Monitoring Property Boundaries for the Appalachian National Scenic Trail Using Satellite Images

By

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(ABSTRACT)

The Appalachian National Scenic Trail is a unit of the National Park System created by the National Trails Act of 1968. Commonly referred to as the Appalachian Trail, or the AT, this National Park has some of the longest boundaries of any park. The AT is routed more than 2000 miles along the mountains of the eastern United States. The land purchased for the protection of the AT creates a separate boundary on each side of the trail. Monitoring these boundaries for intrusions or encroachments is a difficult and time-consuming task when done totally by field methods. This thesis presents a more efficient and consistent monitoring process using remote sensing data and change detection algorithms.

Using Landsat TM images, Normalized Difference Vegetation Index (NDVI), and image difference change detection, this research shows that major boundary encroachments can be detected. Detection of sub-pixel vegetation index decreases identifies specific locations for field inspection. Assuming low cost multispectral Landsat imagery is available, simple NDVI difference calculation allows this technique to be applied to the entire AT one or more times per year. This procedure would improve the response time for encroachment mediation.

The producer’s accuracy for finding possible encroachments was 100 percent and the consumer’s accuracy for possible encroachments indicated was 78.3 percent.

Due to limited image availability, this study only examines change between one pair of Landsat images. Further refinement of these techniques should investigate other Landsat images at other times. Use of other remote sensing systems and change detection algorithms could be the focus of further research.

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1 Introduction

> *“which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.”* (NPS Organic Act, 1916)

Congress created the National Park Service in the Department of the Interior with the 1916 Organic Act. From their very beginning, our National Parks have been considered a valuable resource requiring protection. This protection is a duty incumbent on the current generation for the benefit of future generations.

This thesis research addresses one aspect of protecting our National Parks, boundary monitoring. The periodic monitoring of park boundaries is a difficult and time-consuming task when done totally by field methods. This thesis evaluates a more efficient and consistent monitoring process using remote sensing data and change detection algorithms.

1.1 Overview of Park Boundary Monitoring

The Appalachian National Scenic Trail is a unit of the National Park System created by the National Trails Act of 1968. Commonly referred to as the Appalachian Trail, or the AT, this National Park has some of the longest boundaries of any park. The AT is routed more than 2000 miles along the mountains of the eastern United States. The lands purchased for the AT create a separate park boundary on each side of the AT.

One of the unique aspects of the AT is the delegation of management responsibilities for the park to the local volunteers in the thirty AT maintaining clubs located along the length of the trail. In areas where AT land is located outside the National Forests or an already existing National Park, the responsibility for monitoring is formally delegated to the local club volunteers by the National Park Service. For example, in the Roanoke, Virginia area, the Roanoke Appalachian Trail Club monitors over 60 miles of boundaries with the assistance of the Appalachian Trail Conference (ATC).

1.1.1 Current Monitoring Methods

The current AT monitoring procedure (ATC, 1998) consists of the following.

1. Yearly, each trail club appoints or elects a Monitor Coordinator who leads the club’s monitoring activities. As needed, this coordinator recruits and trains individual monitors, defines monitoring sections, determines the frequency of monitoring for each section, coordinates follow-up to identified encroachments or problems, and prepares an annual summary.

2. Each individual monitor visits his or her assigned section and inspects the corridor boundaries looking for encroachments. Each monitor generates a report of any encroachments of the park boundaries.
3. The Monitor Coordinator reports all encroachments of the boundaries to the National Park Service and monitors all problems until a solution is implemented.

The AT corridor-monitoring program has evolved since 1984 from the knowledge and experience of personnel from the Appalachian Trail Conference (ATC), the National Park Service (NPS), and the local AT maintaining clubs (ATC, 1998). The monitoring program consists of training manuals and workshops developed over the years for instructing individual volunteer monitors. One of the guidelines of this training is that property boundaries should be walked at least once a year. This research does not investigate property boundary monitoring techniques by other organizations. Research into the techniques and effectiveness of property boundary monitoring by other organizations could be a beneficial future research topic.

1.1.2 Boundary Intrusion Types

Boundary intrusions or encroachments include any of the following activities (ATC, 1998):

1. Timber Theft
2. Unauthorized Trails or Roads
3. Dumping
    a. Household or Industrial Trash
    b. Vehicles, Cars or Trucks
    c. Brush, Stumps, or Other Debris
4. Horse, Mountain Bike, or ATV Use
5. Adjoining Landowner Activities
    a. Mowing or Vegetation Removal
    b. New Structures and Driveways

Actual examples of past encroachments (Register, 1991):

1. Maine – Twenty Acres of Timber Removed
2. New York – Sewage Treatment Line Installed
3. Pennsylvania – Two Acres of Timber Removed
4. Linden, Virginia – New Swimming Pool Built
5. Catawba, Virginia – Access Roads built by Power Company
6. Daleville, Virginia – Gas Station Parking Lot Built

It is important to detect these intrusions as soon as possible so that timely corrective action can be implemented. Because the current monitoring system relies on direct observation, this detection is not as timely as desired. At best, yearly boundary monitoring is feasible and its thoroughness is often questionable.

This research is intended to add a timely monitoring component to the current system. Satellite remotely sensed data could be used to monitor park boundaries one or more times a year.

1.2 Purpose

The purpose of park boundary monitoring is to detect intrusions in a timely manner so that park law enforcement officers can take corrective action. Detecting intrusions quickly will lead to better resolution, correction, and prevention. Intrusions undetected for a year or more make corrective action more difficult and less effective. The purpose of this and subsequent research is to enhance the current monitoring system to improve timeliness and thoroughness. The purpose is not to replace any part of the current monitoring system. Each part of the current monitoring system will still be necessary even if this research is successful.

The current monitoring system relies exclusively on people to physically walk the boundaries. The boundaries are typically located on very difficult terrain. People often have difficulty finding both the time and energy to do this task over and over again. It is too much to ask a person to complete this task more than once per year. Even on a yearly monitoring trip of many miles a person will get physically tired and not walk precisely on the boundary line. Thus, intrusions can be missed by a physical inspection of the boundary.

Satellite remotely sensed data images are available on a regular periodic basis. Comparing old and new satellite images one or more times per year could be very realistic. Techniques need to be identified to detect changes between periodic images for the types of boundary intrusions outlined above. When an intrusion is detected a person would still need to investigate, but this effort could be targeted at a specific location and not require walking long sections of boundary.

The purpose of this research is to investigate the addition of a lower level tier to the monitoring system as shown in Table 1. This new tier of monitoring would be done when relatively cloud free satellite images were available.

Table 1: Periodicity of Monitoring Activities

Period of Monitoring Activity	Activity Description
One or more times per year	Analyze satellite images for changes and investigate only those changed areas in the field. This is the new added tier.
Yearly as a goal	Monitor Boundary in the field. This monitoring would be needed to find intrusions that are not detectable with the satellite images.
Every 5 to 7 years	Maintain Boundary Markings

1.3 Objective

Because very little if any research has applied remotely sense data and change detection algorithms to park boundary monitoring, the objective of this thesis is to initiate research on this topic. This thesis investigates feasibility using well-defined techniques with commonly available data. This and subsequent research could lead to an enhancement to the park boundary monitoring process that would significantly improve thoroughness and timeliness.

The evaluation part of this research compares the results of this technique to a set of reference data. The reference data are known actual ground conditions at the time of image acquisition. An error matrix is used to make this comparison.

The specific objective is to identify a remote sensing data source and processing techniques such that missed possible encroachments are very unlikely and false indications are minimized. An error matrix is the typical method used to display these measurements (Campbell, 2002; Congalton, 1991). The error matrix compares the generated change detection map indications to the actual conditions on the ground. Table 2 shows a hypothetical example of the error matrix to be used in this thesis. Actual results are presented later.

Table 2: Error Matrix with Hypothetical Values

		Actual Ground Conditions			
	Error Matrix	Possible Encroachment Not Found	Possible Encroachment Found	Total	Consumer's Accuracy
Indication on Map	Possible Encroachment Not Indicated	45	1	46	45/46 = 97.8%
	Possible Encroachment Indicated	15	59	74	59/74 = 79.7%
	Total	60	60	120	
	Producer’s Accuracy	45/60 = 75.0%	59/60 = 98.3%		

In Table 2, the producer’s accuracy under the column labeled “Possible Encroachment Found” is the most important measurement for this research. The procedures identified by this research should be the most sensitive to this measurement. Ideally a value of 100% would indicate that the process does not miss possible intrusions or encroachments. The second most important measurement is the consumer’s accuracy in the row labeled “Possible Encroachment Indicated”. This percentage measures how many false indications the process generates. The procedures identified by this research should also be sensitive to this measurement of false indications. False indications will result in an unnecessary field inspection.

The objective of this thesis research is to measure these two criteria, missed and false indications, using a specific set of remote sensing images and a specific change detection algorithm.

The term “Possible Encroachment” is used in the error matrix because a person must evaluate any change to determine if a true encroachment has occurred. The techniques identified by this research will not be able to distinguish between a human or natural change. For example, if a stand of trees has been destroyed, a person will be required to evaluate the situation and determine first-hand if the cause was weather-related or a timber theft. This level of investigation would be required to identify the disturbance as a genuine, human initiated, encroachment.

1.4 Research Questions

The following five areas of research are addressed by this thesis.

1. Data Sources
2. Change Detection Algorithms
3. Threshold Parameter Settings
4. Minimum Size of a Detected Intrusion
5. Retained Historical Data Requirements

Each area is briefly described below.

1.4.1 Data Sources

Selecting a remote sensing data source or satellite observation system will set both the spatial and spectral resolution used in this research. The unit of analysis for this research is a pixel of remotely sensed data. Selection of a data source will specify pixel size or spatial resolution. Smaller pixel size could mean smaller intrusion detection but the data cost may be prohibitive. Spectral resolution designates the wavelength segments or bands of collected data. More bands of data may help identify different intrusion types, but again the data cost will be higher for more detailed data. Identifying the least expensive data source that is effective in detecting the most intrusions is the goal of this research. How well can an inexpensive data source detect the more obtrusive types of intrusions or encroachments?

Also, the selected data source must have the necessary temporal resolution in order to compare change between two time periods. A data source will need to have images available at the same seasonal time each year. A data source that produces one image a year at different seasonal timing will be of little use for detecting change. Comparing a “leaf off” versus a “leaf on” image is not practical for this research.

1.4.2 Change Detection Algorithms

A change detection algorithm is the computational method used to compare recent remotely sensed data to historical data for a given point on the earth. Selection of a change detection algorithm that will adequately perform this boundary monitoring function, but be as simple as possible is an important dimension of this research. If a simple change detection method can be identified, then inexpensive, simple, software tools can be used.

1.4.3 Threshold Parameter Settings

A change detection algorithm has parameters that require specification of values that adjust the sensitivity of the algorithm to detection of changes. These threshold settings define how much change is necessary before a change is detected. Some changes portrayed in the remotely sensed data are normal and do not represent significant prospects for possible boundary encroachments. The results of this research suggest recommendations on specific values of these parameters for the selected algorithm. These parameters, together with the change detection algorithm, must have the ability to minimize false indications, while missing few actual intrusions.

1.4.4 Minimum Size of a Detected Intrusion

The pixel size of the remotely sensed data does not necessarily set the minimum size of a detected intrusion. Some change detection methods allow for sub-pixel change detection. This research estimates the minimum area of a detected intrusion.

1.4.5 Retained Historical Data Requirements

The simplest historical data to maintain for comparison would be the prior data from a previous time period. For example, if new remote sensed data for July 2003 are available, we could have saved the same data from July 2002 to use for our comparison. This simple approach may not be sufficient. For example, the July 2002 data may not be available due to weather conditions or instrument problems. An estimate of the historical data requirements for the selected change detection algorithm is presented.

1.5 Spatial Scale and Study Area Location

The maps and surveys for the Appalachian Trail use the Virginia South State Plane coordinate grid system that uses coordinates measured in feet. For this research, boundary lengths are presented in feet. Length in miles is used to report on longer sections of boundary or other longer distances.

Two specific study areas are used in this thesis research. Both areas are located about 5 miles from Roanoke, Virginia. These two areas are defined as follows.

1.5.1 AOI Study Area

The Area of Interest (AOI) Study Area (Figure 1) is located on a mountain ridge south of Roanoke, Virginia. This area was chosen because of the known changes on this mountain ridge due to sub-division development. The changes to the landscape created by the sub-division development are very similar to the types of intrusions being monitored for along the Appalachian Trail. In Figure 1 the red circle shows the approximate location and size of this area. This area is known as Phase IV of the Belden Woods sub-division located on the Franklin/Roanoke County line.

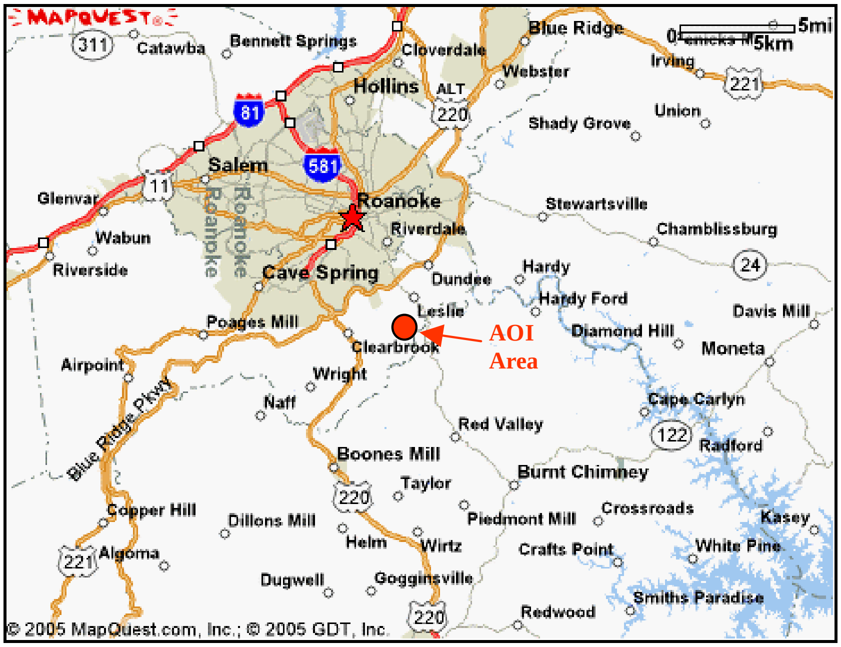

Figure 1: AOI Study Area Location Shown by Red Circle

1.5.2 AT Study Area

The Appalachian Trail (AT) Study Area is located on the mountain ridge north of Roanoke, Virginia (Figure 2). Note the red arrow pointing to a red circle. This red circle shows the approximate location and size of this area. The AT crosses US Route 220 just north of Interstate 81 at Exit 150.

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Figure 2: AT Study Area Location Shown by Red Circle

2 Literature Review

Research publications directed towards property boundary monitoring using remote sensing data are few and difficult to locate. No relevant publications have been found to date. Most remote sensing change detection publications are focused on post-classification change detection of larger areas covering many pixels. Change detection for these larger areas is not useful for boundary monitoring.

2.1 Remote Sensing Data Types

Selection of a specific remote sensing data type from the already existing satellite based system is one of the objectives of this research. This selection must be done in parallel with the selection of a specific change detection algorithm. Each algorithm uses a selected band or bands of remotely sensed data in different ways (Jensen, 1996).

Several bands of the Landsat Thematic Mapper (Campbell, 2002) are applicable to this research. The most likely bands are number 2 (Green) for radiation reflected from healthy vegetation, number 3 (Red) for chlorophyll absorption important for plant-type discrimination, and number 4 (Near Infrared) for plant vigor. The Landsat Thematic Mapper may have a spatial resolution that is too coarse for this application. Other satellite systems like SPOT HRV or IKONOS, with finer spatial resolutions, may be better suited to monitoring boundaries, although costs may be prohibitive.

When comparing remotely sensed data from two different dates, consistency of the data acquisition is very important. For example, look angle and sun angle (Star et al., 1997) should be kept constant. Using the same satellite system and sensors and comparing images from the same time of the year can maintain consistency.

2.2 Overview of Change Detection Algorithms

There are many documented change detection methods or algorithms utilizing remotely sensed data. Most methods compare two remotely sensed images acquired on different dates. Some methods are as simple as manual On-Screen Digitization of Change (Boone, 1989). Other algorithms do more complex calculations (Eastman, 1992). One way to summarize the various algorithms is to group them as pre-classification and post-classification comparisons. Two examples from each group are summarized below.

2.2.1 Pre-classification Change Detection Algorithms

1. Image Differencing (Green et al., 1994)

   Image differencing simply subtracts band values between two remotely sensed images acquired on different dates. A result of zero would indicate no change. Assuming radiance values between 0 and

255, the range of results would be from –255 to +255. This algorithm is very efficient in identifying pixels that have changed but it requires a careful selection of the threshold for indicating significant change.

2. Spectral Change Vector Analysis (Malila, 1980; Michalek et al., 1993)

   Two remotely sensed image bands are selected and each pixel set is plotted in a Cartesian grid. One band is plotted on the Y-axis the other on the X-axis. The two points from the two different image dates of the same pixel define a change vector. This change vector has both a magnitude and direction. Thresholds for indicating significant change must be defined. These thresholds consist of a vector magnitude and direction. This method can be applied to as many bands as necessary. Two or three bands are easier to visualize.

2.2.2 Post-Classification Change Detection Algorithms

1. Direct Comparison (Jensen et al., 1993)

   The remotely sensed image for each of the two dates is first individually classified to define the type of land use or cover. Examples are forest, pasture, or urban. Then each pixel on the two classified images is compared for changes. For example, a certain area may have changed from forest to urban. The advantage of this algorithm is that it gives the actual “from/to” change information directly. The disadvantage is that any errors in classification will impact the change detection results.

2. Binary Change Mask Applied to Date 2 (Dobson and Bright, 1992)

   This change detection algorithm is really a combination of pre- and post-classification techniques. First, a band is selected from both image dates and compared using a pre-classification method like Direct Comparison explained above. Then the two images are classified and compared only where the pre-classification change detection indicated that there is a significant change. This method reduces dependence on accurate classification, but it depends on the initial change detection algorithm to identify change and is a more complex algorithm in general.

Post-classification change detection is not necessary for boundary monitoring. It is sufficient for boundary monitoring to indicate that a change has occurred and field verification is needed. The errors induced by classification could hinder the sensitivity of the detection process. Post-classification change detection is not part of this research.

Within the category of pre-classification change detection algorithms, image differencing was selected for this research because of simplicity. The simpler method needs to be applied and tested before more complicated techniques are researched.

2.3 Vegetation Indices

Principal component, Tasseled Cap (Kauth and Thomas, 1976), and a vegetation index were all initially studied as preprocessing steps prior to change detection. All three of these techniques gave similar results and it was decided to focus this research on a vegetation index.

Vegetation indices based upon digital brightness values attempt to measure biomass or vegetation vigor (Campbell, 2002). Healthy vegetation strongly reflects near infrared and absorbs red radiation. Figure 3 shows the reflectance for a living leaf. There are many methods to compute a vegetation index; the simplest is to divide the near infrared reflectance value by the red reflectance value. Healthy vegetation will produce a high value.

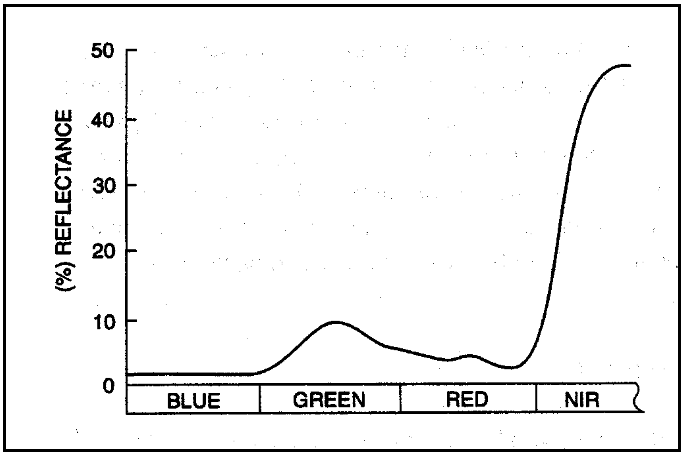


Figure 3: Typical Spectral Reflectance from a Living Leaf (Campbell, 2002, p462)

Past research has related vegetation indices to plant health and abundance. Leaf Area Index (LAI) is a measure of leaf surface area per unit of soil area. Clevers, et al, (1993) demonstrated the relationship of LAI to a vegetation index. Cohen (1991) analyzed the relationship between leaf stress and vegetation indices.

The normalized difference vegetation index (Tucker, 1979) is a specific and widely used vegetation index. Subtracting the red reflectance from the near infrared (NIR) reflectance and then dividing by the sum calculates normalized difference vegetation index (NDVI).

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

There are many published papers on the use of NDVI in change detection calculations with remotely sensed images. D. Lu, et al (2004) gives a summary of change detection techniques and references successful studies using NDVI image differencing change detection. Lu's paper contains a very exhaustive summary of the use of change detection algorithms in various situations. In some studies, NDVI image differencing was determined to be the best technique. In other studies, different vegetation indices and change detection algorithms produced better results when applied to other vegetation conditions and locations. No one technique was considered superior.

Thomson et al, (2004) used NDVI change detection for a salt marsh in the Netherlands. Thomson demonstrates that changes of salt marsh vegetation can be detected with NDVI image differencing change detection. The minimum size of the detected changes by Thomson is larger then that needed for this research. Thomson uses aerial photography for accuracy assessment similar to this research.

NDVI can be influenced by atmospheric conditions. Atmospheric haze is created by water and other particles in the atmosphere between the sensor and the ground. These particles scatter the reflected sunlight, reducing the amount of radiation returning to the sensor. The amount of radiation scattered is dependent on the wavelength (Campbell, 2002). Figure 4 shows the amount of scattering as a function of wavelength. Because the Red and Near Infrared (NIR) bands scatter at different intensities, the NDVI ratio can be influenced by the atmospheric conditions.

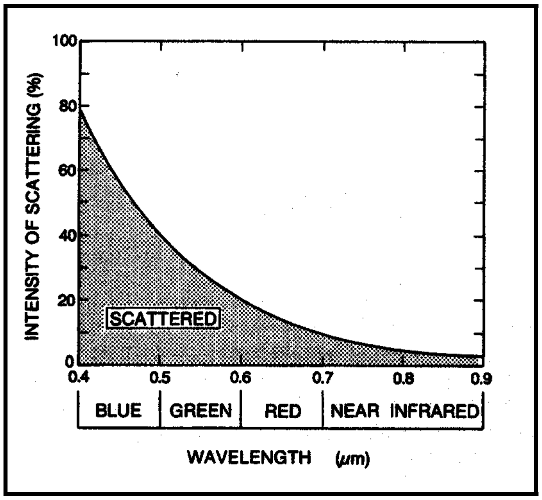


Figure 4: Scattering Intensity versus Wavelength (Campbell, 2002, p34)

When using image differencing change detection with two separately dated images it is likely that the atmospheric conditions differed on the two dates. As a preprocessing step prior to calculating NDVI, the images need to be checked and corrected if needed for different atmospheric conditions. One method to check and correct for atmospheric haze is referred to as dark object subtraction (Chavez, 1975). The use of dark object subtraction in this research is detailed in the appendix.

Another influence on NDVI is the sensor viewing angle or off-nadir viewing. This influence on NDVI is also caused by atmospheric conditions as explained above.

Images acquired at different viewing angles will have different distances from the sensor and ground. These different lengths of atmosphere will result in different amounts of scattering. This research uses the Landsat sensor that does not acquire images at different viewing angles. For this research corrections for viewing angle are not investigated.

2.4 Summary

This literature search was not successful in locating any research applying remote sensing data and change detection algorithms to property boundary monitoring. Most research is directed at detecting relatively large areas of change represented by many pixels of remotely sensed data. These large areas are not applicable to boundary monitoring. This thesis research is concerned with detecting change of sub-pixel size. Using Landsat images and NDVI image differencing change detection seems to be the best technique to investigate first.

3 Materials and Methods

Input data sources, computer processing procedures, and other techniques are documented in this section. Results are then presented in the following section.

3.1 Input Data

Three types of data were used for this research.

1. Remote sensing imagery was used for change detection calculations.
2. Aerial photography was used for accuracy assessment of the change detection process and digitizing of property boundaries.
3. Survey data were used to digitize the property boundaries.

3.1.1 Imagery

The Virginia Tech Forestry department owns two Landsat TM images of SW Virginia acquired on the dates of April 3, 2000 and March 28, 2002. These are Landsat scenes of satellite path 17, row 34. Copies of these two images were obtained for this research.

3.1.2 Aerial Photography

Two sets of aerial photography were used in this research as listed below.

1. Virginia Digital Orthophoto Quarter Quadrangles (DOQQs)

   The USGS produces Digital Orthophoto Quarter Quads (DOQQs) that are scanned aerial photographs corrected for geometric distortion. The DOQQs used for this research were taken in 1995 and are color infrared.

2. Virginia Base Mapping Program (VBMP)

   The VBMP produced digital orthophotos that are rectified so that accurate measurements can be taken from the image. This research used these VBMP orthophotos with 2 foot and 1 foot resolution. The orthophotos were acquired in 2002 for both of the study areas.

3.1.3 Boundary Surveys

The Appalachian National Scenic Trail (ANST) property boundaries are specified in a set of paper based surveys referred to as Exterior Corridor Boundary Surveys (ECBS). Two ECBS documents for the Daleville area of Botetourt County, Virginia were used for this research.

1. ECBS of the ANST prepared by Stultz & Associates, Inc., Consulting Engineers & Land Surveyors, Romney, West Virginia, dated September 1990. Purchase Order No. PX0001-0-4142, Segments 473 and 474.
2. ECBS of the ANST prepared by Hartmann Associates, Inc., Professional Land Surveyors, Pittsburgh, Pennsylvania, dated September 1999. Contract No.

1443CX0001-97-003, Project No. 1443PX254198168, Segments 474, 475, 476, and 477.

Figure 5 is an example portion of the ECBS. Note that the survey consists of bearing and distances between survey monuments. Shown in the upper right corner 571.54 feet separate monument 474-VA-15 and 474-VA-16 at a bearing of North 55 degrees, 22 minutes, 23 seconds East. Figures 6 and 7 are photographs of monument 474-VA-15.

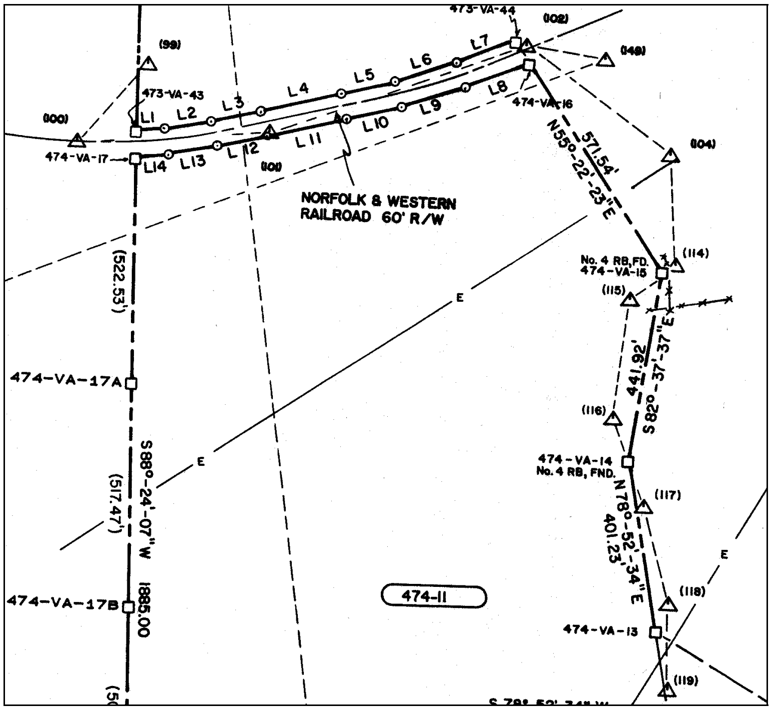


Figure 5: ECBS Example

(Photo by James F. Hutchings)

Figure 6: ECBS Monument 474-VA-15 Close Up

(Photo by James F. Hutchings)

Figure 7: ECBS Monument 474-VA-15

3.2 Processing

Two processing operations were applied. The first was to process the remotely sensed images for the vegetation index and change detection method. Second, the property boundaries were digitized from the surveys.

3.2.1 Imagery

The two Landsat images specified above were processed using ERDAS Imagine as follows. Figure 8 is a flowchart of these processing steps.

1. Subsets for each study area were produced for each of these images. This step reduces the amount of data. This process produced four smaller images, two for each study area (AOI and AT study areas) and two for each year (2000 and 2002).
2. Registration of the two Landsat images insures that a given point in one image is the same location on the other. The details of registration for this research are presented in the appendix. Both of the Landsat images and the aerial photographs were well registered and no further registration was needed for this research.
3. Atmospheric correction adjusts the two Landsat images for any effects of scattering as explained above. The details of atmospheric correction for this research are presented in the appendix.
4. A NDVI calculation was done for each of the four images from step 1 above. The NDVI calculation used the red and near infrared bands of the Landsat images as explained previously.
5. For each study area the Year 2000 NDVI image values were subtracted from the Year 2002 NDVI image values. This is the image differencing change detection calculation as explained above. These two NDVI difference images, one for each study area, become the subject for the change detection threshold investigation.

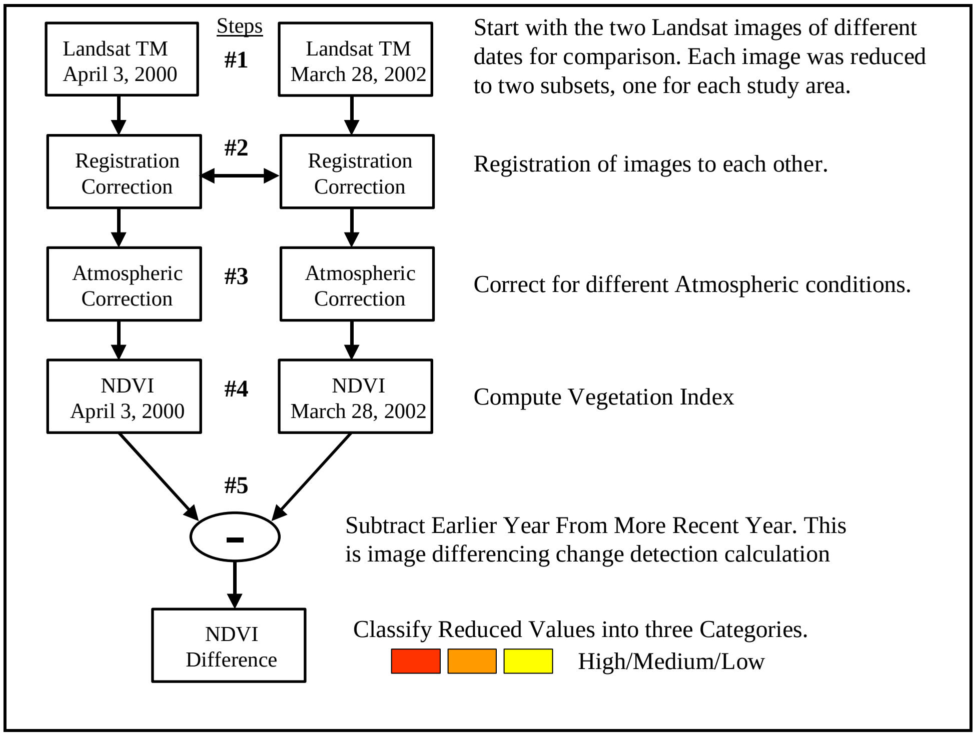


Figure 8: Processing Flowchart

3.2.2 Property Boundaries

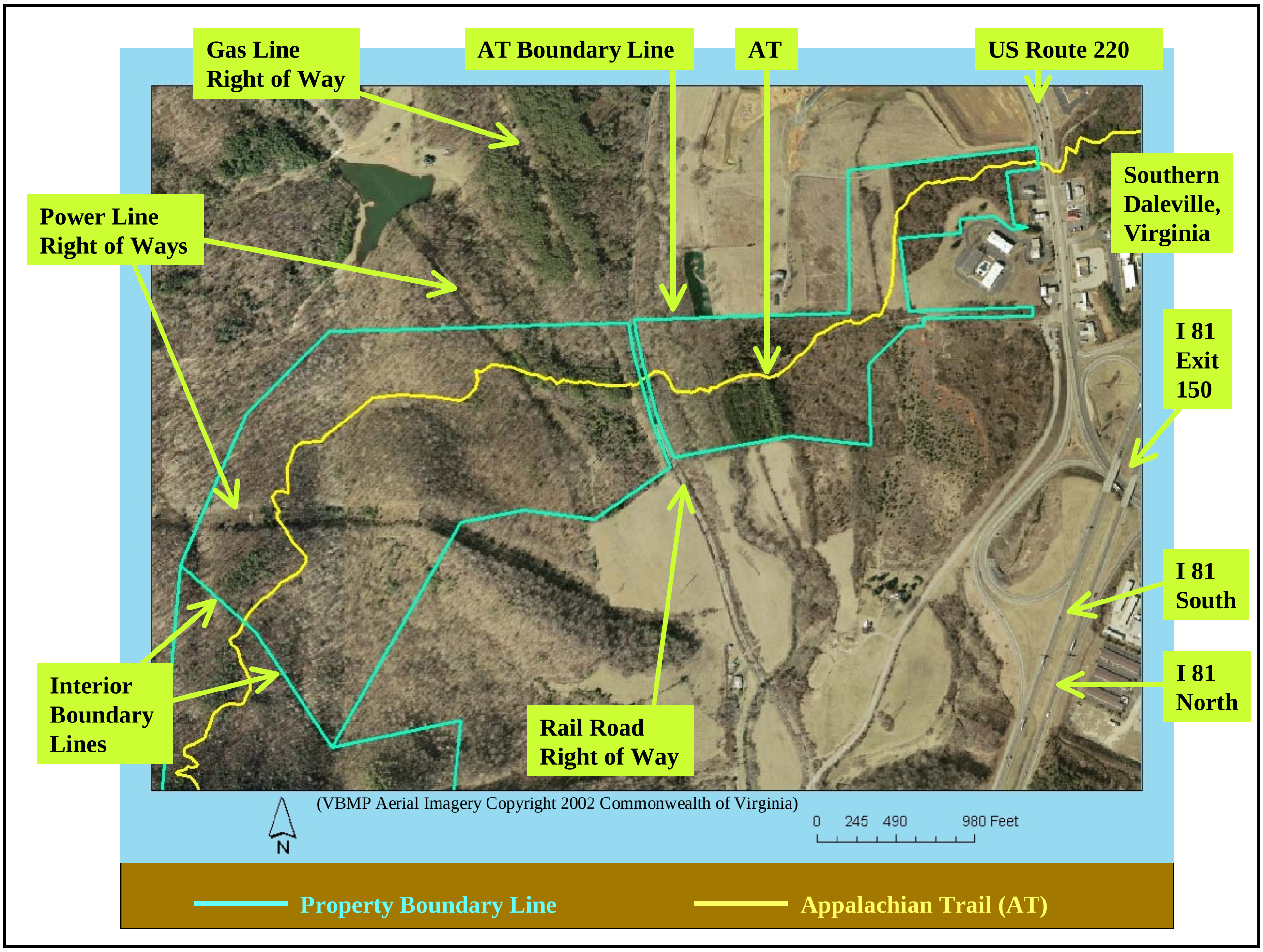
The two Exterior Corridor Boundary Surveys (ECBS) specified earlier were digitized into a shape file for analysis using ArcGIS. This process was evaluated by reference to the Virginia Base Mapping Program (VBMP) photos described earlier. This process is further explained below.

1. Because the surveys did not specify coordinates, two well-defined points were located by GPS in the field. These two locations were used as starting points for digitizing the survey lines into the shape file.
2. For each survey line the bearing was converted to an angle from east to north in decimal degrees for input into ArcGIS. This conversion was done in a spreadsheet.
3. The survey lines were then entered into an ArcGIS shape file using the editor tools.

Figure 9 shows a portion of these ECBS boundaries. Note that the railroad right of way shown in the top of Figure 5 is in the center of Figure 9. The light blue lines are the property boundaries and the yellow line is the centerline of the Appalachian Trail (AT). Exit 150 of Interstate 81 is shown in the right center of Figure 9.

Interior boundary lines are shown for convenience only and are not necessary for boundary monitoring. The surveys contain interior lines for accuracy checking.

These interior lines result in a closed loop returning to the same point. When digitizing the survey lines it is convenient to enter the interior lines and check the error in the digitizing process.



(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 9: Property Boundaries in Valley Area, VBMP Aerial Photograph

3.3 Threshold Value Entry and Display

Threshold values were studied and selected using known changes in the Area of Interest (AOI) Study Area. The main known change was the addition of a sub-division road and cul-de-sac. Surrounding this cul-de-sac are two small roads, a driveway, and a drainage ditch. These various changes of different sizes and characteristics allowed for meaningful threshold value investigation. Threshold value investigation is covered later in the results section. The purpose of this section is to explain the method of threshold value entry and display.

Two aerial photos show clearly this addition of this cul-de-sac to the forested landscape. Figure 10 is an aerial photo prior to the addition of the cul-de-sac and Figure 11 is after the addition. Note that Figure 10 shows that a double tennis court and a parking area existed prior to the cul-de-sac addition. Also, a narrow dirt/gravel road to the parking area existed prior to the sub-division expansion. Figure 11 shows the new cul-de-sac located above and to the left of the existing tennis courts.

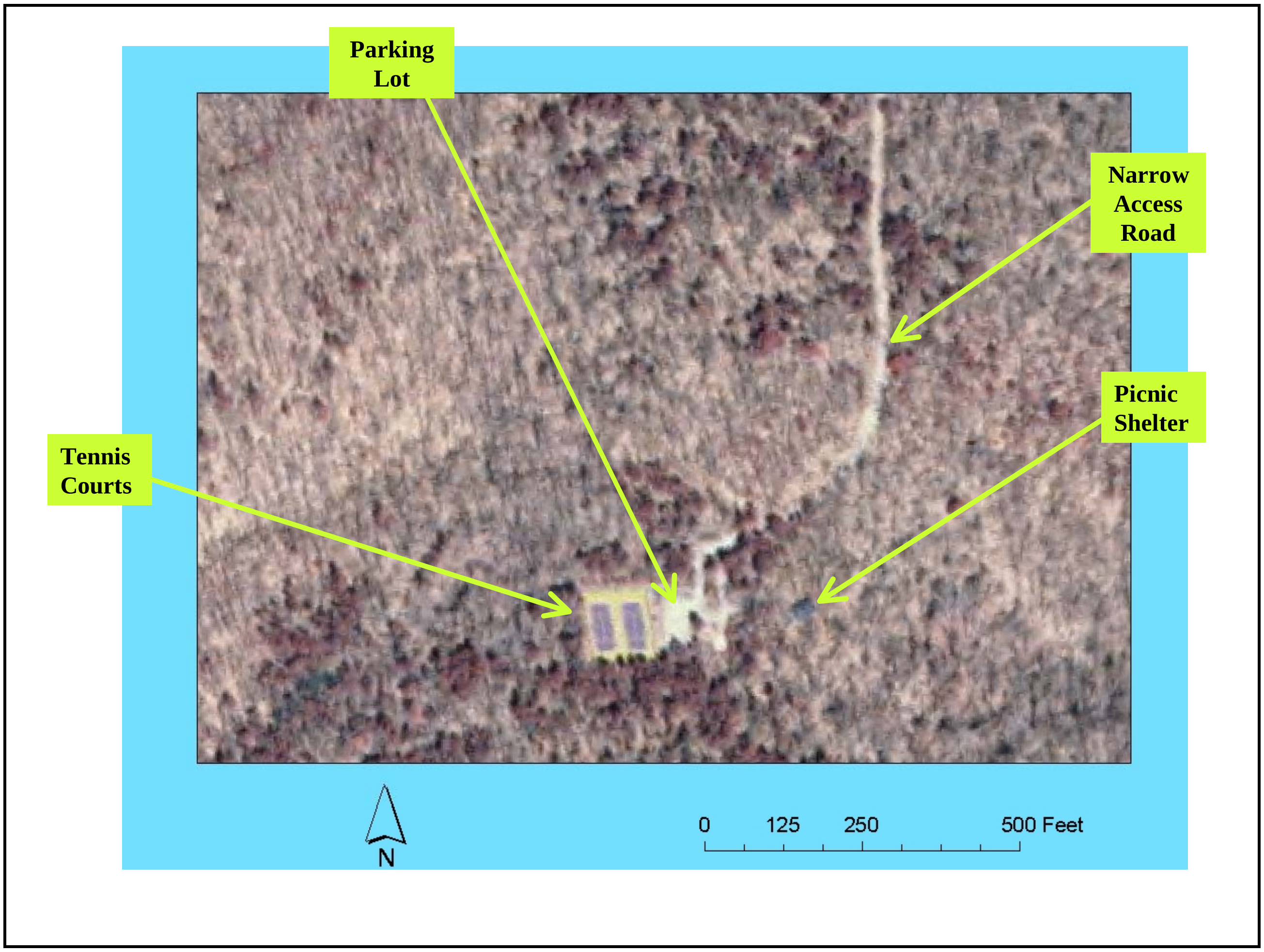
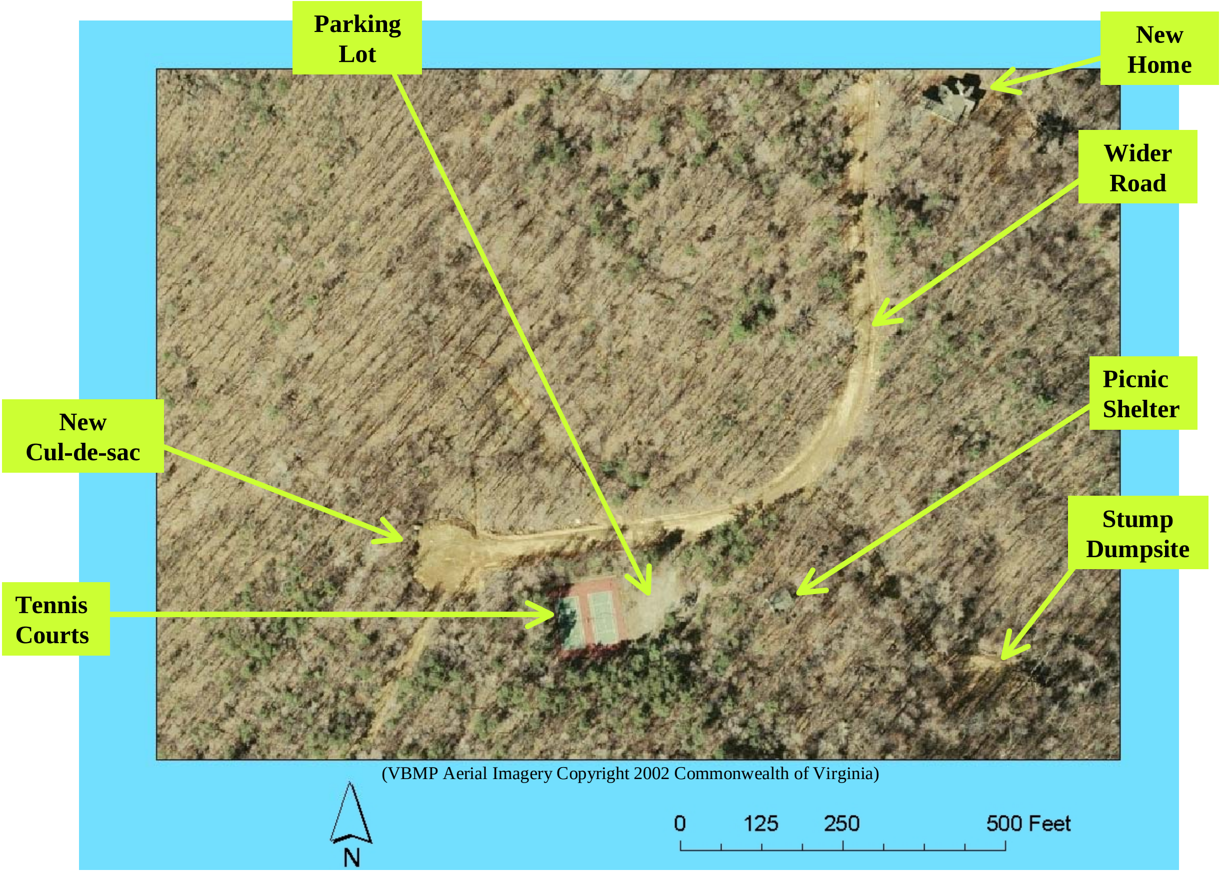


Figure 10: Prior to Cul-de-sac Addition.

1995 DOQQ photograph documents conditions prior to sub-division expansion into this mainly forested area.



(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 11: After Cul-de-sac Addition.

2002 VBMP photograph documents additions to the area. Note the widening and lengthening of the road, addition of the cul-de-sac, and new home.

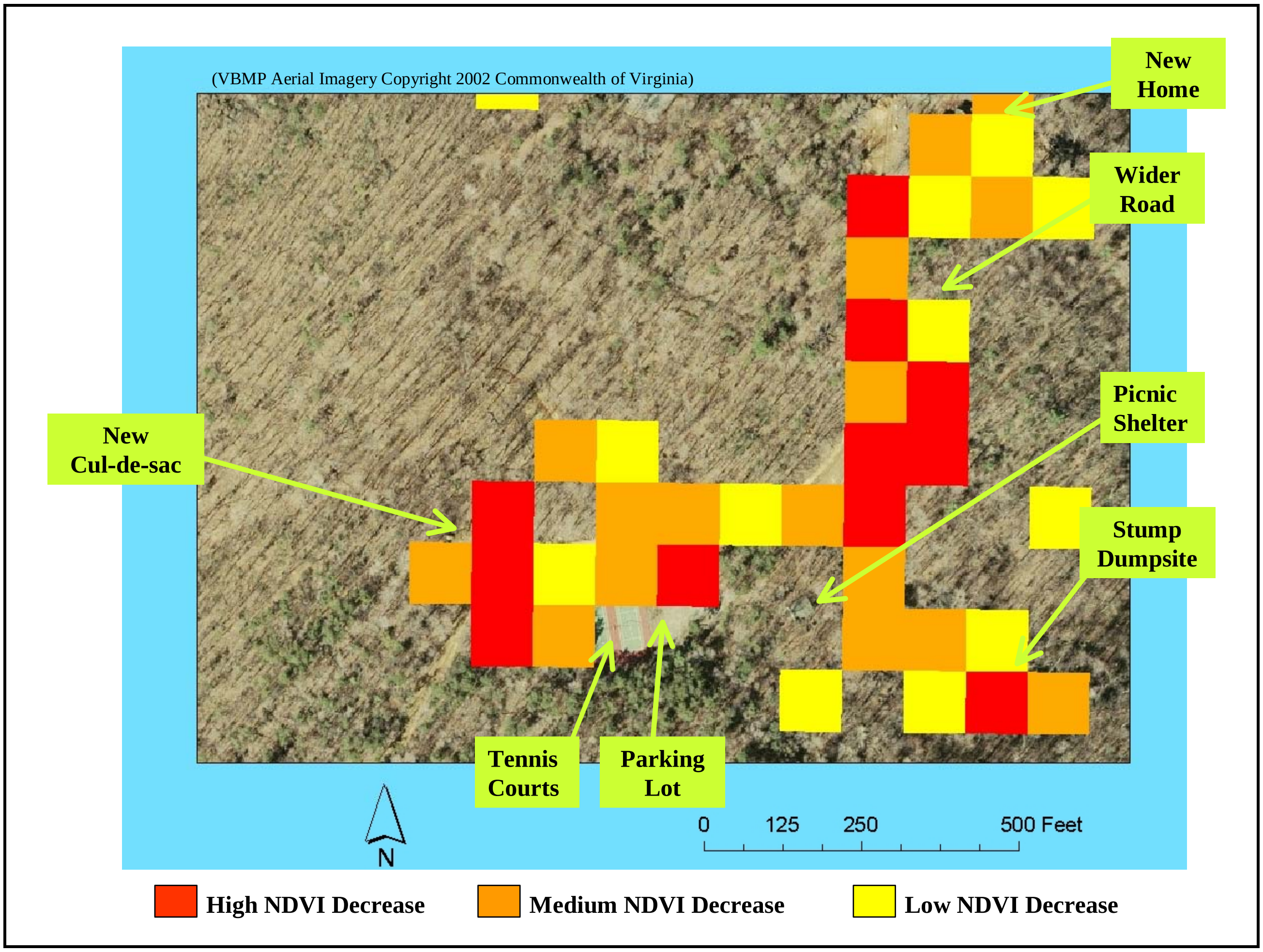


Figure 12: Change Thresholds Selected and Displayed.

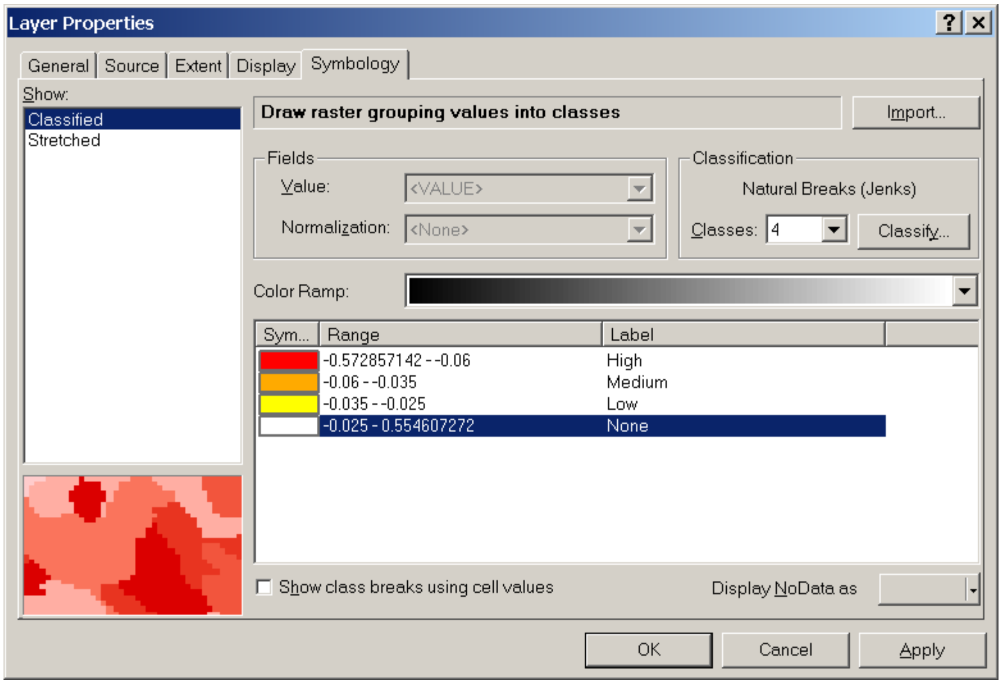
Thresholds are shown superimposed over the 2002 VBMP photograph. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the aerial photograph is displayed.

Figure 12 shows the results of setting specific threshold values. The NDVI difference values are displayed superimposed on the aerial photo shown in Figure 11. Each Landsat pixel, 30 meters square, that has a decline in NDVI greater then a threshold value is colored yellow, gold, or red. If a given Landsat pixel area has no NDVI decline or a decline less then the chosen threshold then the pixel is displayed with no color so that the underlying aerial photo is visible.

Note that in Figure 12 the new cul-de-sac and the wider road are both detected by this threshold selection. A new home is detected in the upper right corner of Figure 11. The Results section will detail a smaller dirt road also detected in Figure 12.

Figures 13 and 14 show how a set of threshold values are selected using the ArcGIS/ArcMAP Layer Properties dialogs. A single threshold setting is selected by specifying three values for the High (Red), Medium (Gold), and Low (Yellow) pixel displays. Figure 13 shows these selections with a –0.06 setting for High, -0.035 setting for Medium, and –0.025 setting for Low. Pixels with a NDVI difference above the threshold values are not colored so that the aerial photograph is visible.

Figure 14 shows the Classify dialog where the actual numbers are entered in the lower right text box. Figure 14 also shows the distribution of NDVI difference values.



Draw raster grouping values into classes

Value: <VALUE>

Normalization: <None>

Natural Breaks (Jenks)

Classes: 4

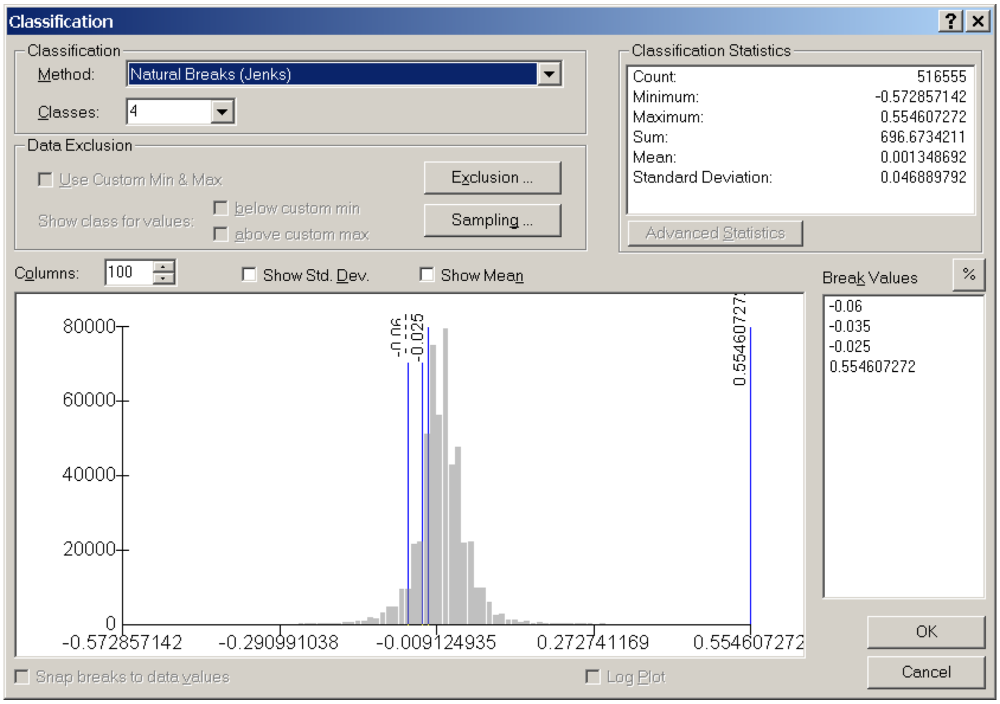
Sym...	Range	Label
🟥	-0.572857142 - -0.06	High
🟧	-0.06 - -0.035	Medium
🟨	-0.035 - -0.025	Low
⬜	-0.025 - 0.554607272	None

☐ Show class breaks using cell values

Display NoData as

Figure 13: ArcGIS/ArcMAP NDVI Difference Layer Properties Dialog.

The purpose of Figures 13 and 14 is to show how easily different threshold settings can be entered and displayed. Deciding on a specific value for the threshold setting and then evaluating the setting’s effectiveness with respect to boundary monitoring encroachment detection is analyzed in the following results section.


Classification

Classification
Method: Natural Breaks (Jenks)
Classes: 4

Data Exclusion
☐ Use Custom Min & Max
Show class for values: ☐ below custom min ☐ above custom max

Classification Statistics

Count:	516555
Minimum:	-0.572857142
Maximum:	0.554607272
Sum:	696.6734211
Mean:	0.001348692
Standard Deviation:	0.046889792

Columns: 100 ☐ Show Std. Dev. ☐ Show Mean

Break Values
-0.06
-0.035
-0.025
0.554607272

☐ Snap breaks to data values ☐ Log Plot

Figure 14: ArcGIS/MAP NDVI Difference Classification Dialog of Layer Properties

3.4 *Accuracy Assessment Sampling*

The accuracy assessment was completed on the AT (Appalachian Trail) study area. The accuracy assessment used a stratified random sampling technique. Sixty sample points were randomly selected from each of two land classification types for a total of 120 points. The ground conditions for each of the sample points were assessed in the office. Some of the points were also assessed in the field. The following further details these procedures.

The land classification types of “Encroached” and “Not Encroached” are not meant to mean that a true human initiated encroachment has occurred. Land classified as “Encroached” means that it is possible that a true encroachment has occurred and a person needs to investigate this location on the ground. Land classified as “Encroached” may be changed due to a climate related phenomenon, for example, an ice storm. Only a person investigating the ground conditions can determine the occurrence of a true encroachment.

3.4.1 Sample Point Selection

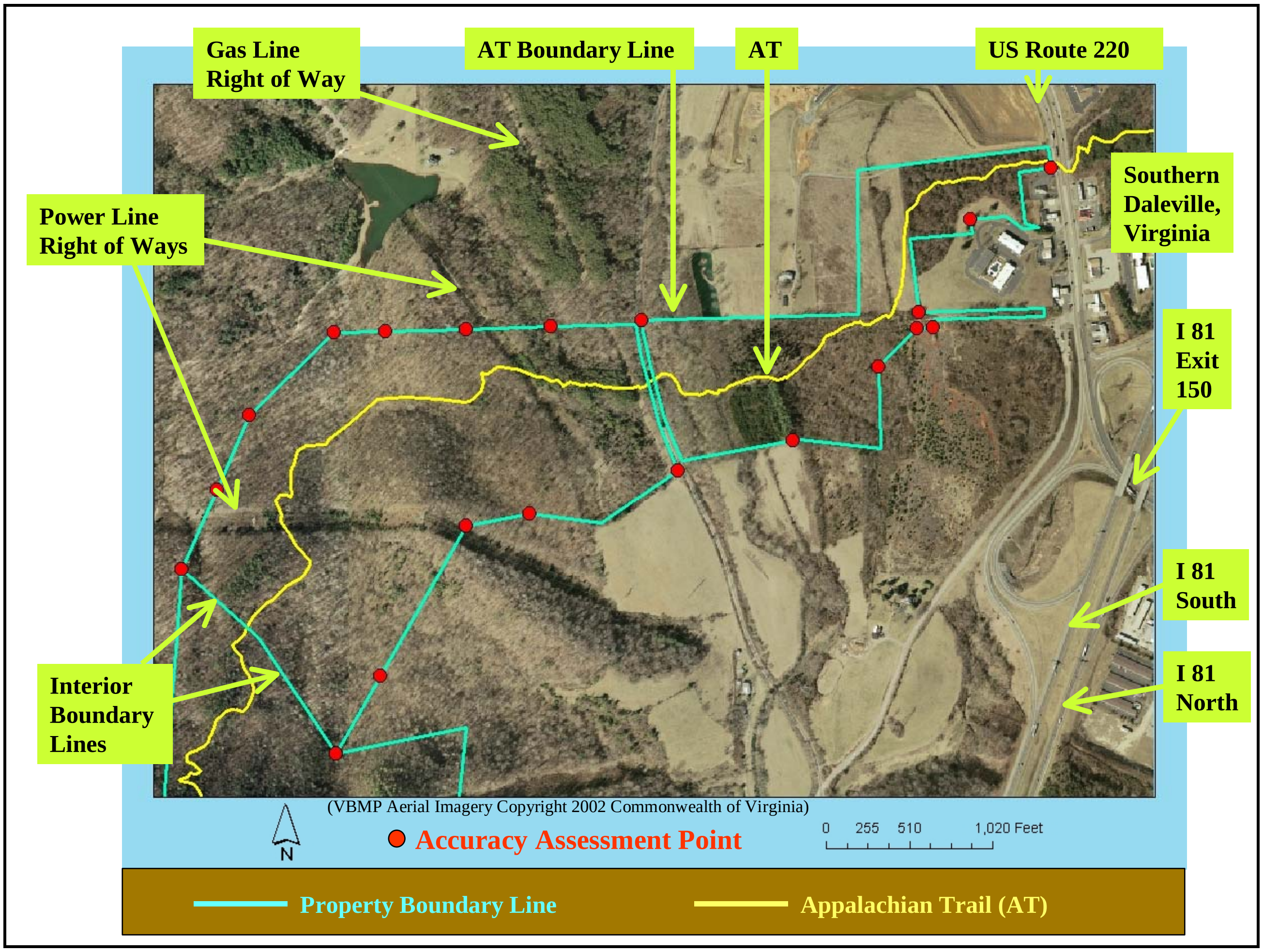
Sample points were randomly selected from the two land classification types of encroached and not encroached. Within these two land types, three subtypes were identified. The three subtypes were points located in the lower elevation valley region, points on the side of the ridge west of the AT, and points on the side of the ridge east of the AT. Table 3 further defines these points.

Table 3: Stratified Sample Selection

Major Land Classification	Secondary Land Classification	Total Points Randomly Selected From	Points Selected
Not Encroached	Valley	43	20
	West Ridge	57	20
	East Ridge	54	20
Encroached	Valley	39	20
	West Ridge	66	20
	East Ridge	63	20
	Totals	322	120

Selection of points that were not encroached was done using the property boundary monument points. These monument points represented 3 miles of boundary in the valley region and 5 ½ miles in each of the east and west of the AT ridge regions. Per table 3, in the lower elevation valley region, there are forty-three monuments. Twenty of these forty-three monument points were randomly selected for the accuracy assessment. Figure 15 shows this valley region and the not encroached selected points as red circles.

Using boundary monument points allowed for verification of the GIS data in the field. As shown in Figures 6 and 7, each monument point is well marked and easily identified. Using the coordinates from the GIS database to navigate to the monuments in the field verified the boundary line digitization process.



(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 15: Selected Not Encroached Points in Valley Area with VBMP Photograph.

Each red circle shows the location of a monument point along the property boundary. These 20 points were randomly selected from the total 43 monument points in the valley area. These 20 points were evaluated in the accuracy assessment.

Numbering all the indicated encroached areas and then randomly selecting points within the numbered group accomplished the selection of encroached points for the accuracy assessment. Per table 3, in the lower elevation valley region, there are thirty-nine encroached areas. Twenty of these thirty-nine points were randomly selected for the accuracy assessment. Figure 16 shows this valley region and the encroached selected points.

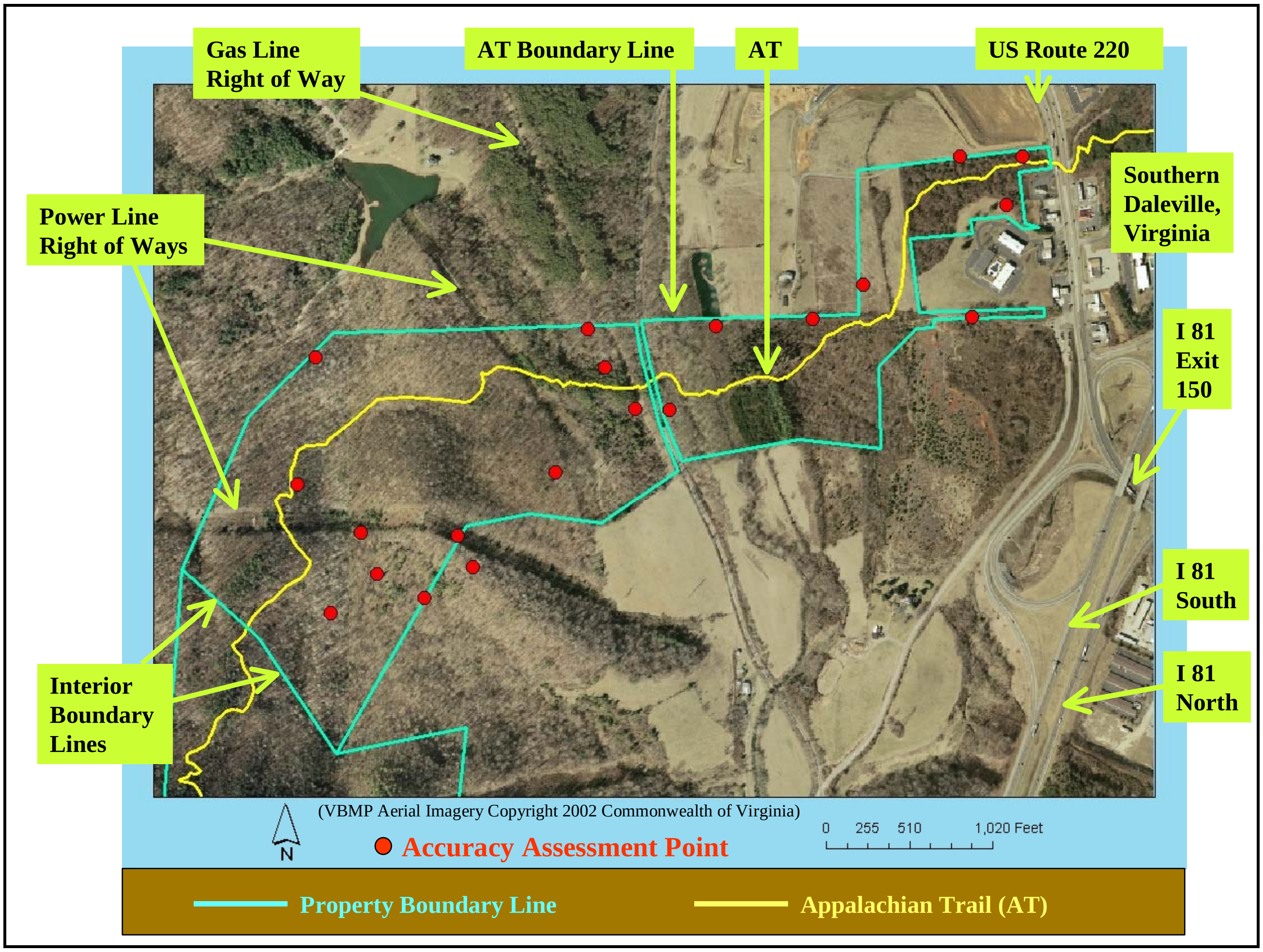


Figure 16: Selected Encroached Points in Valley Area with VBMP Photograph.

Each red circle shows the location of a possible encroached point in or near the AT property. These 20 points were randomly selected from the total 39 possible encroached points in the valley area. These 20 points were evaluated in the accuracy assessment.

3.4.2 Field and Office Methods

To complete the accuracy assessment, each candidate point, possibly encroached or not, had to be evaluated to decide if the point was actually a changed area that needed to be inspected by a person for a true encroachment. All the points were evaluated in the office; some points were evaluated on the ground. This evaluation is to ascertain the ground conditions in the spring of 2000 versus 2002. In the office, each point was evaluated using the two sets of aerial photographs. On the ground, a point's position was identified using a GPS receiver, photographed, and conditions noted. The results of this evaluation are given in the appendix and used in the following accuracy assessment tables.

4 Results

4.1 *Threshold Investigation*

A threshold setting is the value of NDVI difference or NDVI reduction that is considered significant enough to require a field inspection. Figure 17 shows the NDVI difference distribution for the two images. Negative values are to the left side of the distribution and represent a reduction of NDVI in the 2002 image when compared to the 2000 image. At the bottom of Figure 17 is a specific threshold selection. Yellow, Gold, Red, or Low, Medium, High settings are used to indicate the strength of a difference at a given pixel location. A reduction of –0.025 to –0.035 is considered low. A reduction from –0.035 to –0.06 is considered medium. A reduction greater than –0.06 is considered high. For these settings, the actual threshold number would be –0.025. It is at this setting that an NDVI difference would be considered significant enough to trigger a field inspection.

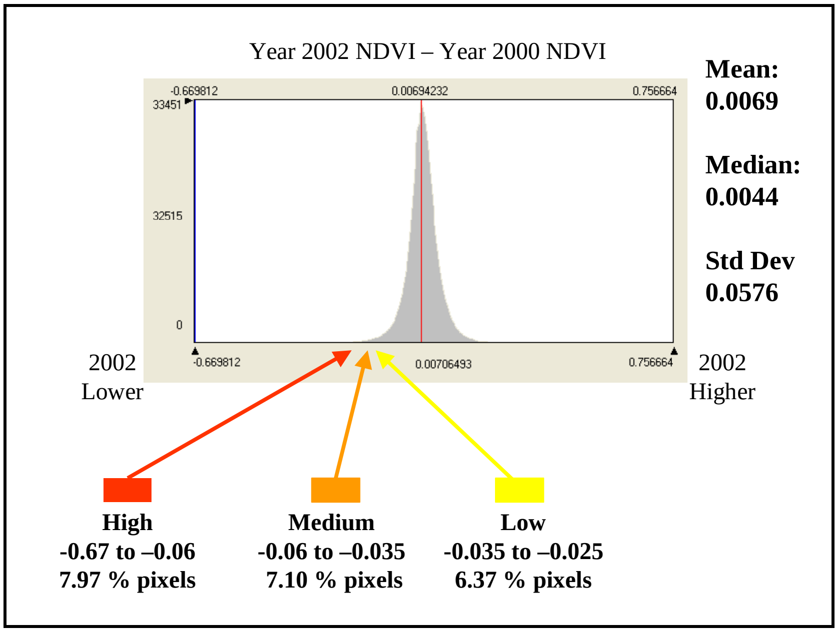


Figure 17: Threshold Distribution

4.1.1 Selection using AOI Study Area

The Area of Interest (AOI) Study Area was used to investigate settings of threshold values. Known changes were used to select threshold values that highlighted the changed area without causing too many false indications. Figures 10, 11, and 12 above show the results for the new sub-division road and cul-de-sac. This cul-de-sac is a large area of change that covers a whole Landsat 30-meter pixel in area.

A smaller road extending off of the new sub-division road is an example of a sub-pixel sized change that was used to refine the selection of threshold values. Figure

18 is a ground photograph of this small dirt road extending off of the sub-division road and ending in an area where tree stumps and brush were discarded at a dumpsite. This narrow road, less than 15 feet wide, is precisely the type of encroachment that should be detected by AT property boundary monitoring.

(Photo by James F. Hutchings)

Figure 18: Small Dirt Road to Dumpsite Ground Photograph

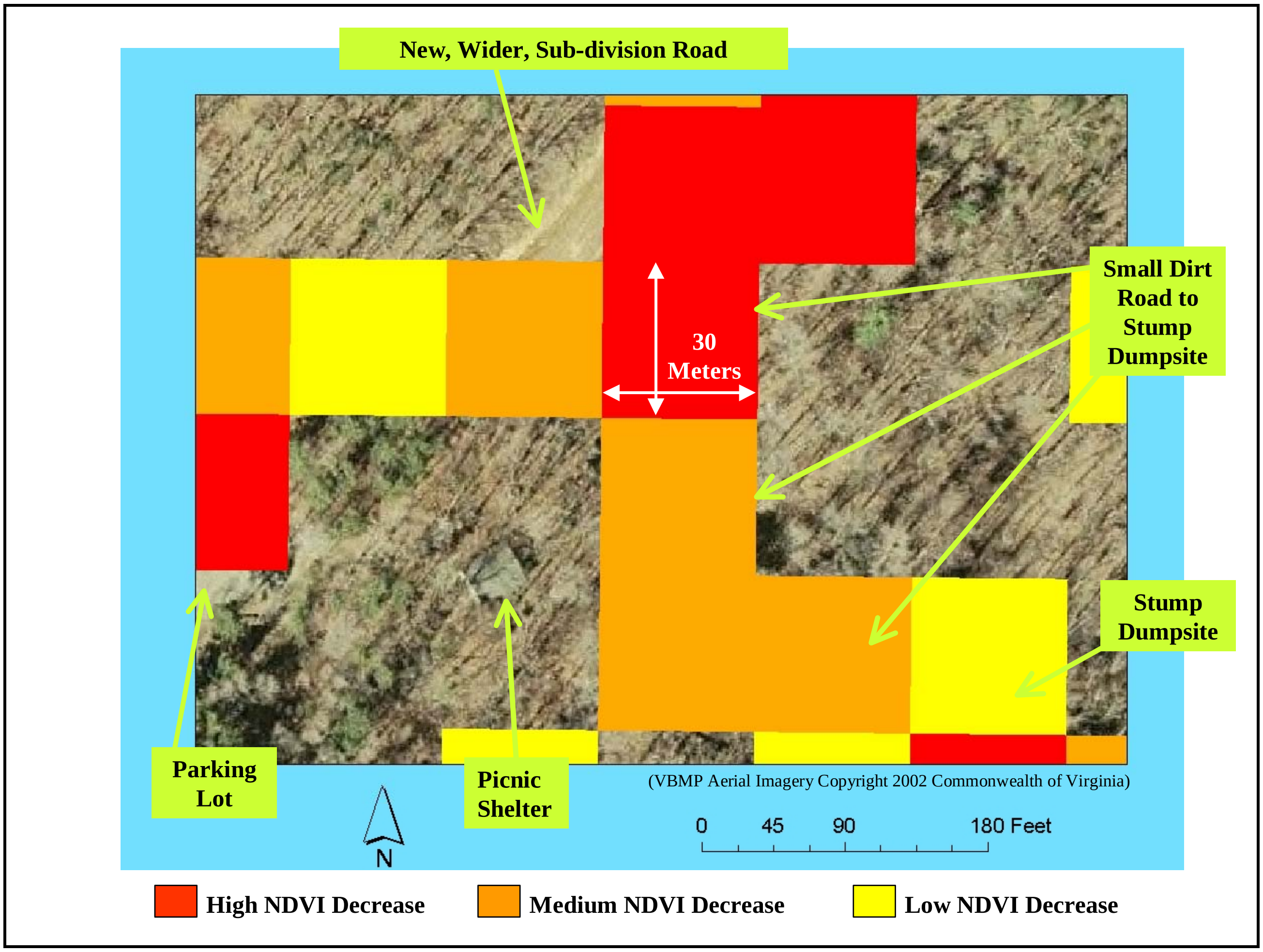
Figure 19 shows an aerial photograph of this dirt road at about the same time as the Landsat 2002 image was acquired. The arrows point to this narrow dirt road. This dirt road starts in the center of the photo where it connects to the main sub-division road. The road ends at the dumpsite which is at the bottom right of the photo. Figure 20 shows this same aerial photograph superimposed with pixel change indications for a selected threshold setting.

The important section of this dirt road is the connection between the sub-division road and the dumpsite. At the sub-division road and dumpsite there is a very strong decrease in NDVI as expected. The important indications are the three medium or gold pixels that connect the sub-division road to the dumpsite. The threshold setting has been selected such that these pixels are highlighted as a moderate or medium change.

(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 19: Small Dirt Road to Dumpsite VBMP Aerial Photograph.

Note the small dirt road that connects the sub-division road to the stump dumpsite.



(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 20: Small Dirt Road to Dumpsite with Threshold Settings.

Note that the small dirt road is highlight by medium and high NDVI decrease pixels. Thresholds are shown superimposed over the 2002 VBMP photograph. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the aerial photograph is displayed.

The dirt road shown in Figures 18 through 20 was not the only change in the AOI study area used for threshold selection. There were numerous driveways, drainage ditches, and home sites that also helped in this selection.

4.1.2 Applied to AT Study Area

The threshold setting described above was then applied to the AT study area. Figures 21 through 24 show smaller scale images of the AT study area with changes highlighted. Note how this detection method detects large changes in the valley areas and little change along the route of the AT.

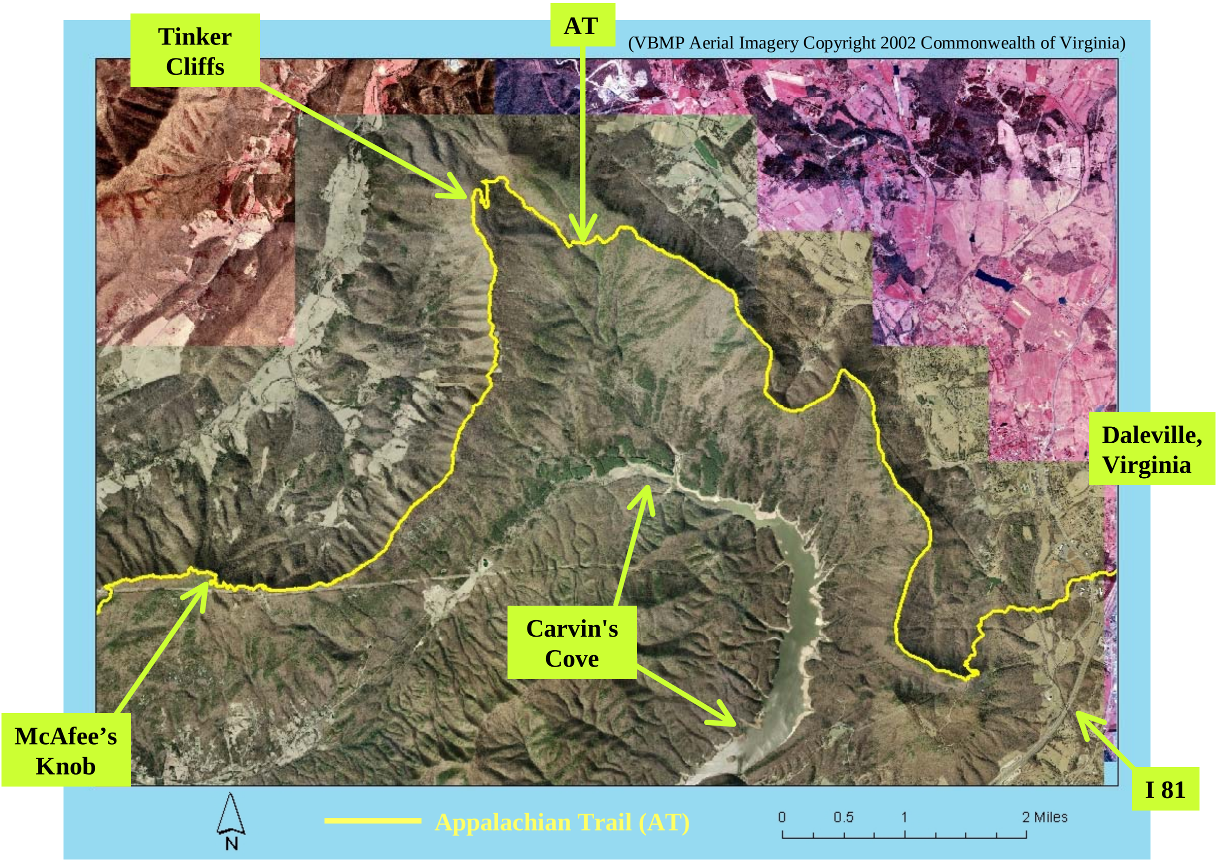


Figure 21: The AT from McAfee's Knob to Daleville, VA

Note that the AT is located mostly on a mountain ridge above Carvin's Cove. To the east the AT crosses Interstate 81 and climbs to the ridge top above Carvin's Cove. The AT Study Area for this research is the right or eastern portion of this figure.

The aerial photography used in this figure is mostly from the VBMP except for the top right and left corners that are from the Virginia DOQQs.

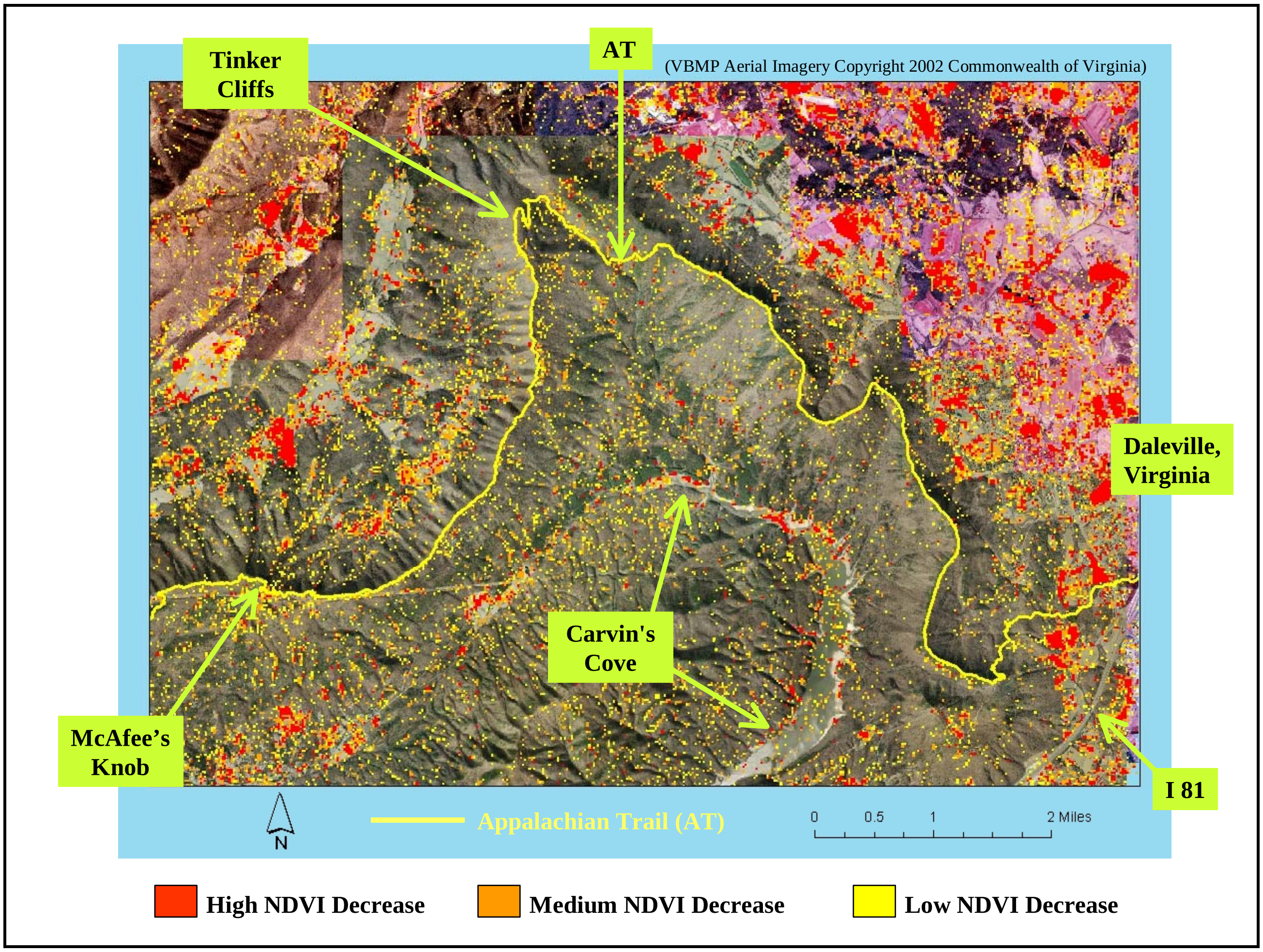


Figure 22: The AT from McAfee's Knob to Daleville, VA. With Change Indications

This image is the same area as Figure 21 above. Note the larger areas of change, clusters of red, detected in the lower elevations. These larger areas are development or agricultural activities. Note that along the route of the AT there is less change indicated. The AT Study Area for this research is the right or eastern portion of this figure.

Thresholds are shown superimposed over the aerial photography. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the aerial photograph is displayed.

The aerial photography used in this figure is mostly from the VBMP except for the top right and left corners that are from the Virginia DOQQs.

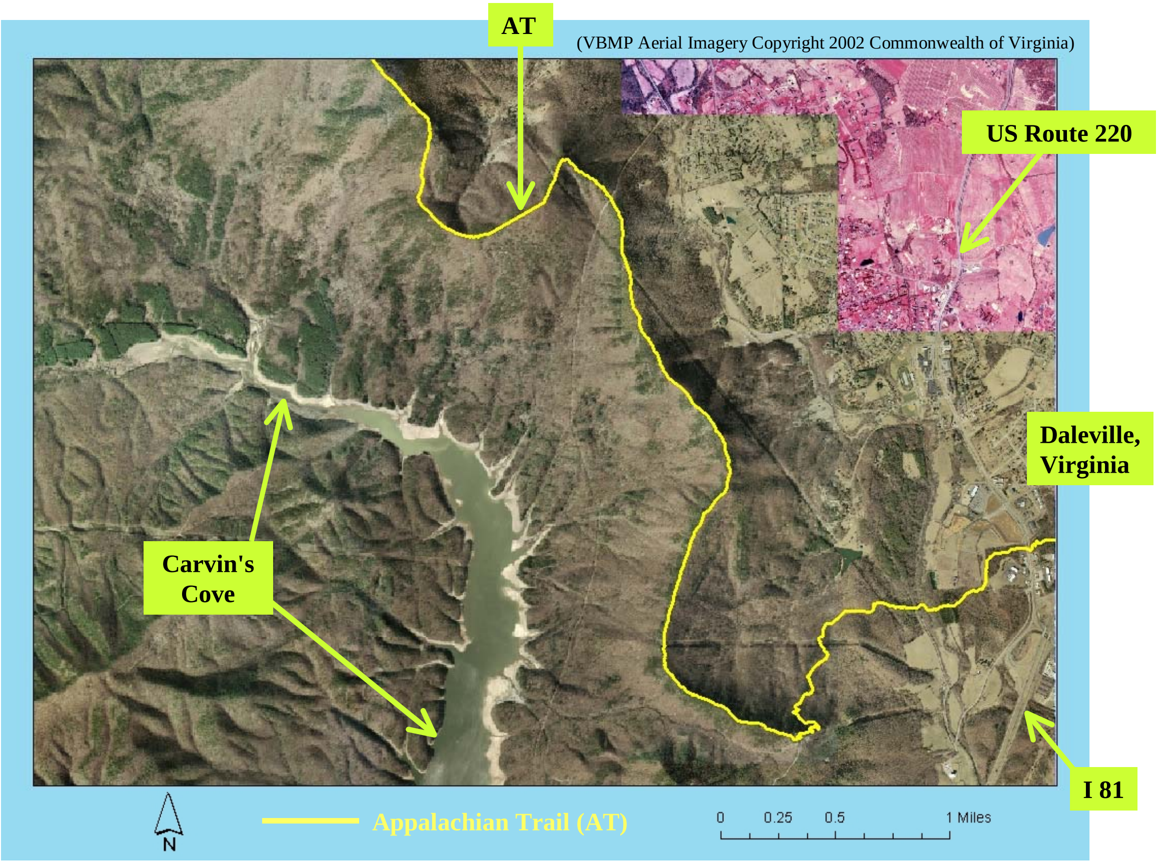


Figure 23: The AT Southwest of Daleville, VA

Note that the AT is located mostly on a mountain ridge above and to the northeast of Carvin’s Cove. In the eastern portion of this figure the AT crosses Interstate 81 and climbs to the ridge top above Carvin’s Cove. This figure shows the AT Study Area for this research.

The aerial photography used in this figure is mostly from the VBMP except for the top right or northeast corner. The top right corner is from the Virginia DOQQs.

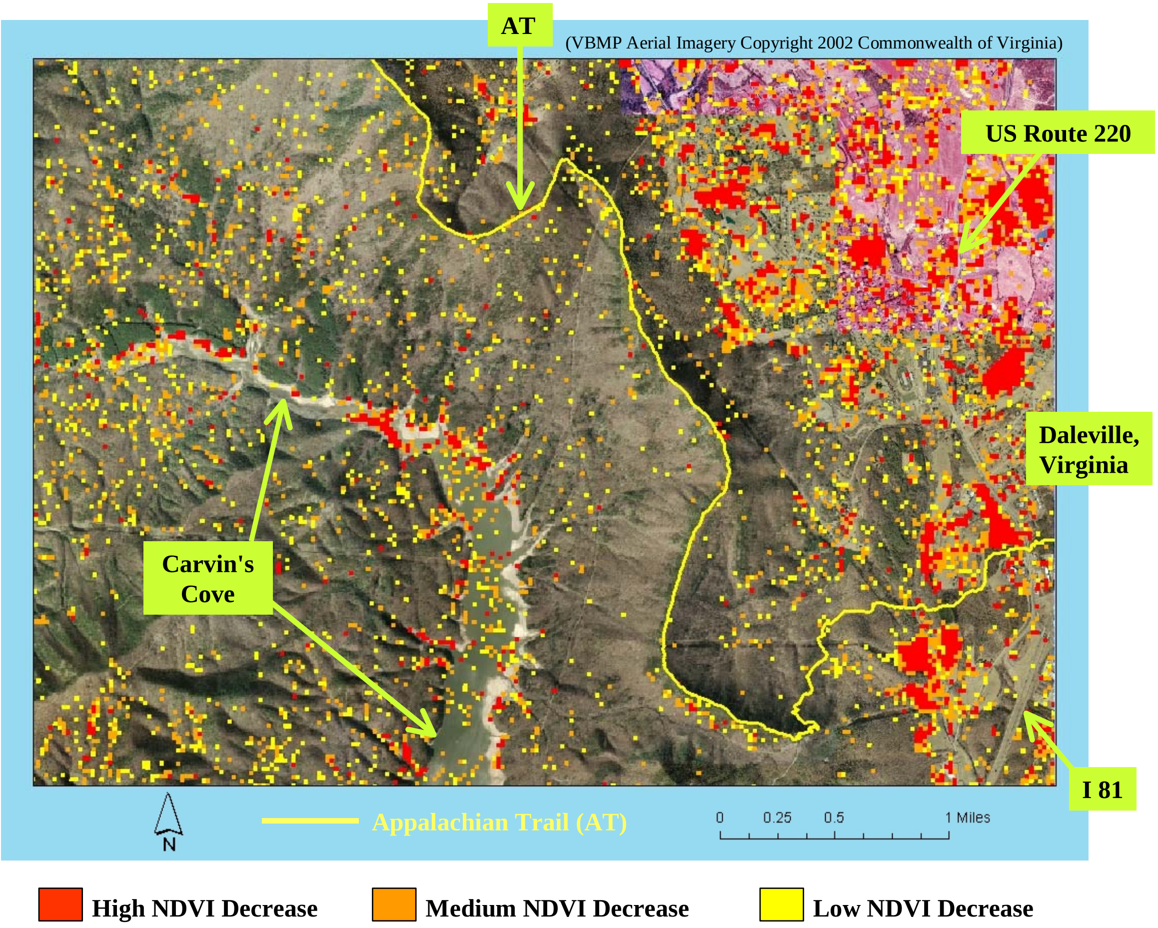


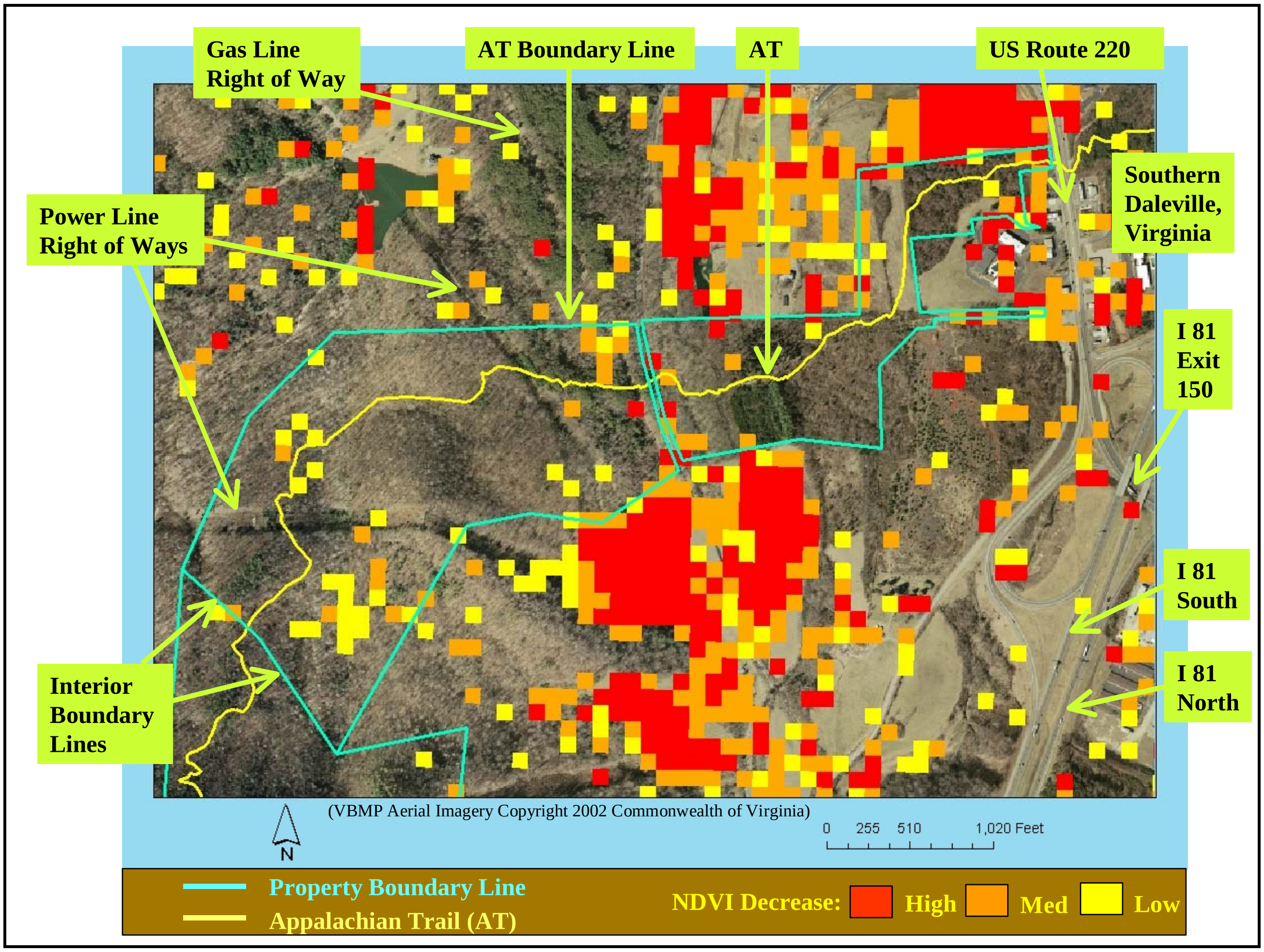
Figure 24: The AT Southwest of Daleville, VA. With Change Indications

This image is the same area as Figure 23 above. Note the larger areas of change, clusters of red, detected in the lower elevations. These larger areas are development or agricultural activities. Note that along the route of the AT there is less change indicated.

Thresholds are shown superimposed over the aerial photography. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the aerial photograph is displayed.

The aerial photography used in this figure is mostly from the VBMP except for the top right or northeast corner. The top right corner is from the Virginia DOQQs.

Figure 25 shows a larger scale image of the valley region of the AT study area. The property boundaries are shown in light blue and the centerline of the AT is shown in yellow. Figure 25 also includes the change mask or Landsat pixels that have decreased in NDVI values per the selected threshold values from above. Note the large amount of change outside the AT property boundaries. These changes are in new sub-divisions and commercial construction areas. Within the AT boundaries there is less change indicated. Because it is known that little has changed within the AT boundaries, this is anecdotal evidence that the threshold selection may be useful in detecting encroachments.



(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 25: Change Indications in AT Valley Region.

Note that outside the AT boundaries there is significant change indicated due to development. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the VBMP aerial photograph is displayed.

4.1.3 Three Threshold Settings

Three threshold settings are presented in this section and will be formally analyzed later. First, the threshold setting reviewed in the previous section will be used. This setting will be referred to as the medium setting. The specific values for this setting are given in the middle row of Table 4. The other two threshold settings will provide a stronger (higher) value and a weaker (lower) value than the medium setting. These stronger and weaker settings are upper and lower limits for the medium setting. The selection of these higher and lower settings is described below.

The weaker (lower) setting was selected such that the dirt road to the dumpsite shown in Figures 18 through 20 is not detected. This lower threshold value selection should provide an example in which possible encroachments are missed. This lower setting is specified in the first row of Table 4. Figure 26 uses this lower setting for the dirt road from Figures 18 through 20. Note that the dirt road is not highlighted in Figure 26 as it is in Figure 20.

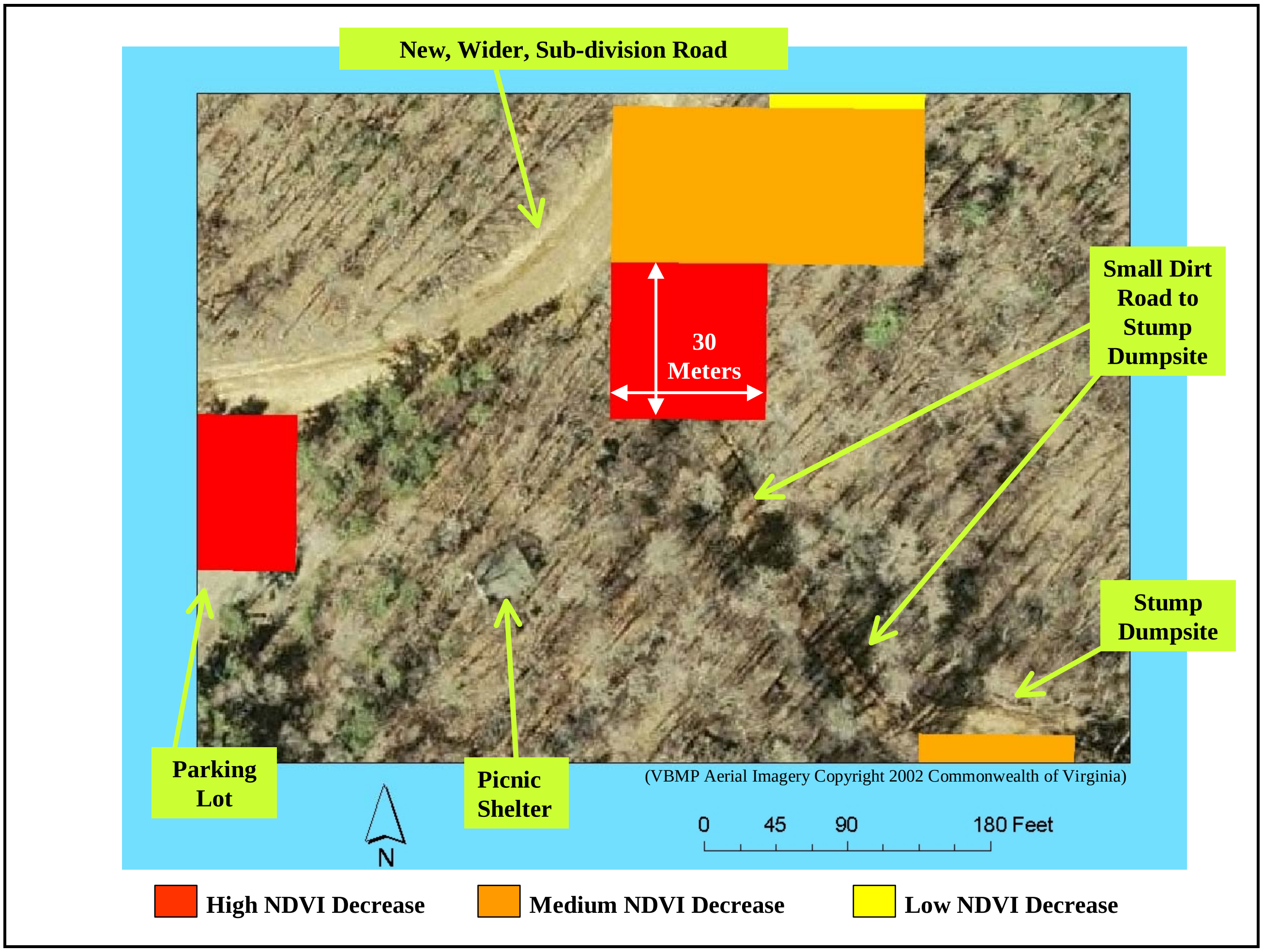
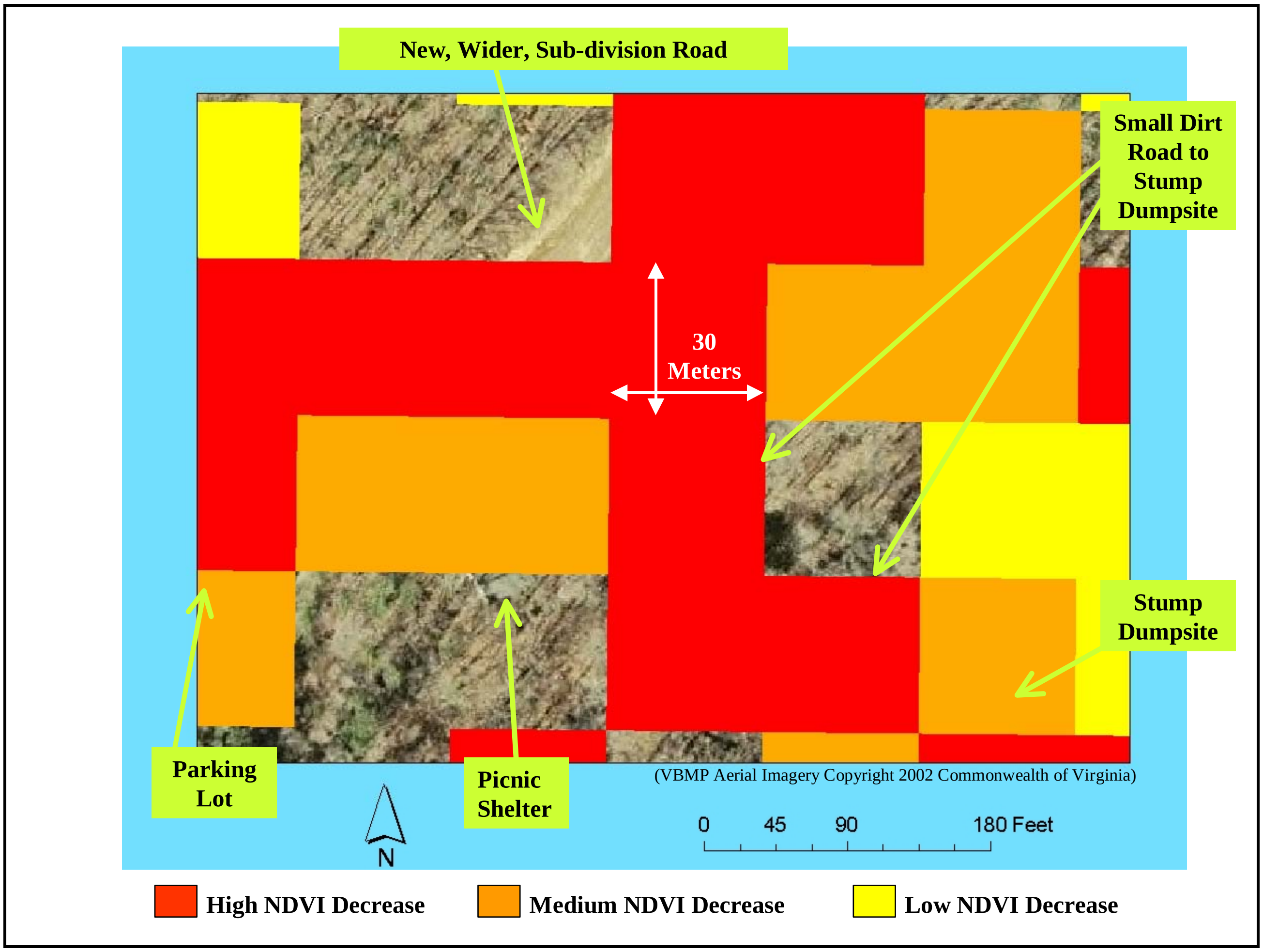


Figure 26: Dirt Road with Low Threshold Setting.

Note that the small dirt road is not highlight by any NDVI decrease pixels. Thresholds are shown superimposed over the 2002 VBMP photograph. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the VBMP aerial photograph is displayed.

The stronger (higher) setting was selected such that any decrease in NDVI value is detected. This higher threshold value selection should be an example where too many false possible encroachments are detected. This higher setting is specified in the third row of Table 4. Figure 27 uses this higher setting for the dirt road shown in Figures 18 and 19. This stronger (higher) setting detects the dirt road, but generates false positives.



(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 27: Dirt Road with High Threshold Setting.

Note that the small dirt road is totally highlighted by high NDVI decrease pixels. Also note that other pixels have been marked as changed. Thresholds are shown superimposed over the 2002 VBMP photograph. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the VBMP aerial photograph is displayed.

Table 4: Three Threshold Settings Values

Threshold Value Setting Type	High (Red) Decrease Of NDVI Value	Medium (Gold) Decrease Of NDVI Value	Low (Yellow) Decrease Of NDVI Value
Low or Weaker	-0.075	-0.065	-0.055
Medium	-0.060	-0.035	-0.025
High or Stronger	-0.030	-0.015	0.000

Figures 28 and 29 show the valley region of the AT study area similar to Figure 25 where the medium threshold setting is displayed. Figure 28 uses the low threshold setting and Figure 29 uses the high setting. In Figure 28 there are very few possible encroachments indicated within the AT boundaries (light blue lines). This is anecdotal evidence that the low threshold setting may be missing possible encroachments. Similarly, Figure 29 seems to show too many encroachments. The following accuracy assessment will formally measure the performance of these threshold settings.

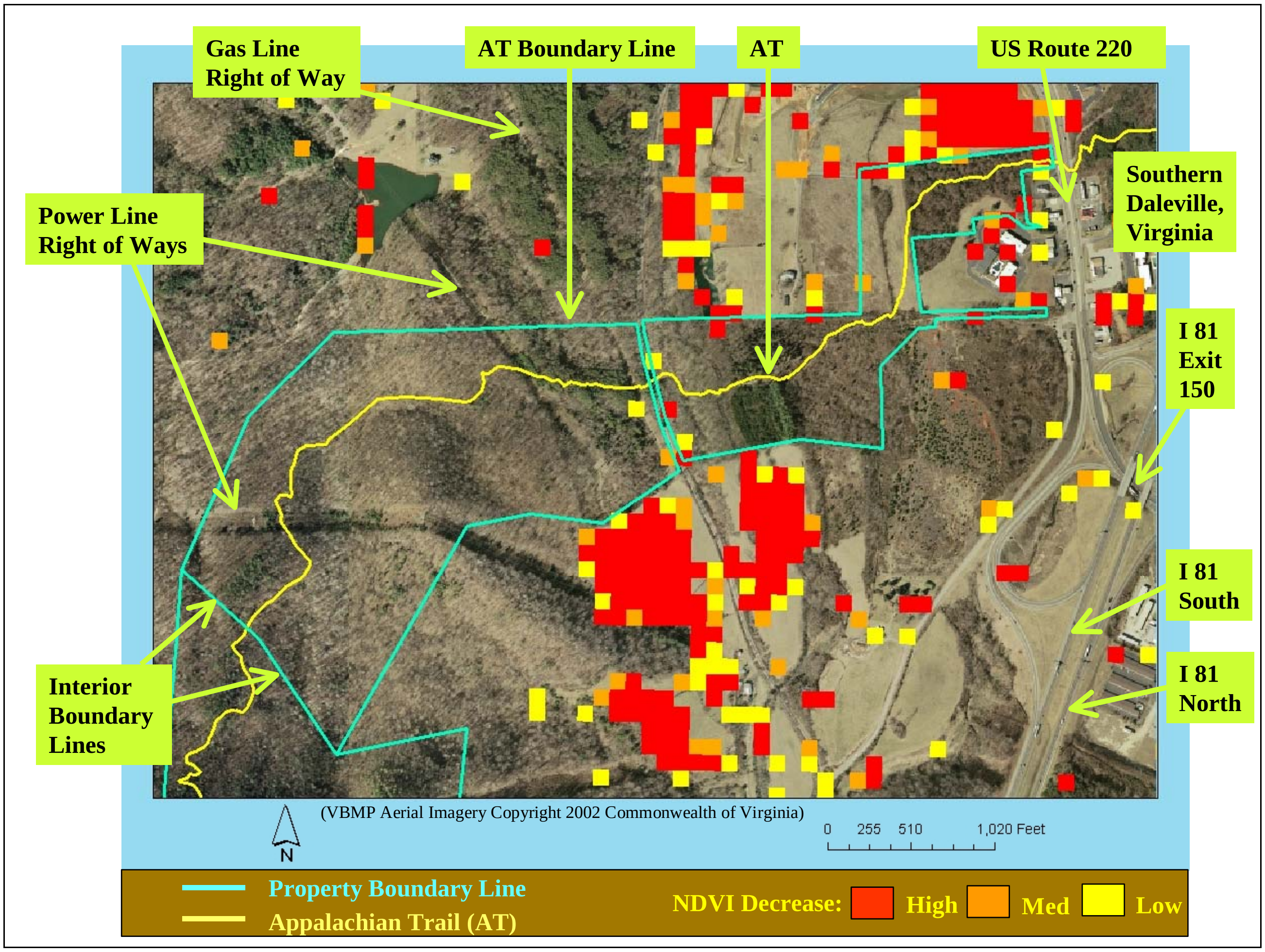


Figure 28: AT Valley Region with Low Threshold Setting.

Note that inside the AT boundaries there are very few significant decreases in NDVI indicated. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the VBMP aerial photograph is displayed.

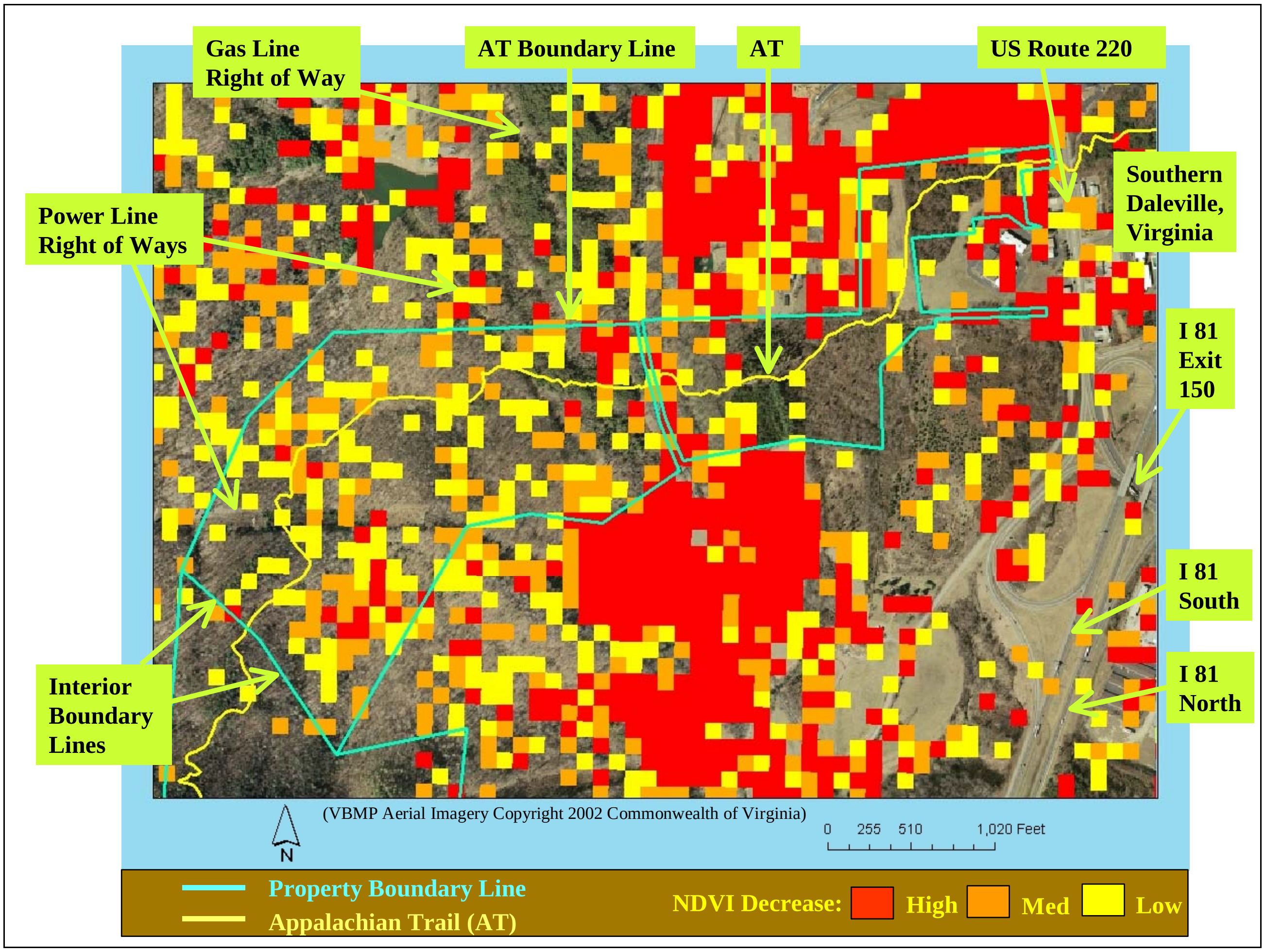


Figure 29: AT Valley Region with High Threshold Setting.

Note that inside the AT boundaries there are many significant decreases in NDVI indicated. Each 30 meter square pixel where NDVI decreased by the threshold setting is displayed red, gold, or yellow depending on the magnitude of decrease. If the NDVI did not decrease by the threshold value then the pixel square is given no color and the VBMP aerial photograph is displayed.

4.2 Accuracy Assessment

Tables 5, 6, and 7 show the results of the accuracy assessment for the three threshold settings of High (Strong), Medium, and Low (Weak). These tables are in an error matrix format as explained above. Point sampling for this accuracy assessment was also detailed earlier. The details of each assessed point are given in the appendix.

Table 5: Accuracy Assessment for the High or Strong Threshold

Actual Ground Conditions

	Error Matrix	Possible Encroachment Not Found	Possible Encroachment Found	Total	Consumer's Accuracy
Indication on Map	Possible Encroachment Not Indicated	42	0	42	42/42 = 100%
	Possible Encroachment Indicated	31	47	78	47/78 = 60.3%
	Total	73	47	120	Overall
	Producer’s Accuracy	42 / 73 = 57.5%	47/ 47 = 100%		89/120= 74.2%

Table 6: Accuracy Assessment for the Medium Threshold

Actual Ground Conditions

	Error Matrix	Possible Encroachment Not Found	Possible Encroachment Found	Total	Consumer's Accuracy
Indication on Map	Possible Encroachment Not Indicated	60	0	60	60/60 = 100%
	Possible Encroachment Indicated	13	47	60	47/60 = 78.3%
	Total	73	47	120	Overall
	Producer’s Accuracy	60/73 = 82.2%	47/47 = 100%		107/120 = 89.2%

Table 7: Accuracy Assessment for the Low or Weak Threshold

Actual Ground Conditions

	Error Matrix	Possible Encroachment Not Found	Possible Encroachment Found	Total	Consumer's Accuracy
Indication on Map	Possible Encroachment Not Indicated	72	32	104	72 /104 = 69.2%
	Possible Encroachment Indicated	1	15	16	15/16 = 93.8%
	Total	73	47	120	Overall
	Producer’s Accuracy	72/73 = 98.6%	15/47 = 31.9%		87/120 = 72.5%

4.3 Accuracy Assessment Statistics

As discussed earlier, the two most important measurements from the error matrix are the producer's accuracy in the "Possible Encroachment Found" column and the consumer's accuracy in the "Possible Encroachment Indicated" row. These two measurements are extracted from Tables 5, 6, and 7 and summarized in Table 8.

Table 8: Accuracy Assessment Percentages

Accuracy Assessment Summary	Producers Accuracy for Possible Encroachment Found	Consumers Accuracy for Possible Encroachment Indicated	Overall Accuracy
High or Strong Threshold Setting	100%	60.3%	74.2%
Medium Threshold Setting	100%	78.3%	89.2%
Low or Weak Threshold Setting	31.9%	93.8%	72.5%

The medium threshold setting gives the best balance between finding all the possible encroachments and producing the least number of indicated false possible encroachments.

Table 9 summarizes the Kappa coefficients (Cohen, 1960) and Z scores for each of the error matrixes of Tables 5, 6, and 7.

Table 9: Accuracy Assessment Kappa Statistics

Accuracy Assessment Summary	Kappa Coefficient	Kappa Standard Deviation	Kappa Z Score	Confidence Coefficient Not Zero
High or Strong Threshold Setting	0.5149	0.1543	3.34	Greater Than 95%
Medium Threshold Setting	0.7833	0.1091	7.18	Greater Than 95%
Low or Weak Threshold Setting	0.3460	0.2065	1.68	Greater Than 90%

The Kappa statistic indicates how much better the given threshold setting is than just change assignment. The medium threshold setting gives a Kappa coefficient of 0.7833 that is approaching the strong range of above 0.8.

Table 10 compares each pair of threshold error matrixes for independence. The Kappa coefficients and standard deviations from Table 9 are used to calculate these Z scores.

Table 10: Accuracy Assessment Error Matrixes Comparison

Accuracy Assessment Summary	Comparison Z Score	Confidence That Error Matrixes Are Independent
Medium Verses High Threshold Settings	1.42	Greater Than 80%
Medium Verses Low Threshold Settings	1.78	Greater Than 90%
High Verses Low Threshold Settings	0.66	Less Than 60%

The medium threshold is most likely a separate threshold setting from the high and low settings. The low and high settings are very close to one another using this statistical method.

4.4 Monitoring Buffer Size

Because of small errors in image registration and errors in the digitizing of property boundaries, a small portion of land outside the property boundaries should be monitored for possible encroachments. This small portion of land or buffer could be referred to as the Monitoring Buffer. The property surveys contain extra survey lines through the property that form closed survey loops. Closing these loops when digitizing the boundaries gives some indication of the error in the boundary digitizing process. It was found that there was less than 50 feet error in the boundary lines digitized for this research. Also, some of the known encroachments seemed to demonstrate a registration error of at the very most one half of a pixel, or about 15 meters. Adding both of these errors together and then realizing that the boundary lines do not necessarily lineup with pixel boundaries, it is felt that a monitoring buffer of about 200 feet or about two Landsat 30 meter pixels would be more than enough to insure all possible encroachments are investigated on the ground. More research into this topic could help eliminate these errors and thus reduce this buffer distance. Although, in completing this research, it seemed that this small area does not add much effort to the monitoring process.

5 Conclusion

This research was successful in measuring how well remote sensing can be used in monitoring park boundaries. Table 8 shows that possible encroachments can be detected reliably with a false indication level of less than one in four. These results are very promising and further work and research in these methods is warranted.

The following are detailed concluding comments:

1. The simplicity of this change detection method is important. With only a single copy of GIS software like ArcGIS, one person could register, atmospheric correct, and compute NDVI changes. This one person could then send the results to other AT boundary monitor personnel for viewing with a public domain (no cost) GIS viewer like ArcExplorer. There would be no need for expensive image analyzing software.
2. Using a vegetation index to detect changes across the entire property has the added advantage of detecting other vegetation problems. For example insect infestations could be detected.
3. Using a vegetation index has the disadvantage of not working well for non-vegetated boundaries. Almost all of the AT boundaries are vegetated. Other long distance trails may not be able to rely on a vegetation index based change detection method.
4. Only two remotely sensed images were used in this research. These results are for only one image pair. These methods need to be applied to more image pairs.
5. The two images used for this research were during leaf off conditions. Other seasons of the year need to be tested.
6. Because of items 4 and 5 above, the threshold settings used in this research are not applicable to all image pairs. There may not be a single threshold setting for all image pairs. More investigation is needed.
7. The minimum size of a detected intrusion seems to be about 10 to 15 feet with these methods. This size would not detect an ATV trail or other smaller encroachments. Possibly higher resolution images may detect smaller changes.
8. Judging vegetation changes from aerial photographs at these scales can be subjective. The measurement of Consumers Accuracy for Possible Encroachment Indicated is the most susceptible to these judgments. This measurement could be overstated.

5.1 Discussion

The following discussion items are presented in three groups. First, continuing work using the methods developed in this research is listed. Second, new research efforts to further improve the boundary monitoring process are suggested. Finally, a comparison of encroachments and vegetation impact is presented.

5.1.1 Continuing Work

1. The National Park Service, Appalachian Trail Park Office (NPS/ATPO) is currently investigating obtaining the Landsat images for the scene that covers the AT study area of this research. NPS/ATPO feels that the cost, which may be very minimal, is well within their funding levels.
2. Threshold value selection methods need to be investigated when new image pairs are available. The technique used in this research depended on training data in a near by sub-division. In the future it may be possible to select a threshold value without training data. The threshold value could be selected high enough that change is indicated on lands surrounding the AT, but not so high as to give too many indications on the AT lands. This or other techniques will need to be evaluated with an accuracy assessment as done for this research.
3. Basing this work on the Landsat satellite system has some risk into the future. We must continue to monitor the status of the Landsat system. Landsat 5 runs out of fuel in 2009. Landsat 7 runs out of fuel in 2010 and currently has other problems. Government representatives presenting at the March 2005, ASPRS conference, were very positive about the future of the Landsat program. A new Landsat sensor is funded and scheduled to launch in 2010. The Landsat system is now considered an operational system by the government and will continue to be maintained and replaced. Still, there could be a gap in Landsat data in the next few years.
4. Continue to monitor and investigate using Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) images for this work. ASTER images are 15-meter resolution, more detailed than that of Landsat. ASTER images are also free for public use. At the time of this research there were no ASTER pairs of images that were cloud free, of the same temporal period, and covering the AT study area.
5. Complete digitizing of the AT survey boundary (ECBS) lines for the 30 mile section of AT in the Roanoke, Virginia area. These techniques could then be applied on a larger area.
6. Investigate applying these same methods to the boundaries of the United States Forest Service (USFS) lands contained in the same Landsat scene.

7. Investigate new known intrusions over time such that the accuracy of these methods can be analyzed further. An example of a known intrusion that occurs regularly is power line maintenance.
8. Historical data requirements and periodicity of monitoring needs to be investigated. The timing of clear images must be considered. Table 11 shows the availability of mostly clear Landsat 5 images for the Landsat scene of the AT study area. It seems that about a 4-year historical library of images would offer the best coverage for past data. A monitoring period of 2 to 4 times per year would be possible, but note that in 2004 there was only one mostly clear image.

Table 11: Past Mostly Clear Landsat 5 Images

Month/Year	2004	2003	2002	2001	2000
January			1/15/2002	1/28/2001	
February					
March	3/25/2004			3/1/2001	
April		4/24/2003		4/2/2001	
May			5/23/2002	5/4/2001	
June			6/8/2002		6/2/2000
July		7/13/2003		7/23/2001	
August			8/11/2002	8/8/2001	
September			9/12/2002		
			9/28/2002		
October			10/14/2002		
November		11/2/2003		11/12/2001	
				11/28/2001	
December				12/30/2001	

5.1.2 Future Research

1. There are numerous other vegetation indices that could be researched and applied to boundary monitoring.
2. There are other Change Detection (CD) techniques that could be applied. One such CD algorithm is called Spectral Change Vector Analysis as noted earlier. This CD technique might work as well or better then NDVI differencing.
3. The development of a less subjective threshold value selection method would be of benefit if possible. This more objective threshold selection process would calculate the best threshold value for an image pair. This calculated threshold value would result in few missed encroachments with a minimum of false indications.

4. This work could be applied to other regions and land owning organizations. For example, the Pacific Crest National Scenic Trail (PCT) is currently purchasing land for protection. Other government agencies and organizations that have land-monitoring responsibilities and could benefit from continuing this research include the following.
    a. U. S. Department of Agriculture – Forest Service
    b. U. S. Department of Interior – Bureau of Land Management
    c. U. S. Department of Defense – U. S. Army Corps of Engineers
    d. U. S. Department of Interior – National Park Service. Many other National Parks other than the Appalachian National Scenic Trail
    e. State Parks
    f. Land Trusts
5. Higher resolution imaging could be used if available. A search for higher resolutions remote sensing images during this research showed that image vendors did not regularly acquire images of the study areas. Obtaining higher resolution images would have incurred costs too large for this study.

5.1.3 Boundary Encroachments and Impact on Vegetation

As presented earlier, the list of boundary encroachments is presented below with comments concerning the impact on vegetation. The purpose here is to show that almost all typical types of encroachments result in vegetation reduction and thus a decrease in vegetation index. The important issue is the spatial extent of the encroachment and the sensitivity of the change detection technique.

1. Timber Theft – Detection using a vegetation index decrease depends on the area of timber removal. Also, the period of monitoring needs to be short enough such that vegetation regeneration does not increase vegetation index. For deciduous forests the summer or “leaf on” season could be the best detection time. Timber thefts of coniferous forests should be detected in any season.
2. Unauthorized Trails or Roads – Assuming a trail or road of any meaningful length (10 feet long or more), detection using a vegetation index decrease depends on the road width. Any road wide enough for construction equipment should be detected. This type of road is used as a threshold calibration point in this research. A narrow hiking trail would most likely not be detected with the technique used in this research.

    Trails and roads should be detected in both forest and non-forest conditions. In either condition, the vegetation will be removed by the road or trail activity. This vegetation removal, if large enough in area, will be detected by a decrease in the vegetation index.
3. Dumping
    a. Household or Industrial Trash

   b. Vehicles, Cars or Trucks
   c. Brush, Stumps, or Other Debris

      Detecting a dumpsite using a vegetation index decrease depends on area of the dump and the site conditions. If the dumpsite is under the forest canopy and the trees are not disturbed it is possible that no decrease in vegetation index would result. A dumpsite in a field would cover the vegetation and be detected if large enough in area.

4. Horse, Mountain Bike, or ATV Use – Like roads and trails, these activities will be detected if the area impacted is large enough. Normally these activities produce a narrow trail that would not decease the vegetation index enough for detection, but this depends on the extent of the activity and the resolution of the remotely sensed data.
5. Adjoining Landowner Activities
   a. Mowing or Vegetation Removal – Again, detection depends on the area impacted. There is no question that the vegetation index will be reduced after the activity, but the periodicity of the monitoring is important. Some time after mowing the vegetation could regenerate stronger then before and thus miss detection.
   b. New Structures and Driveways – Most structures of any size require enough vegetation removal that the decrease in vegetation index will be detected.

This thesis research only starts to answer some of these detailed detection issues. For example the minimum width of a road detected with Landsat data is estimated. Further experience and analysis will be required to understand and evaluate the sensitivity of these techniques in each encroachment situation.

This research did not investigate vegetation decrease sensitivity in non-forested areas. Non-forested areas may require a different threshold value for the detection of new roads or trails. Future research will be needed with training data in non-forested areas.

Using a decrease in vegetation index as a detection technique will detect more than encroachments. Fire, insect, and weather damage to the vegetation will also be detected. To boundary monitoring personnel these indication are false alarms and could be viewed as a nuisances. In the broader context, these changes to the public lands need to be detected and documented.

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7 Appendix

7.1 Registration

Registration of images insures that a given point in each image is the same location. For this research, it is important that the two sets of Landsat images and the two sets of aerial photographs are well referenced or registered to one another. These four images were compared at a number of road intersections to verify their registration. It was felt that no further registration was necessary for these images. Figures 30 through 33 show one of the major road intersections located about 1200 feet from the AT Study Area. This intersection is Exit 150 of Interstate 81. Note that the red dot in these figures is in the center between the two Interstate 81 overpasses of US Route 220. This red dot is in the same location in all four of the figures.

Figures 32 and 33 show the same road intersection using the Landsat images at a much smaller scale. This smaller scale is necessary because the Landsat images are acquired at a lower resolution and it is difficult to identify points at larger scales. The position of the red dot is at the same location as in Figures 30 and 31. The Landsat images were clipped just east of this intersection so the right sides of these figures show the DOQQ photograph. Similar to other figures the AT is shown by the yellow line and the AT property boundaries are shown in light blue.


(VBMP Aerial Imagery Copyright 2002 Commonwealth of Virginia)

Figure 30: VBMP Photograph at Interstate 81 Exit 150. Note position of red circle.

Figure 31: DOQQ Photograph at Interstate 81 Exit 150. Note position of red circle.

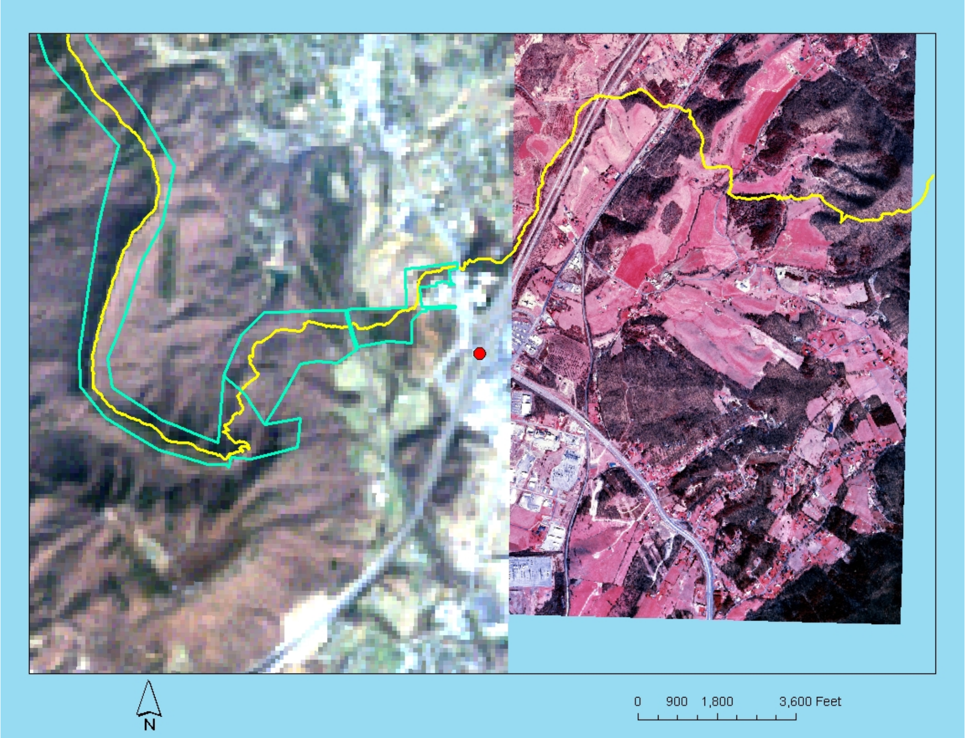

Figure 32: Landsat Year 2000 Image at Interstate 81 Exit 150.
Note position of red circle. Yellow and light blue lines are the AT and boundary lines as described above.

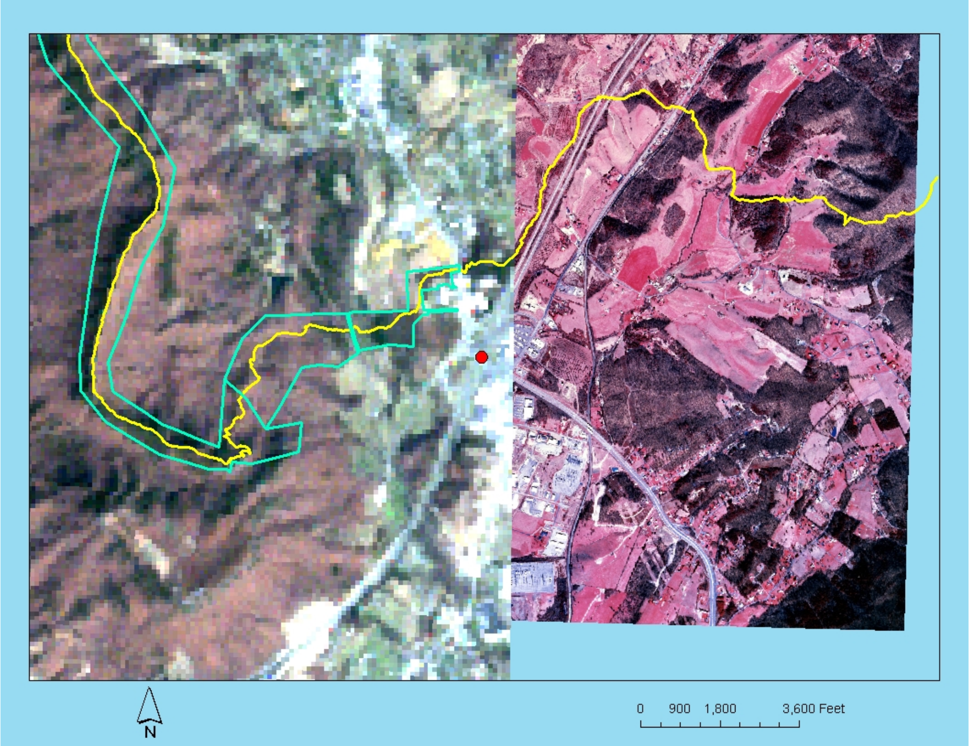

Figure 33: Landsat Year 2002 Image at Interstate 81 Exit 150.

Registration of images is very important to the success of accurate change detection and should always be checked and adjusted as needed. Future Landsat images used for this process may need to be registered prior to their use.

7.2 Atmospheric Correction

Prior to computing the NDVI values and the change detection calculation, both Landsat images were analyzed for possible atmospheric distortions of the radiometric values. Two separate image atmospheric correction techniques were applied to the two Landsat images. First, a haze filter was applied to the images and the results compared to the original images. Second, a dark object subtraction was performed.

7.2.1 Haze Filtering

The ERDAS Imagine software package contains a haze filter that was applied to both the year 2000 and year 2002 Landsat images. After the haze filter was applied, the resulting images were used in the NDVI computation and the change detection calculation. Using the same threshold settings, the detection results were compared with the results using the images without haze reduction. No noticeable differences in performance were found. Figure 34 shows the same image as Figure 12 except Figure 34 uses the haze corrected images. The change detection results are the same. For these two images the haze filter did not affect the results.

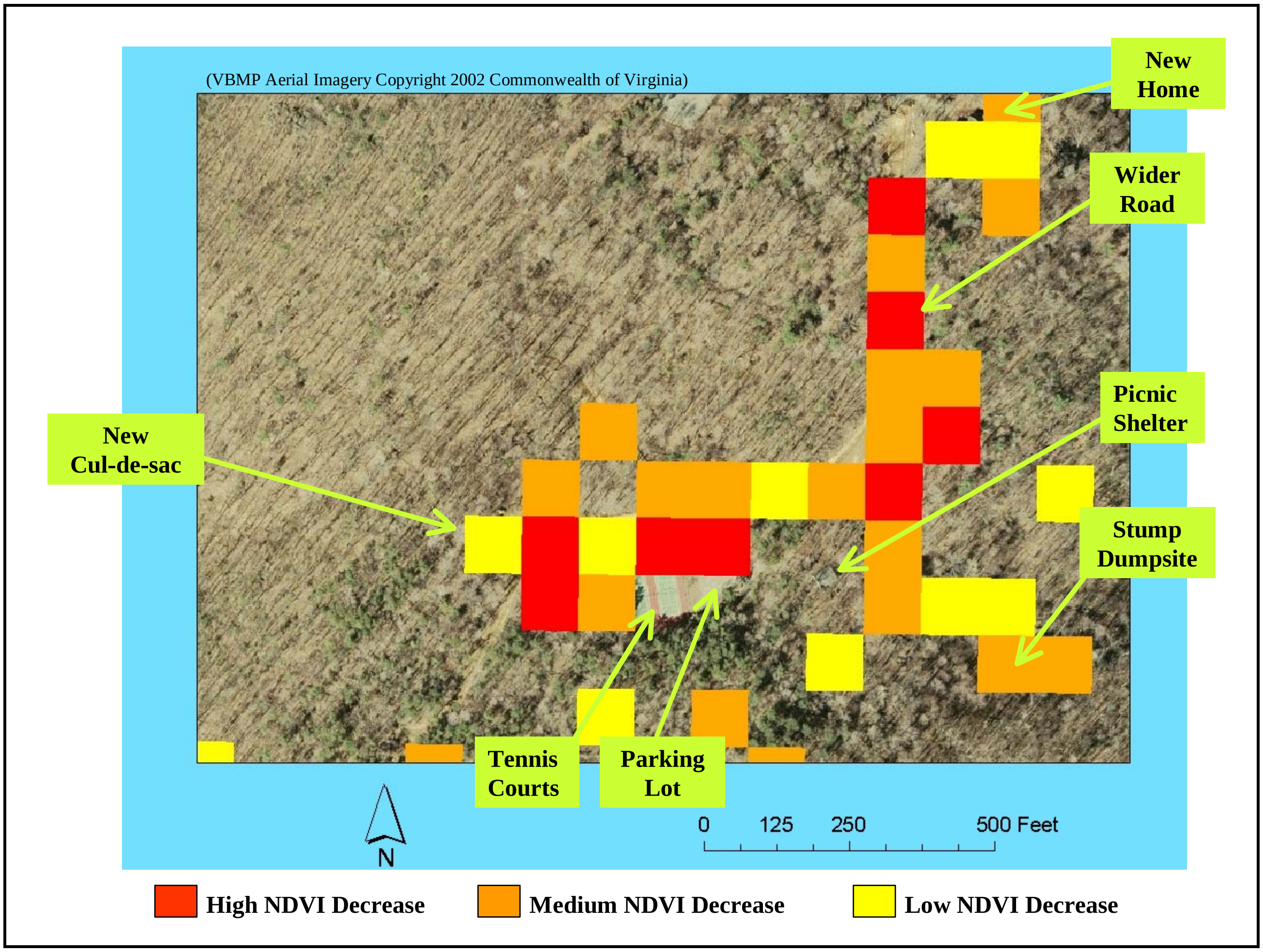

Figure 34: Haze Corrected Change Detection.
Note that the changes highlighted are the same as the uncorrected results.

7.2.2 Dark Object Subtraction

Dark Object Subtraction is a different atmospheric correction technique that plots radiometric numbers for the Red and Near Infrared (NIR) bands. Table 12 shows some pixel values for these bands in the two Landsat images. These values are for pixels at the same location in both images, where water is used as a dark object.

Table 12: Dark Object Values

Point	2000	2000	2002	2002
Description	NIR	Red	NIR	Red
Carvin's Cove North	14	35	14	36
Carvin's Cove North	14	37	14	38
Carvin's Cove North	15	34	14	38
Carvin's Cove Central	13	33	13	34
Carvin's Cove Central	13	33	14	33
Carvin's Cove Central	13	35	14	37
Carvin's Cove South	13	33	14	33
Carvin's Cove South	14	35	15	39
Carvin's Cove South	13	32	14	36
Roanoke River	15	44	13	46
Roanoke River	14	38	15	45
Roanoke River	15	39	15	41

Two observations were made concerning Table 12. First, the pixel values for both images are very similar for each point. Any correction would impact the two images the same thus there would not be a change in the change detection results. Second, plotting these values for each image, Red versus NIR, results in a very small value for correction of the Red values.

It was decided not to correct the two Landsat images for atmospheric conditions in this study. However, atmospheric correction is very important for change detection and in the future, new Landsat images must be checked and corrected if needed.

7.3 *Accuracy Assessment Points*

The following six tables cover each of the 120 points used in the accuracy assessment. Each point has a unique name and location used for reference in the GPS unit. The PE column documents whether the location has a possible encroachment. The FC column documents if the location was field checked. The TL, TM, and TH columns document if the low, medium, and high threshold setting indicated a possible encroachment.

Table 13: Accuracy Assessment Points, Valley Not Encroached

Point Name	Location	PE	FC	TL	TM	TH	Description
474-14	N37.3878206 W79.91752681	No	No	No	No	No	Line in Woods
474-18	N37.39082376 W79.92173059	No	Yes	No	No	No	Line in Woods
47417C	N37.39086091 W79.92064731	No	Yes	No	No	No	Line in Woods
474-20	N37.38678874 W79.92486709	No	No	No	No	Yes	Line in Woods
473-56	N37.39289706 W79.90829474	No	No	No	No	No	Motel Lawn
473-62	N37.39378345 W79.90661674	No	No	No	No	Yes	Major Highway
473-43	N37.39111035 W79.91523134	No	No	No	No	Yes	Corner at RR
47412A	N37.38503669 W79.92064259	No	No	No	No	No	Line in Woods
474-16	N37.38859416 W79.91441367	No	No	No	No	No	Corner at RR
473-49	N37.39106154 W79.90905042	No	No	No	No	Yes	Old House Site
474-12	N37.38371375 W79.92155632	No	No	No	No	No	Line in Woods
473-53	N37.39131682 W79.90936071	No	No	No	No	No	Wooded Corner
474-19	N37.38941581 W79.92348549	No	No	No	No	No	Line in Woods
4734RB	N37.38912711 W79.91198222	No	No	No	No	Yes	Edge of Field
473-48	N37.39104983 W79.90939467	No	No	No	No	No	In Field
47417A	N37.39098081 W79.91714824	No	Yes	No	No	Yes	Line in Woods
473-47	N37.39039121 W79.91019936	No	No	No	No	No	Line in Woods
47417B	N37.39091984 W79.91892782	No	Yes	No	No	No	Line in Woods
474-13	N37.38759178 W79.91887775	No	No	No	No	Yes	Power Edge
47419A	N37.38814954 W79.92415144	No	No	No	No	No	Line in Woods

Table 14: Accuracy Assessment Points, Valley Encroached

Point Name	Location	PE	FC	TL	TM	TH	Description
VAL02	N37.39040148 W79.9221126	No	No	No	Yes	Yes	Shaded Ridge
VAL04	N37.3860878 W79.92170373	Yes	No	No	Yes	Yes	Tree Loss
VAL05	N37.3867603 W79.92073414	Yes	No	No	Yes	Yes	Loss of Pines
VAL06	N37.38744757 W79.92109379	Yes	No	No	Yes	Yes	Power Line Right of Way
VAL08	N37.38635963 W79.91972884	Yes	No	No	Yes	Yes	Loss of Pines
VAL09	N37.38824596 W79.92243786	Yes	No	No	Yes	Yes	Tree Loss
VAL10	N37.38689212 W79.91871426	Yes	No	No	Yes	Yes	Power Line Right of Way
VAL11	N37.38742621 W79.91903249	Yes	No	No	Yes	Yes	Power Line Right of Way
VAL16	N37.38962232 W79.91531792	Yes	Yes	Yes	Yes	Yes	Gas Line Right of Way
VAL17	N37.39030615 W79.9159664	Yes	No	No	Yes	Yes	Power Line Service Road
VAL18	N37.39094711 W79.91634442	No	Yes	No	Yes	Yes	Trees Canopy No Change
VAL21	N37.38852647 W79.9169923	Yes	No	No	Yes	Yes	Loss of Pines
VAL23	N37.38960011 W79.91460484	Yes	No	Yes	Yes	Yes	Rail Road Right of Way
VAL28	N37.39102545 W79.91364927	Yes	Yes	Yes	Yes	Yes	Woods by Pond
VAL29	N37.39117297 W79.91159104	Yes	Yes	Yes	Yes	Yes	Woods by Field
VAL30	N37.39124386 W79.90822157	Yes	No	Yes	Yes	Yes	Narrow Access Trail
VAL32	N37.39314227 W79.90754437	Yes	No	No	Yes	Yes	Motel Lawn
VAL35	N37.39394493 W79.90854175	Yes	No	Yes	Yes	Yes	Access Road
VAL34	N37.39397611 W79.90721323	Yes	No	No	Yes	Yes	Access Road
VAL38	N37.39176948 W79.91054282	Yes	No	Yes	Yes	Yes	Field Dry Eroded Area

Table 15: Accuracy Assessment Points, Ridge East, Not Encroached

Point Name	Location	PE	FC	TL	TM	TH	Description
474-24	N37.3877717 W79.93397447	No	No	No	No	Yes	Close to Power Line Right of Way
474-32	N37.41548164 W79.93778079	No	No	No	No	No	Line On Wooded Ridge
474-36	N37.41977302 W79.94118424	No	No	No	No	Yes	Line On Wooded Ridge
475-7A	N37.42208659 W79.95405135	No	No	No	No	Yes	Line On Wooded Ridge
475-2D	N37.41495502 W79.95088235	No	No	No	No	No	Line On Wooded Ridge
475-2A	N37.41766178 W79.94698865	No	No	No	No	No	Line On Wooded Ridge
474-38	N37.42192145 W79.9450159	No	No	No	No	No	Corner Near Field
474-31	N37.41090104 W79.93670602	No	No	No	No	No	Line On Wooded Ridge
47430A	N37.40922178 W79.93631204	No	No	No	No	No	Close to Power Line Right of Way
475-7	N37.42102959 W79.95295218	No	No	No	No	No	Line On Wooded Ridge
47427A	N37.39798299 W79.92946161	No	No	No	No	No	Line On Wooded Ridge
475-9	N37.42488794 W79.95696469	No	No	No	No	No	Line On Wooded Ridge
47422A	N37.38468785 W79.93115676	No	No	No	No	No	Line On Wooded Ridge
475-4	N37.41532283 W79.9524783	No	No	No	No	No	Line On Wooded Ridge
475-6	N37.41669076 W79.95263893	No	No	No	No	Yes	Line On Wooded Ridge
475-2C	N37.41585728 W79.94958448	No	No	No	No	Yes	Line On Wooded Ridge
474-25	N37.39080341 W79.93256548	No	No	No	No	No	Line On Wooded Ridge
475-8	N37.42304104 W79.95504392	No	No	No	No	No	Line On Wooded Ridge
474-29	N37.4034715 W79.93162696	No	No	No	No	No	Line On Wooded Ridge
47431B	N37.41414054 W79.93746611	No	No	No	No	No	Line On Wooded Ridge

Table 16: Accuracy Assessment Points, Ridge East, Encroached

Point Name	Location	PE	FC	TL	TM	TH	Description
RGE05	N37.38897411 W79.93468244	Yes	No	No	Yes	Yes	Loss Pine Trees
RGE06	N37.39306854 W79.93162069	Yes	No	No	Yes	Yes	Loss Pine Trees
RGE09	N37.39630361 W79.93098872	Yes	No	No	Yes	Yes	Wooded Ridge Loss Trees
RGE10	N37.39713891 W79.9292709	No	No	No	Yes	Yes	Wooded Ridge
RGE11	N37.4006268 W79.93060853	Yes	No	Yes	Yes	Yes	Wooded Ridge Loss Trees
RGE16	N37.40631224 W79.93576413	No	No	No	Yes	Yes	Wooded Ridge
RGE19	N37.4052426 W79.93271908	Yes	No	Yes	Yes	Yes	Power Line Right of Way
RGE21	N37.40819841 W79.93610835	Yes	No	No	Yes	Yes	Power Line Right of Way
RGE23	N37.40952348 W79.93709694	Yes	No	No	Yes	Yes	Power Line Right of Way
RGE28	N37.41305838 W79.93708734	Yes	No	No	Yes	Yes	Missing Trees
RGE30	N37.41307601 W79.93816665	Yes	No	No	Yes	Yes	Missing Trees
RGE32	N37.41332879 W79.9388651	Yes	No	No	Yes	Yes	Missing Trees
RGE37	N37.41763783 W79.94091284	No	No	No	Yes	Yes	Wooded Side of Ridge
RGE43	N37.42142757 W79.94395287	Yes	No	No	Yes	Yes	Missing Trees
RGE46	N37.41413932 W79.94801344	Yes	No	No	Yes	Yes	Loss of Pines
RGE51	N37.41622857 W79.95310189	Yes	No	No	Yes	Yes	Loss of Pines
RGE56	N37.42296856 W79.95616101	No	No	No	Yes	Yes	Wooded Side of Ridge
RGE55	N37.42190911 W79.95483018	No	No	No	Yes	Yes	Wooded Side of Ridge
RGE59	N37.42433528 W79.95749782	No	No	Yes	Yes	Yes	Wooded Side of Ridge
RGE62	N37.42808309 W79.95891937	No	No	No	Yes	Yes	Wooded Side of Ridge

Table 17: Accuracy Assessment Points, Ridge West, Not Encroached

Point Name	Location	PE	FC	TL	TM	TH	Description
474-8	N37.38164592 W79.92421369	No	Yes	No	No	No	Line on Wooded Ridge
474-39	N37.40122259 W79.93342194	No	No	No	No	No	Line on Wooded Ridge
47562A	N37.413923 W79.9449158	No	No	No	No	Yes	Line on Wooded Ridge
475-64	N37.41519656 W79.94273725	No	No	No	No	Yes	Corner next to Power Line RW
475-60	N37.41227389 W79.95334276	No	No	No	No	No	Line on Wooded Ridge
474-1	N37.3881264 W79.93621127	No	No	No	No	No	Line on Wooded Ridge
47440C	N37.39134584 W79.93569375	No	No	No	No	No	Line on Wooded Ridge
475-61	N37.41182476 W79.94977159	No	No	No	No	No	Line on Wooded Ridge
47564C	N37.41089663 W79.94094376	No	No	No	No	No	Line on Wooded Ridge
474-2	N37.38597325 W79.93614292	No	No	No	No	No	Line on Wooded Ridge
47557B	N37.42580839 W79.96246055	No	No	No	No	Yes	Line on Wooded Ridge
474-7	N37.38103356 W79.92434332	No	Yes	No	No	No	Line on Wooded Ridge
47557D	N37.42368797 W79.96031551	No	No	No	No	No	Line on Wooded Ridge
474-10	N37.38232582 W79.91901029	No	No	No	No	No	Line on Wooded Ridge
474-2A	N37.3849124 W79.93505012	No	No	No	No	Yes	Line on Wooded Ridge
47564B	N37.41232994 W79.94154157	No	No	No	No	No	Gas Line Right of Way
47559B	N37.41308551 W79.95460114	No	No	No	No	Yes	Line on Wooded Ridge
47439A	N37.39956604 W79.93391609	No	No	No	No	Yes	Line on Wooded Ridge
474-11	N37.3841983 W79.91881142	No	No	No	No	No	Line on Wooded Ridge
47564D	N37.40946332 W79.94034597	No	No	No	No	No	Line on Wooded Ridge

Table 18: Accuracy Assessment Points, Ridge West, Encroached

Point Name	Location	PE	FC	TL	TM	TH	Description
RGW05	N37.3817243 W79.92543471	Yes	Yes	No	Yes	Yes	Power Line Right of Way
RGW06	N37.3822326 W79.9291614	Yes	Yes	No	Yes	Yes	Tree Loss
RGW09	N37.38329324 W79.93295642	Yes	Yes	Yes	Yes	Yes	Tree Loss
RGW11	N37.38366687 W79.93383022	No	Yes	No	Yes	Yes	Seems to be no change
RGW10	N37.38309189 W79.93181627	Yes	Yes	No	Yes	Yes	Tree Loss
RGW16	N37.39873406 W79.93334654	Yes	No	Yes	Yes	Yes	Tree Loss
RGW19	N37.40090639 W79.93163484	Yes	No	No	Yes	Yes	Tree Loss
RGW21	N37.40467115 W79.93675389	Yes	No	No	Yes	Yes	Tree Loss, Rock Slide
RGW23	N37.40574569 W79.93812298	Yes	No	Yes	Yes	Yes	Tree Loss, Rock Slide
RGW28	N37.40842582 W79.94015858	No	No	No	Yes	Yes	Seems to be no change
RGW30	N37.41275397 W79.94189834	No	No	No	Yes	Yes	Seems to be no change
RGW32	N37.41405717 W79.93963046	Yes	No	No	Yes	Yes	Tree Loss
RGW43	N37.41187905 W79.94935721	No	No	No	Yes	Yes	Seems to be no change
RGW46	N37.41292295 W79.95070675	Yes	No	Yes	Yes	Yes	Tree Loss
RGW51	N37.41813592 W79.95547021	Yes	No	Yes	Yes	Yes	Tree Loss
RGW55	N37.42054823 W79.95551684	Yes	No	No	Yes	Yes	Tree Loss
RGW56	N37.42080821 W79.95687073	Yes	No	Yes	Yes	Yes	Tree Loss
RGW59	N37.423223 W79.95921059	Yes	No	No	Yes	Yes	Tree Loss
RGW62	N37.42594386 W79.96165289	Yes	No	No	Yes	Yes	Tree Loss
RGW64	N37.42726824 W79.9626807	Yes	No	No	Yes	Yes	Tree Loss

8 Vita

James (Jim) Forrest Hutchings grew-up along the eastern shore of Lake Michigan, a few miles south of Muskegon, Michigan. After graduating from Mona Shores High School, he attended Michigan Technological University in Houghton, Michigan, receiving his Bachelors of Science in Electrical Engineering.

While working as an engineer for a major industrial controls manufacturer, he earned a Masters of Science in Industrial Administration from Union College, located in Schenectady, New York, and a Masters of Science in Computer Science from Virginia Tech, located in Blacksburg, Virginia.

As a volunteer for the Appalachian National Scenic Trail, he has served in many leadership positions including President of the Roanoke Appalachian Trail Club and Southern Vice Chair of the Appalachian Trail Conference.

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