

## METHODS

### The Study Area

To understand the methods used to map the land cover of Virginia, it is useful to have a brief description of the Commonwealth in mind. Virginia is 102,830 km<sup>2</sup> in size. Most of it is privately owned. It is located roughly at the mid-point of the eastern coast of the United States, between 36° 30' N and 39°30'N latitude. This area on the North American continent contains the southern end of the ranges of boreal species and the northern end of the austral species. The union of ranges, along with favorable climate and a variety of landforms account for great flora and faunal diversity (Woodward and Hoffman 1991).

The climate is considered within the humid subtropical zone, with generally warm to hot summers and mild winters. The average precipitation is 1150 mm. Both temperature and precipitation are heavily influenced by local topography.

The Commonwealth is topographically very diverse. Due to the east-west orientation of Virginia, the state crosses 5 of 20 physiographic provinces of North America (Figure 2). The 3 western mountainous physiographic regions include, west to east, the Appalachian Plateau, the Ridge and Valley Province, and the Blue Ridge. East of the Blue Ridge is the rolling topography of the Piedmont Plateau and the flat Coastal Plain (Daniels et al. 1973).

The southwestern counties of Buchanan, Dickenson, and Wise fall within the Appalachian Plateau (Figure 3). This region is defined by horizontal Paleozoic sedimentary rocks, which have been carved throughout by small streams. The erosion of these streams has caused a dendritic pattern with a network of deep valleys (Daniels et al. 1973). This mountainous area has been heavily mined for coal (Woodward and Hoffman 1991).

The Ridge and Valley Province accounts for most of the land area in the western third of Virginia. This region contains the same sedimentary basin as the Appalachian

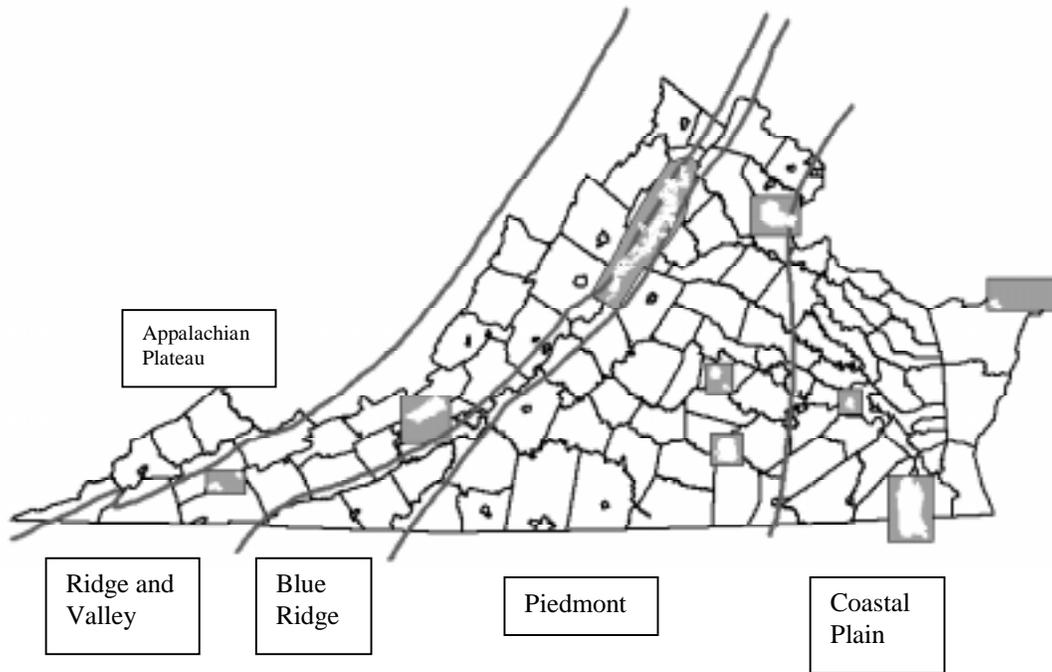


Figure 2. Physiographic provinces of Virginia with study areas. The study areas are outlined in gray boxes with individual maples shown in white.

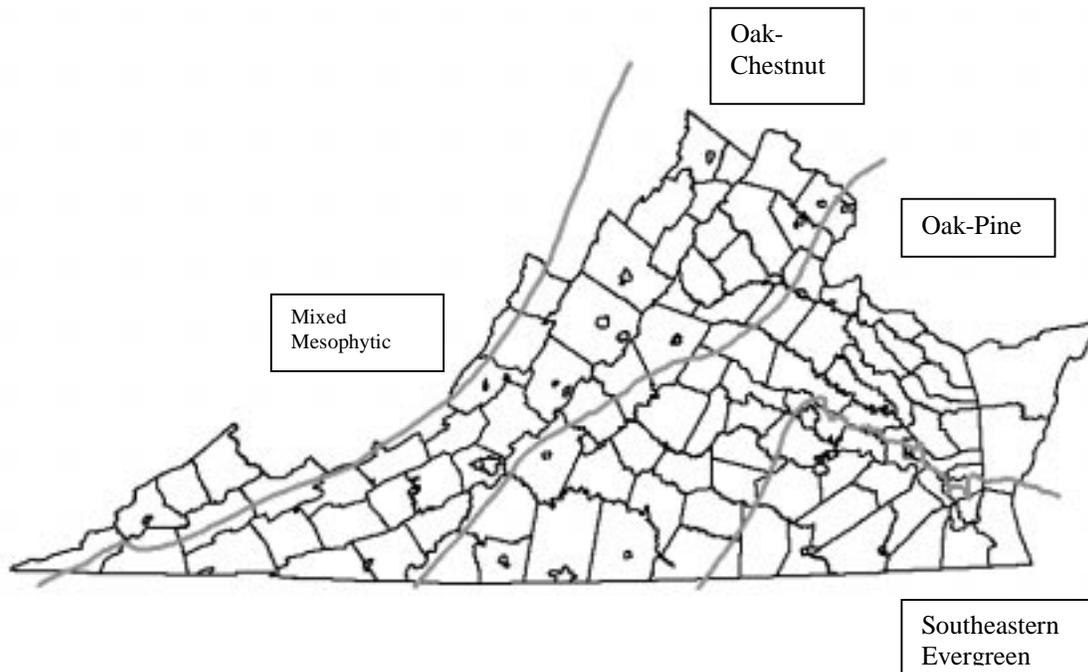


Figure 3. Natural vegetation of Virginia according to Braun (1950).

Plateau and is characterized by the folding and faulting that these rock have undergone. Folds, faults, and the erosion of less-resistant rocks have created a pattern of long thin parallel ridges and valleys. Karst topography, formed by the dissolution of carbonate rocks, is also found throughout this region. Large sinkholes, extensive caverns, and disappearing streams, typical of Karst landscapes are present. The Allegheny Mountains define the western part of the Ridge and Valley Province. The Great Valley, which stretches from New York to Alabama, makes up the eastern border of this province.

On the eastern edge of the Great Valley, known locally as the Valley of Virginia, lies the Blue Ridge Mountains. Geologically this region is much different than the previous 2 mountain provinces. This high-relief terrain contains granites, quartzites, and greenstones (Conners 1988). The northern Virginia Blue Ridge is fairly narrow and averages 600 m elevation. The elevation increases southward, peaking at the highest summit in the Commonwealth, Mount Rogers at 1746 m. South of the City of Roanoke the Blue Ridge widens (Figure 2).

The Blue Ridge escarpment divides the Blue Ridge physiographic province from the rolling hills of the Piedmont Plateau. Like the Blue Ridge, the Piedmont is narrow in Northern Virginia and broadens southward. This Province, dominated by metamorphic rock (Woodward and Hoffman 1991), has the largest land area of any of the 5 regions. From 300 m above sea level (asl) at the Blue Ridge escarpment, the Piedmont gently slopes eastward to an elevation of only 60 m asl at the Fall Line.

Quite obvious in the north and less pronounced in the south, the Fall Line is the border between the Piedmont Plateau and the Coastal Plain (Figure 2). Young sedimentary rock defines the geology of the Coastal Plain province (Woodward and Hoffman 1991). The last of the 5 provinces gradually slopes from the Fall Line to the Atlantic Ocean, where dunes and beaches are common. Rich coastal wetlands exist in this estuarine zone.

The diversity of landforms in Virginia has produced a variety of natural vegetation. Due mainly to climate, the natural climax vegetation form is typically forest. Several researchers have placed the Commonwealth into zones of natural vegetation. Braun (1950) delineated 5 general classes of vegetation (Figure 3). Southeastern evergreen forest indicated by longleaf pine (*Pinus palustris*) occupies a small corner of the southeast. The transitional oak-pine forest, dominated by Virginia pine (*Pinus virginiana*), shortleaf pine (*Pinus echinata*), and several oaks (*Quercus* spp.), is present in the piedmont and northern coastal plain. Within the Blue Ridge and Ridge and Valley provinces, the oak-chestnut forest occurs. The associated species of this type include white oak (*Quercus alba*), chestnut oak (*Quercus prinus*), and northern red oak (*Quercus rubra*). American chestnut (*Castanea dentata*) dominated this zone until it was extirpated by a blight in the early 1900s (Woodward and Hoffman 1991). The most diverse natural vegetation class is the mixed-mesophytic forest found primarily in the Appalachian Plateau. Several species dominate this zone. These include American beech (*Fagus grandifolia*), eastern hemlock (*Tsuga canadensis*), yellow poplar (*Liriodendron tulipifera*) or tulip tree, sugar maple (*Acer saccharum*), red oak, white oak, various hickories (*Carya* spp.), and ashes (*Fraxinus* spp.). The last group, relict boreal forest, is sprinkled throughout the mountains at high elevations. Red spruce (*Picea rubens*), Fraser fir (*Abies fraseri*), and balsam fir (*Abies balsamea*) make up this forest type.

Kuchler (1964) mapped potential natural vegetation throughout the United States. He outlined 6 zones in Virginia. Within the Appalachian Plateau, the Mixed Mesophytic Forest occurs. Sugar maple, beech, buckeye (*Aesculus octandra*), yellow poplar, white oak, northern red oak, and basswood (*Tilia heterophylla*) dominate. The Appalachian Oak Forest type, found in the southern Ridge and Valley and the entire Blue Ridge provinces, is characterized by northern red and white oaks. At high elevations within the mountainous physiographic provinces, the Northern Hardwood zone occurs. Dominants

in this group include sugar maple, beech, yellow birch (*Betula allegheniensis*), and eastern hemlock. Covering the greatest land area in Virginia, encompassing the northern Ridge and Valley, the entire Piedmont, and most of the Coastal Plain, is the Oak-Hickory-Pine Forest. This medium-tall to tall forest consists of hickories, loblolly pine (*Pinus taeda*), shortleaf pine, white oak, and post oak (*Quercus stellata*). Along the Atlantic coast, Northern Cordgrass Prairie is the potential natural vegetation type. This dense, medium-to-tall grassland is dominated by seashore saltgrass (*Distichlis spicata*) and cordgrass (*Spartina* spp.). The last type, Southern Floodplain Forest, occurs in the extreme southeast corner of Virginia. Dominants in this zone include water tupelo (*Nyssa aquatica*), various oaks (*Quercus* spp.), and bald cypress (*Taxodium distichum*).

Bailey (1976) mapped ecoregions that can be related to natural vegetation, climate, and landform. He claimed that 2 ecoregions (or provinces) occur in Virginia. The Eastern Deciduous Forest Province covers the area within the Blue Ridge, Ridge and Valley, and Appalachian Plateau provinces. This area is described as having adequate precipitation year round, warm summers and cold winters, and forest canopies dominated by temperate deciduous tree species. The Southeastern Mixed Forest Province, the eastern most of Bailey's 2 ecoregions, encompasses the Piedmont and the Coastal Plain. Mild winters and hot humid summers, precipitation generally greater than evaporation, and forests of evergreen and deciduous species characterize this ecoregion.

Bailey's (1976) classic work, described above, has since been updated (Bailey 1995). Virginia now is considered to occupy 3 regions. The Eastern Deciduous Forest Provinces, described above, is now called Central Appalachian Broadleaf Forest - Coniferous Forest - Meadow Province. This area, described essentially the same as in Bailey (1976), is defined by varying natural vegetation communities at various elevations. The Southeastern Mixed Forest Province still covers the Piedmont. The Outer Coastal Plain Mixed Forest Province is the added region, encompassing the coastal plain physiographic province. Virginia is in the northern range of this newly defined

province, a province that has a description similar to Kuchler's (1964) Southern Floodplain Forest.

Besides the natural ecological processes implicit within the categories mentioned above, the presence of a land cover type on an area is dependent on past disturbance and human use. Virginia, like most eastern U.S. states, has a long history of human dominance over the landscape. Most of the forests have been cleared at least once during the eighteenth and nineteenth century for timber, agriculture, charcoal, and other miscellaneous reasons (Woodward and Hoffman 1991). Some are in their fifth harvest cycle.

Coal mining is a major industry in the Appalachian Plateau. Strip mines throughout 7 of the extreme western counties (e.g., Buchanan and Dickenson counties) are evidence to this activity. This region is fairly underdeveloped in agriculture or settlements as compared to other provinces.

Both the Ridge and Valley Province and the Blue Ridge have similar land use patterns. The lower elevation, more productive, and easily accessible lands are used in agriculture. Grazing is the dominant agriculture activity. The high elevation, highly sloping lands are covered in second growth forest. Most of public land in Virginia, the U.S. Forest Service's Jefferson and George Washington National Forests and the National Park Service's Shenandoah National Park and Blue Ridge Parkway, fall into this category of mountainous second growth forest. Several wildlife management areas (WMAs) of the Virginia Department of Game and Inland Fisheries are on these comparatively-less-productive lands.

The rich soils of the Piedmont Plateau give rise to a mosaic of forest and agriculture. Tobacco, wheat, and dairy are the most common forms of agriculture. Pine plantations and Christmas tree farms are also popular. The majority of the land managed by the Virginia Department of Forestry occurs in this region. A highly urbanized

landscape is present in the northern Piedmont, near Washington, D.C. This area is rapidly moving from rural agriculture to urban/suburban (Hawkins 1995).

Highly urbanized areas also occur around Richmond, through Newport News, and into Norfolk and Virginia Beach. An agricultural mosaic dominates the rest of the Coastal Plain. Cotton, tobacco, and peanut plantations are common. Closer to the Atlantic Ocean, coastal wetlands, sandy beaches, and wind-swept dunes are found. The Great Dismal Swamp National Wildlife Refuge (managed by the U.S. Fish and Wildlife Service) is the largest area in the region of relatively undisturbed, forested, public land. The Eastern Shore (or Delmarva Peninsula) has a similar landscape to that of the mainland Coastal Plain with the exception of an abundance of truck crops. Ever-changing barrier islands are located off of the Atlantic coast of the Delmarva Peninsula.

### **Select Study Areas**

The landscape of Virginia is extremely diverse. In order to map land cover on a statewide scale, at a relatively fine resolution (30m x 30m cells), it is necessary to understand the structure and dynamics of land cover on a local scale. To this end, 9 study areas were located throughout the Commonwealth (Figure 2). Each major physiographic region, i.e., mountains, piedmont, and coastal plain, contains 3 sites. These 3 regions also follow Bailey's (1995) ecoregions, described above. For digital remote sensing purposes, the Appalachian Plateau, Blue Ridge, and Ridge and Valley provinces were combined into one "mountain" region because of their common topographic relief. Besides the obvious differences in landform, the mountain, piedmont, and coastal plain regions were separated, since they were known to have different climate conditions, natural plant communities, and land use. Each study site was chosen on several criteria: ease of access (i.e., public ownership) to allow comparison of actual land cover to images in hand, availability of current digital cover maps, large distance from other study sites (i.e., even distribution across the Commonwealth), and representation of regional land cover.

The 3 mountain study areas are Hidden Valley/Clinch Mountain, Craig Creek, and Shenandoah National Park. Hidden Valley and Clinch Mountain (HV/CM) are 2 proximal wildlife management areas, managed by the Virginia Department of Game and Inland Fisheries (VDGIF). Both have high elevations with steep slopes. The natural vegetation consists of second growth forest, mostly oaks, maples, hickories, beech, yellow poplar, and hemlock. Both have red spruce stands at the highest elevations (VDGIF 1996). This far-southwestern study area also includes the ridges and valleys between the wildlife management areas. The whole site is fairly indicative of landscapes within the southern Ridge and Valley Province.

The other mountain study site within the Ridge and Valley Province is the Craig Creek area. Land features in this area include the entire Craig Creek watershed (an area managed by the Blacksburg Ranger District of the Jefferson National Forest, U.S. Forest Service), the town of Blacksburg, the eastern section of the Radford Arsenal (U.S. Army), a small section of the New River, Mountain Lake, and the Mountain Lake Preserve. Blacksburg contains Virginia Polytechnic Institute and State University, the site of the analyses being reported. This study site thus allowed short distances to be traveled for field verification and also advice from local experts.

The last mountain study site on the list is Shenandoah National Park. This is the largest of the study areas encompassing over 9,000 km<sup>2</sup> of the Blue Ridge Province. Second growth forest, dominated by chestnut oak (*Quercus prinus*), northern red oak, black locust (*Robinia pseudoacacia*), yellow poplar, cove hardwoods, various pines, and eastern hemlock, cover Shenandoah Mountain. Agricultural endeavors cover the lower productive Shenandoah Valley to the east. The Piedmont Plateau lies to the west.

Fort Pickett, Amelia/Powhatan Wildlife Management Areas, and Quantico Marine Corp Base are the 3 Piedmont study sites. Fort Pickett, administered by the U.S. Army, contains over 18,000 ha in parts of Nottoway, Dinwiddie, and Brunswick counties. The land cover does not contain the variety of agricultural activities of the surrounding area

but has a slightly higher percentage of forested land at 82% (DCR 1994). Natural vegetative communities are fairly typical of the region. A unique feature of Fort Pickett is the 4,000 ha “impact area”. Through years of military training and testing, ammunition-ignited wildfires, and control burns, a rare fire-influence ecosystem has risen, the only such systems in Virginia (DCR 1994). This savanna-like setting (oak-pine grassland) is home to several endangered species and one of the most dense quail populations in the Commonwealth (DCR 1994).

Amelia and Powatan are 2 wildlife management areas within 8 km of each other. These lands, managed by VDGIF, contain a mix of early, middle, and late successional stage communities (VDGIF 1996). The area between the wildlife management areas is a mosaic of agriculture and private forests. The total study site is approximately 250 km<sup>2</sup>.

The northern and eastern-most piedmont study area is Quantico Marine Corps Base. This area contains approximately 21,000 ha of forest, 2,000 ha of herbaceous cover, and 550 ha of wetlands (Casabona 1995). Just north of this site is the urban sprawl of northern Virginia (Arlington/Washington, D.C. outskirts). The eastern tip of Quantico, part of which borders the Potomac River, falls within the Coastal Plain.

Chickahominy Wildlife Management Area, Saxis Wildlife Management Area/Chincoteague NWR, and Great Dismal Swamp NWR make up the 3 Coastal Plain Province study sites. Chickahominy Wildlife Management Area, while containing several tidal creeks and marshy wetlands, is mostly uplands. Located within Charles City County on the Chickahominy River, this site has over 2000 ha of land in a variety of successional stages (VDGIF 1996). The surrounding private land, typical of the central Coastal Plain, is included in this site.

The Saxis Wildlife Management Area/Chincoteague NWR study area provides a cross section of the Eastern Shore of Virginia. Saxis Wildlife Management Area, on the Chesapeake bay side of the Delmarva Peninsula, is almost entirely pristine tidal marsh. The wildlife management area, totaling over 2000 ha, is divided into a northern and a

southern section by Messongo Creek (VDGIF 1996). The land between Saxis and Chincoteague is mostly privately owned and dominated by agriculture. Chincoteague National Wildlife Refuge occupies the southern portion of Assateague Island. This barrier island along the Atlantic Ocean, has a variety of land cover types including: sandy beaches, dunes, herbaceous and shrubby upland, loblolly pine and hardwood forests, and protected tidal marshes.

The Great Dismal Swamp National Wildlife Refuge is the ninth study site. Managed by the U.S. Fish and Wildlife Service, this 40,000 ha forested wetland is located in extreme southeast Virginia and northeast North Carolina. The area has a long history of human disturbance including logging, controlled burning, and agriculture (Gammon and Carter 1979). Several plant communities are present including: pine, Atlantic white-cedar (*Chamaecyparis thyoides*), tupelo<sup>1</sup>-baldcypress<sup>2</sup>, red maple-blackgum, sweetgum<sup>3</sup>-oak-poplar, marsh, evergreen pocosin shrub, and sphagnum bog. Lake Drummond, one of only 2 natural lakes in Virginia, lies at the center of the swamp. To the north of the refuge lie the urban centers of Norfolk, Suffolk, and Virginia Beach.

### **Classification Scheme**

The first step in land cover mapping was to determine a classification system, i.e., to list the land categories (or information classes) to be mapped. Several items were considered in this process: the wildlife-oriented primary objective; the secondary objective of multiple uses; the size of area mapped; the time limitations; the characteristics of the data; and the accuracy requirements.

As in most well planned mapping efforts, the objectives determined the classes and the procedures used. Since the objective of the land cover map to be created was to

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<sup>1</sup> (*Nyssa* spp.)

<sup>2</sup> (*Taxodium distichum*)

<sup>3</sup> (*Liquidambar styraciflua*)

identify gross-scale habitat, emphasis was placed on natural vegetative assemblages or communities. Different vegetation types as well as differences in age and structure of these types are important to wildlife. In land cover mapping it is desirable to have all-encompassing and mutually exclusive categories. To that end and also to fulfill the secondary objective of multiple uses of the map, categories were considered, such as developed areas, indirectly related to terrestrial wildlife.

The objectives also stated that the extent of this map include the over 100,000 km<sup>2</sup> of Virginia. It was to be completed in a reasonable amount of time, and be done on microcomputers (or personal computers). The personnel, both their number and skill, were also limited. The large area mapped and the limited resources dictated a relatively low level of detail. It would be impossible to map very specific habitat types in this broad-scale approach with a high level of accuracy.

The data available also determined the level of detail. Ideally, only the mapping objectives should determine the classification scheme, but realistically the characteristics and quality of the available data play a role. The data used are discussed in detail in the following sections. The Landsat TM imagery is probably the best data currently available. The high radiometric detail of this imagery offers the best opportunities for discriminating a variety of cover types among any available satellite data covering a large area. However, detailed vegetation communities are very difficult to delineate (Ioka and Koda 1986, Huber and Casler 1990). The 30 m pixel size offers adequate resolution except for small entities such as small wetlands or individual buildings. It is unrealistic to try to map individual trees, buildings, or thin hedgerows.

Accuracy of mapping is always a consideration. Many classes of information in a Landsat scene can be mapped, but not all classes can be mapped with reasonable accuracy. It is difficult to determine what “reasonable” accuracy means. “Reasonable” probably relates the above mentioned criteria of time, money, skill of interpretation, data quality, supporting data quality, and the realistic uses to which the product will be put. It

was anticipated that the results of this land cover mapping effort would be used in a variety of wildlife-related GIS operations. The output of overlays, distance measurements, landscape metrics, and other GIS procedures, potentially used in a wildlife habitat analysis, are all affected by accuracy. For example, if 2 GIS layers, each having an 80% accuracy, are then combined to create a third layer, the expected accuracy of this output layer could be as low as 64% (or  $0.8 \times 0.8$ ). Therefore, it is usually unproductive to attempt to map a land cover category that is known *a priori* to have a high potential for low accuracy.

The last consideration in determining the land cover classes mapped was past classification systems. The Anderson scheme (Anderson et al. 1976) was selected, due to its reliance on remote sensing data to determine land cover. This system is also important in that it covers all land cover categories. The SAF forest type classification (Erye 1980) and the The Nature Conservancy (TNC1994) classifications were also considered due to their relevance to natural vegetation and wildlife habitat in general. Many wildlife habitat models and much past research have been based on SAF forest types. However, the emphasis on remote sensing data and the broadness of categories prompted the focus on the Anderson system. The classification that resulted within this thesis is a modification of the Anderson scheme mostly at level I, but with the forest and wetland categories (both of which are critical to many wildlife species and also emphasized within the SAF and TNC schemes) separated to level II. Therefore this scheme is labeled a modified Anderson Level I and is listed in Table 2. Each land cover class is discussed below.

#### Herbaceous/Agriculture Vegetation

Agricultural lands are used predominantly for producing food and fiber. Short herbaceous ground cover defines this type. Included in this category are: cropland, vineyards, ornamental horticulture, pasture, fallow fields, rangeland, golf courses, large

Table 2. Land cover classification scheme.

Land Cover Type	Raster Cell Value
Deciduous Forest	11
Coniferous Forest	12
Mixed Forest	13
Shrub/Scrub	20
Herbaceous (mostly agriculture)	30
Open Water	40
Disturbed	50
Coastal Wetlands	60

lawns, recent clear cuts, and other forest openings and agricultural land. Road rights-of-way can also show up in this category. This is an early successional stage and/or intensively managed class.

### Shrub

In Virginia, shrublands are typically a successional stage between herbaceous (agriculture) and forest. Woody vegetation less than 3 m tall dominates these areas. Shrubs also define edges between forest and agriculture or fallow fields. Some pasture land falls into this category. Such areas present the challenges in classifying sites which occur on a continuum of ages among cropland and managed pasture through fallow fields, rough pasture, and recently-harvested forest land.

### Forest

Lands classified as “forest” are dominated by woody vegetation over 3 m tall. Tree basal area must be greater than 10 % of a pixel. There are 3 sub-classes:

#### Coniferous Forest

Areas dominated by overstory trees with year-round green leaves, there must be 70 % evergreens present.

#### Deciduous Forest

Forested lands containing predominately overstory trees which loose their leaves during winter, 70 % deciduous trees must be present.

#### Mixed Forest

Areas with both coniferous and deciduous overstory trees, there must be less than 70 % coniferous trees and less than 70% deciduous trees.

### Open Water

This category includes any open water area larger than the minimum mapping unit or 30 m x 30 m TM resolution. Lakes, reservoirs, streams, rivers, bays, and ponds

are all included. Due to area limitations, small water bodies, often valuable to a variety of wildlife, will rarely be included.

### Disturbed

This class includes the “barren” and “urban or built-up” categories in Anderson et al. (1976). “Disturbed” does not necessarily imply human disturbance. This cover-type includes such things as: cities, airstrips, landfills, industrial centers, bare soil, bare rock, cement, quarries, strip mines, sandy beaches, and lone developments.

### Coastal Wetlands

This class includes large coastal wetlands. Small inland wetlands are better mapped using higher (than 30 m) resolution data. The water table must be at, near, or above the ground for a significant part of most years, for the area to be a wetland (Anderson et al. 1976). Vegetation must be present or the water level must be shallow to separate this category from water.

### Other

The last category is for unclassifiable map cells. If a map unit does not fit well in any category, it may be placed in the “other” class. The initial intent of this category was to hold areas dominated by heavy cloud cover or shadow. Further work on these sites may eventually allow them to be removed from this class.

## **Future Ancillary Datasets**

It is assumed that additional datasets will be available in the near-future to supplement this classification. A “developed lands” layer has been created by VDGIF and personnel at Virginia Tech (Jones and Phillips 1996). A road-buffering algorithm was used, under the assumption that high road densities equated to developed areas. This information will divide the disturbed category above into “urban and built-up” and “barren.” However, this layer has not yet been fully evaluated.

Wetlands information is also available in the form of the National Wetlands Inventory (NWI). NWI is a project of the U.S. Fish and Wildlife Service. Wetlands mapped at 1:12,000 scale will soon be complete for the entire commonwealth (Shaffer 1997). This fine scale product is much better suited to evaluating these communities than is the processing of Landsat imagery.

This thesis research was conducted with the knowledge of the NWI and developed lands data. It was felt that including these information layers was beyond the scope of this project. Both of the NWI and the developed lands layers will be welcome additions to the land cover map present here.

### **Landsat Imagery**

Landsat TM imagery is the basic dataset from which land cover was mapped. These data have a 30 m x 30 m cell size with 7 bands of information (Table 1), however band 6 was not available. These images were provided by the Multi-Resolution Land Characteristics (MRLC) consortium. The MRLC is a group of government agencies who pooled their resources to purchase remote sensing data (Loveland and Shaw 1996). The Landsat TM scenes used in this study were provided for the Virginia Gap Analysis Project (Scott et al. 1993). This digital imagery set was transferred from the United States Geological Survey's (U.S.G.S.) EROS Data Center via 8mm tape. Each band of each scene contained a header file. On each header file were such items as georeferencing, scene date, and other source information.

Fourteen scenes were required to cover the area of Virginia (Figure 4). To fulfill the mapping objectives of the MRLC and the Virginia Gap Analysis Project (both of which require greater thematic detail than this thesis permits) images of leaf-off period and leaf-on period were required. Eleven of the 14 Virginia scenes had 2 dates. However, many of the pairs were not truly leaf-on and leaf-off; several were either both leaf-off or both leaf-on. The full geographic extent of the scenes can be seen in Figure 4.

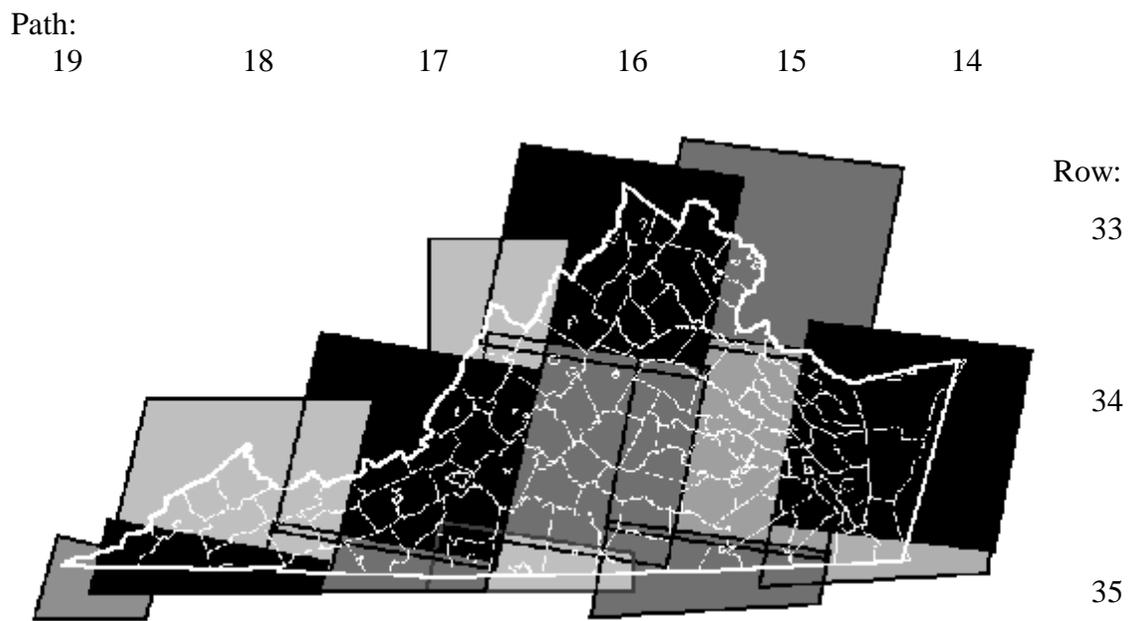


Figure 4. Landsat TM scenes within Virginia.

Due to the seemingly few thematic land cover categories to be mapped, the time and hardware/ software limitations of this project, and availability of only 1 date for several scenes, it was decided that only 1 scene date would be processed from each multi-date pair. The dates in Table 3 represent the dates of the image used in this project.

Another data type that was provided along with the 6-band TM imagery was a hypercluster aggregation of each scene date (Loveland and Shaw 1996). Hyperclusters are the results of an unsupervised clustering of the raw 6-band data. The hypercluster data represent a type of data that differs from other unsupervised clustering because they result in a high number of clusters (spectrally related groupings). There are 240 unlabeled clusters in these data (Kelley and White 1993). Kelley and White (1993) present a technical description of the hyperclustering process.

The intended purpose of these products was to aid operators with limited experience in image processing (Benjamin et al. 1996). Since the clustering is complete, only assigning clusters to information classes was required. While this was a very efficient method for image interpretation, it did preclude any preprocessing (typically completed before classification), including adjustments for atmospheric, topographic, or other effects.

### **Training Data**

In any digital image processing, large amounts of evenly distributed and representative ground data are required. In supervised classification, training data are needed at the start of classification. In unsupervised classification, training data are essential for assigning clusters to land cover categories. These methods were discussed earlier in the Image Processing section of the Literature Review.

**Table 3. Dates of Landsat TM scenes used in classification.**

Landsat TM Scene	Date used
1435	6/23/92
1434	8/10/92
1535	5/16/93
1534	10/18/92
1533	9/16/91
1635	3/1/92
1634	9/28/93
1633	3/1/92
1735	11/3/92
1734	10/2/92
1733	7/17/93
1835	10/29/92
1834	11/29/93
1935	4/23/92

Training data were acquired from a variety of sources across Virginia. Each of the 9 study sites, described above, was chosen partially because of the existence of ground information. Most of the information available consisted of vector-based maps (known as “digital maplets”) that contain land cover as one of the polygon attributes.

Hidden Valley/Clinch, Amelia/Powhatan, Chickahominy, and Saxis (part of Saxis/Chincoteague) study areas all contained maplets created by the VDGIF’s Habitat Inventory Project. These vector polygon coverages are part of this project. The project will eventually map all of VDGIF’s properties at a scale of 1:12,000. Aerial photographs are the source of information. The land cover, including SAF forest types, has been checked in the field by local biologists.

The military installations of Fort Pickett and Quantico have land cover vector maps produced by their respective natural resource management divisions. The Fort Pickett inventory was done in cooperation with VDGIF. Many of the same procedures used to build VDGIF’s Habitat Inventory Project were applied to the land cover survey of Fort Pickett. The Quantico maplet was completed by a private contractor using 1988-1991 aerial photographs and was ground checked sparingly.

The Blacksburg/Craig Creek study site contained Continuous Inventory of Stand Condition (CISC) data provided by the Jefferson National Forest (U.S. Forest Service). CISC is the main spatial database used by the Jefferson National Forest to inventory and monitor their resources. This approximately 45,000 ha area contained 22 compartments with approximately 600 stands (Trani 1996).

Great Dismal Swamp National Wildlife Refuge (GDSNWR) and Shenandoah National Park (SNP) also had digital land cover maps. The GDSNWR map is a digitized version of the vegetation map discussed in Gammon and Carter (1979). Using seasonal infrared photography, this map was produced at a scale of 1:100,000. The training data for SNP consisted of a forest cover map with the following SAF classes: pines (*Pinus* spp.), red oak/ash/basswood, eastern hemlock, chestnut oak, northern red oak, black

locust, yellow poplar, open areas/grasslands, and barren. Aerial photography interpretation and field verification were used in this survey.

The second major type of training data was aerial photography. It was desirable to have training data that covered an area greater than the digital maplets. The maplets also tended to be biased toward forested lands due to the missions of the agencies who created these coverages. Color-infrared photographs provided independent data sources. The areas selected included representative areas of the agricultural, shrub, developed, and disturbed categories.

Color-infrared aerial photographs were obtained through the USGS. These images were part of the National Aerial Photography Program (NAPP). These 9 inch x 9 inch (35.5 cm x 35.5 cm) prints are land images at a scale of 1:40,000 and cover an area of about 13 km<sup>2</sup> (33 miles<sup>2</sup>). The dates of the photographs ranged from 1988 to 1994, with the majority in 1994. All the images were taken in either March or April, a period that is considered leaf-off. The 28 images covered 6 of the 9 study areas including: 9 photos over Blacksburg/Craig Creek, 4 over Hidden Valley/Cinch Mountain, 5 over Shenandoah National Park, 1 in Powhatan/Amelia, 3 around Chickahominy, and 6 over Saxis/Chincoteague. Fort Pickett, Quantico Marine Corps Base and Dismal Swamp were not included in the NAPP set due to the excellence of their digital land cover maps and also because of the national security issues regarding the military installations. Light (1993) presented a good review of NAPP technical specifications.

The last type of training data used was expert knowledge and review. Local land managers, biologists, and creators of the digital maplets were consulted on several occasions. Managers and biologists were asked to point out any unique land cover entities and also to review intermediate stages of the output. Creators and users of the digital maplets were queried about the confidence or perceived accuracy in their maps. Their comments provided a general idea of the usefulness of each land cover class in the digital maplets. Much of this review took place during a visit to each of the 9 study areas

in June of 1995. This trip allowed a first-hand observation of each of the diverse study sites. The use of expert knowledge, aerial photographs, and existing small area digital land cover maps resulted in an excellent understanding of each study area as well as a general idea of the land cover variation across Virginia.

### **Image Preprocessing**

Before the Landsat TM images could be classified, some preprocessing was required. The majority of preprocessing was completed at the EROS Data Center (EDC) of USGS, prior to shipment. Radiometric correction was performed by using a debanding algorithm to remove striping and, where necessary, a line averaging process to correct for dropped lines. EDC also completed a geometric correction on each scene. Control points were obtained from 1:100,000 scale DLGs. The X and Y coordinates were attached to a line and column coordinate within the raster image. Elevation values from 1:250,000 DEMs, which are also known as 3 arc-second digital terrain and elevation data (DTED) because an elevation is recorded at every 3 arc-second latitude/longitude interval (approximately every 80 m), were used in a terrain correction. Terrain correction accounts for the differences in 2-dimensional area between flat areas and highly sloping areas. Cubic convolution resampling was then used to output the data to Universal Transverse Mercator (UTM) projection, NAD83 datum, and 30 m x 30 m pixels. This process resulted in a reported plus-or-minus one pixel (or 30 m) root mean square error (RSME) positional accuracy.

The Landsat TM data arrived on 8 mm tapes in a generic raster format with separate header text files for each band. The header files contained information such as georeferencing (coordinates for the 4 corners), number of lines and columns within the raster, and the date the image was recorded.

The tapes were read into a SUN UNIX workstation. The data were then transferred via FTP, as binary computer files, to a local personal computer. Other

transfer and storage media utilized were large capacity 1.2 gigabyte optical cartridges. This was a time consuming operation due to the size of the files. One band is over 50 megabytes (mb) and a 6-band scene takes up about 350 mb of computer space. Once a scene was in place, it was converted to MIPS file format and examined. Any major errors in the image or files were reported to EDC and replacements obtained (on one occasion it was impossible to determine where in Virginia a scene was located; later it was realized that the image depicted parts of Michigan's Upper Peninsula!).

The next step was to georeference the TM data using the coordinates provided in the header files. This was completed in the Georeferencing module within MIPS. Upon comparison with other geographical information (such as DLG roads and rivers, county boundaries, and SPOT satellite images) it was determined that the EDC georeferencing for the Landsat scenes was inaccurate. Rivers and roads were displayed on the Landsat image 500 m from where they were actually located. Based on this discrepancy, it was decided to perform a second georeferencing. This would also allow the transformation of geographic datum from NAD83 (North American Datum 1983) to NAD27 (North American Datum 1927). This later model of the Earth's surface (NAD27) is more common among required ancillary data, such as DLGs, wetland maps, and training data.

SPOT Panchromatic satellite imagery, which has a 10 m x 10 m pixel resolution, was used as ground reference data. The SPOT images were recorded in 1994 and contain the highest level of preprocessing available (i.e., SPOTview products). These data were originally georeferenced using 1:24,000 topographic quads. This georeferencing is at a much finer scale than the 1:250,000 DLG layers used in the original Landsat processing. The SPOTview products also have a reported RMSE positional error half that reported by EDC for the TM scenes (15 m as opposed to 30 m).

The geo-correction process was completed within the PCI EASI/PACE image processing software package, for Windows 3.11. Within the GCPworks module, ground control points were located on both the SPOT image and corresponding Landsat scene.

These points were typically airport runway intersection, road intersections, ends of lake dams, or other such permanent, high-contrasting, visible features. To be high contrasting, a feature must be significantly spectrally different from surrounding land cover. As an example, a herbaceous field bordering on a concrete road or runway produces such contrast. These sites are easily identified on both 10 m SPOT and 30 m Landsat pixels. The UTM coordinate from the SPOT image is then transferred to the Landsat pixel, which is identified by a row and column address. Twenty to 50 ground control points were used for each scene. After all control points were identified, a nearest-neighbor resampling function was performed using a first-order transformation. A geometrically accurate Landsat scene resulted, with neither the pixel quantity or values altered. The final image was again compared to independent data to verify the geometric accuracy. The locational accuracy was much improved.

To reduce machine time and hard disk space, several scenes were subset to only include areas within 30 km of the Virginia border. This was a significant time saving factor for the following scenes: 1435, 1535, 1635, 1735, 1733, 1835, and 1935.

### **Image Classification**

The first step in classification was to inspect the scenes (both dates in multi-temporal scenes), including hyperclustered scenes. The images were inspected for clouds, haze, topographic influence, vegetative development (i.e., consistent phenology), and overall quality. Due to limited computing resources and time, only 1 scene date was used in classification. Leaf-off scenes were chosen over leaf-on scenes due to the greater potential of discriminating between coniferous, deciduous, and mixed forests. Other factors considered in choosing a scene date included: lack of clouds and/or haze; consistent phenology -- meaning that all of the image was either leaf-on or leaf-off (e.g., high elevations were in the same seasonal stage as lower elevations); lack of banding or other image errors; suitable sun angle when the image was recorded (the lower sun angle

of winter images creates problems with deep shadows); and closeness of the image date to the present. Once an image was inspected for quality and deemed to be the best of the available dates, classification could begin.

Initially, it was believed that only the single-date hyperclusters would be needed for statewide classification. As discussed above, the hyperclusters contained unlabeled classes with values from 1 to 240. By highlighting each hypercluster value individually, by altering the color value within the color palette editor (i.e., turning one of the 240 gray values to pink) and by comparing the highlighted areas to the training data (digital maplets and aerial photographs), it was possible to label each class. This multi-step process was completed in the TNT-MIPS software package.

MIPS was well suited for making these comparisons due to its ease of handling both raster and vector GIS data (the TM hyperclusters were rasters while the maplets were vectors). By zooming into a study area and overlaying the digital land cover maplet or visually assessing an aerial photograph, it was possible to compare each of the 240 hypercluster values to actual land cover.

The Virginia Atlas and Gazetteer (DeLorme 1989) was also used to locate water bodies and disturbed areas (e.g., roads, towns, strip mines). If necessary, the previous classification of an overlapping scene was also used as training data.

A whole scene was analyzed at once. After labeling was complete, each of the 240 classes were color-coded to each of the 9 land cover classes: deciduous forest was green, coniferous forest was dark green, mixed forest was aqua, shrub/scrub was orange, herbaceous was yellow, disturbed was red, open water was blue, coastal wetlands were pink, and other was white. Displaying this initial classification allowed the entire scene to be inspected. It also allowed me to print maps of certain areas for closer scrutiny. If the classification passed this qualitative inspection, it was considered finished. When possible, local experts were included in this process.

Next, the hypercluster was exported to ERDAS image processing software format and then imported into PCI EASI/PACE software. It was necessary to use the ERDAS format as intermediate to PCI to maintain image and georeferencing fidelity. Using several file formats greatly slowed the entire process and required extra hard-disk space. An aggregation procedure then transformed the 240 classes, each now with an associate land cover label, into an image with only the 9 land cover categories. The aggregation was performed within the AGGREG module of PCI.

While the method of classification described above was simple and efficient, it was very limited. It was very obvious, after the first study area was completed, that other factors needed to be considered. The first study area classified was Craig Creek/Blacksburg. Remotely sensed images of this mountainous area are affected by the different reflectance from the sloping terrain. South-facing slopes reflect more radiation, resulting in different spectra, than flat areas and much more than north facing slopes. Most of the mountains within this area, and in Virginia as a whole, occur in the form of southwest-northeast running ridges. The general orientation, therefore, can create a large discrepancy in reflectance patterns. The energy recorded (BV) by the Landsat TM sensor for a land cover type on south-facing slopes is different than the BV of the same land cover type on north facing slopes. The BV is typically higher on south facing slopes. This creates problems in digital image classification. The hyperclusters have a high number of possible categories (240), but this number of classes cannot cover the entire realm of possible land cover variations.

The initial land cover classification of Craig Creek shows a distinct pattern in the mountains (Figure 5). Deciduous forest was shown on the south-facing slopes and coniferous forest on the north-facing slope. Some of the deep coves, where little energy is reflected, were labeled as open water. These patterns do not reflect the actual land

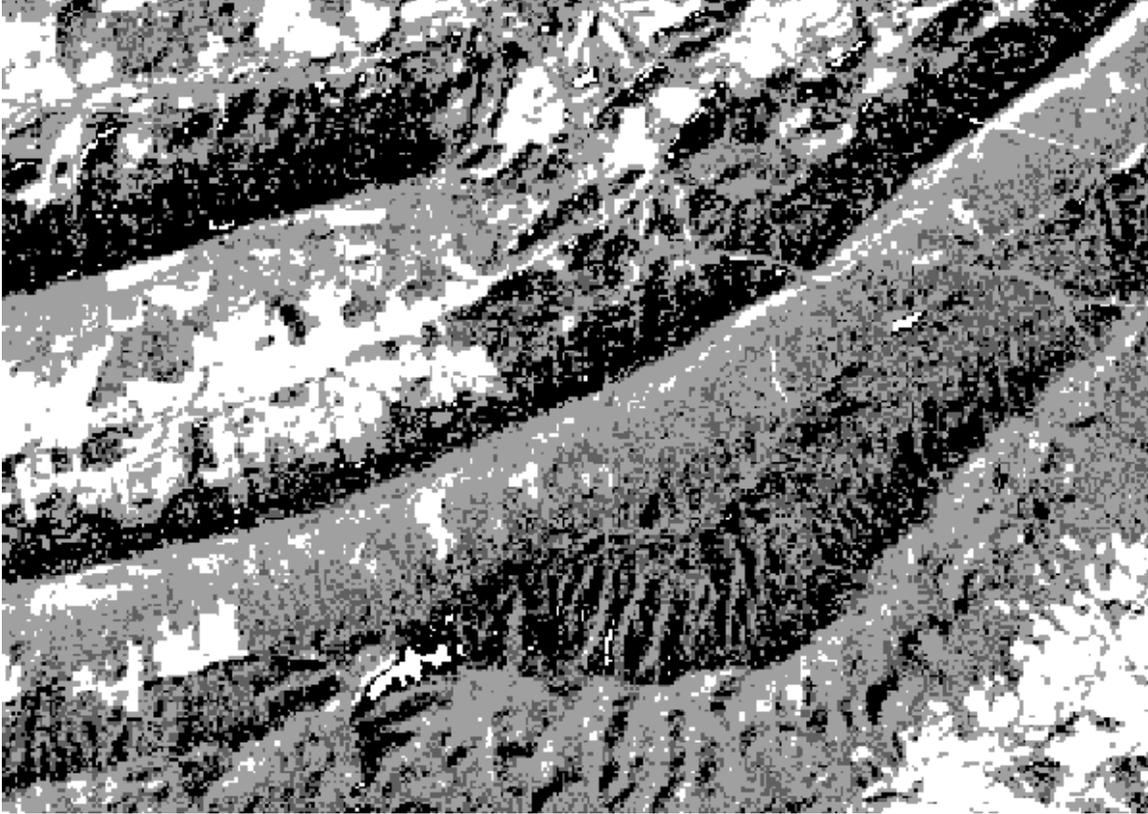


Figure 5. Initial forest classification of the Craig Creek study area. The black areas represent coniferous forest, light gray is deciduous forest, medium gray is mixed forest, and white is non-forested. Notice the distinct break between coniferous dominated north facing slopes and deciduous south facing slopes.

cover. The appearance of coniferous forest was the results of less reflection, while the misclassification of deep coves was the result of the areas acting as virtual black bodies (reflecting almost no energy), much the same as open water. The hyperclusters did not allow any flexibility in classifying topographically diverse landscapes. It was therefore decided, not to use the hyperclusters in the mountainous regions.

Upon inspection of raw (unprocessed) 6-band images near the coast, primarily scenes 1533, 1434, and 1435, another problem was apparent. A variable film of haze and several light clouds were present in some areas of these Landsat scenes. Haze and other scattering are worse as wavelength decreases (Campbell 1996). This means that the visible bands, especially blue, show the worst haze and scattering effects while the mid-infrared bands display the least response. Unfortunately, the haze problems transferred to the hyperclusters. Again, since the hypercluster is one image and not a set of bands, it is inflexible for use with a wavelength-related issue, which would normally be applied to raw bands. A more complex classification process was needed on these images.

The 3 scenes in the central Piedmont, 1635, 1534, and 1535, proved to be well suited to hypercluster driven classification. Scenes 1534, 1434, and 1435 were classified using supervised classification with a haze reduction procedure. A supervised classification, with special attention to differing aspects, was applied to the remainder of the Landsat images. Supervised classification was employed because it allows greater control during clustering than hypercluster aggregation (unsupervised classification).

Several methods were attempted to alleviate the topographic effect in classification. The initial idea was to use digital elevation models (DEM) and information about solar radiation to model where shadows and bright areas occurred.

This model could then be used as a correction factor to the raw bands. The topographic normalization technique reported by Civco (1989) appeared very promising. This 2-stage process was tested on the Shenandoah Study Area. The first stage used DEMs to normalize the topographic effect. By knowing the exact sun angle and elevation when the Landsat TM image was recorded, a hillshading (also referred to as shaded relief) model could be created with the elevation data (Figure 6). The hillshading model provides an illumination index, which should be relatively, the same as when the image was recorded, for each Landsat pixel. The raw 6 bands were then normalized according to these values in the following equation (Civco 1989):

$$CDN_{xij} = DN_{xij} + (DN_{xij} * \frac{(U_k - X_{ij})}{U_k} )$$

where

$CDN_{xij}$  = the normalized digital number for pixel<sub>ij</sub> in band<sub>x</sub>

$DN_{xij}$  = the raw digital number for pixel<sub>ij</sub> in band<sub>x</sub>

$U_k$  = the mean brightness value for the entire hillshading model

$X_{ij}$  = the hillshading illumination value for pixel<sub>ij</sub>

This equation was written into a MIPS spatial macro language (SML) program and run for the 6 bands in the Shenandoah study site. The image that resulted appeared much flatter than the raw image (Figure 7). However, there was much more extreme brightness and shadow than on the raw imagery. These negative artifacts rendered this process useless. The high elevations and large relief changes may have worked against this type of operation. The second stage of this process, which uses a correction factor derived from the means and variances of uniform pixels on North-facing and South-facing slopes within the equation above, was dropped due the failure of the first stage. However, the basic idea of this second stage normalization was used to develop the final classification methods within this physiographic province.

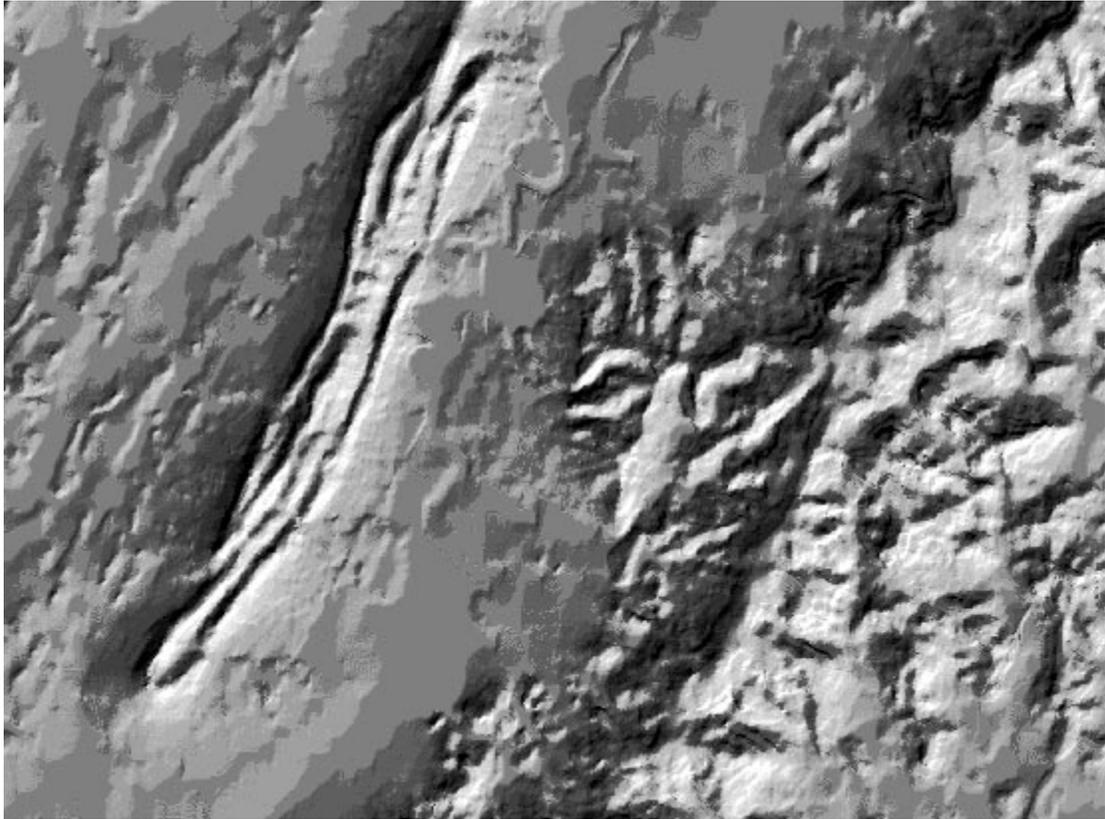


Figure 6. Hillshading model of central Shenandoah National Park and Massanutten Mountain. This model was created for the 3/1/92 date of scene 1633 with a sun elevation of 35 and an azimuth of 140 degrees.

A)



B)

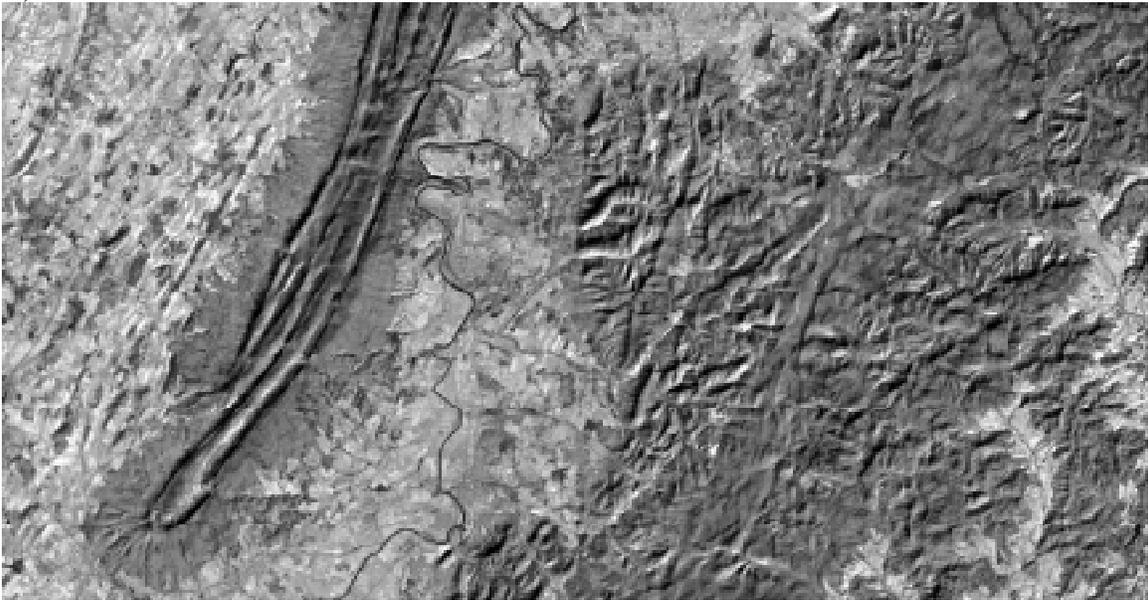


Figure 7. First stage topographic normalization of the Central Shenandoah area according to procedures outlined in Civco (1989). A) shows the 4,5,3 band composite before topographic normalization. B) is the same gray-scale composite after normalization.

Since the topographic effect caused such varied reflectance, it was decided to treat different aspects as different classes. In addition to the deciduous forest, coniferous forest, mixed forest, shrub/scrub, herbaceous, open water, disturbed, and wetlands 2 additional categories for each of the forest types, North-facing and South-facing, were added. Therefore each forest type had 3 classes, based on aspect (north, south, and flat). Only forest types were given aspect classes. This was due to past land use. The steep slopes are forested while most of the flatter slopes have been harvested and are now used in agriculture or urban development. There was also a lack of training data for each category for each aspect. Training data were adequate for the forest types, except that the mixed forest class was more difficult to identify on the aerial photographs than either deciduous or coniferous.

The supervised classification procedure was performed within the PCI EASI/PACE software package, running under Microsoft Windows 3.11. The specific operation took place within the Supervised application of Imageworks. Land units of uniform land cover were first identified on the training data. Corresponding areas on the raw imagery were located using the Imageworks module. Using on-screen digitizing (i.e., delineating areas with the computer mouse), these areas were made into training areas. Training areas are aggregations of pixels of a homogeneous land cover type. Training areas were representative of a land cover class. Several training areas were required to obtain the overall variety of spectral values within each class. From the pixels within the training areas, the computer calculated means and standard deviations for each category. All 6 Landsat TM spectral bands were used. During classification the computer compared each pixel to the means and standard deviations (calculated from the

training areas) of each class in order to assign it to the closest land cover class. A maximum likelihood algorithm was used (PCI 1994).

Lillesand and Kiefer (1994) discussed the maximum likelihood classification algorithm. This method is also called the Gaussian maximum likelihood classifier because of its assumption of normal distributions for each training set. This assumption seems reasonable due to the nature and large sample size of spectral data (Lillesand and Kiefer 1994).

Several features within the Supervised application of Imageworks (PCI software) made this process powerful and efficient. Within each class definition, the analyst inputs a threshold and a bias. Once the mean and variance are calculated for each class from the training data, the threshold determines the maximum spectral distance within which pixels could occur while still being within the same class. Threshold is measured in standard deviations. The area (threshold) and position (mean) of a category within spectral space is thereby delineated for each class. Invariably, land cover categories will overlap in spectral space. The bias determines which category will be assigned to the overlapping pixels (i.e., a tiebreaker). Therefore, the threshold is an *a priori* estimation of variance and the bias is an *a priori* estimation of frequency. Typically the deciduous forest categories were dominant (occurred frequently) and variable. These classes were given high threshold and high bias values. The water category was spectrally distinct from other classes, yet had a high variability. This class was usually given a high standard deviation and a low bias. The default values within PCI were 3.0 for threshold and 1.0 for bias. A listing of typical values for each variable within each category is shown below (Table 4).

An advantage of the PCI software is the Classification Preview option. This option displays a visual image of the classification before an output computer file is

Table 4. Threshold and bias values used during the supervised classification of TM scene 1734.

Land Cover Type	Threshold	Bias
Deciduous flat-slope	4.00	10.00
Deciduous south-slope	3.70	9.00
Deciduous north-slope	3.70	9.00
Mixed forest flat-slope	2.80	2.00
Mixed forest south-slope	2.80	2.00
Mixed forest north-slope	2.80	2.00
Coniferous flat-slope	3.90	9.50
Coniferous south-slope	3.65	8.00
Coniferous north-slope	3.70	7.50
Shrub/scrub	2.85	2.00
Open water	3.50	3.00
Herbaceous	6.25	5.00
Disturbed	3.40	2.00

written. Observing such an image allows the analyst to examine what the output would look like using the current training areas and corresponding threshold and bias values. Comparing the preview classification with the training data allows a qualitative assessment before actual classification. This creates an iterative process that allows maximum control by an analyst. Once the preview appeared exactly like the training data, the actual classification was completed.

Other functions in PCI's Imageworks classification module include Scatterplot Report and Signature Statistics. Both of these operations aid in evaluating the classification signatures. These were not used with the same frequency as the Classification Preview and the Threshold and Bias functions.

Besides allowing for control over topographic variation, supervised classification allowed more control over atmospheric variations than unsupervised classification. The hazy scenes required considerably different preprocessing and a slightly different classification method. In order to limit the amount of atmospheric noise in each individual band, a de-hazing process outlined by Lavreau (1991) was performed prior to classification. The first step was to quantify the haze. This was accomplished by calculating the fourth tasseled cap (TC4) transformation. The tasseled cap is a linear transformation that puts the major components of soil and vegetation into two-dimensional space (Kauth and Thomas 1976). The first 3 transformations are brightness, greenness, and wetness respectively (Lavreau 1991). The fourth transformation is noise and atmospheric effects. It is calculated using the 6 non-thermal bands of Landsat TM. For Landsat 5 the equation is:

$$TC4 = 0.8461*TM1 - 0.7031*TM2 - 0.4640*TM3 - 0.0032*TM4 - 0.0492* TM5 - 0.0119*TM7 + 0.7879 \quad (\text{Crist et al. 1986})$$

The transformation that results is an index to atmospheric noise, and it can be used to adjust specific areas of a scene, which are hazy. Other atmospheric correction procedures, such as dark object subtraction (Chavez 1988), apply a fix to all of the pixels within the scene. This Lavreau method had the advantage of only correcting the pixels that had atmospheric problems. The next step was to examine hazy pixels over a homogeneous land cover area, ideally containing only one or two DNs (when not affected by atmospheric factors). The purpose of using a homogenous area was to avoid introducing variability of various ground conditions. Open water areas were always chosen due to their relative consistency. A linear relationship was calculated between these hazy areas within each of the 6 bands and the TC4 band. This equation took the form of:

$$TM_x = A \times TC4 + B$$

where

A = slope of the line

B = intercept of the line

A threshold was then calculated using non-hazy pixels of the same consistent cover type. Using the non-hazy values of each band, the TC4 threshold value was calculated using the linear equations determined in the previous step for each band. The thresholds for each band were averaged and then used in the final equation to determine when the corrections should take place. The final equation took the form of:

$$(TM_{x,i})_c = TM_{x,i} - (TC4_i - TC4_o)A_x$$

where

$(TM_{x,i})_c$  = final corrected Landsat TM pixel  $j$  of band  $x$

$TM_{x,i}$  = raw Landsat TM pixel  $j$  of band  $x$

$TC4_i$  = fourth tasseled cap transformation of pixel  $i$

$TC4_o$  = TC4 threshold value (constant throughout)

$A_x$  = slope from the linear equation for band  $x$

This process had mixed results. It cleared up scenes 1434 and 1435 (Figure 8) better than 1533. When this process failed to reduce haze significantly, band 1 was removed from further processing. If haze was still affecting classification, then band 2 was also eliminated. These 2 bands have the shortest wavelengths and therefore most prone to the influence of atmospheric noise.

The same supervised classification procedure within PCI that was used for processing the topographically affected scenes was used to classify the atmospherically adjusted images. Altering the Threshold and Bias values, along with defining and re-defining training areas, was influenced, as previously stated, by the feedback of the Classification Preview function.

### **Image Postprocessing**

After the scene passed an overall visual inspection, it was considered classified. The last step was to perform post-classification smoothing. A 3 pixel by 3 pixel mode or majority filter was used. This operation removed any “salt and pepper” or speckling on the image. These speckles usually result from random sensor error or extreme spectral mixing. The final image appears much more homogeneous or smooth.

### **Accuracy Assessment**

Before a map should be used, it is necessary to know its accuracy (Congalton 1996). A map covering the area of state at the resolution of 30 m needs thousands of reference points. The resources available to obtain reference data balance this requirement. A general rule of thumb is 75 to 100 reference points per category for a large image (Congalton 1996). Aerial videography is an effective method to obtain this large number of ground locations in a timely, low cost manner (Graham 1993).

A)



B)

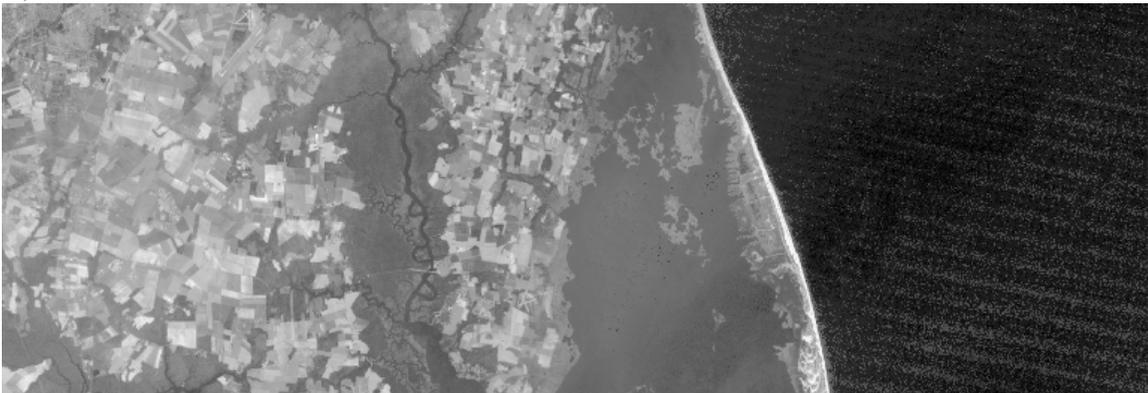


Figure 8. Haze correction applied to scene 1435 east of Great Dismal Swamp National Wildlife Refuge. A) gray-scale image of 4,5,3 band composite before haze correction. B) gray-scale image of the same band composite after haze correction.

By attaching 2 analog 8 mm video-cameras to a laptop computer and a global positioning system (GPS) mounted on the side of a high-winged aircraft, it is possible to record the ground below the flight paths with spatial attributes. Since the GPS can record a point every second and simultaneously record this with a printed time code for each point on each video frame, many reference points can be obtained in a short amount of time. Slaymaker et al. (1996) outlined the basic methodology.

Two Sony Hi-8 video cameras were flown at 600 m (2300 ft) above ground level. One was zoomed in to the maximum magnification and the other was panned out to obtain a large field-of-view. This produced swaths of 0.4 km and 30 m respectively. The cameras fit within an aluminum custom-built mount that was attached to the window of a Cessna 172 high-winged aircraft. Flight speed was approximately 100 knots. Location and time were recorded from a Trimble Geoexplorer GPS unit onto a laptop computer and to 8 mm tape via two Horita time coders. A GPS antenna extension was placed just behind the windshield. The time coders imprinted the time down to 1/30<sup>th</sup> of a second directly on to the video frames. The laptop recording the GPS points was a 75 MHz Pentium running GeoLink software. GeoLink allowed the observer to monitor the GPS point collection and flight line. The current flight path could then be compared against a predetermined sampling pattern for direct feedback on course heading. The video points could also be annotated directly.

Several flights were taken during the fall of 1995. Autumn was optimal for identifying tree species, and therefore forest communities, due to the species-specific differences in changing of leaf color. The flights started later in 1995 than planned (due to technical problems) and were concentrated in the eastern part of Virginia where the

leaves were still on the trees. Additional flights were flown in spring of 1996. It was hoped that these spring flights, which were concentrated in the western part of Virginia, would record bud-out and also (by knowing phenology) allow the distinguishing of tree species and communities. These spring flights showed much less variation between individual species than did the fall missions, but were adequate for assessing the basic land cover categories covered in this thesis. These first video missions were pilot studies aimed at testing the use of videography for both training data and validation information for use in detailed forest cover mapping. Due to the experimental nature of this operation and the need to find optimal phenological conditions, the flight lines do not appear as evenly spaced as would otherwise be planned. The flights do, however, cover the majority of the Commonwealth at a fairly regular sampling intensity (Figure 9). Around 100,000 potential reference points resulted.

The videography points were interpreted by first differentially correcting the GPS points using GPS base station data from Blacksburg, Virginia, for the western flights and Charlottesville, Virginia, for the eastern missions. Trimble's Pfinder software was used to perform the correction.

The video points were interpreted into land cover classes using a 2-monitor, 2-videocassette recorder (VCR) setup. There was one monitor and one VCR for each of the wide-angle and the zoom recordings. This allowed the 30 m zoom image to be interpreted within the context of the 0.4 km image. The VCRs were high quality Sony EV-C200s which allowed an analyst to pause, then make frame-by-frame advances while maintaining a crisp, clear image.

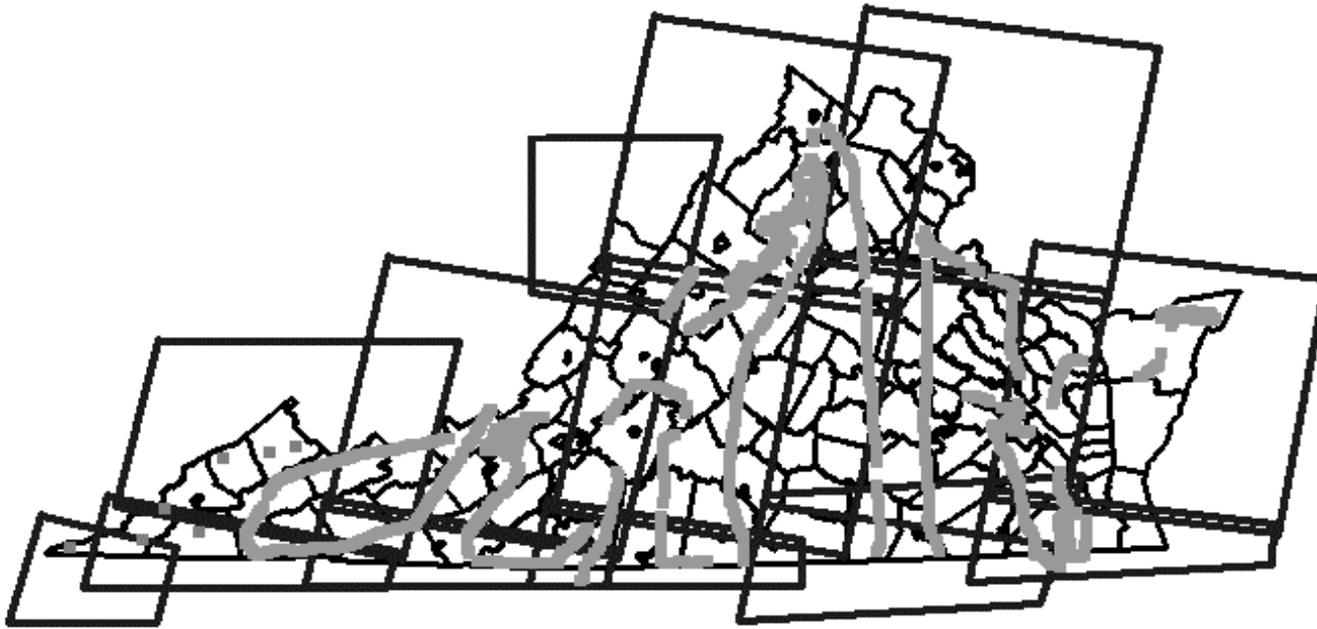


Figure 9. Accuracy assessment reference data across the Landsat TM scenes of Virginia. The videography data appear as gray continuous lines while the 7 SAA photograph sets are the gray squares in the western section of the Commonwealth.

Points were chosen randomly for interpretation. Interpretation consisted of adding a label to the point database that corresponded to 1 of the 8 land cover classes. This label was added through the Edit Vector function within TNT-MIPS. Points were only labeled if 90% of the land cover was consistent within a 70 m by 70 m area. A grease pencil was used to draw an approximate 70 m by 70 m box on the center of both wide-angle and zoom monitors. If a major land cover edge occurred within the 70 m video frame, the interpreter moved on to the next reference point. After the first point was coded, the next random point was chosen. Both the zoom and wide-angle videotapes were advanced to the corresponding time. This process was completed until the end of that particular flight was reached. If for any reason a point was not interpretable (i.e., due to focus or an unidentifiable cover type) the interpreter went on to the next point. Certain sections of each transect were deleted due to excessive tilt, pitch, or yaw in the aircraft.

The far western portion of Virginia did not receive as much video coverage as the rest of the Commonwealth (Fig. 9). It was therefore necessary to obtain an alternate source of reference data. Seven sites, containing 3 still photographs each, from the SAA (Southern Appalachian Assessment) were used for this purpose (Fig. 9). These CIR 9 inch by 9 inch (22.9 cm x 22.9 cm) images were flown at approximately 1:12,000 scale. These photos were not geo-rectified. Each site had overlapping photographs covering an area about 3 km by 5 km on the ground. The interpretation of these photos attempted to follow the protocols set for videography point labeling. It was determined that the sampling density (points per area) for the videography was approximately 1.3 points per kilometer. This translated into 7 points per 5 km study site. These 7 points were randomly chosen using a grid overlaid on top of the photographs. If the range of land cover types within the site was not adequately represented in the random samples additional points were located. These over-samples assured that some of the less abundant cover types, such as shrub, disturbed, or mixed forest, were present in the accuracy assessment for this area of the Commonwealth. All of the points were

interpreted on the photos and then located on SPOT panchromatic satellite imagery. The 10 m resolution of the SPOT images allowed more precise geographic location than the raw Landsat image. The UTM coordinates along with the land cover label were entered into a point database similar to the database for the videography.

Spatial inaccuracies inherent to videography and the use of unrectified aerial photographs necessitate additional image processing. Using the 70 m x 70 m frame in videography interpretation assured the point was within a homogeneous land cover stand. However, it did not account for spatial inaccuracies of this data-type. The GPS point is the location directly below the plane. The cameras are intended to record this same point, however, pitch or yaw from the plane or a slight tilt in the camera mount could place the video frame away from the GPS point location. Slaymaker et al. reported in (1996), commonly found positional errors of 70 m between the video frames and the actual GPS location.

To investigate the effects of this error and to account for it in the final accuracy assessment, the land cover maps were assessed at different levels. Each scene was evaluated on an “every pixel” level, a “3x3 homogeneous” level (i.e., only homogeneous pixels within a 3x3-pixel matrix), and a “5x5 homogeneous” level (i.e., only homogeneous pixels within a 5x5-pixel matrix). The every-pixel level was a standard assessment of each pixel and each video point. The 3x3 homogeneous assessment evaluated only the pixels that were located in the center of a 3x3-cell matrix containing only 1 value (i.e., all 9 pixels had to be one cover-type). A spatial macro language (SML) program was written in TNT-MIPS to identify these homogeneous 3x3 pixels. The 5x5 homogeneous assessment was similar to that used in the 3x3 method. A SML was also written for this application. The 5x5 homogeneous evaluation was thought to most accurately portray the true accuracy because it accounts for at least 60 m (two 30-m pixels) of spatial error in the videography data (Figure 10).

Each individual classified Landsat scene was evaluated at the three levels. An error matrix, overall accuracy, producer's and user's accuracy for each class, and Kappa statistics were reported. A program called Acc4wind was used to calculate the above statistics. This software was written by Jonathan Chipman of the University of Wisconsin (Wynne *per. comm*). The classified scene, in the form of an ERDAS (a common image processing software package) and a text file with the reference points are required as input. The output consists of an error matrix, an accuracy report, with the overall accuracy, the Kappa statistic, and both user's and producer's accuracy, and a listing of each reference point with the geographic coordinates, reference land cover class, and classified land cover class. For both the 3x3 homogeneous and 5x5 homogeneous levels the overall accuracy, class user's and producer's accuracy, and Kappa statistics were recalculated from the error matrix. The Kappa statistic was computed using the method outlined in Campbell (1996).

A statewide image was produced by creating a mosaic of the 14 classified scenes. The creation of this mosaic took place in TNT-MIPS. The area of overlap for each scene was determined by the overall accuracy of the individual scene, at the 5x5 homogeneous level. Scenes with relatively high accuracy had more areas of overlap than neighboring scenes of relatively low accuracy (i.e., higher accuracy scenes were placed on top of lower accuracy scenes). The final map was evaluated using all of the available reference points. Before this final assessment was performed, the Commonwealth was split in half. This division allowed the Acc4wind software to perform. Due to size of this dataset (411 mb, 13,991 lines, and 28,041 columns) this assessment could not be completed on current personal computers (without RAM above 64 mb) without the split. The size of the final image was an inconvenience, but was not a barrier to the use of personal computers. The division was made near the split between UTM zone 17 and 18. The reference points were used within their respective zones.

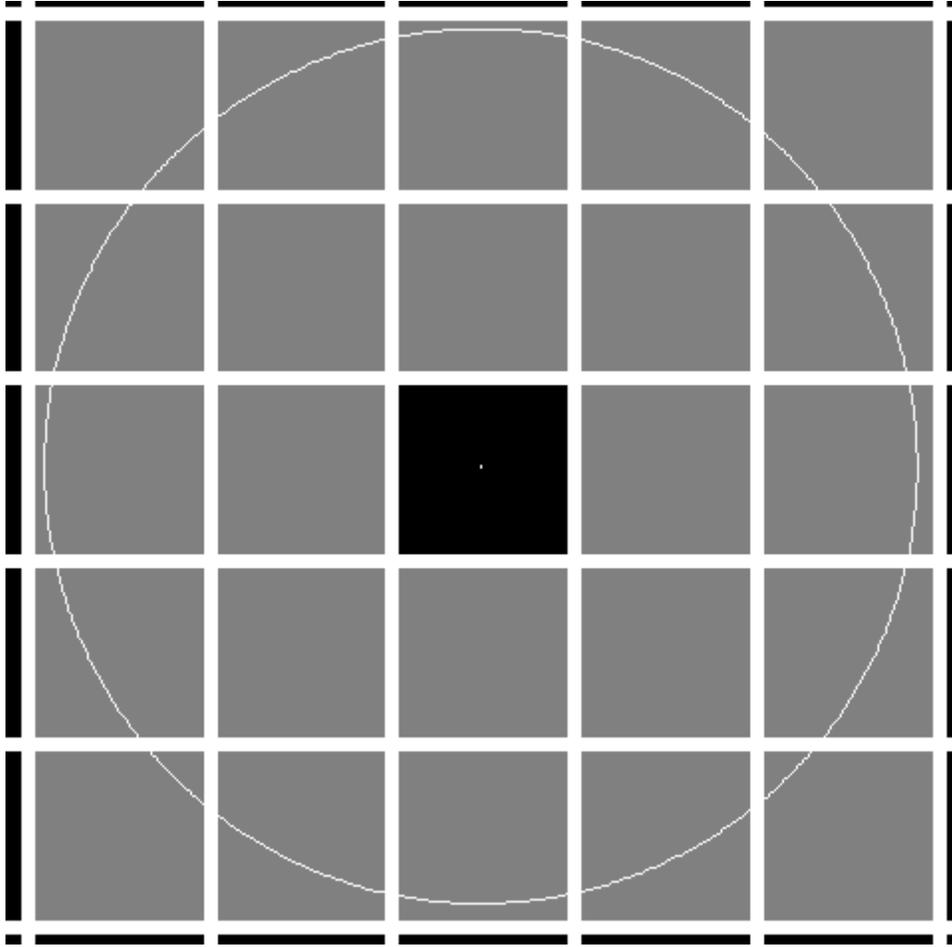


Figure 10. 5 pixel by 5 pixel area used in the 5x5 homogeneous error assessment. All 25 cells need to be the same land cover type for the center cell to be assessed for accuracy. The white circle represents the possible 70 m error of a videography point in the center of the middle pixel.