD	*Sceloporus undulatus*	Northern fence lizard	60.0	40.0	<0.001
DD	*Elaphe obsoleta*	Black rat snake	59.1	40.9	<0.001

There is only one snake species identified with more than 60% of the habitat distributed in the capland. The rough green snake has very limited distributions in the Appalachian Plateaus, and only occurs in the undulating uplands of the Waynesburg Hills. They favor deciduous or mixed forest, and avoid herbaceous, water, wetland and urban areas.

Seven species in this group were identified as key species in the dual drainages. The northern copperhead, eastern massasauga, Kirtland's snake, queen snake and eastern worm snake all require valley bottom habitats which occur more in the dual drainage LTA units. Among these species, the eastern massasauga, Kirtland's snake and queen snake occupy palustrine herbaceous habitats related to streams or open water areas, whereas the northern copperhead and eastern worm snake occupy deciduous and mixed forests. The northern fence lizard and the black rat snake occupy forested habitat and have some tolerance to low-density urban and rural disturbances. These two species occur often in the dual drainage areas of the Pittsburgh Low Plateau and Glaciated Low Plateau subsections.

Turtle species habitat distributions:

There are ten turtle species distributed in the Appalachian Plateaus. All of them are key species in the dual drainage habitats as listed in Table 9.6, which shows that these turtle species have strong affinity for the dual drainage LTA units due to the valley bottom or mid-slope topographic position requirement in their habitat models. Except for the eastern box turtle which needs deciduous or mixed forests, and bog turtle which needs palustrine herbaceous areas, all the remaining eight turtle species are closely associated with streams. Their habitat models all stipulate third and higher order streams or wetlands, and their potential habitats were generated based on these streams and wetlands with buffers. This also determines that these turtle species favor dual drainage areas since these higher order streams are more likely to occur in the DD LTA units.

Table 9.6 Key cupland turtle species in the Appalachian Plateaus

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Clemmys muhlenbergii*	Bog turtle	88.9	11.1	<0.001
DD	*Graptemys geographica*	Map turtle	77.1	22.9	<0.001
DD	*Sternotherus odoratus*	Stinkpot turtle	70.4	29.6	<0.001
DD	*Pseudemys rubriventris*	Redbellied turtle	67.9	32.1	<0.001
DD	*Clemmys guttata*	Spotted turtle	66.8	33.2	<0.001
DD	*Chrysemys picta*	Midland painted turtle	65.7	34.3	<0.001
DD	*Chelydra serpentina*	Common snapping turtle	64.8	35.2	<0.001
DD	*Apalone spinifera*	Eastern spiny softshell	62.0	38.0	<0.001
DD	*Clemmys insculpta*	Wood turtle	60.1	39.9	<0.001
DD	*Terrapene carolina*	Eastern box turtle	59.9	40.1	<0.001

Habitat Affinity of Species in the Ridge and Valley

Amphibian species habitat distributions:

There are 30 amphibian species habitats modeled in the Ridge and Valley. Among them, 6 species were considered favoring caplands, and 9 species were considered favoring cuplands (Appendix C1). With the higher 60% criterion proportion test, however, there are only two species identified as key capland species (Table 9.7), and no key species were identified for the dual drainages. This might be due to the special habitat requirements of these amphibian species. Most of them occur close to streams, water bodies or wetlands, but they also need to be in areas with deciduous forest or mixed forest cover. Although dual drainage areas include more streams, water and wetlands, they do not have a lot of forest cover in the Ridge and Valley. Thus the amphibian species tend not to use these dual drainages as their primary habitats. In the highland habitats, the two key species have very limited distributions. The eastern mud salamander only occupies 357 km^2 areas in the Ridge and Valley, and most of these habitats are distributed in the multi-mount units of South Mountain. The habitat of Appalachian seal salamander only occupies 155 km^2 in the Ridge and Valley. Although most of its habitat in this physiographic component is distributed in the regional ridge units, the habitat size here is too small to show this species as favoring highland habitats. Actually, most of the Appalachian seal salamander's habitat is located in the Appalachian Plateaus, where this species was identified as a key species in the dual drainages. Considering all the habitats in the state for this species, there is more affinity for the dual drainages.

Table 9.7 Key capland amphibian species in the Ridge and Valley

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Pseudotriton montanus*	Eastern mud salamander	5.7	94.3	<0.001
HH	*Desmognathus monticola*	Appalachian seal	29.8	70.2	<0.001

<u>Bird species habitat distributions:</u>

Among the 180 bird species having distributions in the Ridge and Valley, 59 of them were identified as species favoring highland habitats, and 78 of them were considered as species favoring dual drainages (Appendix C2). Table 9.8 lists key species that have 60% or more of their habitats in one kind of LTA unit. There are 24 species identified as highland key species, and 8 species identified as dual drainage species.

All the 24 highland key species have elevation requirements in their habitat models, whereby they are located above a certain elevation. For example, dark-eyed junco and yellow-throated vireo have habitats above 600 meters, and Swainson's thrush is above 500 meters. Most of the dual drainage units have average elevation below 500 meters in this physiographic component, so these species are more likely to occur in the highland habitats. Another reason why these species are highland species is that they all have forest areas as their primary habitats. In their habitat distribution models, some of the species need deciduous or mixed forest cover, and others need conifer forest. Furthermore, they all avoid urban, herbaceous, and water areas. Forest dominates the highland habitats in the Ridge and Valley, whereas pasture and urban take up more areas in the dual drainage units. Therefore, these species are more likely to be in the highland habitat units compared to the dual drainages.

Table 9.8 Key capland and cupland bird species in the Ridge and Valley

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Dendroica striata*	Blackpoll warbler	0.0	100.0	<0.001
HH	*Seiurus noveboracensis*	Northern waterthrush	3.9	96.1	<0.001
HH	*Troglodytes troglodytes*	Winter wren	4.7	95.3	<0.001
HH	*Junco hyemalis*	Dark-eyed junco	10.7	89.3	<0.001
HH	*Vireo flavifrons*	Yellow-throated vireo	10.9	89.1	<0.001
HH	*Catharus ustulatus*	Swainson's thrush	15.6	84.4	<0.001
HH	*Dendroica magnolia*	Magnolia warbler	16.4	83.6	<0.001
HH	*Catharus guttatus*	Hermit thrush	19.3	80.7	<0.001
HH	*Contopus borealis*	Olive-sided flycatcher	22.6	77.4	<0.001
HH	*Sphyrapicus varius*	Yellow-bellied sapsucker	22.6	77.4	<0.001
HH	*Vireo solitarius*	Blue-headed vireo	24.0	76.0	<0.001
HH	*Vireo gilvus*	Warbling vireo	26.4	73.6	<0.001
HH	*Dendroica virens*	Black-throated green warbler	34.7	65.3	<0.001
HH	*Zonotrichia albicollis*	White-throated sparrow	34.9	65.1	<0.001
HH	*Dendroica fusca*	Blackburnian warbler	35.2	64.8	<0.001
HH	*Dendroica coronata*	Yellow-rumped warbler	35.9	64.1	<0.001
HH	*Dendroica caerulescens*	Black-throated blue warbler	35.9	64.1	<0.001
HH	*Pheucticus ludovicianus*	Rose-breasted grosbeak	36.2	63.8	<0.001
HH	*Dendroica pensylvanica*	Chestnut-sided warbler	36.4	63.6	<0.001
HH	*Oporornis philadelphia*	Mourning warbler	36.5	63.5	<0.001
HH	*Aegolius acadicus*	Northern saw-whet owl	36.5	63.5	<0.001
HH	*Empidonax alnorum*	Alder flycatcher	36.9	63.1	<0.001
HH	*Carpodacus purpureus*	Purple finch	37.8	62.2	<0.001
HH	*Vermivora ruficapilla*	Nashville warbler	38.5	61.5	<0.001
DD	*Anas clypeata*	Northern shoveler	84.6	15.4	<0.001
DD	*Egretta thula*	Snowy egret	81.9	18.1	<0.001
DD	*Spiza americana*	Dickcissel	80.5	19.5	<0.001
DD	*Bulbulcus ibis*	Cattle egret	76.1	23.9	<0.001
DD	*Anas crecca*	Green-winged teal	75.6	24.4	<0.001
DD	*Cistothorus platensis*	Sedge wren	74.1	25.9	<0.001
DD	*Nycticorax violaceus*	Yellow-crowned night-heron	73.5	26.5	<0.001
DD	*Guiraca caerulea*	Blue grosbeak	73.2	26.8	<0.001

The eight dual drainage species avoid forest areas. Five of them (northern shoveler, snowy egret, cattle egret, green-winged teal and yellow-crowned night-heron) are highly dependent on streams. They favor palustrine herbaceous or woody wetlands, and are found around second or higher order streams. The dual drainage units include more streams, and are more likely to provide these kinds of habitats compared to the highland habitats. The blue grosbeak has its habitat below 300 meters in herbaceous cover. Most of the highland habitats are higher than this elevation, so this species also favors dual drainage areas. The primary habitat for the anomalous Dickcissel is also herbaceous, which occupies more area in the dual drainage units. The Sedge wren has sparse distribution in association with palustrine herbaceous wetlands, so it also has more possibilities of occurrence in the dual drainage areas.

<u>Fish species habitat distributions:</u>

There are 82 fish species distributed in the Ridge and Valley. Among them, 26 species were identified as favoring highland habitats, and 45 species were identified as favoring dual drainages (Appendix C3). With the 60% proportion test, 13 fish species have definite associations, including 6 highland habitat species and 7 dual drainage species (Table 9.9).

Table 9.9 Key capland and cupland fish species in the Ridge and Valley

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Morone saxatilis*	Striped bass	17.0	83.0	<0.001
HH	*Enneacanthus gloriosus*	Bluespotted sunfish	32.9	67.1	<0.001
HH	*Salvelinus fontinalis*	Brook trout	36.6	63.4	<0.001
HH	*Cottus cognatus*	Slimy sculpin	37.0	63.0	<0.001
HH	*Erimyzon oblongus*	Creek chubsucker	38.0	62.0	<0.001
HH	*Lepomis megalotis*	Longear sunfish	39.6	60.4	<0.001
DD	*Apeltes quadracus*	Fourspine stickleback	82.7	17.3	<0.001
DD	*Gasterosteus aculeatus*	Threespine stickleback	82.4	17.6	<0.001
DD	*Osmerus mordax*	Rainbow smelt	78.1	21.9	0.002
DD	*Morone americana*	White perch	73.8	26.2	<0.001
DD	*Amia calva*	Bowfin	73.1	26.9	<0.001
DD	*Alosa sapidissima*	American shad	71.5	28.5	<0.001
DD	*Carpoides cyprinus*	Quillback	69.9	30.1	0.001

The six highland habitat key species have low tolerance for human disturbances. In the habitat models, human disturbance was defined by the nonforest areas due to agriculture and/or development. So these species show more affinity for forest areas. In the Ridge and Valley, highland habitats have much more forests than the dual drainages, so these HH units can provide better potential habitats for these species. Furthermore, all of these six species need to be in medium or high slope watersheds. The highland habitat LTA units usually have steeper slopes than the dual drainages in the Ridge and Valley, and thus contain more suitable habitat for these species. Also, these six species occur in small or medium streams, which occur often in the HH units.

The seven dual drainage key species tend to be in medium, large or even extra-large streams, which places their habitats in the dual drainage areas. They also occupy low slope watersheds, and dual drainages have more such topography. Another factor linking them to dual drainages is that they are all tolerate moderate to high level human disturbances. The dual drainages have much more nonforest areas compared to highland habitats.

<u>Mammal species habitat distributions:</u>

Among the 61 mammal species in the Ridge and Valley, 15 of them were considered to have more habitat in the HH units, and 10 of them to have more habitat in the DD units (Appendix C4). Table 9.10 lists the species having 60% or more habitat in one kind of LTA unit. There are 6 key highland habitat mammal species and 2 dual drainage key species in this physiographic component.

Five of the six highland habitat key species, including snowshoe hare, pygmy shrew, woodland jumping mouse, Appalachian cottontail and eastern spotted skunk, are associated with ridge tops. Thus, they have much more habitat in the HH units. Besides this topographic position, they also reside in forest areas and avoid urban, herbaceous or open water areas. Highland habitats in this physiographic component have much more forest than the dual drainages, as well as less urban or pastures, thus being the primary places for these species.

For the key dual drainage species, least shrew occurs in transitional land cover type along with herbaceous or low-density urban areas. They have small habitat occupancy in the state. In the Ridge and Valley, they only occur in some original outflows and branching basins of the Great Valley area. Elk habitat is determined by restocking in the Appalachian Plateaus. In the Ridge and Valley, it only occupies 120 km^2. More than 90% of its habitats are in the dual drainages.

Table 9.10 Key capland and cupland mammal species in the Ridge and Valley

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Lepus americanus*	Snowshoe hare	28.0	72.0	<0.001
HH	*Sorex hoyi*	Pygmy shrew	31.2	68.8	<0.001
HH	*Napaeozapus insignis*	Woodland jumping mouse	31.8	68.2	<0.001
HH	*Sylvilagus obscurus*	Appalachian cottontail	33.7	66.3	<0.001
HH	*Spilogale putorius*	Eastern spotted skunk	33.8	66.2	<0.001
HH	*Neotoma magister*	Allegheny woodrat	36.0	64.0	<0.001
DD	*Cervus canadensis*	Elk	94.8	5.2	<0.001
DD	*Cryptotis parva*	Least shrew	82.8	17.2	<0.001

Snake and lizard species habitat distributions:

There are 19 snake and lizard species in the Ridge and Valley. Among them, 5 species have more habitat in the highland habitat areas, and 7 species have more habitat in the dual drainage areas (Appendix C5). With a 60% proportion test, only northern coal skink was indicated as a key species in highland habitats (Table 9.11), and none were identified in the dual drainage areas. Most of the snake and lizard species in the Ridge and Valley have valley bottom or mid-slope habitats as well as utilizing forest cover or herbaceous environment and avoiding urban areas. In the Ridge and Valley, the valley bottom areas which are dual drainages are usually developed or used for agriculture, so there are no species here with more than 60% of the habitat in DD units. Different from all the other snake and lizard species, the northern coal skink favors ridge top areas with deciduous or mixed forest and avoids streams, water or wetlands. The HH units in this physiographic component meet these special requirements and provide potential habitat for this species. Therefore, most of the northern coal skink's habitat in the Ridge and Valley is in the regional ridge and multi-mount LTA units.

Table 9.11 Key capland snake and lizard species in the Ridge and Valley

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Eumeces anthracinus*	Northern coal skink	19.6	80.4	<0.001

Turtle species habitat distributions:

There are 9 turtle species in the Ridge and Valley. Among them, only one species has slight affinity for the highland habitats, and another 7 species favor the dual drainage areas (Appendix C6). With the 60% proportion test, there is no species identified as key species in either highland habitats or dual drainages. Wood turtle, the only species having more habitat in the caplands occupies forested mid-slope or valley bottom habitats. Although the DD units have more possibility of meeting this topographic requirement, the highlands here have advantages in the forest cover and provide more potential habitat for this species. The seven dual drainage species utilize valley bottom areas in palustrine ecosystems close to streams, water bodies or wetlands, and avoid urban areas. In this physiographic component, many dual drainage areas are used for row crops or urban areas, so most of these dual drainage species have limited distributions and do not show strong differences between the HH and DD LTA units.

Habitat Affinity of Species in the Piedmont

Amphibian species habitat distributions:

There are 27 amphibian species in the Piedmont. Among them, 5 species were identified as favoring highland habitats, and 14 species as favoring dual drainage areas (Appendix D1). Table 9.12 is the list of key amphibian species in HH and DD units. There is only one species having 60% or more of the habitat in the caplands, and one species in cuplands.

Table 9.12 Key capland and cupland amphibian species in the Piedmont

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Hemidactylium scutatum*	Four-toed salamander	38.9	61.1	0.000
DD	*Scaphiopus holbrookii*	Eastern spadefoot toad	84.8	15.2	0.000

The four-toed salamander inhabits forest areas or wetlands and avoids urban, streams or herbaceous environments. In the Piedmont, most of the areas for both highland habitats and dual drainages are used for development or agriculture. Habitat for this species is thus relegated to some elevated exposure units in the Gettysburg-Newark Lowland and Piedmont Upland where the forests remain.

The eastern spadefood toad has special habitat requirements. Although it occupies forested areas, this species also needs sandy soils and vernal pools. Therefore, it has very limited distribution in this region, and only occurs in some branching basins or original outflows of the Gettysburg-Newark Lowland.

Bird species habitat distributions:

Among the 164 bird species in the Piedmont, 50 of them were identified as favoring highland habitats and 35 of them as favoring dual drainages (Appendix D2). Table 9.13 gives the list of key bird species in capland and cupland for this physiographic component. There are 8 bird species here having 60% or more of the habitat in the highland habitat units, and 5 key species in the dual drainage areas.

Most of the key species in highland habitats have specific elevation situations. The Canada warbler is most common above 460 meters. The bobolink, chestnut-sided warbler, rose-breasted grosbeak and purple finch all tend to be distributed above 300 meters. The golden-winged warbler uses habitats above

200 meters. In the Piedmont, the average elevations for dual drainages are less than 300 meters, so these species are more likely to be in the highland habitats.

Table 9.13 Key capland and cupland bird species in the Piedmont

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Dolichonyx orizyvorus*	Bobolink	9.8	90.2	0.000
HH	*Wilsonia canadensis*	Canada warbler	14.4	85.6	0.000
HH	*Dendroica pensylvanica*	Chestnut-sided warbler	16.1	83.9	0.000
HH	*Pheucticus ludovicianus*	Rose-breasted grosbeak	20.5	79.5	0.000
HH	*Vermivora chrysoptera*	Golden-winged warbler	22.1	77.9	0.000
HH	*Carpodacus purpureus*	Purple finch	27.2	72.8	0.000
HH	*Regulus satrapa*	Golden-crowned kinglet	39.2	60.8	0.002
HH	*Bartramia longicauda*	Upland sandpiper	41.3	58.7	0.005
DD	*Dendroica fusca*	Blackburnian warbler	100.0	0.0	0.006
DD	*Asio flammeus*	Short-eared owl	85.0	15.0	0.000
DD	*Lanius ludovicianus*	Loggerhead shrike	83.6	16.4	0.000
DD	*Corvus corax*	Common raven	83.1	16.9	0.000
DD	*Falco peregrinus*	Peregrine falcon	78.1	21.9	0.001

In the five dual drainage key species, the peregrine falcon is a special case for urban areas. The loggerhead shrike and short-eared owl favor perennial herbaceous and avoid forest areas. In the Piedmont, these two species both have very limited distributions and only occur in some dual drainage areas in the Gettysburg-Newark Lowland close to the South Mountain. The common raven and blackburnian warbler have most of their habitat in the Ridge and Valley physiographic component. They have some occurrence in the Gettysburg-Newark Lowland as extension areas from the Ridge and Valley. Since most of the areas in the Gettysburg-Newark Lowland are dual drainages, these two species have more potential habitat in the DD units in this physiographic component.

<u>Fish species habitat distributions:</u>

Among the 80 fish species in the Piedmont, 31 of them were identified as having more habitat in the highland areas, and 36 of them as having more habitat in the dual drainages (Appendix D3). Table 9.14 shows the key fish species in capland and cupland in this physiographic component. There are 7 species here having 60% or more of their habitat in HH units, and another 7 species in the DD units.

Table 9.14 Key capland and cupland fish species in the Piedmont

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Apeltes quadracus*	Fourspine stickleback	23.9	76.1	<0.00
HH	*Percina caprodes*	Logperch	24.8	75.2	<0.00
HH	*Cottus bairdi*	Mottled sculpin	27.2	72.8	<0.00
HH	*Etheostoma blennioides*	Greenside darter	33.5	66.5	<0.00
HH	*Notropis volucellus*	Mimic shiner	38.5	61.5	<0.00
HH	*Etheostoma zonale*	Banded darter	38.6	61.4	<0.00
HH	*Morone saxatilis*	Striped bass	40.3	59.7	0.001
DD	*Hybognathus regius*	Eastern silvery minnow	100.0	0.0	0.008
DD	*Acipenser oxyrinchus*	Atlantic sturgeon	100.0	0.0	<0.00
DD	*Alosa mediocris*	Hickory shad	100.0	0.0	<0.00
DD	*Alosa aestivalis*	Blueback herring	100.0	0.0	<0.00
DD	*Alosa sapidissima*	American shad	85.5	14.5	<0.00
DD	*Stizostedion vitreum vitreum*	Walleye	78.9	21.1	<0.00
DD	*Cyprinella analostana*	Satinfin shiner	70.8	29.2	<0.00

The seven key species in highland habitats are mainly distributed in the Susquehanna basin. They favor medium or small size streams, and medium to high slope watersheds. Although the highland habitats in the Piedmont are mainly elevated exposures and do not have steep slopes, they are still steeper than the dual drainage areas in this physiographic component. Thus, both the stream and topography conditions of these seven species make HH units more suitable to them as potential habitats.

The seven dual drainage key species are mainly in the Delaware basin. In their habitat distribution models, they need large streams and favor low slope watersheds. The larger streams only occur in the dual drainage areas, so these species are more likely to be in the DD units. The DD units in the Piedmont are mainly composed of branching basins and original outflows having gentle slopes that meet the topographic environment in these species habitat models.

Mammal species habitat distributions:

There are 49 mammal species in the Piedmont. Eight species were identified as favoring highland habitats, and 6 species as favoring dual drainages (Appendix D4). With the 60% proportion test, there is only one key species picked out in the HH units, and three key species in the dual drainages (Table 9.15). Most of the mammal species inhabit forests and avoid urban areas. However, most areas in the Piedmont are developed or used for agriculture, and do not meet these habitat requirements. Thus, they have very limited distributions here.

Table 9.15 Key capland and cupland mammal species in the Piedmont

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Neotoma magister*	Allegheny woodrat	34.2	65.8	0.002
DD	*Sorex hoyi*	Pygmy shrew	82.8	17.2	0.006
DD	*Sciurus niger*	Fox squirrel	81.0	19.0	<0.001
DD	*Lynx rufus*	Bobcat	80.6	19.4	<0.001

The Allegheny woodrat was identified as the only highland habitat key species here. It favors forest cliffs/talus and avoids streams, wetlands and urban. In the Piedmont, this species only occurs in some elevated exposure units in the Gettysburg-Newark Lowland, with most of its habitat being in the Ridge and Valley and the Appalachian Plateaus.

Although the pygmy shrew, fox squirrel and bobcat were identified as the dual drainage key species in this physiographic component, they have very limited distributions in this area with most of their habitats occurring in the Appalachian Plateaus or the Ridge and Valley areas. In the Piedmont, they only occur in some dual drainage units in the Gettysburg-Newark Lowland.

Snake and lizard species habitat distributions:

Among the 20 snake and lizard species in the Piedmont, 4 of them were identified as favoring highland habitats, and 8 species as favoring dual drainages (Appendix D5). With the 60% proportion test, there are only two key snake species identified for the dual drainages, and no key species for the highland habitats (Table 9.16).

Table 9.16 Key cupland snake species in the Piedmont

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Storeria occipitomaculata*	Northern redbellied snake	75.1	24.9	0.001
DD	*Regina septemvittata*	Queen snake	71.4	28.6	0.001

The queen snake favors valley bottom environments and depends on streams and palustrine herbaceous wetlands, so their potential habitat in the Piedmont mainly occurs in dual drainage areas. The northern redbellied snake favors deciduous or mixed forest. In the Piedmont, this species has limited distribution in the eastern corner where dual drainages dominate the landscape. In the state as a whole, however, this species mainly occurs in the northern part where highland habitats occupy most of the area.

Turtle species habitat distributions:

There are 9 turtle species in the Piedmont, and all of them have more habitat in the dual drainage areas (Appendix D6). With the 60% proportion test, however, none of them was identified as being key species in dual drainages.

All of these nine species require valley bottom areas as their primary habitats. The eastern box turtle and wood turtle can also live in the mid-slope areas with deciduous or mixed forest. All of the other seven species need habitats close to medium or large streams, and avoid high density urban areas. All of these habitat requirements make turtle species here more characteristic of dual drainage units, which are largely made less suitable by extensive development for agriculture.

Summary

The results above indicate that in each physiographic component, many of the species in every vertebrate group have significantly different habitat distributions between the HH/TT and DD LTA units. Furthermore, in most of the groups, there are some key species that strongly favor one kind of LTA unit. Comparing these results with the habitat distribution models in the GAP Analysis Project, the species preferring highland habitats or transitional terraces usually have the following habitat requirements. First, they require habitats to be in upper topographic positions. Second, they favor small or medium size streams. Third, they need forest land cover and tend to avoid human disturbances. The highland habitats or transitional terraces are areas with headwater streams and they have relatively higher elevations with capping land surfaces, so they can provide potential habitats for these species from the topographic and hydrologic point of view. In addition, as described in chapter 8, highland habitat or transitional terrace areas tend to have more forest cover and less human disturbances than the dual drainages. Therefore, HH/TT units can provide excellent potential habitats for the species with such requirements.

The dual drainages in this mapping system include large streams and more wetlands. They also have more urban areas as described in chapter 8. Species favoring large streams, wetlands or tolerant of human disturbances tend to distribute in these lowland areas. Therefore, it can be concluded that LTA units do separate different habitats at the landscape level. Nevertheless, species habitat distributions are influenced by multiple factors, which not only include the environmental differences at the landscape scale, but also include large scale factors such as climate, and small scale ones such as the unique combination of some specific soil and wetland conditions. The LTA delineation here only provides spatial references for habitat classification at landscape scale. More detailed habitat examination is required at site specific scales.

Chapter 10

Conclusion

Ecological mapping provides basic landscape units for ecosystem management, planning and research. In this study, landtype associations and ecological landtypes are mapped for Pennsylvania based on topography and other related information at the landscape and site level to separate different ecological features and provide references for management at relevant scales.

With topography and terrain topology information, the landtype associations were mapped to separate headwater areas from the downstream drainage areas at landscape scale with the concern for ecological, hydrologic and environmental aspects of the area. For this purpose, the concept of landscape was operationalized as the LTA polygon and its neighboring LTA units. In this study, a zero-order landscape is a particular LTA polygon with size of 40 to 2,000 hectares. An order-one landscape is defined as a zero-order landscape augmented by all neighboring LTA polygons that make contact on a boundary. The mapping results indicate that this order-one landscape can include 3 to 23 LTA polygons with size of 844 to 22,968 hectares.

The relationships between LTA units and other spatial information suggest that the landtype associations mapped in this study can effectively separate different physiographic features, stream network structures, land cover patterns and vertebrate species habitat distributions. Since these are all major factors in determining ecosystems, the LTA units are thus considered to be able to provide basic boundaries for landscape level ecosystem management.

At the ecological landtype level, ELT units are defined as combinations of topographic information and soil characteristics with the goal of capturing differences in water and nutrient availability for natural communities at the site level.

The ELT unit and its mapping method designed in this study are transferable among regions although the average physiographic characters of ELT units are different in different LTA types.

These two levels of ecological units can be used directly in actual resource management and planning. The LTAs themselves have collective properties that are relevant to management decisions. Occurrences of a particular type of LTA should trigger an associated set of considerations appropriate to that LTA type. ELTs can be used to assess site-specific conditions including forest growth, succession, health, and various physical conditions (e.g. soil compaction, erosion potential and water quality). When the system is adopted, landtypes become the basic unit of management. Through these ecological units, managers can obtain information about the geographic patterns in ecosystems. Representative ecological units can be sampled and information can then be extended to analogous unsampled ecological units, thereby reducing cost and time for inventory and monitoring. The results of effectiveness and validation monitoring can be extrapolated to estimate effects and set standards in similar ecological units. Information on LTAs and ELTs will also help to establish management objectives and will support management activities such as protection of habitats of sensitive, threatened, and endangered species, or improvement of forest and rangeland health to meet conservation, restoration, and human needs.

The output coverages of the LTA and ELT maps also include information that can be used as decision support tools for regional planning and cumulative impact assessment. An array of spatial data layers can be used to provide distance, area, adjacency and proximity relations for features in a region of interest. GIS layers can facilitate geographic analysis for queries and planning through joining and unioning coverages of thematic features for rapid assessment. Landtype associations are particularly useful for decision-making and land allocations at the scale of a county, state park, or state forest. LTAs can be related to past, present, and future conditions. Past conditions serve as a model of functioning ecosystems, and provide insight into natural processes. This is helpful in understanding ecological processes and in planning. LTAs will be useful in delineating land units at relevant analysis scales for planning.

For ecosystem researchers, this classification system provides a basis for stratifying study areas. Inasmuch as LTAs integrate basic environmental features in ways unique to that type of LTA, it may make sense for field data to be collected with respect to these map units. The system also provides researchers with a vehicle for quick transfer of research results to the practitioner. Study results can be reported on the basis of their applicability to specific landtypes or landtype associations according to these mapping results.

The LTAs and ELTs can also be used in ecosystem assessment. They provide information about the potential conditions of the ecosystem that are relatively stable. Combined with the other resource information in geographic information systems, the ecosystems can be more effectively assessed.

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Appendix A. VBA code in ArcGIS for generating ELT units.

```
Private Sub ELT_Click()
    Dim pMxDoc As IMxDocument
    Set pMxDoc = ThisDocument
    Dim pMap As IMap
    Set pMap = pMxDoc.FocusMap
    Dim pSelLayer As ILayer
    Set pSelLayer = pMxDoc.SelectedLayer
    If pSelLayer Is Nothing Then
        MsgBox "Please select a layer.", vbCritical, "Error."
        Exit Sub
    End If

    Dim pFlayer As IFeatureLayer
    Set pFlayer = pSelLayer
    Dim pFclass As IFeatureClass
    Set pFclass = pFlayer.FeatureClass
    Dim pFields As IFields
    Set pFields = pFclass.Fields
    Dim pDataset As IDataset
    Set pDataset = pFclass
    Dim pWorkSpace As IWorkspace
    Set pWorkSpace = pDataset.Workspace
    Dim pWorkSpaceEdit As IWorkspaceEdit
    Set pWorkSpaceEdit = pWorkSpace
    Dim intMeanSlp As Integer
    intMeanSlp = pFields.FindField("slpmean")
    Dim intStdSlp As Integer
    intStdSlp = pFields.FindField("slpstd")
    Dim intAspMaj As Integer
    intAspMaj = pFields.FindField("aspmaj")
    Dim intcountcell As Integer
    intcountcell = pFields.FindField("count")
    Dim intAcre As Integer
    intAcre = pFields.FindField("Acres")
    Dim intSoil As Integer
    intSoil = pFields.FindField("Soil")
    Dim intLta As Integer
    intLta = pFields.FindField("GAMAID")
    Dim intDone As Integer
    intDone = pFields.FindField("Done")

    If intMeanSlp = -1 Then
        MsgBox "No slpmean field exist in the attribute table!",
vbInformation, "Error of table"
        Exit Sub
    End If
    If intStdSlp = -1 Then
        MsgBox "No slpstd field exist in the attribute table!",
vbInformation, "Error of table"
        Exit Sub
    End If
    If intAspMaj = -1 Then
        MsgBox "No aspmaj field exist in the attribute table!",
vbInformation, "Error of table"
        Exit Sub
    End If
    If intcountcell = -1 Then
        MsgBox "No count field exist in the attribute table!",
vbInformation, "Error of table"
        Exit Sub
    End If
    If intAcre = -1 Then
```

```
        MsgBox "No Acres field exist in the attribute table",
vbInformation, "Error of table"
        Exit Sub
    End If
    If intAcre = -1 Then
        MsgBox "No Soil series field exist in the attribute table",
vbInformation, "Error of table"
        Exit Sub
    End If
    If intLta = -1 Then
        MsgBox "No Lta field exist in the attribute table",
vbInformation, "Error of table"
        Exit Sub
    End If
    If intDone <> -1 Then
        MsgBox "The 'Done' field already exist in the attribute
table", vbInformation, "Error of table"
        Exit Sub
    End If

    Dim pFieldEdit As IFieldEdit
    Set pFieldEdit = New Field
    pFieldEdit.Name = "Done"
    pFieldEdit.Type = esriFieldTypeInteger
    pFclass.AddField pFieldEdit
    intDone = pFields.FindField("Done")
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    'Begin search for every polygon
    Dim pFCursor As IFeatureCursor
    Dim pFeature As IFeature
    Dim pStatusBar As IStatusBar
    Set pStatusBar = Application.StatusBar
    Dim longcount As Long
    longcount = pFclass.FeatureCount(Nothing) 'polygons to be
treated
    Dim longstatusbar As Long
    longstatusbar = pFclass.FeatureCount(Nothing)
    Dim ArrayDeletedFeature() As Long
    Dim ArrayIndex() As Long
    Dim longDeleteFNumber As Long
    Dim ii As Long
    ii = 0   'the index in Arrayindex()
    Dim longfcount As Integer
    longfcount = 0

    pWorkSpaceEdit.StartEditing (False)
    pWorkSpaceEdit.StartEditOperation

    Do While longcount > 0

    Set pFCursor = pFclass.Search(Nothing, False)
    Set pFeature = pFCursor.NextFeature
    Erase ArrayDeletedFeature
    Erase ArrayIndex
    longDeleteFNumber = 0
    longfcount = longfcount + 1

    Do While Not pFeature Is Nothing
        pStatusBar.ShowProgressBar "Turn: " & longfcount & "
        Longcount: " & longcount, 0, longstatusbar, 1, True
```

```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
        'If the polygon > 100 acres, it won't be merged with others.
        If (pFeature.Value(intAcre) >= 100) And_
           (pFeature.Value(intcountcell) <> 0) And _
           (pFeature.Value(intDone) <> 1) Then
            pFeature.Value(intDone) = 1
            longcount = longcount - 1
            pStatusBar.StepProgressBar
            pFeature.Store
            Set pFeature = pFCursor.NextFeature
            If (longDeleteFNumber>0) And (Not pFeature Is Nothing)
Then
            For ii = 0 To UBound(ArrayDeletedFeature)
             If (Not pFeature Is Nothing) Then
             If (pFeature.OID=ArrayDeletedFeature(ArrayIndex(ii)))
Then
                    Set pFeature = pFCursor.NextFeature
             End If
             End If
            Next
            End If
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
        'If the polygon is between 10 to 100 acres, it will be
merged
        'with adjacent one with same soil, aspect, and similar
slope.
        ElseIf (pFeature.Value(intAcre) >= 10) And_
               (pFeature.Value(intcountcell) <> 0) And _
               (pFeature.Value(intDone) <> 1) Then
            Dim pGeometry As IGeometry
            Set pGeometry = pFeature.Shape
            Dim pFilter As ISpatialFilter
            Set pFilter = New SpatialFilter
            With pFilter
            Set .Geometry = pGeometry
                .GeometryField = "SHAPE"
                .SpatialRel = esriSpatialRelIntersects
            End With
            'Search for adjacent polygons
            Dim pFAdjFCursor As IFeatureCursor
            Set pFAdjFCursor = pFclass.Search(pFilter, False)
            Dim pFAdjFeature As IFeature
            Set pFAdjFeature = pFAdjFCursor.NextFeature
            Dim dblMaxAlpha As Double
            dblMaxAlpha = 0
            Dim pSimFeature As IFeature

         Do While Not pFAdjFeature Is Nothing
         If ((pFAdjFeature.Value(intSoil)=pFeature.Value(intSoil))
Or _
         (pFAdjFeature.Value(intSoil) = "") Or_
         (pFeature.Value(intSoil) = "")) And _
        (pFAdjFeature.Value(intAspMaj)=pFeature.Value(intAspMaj))
And _
         (pFAdjFeature.Value(intLta) = pFeature.Value(intLta)) And
_
        (pFAdjFeature.Value(intAcre)+pFeature.Value(intAcre)<100)
And _
         (pFAdjFeature.Value(0) <> pFeature.Value(0)) And _
         (pFAdjFeature.Value(intcountcell) <> 0) Then
           'Save new variance
           Dim dblNewStdsq As Double
           If (pFAdjFeature.Value(intcountcell)+ _
```

```
               pFeature.Value(intcountcell) > 2) Then
               dblNewStdsq = ((pFAdjFeature.Value(intcountcell) - 1)
_
                    * pFAdjFeature.Value(intStdSlp) * _
                    pFAdjFeature.Value(intStdSlp) _
                    + (pFeature.Value(intcountcell) - 1) * _
                pFeature.Value(intStdSlp)*
pFeature.Value(intStdSlp)) _
                / (pFAdjFeature.Value(intcountcell) _
                    + pFeature.Value(intcountcell) - 2)
            Else
               dblNewStdsq = 0
            End If
            't-value
            Dim dbltSlp As Double
            If (dblNewStdsq <> 0) And _
               (pFAdjFeature.Value(intcountcell) <> 0) And _
               (pFeature.Value(intcountcell) <> 0) Then
                dbltSlp = (pFAdjFeature.Value(intMeanSlp) - _
                    pFeature.Value(intMeanSlp)) _
                    / Sqr(dblNewStdsq * (1 / _
                    pFAdjFeature.Value(intcountcell) _
                   + 1 / pFeature.Value(intcountcell)))
             Else
                dbltSlp = 99.99
             End If

             Dim dblAlpha As Double
             If dbltSlp = 0 Then
                dblAlpha = 1
             ElseIf (pFAdjFeature.Value(intcountcell) + _
                     pFeature.Value(intcountcell) <= 2) Then
                dblAlpha = 0
             Else
                 dblAlpha=tDist(dbltSlp, _
                       (pFAdjFeature.Value(intcountcell) + _
                         pFeature.Value(intcountcell) - 2), 2)
             End If
             If (dblAlpha > dblMaxAlpha) Then
                 dblMaxAlpha = dblAlpha
                 Set pSimFeature = pFAdjFeature
              End If
              End If
              Set pFAdjFeature = pFAdjFCursor.NextFeature
            Loop

            If (dblMaxAlpha > 0.32) Then
            'Merge the two polygons
            Dim poly1 As IGeometry
            Dim poly2 As IGeometry
            Set poly1 = pFeature.ShapeCopy
            Set poly2 = pSimFeature.ShapeCopy
            Dim pTopoOperator As ITopologicalOperator
            Dim newpoly As IGeometry
            Set pTopoOperator = poly1
            Set newpoly = pTopoOperator.Union(poly2)

            Dim pNewFeature As IFeature
            Set pNewFeature = pFclass.CreateFeature
            Set pNewFeature.Shape = newpoly
            pNewFeature.Value(pNewFeature.Fields.FindField("count"))
_
       = pFeature.Value(intcountcell) +
pSimFeature.Value(intcountcell)
```

```
            pNewFeature.Value(intAcre) = pFeature.Value(intAcre) +
_
                                         pSimFeature.Value(intAcre)
            pNewFeature.Value(intLta) = pFeature.Value(intLta)
            pNewFeature.Value(intSoil) = pFeature.Value(intSoil)
            pNewFeature.Value(intAspMaj)  =  pFeature.Value(intAspMaj)
            If (pSimFeature.Value(intcountcell) +
pFeature.Value(intcountcell) <> 0) Then
                pNewFeature.Value(intMeanSlp) =
(pFeature.Value(intMeanSlp) * pFeature.Value(intcountcell) +
pSimFeature.Value(intMeanSlp) * _
                pSimFeature.Value(intcountcell)) /
(pFeature.Value(intcountcell) + pSimFeature.Value(intcountcell))
            Else
                pNewFeature.Value(intMeanSlp) =
pFeature.Value(intMeanSlp)
            End If
            If (pSimFeature.Value(intcountcell) +
pFeature.Value(intcountcell) > 2) And (pFeature.Value(intcountcell)
<> 0) And _
                (pSimFeature.Value(intcountcell) <> 0) Then
                pNewFeature.Value(intStdSlp) =
Sqr(((pSimFeature.Value(intcountcell) - 1) _
                    * pSimFeature.Value(intStdSlp) *
pSimFeature.Value(intStdSlp) _
                    + (pFeature.Value(intcountcell) - 1) *
pFeature.Value(intStdSlp) _
                    * pFeature.Value(intStdSlp)) /
(pSimFeature.Value(intcountcell) _
                    + pFeature.Value(intcountcell) - 2))
            Else
                pNewFeature.Value(intStdSlp) = 0
            End If
            pNewFeature.Store

            If (pSimFeature.OID > pFeature.OID) Then
                ReDim Preserve
ArrayDeletedFeature(longDeleteFNumber)
                ArrayDeletedFeature(longDeleteFNumber) =
pSimFeature.OID
                ReDim ArrayIndex(longDeleteFNumber) As Long
                ArrayIndex = HeapSort(ArrayDeletedFeature)
                longDeleteFNumber = longDeleteFNumber + 1
            End If
            If pSimFeature.Value(intDone) = 1 Then
                longcount = longcount + 1
            Else
                pStatusBar.StepProgressBar
            End If

            pSimFeature.Delete
            pFeature.Delete
            longcount = longcount - 1

            Set pFeature = pFCursor.NextFeature
            If (longDeleteFNumber > 0) And (Not pFeature Is Nothing)
Then
            For ii = 0 To UBound(ArrayDeletedFeature)
                If (Not pFeature Is Nothing) Then
                If (pFeature.OID =
ArrayDeletedFeature(ArrayIndex(ii))) Then
                    Set pFeature = pFCursor.NextFeature
                End If
                End If
```

```
            Next
            End If
            Else
                pFeature.Value(intDone) = 1
                pFeature.Store
                longcount = longcount - 1
                pStatusBar.StepProgressBar
                Set pFeature = pFCursor.NextFeature
                If (longDeleteFNumber > 0) And (Not pFeature Is
Nothing) Then
                For ii = 0 To UBound(ArrayDeletedFeature)
                    If (Not pFeature Is Nothing) Then
                    If (pFeature.OID =
ArrayDeletedFeature(ArrayIndex(ii))) Then
                        Set pFeature = pFCursor.NextFeature
                    End If
                    End If
                Next
                End If

            End If

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
        'If the polygon < 10 acres, it need to be merged anyway.
The
        'priority is that same soil, aspect, or longest boundary.
        ElseIf (pFeature.Value(intAcre) < 10) And _
            (pFeature.Value(intDone) <> 1) Then
            Dim pGeometry2 As IGeometry
            Set pGeometry2 = pFeature.Shape
            Dim pFilter2 As ISpatialFilter
            Set pFilter2 = New SpatialFilter
            With pFilter2
            Set .Geometry = pGeometry2
                .GeometryField = "SHAPE"
                .SpatialRel = esriSpatialRelTouches
            End With
            'Search for adjacent polygons
            Dim pFAdjFCursor2 As IFeatureCursor
            Set pFAdjFCursor2 = pFclass.Search(pFilter2, False)
            Dim pFAdjFeature2 As IFeature
            Set pFAdjFeature2 = pFAdjFCursor2.NextFeature
            Dim dbllength As Double
            Dim dblLonglength As Double
            dblLonglength = 0
            Dim dblSLonglength As Double
            dblSLonglength = 0
            Dim dblALonglength As Double
            dblALonglength = 0
            Dim dblSALonglength As Double
            dblSALonglength = 0
            Dim pPoint As IPointCollection
            Dim pLine As IPolyline
            Dim pTopoOp As ITopologicalOperator
            Dim pSimFeature2 As IFeature
            Dim pSimSFeature As IFeature
            Dim pSimAFeature As IFeature
            Dim pSimSAFeature As IFeature
            Set pSimFeature2 = Nothing

            Do While Not pFAdjFeature2 Is Nothing
                If (pFAdjFeature2.Value(0) <> pFeature.Value(0))
And _
```

```
                    (pFAdjFeature2.Value(intLta) =
pFeature.Value(intLta)) And _
                    (pFeature.Value(intcountcell) <> 0) Then
                    Set pTopoOp = pFeature.Shape
                    Set pPoint =
pTopoOp.Intersect(pFAdjFeature2.Shape, esriGeometry1Dimension)
                    Set pLine = pPoint
                    dbllength = pLine.Length

                    If (pFAdjFeature2.Value(intSoil) =
pFeature.Value(intSoil)) And _
                        (pFAdjFeature2.Value(intAspMaj) =
pFeature.Value(intAspMaj)) And _
                        (dbllength > dblSALonglength) Then
                        dblSALonglength = dbllength
                        Set pSimSAFeature = pFAdjFeature2
                    ElseIf (pFAdjFeature2.Value(intSoil) =
pFeature.Value(intSoil)) And _
                        (dbllength > dblSLonglength) Then
                        dblSLonglength = dbllength
                        Set pSimSFeature = pFAdjFeature2
                    ElseIf (pFAdjFeature2.Value(intAspMaj) =
pFeature.Value(intAspMaj)) And _
                        (dbllength > dblALonglength) Then
                        dblALonglength = dbllength
                        Set pSimAFeature = pFAdjFeature2
                    End If
                    If dbllength > dblLonglength Then
                        dblLonglength = dbllength
                        Set pSimFeature2 = pFAdjFeature2
                    End If
                ElseIf (pFAdjFeature2.Value(0) <> pFeature.Value(0))
And _
                    (pFAdjFeature2.Value(intLta) =
pFeature.Value(intLta)) And _
                    (pFeature.Value(intcountcell) = 0) Then
                    Set pTopoOp = pFeature.Shape
                    Set pPoint =
pTopoOp.Intersect(pFAdjFeature2.Shape, esriGeometry1Dimension)
                    Set pLine = pPoint
                    dbllength = pLine.Length
                    If dbllength > dblLonglength Then
                        dblLonglength = dbllength
                        Set pSimFeature2 = pFAdjFeature2
                    End If
                End If
                Set pFAdjFeature2 = pFAdjFCursor2.NextFeature
            Loop
            If dblSALonglength <> 0 Then
                Set pSimFeature2 = pSimSAFeature
            ElseIf dblSLonglength <> 0 Then
                Set pSimFeature2 = pSimSFeature
            ElseIf dblALonglength <> 0 Then
                Set pSimFeature2 = pSimAFeature
            End If
            If (Not pSimFeature2 Is Nothing) Then
            'Merge polygons
                Dim poly3 As IGeometry
                Dim poly4 As IGeometry
                Set poly3 = pFeature.ShapeCopy
                Set poly4 = pSimFeature2.ShapeCopy
                Dim pTopoOperator2 As ITopologicalOperator
                Dim newpoly2 As IGeometry
                Set pTopoOperator2 = poly3
```

```
                Set newpoly2 = pTopoOperator2.Union(poly4)
                Dim pNewFeature2 As IFeature
                Set pNewFeature2 = pFclass.CreateFeature
                Set pNewFeature2.Shape = newpoly2

pNewFeature2.Value(pNewFeature2.Fields.FindField("count")) =
pFeature.Value(intcountcell) + pSimFeature2.Value(intcountcell)
                pNewFeature2.Value(intAcre) =
pFeature.Value(intAcre) + pSimFeature2.Value(intAcre)
                pNewFeature2.Value(intLta) = pFeature.Value(intLta)
                If pSimFeature2.Value(intAcre) > 10 Then
                    pNewFeature2.Value(intSoil) =
pSimFeature2.Value(intSoil)
                    pNewFeature2.Value(intAspMaj) =
pSimFeature2.Value(intAspMaj)
                ElseIf dblSLonglength > 0 And
pFeature.Value(intAspMaj) = pSimFeature2.Value(intAspMaj) Then
                    pNewFeature2.Value(intSoil) =
pSimFeature2.Value(intSoil)
                    pNewFeature2.Value(intAspMaj) =
pSimFeature2.Value(intAspMaj)
                ElseIf dblSLonglength > 0 Then
                    pNewFeature2.Value(intSoil) =
pSimFeature2.Value(intSoil)
                    pNewFeature2.Value(intAspMaj) = 9
                ElseIf dblALonglength > 0 Then
                    pNewFeature2.Value(intAspMaj) =
pSimFeature2.Value(intAspMaj)
                Else
                    pNewFeature2.Value(intAspMaj) = 9
                End If
                If (pFeature.Value(intcountcell) +
pSimFeature2.Value(intcountcell) > 0) Then
                    pNewFeature2.Value(intMeanSlp) =
(pFeature.Value(intMeanSlp) * pFeature.Value(intcountcell) +
pSimFeature2.Value(intMeanSlp) * _

pSimFeature2.Value(intcountcell)) / (pFeature.Value(intcountcell) +
pSimFeature2.Value(intcountcell))
                Else
                    pNewFeature2.Value(intMeanSlp) = 0
                End If
                If (pFeature.Value(intcountcell) +
pSimFeature2.Value(intcountcell) > 3) And _
                    (pFeature.Value(intcountcell) > 0) And
(pSimFeature2.Value(intcountcell) > 0) Then
                    pNewFeature2.Value(intStdSlp) =
Sqr(((pSimFeature2.Value(intcountcell) - 1) _
                    * pSimFeature2.Value(intStdSlp) *
pSimFeature2.Value(intStdSlp) _
                    + (pFeature.Value(intcountcell) - 1) *
pFeature.Value(intStdSlp) _
                    * pFeature.Value(intStdSlp)) /
(pSimFeature2.Value(intcountcell) _
                    + pFeature.Value(intcountcell) - 2))
                ElseIf (pFeature.Value(intcountcell) +
pSimFeature2.Value(intcountcell) > 3) And _
                    (pFeature.Value(intcountcell) = 0) Then
                    pNewFeature2.Value(intStdSlp) =
pSimFeature2.Value(intStdSlp)
                ElseIf (pFeature.Value(intcountcell) +
pSimFeature2.Value(intcountcell) > 3) And _
                    (pSimFeature2.Value(intcountcell) = 0) Then
```

```
                    pNewFeature2.Value(intStdSlp) =
pFeature.Value(intStdSlp)
                Else
                    pNewFeature2.Value(intStdSlp) = 0
                End If
                pNewFeature2.Store

                Dim tempIndex As Long
                Dim bInserted As Boolean
                If (pSimFeature2.OID > pFeature.OID) Then
                    ReDim Preserve
ArrayDeletedFeature(longDeleteFNumber)
                    ArrayDeletedFeature(longDeleteFNumber) =
pSimFeature2.OID
                    ReDim ArrayIndex(longDeleteFNumber) As Long
                    ArrayIndex = HeapSort(ArrayDeletedFeature)
                    longDeleteFNumber = longDeleteFNumber + 1
                End If

                If (pSimFeature2.Value(intDone) = 1) Then
                    longcount = longcount + 1
                Else
                    pStatusBar.StepProgressBar
                End If
                pSimFeature2.Delete
                Set pSimFeature2 = Nothing
                pFeature.Delete
                longcount = longcount - 1

                Set pFeature = pFCursor.NextFeature
                If (longDeleteFNumber > 0) And (Not pFeature Is
Nothing) Then
                For ii = 0 To UBound(ArrayDeletedFeature)
                    If (Not pFeature Is Nothing) Then
                    If (pFeature.OID =
ArrayDeletedFeature(ArrayIndex(ii))) Then
                        Set pFeature = pFCursor.NextFeature
                    End If
                    End If
                Next
                End If

            Else
                 pFeature.Value(intDone) = 1
                 pFeature.Store
                 longcount = longcount - 1
                 pStatusBar.StepProgressBar
                 Set pFeature = pFCursor.NextFeature
                 If (longDeleteFNumber > 0) And (Not pFeature Is
Nothing) Then
                 For ii = 0 To UBound(ArrayDeletedFeature)
                    If (Not pFeature Is Nothing) Then
                    If (pFeature.OID =
ArrayDeletedFeature(ArrayIndex(ii))) Then
                        Set pFeature = pFCursor.NextFeature
                    End If
                    End If
                 Next
                 End If
            End If

            Else
                Set pFeature = pFCursor.NextFeature
```

```
                If (longDeleteFNumber > 0) And (Not pFeature Is
Nothing) Then
                For ii = 0 To UBound(ArrayDeletedFeature)
                    If (Not pFeature Is Nothing) Then
                    If (pFeature.OID =
ArrayDeletedFeature(ArrayIndex(ii))) Then
                        Set pFeature = pFCursor.NextFeature
                    End If
                    End If
                Next
                End If
        End If
    Loop
   pStatusBar.HideProgressBar
    Loop
   pWorkSpaceEdit.StopEditOperation
   pWorkSpaceEdit.StopEditing (True)
End Sub
```

Appendix B1. Capland and cupland amphibian species in the Appalachian Plateaus.*

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Acris crepitans*	Northern cricket frog	0	100	<0.001
HH	*Plethodon wehrlei*	Wehrle's salamander	47.9	52.1	<0.001
HH	*Gyrinophilus porphyriticus*	Northern spring salamander	48.8	51.2	<0.001
DD	*Ambystoma opacum*	Marbled salamander	68.3	31.7	<0.001
DD	*Necturus maculosus*	Mudpuppy salamander	67.4	32.6	<0.001
DD	*Desmognathus monticola*	Appalachian seal salamander	65.2	34.8	<0.001
DD	*Plethodon hoffmani*	Valley & ridge salamander	65.1	34.9	<0.001
DD	*Cryptobranchus alleganiensis*	Eastern hellbender	63.9	36.1	<0.001
DD	*Bufo woodhousii*	Fowlers toad	63.7	36.3	<0.001
DD	*Pseudacris brachyphona*	Mountain chorus frog	63.0	37.0	<0.001
DD	*Aneides aeneus*	Green salamander	61.2	38.8	<0.001
DD	*Rana pipiens*	Northern leopard frog	56.0	44.0	<0.001
DD	*Hyla versicolor*	Eastern gray treefrog	55.8	44.2	<0.001
DD	*Eurycea longicauda*	Longtail salamander	55.1	44.9	<0.001
DD	*Pseudotriton ruber*	Northern red salamander	54.4	45.6	<0.001
DD	*Ambystoma jeffersonianum*	Jefferson salamander	53.7	46.3	<0.001
DD	*Pseudacris triseriata*	Western chorus frog	53.6	46.4	<0.001
DD	*Plethodon richmondi*	Ravine salamander	53.4	46.6	<0.001
DD	*Ambystoma maculatum*	Spotted salamander	51.7	48.3	<0.001
DD	*Rana catesbeiana*	Bullfrog	51.7	48.3	<0.001

* All the scientific names and common names are cited from the final report of Pennsylvania Gap Analysis project.

Appendix B2. Capland and cupland bird species in the Appalachian Plateaus.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Empidonax flaviventris*	Yellow-bellied flycatcher	0.0	100.0	<0.001
HH	*Dendroica striata*	Blackpoll warbler	0.6	99.4	<0.001
HH	*Troglodytes troglodytes*	Winter wren	10.1	89.9	<0.001
HH	*Junco hyemalis*	Dark-eyed junco	16.9	83.1	<0.001
HH	*Vireo flavifrons*	Yellow-throated vireo	17.2	82.8	<0.001
HH	*Seiurus noveboracensis*	Northern waterthrush	19.1	80.9	<0.001
HH	*Catharus ustulatus*	Swainson's thrush	25.0	75.0	<0.001
HH	*Contopus borealis*	Olive-sided flycatcher	28.3	71.7	<0.001
HH	*Catharus guttatus*	Hermit thrush	35.9	64.1	<0.001
HH	*Dendroica magnolia*	Magnolia warbler	36.6	63.4	<0.001
HH	*Sphyrapicus varius*	Yellow-bellied sapsucker	37.6	62.4	<0.001
HH	*Limnothlypis swainsonii*	Swainson's warbler	40.8	59.2	<0.001
HH	*Anas americana*	American wigeon	41.0	59.0	<0.001
HH	*Asio otus*	Long-eared owl	41.1	58.9	<0.001
HH	*Zonotrichia albicollis*	White-throated sparrow	43.0	57.0	<0.001
HH	*Protonotaria citrea*	Prothonotary warbler	44.2	55.8	<0.001
HH	*Vireo gilvus*	Warbling vireo	44.3	55.7	<0.001
HH	*Accipiter gentilis*	Northern goshawk	44.3	55.7	<0.001
HH	*Aegolius acadicus*	Northern saw-whet owl	44.8	55.2	<0.001
HH	*Oporornis philadelphia*	Mourning warbler	45.4	54.6	<0.001
HH	*Lophodytes cucullatus*	Hooded merganser	45.4	54.6	<0.001
HH	*Rallus elegans*	King rail	45.5	54.5	<0.001
HH	*Gallinago gallinago*	Common snipe	45.9	54.1	<0.001
HH	*Vermivora ruficapilla*	Nashville warbler	46.0	54.0	<0.001
HH	*Empidonax alnorum*	Alder flycatcher	46.4	53.6	<0.001
HH	*Wilsonia canadensis*	Canada warbler	46.7	53.3	<0.001
HH	*Dendroica coronata*	Yellow-rumped warbler	47.1	52.9	<0.001
HH	*Dendroica caerulescens*	Black-throated blue warbler	47.2	52.8	<0.001
HH	*Carduelis pinus*	Pine siskin	47.2	52.8	<0.001
HH	*Corvus corax*	Common raven	47.6	52.4	<0.001
HH	*Dendroica fusca*	Blackburnian warbler	47.8	52.2	<0.001
HH	*Gallinula chloropus*	Common moorhen	47.9	52.1	<0.001
HH	*Riparia riparia*	Bank swallow	48.4	51.6	<0.001
HH	*Pheucticus ludovicianus*	Rose-breasted grosbeak	49.4	50.6	<0.001
HH	*Dendroica pensylvanica*	Chestnut-sided warbler	49.4	50.6	<0.001
HH	*Dendroica virens*	Black-throated green warbler	49.5	50.5	<0.001
HH	*Wilsonia citrina*	Hooded warbler	49.5	50.5	<0.001
HH	*Mniotilta varia*	Black-and-white warbler	49.5	50.5	<0.001
DD	*Guiraca caerulea*	Blue grosbeak	100.0	0.0	<0.001
DD	*Corvus ossifragus*	Fish crow	87.5	12.5	<0.001
DD	*Asio flammeus*	Short-eared owl	79.3	20.7	<0.001
DD	*Chlidonias niger*	Black tern	74.6	25.4	<0.001
DD	*Caprimulgus carolinensis*	Chuck will's widow	69.4	30.6	<0.001
DD	*Sturnella neglecta*	Western meadowlark	68.1	31.9	<0.001
DD	*Spizella pallida*	Clay-colored sparrow	67.9	32.1	<0.001
DD	*Vermivora pinus*	Blue-winged warbler	65.8	34.2	<0.001
DD	*Falco peregrinus*	Peregrine falcon	65.7	34.3	<0.001
DD	*Cistothorus palustris*	Marsh wren	62.2	37.8	<0.001

(Appendix B2 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Cistothorus platensis*	Sedge wren	60.2	39.8	<0.001
DD	*Dendroica dominica*	Yellow-throated warbler	57.2	42.8	<0.001
DD	*Oporornis formosus*	Kentucky warbler	57.0	43.0	<0.001
DD	*Regulus satrapa*	Golden-crowned kinglet	56.5	43.5	<0.001
DD	*Cygnus olor*	Mute swan	56.3	43.7	<0.001
DD	*Fulica americana*	American coot	55.8	44.2	<0.001
DD	*Columba livia*	Rock dove	55.2	44.8	<0.001
DD	*Coragyps atratus*	Black vulture	54.9	45.1	<0.001
DD	*Dendroica pinus*	Pine warbler	54.9	45.1	<0.001
DD	*Branta canadensis*	Canada goose	54.7	45.3	<0.001
DD	*Dendroica discolor*	Prairie warbler	54.6	45.4	<0.001
DD	*Ammodramus henslowii*	Henslow's sparrow	54.1	45.9	<0.001
DD	*Haliaeetus leucocephalus*	Bald eagle	54.1	45.9	<0.001
DD	*Icterus spurius*	Orchard oriole	53.8	46.2	<0.001
DD	*Melanerpes erythrocephalus*	Red-headed woodpecker	53.4	46.6	<0.001
DD	*Eremophila alpestris*	Horned lark	53.4	46.6	<0.001
DD	*Nycticorax nycticorax*	Black-crowned night-heron	53.1	46.9	<0.001
DD	*Rallus limicola*	Virginia rail	53.0	47.0	<0.001
DD	*Bartramia longicauda*	Upland sandpiper	53.0	47.0	<0.001
DD	*Vermivora chrysoptera*	Golden-winged warbler	52.9	47.1	<0.001
DD	*Melanerpes carolinus*	Red-bellied woodpecker	52.8	47.2	<0.001
DD	*Helmitheros vermivorus*	Worm-eating warbler	52.7	47.3	<0.001
DD	*Empidonax traillii*	Willow flycatcher	52.7	47.3	<0.001
DD	*Otus asio*	Eastern screech owl	52.5	47.5	<0.001
DD	*Chaetura pelagica*	Chimney swift	52.5	47.5	<0.001
DD	*Myiarchus crinitus*	Great crested flycatcher	52.3	47.7	<0.001
DD	*Anas discors*	Blue-winged teal	52.3	47.7	<0.001
DD	*Tyto alba*	Barn owl	52.2	47.8	<0.001
DD	*Cardinalis cardinalis*	Northern cardinal	52.1	47.9	<0.001
DD	*Pooecetes gramineus*	Vesper sparrow	52.1	47.9	<0.001
DD	*Ardea herodias*	Great blue heron	51.9	48.1	<0.001
DD	*Anas platyrhynchos*	Mallard	51.9	48.1	<0.001
DD	*Icteria virens*	Yellow-breasted chat	51.8	48.2	<0.001
DD	*Charadrius vociferus*	Killdeer	51.8	48.2	<0.001
DD	*Passer domesticus*	House sparrow	51.7	48.3	<0.001
DD	*Ammodramus savannarum*	Grasshopper sparrow	51.6	48.4	<0.001
DD	*Progne subis*	Purple martin	51.6	48.4	<0.001
DD	*Caprimulgus vociferus*	Whip-poor-will	51.5	48.5	<0.001
DD	*Piranga rubra*	Summer tanager	51.5	48.5	0.001
DD	*Dendroica cerulea*	Cerulean warbler	51.5	48.5	<0.001
DD	*Vireo griseus*	White-eyed vireo	51.4	48.6	<0.001
DD	*Phasianus colchicus*	Ring-necked pheasant	51.4	48.6	<0.001
DD	*Sturnella magna*	Eastern meadowlark	51.4	48.6	<0.001
DD	*Podilymbus podiceps*	Pied-billed grebe	51.2	48.8	<0.001
DD	*Hirundo pyrrhonota*	Cliff swallow	51.2	48.8	<0.001
DD	*Circus cyaneus*	Northern harrier	51.1	48.9	<0.001
DD	*Parula americana*	Northern parula	51.1	48.9	<0.001
DD	*Passerculus sandwichensis*	Savannah sparrow	51.1	48.9	<0.001

(Appendix B2 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Dolichonyx orizyvorus*	Bobolink	50.9	49.1	<0.001
DD	*Porzana caroliniana*	Sora	50.9	49.1	0.001
DD	*Chordeiles minor*	Common nighthawk	50.8	49.2	<0.001
DD	*Dendroica petechia*	Yellow warbler	50.8	49.2	<0.001
DD	*Sturnus vulgaris*	European starling	50.7	49.3	<0.001
DD	*Carpodacus mexicanus*	House finch	50.6	49.4	<0.001
DD	*Mimus polyglottos*	Northern mockingbird	50.5	49.5	<0.001

Appendix B3. Capland and cupland fish species in the Appalachian Plateaus

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Catostomus catostomus*	Longnose sucker	19.3	80.7	<0.001
HH	*Amia calva*	Bowfin	20.8	79.2	<0.001
HH	*Nocomis biguttatus*	Hornyhead chub	22.3	77.7	<0.001
HH	*Clinostomus funduloides*	Rosyside dace	22.9	77.1	<0.001
HH	*Notropis dorsalis*	Bigmouth shiner	30.7	69.3	<0.001
HH	*Lampetra appendix*	American brook lamprey	36.4	63.6	<0.001
HH	*Hybopsis amblops*	Bigeye chub	37.7	62.3	<0.001
HH	*Notropis photogenis*	Silver shiner	38.4	61.6	<0.001
HH	*Phoxinus erythrogaster*	Southern redbelly dace	38.9	61.1	<0.001
HH	*Esox niger*	Chain pickerel	43.1	56.9	<0.001
HH	*Cottus cognatus*	Slimy sculpin	43.2	56.8	<0.001
HH	*Margariscus margarita*	Pearl dace	43.4	56.6	<0.001
HH	*Clinostomus elongatus*	Redside dace	44.6	55.4	<0.001
HH	*Lota lota*	Burbot	44.7	55.3	<0.001
HH	*Salvelinus fontinalis*	Brook trout	44.8	55.2	<0.001
HH	*Enneacanthus gloriosus*	Bluespotted sunfish	45.2	54.8	<0.001
HH	*Esox americanus*	Redfin pickerel	46.4	53.6	0.006
HH	*Lepomis megalotis*	Longear sunfish	47.6	52.4	<0.001
HH	*Exoglossum laurae*	Tonguetied minnow	47.8	52.2	<0.001
HH	*Noturus insignis*	Margined madtom	47.8	52.2	<0.001
HH	*Oncorhynchus mykiss*	Rainbow trout	48.0	52.0	<0.001
HH	*Salmo trutta*	Brown trout	48.0	52.0	<0.001
HH	*Semotilus corporalis*	Fallfish	48.1	51.9	<0.001
HH	*Cottus bairdi*	Mottled sculpin	48.8	51.2	<0.001
HH	*Ameiurus nebulosus*	Brown bullhead	48.9	51.1	<0.001
HH	*Exoglossum maxillingua*	Cutlips minnow	49.1	50.9	<0.001
HH	*Catostomus commersoni*	White sucker	49.3	50.7	<0.001
HH	*Rhinichthys atratulus*	Blacknose dace	49.6	50.4	0.005
HH	*Lepomis gibbosus*	Pumpkinseed	49.6	50.4	0.005
HH	*Lepomis macrochirus*	Bluegill	49.6	50.4	0.005
DD	*Ictiobus cyprinellus*	Bigmouth buffalo	100.0	0.0	0.003
DD	*Etheostoma exile*	Iowa darter	90.3	9.7	<0.001
DD	*Hiodon tergisus*	Mooneye	89.3	10.7	<0.001
DD	*Alosa sapidissima*	American shad	88.4	11.6	<0.001
DD	*Alosa chrysocloris*	Skipjack herring	87.0	13.0	<0.001
DD	*Oncorhynchus nerka*	Sockeye salmon	79.9	20.1	<0.001
DD	*Oncorhynchus tshawytscha*	Chinook salmon	79.9	20.1	<0.001
DD	*Ichthyomyzon unicuspis*	Silver lamprey	79.8	20.2	<0.001
DD	*Micropterus punctulatus*	Spotted bass	79.0	21.0	<0.001
DD	*Osmerus mordax*	Rainbow smelt	78.5	21.5	<0.001
DD	*Ictiobus bubalus*	Smallmouth buffalo	78.4	21.6	<0.001
DD	*Aplodinotus grunniens*	Freshwater drum	78.1	21.9	<0.001
DD	*Stizostedion canadense*	Sauger	78.1	21.9	<0.001
DD	*Lepisosteus osseus*	Longnose gar	77.4	22.6	<0.001
DD	*Notropis buchanani*	Ghost shiner	77.4	22.6	<0.001
DD	*Hiodon alosoides*	Goldeye	76.3	23.7	<0.001
DD	*Moxostoma macrolepidotum*	Shorthead redhorse	75.2	24.8	<0.001
DD	*Ictalurus punctatus*	Channel catfish	73.5	26.5	<0.001

(Appendix B3 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Morone chrysops*	White bass	73.5	26.5	<0.001
DD	*Carpoides cyprinus*	Quillback	71.8	28.2	<0.001
DD	*Erimystax dissimilis*	Streamline chub	71.4	28.6	<0.001
DD	*Stizostedion vitreum vitreum*	Walleye	71.4	28.6	<0.001
DD	*Oncorhynchus mykiss*	Steelhead trout	71.0	29.0	<0.001
DD	*Macrhybopsis storeriana*	Silver chub	70.7	29.3	<0.001
DD	*Coregonus artedi*	Cisco	70.3	29.7	<0.001
DD	*Notropis atherinoides*	Emerald shiner	69.8	30.2	<0.001
DD	*Ameiurus catus*	White catfish	66.8	33.2	<0.001
DD	*Etheostoma blennioides*	Greenside darter	65.9	34.1	<0.001
DD	*Petromyzon marinus*	Sea lamprey	65.8	34.2	<0.001
DD	*Notropis amoenus*	Comely shiner	65.0	35.0	<0.001
DD	*Oncorhynchus kisutch*	Coho salmon	65.0	35.0	<0.001
DD	*Noturus miurus*	Brindled madtom	64.7	35.3	<0.001
DD	*Etheostoma maculatum*	Spotted darter	64.0	36.0	<0.001
DD	*Pylodictis olivaris*	Flathead catfish	63.8	36.2	<0.001
DD	*Noturus stigmosus*	Northern madtom	63.8	36.2	<0.001
DD	*Ammocrypta pellucida*	Eastern sand darter	63.8	36.2	<0.001
DD	*Ichthyomyzon fossor*	Northern brook lamprey	63.3	36.7	<0.001
DD	*Labidesthes sicculus*	Brook silverside	63.3	36.7	<0.001
DD	*Noturus eleutherus*	Mountain madtom	63.1	36.9	<0.001
DD	*Etheostoma tippecanoe*	Tippecanoe darter	63.1	36.9	<0.001
DD	*Lampetra aepyptera*	Least brook lamprey	61.9	38.1	<0.001
DD	*Fundulus diaphanus*	Banded killifish	61.3	38.7	<0.001
DD	*Lepisosteus oculatus*	Spotted gar	61.1	38.9	<0.001
DD	*Etheostoma camurum*	Bluebreast darter	60.2	39.8	<0.001
DD	*Noturus gyrinus*	Tadpole madtom	60.1	39.9	<0.001
DD	*Luxilus spiloptera*	Spotfin shiner	59.8	40.2	<0.001
DD	*Percina evides*	Gilt darter	59.7	40.3	<0.001
DD	*Ameiurus natalis*	Yellow bullhead	59.6	40.4	<0.001
DD	*Percopsis omiscomaycus*	Trout-perch	59.2	40.8	<0.001
DD	*Erimyzon oblongus*	Creek chubsucker	59.0	41.0	<0.001
DD	*Luxilus chrysocephalus*	Striped shiner	58.7	41.3	<0.001
DD	*Notropis volucellus*	Mimic shiner	58.5	41.5	<0.001
DD	*Lepomis gulosus*	Warmouth	58.0	42.0	<0.001
DD	*Etheostoma flabellare*	Fantail darter	57.9	42.1	<0.001
DD	*Notropis stramineus*	Sand shiner	57.6	42.4	<0.001
DD	*Cyprinella analostana*	Satinfin shiner	57.5	42.5	<0.001
DD	*Notropis buccata*	Silverjaw minnow	56.9	43.1	<0.001
DD	*Notropis procne*	Swallowtail shiner	56.1	43.9	<0.001
DD	*Dorosoma cepedianum*	Gizzard shad	56.1	43.9	<0.001
DD	*Moxostoma duquesnei*	Black redhorse	55.9	44.1	<0.001
DD	*Etheostoma olmstedi*	Tessellated darter	55.7	44.3	<0.001
DD	*Notropis blennius*	River shiner	55.5	44.5	<0.001
DD	*Pomoxis annularis*	White crappie	55.4	44.6	<0.001
DD	*Moxostoma carinatum*	River redhorse	55.4	44.6	<0.001
DD	*Pomoxis nigromaculatus*	Black crappie	55.3	44.7	<0.001
DD	*Percina copelandi*	Channel darter	55.3	44.7	<0.001

(Appendix B3 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Moxostoma anisurum*	Silver redhorse	55.1	44.9	<0.001
DD	*Micropterus dolomieu*	Smallmouth bass	54.9	45.1	<0.001
DD	*Ichthyomyzon greeleyi*	Mt. brook lamprey	54.8	45.2	<0.001
DD	*Minytrema melanops*	Spotted sucker	54.7	45.3	<0.001
DD	*Pimephales promelas*	Fathead minnow	54.7	45.3	<0.001
DD	*Pimephales notatus*	Bluntnose minnow	54.5	45.5	<0.001
DD	*Moxostoma erythrurum*	Golden redhorse	54.4	45.6	<0.001
DD	*Nocomis micropogon*	River chub	54.2	45.8	<0.001
DD	*Noturus flavus*	Stonecat	54.0	46.0	<0.001
DD	*Esox masquinongy*	Muskellunge	53.7	46.3	<0.001
DD	*Luxilus cornutus*	Common shiner	53.6	46.4	<0.001
DD	*Rhinichthys cataractae*	Longnose dace	53.5	46.5	<0.001
DD	*Semotilus atromaculatus*	Creek chub	53.1	46.9	<0.001
DD	*Carassius auratus*	Goldfish	52.9	47.1	<0.001
DD	*Cyprinus carpio*	Common carp	52.7	47.3	<0.001
DD	*Lepomis cyanellus*	Green sunfish	52.7	47.3	<0.001
DD	*Percina macrocephala*	Longhead darter	52.6	47.4	<0.001
DD	*Notemigonus crysoleucas*	Golden shiner	52.4	47.6	<0.001
DD	*Perca flavescens*	Yellow perch	52.2	47.8	<0.001
DD	*Notropis rubellus*	Rosyface shiner	52.1	47.9	<0.001
DD	*Ameiurus melas*	Black bullhead	52.1	47.9	<0.001
DD	*Percina maculata*	Blackside darter	51.6	48.4	<0.001
DD	*Percina caprodes*	Logperch	51.5	48.5	<0.001
DD	*Etheostoma caeruleum*	Rainbow darter	51.5	48.5	<0.001
DD	*Campostoma anomalum*	Central stoneroller	51.5	48.5	<0.001
DD	*Ambloplites rupestris*	Rock bass	51.4	48.6	<0.001
DD	*Micropterus salmoides*	Largemouth bass	51.3	48.7	<0.001
DD	*Esox lucius*	Northern pike	51.3	48.7	<0.001
DD	*Etheostoma zonale*	Banded darter	51.1	48.9	<0.001

Appendix B4. Capland and cupland mammal species in the Appalachian Plateaus.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Spilogale putorius*	Eastern spotted skunk	26.3	73.7	<0.001
HH	*Microtus chrotorrhinus*	Rock vole	27.8	72.2	<0.001
HH	*Mytotis sodalis*	Indiana myotis	30.4	69.6	<0.001
HH	*Sylvilagus obscurus*	Appalachian cottontail	34.3	65.7	<0.001
HH	*Sorex palustris*	Northern water shrew	35.4	64.6	<0.001
HH	*Lontra canadensis*	River otter	40.4	59.6	<0.001
HH	*Cryptotis parva*	Least shrew	41.2	58.8	<0.001
HH	*Lepus americanus*	Snowshoe hare	42.2	57.8	<0.001
HH	*Sorex hoyi*	Pygmy shrew	44.2	55.8	<0.001
HH	*Glaucomys sabrinus*	Northern flying squirrel	46.2	53.8	<0.001
HH	*Napaeozapus insignis*	Woodland jumping mouse	46.3	53.7	<0.001
HH	*Erethizon dorsatum*	Common porcupine	46.6	53.4	<0.001
HH	*Lynx rufus*	Bobcat	46.7	53.3	<0.001
HH	*Ursus americanus*	Black bear	46.7	53.3	<0.001
HH	*Clethrionomys gapperi*	Southern redback vole	49.5	50.5	<0.001
DD	*Mustela nivalis*	Least weasel	55.3	44.7	<0.001
DD	*Sciurus niger*	Fox squirrel	54.3	45.7	<0.001
DD	*Sorex dispar*	Longtail shrew	51.9	48.1	<0.001
DD	*Cervus canadensis*	Elk	51.7	48.3	<0.001
DD	*Rattus norvegicus*	Norway rat	51.6	48.4	<0.001
DD	*Mus musculus*	House mouse	51.6	48.4	<0.001
DD	*Martes pennanti*	Fisher	51.2	48.8	<0.001
DD	*Zapus hudsonicus*	Meadow jumping mouse	50.6	49.4	<0.001
DD	*Sorex cinereus*	Masked shrew	50.6	49.4	<0.001
DD	*Condylura cristata*	Starnose mole	50.4	49.6	0.002

Appendix B5. Capland and cupland snake and lizard species in the Appalachian Plateaus.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Opheodrys aestivus*	Rough green snake	26.0	74.0	<0.001
HH	*Eumeces anthracinus*	Northern coal skink	37.9	62.1	<0.001
HH	*Storeria occipitomaculata*	Northern redbellied snake	45.6	54.4	<0.001
HH	*Crotalus horridus*	Timber rattlesnake	46.2	53.8	<0.001
HH	*Heterodon platirhinos*	Eastern hognose snake	48.3	51.7	0.001
HH	*Virginia valeriae*	Earth snake	49.1	50.9	0.008
DD	*Agkistrodon contortrix*	Northern copperhead snake	68.3	31.7	<0.001
DD	*Sistrurus catenatus*	Eastern massasauga	67.0	33.0	<0.001
DD	*Clonophis kirtlandii*	Kirtland's snake	66.8	33.2	<0.001
DD	*Regina septemvittata*	Queen snake	64.6	35.4	<0.001
DD	*Carphophis amoenus*	Eastern worm snake	61.2	38.8	<0.001
DD	*Sceloporus undulatus*	Northern fence lizard	60.0	40.0	<0.001
DD	*Elaphe obsoleta*	Black rat snake	59.1	40.9	<0.001
DD	*Eumeces faciatus*	Five-lined skink	58.3	41.7	<0.001
DD	*Nerodia sipedon*	Northern water snake	58.0	42.0	<0.001
DD	*Thamnophis sauritus*	Ribbon snake	54.8	45.2	<0.001
DD	*Storeria dekayi*	Northern brown snake	54.6	45.4	<0.001
DD	*Opheodrys vernalis*	Eastern smooth green snake	53.9	46.1	<0.001
DD	*Thamnophis brachystoma*	Shorthead garter snake	52.6	47.4	<0.001
DD	*Coluber constrictor*	Northern black racer snake	50.7	49.3	<0.001

Appendix C1. Capland and cupland amphibian species in the Ridge and Valley.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Pseudotriton montanus*	Eastern mud salamander	5.7	94.3	<0.001
HH	*Desmognathus monticola*	Appalachian seal salamander	29.8	70.2	<0.001
HH	*Plethodon wehrlei*	Wehrle's salamander	38.9	61.1	<0.001
HH	*Hemidactylium scutatum*	Four-toed salamander	48.1	51.9	<0.001
HH	*Plethodon hoffmani*	Valley & ridge salamander	48.3	51.7	<0.001
HH	*Desmognathus ochrophaeus*	Mountain dusky salamander	48.6	51.4	<0.001
DD	*Cryptobranchus alleganiensis*	Eastern hellbender	61.9	38.1	<0.001
DD	*Acris crepitans*	Northern cricket frog	59.4	40.6	<0.001
DD	*Rana pipiens*	Northern leopard frog	58.6	41.4	<0.001
DD	*Pseudacris triseriata*	Western chorus frog	58.0	42.0	<0.001
DD	*Bufo woodhousii*	Fowlers toad	54.3	45.7	<0.001
DD	*Hyla versicolor*	Eastern gray treefrog	53.4	46.6	<0.001
DD	*Rana catesbeiana*	Bullfrog	53.2	46.8	<0.001
DD	*Gyrinophilus porphyriticus*	Northern spring salamander	51.2	48.8	<0.001
DD	*Rana clamitans*	Northern green frog	51.0	49.0	<0.001

Appendix C2. Capland and cupland bird species in the Ridge and Valley.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Dendroica striata*	Blackpoll warbler	0.0	100.0	<0.001
HH	*Seiurus noveboracensis*	Northern waterthrush	3.9	96.1	<0.001
HH	*Troglodytes troglodytes*	Winter wren	4.7	95.3	<0.001
HH	*Junco hyemalis*	Dark-eyed junco	10.7	89.3	<0.001
HH	*Vireo flavifrons*	Yellow-throated vireo	10.9	89.1	<0.001
HH	*Catharus ustulatus*	Swainson's thrush	15.6	84.4	<0.001
HH	*Dendroica magnolia*	Magnolia warbler	16.4	83.6	<0.001
HH	*Catharus guttatus*	Hermit thrush	19.3	80.7	<0.001
HH	*Contopus borealis*	Olive-sided flycatcher	22.6	77.4	<0.001
HH	*Sphyrapicus varius*	Yellow-bellied sapsucker	22.6	77.4	<0.001
HH	*Vireo solitarius*	Blue-headed vireo	24.0	76.0	<0.001
HH	*Vireo gilvus*	Warbling vireo	26.4	73.6	<0.001
HH	*Dendroica virens*	Black-throated green warbler	34.7	65.3	<0.001
HH	*Zonotrichia albicollis*	White-throated sparrow	34.9	65.1	<0.001
HH	*Dendroica fusca*	Blackburnian warbler	35.2	64.8	<0.001
HH	*Dendroica coronata*	Yellow-rumped warbler	35.9	64.1	<0.001
HH	*Dendroica caerulescens*	Black-throated blue warbler	35.9	64.1	<0.001
HH	*Pheucticus ludovicianus*	Rose-breasted grosbeak	36.2	63.8	<0.001
HH	*Dendroica pensylvanica*	Chestnut-sided warbler	36.4	63.6	<0.001
HH	*Oporornis philadelphia*	Mourning warbler	36.5	63.5	<0.001
HH	*Aegolius acadicus*	Northern saw-whet owl	36.5	63.5	<0.001
HH	*Empidonax alnorum*	Alder flycatcher	36.9	63.1	<0.001
HH	*Carpodacus purpureus*	Purple finch	37.8	62.2	<0.001
HH	*Vermivora ruficapilla*	Nashville warbler	38.5	61.5	<0.001
HH	*Vermivora chrysoptera*	Golden-winged warbler	44.2	55.8	<0.001
HH	*Accipiter gentilis*	Northern goshawk	44.5	55.5	<0.001
HH	*Dolichonyx orizyvorus*	Bobolink	45.4	54.6	<0.001
HH	*Wilsonia canadensis*	Canada warbler	45.5	54.5	<0.001
HH	*Helmitheros vermivorus*	Worm-eating warbler	45.5	54.5	<0.001
HH	*Dendroica pinus*	Pine warbler	46.1	53.9	<0.001
HH	*Sitta canadensis*	Red-breasted nuthatch	46.4	53.6	<0.001
HH	*Mniotilta varia*	Black-and-white warbler	46.9	53.1	<0.001
HH	*Regulus satrapa*	Golden-crowned kinglet	47.1	52.9	<0.001
HH	*Catharus fuscescens*	Veery	47.3	52.7	<0.001
HH	*Accipiter striatus*	Sharp-shinned hawk	47.5	52.5	<0.001
HH	*Piranga olivacea*	Scarlet tanager	47.5	52.5	<0.001
HH	*Certhia americana*	Brown creeper	47.7	52.3	<0.001
HH	*Piranga rubra*	Summer tanager	47.8	52.2	0.002
HH	*Oporornis formosus*	Kentucky warbler	48.0	52.0	<0.001
HH	*Seiurus motacilla*	Louisiana waterthrush	48.1	51.9	<0.001
HH	*Seiurus aurocapillus*	Ovenbird	48.1	51.9	<0.001
HH	*Buteo lineatus*	Red-shouldered hawk	48.3	51.7	<0.001
HH	*Strix varia*	Barred owl	48.4	51.6	<0.001
HH	*Wilsonia citrina*	Hooded warbler	48.4	51.6	<0.001
HH	*Corvus corax*	Common raven	48.5	51.5	<0.001
HH	*Hylocichla mustelina*	Wood thrush	48.6	51.4	<0.001
HH	*Dendroica cerulea*	Cerulean warbler	48.7	51.3	<0.001
HH	*Caprimulgus vociferus*	Whip-poor-will	48.7	51.3	<0.001

(Appendix C2 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Parula americana*	Northern parula	48.8	51.2	<0.001
HH	*Buteo platypterus*	Broad-winged hawk	48.8	51.2	<0.001
HH	*Empidonax minimum*	Least flycatcher	49.1	50.9	<0.001
HH	*Vireo olivaceus*	Red-eyed vireo	49.1	50.9	<0.001
HH	*Pandion haliaetus*	Osprey	49.2	50.8	0.002
HH	*Setophaga ruticilla*	American redstart	49.3	50.7	<0.001
HH	*Empidonax virescens*	Acadian flycatcher	49.3	50.7	0.001
HH	*Dryocopus pileatus*	Pileated woodpecker	49.3	50.7	0.001
HH	*Coccyzus americanus*	Yellow-billed cuckoo	49.3	50.7	0.001
HH	*Polioptila caerulea*	Blue-gray gnatcatcher	49.4	50.6	0.002
HH	*Bonasa umbellus*	Ruffed grouse	49.4	50.6	0.004
DD	*Anas clypeata*	Northern shoveler	84.6	15.4	<0.001
DD	*Egretta thula*	Snowy egret	81.9	18.1	<0.001
DD	*Spiza americana*	Dickcissel	80.5	19.5	<0.001
DD	*Bulbulcus ibis*	Cattle egret	76.1	23.9	<0.001
DD	*Anas crecca*	Green-winged teal	75.6	24.4	<0.001
DD	*Cistothorus platensis*	Sedge wren	74.1	25.9	<0.001
DD	*Nycticorax violaceus*	Yellow-crowned night-heron	73.5	26.5	<0.001
DD	*Guiraca caerulea*	Blue grosbeak	73.2	26.8	<0.001
DD	*Cistothorus palustris*	Marsh wren	70.9	29.1	<0.001
DD	*Bartramia longicauda*	Upland sandpiper	69.0	31.0	<0.001
DD	*Caprimulgus carolinensis*	Chuck will's widow	68.4	31.6	<0.001
DD	*Sturnella neglecta*	Western meadowlark	68.2	31.8	<0.001
DD	*Cygnus olor*	Mute swan	65.2	34.8	<0.001
DD	*Corvus ossifragus*	Fish crow	64.9	35.1	<0.001
DD	*Falco peregrinus*	Peregrine falcon	64.1	35.9	<0.001
DD	*Ixobrychus exilis*	Least bittern	63.8	36.2	<0.001
DD	*Ardea alba*	Great egret	63.5	36.5	<0.001
DD	*Anas discors*	Blue-winged teal	63.4	36.6	<0.001
DD	*Circus cyaneus*	Northern harrier	63.1	36.9	<0.001
DD	*Columba livia*	Rock dove	62.4	37.6	<0.001
DD	*Gallinago gallinago*	Common snipe	62.4	37.6	<0.001
DD	*Lanius ludovicianus*	Loggerhead shrike	61.9	38.1	<0.001
DD	*Ammodramus henslowii*	Henslow's sparrow	61.6	38.4	<0.001
DD	*Sturnella magna*	Eastern meadowlark	61.0	39.0	<0.001
DD	*Botarus lentiginosus*	American bittern	58.6	41.4	<0.001
DD	*Branta canadensis*	Canada goose	58.5	41.5	<0.001
DD	*Eremophila alpestris*	Horned lark	58.2	41.8	<0.001
DD	*Podilymbus podiceps*	Pied-billed grebe	58.0	42.0	<0.001
DD	*Pooecetes gramineus*	Vesper sparrow	57.8	42.2	<0.001
DD	*Ammodramus savannarum*	Grasshopper sparrow	57.7	42.3	<0.001
DD	*Passerculus sandwichensis*	Savannah sparrow	57.5	42.5	<0.001
DD	*Passer domesticus*	House sparrow	57.5	42.5	<0.001
DD	*Gallinula chloropus*	Common moorhen	57.2	42.8	<0.001
DD	*Charadrius vociferus*	Killdeer	56.8	43.2	<0.001
DD	*Haliaeetus leucocephalus*	Bald eagle	56.8	43.2	<0.001
DD	*Vermivora pinus*	Blue-winged warbler	56.6	43.4	<0.001
DD	*Porzana caroliniana*	Sora	56.4	43.6	<0.001

(Appendix C2 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Mergus merganser*	Common merganser	56.3	43.7	<0.001
DD	*Protonotaria citrea*	Prothonotary warbler	56.3	43.7	<0.001
DD	*Anas platyrhynchos*	Mallard	56.3	43.7	<0.001
DD	*Nycticorax nycticorax*	Black-crowned night-heron	56.1	43.9	<0.001
DD	*Phasianus colchicus*	Ring-necked pheasant	56.1	43.9	<0.001
DD	*Anas rubripes*	American black duck	55.2	44.8	<0.001
DD	*Colinus virginianus*	Northern bobwhite	54.7	45.3	<0.001
DD	*Spizella pusilla*	Field sparrow	54.4	45.6	<0.001
DD	*Carpodacus mexicanus*	House finch	54.3	45.7	<0.001
DD	*Vireo griseus*	White-eyed vireo	53.7	46.3	<0.001
DD	*Tyto alba*	Barn owl	53.7	46.3	<0.001
DD	*Sturnus vulgaris*	European starling	53.5	46.5	<0.001
DD	*Rallus limicola*	Virginia rail	53.3	46.7	<0.001
DD	*Dendroica discolor*	Prairie warbler	53.1	46.9	<0.001
DD	*Dendroica petechia*	Yellow warbler	53.1	46.9	<0.001
DD	*Asio otus*	Long-eared owl	53.0	47.0	<0.001
DD	*Chaetura pelagica*	Chimney swift	53.0	47.0	<0.001
DD	*Carduelis pinus*	Pine siskin	53.0	47.0	<0.001
DD	*Ardea herodias*	Great blue heron	52.2	47.8	<0.001
DD	*Hirundo pyrrhonota*	Cliff swallow	52.0	48.0	<0.001
DD	*Progne subis*	Purple martin	52.0	48.0	<0.001
DD	*Riparia riparia*	Bank swallow	51.9	48.1	<0.001
DD	*Actitis macularia*	Spotted sandpiper	51.6	48.4	<0.001
DD	*Hirundo rustica*	Barn swallow	51.4	48.6	<0.001
DD	*Tachycineta bicolor*	Tree swallow	51.3	48.7	<0.001
DD	*Aix sponsa*	Wood duck	51.2	48.8	<0.001
DD	*Agelaius phoeniceus*	Red-winged blackbird	51.2	48.8	<0.001
DD	*Melospiza georgiana*	Swamp sparrow	51.1	48.9	<0.001
DD	*Icteria virens*	Yellow-breasted chat	51.1	48.9	<0.001
DD	*Ceryle alcyon*	Belted kingfisher	50.9	49.1	<0.001
DD	*Chordeiles minor*	Common nighthawk	50.9	49.1	<0.001
DD	*Butorides striatus*	Green heron	50.9	49.1	<0.001
DD	*Empidonax traillii*	Willow flycatcher	50.8	49.2	<0.001
DD	*Melospiza melodia*	Song sparrow	50.8	49.2	<0.001
DD	*Geothlypis trichas*	Common yellowthroat	50.8	49.2	<0.001
DD	*Sialia sialis*	Eastern bluebird	50.7	49.3	0.001
DD	*Coragyps atratus*	Black vulture	50.7	49.3	0.005
DD	*Scolopax minor*	American woodcock	50.7	49.3	0.002
DD	*Tyrannus tyrannus*	Eastern kingbird	50.6	49.4	0.003
DD	*Quiscalus quiscula*	Common grackle	50.6	49.4	0.003

Appendix C3. Capland and cupland fish species in the Ridge and Valley.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Morone saxatilis*	Striped bass	17.0	83.0	<0.001
HH	*Enneacanthus gloriosus*	Bluespotted sunfish	32.9	67.1	<0.001
HH	*Salvelinus fontinalis*	Brook trout	36.6	63.4	<0.001
HH	*Cottus cognatus*	Slimy sculpin	37.0	63.0	<0.001
HH	*Erimyzon oblongus*	Creek chubsucker	38.0	62.0	<0.001
HH	*Lepomis megalotis*	Longear sunfish	39.6	60.4	<0.001
HH	*Cottus girardi*	Potomac sculpin	44.1	55.9	<0.001
HH	*Petromyzon marinus*	Sea lamprey	44.6	55.4	<0.001
HH	*Oncorhynchus mykiss*	Rainbow trout	45.8	54.2	<0.001
HH	*Salmo trutta*	Brown trout	45.8	54.2	<0.001
HH	*Exoglossum maxillingua*	Cutlips minnow	47.7	52.3	<0.001
HH	*Noturus insignis*	Margined madtom	47.7	52.3	<0.001
HH	*Noturus flavus*	Stonecat	47.7	52.3	<0.001
HH	*Notropis hudsonicus*	Spottail shiner	47.8	52.2	<0.001
HH	*Semotilus corporalis*	Fallfish	48.0	52.0	<0.001
HH	*Rhinichthys atratulus*	Blacknose dace	48.0	52.0	<0.001
HH	*Lepomis gibbosus*	Pumpkinseed	48.0	52.0	<0.001
HH	*Lepomis macrochirus*	Bluegill	48.0	52.0	<0.001
HH	*Lepomis cyanellus*	Green sunfish	48.0	52.0	<0.001
HH	*Cottus bairdi*	Mottled sculpin	48.1	51.9	<0.001
HH	*Esox niger*	Chain pickerel	48.4	51.6	<0.001
HH	*Catostomus commersoni*	White sucker	48.5	51.5	<0.001
HH	*Ameiurus nebulosus*	Brown bullhead	48.7	51.3	<0.001
HH	*Hypentelium nigricans*	Northern hog sucker	48.8	51.2	<0.001
HH	*Etheostoma zonale*	Banded darter	49.3	50.7	0.005
HH	*Anguilla rostrata*	American eel	49.4	50.6	0.008
DD	*Apeltes quadracus*	Fourspine stickleback	82.7	17.3	<0.001
DD	*Gasterosteus aculeatus*	Threespine stickleback	82.4	17.6	<0.001
DD	*Alosa pseudoharengus*	Alewife	82.1	17.9	<0.001
DD	*Osmerus mordax*	Rainbow smelt	78.1	21.9	<0.001
DD	*Morone americana*	White perch	73.8	26.2	<0.001
DD	*Amia calva*	Bowfin	73.1	26.9	<0.001
DD	*Alosa sapidissima*	American shad	71.5	28.5	<0.001
DD	*Carpoides cyprinus*	Quillback	69.9	30.1	<0.001
DD	*Cyprinus carpio*	Common carp	65.0	35.0	<0.001
DD	*Notemigonus crysoleucas*	Golden shiner	64.2	35.8	<0.001
DD	*Carassius auratus*	Goldfish	63.6	36.4	<0.001
DD	*Stizostedion vitreum vitreum*	Walleye	63.0	37.0	<0.001
DD	*Etheostoma blennioides*	Greenside darter	62.0	38.0	<0.001
DD	*Ameiurus catus*	White catfish	61.8	38.2	<0.001
DD	*Ictalurus punctatus*	Channel catfish	61.8	38.2	<0.001
DD	*Perca flavescens*	Yellow perch	61.7	38.3	<0.001
DD	*Esox masquinongy*	Muskellunge	61.7	38.3	<0.001
DD	*Esox americanus americanus*	Redfin pickerel	61.4	38.6	<0.001
DD	*Moxostoma macrolepidotum*	Shorthead redhorse	61.3	38.7	<0.001
DD	*Clinostomus funduloides*	Rosyside dace	61.1	38.9	<0.001
DD	*Notropis amoenus*	Comely shiner	60.7	39.3	<0.001
DD	*Etheostoma olmstedi*	Tessellated darter	59.7	40.3	<0.001

(Appendix C3 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Cyprinella analostana*	Satinfin shiner	59.6	40.4	<0.001
DD	*Margariscus margarita*	Pearl dace	58.5	41.5	<0.001
DD	*Notropis buccata*	Silverjaw minnow	57.8	42.2	<0.001
DD	*Notropis rubellus*	Rosyface shiner	57.8	42.2	<0.001
DD	*Notropis procne*	Swallowtail shiner	57.1	42.9	<0.001
DD	*Esox lucius*	Northern pike	56.6	43.4	<0.001
DD	*Ameiurus natalis*	Yellow bullhead	56.5	43.5	<0.001
DD	*Dorosoma cepedianum*	Gizzard shad	56.2	43.8	<0.001
DD	*Luxilus spiloptera*	Spotfin shiner	56.0	44.0	<0.001
DD	*Pimephales notatus*	Bluntnose minnow	55.2	44.8	<0.001
DD	*Pomoxis nigromaculatus*	Black crappie	55.0	45.0	<0.001
DD	*Etheostoma flabellare*	Fantail darter	54.8	45.2	<0.001
DD	*Pomoxis annularis*	White crappie	54.7	45.3	<0.001
DD	*Fundulus diaphanus*	Banded killifish	54.7	45.3	<0.001
DD	*Luxilus cornutus*	Common shiner	54.7	45.3	<0.001
DD	*Semotilus atromaculatus*	Creek chub	54.4	45.6	<0.001
DD	*Micropterus dolomieu*	Smallmouth bass	54.3	45.7	<0.001
DD	*Pimephales promelas*	Fathead minnow	54.3	45.7	<0.001
DD	*Nocomis micropogon*	River chub	53.8	46.2	<0.001
DD	*Rhinichthys cataractae*	Longnose dace	53.4	46.6	<0.001
DD	*Lepomis auritus*	Redbreast sunfish	52.6	47.4	<0.001
DD	*Noturus gyrinus*	Tadpole madtom	51.5	48.5	<0.001
DD	*Campostoma anomalum*	Central stoneroller	51.1	48.9	<0.001

Appendix C4. Capland and cupland mammal species in the Ridge and Valley.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Lepus americanus*	Snowshoe hare	28.0	72.0	<0.001
HH	*Sorex hoyi*	Pygmy shrew	31.2	68.8	<0.001
HH	*Napaeozapus insignis*	Woodland jumping mouse	31.8	68.2	<0.001
HH	*Sylvilagus obscurus*	Appalachian cottontail	33.7	66.3	<0.001
HH	*Spilogale putorius*	Eastern spotted skunk	33.8	66.2	<0.001
HH	*Neotoma magister*	Allegheny woodrat	36.0	64.0	<0.001
HH	*Erethizon dorsatum*	Common porcupine	43.2	56.8	<0.001
HH	*Sorex dispar*	Longtail shrew	44.3	55.7	<0.001
HH	*Mustela erminea*	Ermine	45.8	54.2	<0.001
HH	*Lynx rufus*	Bobcat	46.3	53.7	<0.001
HH	*Sciurus niger*	Fox squirrel	46.5	53.5	<0.001
HH	*Ursus americanus*	Black bear	48.5	51.5	<0.001
HH	*Parascalops breweri*	Hairy tail mole	49.1	50.9	0.001
HH	*Tamiasciurus hudsonicus*	Red squirrel	49.4	50.6	0.005
HH	*Glaucomys volans*	Southern flying squirrel	49.4	50.6	0.005
DD	*Cervus canadensis*	Elk	94.8	5.2	<0.001
DD	*Cryptotis parva*	Least shrew	82.8	17.2	<0.001
DD	*Rattus norvegicus*	Norway rat	58.0	42.0	<0.001
DD	*Mus musculus*	House mouse	58.0	42.0	<0.001
DD	*Mustela nivalis*	Least weasel	55.2	44.8	<0.001
DD	*Zapus hudsonicus*	Meadow jumping mouse	53.8	46.2	<0.001
DD	*Scalopus aquaticus*	Eastern mole	53.7	46.3	<0.001
DD	*Lontra canadensis*	River otter	52.3	47.7	<0.001
DD	*Ondatra zibethicus*	Common muskrat	51.2	48.8	<0.001
DD	*Condylura cristata*	Starnose mole	50.8	49.2	0.001

Appendix C5. Capland and cupland snake and lizard species in the Ridge and Valley.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Eumeces anthracinus*	Northern coal skink	19.6	80.4	<0.001
HH	*Storeria occipitomaculata*	Northern redbellied snake	43.8	56.2	<0.001
HH	*Crotalus horridus*	Timber rattlesnake	44.6	55.4	<0.001
HH	*Heterodon platirhinos*	Eastern hognose snake	48.7	51.3	<0.001
HH	*Eumeces faciatus*	Five-lined skink	48.7	51.3	0.002
DD	*Regina septemvittata*	Queen snake	60.8	39.2	<0.001
DD	*Storeria dekayi*	Northern brown snake	57.4	42.6	<0.001
DD	*Agkistrodon contortrix*	Northern copperhead snake	55.4	44.6	<0.001
DD	*Nerodia sipedon*	Northern water snake	54.1	45.9	<0.001
DD	*Thamnophis sauritus*	Ribbon snake	53.3	46.7	<0.001
DD	*Elaphe obsoleta*	Black rat snake	52.9	47.1	<0.001
DD	*Sceloporus undulatus*	Northern fence lizard	52.4	47.6	<0.001

Appendix C6. Capland and cupland turtle species in the Ridge and Valley.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Clemmys insculpta*	Wood turtle	46.8	53.2	<0.001
DD	*Graptemys geographica*	Map turtle	70.1	29.9	<0.001
DD	*Clemmys muhlenbergii*	Bog turtle	65.5	34.5	<0.001
DD	*Clemmys guttata*	Spotted turtle	61.2	38.8	<0.001
DD	*Pseudemys rubriventris*	Redbellied turtle	59.8	40.2	<0.001
DD	*Chrysemys picta*	Midland painted turtle	59.0	41.0	<0.001
DD	*Chelydra serpentina*	Common snapping turtle	58.2	41.8	<0.001
DD	*Sternotherus odoratus*	Stinkpot turtle	54.0	46.0	<0.001

Appendix D1. Capland and cupland amphibian species in the Piedmont.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Hemidactylium scutatum*	Four-toed salamander	38.9	61.1	<0.001
HH	*Eurycea bislineata*	Northern two lined salamander	48.8	51.2	0.002
HH	*Desmognathus fuscus*	Northern dusky salamander	48.8	51.2	0.002
HH	*Plethodon cinereus*	Redback salamander	49.0	51.0	0.005
HH	*Plethodon glutinosus*	Slimy salamander	49.0	51.0	0.005
DD	*Scaphiopus holbrookii*	Eastern spadefoot toad	84.8	15.2	<0.001
DD	*Plethodon hoffmani*	Valley & ridge salamander	69.8	30.2	<0.001
DD	*Rana sphenocephala*	Southern leopard frog	65.7	34.3	<0.001
DD	*Cryptobranchus alleganiensis*	Eastern hellbender	65.6	34.4	<0.001
DD	*Gyrinophilus porphyriticus*	Northern spring salamander	64.8	35.2	<0.001
DD	*Pseudotriton ruber*	Northern red salamander	59.1	40.9	<0.001
DD	*Eurycea longicauda*	Longtail salamander	58.0	42.0	<0.001
DD	*Hyla versicolor*	Eastern gray treefrog	57.6	42.4	<0.001
DD	*Pseudacris triseriata*	Western chorus frog	55.0	45.0	<0.001
DD	*Rana pipiens*	Northern leopard frog	54.9	45.1	<0.001
DD	*Bufo woodhousii*	Fowlers toad	54.0	46.0	<0.001
DD	*Ambystoma opacum*	Marbled salamander	53.5	46.5	<0.001
DD	*Acris crepitans*	Northern cricket frog	53.1	46.9	<0.001
DD	*Ambystoma maculatum*	Spotted salamander	52.1	47.9	<0.001

Appendix D2. Capland and cupland bird species in the Piedmont.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Dolichonyx orizyvorus*	Bobolink	9.8	90.2	<0.001
HH	*Wilsonia canadensis*	Canada warbler	14.4	85.6	<0.001
HH	*Dendroica pensylvanica*	Chestnut-sided warbler	16.1	83.9	<0.001
HH	*Pheucticus ludovicianus*	Rose-breasted grosbeak	20.5	79.5	<0.001
HH	*Vermivora chrysoptera*	Golden-winged warbler	22.1	77.9	<0.001
HH	*Carpodacus purpureus*	Purple finch	27.2	72.8	<0.001
HH	*Regulus satrapa*	Golden-crowned kinglet	39.2	60.8	<0.001
HH	*Dendroica virens*	Black-throated green warbler	39.4	60.6	0.010
HH	*Bartramia longicauda*	Upland sandpiper	41.3	58.7	<0.001
HH	*Circus cyaneus*	Northern harrier	44.1	55.9	<0.001
HH	*Gallinula chloropus*	Common moorhen	44.4	55.6	<0.001
HH	*Helmitheros vermivorus*	Worm-eating warbler	44.9	55.1	<0.001
HH	*Hirundo pyrrhonota*	Cliff swallow	45.0	55.0	<0.001
HH	*Certhia americana*	Brown creeper	45.1	54.9	<0.001
HH	*Bulbulcus ibis*	Cattle egret	45.5	54.5	<0.001
HH	*Ixobrychus exilis*	Least bittern	45.5	54.5	<0.001
HH	*Dendroica pinus*	Pine warbler	45.6	54.4	<0.001
HH	*Eremophila alpestris*	Horned lark	45.8	54.2	<0.001
HH	*Caprimulgus vociferus*	Whip-poor-will	46.2	53.8	<0.001
HH	*Pooecetes gramineus*	Vesper sparrow	46.2	53.8	<0.001
HH	*Accipiter cooperii*	Cooper's hawk	46.3	53.7	<0.001
HH	*Meleagris gallopavo*	Wild turkey	46.3	53.7	<0.001
HH	*Dendroica cerulea*	Cerulean warbler	46.5	53.5	<0.001
HH	*Piranga olivacea*	Scarlet tanager	47.3	52.7	<0.001
HH	*Mniotilta varia*	Black-and-white warbler	47.3	52.7	<0.001
HH	*Catharus fuscescens*	Veery	47.3	52.7	<0.001
HH	*Oporornis formosus*	Kentucky warbler	47.4	52.6	<0.001
HH	*Seiurus aurocapillus*	Ovenbird	47.5	52.5	<0.001
HH	*Hylocichla mustelina*	Wood thrush	47.5	52.5	<0.001
HH	*Strix varia*	Barred owl	47.6	52.4	<0.001
HH	*Wilsonia citrina*	Hooded warbler	48.0	52.0	<0.001
HH	*Seiurus motacilla*	Louisiana waterthrush	48.4	51.6	<0.001
HH	*Coragyps atratus*	Black vulture	48.4	51.6	<0.001
HH	*Melanerpes erythrocephalus*	Red-headed woodpecker	48.4	51.6	<0.001
HH	*Empidonax virescens*	Acadian flycatcher	48.5	51.5	<0.001
HH	*Buteo platypterus*	Broad-winged hawk	48.6	51.4	<0.001
HH	*Parula americana*	Northern parula	48.6	51.4	<0.001
HH	*Setophaga ruticilla*	American redstart	48.6	51.4	<0.001
HH	*Polioptila caerulea*	Blue-gray gnatcatcher	48.6	51.4	<0.001
HH	*Coccyzus americanus*	Yellow-billed cuckoo	48.6	51.4	<0.001
HH	*Dryocopus pileatus*	Pileated woodpecker	48.7	51.3	<0.001
HH	*Guiraca caerulea*	Blue grosbeak	48.7	51.3	<0.001
HH	*Vireo olivaceus*	Red-eyed vireo	48.7	51.3	<0.001
HH	*Ammodramus savannarum*	Grasshopper sparrow	48.8	51.2	0.001
HH	*Tyto alba*	Barn owl	48.8	51.2	0.001
HH	*Colinus virginianus*	Northern bobwhite	48.8	51.2	0.001
HH	*Corvus ossifragus*	Fish crow	49.0	51.0	0.003
HH	*Actitis macularia*	Spotted sandpiper	49.0	51.0	0.007

(Appendix D2 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Myiarchus crinitus*	Great crested flycatcher	49.0	51.0	0.007
HH	*Coccyzus erythrophthalmus*	Black-billed cuckoo	49.1	50.9	0.009
DD	*Dendroica fusca*	Blackburnian warbler	100.0	0.0	<0.001
DD	*Asio flammeus*	Short-eared owl	85.0	15.0	<0.001
DD	*Lanius ludovicianus*	Loggerhead shrike	83.6	16.4	<0.001
DD	*Corvus corax*	Common raven	83.1	16.9	<0.001
DD	*Falco peregrinus*	Peregrine falcon	78.1	21.9	<0.001
DD	*Spiza americana*	Dickcissel	71.8	28.2	<0.001
DD	*Carduelis pinus*	Pine siskin	70.8	29.2	<0.001
DD	*Asio otus*	Long-eared owl	70.0	30.0	<0.001
DD	*Accipiter gentilis*	Northern goshawk	69.3	30.7	<0.001
DD	*Cistothorus platensis*	Sedge wren	69.3	30.7	<0.001
DD	*Lophodytes cucullatus*	Hooded merganser	66.6	33.4	<0.001
DD	*Ardea alba*	Great egret	64.6	35.4	<0.001
DD	*Podilymbus podiceps*	Pied-billed grebe	61.5	38.5	<0.001
DD	*Fulica americana*	American coot	60.7	39.3	<0.001
DD	*Nycticorax violaceus*	Yellow-crowned night-heron	60.6	39.4	<0.001
DD	*Piranga rubra*	Summer tanager	59.3	40.7	<0.001
DD	*Anas discors*	Blue-winged teal	59.2	40.8	<0.001
DD	*Rallus elegans*	King rail	58.5	41.5	0.001
DD	*Cistothorus palustris*	Marsh wren	58.2	41.8	<0.001
DD	*Cygnus olor*	Mute swan	56.7	43.3	<0.001
DD	*Empidonax minimum*	Least flycatcher	56.3	43.7	<0.001
DD	*Egretta thula*	Snowy egret	55.6	44.4	<0.001
DD	*Anas clypeata*	Northern shoveler	55.4	44.6	<0.001
DD	*Rallus limicola*	Virginia rail	55.1	44.9	<0.001
DD	*Bonasa umbellus*	Ruffed grouse	54.0	46.0	<0.001
DD	*Protonotaria citrea*	Prothonotary warbler	53.8	46.2	<0.001
DD	*Botarus lentiginosus*	American bittern	53.5	46.5	0.008
DD	*Parus atricapillus*	Black-capped chickadee	52.8	47.2	<0.001
DD	*Chaetura pelagica*	Chimney swift	52.4	47.6	<0.001
DD	*Dendroica dominica*	Yellow-throated warbler	51.8	48.2	0.001
DD	*Anas rubripes*	American black duck	51.8	48.2	0.001
DD	*Melospiza georgiana*	Swamp sparrow	51.5	48.5	<0.001
DD	*Passerculus sandwichensis*	Savannah sparrow	51.4	48.6	0.001
DD	*Columba livia*	Rock dove	51.0	49.0	0.008

Appendix D3. Capland and cupland fish species in the Piedmont.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Apeltes quadracus*	Fourspine stickleback	23.9	76.1	<0.001
HH	*Percina caprodes*	Logperch	24.8	75.2	<0.001
HH	*Cottus bairdi*	Mottled sculpin	27.2	72.8	<0.001
HH	*Etheostoma blennioides*	Greenside darter	33.5	66.5	<0.001
HH	*Notropis volucellus*	Mimic shiner	38.5	61.5	<0.001
HH	*Etheostoma zonale*	Banded darter	38.6	61.4	<0.001
HH	*Morone saxatilis*	Striped bass	40.3	59.7	<0.001
HH	*Petromyzon marinus*	Sea lamprey	45.1	54.9	<0.001
HH	*Noturus flavus*	Stonecat	45.3	54.7	<0.001
HH	*Catostomus commersoni*	White sucker	45.5	54.5	<0.001
HH	*Hypentelium nigricans*	Northern hog sucker	45.7	54.3	<0.001
HH	*Oncorhynchus mykiss*	Rainbow trout	46.0	54.0	<0.001
HH	*Salmo trutta*	Brown trout	46.0	54.0	<0.001
HH	*Exoglossum maxillingua*	Cutlips minnow	46.0	54.0	<0.001
HH	*Noturus insignis*	Margined madtom	46.0	54.0	<0.001
HH	*Rhinichthys atratulus*	Blacknose dace	46.3	53.7	<0.001
HH	*Lepomis cyanellus*	Green sunfish	46.3	53.7	<0.001
HH	*Lepomis gibbosus*	Pumpkinseed	46.3	53.7	<0.001
HH	*Lepomis macrochirus*	Bluegill	46.3	53.7	<0.001
HH	*Semotilus corporalis*	Fallfish	46.3	53.7	<0.001
HH	*Rhinichthys cataractae*	Longnose dace	46.6	53.4	<0.001
HH	*Pimephales promelas*	Fathead minnow	46.9	53.1	<0.001
HH	*Semotilus atromaculatus*	Creek chub	47.5	52.5	<0.001
HH	*Nocomis micropogon*	River chub	47.6	52.4	<0.001
HH	*Luxilus cornutus*	Common shiner	47.7	52.3	<0.001
HH	*Fundulus diaphanus*	Banded killifish	47.7	52.3	<0.001
HH	*Percina peltata*	Shield darter	48.2	51.8	<0.001
HH	*Anguilla rostrata*	American eel	48.3	51.7	0.001
HH	*Notropis hudsonicus*	Spottail shiner	48.3	51.7	<0.001
HH	*Micropterus dolomieu*	Smallmouth bass	48.4	51.6	0.001
HH	*Ameiurus nebulosus*	Brown bullhead	48.9	51.1	0.003
DD	*Acipenser brevirostrum*	Shortnose sturgeon	100.0	0.0	0.001
DD	*Acipenser oxyrinchus*	Atlantic sturgeon	100.0	0.0	<0.001
DD	*Alosa aestivalis*	Blueback herring	100.0	0.0	<0.001
DD	*Alosa mediocris*	Hickory shad	100.0	0.0	<0.001
DD	*Hybognathus regius*	Eastern silvery minnow	100.0	0.0	<0.001
DD	*Alosa sapidissima*	American shad	85.5	14.5	<0.001
DD	*Stizostedion vitreum vitreum*	Walleye	78.9	21.1	<0.001
DD	*Carpoides cyprinus*	Quillback	71.0	29.0	<0.001
DD	*Cyprinella analostana*	Satinfin shiner	70.8	29.2	<0.001
DD	*Notropis buccata*	Silverjaw minnow	69.6	30.4	<0.001
DD	*Amia calva*	Bowfin	66.7	33.3	<0.001
DD	*Ictalurus punctatus*	Channel catfish	65.4	34.6	<0.001
DD	*Umbra pygmaea*	Eastern mudminnow	62.0	38.0	<0.001
DD	*Alosa pseudoharengus*	Alewife	60.1	39.9	<0.001
DD	*Ameiurus catus*	White catfish	59.1	40.9	<0.001
DD	*Esox masquinongy*	Muskellunge	59.0	41.0	<0.001
DD	*Esox niger*	Chain pickerel	58.7	41.3	<0.001

(Appendix D3 continued)

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Notropis bifrenatus*	Bridle shiner	58.0	42.0	0.006
DD	*Etheostoma flabellare*	Fantail darter	57.5	42.5	<0.001
DD	*Morone americana*	White perch	57.0	43.0	<0.001
DD	*Perca flavescens*	Yellow perch	56.6	43.4	<0.001
DD	*Lampetra appendix*	American brook lamprey	56.2	43.8	<0.001
DD	*Cyprinus carpio*	Common carp	56.1	43.9	<0.001
DD	*Notemigonus crysoleucas*	Golden shiner	56.1	43.9	<0.001
DD	*Etheostoma olmstedi*	Tessellated darter	55.9	44.1	<0.001
DD	*Notropis rubellus*	Rosyface shiner	55.7	44.3	<0.001
DD	*Moxostoma macrolepidotum*	Shorthead redhorse	55.7	44.3	<0.001
DD	*Fundulus heteroclitus*	Mummichog	55.5	44.5	<0.001
DD	*Dorosoma cepedianum*	Gizzard shad	53.8	46.2	<0.001
DD	*Ameiurus natalis*	Yellow bullhead	52.9	47.1	<0.001
DD	*Notropis procne*	Swallowtail shiner	52.7	47.3	<0.001

Appendix D4. Capland and cupland mammal species in the Piedmont.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Neotoma magister*	Allegheny woodrat	34.2	65.8	<0.001
HH	*Erethizon dorsatum*	Common porcupine	41.0	59.0	<0.001
HH	*Lontra canadensis*	River otter	42.8	57.2	<0.001
HH	*Peromyscus maniculatus*	Deer mouse	43.3	56.7	<0.001
HH	*Parascalops breweri*	Hairy tail mole	45.0	55.0	<0.001
HH	*Sorex fumeus*	Smoky shrew	47.0	53.0	<0.001
HH	*Tamiasciurus hudsonicus*	Red squirrel	48.9	51.1	0.003
HH	*Glaucomys volans*	Southern flying squirrel	48.9	51.1	0.003
DD	*Sorex hoyi*	Pygmy shrew	82.8	17.2	<0.001
DD	*Sciurus niger*	Fox squirrel	81.0	19.0	<0.001
DD	*Lynx rufus*	Bobcat	80.6	19.4	<0.001
DD	*Cryptotis parva*	Least shrew	66.7	33.3	<0.001
DD	*Ursus americanus*	Black bear	63.6	36.4	<0.001
DD	*Clethrionomys gapperi*	Southern redback vole	52.5	47.5	0.002

Appendix D5. Capland and cupland snake and lizard species in the Piedmont.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
HH	*Thamnophis sauritus*	Ribbon snake	42.9	57.1	<0.001
HH	*Opheodrys aestivus*	Rough green snake	43.1	56.9	<0.001
HH	*Sceloporus undulatus*	Northern fence lizard	45.6	54.4	<0.001
HH	*Diadophis punctatus*	Northern ringneck snake	46.1	53.9	<0.001
DD	*Opheodrys vernalis*	Eastern smooth green snake	80.1	19.9	<0.001
DD	*Storeria occipitomaculata*	Northern redbellied snake	75.1	24.9	<0.001
DD	*Regina septemvittata*	Queen snake	71.4	28.6	<0.001
DD	*Nerodia sipedon*	Northern water snake	62.7	37.3	<0.001
DD	*Heterodon platirhinos*	Eastern hognose snake	57.2	42.8	<0.001
DD	*Carphophis amoenus*	Eastern worm snake	55.8	44.2	<0.001
DD	*Agkistrodon contortrix*	Northern copperhead snake	55.3	44.7	<0.001
DD	*Storeria dekayi*	Northern brown snake	54.1	45.9	<0.001

Appendix D6. Cupland turtle species in the Piedmont.

Habitat	Scientific name	Common name	DD%	HH/TT%	p
DD	*Pseudemys rubriventris*	Redbellied turtle	68.8	31.2	<0.001
DD	*Sternotherus odoratus*	Stinkpot turtle	66.6	33.4	<0.001
DD	*Chelydra serpentina*	Common snapping turtle	65.5	34.5	<0.001
DD	*Clemmys insculpta*	Wood turtle	65.5	34.5	<0.001
DD	*Clemmys muhlenbergii*	Bog turtle	64.6	35.4	<0.001
DD	*Chrysemys picta*	Midland painted turtle	64.5	35.5	<0.001
DD	*Graptemys geographica*	Map turtle	64.3	35.7	<0.001
DD	*Clemmys guttata*	Spotted turtle	62.2	37.8	<0.001
DD	*Terrapene carolina*	Eastern box turtle	57.0	43.0	<0.001

Curriculum Vitae

Ningning Kong
5 Land & Water Bldg.
University Park, PA 16802

Email: kongnn@psu.edu
Phone: 814-574-9188

Education:

Ph.D. in Ecology, 2006, The Pennsylvania State University.

M.S. in Landscape Ecology, 2001, Peking University.

B.S. in Environmental Science, 1999, Peking University.

Teaching Experiences:

Teaching Assistant, Fall 2002-2005, Remote Sensing and Spatial Data Handling (Forestry 455).

Teaching Assistant, 2002-2006, Natural Resources GIS (Forestry 496A/B).

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