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Hyperspectral Landcover Classification for the Yakima Training Center, Yakima, Washington

K. L. Steinmaus, Project Manager
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April 1998

Prepared for
the National Imagery and Mapping Agency (NIMA)
Pacific Northwest National Laboratory

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This research was conducted by the Pacific Northwest National Laboratory for the Terrain Modeling Project Office (TMPO) of the National Imagery and Mapping Agency (NIMA). Funding for this research was provided by the Defense Modeling and Simulation Office (DMSO).

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Summary

The U.S. Department of Energy's (DOE's) Pacific Northwest National Laboratory (PNNL) was tasked in FY97-98 to conduct a multisensor feature extraction project for the Terrain Modeling Project Office (TMPO) of the National Imagery and Mapping Agency (NIMA). The goal of this research is the development of near-autonomous methods to remotely classify and characterize regions of military interest, in support of the TMPO of NIMA. These methods exploit remotely sensed datasets including hyperspectral (HYDICE) imagery, near-infrared and thermal infrared (Daedalus 3600), radar, and terrain datasets. Important criteria for the project included the need to:

- demonstrate how feature and elevation data derived from new, high-resolution sources could meet and/or exceed existing NIMA product accuracy standards
- develop innovative, automated approaches to multisensor landcover mapping
- generate standardized, reproducible mapping products that report all feature data according to the Feature and Attribute Coding Catalogue (FACC) and metadata according to Federal Geographic Data Committee (FGDC) metadata standards.

The study site for this project is the U.S. Army's Yakima Training Center (YTC), a 326,741-acre training area located near Yakima, Washington. Two study areas at the YTC were selected to conduct and demonstrate multisensor feature extraction, the 2-km x 2-km Cantonment Area and the 3-km x 3-km Choke Point area. Classification of the Cantonment area afforded a comparison of classification results at different scales. These results indicate that 1-m resolution data may be significantly better at defining man-made structures such as buildings and roads. However, for larger features such as fields, lawns, orchards, and areas of brushland, the 3-m resolution is equal or preferable to the 1-m data. Also, the Cantonment study area demonstrated that the use of spatial information is critical for determining landuse information from landcover classifications. The Choke Point area was selected for the availability of high resolution terrain data. Terrain information derived from lidar imagery proved to be valuable for identifying and characterizing features (trees, obstacles). Classification results from the Choke Point area also demonstrated that the use of derived parameters, such as the Normalized Difference Vegetation Index (NDVI), may be very useful.

The results of the classifications, expressed in terms of the classification error assessments, were quite encouraging. The classification error assessments were quite encouraging. The overall classification accuracies at the coverage level were 93% for the 3-m Cantonment, 90% for the 1-m Cantonment, and 94% for the 3-m Choke Point Classification. Error analyses were also performed at the attribute level for vegetation (based on the veg attribute). For the vegetation accuracy assessments, the results were encouraging as well: 83% for the 3-m Cantonment area, 87% for the 1-m Cantonment area, and 85% for the 3-m Choke Point area.

Future needs were identified as a result of the classification work. Evaluation of the processing time indicates that the image registration is the most time-consuming data processing step. The HYDICE and

AVIRIS imagery are challenging because platform attitude data (pitch , roll, and yaw) are not available, so autoregistration of this type of airborne imagery may depend on the ability to automatically select control points. Testing of PNNL software for a single HYDICE frame resulted in a poor distribution of control points, thus not suitable for triangulation. The conversion of landcover information (surface material) to landuse is also a lengthy step. This process would be expedited by the use of improved shape filters that would provide characteristics of individual objects.

Acknowledgments

The authors would like to acknowledge and thank the U.S. Army, Directorate of Environment and Natural Resources, and the Fort Lewis Environmental and Natural Resources Division for their support to this effort. This project utilized unique databases and prior analyses that significantly contributed to the overall success of the project.

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1.0 Introduction

1.1 Purpose and Description of the Site

The U.S. Department of Energy's (DOE's) Pacific Northwest National Laboratory (PNNL) was tasked in FY97-98 to conduct a multisensor feature extraction project for the Terrain Modeling Project Office (TMPO) of the National Imagery and Mapping Agency (NIMA). The sponsor for this research activity was the Defense Modeling and Simulation Office (DMSO). The objective of this research project was to generate a highly attributed geospatial terrain database using multisensor imagery. The TMPO's interest in this project was to determine how well multisensor-derived terrain feature data could support new and evolving U.S. Department of Defense (DoD) modeling and simulation requirements. Accordingly, important criteria for the project included the need to:

- demonstrate how the feature and elevation data derived from new, high-resolution sources could meet and/or exceed existing NIMA product accuracy standards

- develop innovative, automated approaches to multisensor landcover mapping

- generate standardized, reproducible mapping products (see Appendix A) that report all feature data according to the Feature and Attribute Coding Catalogue (FACC) and metadata according to Federal Geographic Data Committee (FGDC) metadata standards (see examples in Appendix B).

The study site for this project is the U.S. Army's Yakima Training Center (YTC), located near Yakima, Washington. The YTC is a 326,741-acre training area in the northwestern corner of the Columbia Basin in south-central Washington. It is a roughly rectangular training site bordered on the east by the Columbia River, on the west by Interstate 82, and on the north by Interstate 90. The YTC is primarily used by forces stationed at Fort Lewis, but is also used by Reserve and National Guard forces, as well as other DoD, NATO, and state and local law enforcement agencies for maneuver and gunnery training. PNNL has been under contract with the YTC Directorate of Environment and Natural Resources (DENR) and the U.S. Army's I Corps and Fort Lewis, Environmental and Natural Resources Division (ENRD) to develop and deploy customized remote sensing and geographic information system (GIS) technologies to monitor training effects and restoration activities effectively at the YTC. In conjunction with this effort, an extensive and unique database of satellite, aircraft, and field observations has been acquired. This project was able to take advantage of the prior data collections, orthoregistered basemaps, and familiarity/knowledge of the site.

Two study areas at the YTC were selected to conduct and demonstrate multisensor feature extraction (Figure 1.1). The first is the 2-km x 2-km Cantonment area. This area was selected because it contains

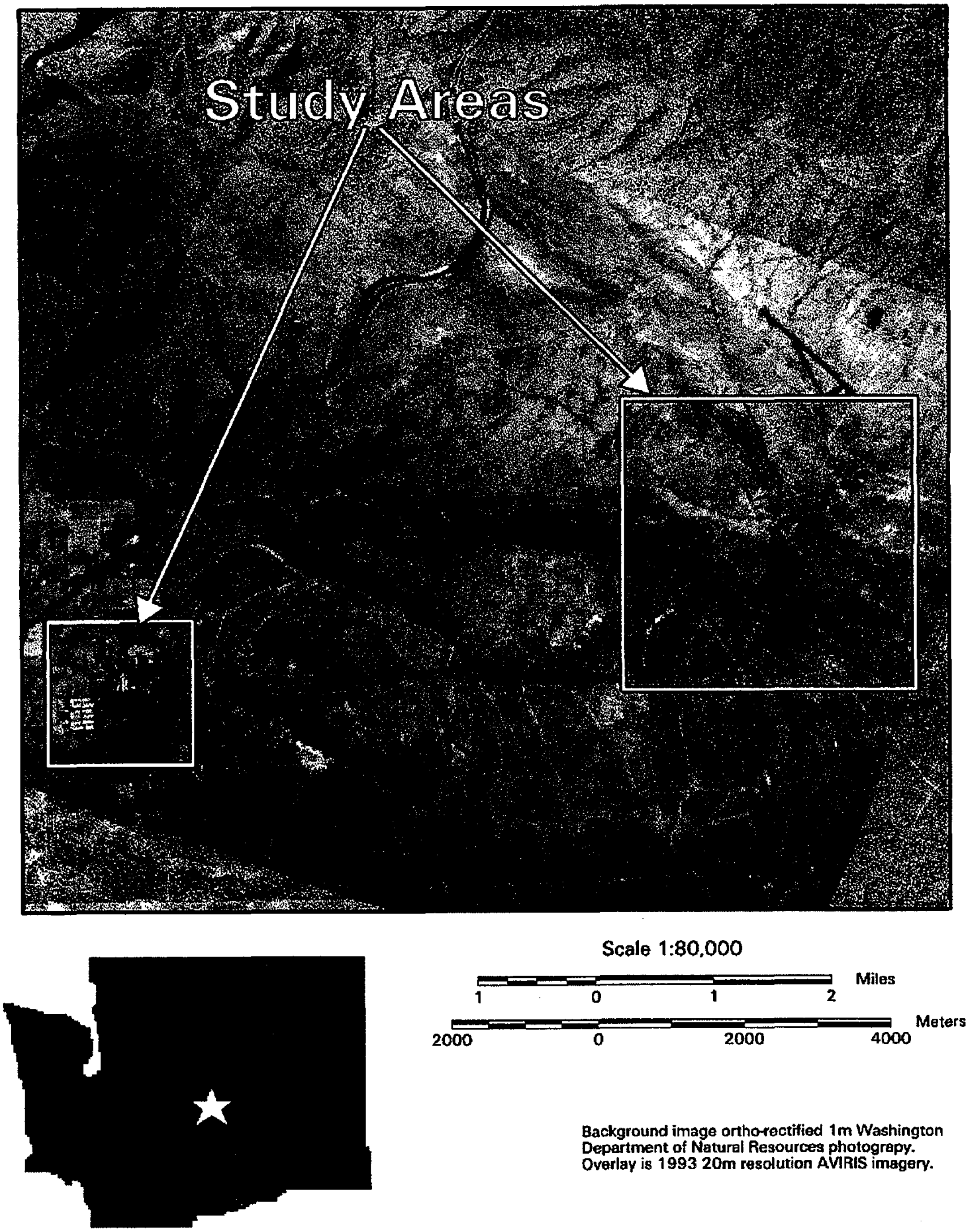


Figure 1.1. Study Areas at the Yakima Training Center

diverse features, both man-made (buildings, fence-lines, military vehicles storage lots, etc.) and natural (trees, irrigated and native shrub-steppe vegetation). The Cantonment area was also chosen because of the unique combination of hyperspectral, thermal, and radar imagery at different scales that have been collected for that area. Datasets used in the Cantonment area study include:

- hyperspectral imagery from the Naval Research Laboratory's (NRL) Hyperspectral Digital Imagery Collection Experiment (HYDICE), both 1- and 3-m resolution
- hyperspectral imagery from NASA's Airborne Visible-Infrared Imaging Spectrometer (AVIRIS), 20-m resolution
- multispectral scanner data from DOE's Airborne Multispectral Pod System (AMPS) suite of sensors, 1-m resolution
- Orthoregistered air photo basemap from the Washington State Department of Natural Resources (DNR), 1-m resolution
- 30-m digital elevation data (USGS) model (DEM).

The objective for the Cantonment area site is to evaluate the optimum resolution for landuse mapping.

The second study area, called the Choke Point, is a 3-km x 3-km area in the southwest corner of the YTC. The Choke Point area is characterized by high relief (approximately 200 m) with several river crossings and riparian and shrub-steppe vegetation. Datasets used in the Choke Point area include:

- HYDICE hyperspectral imagery, 3-m resolution
- AVIRIS hyperspectral imagery, 20-m resolution
- orthoregistered air photo basemap, 1-m accuracy
- NIMA Level 4 Digital Terrain Elevation Data (DTED®)[1]
- lidar-derived terrain data, 1-m vertical accuracy, 2-m horizontal accuracy.

The primary objective of study at this area is to evaluate the use of digital terrain information to delineate and describe features and to compare elevation derived from different sources (lidar vs. high-resolution DTED).

The YTC landcover analysis focuses on the development of approaches and procedures to derive land use from remotely sensed high-resolution data. This report provides product descriptions and documents the approach and processes required to generate land use categories for the two study areas. The report is

[1] DTED is a registered trademark owned by the National Imagery and Mapping Agency.

organized according to the major processes involved: database compilation, data registration, image normalization, hyperspectral/multisensor landcover classification, vectorization, and error analysis. The final deliverables consist of raster and vector versions of the landcover/landuse classes extracted from the hyperspectral and multisensor classifications.

1.2 Data Sources

1.2.1 HYDICE Hyperspectral Imagery and Digital Photography

The HYDICE sensor was flown at two elevations (providing 0.75- and 3-m pixels) over both the Cantonment and Choke Point areas during July 1996. The HYDICE sensor is a push broom system, generating image data cubes with 210 bands (from 400 to 2500 nm) and a 320-pixel swath width. For the Cantonment area classifications, two high-altitude flightlines, oriented east-west, were mosaicked (12 frames of 320 x 320 pixels) to cover most of the site. Because of data omission, only two low-altitude flightlines were available (also oriented east-west); 18 frames were mosaicked to cover the central portion of the Cantonment area. For the Choke Point classifications, five north-south orientated high-altitude flightlines were mosaicked (25 frames of 320 x 320 pixels) to cover most of the study area. No low-altitude imagery was used in the classifications at this study area.

Air photos were also collected during the HYDICE mission, at altitudes resulting in 1- and 3-m photography. An examination of the film indicated an effective ground resolution of 1 ft. or better. This photography was not used directly in the classifications, but was used as a source for 'ground truth' verification.

1.2.2 Orthophotography Basemap

This study utilized 1993, 1-m resolution panchromatic orthophotographs purchased from the DNR. PNNL had previously compiled these orthophotos into a mosaicked basemap for the entire YTC under a U.S. Army project. This dataset was used as the basis for registration of the HYDICE, AVIRIS, and Daedalus imagery.

1.2.3 AVIRIS Hyperspectral Data

The NASA Jet Propulsion Laboratory's AVIRIS hyperspectral sensor was flown over the YTC during May and September of 1993. The AVIRIS instrument is a whisk broom (scanning) system with 224 detectors (channels) in the 400 to 2500 nm range, generating 614 pixel-wide swaths. The ground pixel resolution was approximately 20 m. The Cantonment and Choke Point areas were contained in two separate AVIRIS frames (614 x 512 pixels). These were not mosaicked.

1.2.4 Digital Elevation Data

For the Cantonment area, USGS 30-m Digital Elevation Model (DEM) data were available for the area but were not used for any classification. For the Choke Point area, two sources of terrain data were used: 1) NIMA Level 4 DTED, gridded by PNNL to 5-m cell sizes, and 2) lidar-derived terrain data (collected by Airborne Laser Mapping, Bremerton, Washington), with 1-m vertical accuracy and 2-m horizontal accuracy. The lidar terrain data represented the ground elevation data, expressed as x, y, and z data points. PNNL performed additional data processing to smooth the data and fill in collection gaps (missing data).

1.2.5 Airborne Multisensor Pod System (AMPS) Data

The DOE AMPS was flown during September of 1994 over the Cantonment area. One of the sensors, a Daedalus 3600 multispectral scanner, was flown at approximately 4500 feet above ground level for an effective ground pixel size of 3 m; three bands were collected at 0.91-1.05, 3.0-5.5, and 8.4-14.5 microns (Daedalus 3600 bands 8, 9, and 10) and used in conjunction with this study. In addition to the Daedalus 3600, several other sensors were flown:

- Ku-band (15 gigahertz) synthetic aperture radar (SAR)
- CASI, a hyperspectral imager
- Wild Heerbrugg RC-30, a large-format, high-resolution aerial camera
- Sony DXC-750, a high-resolution color video camera, and low-light video
- COHU 5560, a high-resolution, low-light CCD camera
- Barr & Stroud IR18 Thermal Imager, a passive thermal infrared sensor.

These datasets were not directly used in the classifications, but contributed to different aspects of the studies, as will be discussed in subsequent sections.

1.2.6 Data Preparation

Before developing the landcover classifications, the individual image datasets required processing for geometric correction and radiometric normalization. First, the image datasets were registered to the DNR orthophotography for each site. Second, radiometric normalization of the HYDICE imagery was performed in order to mosaic the individual images. Last, terrain normalization was performed for the images over the Choke Point area to correct for apparent differences in reflectance due to the differences in slope and aspect. These data preparation steps are explained in greater detail in Section 2.0.

2.0 Registration and Calibration of the Image Datasets

2.1 Overview

To compare imagery from different instruments, raw imagery requires geometric correction to a common spheroid and datum, which is a process of warping an image to known geographic coordinates. An accurate registration of the data between different datasets and among multiple flightlines, pixel by pixel, is essential for data analysis. Any misregistration will result in erroneous spectral classification.

Registration of the hyperspectral and multispectral data was one of the primary tasks in data preparation. Spectral normalization between flightlines of the same datasets are addressed in a subsequent section of this report. All tasks in the image registration process were performed using ERDAS Imagine image processing software.

Four datasets were registered for classification: the 20-m spatial resolution AVIRIS hyperspectral data, the 1-m spatial resolution Daedalus multispectral data (Cantonment area coverage only), and the 1-m and 3-m spatial resolution HYDICE hyperspectral data. Four flightlines of the 210 band, 320 by 320 frames, were flown on an east-west axis cover the Cantonment area: two flightlines at 1-m spatial resolution and two flightlines at 3-m spatial resolution. The five flightlines were flown on a north-south axis that covers the Choke Point study area, all at 3-m spatial resolution.

2.2 Orthophoto Basemap

A portion of a digital basemap of the entire YTC was used as a reference to register all datasets. A set of thirty-six (36) 1:24,000 panchromatic orthoregistered digital photos (orthophotos) was purchased from the DNR. The DNR orthoregistered the 1993 photos using a 30-m resolution DEM and assessed them at better than 10-m accuracy. The individual orthophotos were resampled to 1-m resolution. The areas of greatest error, the outside edges, were cropped, and the resulting files were mosaicked to three files. Only one of the mosaicked files was needed to register the datasets in both study areas.

2.3 Registration of the HYDICE Hyperspectral Imagery

2.3.1 Selecting Ground Control Points

Topographic and instrument characteristics dictated the selection of approximately 75 ground control points (GCP) per 320 pixel by 320 pixel HYDICE 'frame' (150 to 300 GCP per file) to ensure accurate registration of the HYDICE data. The use of an accurate, 1-m resolution basemap made a large selection of GCP possible. Over 2800 GCP were chosen between the two study areas for HYDICE registration alone.

Hyperspectral data, by nature, are large data files. Each 210-band HYDICE frame is 320 pixels by 320 pixels, yielding approximately a 42-megabyte file. The raw data were merged into manageable file sizes of two to four frame files. Each file was independently registered to the orthophoto basemap. Consequently, two complications arose: 1) the overlap between flightlines was limited, an estimated 10 percent, and 2) there was no overlap between frames of the same flightline. Both of these complications necessitated a large selection of points, particularly along the edges of the datasets, where good ground control may or may not be easily established. The triangulation process allows only localized registration; any areas outside of the point selection allow for significant error. Normally, the edges would be trimmed to reduce those areas with the greatest error. Therefore, a concerted effort was made to find good control points to increase the accuracy of the triangulation along the edges.

Aircraft altitude with push broom instruments becomes a significant factor in data registration. The roll, pitch, and yaw inherent in airborne collection becomes exaggerated at higher altitudes. Consequently, the 3-m spatial resolution HYDICE imagery had more aircraft-induced distortion and required a large selection of GCP to correct. However, the higher spatial resolution, lower altitude 1-m imagery covering the Cantonment area had less distortion but the higher spatial resolution allowed a larger number of GCP due to the resolution and the number of fixed features.

Point selection was also complicated by the changes that have occurred in the Choke Point study area between the time the imagery for the basemap was collected (1993) and the time the HYDICE imagery was collected (1996). A large exercise in 1995, 'Cascade Sage,' contributed to the change, creating many new roads and degraded areas. New construction and the addition of tank emplacements further complicated GCP selection.

2.4 Registration of the Daedalus Multispectral Imagery

2.4.1 Correcting the X-Track Angular Distortion for Daedalus Multispectral Data

The Daedalus scanner has a constant angular field of view that constrains the pixel size in the cross track direction. This characteristic results in pixels that are increasingly elongated in either direction away from nadir. To correct this distortion, the imagery was resampled using a nearest-neighbor algorithm. The end result is consistent pixel dimensions in both cross track and along track directions.

2.4.2 Selecting Ground Control Points

Registration of the Daedalus imagery required a significant number of GCP to assure good accuracy; however, the limited distortion from aircraft characteristics, the more substantial overlap area, and the relatively flat terrain in the Cantonment area allowed good accuracy with fewer GCP per flightline as compared to the HYDICE imagery.

2.5 Registration of the AVIRIS Hyperspectral Imagery

The 20-m resolution of the AVIRIS imagery limited the number of GCP; however, the very large frame size (approximately 10-km swath width) yielded little distortion. Two frames cover the Cantonment and Choke Point study areas (one frame for each). Thus, no overlap issues were relevant, and the resulting registration yielded good accuracy.

2.5.1 Warping the Data

Image registration for all of the datasets followed the following process:

1. selecting GCP, including the four corners, to preserve the entire image
2. triangular-warping of the imagery
3. performing an error check against the orthophoto basemap
4. selecting additional GCP to improve the accuracy in localized areas
5. repeating the registration and error analysis process until error is reduced to minimal levels.

All of the raw imagery datasets were geometrically corrected using a triangulation process, whereby the areas between three GCP are locally registered. Tests with other commercial image processing software (ENVI) triangulation tools proved comparable to the results from ERDAS Imagine's triangulation. Previously, the imagery and GCP files had to be exported to ENVI format, substantially increasing time and space requirements.

Working with ERDAS Imagine software, the triangulation process was preferred over a general polynomial warp due to the improved, localized registration accuracy. Polynomial warping is preferred when relatively few GCP are available. A polynomial equation is applied across the entire image generated. The Choke Point study site consists of areas of rugged terrain and relatively flat fields. Using a general polynomial equation based on these drastically different terrains resulted in unacceptable error. This was especially true with the distortion of the HYDICE imagery due to aircraft movement, as previously noted, and high relief that is typically more prone to image distortion.

2.5.2 Merging the HYDICE Flightlines

The geo-registered HYDICE files were subset to 44 bands (see Section 2.7 for details) and mosaicked by flightline. No spectral normalization was necessary since the calibration is consistent throughout each flightline. Minimal areas along the edges of the images were trimmed as necessary to eliminate those areas with significant error that could not be corrected with registration.

2.5.3 Spatial Error Assessment for the Registered HYDICE Imagery

One drawback of using triangulation in image registration is that the errors are localized and not easily determined. To estimate the overall spatial accuracy, root mean square error (RMSE) values were determined for each of the image frames. These RMSE values were based on the first order polynomial fit of the GCP for that frame. These RMSE values are reported in Table 2.1.

Table 2.1. Registration Root Mean Square Errors

Resolution	File	RMS (Second Degree)
1 m	run06_frame2-4.img	3.688
1 m	run06_frame5-7.img	2.568
1 m	run06_frame8-10.img	2.992
1 m	run08_frame2-4.img	3.307
1 m	run08_frame5-7.img	2.168
1 m	run08_frame8-10.img	4.587
3 m	run12_frame31-34.img	5.673
3 m	run14_frame53-56.img	11.249
3 m	run16_frame71-77.img	5.628
3 m	run31_frame5-7.img	6.797
3 m	run33_frame11-12.img	3.536
3 m	run33_frame8-10.img	2.441
3 m	run22_frame48-50.img	3.239
3 m	run22_frame51-52.img	8.117
3 m	run36_frame48-50.img	4.047
3 m	run36_frame51-52.img	4.121
3 m	run31_frame8-9.img	5.224
20 m	run2_scene4.img	1.210
20 m	run2_scene5.img	1.448
1 m	ytc.daed0.img	17.569
1 m	ytc.daed2.img	15.750

2.6 Band Reduction of HYDICE Imagery

Because of the high-dimensionality of the spectral bands, hyperspectral datasets pose a challenge in both processing time and memory requirements. This problem is amplified when several frames of imagery are mosaicked (as is the case for HYDICE for both YTC sites). For the YTC landuse classification, the initial intent was to maintain the entire HYDICE band set throughout the pre-processing stage so that classification could be performed on the entire set (or any desired subset) of bands. However, practical constraints of disk storage and processing time required that the original 210 bands of the HYDICE be reduced to a much smaller band configuration. PNNL has developed autonomous band selection approaches (Lundeen et al. 1996) that are based on maximizing target and background separation. However, for the purposes of the YTC landcover classifications, a series of bands was selected that optimized the spectral separation of a range of targets within the study areas. This was done by choosing a series of targets (buildings, soils, vegetation) from the high-resolution (run 6) HYDICE imagery and displaying (and overlaying) the spectral signatures for these targets. A series of bands were then selected that best characterized each of the spectral curves. These bands are shown in Table 2.2.

2.7 Radiometric Normalization

Before classification, the HYDICE imagery was radiometrically normalized. Differences in radiance values from frame to frame exist due to: 1) differences in the HYDICE calibration (the calibration should be consistent within a flightline, but differs between flightlines), and 2) differences in time (and therefore irradiance at the surface) between frames (again, more of a difference between flightlines than from one frame to the next within a flightline). Without some normalization of the individual images before classification, the overall average radiance differences from image to image might mask more subtle radiance differences among surface features. To normalize the HYDICE imagery, the run 6/frame 5 image over the calibration panels was used as the reference frame. All of the other flightlines, both high- and low-altitude, and for both the Cantonment and Choke Point areas, were referenced to this frame. The normalization for each band of each frame was performed using the following formula:

$$\frac{\sigma_{ref}}{\sigma_{src}}(\text{pixel} - \mu_{src}) + \mu_{ref}$$

Where σ_{ref} is the reference image standard deviation (for a given band), σ_{src} is the source image standard deviation, μ_{src} is the source image mean, and μ_{ref} is the reference image mean. The normalization was applied by: 1) outlining an area common to both the reference and source image (creating an ERDAS Imagine 'AOI' [Area of Interest] graphic), 2) computing the statistics for the mean and standard deviation for both the source and reference files (for each band) using the ERDAS Imagine Signature Editor, and 3) applying these statistics (with the above formula) using Imagine's Spatial Modeler. An example model is shown in Figure 2.1.

The procedure to normalize the HYDICE data for the Cantonment area was to select run 6/frame 5 as the reference frame, as this frame covered the calibration panels. Run 8 was then normalized to run 6;

Table 2.2. HYDICE Band Numbers and Wavelength Midpoints for the 44-Band Subset

Band Number	Wavelength (μ)	Original HYDICE Band
1	425.968	10
2	444.316	15
3	464.177	20
4	485.956	25
5	510.116	30
6	537.199	35
7	567.825	40
8	602.688	45
9	642.508	50
10	687.942	55
11	707.797	57
12	728.64	59
13	750.471	61
14	773.283	63
15	797.05	65
16	821.736	67
17	847.29	69
18	873.649	71
19	900.74	73
20	928.484	75
21	956.794	77
22	985.579	79
23	1014.75	81
24	1044.23	83
25	1073.91	85
26	1103.72	87
27	1163.48	91
28	1193.29	93
29	1222.98	95
30	1252.52	97
31	1281.86	99
32	1310.96	101
33	1452.3	111
34	1506.63	115
35	1559.67	119
36	1611.39	123
37	1661.83	127
38	1723.13	132
39	1770.82	136
40	1971.96	154
41	2075.27	164
42	2173.41	174
43	2266.93	184
44	2356.31	194

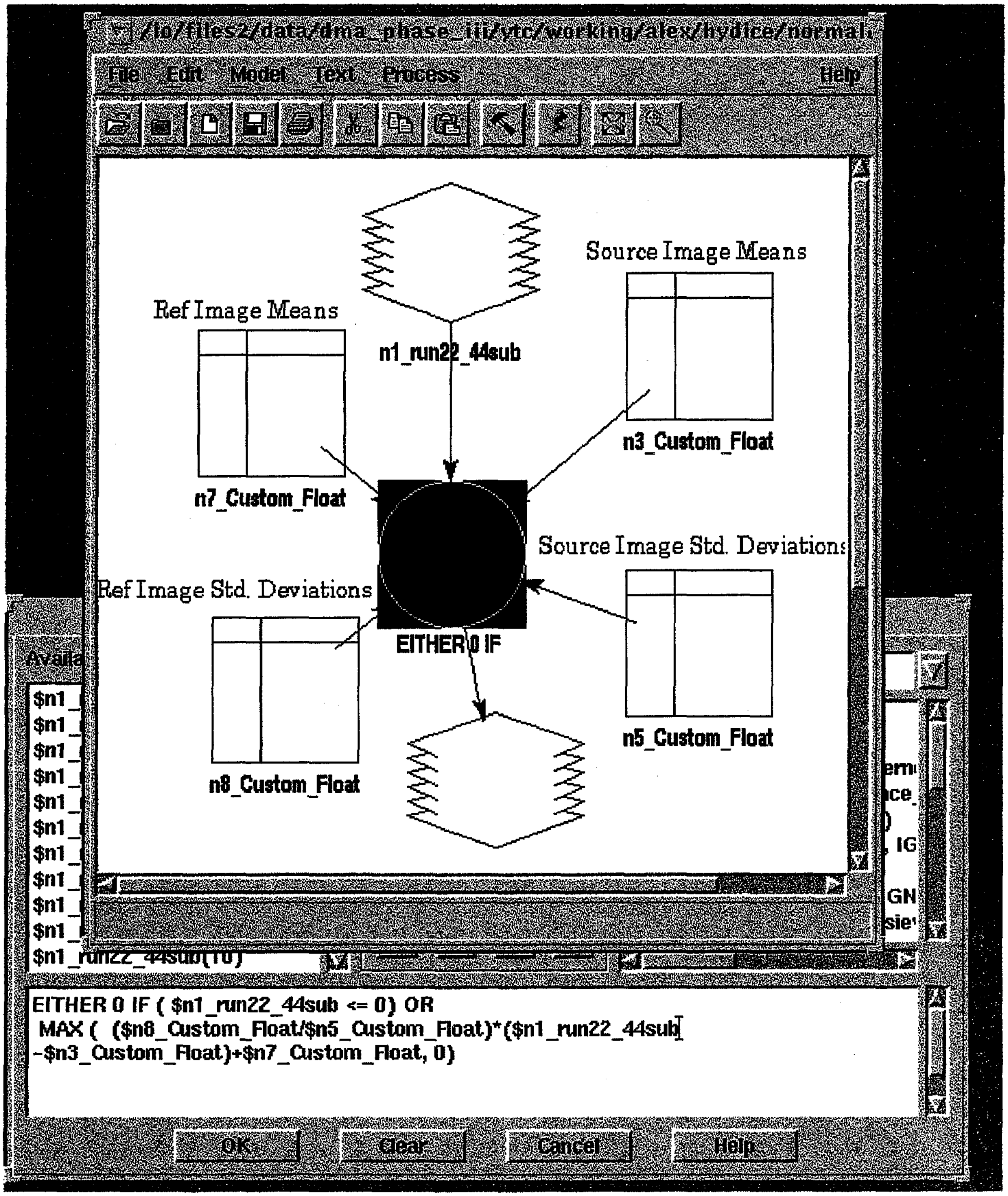


Figure 2.1. An Example ERDAS Imagine Model that Performs Radiometric Normalization of Two Images

these two flightlines then made up the low-altitude mosaic. For the high-altitude data, run 33 was normalized to run 6 by choosing an overlap area (most of run 6), convolving that area of run 6 to 3-m pixels (using ERDAS Imagine Interpreter/Utilities/Degrade) and then normalizing run 33 based on the statistics for the run 33 overlap and the 3-m run 6 overlap. After run 33 was verified, run 31 was normalized to run 33 based on the sidelap area.

For the extension to the Choke Point area, the same statistics (from the Cantonment area) were used to convert the eastern end of run 31. Run 31 then became the reference image for the Choke Point area. Of the five north/south flightlines for the Choke Point area (runs 12, 14, 16, 36, and 22, from west to east), only one (run 12) did not overlap with run 31 (the 3-m east/west line). Originally, four of the north/south flightlines were to be referenced to run 31 independently. However, the images produced a better match by referencing run 16 to run 31, then normalizing run 14 and run 36 to run 16, and finally run 12 and run 22 to run 14 and run 36, respectively.

2.8 Terrain Normalization for HYDICE

In areas of high relief, such as the Choke Point, terrain correction is used to normalize the radiance (or reflectance) values to the equivalent values for a level surface. The basic approach for the Choke Point HYDICE imagery was to use the ERDAS Imagine topographic tools to develop a shaded relief layer and then divide the HYDICE radiance values by the shaded relief values (radiance values less than zero were set to zero). For the terrain correction, the DTED Level 4 data (gridded to 5-m spatial resolution) was used. Initially, a shaded relief model based on solar elevation of 63 degrees and azimuth of 156 degrees (based on the acquisition date and time) was generated. However, the resulting shaded relief model did not match the illumination effects visible in the HYDICE mosaic. After experimentation, the parameters that were found to best approximate the apparent illumination effects were an elevation of 82 degrees, azimuth of 160 degrees, and a scattering factor (lambertian component) of 0.5. The resulting image file is 'hyd_chkpt_5m_terr.img'.

2.9 Lessons Learned

Perhaps the most significant lesson in the registration process came as the result of not subsetting the number of bands in the raw HYDICE data. The sheer volume of data in one HYDICE frame necessitated grouping the HYDICE frames into two to four frame 'files' as the raw data were received from NRL. First, the time taken to select points along the edges of the flightlines between frames could have been eliminated if the subsetting of the bands to 44 had been applied to the raw, instead of the registered data. This would have allowed all files in a flightline to be merged into one file, and the resulting raw, mosaicked file could have been registered without exceeding ERDAS Imagine's file size capacity. Second, the processing time required to register the large 210-band files could have been reduced. Several iterations were usually required to improve accuracy, and the large files required substantial disk space and processing time that could have been reduced with smaller, 44-band files.

Errors in the new version 8.3 of ERDAS Imagine also contributed to many problems in processing the data. For example, while registering the HYDICE data, an error check was performed after the file was triangle-warped. We found that changes or additions to the GCP would only result in far greater error (significant misregistration, data holes, etc.). Only after significant effort was the problem discovered. With Imagine 8.3, it appears that the user must completely exit and reenter the Registration Tool module, otherwise the error was aggravated.

3.0 Hyperspectral Landuse Classification

3.1 Cantonment Area Coverages

HYDICE

The Cantonment area was flown at two altitudes, 5,000 ft. AGL (0.75 m ground resolution), and 20,000 ft. AGL (3-m ground resolution) in multiple overlapping west-to-east flightlines. Two of the low-altitude flightlines (runs 6 and 8), and two of the high-altitude flightlines (runs 31 and 33) were mosaicked to produce a high-resolution dataset referred to as the 1-m dataset, and a lower resolution dataset referred to as the 3-m dataset. These datasets were independently classified using similar methods. The two altitudes presented somewhat different problems in the conversion of spectral classifications of surface materials to use coverage classes. For example, the 3-m dataset had greater diversity of classes due to the larger area of coverage, while the 1-m dataset required a more direct approach to eliminating shadows, which were generally not resolved in the 3-m imagery. In the following discussion, the spatial analysis of the two datasets is addressed separately.

Daedalus

Daedalus multispectral imagery was collected over the Cantonment area by the AMPS system on September 27, 1994. Two Daedalus flightlines at 1500 ft. AGL were registered, mosaicked, and normalized as possible supplements to the HYDICE hyperspectral data. The Daedalus data contained three bands (see Section 1.2.5) with a ground resolution of 1 m. However, after careful evaluation we concluded that the problems introduced into the analysis by incompatibilities in the data outweighed the potential advantages of the extended spectral coverage. The major problems were a 2-year time difference (1994 to 1996), the seasonal difference (July and September), greater geometric distortion (roll and jitters) in the Daedalus scanner data, and the large off-nadir viewing angles of the wide-angle scanner, which accentuated non-lambertion reflectance properties of some of the surface materials.

SAR

SAR imagery was also collected on the AMPS mission (September 28, 1994). This dataset covered a portion of the Cantonment area and had a ground resolution of 1 m. It was not used as a separate band but was examined visually in the process of selecting training sites for the supervised classification. The SAR was particularly helpful in distinguishing asphalt roads from asphalt parking areas, which generally have a rougher texture.

Aerial Photography

Aerial photos at scales of 1:5,000 from AMPS (September 27, 1994) and 1:12,000 from prior surveys of the YTC (July 10 and 11, 1996; September 22, 1997) were used for selecting training sites and identifying surface materials.

3.1.1 Overall Classification (1-m and 3-m Spatial Resolution)

3.1.1.1 Spectral Classification

The Cantonment area contains a variety of man-made structures and natural features. Examples are: barracks, vehicle storage lots, buildings of various types, an air strip, cropland, orchards, trees, water, and arid land. As described in Section 1.1, a major reason for selecting this site was the opportunity to compare the effectiveness of hyperspectral landcover classification at two resolutions (1-m and 3-m). To this end, parallel classifications were carried out on the high- and low-resolution datasets. For the 1-m dataset, only two flightlines were available, restricting the coverage to the central strip of the 2 km x 2 km block. This strip included most of the man-made features. The area outside the two flightlines contained mostly cropland and orchards. The 44-band HYDICE subset was used in each case for the subsequent classifications. A Principal Component Analysis (PCA) of the datasets produced 7 PCA bands with good signal-to-noise ratios. Unsupervised classifications were carried out on the original 44-band files and the 7-band PCA files to compare the effectiveness of the PCA subset in representing the full band set and to indicate the number of separable classes. These experiments indicated that the PCA bands were in fact capturing the non-redundant spectral information. The supervised maximum likelihood classification approach was selected as most effective after experimentation with other classification methods including Spectral Angle Mapper (SAM) and minimum distance. The supervised rather than the unsupervised approach was chosen since as much human input was required to consolidate unsupervised classes as was needed to select training classes, and the training site selection process was more straightforward. Training sites were selected from a combination of aerial photography, ground photography, and AMPS SAR imagery. A 'final' maximum likelihood classification was selected after several iterations in which adjustments and additions were made to the training areas. This classification was used for most of the subsequent spatial analysis; however, in a few cases (described below) additional classifications were required.

3.1.1.2 Spatial Analysis

The last step of using spatial information was an important addition to classical classification methodology since spatial and spectral data are relatively independent sources of information. By combining spatial and spectral approaches, much more accurate and reliable characterization of a scene can be made. For this study, four methods of spatial analysis were particularly useful:

1. **Clump/Sieve**: This methodology follows the standard methodology used by the ERDAS Imagine package. The pixels are first grouped into 'clumps' (or objects) that are connected (either by using the Clump function under the GIS option of the Interpreter or the Clump function in the module. The next step is to connect the clumps into meaningful objects. The user is allowed to define 'connected' if: 1) a pixel touches its neighbor on the left, top, right or bottom side (i.e., four possible matches), or 2) a pixel touches its neighbor on either the sides *or* corners (i.e., eight possible matches). The decision on which definition of connection is used can make a significant difference since using only the sides tends to make more isolated, individual objects. Once all the 'like' pixels in an image have

be clumped together, the Sieve function can be used to remove small clumps that normally represent noise (i.e., single, isolated pixels). The same process can be used on the complement of a file to remove holes below a selected threshold.

2. **Clump/Filter**: This methodology starts with the ERDAS Imagine Clump function but uses more sophisticated shape information to differentiate clumps. Specifically, it uses a PNNL-developed program ('basic_object.c') to characterize changes between two images more effectively (e.g., a clump of changed pixels shaped like a building next to a power line is more interesting then a small isolated change in a wheat field when looking for new factories). In addition to size, the program calculates a number of parameters for each object from the Clump file. For this study, the three most important parameters were: 1) size, 2) surface-to-area ratio, and 3) eccentricity. For example, eccentricity tended to help separate out linear features (e.g., a segment of a channel) from 'blobs' (e.g., ponds or lakes). The table containing these parameters (e.g., file 'subset.out from program basic_object') was then read by a customized program that contains specific rules for separating out features (e.g., if eccentricity <0.89 then this clump is a pond). The output of this program was then input in the Imagine Recode function (found under Interpreter, GIS) to recode the individual clump ID numbers into the appropriate feature type (e.g., channel segments or ponds).

3. **Erode/Mask**: This spatial analysis technique was useful for extracting roads from parking lots. The general protocol was first to erode all the pixels (e.g., grow zeros into asphalt pixels). This removed all the narrow roads but left most of the large parking lots intact. Next, a mask was created by growing the remaining parking lots back to their original size. However, if the original erosion was too severe, too much of the shape information might have been lost and the restored parking lots might not be an exact representation of the originals. This file was then used as a mask to remove parking lots from the original file, leaving only the roads. A side effect of this process is that it can 'create' roads at the edges of parking lots if the restoration of a parking lot is only approximately correct. The extent to which this occurs depends on how roads are defined and used.

4. **Erode/Grow**: This spatial filter was useful to differentiate pixels that were spectrally similar but had different spatial characteristics (for example, trees and orchards). Spectrally, trees and orchards are very similar; however, orchards are large blocky features while individual trees form smaller irregular shapes. However, some trees tend to grow together in a linear fashion; e.g., along a river or roadway. At the 3-m pixel resolution, trees are characterized by clump sizes that can overlap with orchards. However, since they are long and narrow, they will erode before orchards of the same size. The Erode/Grow procedure takes advantage of this by severely eroding all orchard pixels. At the end of this process, only the cores at the center of large blocky orchards remain. The procedure next grows these core center points of the orchard out to the characteristic size of an orchard and restores all the original orchard pixels in the process. Since orchards are structured, regular, man-made features, the procedure next smoothes out any rough edges by first eroding by one pixel and then growing by one pixel. This procedure is not prefect (e.g., small isolated orchards can be removed); however, the overall misclassification between trees and large orchards decreases significantly. Another example application of this procedure involves using it to improve the original general classification to better differentiate blocky dark gravel parking lot pixels from narrow dark asphalt road pixels that were originally misclassified as dark gravel.

The following sections discuss the implementation of the methodologies described above to the NIMA use coverage classes. In general, the 3-m datasets had a greater diversity of classes than the 1-m datasets and more often required a multi-step application of the spatial analysis filters to successfully extract the desired class.

3.1.2 Population Buildings (1-m)

Several building roof classes were defined in the original general classification to account for different roof materials and variations in illumination caused by roof slope and orientation. An ERDAS Imagine model ('hydice_6-8_extract_roof.gmd') was used to extract all the roof pixels and place them in one layer. The Clump/Sieve model was used to eliminate clumps of roof pixels smaller than any realistic roof size. An inverse Clump/Sieve model was then used to fill holes in the remaining blocks of roof pixels.

3.1.3 Transportation Roads

3.1.3.1 Asphalt Roads (3-m)

Using a simple ERDAS Imagine model ('extract_roads.gmd'), asphalt pixels were extracted from the file 'general_classes_with_segments.img'. This model also removed asphalt pixels that were misclassified near bodies of dark water (by growing a mask out from water pixels and ignoring all asphalt pixels in this mask). The file 'general_classes_with_segments.img' is an augmented version of the final class file in that signatures were added to account for road segments near the center of the image where mixed pixel effects were particularly problematic. The next step was using a Clump/Sieve process to remove small (<46) isolated pixels (noise). The Clump/Sieve-cleaned file was then input into an Erode/Mask model ('extract_fine_roads.gmd') to extract roads, and the results were cleaned up with a Clump/Sieve process to remove small (<46 pixels) extraneous features. Next, a Clump/Filter process was used with the following rules: assume it is a line unless it is of medium size (between 300 and 900 pixels) and it is not straight (eccentricity <0.9 pixels); also assume that any feature with a surface-to-area ratio of >=0.9 is a line. The result of this process was then input into ESRI's ArcScan, translated to vectors, and attributed.

Once this translation was completed, the vectors were rasterized and again analyzed with the Clump/ Filter process to identify airports and isolated road segments. In this case, an isolated feature (i.e., not part of a large connected network [>13,000 pixels]) that was the right size for an airport (>100 and <13,000 pixels) and linear in nature (high eccentricity, >99 pixels) was reclassified from road to airport. Linear features that were small (not part of a larger connected network) were considered misclassified as roads and marked for removal.

3.1.3.2 Asphalt Roads (1-m)

Asphalt was classified into three classes to account for new asphalt as well as older, more weathered roads and parking areas. These classes were extracted by the ERDAS Imagine model ('hydice_ 6-8_extract_roads.gmd'). The extracted asphalt was processed in a similar fashion to the 3-m data. The filtered asphalt was vectorized by ArcScan and attributed. The vectorized paved roads were rasterized and grown back to their original width. This road file was later used as a mask to select parking areas from the original asphalt classification.

3.1.3.3 Dirt Roads (3-m)

Characterizing dirt roads used the same analysis procedure as characterizing asphalt roads with the following complications:

- fuzzy definition of a dirt road (e.g., when does a dirt path become a road?)
- linear bare ground features associated with the shoulders of roads
- dirt roads not well engineered to be straight and of constant width
- many patches of bare ground that could be potential roads
- vegetation that can unevenly reclaim roads
- dirt road segments that can be isolated by asphalt roads
- courtyards that look like dirt roads.

The first step was to extract bare ground pixels and fill small internal holes (e.g., 'extract_raw_dirt.gmd') using Clump/Sieve with a threshold of 50 to remove isolated noise. The next step was to use Erode/Mask to extract roads. However, as mentioned above, some bare ground features tended to be confused with real dirt roads. To help account for this, water, asphalt roads, buildings, and gravel were extracted with a liberal hole fill (see 'extact_large_buldings.gmd') and cleaned by Clump/Sieve (<50). The model ('remove_court_yards.gmd') then masked out all bare ground next to courtyards, and a Clump/Sieve operation (<100) was used to remove noise. The next step was to use a Clump/Filter operation with the following rule:

> keep a segment unless it is small (area <500) and stubby (eccentricity<0.95), and not a short bend in a road (area <=300 and area<=400 and eccentricity >0.87) to identify clumps to be vectorized into roads.

This process worked reasonably well, with the significant exception of a large dirt road next to an asphalt road. To account for this, a separate parallel procedure was run that started with the largest clump and roughly replicated the process above, with two major exceptions: 1) the erosion process was larger in the Erode/Mask process to erode the especially wide dirt roads (to differentiate them from parking lots), and 2) there was no masking of extraneous features (to differentiate from a shoulder of an asphalt road). The next step was to Clump/Sieve only the largest clump in the file (it did not extract roads already accounted for). The last step was to combine all the results into one master file ('final_dirt_road.gmd').

3.1.3.4 Dirt Roads (1-m)

The mosaicked 1-m flightlines contained only a few dirt roads but also many patches of bare ground of varying size. The ERDAS Imagine model ('hydice_6-8_extract_bare_ground.gmd') was used to extract bare soil pixels from the original classification. Filtering steps similar to those used on the 3-m data, though less elaborate, were applied to the extracted bare earth pixels. The resulting file was vectorized using ArcScan. The vector file required some editing, using 1:5,000 and 1:12,000 scale aerial photography as reference, to eliminate confusion between patches of bare ground that were connected to dirt roads.

3.1.4 Transportation Vehicle Storage

3.1.4.1 Parking Lots (3-m)

The first step in extracting parking lots was to rasterize the vector road network and expand the roads back to the appropriate width. Potential parking lot pixels were then extracted from the general classification file. As an added step, internal small holes were filled during the extraction process. The road pixels were then used as a mask to remove candidate parking lot pixels. The remaining pixels were clumped and sieved to remove any clumps that were not large enough to hold several cars. A problem with this analysis is that a parking lot is a functional definition. This procedure really only identifies potential parking lots. For instance, the large asphalt area adjacent to the airport fulfills the criteria for a parking lot but is restricted by local rules for airport use only.

3.1.4.2 Parking Lots (1-m)

The candidate parking areas were extracted from the asphalt classification with an ERDAS Imagine model ('hydice_6-8_extract_parking.gmd'). The main function of this model was to mask out paved roads using the earlier classification of asphalt roads. A Clump/Sieve operation was applied to the candidate parking areas to eliminate areas too small to be parking lots, followed by an inverse Clump/ Sieve process to fill holes. As discussed in the 3-m analysis, there is some ambiguity as to the definition of a parking area. Thus, a few large patches of asphalt were placed in this class that actually may not be used for vehicle storage.

3.1.5 Surface Drainage

3.1.5.1 Surface Drainage (3-m)

The water class contained water pixels from both rivers and ponds. At the 3-m pixel size there did not seem to be enough spectral difference to separate out the two features reliability. Moreover, dark water and dark asphalt roads were confused in the original general classification. To deal with the latter, a signature file with only roads and river pixels was created and used (via maximum likelihood) to create the 'river_vs_roads.img' file. This file contained only rivers and roads and was optimized to classify water pixels correctly. However, to separate different types of water pixels, a spatial filter was applied. Specifically, this spatial analysis technique involved the following steps:

1. The model 'extract_water.gmd' was applied to extract water pixels into one layer.

2. Clump/Sieve was used to remove inconsequential clumps (<31 groups of pixels) of water features

3. Clump/Filter was used where a large size (>100 pixels) and line-like characteristics (eccentricity >0.89) denoted line segments of the river. Similarly, a small program 'get_small_segments.c' was used to identify short linear segments (>5 and <20 , and eccentricity >0.99) of channel that were originally excluded in the Clump/Sieve process.

4. The model 'combine_segments_main_channel.gmd' was used to combine these layers, create a file with all channels ('channels.img') and ponds ('ponds.img'), and translate to vector files using ArcScan.

5. In translating the channel raster data into vectors, ArcScan removed gaps in the data caused by such things as bridges and mixed pixel problems. Using the model 'combine_vector_and_raster.gmd,' these corrected data were combined with the original raster data to create the final rasterized file containing both ponds and channels. The final step in this model was using the rasterized vector data ('raster_channels.img') to create a mask of potential channel pixels to either identify channel pixels or fill gaps.

3.1.5.2 Surface Drainage (1-m)

Shallow and deep water classes were extracted from the original classification with the ERDAS Imagine model 'hydice_6-8_extract_water.gmd'. In the 1-m coverage, there were a few ponds and a short segment of a canal. The canal segment was too short to be geometrically isolated as a channel and therefore was considered a pond. In general, water is an easily distinguished class. The main source of confusion for water is shadows. At 1-m resolution more shadows are resolved than at 3-m resolution. However, the shadows tended to be small and/or narrow so a combination of Clump/Sieve and Erode/ Mask was successful in eliminating them. Remaining holes in the water class were filled with an inverse Clump/Sieve operation.

3.1.6 Vegetation

3.1.6.1 Vegetation (3-m)

Separating natural trees from orchards proved to be the most challenging aspect of the vegetation classification analyses. It was necessary to differentiate vegetation types into smaller groups by adding an orchard class so that attribute information could be assigned. For instance, with 3-m pixels it was not reasonable to calculate the distance between trees. However, if an area could be identified as an orchard and the information extracted about tree spacing in orchards from the 1-m datasets, then a reasonable estimation (at least in terms of broad classes) for the tree spacing for orchards was possible. To accomplish this goal, a set of spectral signatures for training purposes was created for trees, cropland, and orchards. Since very fine spectral distinctions were being established, a number of different training signatures were created for each class. For instance, four different orchard training sets were created for orchards, in effect creating four orchard subclasses. The relatively large areal extent of orchards and the negative spacing of trees provide unique signatures that were used to distinguish orchards from other vegetation classes. Once the orchard pixels were identified, they where spatially filtered using the Erode/ Growth procedure.

After completing the spectral classification, assigning vegetation classes was relatively straightforward. Each of the various vegetation classes was extracted, and small holes were filled, cleaned with a Clump/Sieve operation, then merged. A complication was the possible creation of holes caused by removing small irrelevant pixel clumps. This was resolved by overlaying layers from the most general to the most specific. For instance, the crop class was first created by mapping *all* vegetation layers into this one class. Other layers (e.g., orchards, lawns/grass, and trees) were then overlaid on this general layer, which had the effect of assigning any holes to the more general class of vegetation, thereby filling all the holes.

3.1.6.2 Vegetation (1-m)

The extraction of the various vegetation classes at 1 m followed the same procedure used at 3 m, with the exception of trees. At 1-m resolution, trees frequently could be resolved as distinct individuals or small groups. Spectrally, the tree canopies were confused with green lawn or other green crops. However, in many cases the trees cast shadows that were resolved at 1 m as a separate shadow class. Thus, the association of shadow pixels in the neighborhood of green vegetation constituted a tree signature. The ERDAS Imagine model 'hydice_6-8_trees.gmd' was used to process the shadow and green vegetation layers to extract trees. Using the acquisition date and an approximate tree height, the length and direction of a shadow could be predicted. The model tests potential tree pixels by looking for shadow pixels in the appropriate direction and vicinity. If a shadow is found in the correct area, a tree pixel is output. This approach worked well with individual trees and was reasonably successful with small clumps of trees. In the case of clumps, errors occurred when a tree did not occur adjacent to a shadow. The errors occurred most frequently when the shadow was too far away to be detected, and the pair was misclassified.

3.2 Choke Point Area Coverages

3.2.1 General Classifications

The overall approach to generating the raster coverages first involves producing general landcover classifications then using these general classifications (in some combination) to best generate each of the individual coverages. Most of the classifications were performed using the mosaicked HYDICE imagery. As part of the process of generating landcover classifications, several transformations were applied to the HYDICE imagery. The transformations included:

- PCA

- Inverse PCA: The first five principal components were relatively noise-free, and so the inverse Principal Components transformation was used to transform these components back to 44 spectral bands. Note: to do this using the ERDAS Imagine software, a subset file was created that included only the five principal components. For simplicity, this dataset will be referred to as the inverse PCA.

- Spectral Continuum Removal: One of the techniques for classifying hyperspectral imagery is spectral matching, where absorption features in the reference spectra are compared to a target spectra (i.e., the pixel to be classified). This technique requires that spectra representing each pixel be normalized by drawing a curve through the top of the reflectance features. This algorithm was applied using the ENVI software Continuum Removal module.

After applying transformations, several types of classifications were used. The classifications fell *into the categories* of unsupervised, supervised, and spectral. Some classifications could not practically be applied to the 44-band imagery, such as the maximum likelihood. The best overall classification (based on comparison with air photos) was the minimum distance classification applied to the inverse PCA imagery. For this classification, several training sets were selected for man-made features and vegetation. Other classifications that were generated include:

- Maximum Likelihood and Mahalanobis Distance, applied to the PCA (first five bands)

- Normalized Difference Vegetation Index (NDVI) applied to bands 8 and 14 from the 44-band HYDICE imagery (after terrain normalization)

- Spectral Matching, applied to the continuum removal imagery.

In addition to the HYDICE imagery, the Airborne Laser Mapping (ALM) lidar dataset was used both for delineating features and providing attribute information. The ALM provided PNNL with a processed 'ground model' dataset, which represents the ground surface after removal of vegetation and buildings. This dataset was gridded by PNNL to generate a 1.5-m resolution terrain file. The ALM also provided PNNL with the raw data; after review of this data it became clear that the raw data could be very useful for separating the trees from other vegetation and providing building heights. The raw data were also gridded to a 1.5-m spatial resolution. Derived products from the raw and ground model lidar imagery are slope (expressed as percent slope) and the difference between the raw (representing the canopy) and ground model data.

The individual coverages that were generated based on the transformations and classifications of the HYDICE and lidar data are discussed separately below. All processing was performed in ERDAS Imagine 8.3 unless otherwise indicated.

3.2.2 Population Buildings

The Choke Point area does not include any highly populated areas as does the Cantonment area. However, there is a complex of buildings at the National Security Administration (NSA) site and also a few miscellaneous metal buildings scattered throughout the area. (The Choke Point area of interest does not extend as far south as the Range Control buildings.) The goal for developing the population buildings class was to detect and map as many of these building as possible, given the drawbacks of mapping with 3-m spatial data. Earlier results from the Fort Benning, Georgia landcover mapping (Steinmaus et al. 1997) demonstrated the disadvantage of 3-m spatial data over 1-m data for mapping buildings; those results indicated that mixed pixel problems prevented accurate mapping of buildings on the scale of individual family units.

The basic approach to mapping of the buildings was to exploit the capability of the HYDICE imagery to determine surface material types. The work began with performing a 7 x 7 pixel neighborhood filter to 'smooth' the minimum distance (from the inverse PCA). The neighborhood filter, while filling in 'holes' or slight irregularities, does reduce the apparent size of the buildings, so any 'metal roof' pixels from either the minimum distance or the smoother file were assigned as building. The ERDAS Imagine Clump and Sieve function was used to screen out areas with less than 30 adjacent cells classed as building. This eliminated some smaller bright or metal structures (such as the NSA antennae) from being classed as a building. Finally, the output from the Sieve function was reclassed into two classes: unclassed or buildings. The final building file is 'chkpt_bldg.img'. Attributes were added for surface material (metal, based on landcover classification), existence, and function (military operations, since onsite). The height above surface, ZV1 and ZV2 attributes, were left to be filled during the vectorization (based on the lidar terrain data).

The landcover mapping (based on the HYDICE 3-m imagery) was able to detect the NSA buildings but not the small metal buildings scattered in other areas. To detect these smaller buildings, higher spatial resolution optical imagery was required. Alternatively, the raw (unprocessed) lidar data might detect the roofs of these small metal buildings, which would require additional processing of the lidar data.

3.2.3 Transportation Roads

The vast majority of roads in the Choke Point area are unimproved (dirt) roads, but there are gravel roads as well. Some of the gravel roads appear (by inspection of air photos) to have been oiled or treated to reduce dust. One of the challenges to mapping dirt or unimproved roads is deciding what defines a road: in the arid environment of the YTC, one or two passes of a wheeled military vehicle can produce tracks that can be identified as a road in the 3-m imagery. For the purposes of developing the transportation roads coverage, any roads that were visible in the 3-m HYDICE imagery were included.

After evaluation of the basic classifications, it was apparent that component 3 of the PCA transformed (terrain-corrected) imagery was best for separating out roads, although there was some confusion with streams. The ERDAS Imagine (Version 8.2) edge detection function was used, using a 3 x 3 pixel Sobel (non-directional) filter. This edge-detected image was thresholded; values over 600 were classed as road. Then a 3 x 3 pixel majority neighborhood filter was used. The resulting file, 'hyd_pc3_600edge, 3x3maj.img' was used in ArcScan to digitize the roads.

Note: ERDAS Imagine 8.2 was used for the edge detection after problems with version 8.3 were encountered. Basically, version 8.3 was not producing the same edge map when 'apply to whole image' was used, as was produced in the 'on demand' mode.

3.2.4 Transportation Bridges

No raster coverage was created for bridges. The bridge coverage was created entirely as a vector product, as the intersection between streams (surface drainage) and roads (transportation roads). This procedure is described in Section 4.0, Vectorization of Landuse Classifications.

3.2.5 Obstacles

The obstacles that were considered for mapping in the Choke Point area were fences, escarpments (long, linear, natural features), and birms or embankments (long, linear, man-made features). The most likely fence type in the Choke Point area is chainlink around the NSA site. While this fence type might be observable with photography, only indirect evidence of fence obstacles might be feasible given 3-m imagery. Examination of the general classifications (including the NDVI) did not yield any means to determine fence lines. (Although the boundary of the YTC is quite evident in 10-m SPOT panchromatic imagery, as a result of difference in landuse.) Escarpments (and cliffs) are delineated by the slope and extent; for the purposes of the obstacles coverage, areas with slope greater than 60% and area of at least 250 m in length were considered escarpments. Another type of obstacle that is common in the Choke Point area is long, low birms used in training exercises. These appear (according to inspection of the HYDICE imagery and photography) to be approximately 30-60 ft. wide and are much longer than they are wide. For the escarpment and birm features, processing of the lidar terrain data was exploited.

Detection and mapping of the escarpments were based on the unprocessed (raw) lidar data. After generating a slope map (using the ERDAS Imagine topographic tools), all cells with slope greater than or equal to 60% were classed as 1 (all other were set to 0). A 7 x 7 pixel majority neighborhood filter was used to smooth and fill in small clumps. Then the ERDAS Imagine Clump and Sieve function was used to sieve out all areas with fewer than 300 adjacent pixels (to try to capture the areas of 250 m or more in length). An additional pass with the 7 x 7 pixel majority filter was used to fill in the holes created by the Sieve function. Most of the attributes could not be determined, although the slope gradient was added during the digitization process.

The man-made embankments (birms) proved to be too challenging for automated detection. Although these linear features are quite apparent to the human analyst when viewing derived slope or edge detection images (based on the unprocessed lidar data), the features could not be separated from other long, linear features (portions of roads, slope breaks in escarpments, etc.). Models based on combining the slope, obstacle height, and relative smoothness of the surrounding terrain failed to separate these features. It became apparent that what is needed is a type of shape filter that combines width/length ratios with a measure of 'straightness'.

3.2.6 Vegetation

Vegetation in the Choke Point area falls into one of two major categories: shrub-steppe (a combination of shrubs such as big sagebrush and rabbitbrush, annual and bunch grasses) that covers the majority of the site, and a narrow band of riparian vegetation (deciduous trees, shrubs, and grasses) along the streams. Because of the range of spectral bands throughout the visible and into the mid-infrared, the HYDICE imagery was used to identify vegetation types. Several of the general classifications described above were evaluated for the ability to separate the vegetation. In particular, training sites for big sagebrush (the dominant shrub), trees, other riparian vegetation, and grasses were selected and used in several supervised classifications. These classifications were not successful in separating high-density areas of big sagebrush from areas dominated by grasses. Spectral matching (based on matching the apparent absorption features in the reference and target spectra) was applied to try to separate the trees from other riparian vegetation; the approach did detect trees in some areas but failed to detect trees in other areas. An additional band selection was also applied by examining the spectra of several vegetation training sets; a file was generated based on eight bands (2,6,8,9,10,14,16, and 20) of the 44-band inverse PCA imagery that maximized the differences among the spectra. The object was to reduce the bandset so that classifications such as maximum likelihood, which exploit spectral covariance, could be utilized. However, these classifications did not produce any satisfactory vegetation classification. In fact, the maximum likelihood seemed to be very sensitive to some noise in the data; the source of this noise is unknown but appears mainly as broad vertical banding (which does not correspond to the original HYDICE frames that made up the composite).

After consideration of the results of the classifications, the NDVI image appeared to show subtle changes in vegetation that were not apparent in the other classifications. Initially, the NDVI image was stratified by using the average NDVI for group of vegetation (e.g., 0.02-0.02 non-veg; 0.02-0.06 very sparse grass, etc.). However, an unsupervised classification (ERDAS Isodata) produced an automated density slice. Seven classes were selected, and corresponding vegetation types for each of the classes were assigned by inspection of air photos. To generate the thematic layer, a 7 x 7 pixel neighborhood modal filter was used and then the ERDAS Imagine Clump and Sieve functions were used to eliminate groups of less than 10 pixels. Two of the classes were quite similar and were combined. The six classes determined were: barren, very sparse grass/shrubs, sparse grass/shrubs, grass/shrubs, shrubs, and trees/ riparian. Based on these classes, values for the brush/undergrowth density code ('bud') and vegetation characteristics ('veg') attributes were added. The parameters ZV1 and ZV2 were added as part of the digitization. The final thematic raster layer is 'hyd_chkpt_ndvi_sieve_r3.img'.

3.2.7 Surface Drainage

The Choke Point area includes Selah Creek and several smaller tributaries. These streams run intermittently and can be determined indirectly by the type of riparian vegetation that grows along the streambed. From the viewpoint of the optical data, this vegetation is much 'greener' and produces higher values of NDVI. The use of slope, or changes in slope, of the Level 4 DTED was also evaluated. However, the NDVI values seemed to be a much better indicator of the stream channels.

To produce a raster file for digitization, the NDVI image was thresholded so that pixels with NDVI greater than or equal to 0.30 were considered riparian. The resulting file is 'hyd_chkpt_stream_mask.img'. Although ArcScan is capable of digitizing polygons (the streams are represented by polygons, not lines), problems with the ArcScan software forced the use of straight line vector digitization in ERDAS Imagine. The vector line coverage that was created was merged with the raster file 'hyd_chkpt_stream_mask.img' to fill in gaps produced where the stream course was not evident by the vegetation threshold. This merging was done by: 1) creating a 10-pixel-wide buffer zone on both sides of the stream line vector; using this buffer to delete any stray 'stream' pixels (from the stream raster image) that fell outside this zone, and 2) including all cells (within the buffer zone) that were mapped as stream in the raster fine or touched the steam line vector. This merging resulted in a new raster image with all of the stream area connected (no gaps). The final processing was to run the ERDAS Imagine Clump and Sieve function to delete all but the large (>14000) cell polygons that represented the connected streams. The resulting file is 'hyd_stream_sieve.img'. Very little stream attribution could be added at the time this raster layer was created. With additional processing, the vegetation coverage might be used to fill in the 'bank veg left' and 'bank veg right'.

3.2.8 Tree Point Feature

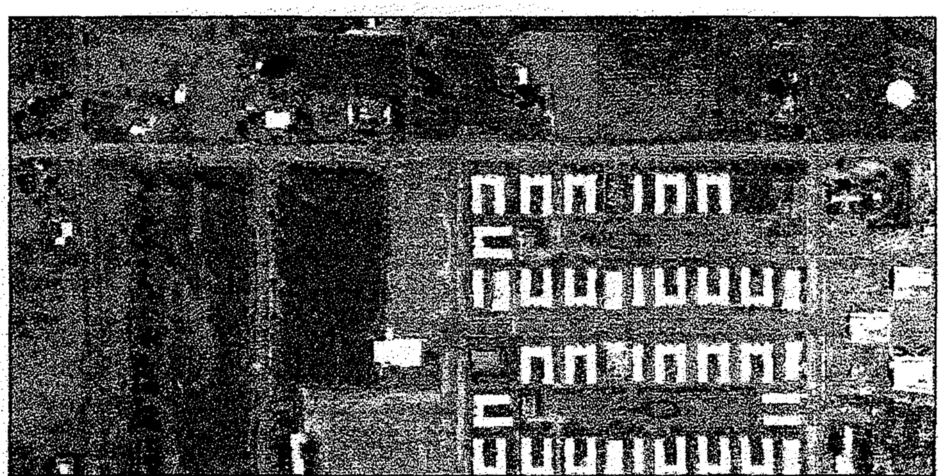
The 3-m spatial resolution of the HYDICE imagery for the Choke Point area was not sufficient to distinguish individual trees along the riparian corridor based on shape; spectrally, the trees looked similar to the other riparian vegetation. However, comparison of the raw (unprocessed) lidar data with aerial photography revealed points from which individual (or groups of) trees could be determined from the lidar data. This information could be used in several ways. First, discussions between TMPO and PNNL on the Fort Benning, Georgia effort indicated that a vector coverage containing isolated tree features would be of interest to TMPO. This coverage was not generated for Fort Benning because none of the datasets used were adequate for accurately and consistently identifying individual trees. The second use of this information on the location of individual or groups of trees is in separating trees from other riparian vegetation (which was not possible using spectral analysis of the HYDICE imagery). A third use of the information is in providing other attributes, such as height, for the vegetation coverage.

The merging of the lidar and HYDICE datasets would require co-registration accuracies close to 3 m (the resolution of the HYDICE imagery) to avoid artifacts introduced as a result of misregistration. However, because of the high relief in the Choke Point area, overlaying the gridded lidar data with the HYDICE imagery indicated that misregistrations might be a great as 30 m in some areas. True exploitation of the lidar with HYDICE data would require further co-registration between the two datasets. As a first approach, a point vector coverage was derived from the lidar data directly, using the HYDICE data only to screen out other objects (such as buildings) that might be confused as trees. This was performed by: 1) creating a 15-pixel (45-m) buffer around the riparian class (from the vegetation coverage), and 2) selecting all cells with height greater 3 m (using the raw minus processed difference file, 'ytc_choke_pt_1.5m_RAW_Pro_flt.img') that fell within the 45-m riparian buffer. The final resulting raster image is 'chkpt_tree_pt.img'.

3.3 Spectral Classification Results and Discussion—1- and 3-m HYDICE Imagery

Figure 3.1 shows a comparison of the 3-m and 1-m classifications for the same area. The 1-m data are significantly better at defining man-made structures such as buildings and roads. Additionally, individual trees, shrubs, and vehicles are often resolved at the 1-m ground resolution. However, for larger features such as fields, lawns, orchards, and areas of brushland, the 3-m resolution is equal or preferable to the 1-m data. The larger ground resolution has the effect of filtering out some of the small scale detail that would be considered 'noise' in these larger scale features.

For these broad, slowly changing natural features, the 3-m classification had several advantages over the 1-m classification. For instance, the amount of storage and processing time was minimized. For large



1 meter Classification Map of Cantonment Area

3 meter Classification Map of Cantonment Area

Legend

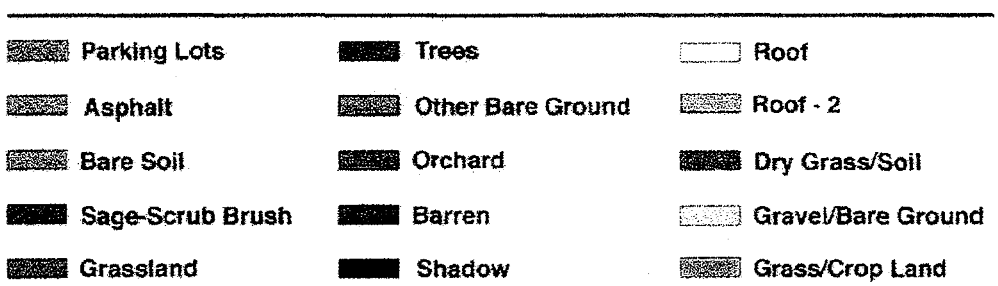


Figure 3.1. Comparison of 1-m and 3-m Classifications

areas of interest to NIMA, this can be of critical practical importance. Further, some of the 'noise' in the scene can be averaged out with larger pixels, thereby improving classification accuracy. In some agricultural cases, the regular spacing of crops may produce a regular mixed pixel signature that can improve the differentiation of classes. For instance, the regular spacing of trees in orchards may have helped produce a constant mixed pixel signature that allowed for the separation of orchards from individual trees.

This study suggests that for some scenes, a multiscale approach might be optimal. For instance, at 3 m, broad areas of homogenous orchards could be identified. Taking advantage of the homogeneity of tree spacing in orchards, it might be possible to estimate the tree spacing and other parameters from a limited sample of 1-m pixel images.

4.0 Vectorization of Landuse Classifications

4.1 Product Vectorization

The deliverable for this project includes a series of CD-ROMs containing raw data, registered image mosaics, raster classifications, vector classifications, and accompanying metadata. Appendix A contains a list of the final products contained on the CD sets. The raw and registered data were provided for completeness. The final products generated by this project consist of the raster and vector landcover maps for the classifications described earlier in this report. NIMA requested that the classifications be provided as vector files in ArcInfo format in addition to the raster classifications that are in ERDAS Imagine format. Automation of processes was an important part of this project. To utilize these, the user creates only a series of ascii files (called control files) containing information about the files to be processed (as described in Sections 4.1.2 and 4.1.3).

4.1.1 Vectorization of the Polygon Classifications

Once the landcover classifications were generated and converted to NIMA use coverage classes, the ERDAS Imagine format raster files were converted to ArcInfo format polygon coverages, attribute information (called "items" in ArcInfo) was assigned, and the coverages were converted to ArcInfo export format (.e00). This was done using scripts written in ArcInfo's macro language (AML). Appendix C contains the AML used for the raster-to-vector conversions as well as example control files read by the AML.

4.1.2 Creation of Polygon Coverages from Raster Files

A comma-delimited export file containing the attribute information was generated from ERDAS Imagine for each raster layer. A column was added to the raster file containing the row number since the row number is not automatically included as an output column in export format. A file was also created containing a lookup table of attributes matching the columns in the raster file. This file specifies attribute name and data format in the following format:

line 1: number of columns to skip in export file
line 2: attribute name, type, output width, number of decimal places (if type = float) etc.

```
example: 2
         f_code,c,32,32
         ohc,f,4,12
```

In addition, a control file called 'vectorize.ctl' was created containing the following information:

line 1: Imagine format raster filename, including path
line 2: attribute export filename, including path
line 3: Lookup table filename, including path etc...

This control file is read by 'vectorize.aml,' which performs the following steps on the files listed in the control file:

1. reads information from control file
2. converts Imagine format raster file to ArcInfo grid file
3. converts ArcInfo grid to polygon coverage
4. reads attribute definitions from lookup table
5. adds items to polygon coverage based on attribute names
6. reads attribute information from export file
7. assigns values to items
8. for all coverages except tree point coverages, assigns the polygon area to attribute (item) ARA
9. writes output file containing name of created coverage for use with 'arc_to_export.aml.'

When calling 'vectorize.aml,' the name of the control file must be specified as an argument. This may be followed by an optional argument specifying the name of the output file to be created (the default is 'export.control').

4.1.3 Creation of Point Coverages from Raster Files

The vegetation class tree is specified as a point feature. The result of the classifications provided polygons that represent trees. These polygons were converted to points using the macro 'convert_trees.aml', and attributes were transferred from the polygon coverage to points located at the centroid of each polygon.

4.1.4 Addition of Elevation Attributes (ZV1 and ZV2)

Two elevation attributes were added as part of the vectorization: ZV1 and ZV2. All of the polygon coverages contain the attributes ZV1 (lowest Z-value) and ZV2 (highest Z-value) except for the obstacles coverage. In the Cantonment area, the elevation values for these attributes were determined using the 30-m DTED. In the Choke Point area, the elevation values were determined using the lidar-derived elevation information, except for the buildings, which used the 30-m DTED. The values in the lidar data were converted to integer centimeters so they could be converted to ArcInfo grid format. The attributes are to be specified in meters, so the values were converted back to meters during processing in ArcInfo.

Three control files were created to be used by 'add_stat_attributes.aml.' They are: 'elevations_1m.ctl', 'elevations_3m.ctl', and 'elevations_chkpt.ctl'. The format of these files is as follows:

line 1: path to Imagine format value grid (e.g., 30-m DTED)
line 2: name of Imagine format value grid (e.g., 30-m DTED)
line 3: conversion factor (divisor), cell size that polygon coverage was based on
line 4: path to coverages
line 5: coverage name, name of item to be assigned, type of statistical operation to perform (e.g., min, max, or mean)
line 6: coverage name, name of item to be assigned, type of statistical operation to perform (e.g., min, max, or mean) etc.

The macro 'add_stat_attributes.aml' assigns attributes to each polygon using the following steps:

1. reads information from control file
2. converts value grid from Imagine format to an ArcInfo grid
3. converts polygon coverage to grid creating a unique zone for each polygon
4. using the 'zonalstats' command, creates a file containing the min, mean, or max value for each zone (polygon) depending on which statistical value was specified in the control file
5. assigns statistical value to the specified item name (attribute) for each polygon.

4.1.5 Addition of Slope Attribute

The attribute for gradient/slope is assigned in much the same way as the elevation attributes. A raster file containing slope was generated for the obstacle coverage. The mean slope was calculated for each polygon and assigned to the gradient/slope attribute using 'add_stat_attributes.' A control file called 'slopes_chkpt.ctl' was created in the same format as 'elevations.ctl'.

4.1.6 Addition of Attributes to Point Coverages

Elevation attributes (ZV1 and ZV2), and tree height (VH1) were added to the tree point coverages by sampling the 30-m DTED at each point and assigning the value to the appropriate attribute.

4.1.7 Conversion from ArcInfo Coverages to ArcInfo Export Files

Once the coverages were created and all of the items populated, each coverage was converted to ArcInfo interchange format (.e00) using the export command. The AML called 'arc_to_export.aml' does this conversion, reading the list of coverages to convert from a control file called 'export.ctl'.

4.2 Vectorization of Road Classifications

4.2.1 Software for the Vectorization of Roads

Raster-to-vector conversion of the road classification was done in ESRI's ArcInfo using the automated vectorization module ArcScan. Editing and the addition of attributes (post-processing) was done in ERDAS Imagine since it offers more user-friendly editing capabilities.

4.2.2 Process of Vectorizing Roads

Once the landcover classifications were converted to NIMA use coverages, ArcScan was used to vectorize, and the boundary extents were added. ArcScan allows fully automated and user-guided modes to vectorize a coverage. The user-guided method was used to improve accuracy and limit manual post-processing.

Manual editing of ArcScan road vector files was limited, with liberal preference settings. The ArcScan preferences are set in three primary categories: Edit Environment, Line Properties, and Straighten Properties. While individual files vary according to pixel size, the following preferences were found to generate accurate vector files with limited manual editing:

Edit Environment:	
Vertex Distance:	30
Node/Arc Snap:	6
Line Properties:	
Width:	(measure individual roads for average)
Gap:	45
Dash:	60
Hole:	25
Straighten Properties:	
Tolerance:	10
Distance:	30
Range:	50

Because of limitations in ArcScan, all attribute information was entered in ERDAS Imagine 8.3. The following list describes the details of the attributes identified for the vectorized road classification of the 3-m classification for the Choke Point area and the 1-m and 3-m classifications for the Cantonment area. The methods describing the details for each attribute are included. The classes, attributes, and corresponding FACC codes are summarized in Appendix A, using the following criteria:

- F Code–FACC Feature Code. All roads were coded as AP030 according to the FACC Feature Code Manual.

- EXS–Existence Category. The state or condition of the feature. All roads vectorized were coded as Operational.

- LOC–Location Category. Status of a feature relative to surrounding area or water. All features were considered to be automobile road features and therefore assumed to be above the surface and not below the water.

- LTN–Track/Lane Number. The number of track(s) or lanes of the feature, including both directions. Paved road features are considered to have two lanes, and dirt lanes according to width are typically from one to one and one-half lanes, but are shown as one lane.

- RST–Road/Runway Surface Types. Paved roads were coded as Hard/Paved and dirt roads were coded as Loose/Unpaved.

- Gradient/Slope. Percentage of slope. See Section 4.1.5.

- SMC–Surface Material Category. Surface material composition excluding internal structural material. All derived from classification. Paved roads were coded as Asphalt. Roads vectorized in the unpaved road classification were coded as Soil.

- USE–Usage. Use (identifies the primary user, function, or controlling authority). Roads within the approved vector boundary layer of the YTC were coded as Military. All offsite areas were coded as Civilian/Public, with the exception of the interstate highway, coded as Interstate due to the wide road widths and unique on/off-ramp.

- WID–Width. Because no automated means of measuring the width of the roads was found, this attribute was coded Unknown.

- WTC–Weather Type Category. Weather conditions under which a feature is usable. Asphalt roads are assumed to be All-Weather. Soil road features are assumed to be Fair/Dry Weather Only.

- ZV1 and ZV2–Lowest Z-value and Highest Z-value. These attributes were added but not populated.

4.3 Creation of Bridge Coverages

The bridge coverages were created by intersecting the roads coverage with the water polygon coverages, leaving a line representing a bridge. The width attribute (WID) and the elevation attributes (ZV1 and ZV2) were transferred from the roads coverage. The f_code attribute was added and assigned the correct code for bridge. The other bridge attributes were added to the bridge coverage but not populated. The macro 'mak_bridges.aml' was used to intersect the coverages and add the appropriate attributes from a lookup table. The bridge coverages represent locations where the roads cross water, not engineered structures. In the Choke Point area in particular, some of the bridges do not appear as perpendicular stream crossings. This is because the nature of the datasets (roads and water) sometimes overlaid in such a manner as to have a road more or less parallel to a stream, yet crossing it at several places. It should also be noted that the map extent of the coverages created in this manner is truncated to include only the bridges. When overlaying these bridge coverages with other coverages, the map extent should be defined by the more extensive coverages.

5.0 Error Assessments of Classifications

5.1 Background

To determine the accuracy of the three YTC classified datasets (Cantonment 3-m, Cantonment 1-m, and Choke Point), a series of error analyses was performed using both aerial photography and ground truth information. Specifically, for each of the three classified datasets, two error analyses were performed: a 'coverage level' error analysis and a 'vegetation attribute level' error analysis. The coverage level error analysis was conducted to assess how accurately principal coverage-level features (such as roads, vegetation, water, etc.) were classified. The vegetation attribute level error analyses were performed to assess the ability to classify specific vegetation types (such as grasslands, shrubs, etc) according to NIMA's FACC. In total, six error analyses were performed. Table 5.1 below lists the coverages/attributes used for each error analysis.

Table 5.1. Coverages and Attributed Layers used in Error Analyses

Classified Dataset	Coverage Level Error Analysis	Attribute Level Error Analysis (Vegetation)
Cantonment 3-m Classification	Vegetation Water Roads Parking Lots Bridges	Cropland Orchard Grassland/Lawn Trees Barren Lands Grassland Brush
Cantonment 1-m Classification	Vegetation Water Roads Parking Lots Bridges Buildings	Orchard Grassland/Lawn Trees Barren Lands Brush
Choke Point Classification	Vegetation Water Roads Obstacles Bridges Buildings	Barren Lands Very Sparse Grass/Shrubs Sparse Shrubs/Grass Shrubs/Grass Shrubs Trees/Riparian

5.2 Methods

Before conducting the error analyses for each dataset, the attributed vector layers were rasterized to a 1-m cell resolution in the ERDAS Imagine Vector to Raster function. All secondary roads and associated bridges were normalized to a width of 11 m based on an average road width value extracted from aerial photography. Similarly, highways and associated bridges were normalized to a width of 17 m. For the coverage level error analyses, raster layers were combined in a simple overlay model created with the ERDAS Imagine 'ModelMaker' tool. For example, in the Cantonment 3-m coverage level error analysis, the following layers were overlaid from bottom to top: vegetation, water, roads, parking, and bridges.

To conduct each error analysis, the ERDAS Imagine Accuracy Assessment function was used to generate 100 randomly stratified points based on the histogram of the dataset.[1] A minimum of five points was used for each category. No random points were generated in areas with zero values. The classification of each point was then verified using aerial photography and/or ground truth information. An error matrix, accuracy totals, and Kappa statistics were generated for each of the six error analyses.

5.2.1 Reference Data

The three YTC classified datasets (Cantonment 3-m, Cantonment 1-m, and Choke Point), were all generated from HYDICE data. Because this error analysis was conducted approximately 18 months following the HYDICE data collection, current ground verification was limited by the potential landcover change over that time. Therefore, in addition to ground verification, the following supplementary aerial photography reference data were utilized to determine the classification accuracy:

• 1:12,000 color photography	July 11, 1996	
• 1:10,000 color infrared photography	July 10, 1996	(Cantonment area only)
• 1: 5,000 AMPS color photography	Sept. 27, 1994	(Cantonment area only)
• 1-m digital orthophotography	1993.	

Also, in the attribute level error analysis for vegetation, the reference data interpretation of a fallow landcover field depended on the actual condition of that field. For example, if a fallow field had grasses growing on it, it was interpreted as grassland and not as cropland. The hyperspectral sensor "sees" only current landcover rather than past or potential land use.

5.3 Results

Presented below are error matrices, accuracy totals, and Kappa statistics for the six error analyses. In the error matrix, the columns represent the reference data, and the rows represent the classification generated from the remotely sensed imagery. For example, in the coverage level error analysis for the

---

[1] The sample size of 100 points was determined based on the small areal extent of the footprint and the small number of categories. Because six separate error analyses were performed, we tried to balance statistical soundness and practicality (time, budget, etc.).

Cantonment 3-m classification, 71 of the 100 points were randomly placed on the vegetation class. Of those 71 points, 66 were actually vegetation according to the reference data. Five of those 71 points were misclassified, and according to the reference data, they are actually roads. In total, 67 points in the field were actually vegetation.

The accuracy totals, which are directly generated from the error matrices, are also presented for each analysis. Dividing the number of correct pixels in a category by either the total number of pixels in the corresponding row or column produces the accuracy totals. For example, in the vegetation class below, 66/67 results in a "producer's accuracy" (omission error) of 98.51%. The producer's accuracy describes how well an area can be classified. Similarly, 66/71 results in a "user's accuracy" (commission error) of 92.96%. The user's accuracy indicates the probability that a pixel classified on the map/image actually represents that category on the ground (Congalton 1991).

The "overall classification accuracy" is a descriptive statistic computed from the error matrix by dividing the sum of the major diagonal by the total number of pixels in the error analysis. Although not specific for each category, this statistic provides a general statement of the accuracy of the classification. Finally, the Kappa statistic, which ranges from 0 (no correlation) to 1 (perfect correlation) is provided for each analysis.

5.3.1 Coverage Level Error Analyses

Table 5.2. Error Matrix—Cantonment 3-m

	Vegetation	Water	Roads	Parking	Bridges	Row Total
Vegetation	66	0	5	0	0	71
Water	0	6	0	0	0	6
Roads	1	0	10	0	0	11
Parking	0	0	0	7	0	7
Bridges	0	1	0	0	4	5
Column Total	67	7	15	7	4	100

Table 5.3. Accuracy Totals—Cantonment 3-m

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Vegetation	67	71	66	98.51%	92.96%
Water	7	6	6	85.71%	100.00%
Roads	15	11	10	66.67%	90.91%
Parking	7	7	7	100.00%	100.00%
Bridges	4	5	4	100.00%	80.00%
Totals	100	100	93		
Overall Classification Accuracy = 93.00%. Overall Kappa Statistic = 0.8591.					

Table 5.4. Error Matrix—Cantonment 1-m

	Vegetation	Water	Roads	Parking	Bridges	Buildings	Row Total
Vegetation	53	0	1	3	0	0	57
Water	0	5	0	0	0	0	5
Roads	1	0	13	0	0	0	14
Parking	0	0	0	11	0	0	11
Bridges	1	4	0	0	0	0	5
Buildings	0	0	0	0	0	8	8
Column Total	55	9	14	14	0	8	100

Table 5.5. Accuracy Totals—Cantonment 1-m

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Vegetation	55	57	53	96.36%	92.98%
Water	9	5	5	55.56%	100.00%
Roads	14	14	13	92.86%	92.86%
Parking	14	11	11	78.57%	100.00%
Bridges	0	5	0	---	---
Buildings	8	8	8	100.00%	100.00%
Totals	100	100	90		
Overall Classification Accuracy = 90.00%. Overall Kappa Statistic = 0.8439.					

Table 5.6. Error Matrix—Choke Point

	Vegetation	Water	Roads	Obstacles	Bridges	Buildings	Row Total
Vegetation	68	1	1	0	0	0	70
Water	0	6	0	0	0	0	6
Roads	0	0	9	0	0	0	9
Obstacles	0	0	0	5	0	0	5
Bridges	0	4	0	0	1	0	5
Buildings	0	0	0	0	0	5	5
Column Total	68	11	10	5	1	5	100

Table 5.7. Accuracy Totals—Choke Point

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Vegetation	68	70	68	100.00%	97.14%
Water	11	6	6	54.55%	100.00%
Roads	10	9	9	90.00%	100.00%
Obstacles	5	5	5	100.00%	100.00%
Bridges	1	5	1	100.00%	20.00%
Buildings	5	5	5	100.00%	100.00%
Totals	100	100	94		
Overall Classification Accuracy = 94.00%. Overall Kappa Statistic = 0.8807.					

5.3.2 Attribute Level Error Analyses - Vegetation

Table 5.8. Error Matrix—Cantonment 3-m Vegetation

	Cropland	Orchard	Grassland/ Lawn	Trees	Barren	Grassland	Brush	Row Total
Cropland	14	1	1	1	2	0	0	19
Orchard	0	7	0	0	0	0	0	7
Grassland/Lawn	1	0	5	0	0	0	0	6
Trees	0	0	0	5	0	0	0	5
Barren	0	0	0	0	21	0	0	21
Grassland	0	0	0	0	0	7	0	7
Brush	0	0	0	0	0	11	24	35
Column Total	15	8	6	6	23	18	24	100

Table 5.9. Accuracy Totals—Cantonment 3-m Vegetation

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Cropland	15	19	14	93.33%	73.68%
Orchard	8	7	7	87.50%	100.00%
Grassland/Lawn	6	6	5	83.33%	83.33%
Trees	6	5	5	83.33%	100.00%
Barren	23	21	21	91.30%	100.00%
Grassland	18	7	7	38.89%	100.00%
Brush	24	35	24	100.00%	68.57%
Totals	100	100	83		
Overall Classification Accuracy = 83.00%. Overall Kappa Statistic = 0.7913.					

Table 5.10. Error Matrix—Cantonment 1-m Vegetation

	Orchard	Grassland/Lawn	Trees	Barren	Brush	Row Total
Orchard	6	0	0	0	0	6
Grassland/Lawn	0	46	1	0	1	48
Trees	0	0	5	0	0	5
Barren	0	1	0	23	0	24
Brush	0	10	0	0	7	17
Column Total	6	57	6	23	8	100

Table 5.11. Accuracy Totals—Cantonment 1-m Vegetation

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Orchard	6	6	6	100.00%	100.00%
Grassland/Lawn	57	48	46	80.70%	95.83%
Trees	6	5	5	83.33%	100.00%
Barren	23	24	23	100.00%	95.83%
Brush	8	17	7	87.50%	41.18%
Totals	100	100	87		
Overall Classification Accuracy = 87.00%. Overall Kappa Statistic = 0.8003.					

Table 5.12. Error Matrix—Choke Point Vegetation

	Barren	Very Sparse Grass/Shrubs	Sparse Shrubs/ Grass	Shrubs/ Grass	Shrubs	Trees/ Riparian	Row Total
Barren	5	0	0	0	0	0	5
Very Sparse Grass/ Shrubs	0	40	1	0	1	0	42
Sparse Shrubs/Grass	0	1	21	0	0	0	22
Shrubs/Grass	1	2	3	10	0	0	16
Shrubs	0	1	4	0	5	0	10
Trees/Riparian	0	0	1	0	0	4	5
Column Total	6	44	30	10	6	4	100

Table 5.13. Accuracy Totals—Choke Point Vegetation

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Barren	6	5	5	83.33%	100.00%
Very Sparse Grass/Shrubs	44	42	40	90.91%	95.24%
Sparse Shrubs/Grass	30	22	21	70.00%	95.45%
Shrubs/Grass	10	16	10	100.00%	62.50%
Shrubs	6	10	5	83.33%	50.00%
Trees/Riparian	4	5	4	100.00%	80.00%
Totals	100	100	85		
Overall Classification Accuracy = 85.00%. Overall Kappa Statistic = 0.7923.					

5.4 Discussion

5.4.1 Coverage Level Error Analysis

For the coverage level error analysis of the three YTC classified datasets (Cantonment 3-m, Cantonment 1-m, and Choke Point), the overall accuracy was very high—93%, 90%, and 94%, respectively. Specifically, the Cantonment 3-m classification error analysis resulted in relatively high producer's and user's accuracy for vegetation, roads, parking areas, and bridges. The producer's accuracy for roads was only 66.67% because some less frequently traveled roads were misclassified as vegetation. Given the areal extent of this classification, and the diversity of landcover features, the overall accuracy was exceptionally high.

The Cantonment 1-m classification overall accuracy of 90% is slightly less than the overall accuracy for the 3-m classification, but because the areal extent of the two classifications is significantly different, they cannot be directly compared. Additionally, the Cantonment 1-m classification included buildings, which was not classified in the 3-m data. In the Cantonment 1-m classification, the producer's and user's accuracy for vegetation, roads, and buildings was very high. Water had a lower producer's accuracy (55.56%) due to a non-existent bridge that was classified where water exists in the reference data. This non-existent bridge was misclassified because the AML model was designed to 'create' a bridge when a road passed over water in the coverage. However, in this case, the model inadvertently classified a road that ran parallel and adjacent to a canal by calling that road a bridge. That bridge feature covered some water in the classification, thus affecting its producer's accuracy. The only real bridge that exists in the footprint of the Cantonment 1-m classification also was not correctly classified, resulting in a producer's and user's accuracy of 0%. In this case, a road passed over a canal, but the AML model did not recognize the road as a bridge because two separate canal polygons (in the water coverage) did not in fact "pass under" the road (in the roads coverage) (see Figure 5.1 below). Some human interaction might be required for correct bridge classification in these cases.

The Choke Point coverage level classification had an overall accuracy of 94%. The producer's and user's accuracy for vegetation, roads, obstacles, and buildings was very high. Concerning the accuracy of bridges and water, a similar situation exists in the Choke Point classification. Once again, the AML model misclassified a road running adjacent and parallel to a body of water, in this case a stream. Therefore, the user's accuracy of bridges fell to 20%. All other bridges in this classification were correctly identified, (resulting in a bridges producer's accuracy of 100%), which suggests that the ability to classify bridges is still very high.

5.4.2 Attribute Level Error Analysis

This series of error analyses focuses on the accuracy of the vegetation attribution for the Cantonment 3-m, Cantonment 1-m and Choke Point classifications. The overall accuracy for the Cantonment 3-m vegetation classification is 83%. The grassland category has a producer's accuracy of only 38.89% due to a polygon of brush that was misclassified as grassland. That same misclassified polygon resulted in a slightly lower user's accuracy (68.57%) for brush. Most other brush polygons were correctly classified.

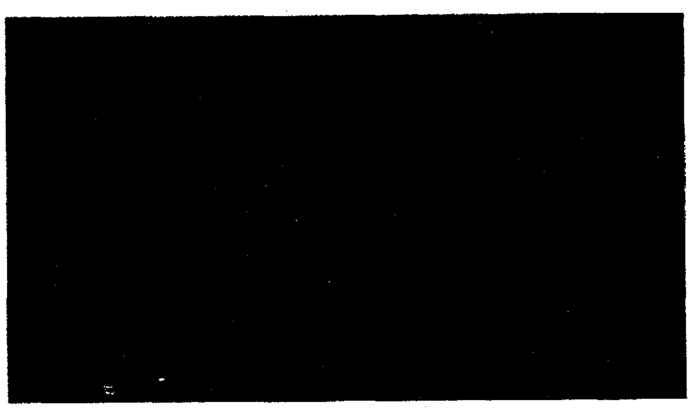


Figure 5.1. Example Error in Classification of Bridges When There is Visible Intersection Between Roads and Water Feature

The producer's and user's accuracy for the other categories (cropland, orchard, grassland/lawn, trees, and barren) were relatively high, suggesting that the 3-m HYDICE data were adequate for classifying vegetation at this level.

The vegetation classification of the Cantonment 1-m data resulted in an overall accuracy of 87%. This is slightly higher than the Cantonment 3-m vegetation classification, primarily due to a smaller areal extent and the fact the fewer vegetation types were classified. For example, the smaller footprint of the Cantonment 1-m data did not include the grassland or cropland category as found in the larger Cantonment 3-m region. The only significant misclassification in this dataset was a medium-sized polygon of grassland that was misclassified as brush. This resulted in a user's accuracy for brush of 41%. Otherwise, the 1-m data was also adequate for classifying vegetation.

Finally, the Choke Point error analysis resulted in an overall accuracy of 85%. This vegetation classification was perhaps more complex than those for the Cantonment area due to the similarity and intermixture of vegetation types, such as shrubs/grass or sparse shrubs/grass. The use of reference data in this analysis was more complicated and required more interpretation due to the greater difficulty in discriminating vegetation classes. For example, it is more difficult to discriminate sparse shrubs/grass and shrubs/grass than grassland or an orchard. Regardless, the producer's and user's accuracy for each category was relatively high. Perhaps the greatest confusion of classes was between shrubs and sparse shrubs/grass, resulting in a user's accuracy of 50% for shrubs. However, even with this complication, the overall vegetation classification was still very successful.

6.0 Results and Discussion (Conclusions)

6.1 Data Processing

The memory and file storage demands of high-dimensional datasets such as the HYDICE imagery pose real challenges for applications such as landuse mapping. Reducing the dataset size prior to intensive processing steps, such as the registration process, could have saved significant time. For example, the selection of GCP could have been based on a single band (or a three-band RGB composite) extracted from the image cubes. Also, before selection of the control points, all of the frames for one flight line should have been combined. This would have eliminated the need for additional control points along the edges of adjacent frames. Band selection (by means of statistical approaches, or by evaluation by an image analyst) should be the first step in the data processing. Not only is it impractical to carry all of the spectral bands (e.g., all 210 HYDICE bands) through all of the processing, but results indicate that a subset of carefully chosen bands will provide comparable or better classification results than using the full hyperspectral bandset.

6.2 Classification Results

Classification of the Cantonment area afforded a comparison of classification results at different scales. These results indicate that 1-m resolution data may be significantly better at defining man-made structures such as buildings and roads. Additionally, individual trees, shrubs, and vehicles can be resolved at the 1-m ground resolution. However, for larger features such as fields, lawns, orchards, and areas of brushland, the 3-m resolution is equal or preferable to the 1-m data. The larger ground resolution has the effect of filtering out some of the small-scale detail that would be considered 'noise' in these larger scale features. For these broad, slowly changing natural features, the 3-m pixel image had several advantages over the 1-m images. For instance, the amount of storage and processing time was minimized. In some agricultural cases, the regular spacing of crops may produce a regular mixed pixel signature that can improve the differentiation of land classes. For instance, the regular spacing of trees in orchards may have helped produce a constant mixed pixel signature that allowed for the separation of orchards from natural trees. The classification results also suggest that for some scenes, a mixture of pixel sizes might be optimal. For instance, using the 3-m dataset, broad areas of homogenous orchards could be identified. Taking advantage of the homogeneity of tree spacing in orchards, it might be possible to estimate the tree spacing and other parameters from a limited sample of 1-m pixel images.

For the Cantonment study area, the use of spatial information was critical to refining classifications. Like pixels were grouped together into objects, and then the spatial characteristics of each object were used to classify that object. For instance, with shape information it was possible to identify whether a pixel (spectrally identified as asphalt) was part of an airport runway or part of a parking lot. Since the airport object (i.e., a group of connected asphalt pixels) was linear in nature and the right length for a runway, it was possible to differentiate it from asphalt pixels that were part of (broad and essentially square) parking lot objects. This improvement in classification is expected for a number of reasons.

First, the spatial and spectral information are relatively independent, and each brings new information to the classification challenge. Second, characterizing objects spatially allows the user to bring and codify an understanding of the problem (i.e., the physics of runway design) in a way that was not possible using only a spectral information.

Classification results from the Choke Point area demonstrated that the use of derived parameters, such as the NDVI, may be very useful. This is interesting because derived parameters can reduce a high-dimensional bandset (e.g., the 210 bands of HYDICE) to a single scaler; that is, reducing the 210*2 bytes required for each pixel to a 2 byte (integer) or 4 byte (floating point) value. Another result from the Choke Point classification was the demonstration of the utility of lidar for providing high-dimensional terrain information. Lidar was very useful for identifying trees and could have been used more fully to attribute the vegetation coverage. However, accurate co-registration of lidar and HYDICE imagery would be required to fully utilize the lidar data.

6.3 Vectorization Results

The construction of vectors from the raster classifications allow for additional analyses and attribution. For both the Cantonment and Choke Point areas, the surface drainage polygons and the transportation roads vectors were analyzed by intersection to determine bridges. Problems with determining bridges in this way were: 1) artifacts, because of adjacent roads and water, and 2) gaps where roads don't intersect bridges. The solution to the first problem is a test that compares the orientation of the bridge object to the waterway and roads (to eliminate cases where a road runs parallel to a waterway). The solution to the second problem is improved mapping of the canals or waterways; for example, where canals are run through enclosed pipe. Both of these solutions indicate the needs for the shape filters, described below.

The vectorization process also demonstrated the automatic generation of attribution that might be difficult for an image analyst to produce. For example, the size of objects (polygons) or the average elevation (ZV1, ZV2) of individual objects.

6.4 Classification Accuracy Assessment

The error assessments were quite encouraging. The overall classification accuracies at the coverage level were 93% for the 3-m Cantonment, 90% for the 1-m Cantonment (note that misclassification of canals in the 1-m imagery impacted the results), and 94% for the 3-m Choke Point classification. Error analyses were also performed at the attribute level for vegetation (based on the veg attribute). For the vegetation accuracy assessments, the results were encouraging as well: 83% for the 3-m Cantonment, 87% for the 1-m Cantonment, and 85% for the 3-m Choke Point.

6.5 Recommendations

Evaluation of the processing time for both the YTC site and the previous Fort Benning study (Steinmaus et al. 1997) indicates that image registration is the most time-consuming data processing step. The HYDICE and AVIRIS imagery are challenging because platform attitude data (pitch , roll, and yaw) are not available, so autoregistration of this type of airborne imagery may depend on the ability to automatically select control points. Testing of PNNL software for a single HYDICE frame resulted in a poor distribution of control points not suitable for triangulation.

The high cost of geo-referencing airborne imagery points to a real need for automated approaches. For future efforts, PNNL would like to collaborate with an industry partner such as ImageLinks (Melbourne, Florida) to develop geometric correction models for airborne imagery such as HYDICE.

The conversion of landcover information (surface material) to landuse is also a lengthy and challenging step. This process would be expedited by the use of shape filters that would provide characterization of individual objects. For example:

- length/width ratios
- object absolute width
- linearity (how straight or curved an object is)
- orientation.

Standard GIS packages do not include these tools but these characteristics must be calculated using extremely tedious methods within the GIS (for example, using the Grow or Erode processing).

7.0 References

Congalton, R. G. 1991. "A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data." *Remote Sensing of Environment*. Vol. 37:35-36.

Lundeen, T. F., P. G. Heasler, and G. M. Petrie. 1996. *Automatic Band Selection for Sensor Optimization.* PNNL-11360, Pacific Northwest National Laboratory, Richland, Washington.

Steinmaus, K. L., E. M. Perry, H. P. Foote, S. K. Wurstner, T. F. Lundeen, C. S. Kimball, D. E. Irwin, A. J. Stephan, and T. A. Warner. 1997. *Multisensor Landcover Classification for McKenna MOUT Ft. Benning, Georgia*. PNNL-11672, Pacific Northwest National Laboratory, Richland, Washington.

Appendix A

Yakima Training Center Landcover Classification
Final Product List and Attribute List

Yakima Training Center Landcover Classification Final Product List

	Product Description	Source ID	Filename	File Description	Size (MB)	Format	Coverage Area
Raw							
	HYDICE	1	crf31m005_bil.cub	run 31 frames 5-7	129	bil	Canton
	HYDICE	2	crf31m008_bil.cub	run 31 frames 8-9	129	bil	Canton
	HYDICE	3	crf31m016_bil.cub	run 31 frames 16-18	129	bil	Choke
	HYDICE	4	crf33m008_bil.cub	run 33 frames 8-10	129	bil	Canton
	HYDICE	5	crf33m011_bil.cub	run 33 frames 11-12	129	bil	Canton
	HYDICE	6	crf12m031_bil.cub	run 12 frames 31-34	129	bil	Choke
	HYDICE	7	crf14m053_bil.cub	run14 frames 53-56	129	bil	Choke
	HYDICE	8	crf16m074_bil.cub	run16 frames 74-77	129	bil	Choke
	HYDICE	9	crf22m048_bil.cub	run 22 frames 48-50	129	bil	Choke
	HYDICE	10	crf22m051_bil.cub	run 22 frames 51-52	129	bil	Choke
	HYDICE	11	crf36m048_bil.cub	run 36 frames 48-50	129	bil	Choke
	HYDICE	12	crf36m051_bil.cub	run 36 frames 51-52	129	bil	Choke
	HYDICE	13	crf06m005_bil.cub	run 6 frames 5-7	129	bil	Canton
	HYDICE	14	crf06m008_bil.cub	run 6 frames 8-10	129	bil	Canton
	HYDICE	15	crf06m002_bil.cub	run 6 frames 2-4	129	bil	Canton
	HYDICE	16	crf08m005_bil.cub	run 8 frames 5-7	129	bil	Canton
	HYDICE	17	crf08m008_bil.cub	run 8 frames 8-10	129	bil	Canton
	HYDICE	18	crf08m002_bil.cub	run 8 frames 2-4	129	bil	Canton
	AVIRIS	19	PG01235-1.bil_image	frame 1235	141	bil	Canton/Choke
	AVIRIS	20	PG01236-1.bil	frame 1236	141	bil	Canton/Choke
	Daedalus	21	daedalus_r0	flightline 0	37	bil	Canton
	Daedalus	22	daedalus_r2	flightline 2	36	bil	Canton
Registered/ Normalized							
	HYDICE	24	hydice_1m_mosaic.img	registered hydice 1m mosaic	124	img	Canton
	HYDICE	25	hydice_3m_cantonement_mosaic.img	registered 3m cantonement mosaic	107	img	Canton
	HYDICE	26	hydice_3m_choke_mosaic.img	registered 3m chokepoint mosaic	91	img	Choke
	AVIRIS	27	aviris_run2_scene4_tri.img	scene 5 registered	167	img	Canton/Choke
	AVIRIS	27b	aviris_run2_scene5_tri.img	scene 4 registered	185	img	Canton/Choke
	Daedalus	28	daed_1m_mosaic.img	registered daedalus mosaic	18	img	Canton
Classifications for Cantonement Area							
raster (3m)							
	Surface Drainage	29	water_3m.img	Surface Drainage	1	img	Canton
	Transportation Parking Areas	30	park_3m.img	Transportation Parking Areas	1	img	Canton
	Vegetation Area	31	veg_3m.img	Vegetation Area	1	img	Canton

Yakima Training Center Landcover Classification Final Product List

	Product Description	Source ID	Filename	File Description	Size (MB)	Format	Coverage Area
vector (3m)							
	Surface Drainage	32	water_3m.e00	Surface Drainage	<1	e00	Canton
	Transportation Bridges	33	bridge_3m.e00	Transportation Bridges	<1	e00	Canton
	Transportation Roads	34	roads_3m.e00	Transportation Roads	<1	e00	Canton
	Transportation Parking Areas	35	park_3m.e00	Transportation Parking Areas	<1	e01	Canton
	Vegetation Area	36	veg_3m.e00	Vegetation Area	14	e00	Canton
raster (1m)						img	Canton
	Population Buildings	37	bldg_1m.img	Population Buildings	2	img	Canton
	Surface Drainage	38	water_1m.img	Surface Drainage	2	img	Canton
	Transportation Parking Areas	39	park_1m.img	Transportation Parking Areas	1	img	Canton
	Vegetation Area	40	veg_1m.img	Vegetation Area	2	img	Canton
	Vegetation trees point	41	tree_1m.img	Vegetation trees point	2	img	Canton
vector (1m)							
	Population Buildings	42	bldg_1m.e00	Population Buildings	1	e00	Canton
	Surface Drainage	43	water_1m.e00	Surface Drainage	<1	e00	Canton
	Transportation Bridges	44	bridge_1m.e00	Transportation Bridges	<1	e00	Canton
	Transportation Roads	45	roads_1m.e00	Transportation Roads	<1	e00	Canton
	Transportation Parking Areas	46	park_1m.img	Transportation Parking Areas	1	e01	Canton
	Vegetation Area	47	veg_1m.e00	Vegetation Area	7	e00	Canton
	Vegetation trees point	48	tree_1m-pt.e00	Vegetation trees point	1	e00	Canton
Classifications for Chokepoint Area							
raster							
	Population Buildings	49	chkpt_bldg.img	Population Buildings	2	img	Choke
	Poulation Obstacles	50	chkpt_obstacle.img	Poulation Obstacles	6	img	Choke
	Surface Drainage	51	chkpt_water.img	Surface Drainage	7	img	Choke
	Vegetation Area	52	chkpt_veg.img	Vegetation Area	2	img	Choke
	Vegetation trees point	53	chkpt_tree_pt.img	Vegetation trees point	3	img	Choke
vector							
	Population Buildings	54	chkpt_bldg.e00	Population Buildings	<1	e00	Choke
	Poulation Obstacles	55	chkpt_obstac.e00	Poulation Obstacles	<1	e00	Choke
	Surface Drainage	56	chkpt_water.e00	Surface Drainage	<1	e00	Choke
	Transportation Bridges	57	chkpt_bridge.e00	Transportation Bridges	<1	e00	Choke
	Transportation Roads	58	chkpt_roads.e00	Transportation Roads	<1	e00	Choke
	Vegetation Area	59	chkpt_veg.e00	Vegetation Area	9	e00	Choke
	Vegetation trees point	60	chkpt_tre-pt.e00	Vegetation trees point	<1	e00	Choke

Yakima Training Center Landcover Classification Final Product List

	Product Description	Source ID	Filename	File Description	Size (MB)	Format	Coverage Area
Ancillary Data							
	Orthophoto Basemap	23	mosaic_subset_central_wgs84.img	Orthophoto Basemap	1505	img	Canton/Choke
	ALM	61	ytc_choke_pt_1.5m_2200x2800_flt.img	ALM data	25	img	Canton
	AVIRIS	62	run2_scene4.dat	GCP File	<1	txt	Canton
	AVIRIS	63	run2_scene5.dat	GCP File	<1	txt	Choke
	Daedalus	64	ytc_daed0.dat	GCP File	<1	txt	Canton
	Daedalus	65	ytc_daedalus_run2.dat	GCP File	<1	txt	Canton
	HYDICE	66	run31_frame5-7.dat	GCP File	<1	txt	Canton
	HYDICE	67	run31_frame8-9_update.dat	GCP File	<1	txt	Canton
	HYDICE	68	run33_frame8-10_update.dat	GCP File	<1	txt	Canton
	HYDICE	69	run33_frame11-12_all.dat	GCP File	<1	txt	Canton
	HYDICE	70	run06_frame2-4.dat	GCP File	<1	txt	Canton
	HYDICE	71	run06_frame5-7_update.dat	GCP File	<1	txt	Canton
	HYDICE	72	run06_frame8-10_update.dat	GCP File	<1	txt	Canton
	HYDICE	73	run08_frame2-4_update.dat	GCP File	<1	txt	Canton
	HYDICE	74	run08_f5-7_update.dat	GCP File	<1	txt	Canton
	HYDICE	75	run08_frame8-10_update.dat	GCP File	<1	txt	Canton
	HYDICE	76	run12_all.dat	GCP File	<1	txt	Choke
	HYDICE	77	run14_update.dat	GCP File	<1	txt	Choke
	HYDICE	78	run16_frame74-77.dat	GCP File	<1	txt	Choke
	HYDICE	79	run22_frame48-50_all.dat	GCP File	<1	txt	Choke
	HYDICE	80	run22_frame51-52_update.dat	GCP File	<1	txt	Choke
	HYDICE	81	run36_frame48-50_update.dat	GCP File	<1	txt	Choke
	HYDICE	82	run36_frame51-52_all.dat	GCP File	<1	txt	Choke
	AML	83	add_stat_attributes.aml	AML	<1	txt	Canton/Choke
	AML	84	add_stat_attributes_points.aml	AML	<1	txt	Canton/Choke
	AML	85	arc_to_export.aml	AML	<1	txt	Canton/Choke
	AML	86	convert_trees.aml	AML	<1	txt	Canton/Choke
	AML	87	mak_bridges.aml	AML	<1	txt	Canton/Choke
	AML	88	vectorize.aml	AML	<1	txt	Canton/Choke
	Control file	89	bridge_1m.ctl	Control file	<1	txt	Canton
	Control file	90	bridge_3m.ctl	Control file	<1	txt	Canton/Choke
	Control file	91	bridge_chkpt.ctl	Control file	<1	txt	Choke
	Control file	92	elevations_1m.ctl	Control file	<1	txt	Canton
	Control file	93	elevations_3m.ctl	Control file	<1	txt	Canton/Choke
	Control file	94	elevations_chkpt-bldg.ctl	Control file	<1	txt	Choke
	Control file	95	elevations_chkpt.ctl	Control file	<1	txt	Choke
	Control file	96	export.ctl	Control file	<1	txt	Canton/Choke
	Control file	97	export_bridges.ctl	Control file	<1	txt	Canton/Choke
	Control file	98	slopes_chkpt.ctl	Control file	<1	txt	Canton/Choke
	Control file	99	tree_hgt_chkpt.ctl	Control file	<1	txt	Canton/Choke
	Control file	100	trees.ctl	Control file	<1	txt	Canton/Choke
	Control file	101	trees_elev.ctl	Control file	<1	txt	Canton/Choke

Yakima Training Center Landcover Classification Final Product List

	Product Description	Source ID	Filename	File Description	Size (MB)	Format	Coverage Area
	Control file	102	vectorize.ctl	Control file	<1	txt	Canton/Choke
	Lookup table	103	bldg.lut	Lookup table	<1	txt	Canton/Choke
	Lookup table	104	chpt_bldg.lut	Lookup table	<1	txt	Choke
	Lookup table	105	bridge.lut	Lookup table	<1	txt	Canton/Choke
	Lookup table	106	obstacle.lut	Lookup table	<1	txt	Canton/Choke
	Lookup table	107	parking.lut	Lookup table	<1	txt	Canton/Choke
	Lookup table	108	roads.lut	Lookup table	<1	txt	Canton/Choke
	Lookup table	109	tree_pt.lut	Lookup table	<1	txt	Canton/Choke
	Lookup table	110	veg.lut	Lookup table	<1	txt	Canton/Choke
	Lookup table	111	water.lut	Lookup table	<1	txt	Canton/Choke

Yakima Training Center Landcover Classification Final Attribute Summary Table

Yakima Training Center Hyperspectral Landcover Classification, Attributes			
Landcover Class	Attributes	FACC Code	Classification
bridge	angle of orientation	AOO	1-m/3-m Cantonment, 3-m Choke Point
bridge	bridge opening type	BOT	1-m/3-m Cantonment, 3-m Choke Point
bridge	existence category	EXS	1-m/3-m Cantonment, 3-m Choke Point
bridge	height	HGT	1-m/3-m Cantonment, 3-m Choke Point
bridge	length	LEN	1-m/3-m Cantonment, 3-m Choke Point
bridge	overhead clearance category	OHC	1-m/3-m Cantonment, 3-m Choke Point
bridge	transportation use category	TUC	1-m/3-m Cantonment, 3-m Choke Point
bridge	width	WID	1-m/3-m Cantonment, 3-m Choke Point
bridge	lowest elevaton value	ZV1	1-m/3-m Cantonment, 3-m Choke Point
bridge	highest elevation value	ZV2	1-m/3-m Cantonment, 3-m Choke Point
building	*building function category*	BFC	1-m Cantonment, 3-m Choke Point
building	existence category	EXS	1-m Cantonment, 3-m Choke Point
building	height	HGT	1-m Cantonment, 3-m Choke Point
building	height	HGT	1-m Cantonment, 3-m Choke Point
building	surface material category	SMC	1-m Cantonment, 3-m Choke Point
building	structure shape of roof	SSR	1-m Cantonment, 3-m Choke Point
building	lowest elevation value	ZV1	1-m Cantonment, 3-m Choke Point
building	highest elevation value	ZV2	1-m Cantonment, 3-m Choke Point
obstacle	area coverage attribute	ARA	3-m Choke Point
obstacle	fence type indicator	FTI	3-m Choke Point
obstacle	material composition category	MCC	3-m Choke Point
obstacle	obstacle height/depth category	OHD	3-m Choke Point
obstacle	predominant feature height	PFH	3-m Choke Point
obstacle	gradient/slope	SGC	3-m Choke Point
road	existence category	EXS	1-m/3-m Cantonment, 3-m Choke Point
road	location category	LOC	1-m/3-m Cantonment, 3-m Choke Point
road	track/lane number	LTN	1-m/3-m Cantonment, 3-m Choke Point
road	road/runway surface type	RST	1-m/3-m Cantonment, 3-m Choke Point

Yakima Training Center Landcover Classification Final Attribute Summary Table

Yakima Training Center Hyperspectral Landcover Classification, Attributes			
Landcover Class	Attributes	FACC Code	Classification
road	gradient/slope	SGC	1-m/3-m Cantonment, 3-m Choke Point
road	surface material category	SMC	1-m/3-m Cantonment, 3-m Choke Point
road	usage	USE	1-m/3-m Cantonment, 3-m Choke Point
road	width	WID	1-m/3-m Cantonment, 3-m Choke Point
road	weather type category	WTC	1-m/3-m Cantonment, 3-m Choke Point
road	lowest elevation value	ZV1	1-m/3-m Cantonment, 3-m Choke Point
road	highest elevation value	ZV2	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	bank vegetation left	BVL	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	bank vegetation right	BVR	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	cover drain attribute	CDA	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	depth below surface level	DEP	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	density measure	DMT	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	depth of water (1)	DW1	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	gap width range (1)	GW1	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	hydrological form category	HFC	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	hydrological category	HYC	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	stem diameter size	SDS	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	tidal/non-tidal category	TID	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	lowest elevation value	ZV1	1-m/3-m Cantonment, 3-m Choke Point
surface drainage	highest elevation value	ZV2	1-m/3-m Cantonment, 3-m Choke Point
surface material	area coverage attribute	ARA	1-m/3-m Cantonment, 3-m Choke Point
surface material	bank height left	BHL	1-m/3-m Cantonment, 3-m Choke Point
surface material	bank height right	BHR	1-m/3-m Cantonment, 3-m Choke Point
surface material	bottom material composition	BMC	1-m/3-m Cantonment, 3-m Choke Point
surface material	slope gradient left	SL1	1-m/3-m Cantonment, 3-m Choke Point
surface material	slope gradient right	SL2	1-m/3-m Cantonment, 3-m Choke Point
surface material	water velocity average (1)	WV1	1-m/3-m Cantonment, 3-m Choke Point
surface material	water depth mean (seasonal high)	YDH	1-m/3-m Cantonment, 3-m Choke Point

Yakima Training Center Landcover Classification Final Attribute Summary Table

Yakima Training Center Hyperspectral Landcover Classification, Attributes			
Landcover Class	**Attributes**	**FACC Code**	**Classification**
surface material	water depth mean (seasonal low)	YDL	1-m/3-m Cantonment, 3-m Choke Point
tree (point feature)	feature configuration	FCO	1-m Cantonment, 3-m Choke Point
tree (point feature)	stem diameter size range (1)	SD1	1-m Cantonment, 3-m Choke Point
tree (point feature)	stem diameter size range (2)	SD2	1-m Cantonment, 3-m Choke Point
tree (point feature)	vegetation characteristic	VEG	1-m Cantonment, 3-m Choke Point
tree (point feature)	predominant vegetation height range (1)	VH1	1-m Cantonment, 3-m Choke Point
tree (point feature)	lowest elevation value	ZV1	1-m Cantonment, 3-m Choke Point
tree (point feature)	highest elevation value	ZV2	1-m Cantonment, 3-m Choke Point
vegetation	area coverage attribute	ARA	1-m/3-m Cantonment, 3-m Choke Point
vegetation	brush/undergrowth density code	BUD	1-m/3-m Cantonment, 3-m Choke Point
vegetation	*height*	HGT	1-m/3-m Cantonment, 3-m Choke Point
vegetation	stem diameter size range (1)	SD1	1-m/3-m Cantonment, 3-m Choke Point
vegetation	stem diameter size range (2)	SD2	1-m/3-m Cantonment, 3-m Choke Point
vegetation	summer tree cover density code	STR	1-m/3-m Cantonment, 3-m Choke Point
vegetation	tree type category	TRE	1-m/3-m Cantonment, 3-m Choke Point
vegetation	tree spacing range (1)	TS2	1-m/3-m Cantonment, 3-m Choke Point
vegetation	vegetation characteristic	VEG	1-m/3-m Cantonment, 3-m Choke Point
vegetation	predominant vegetation height range (1)	VH1	1-m/3-m Cantonment, 3-m Choke Point
vegetation	winter tree cover density code	WTR	1-m/3-m Cantonment, 3-m Choke Point
vegetation	lowest elevation value	ZV1	1-m/3-m Cantonment, 3-m Choke Point
vegetation	highest elevation value	ZV2	1-m/3-m Cantonment, 3-m Choke Point

Appendix B

Example Metadata

Appendix B

Example Metadata

```
Identification_Information:
      Citation:
            Citation_Information:
                  Originator: Naval Research Laboratory
                  Originator: Pacific Northwest National Laboratory (PNNL)
                  Publication_Date: Unknown
                  Publication_Time: Unknown
                  Title: HYDICE 1-Meter Raw Imagery for the Yakima Training
                  Center, WA
                  Geospatial_Data_Presentation_Form: remote-sensing image
      Description:
            Abstract:
                  The data contained in this data set are derived from the
                  Hyperspectral Digital Imagery Collection Experiment
                  (HYDICE) sensor,which was flown during July of 1997. The
                  HYDICE sensor is a pushbroom system, generating image cubes
                  with 210 bands (from 400 to 2500 nm), and a 320 pixel swath
                  width.  The cell size of the data is approximately 1-meter.
                                          ---
                  This data set contains coverage of the cantonement area
                  of the Yakima Training Center.  The cantonement area
                  contains many buildings such as the barracks and officer's
                  club.  Coverage also includes adjacent agricultural areas
                  which fall  outside the Yakima Training Center boundary.
                  ---
                  The imagery in this data set is referred to as "raw" in the
                  sense that no geometric correction has been performed.
                  Therefore, the defined spatial domain is only an estimate.
                  It should be mentioned, however, that HYDICE post-flight
                  processing was conducted including dark current correction,
                  spectral and radiometric calibration, conversion to
                  radiance, and replacement of bad detector elements.
            Purpose:
                  This data set was originally collected at the YTC to
                  evaluate the usability of hyperspectral imagery for remote
                  environmental monitoring.
            Supplemental_Information:
                  A detailed description of this data set and the process
                  steps to create it are in the document entitled, PNNL 11871
                  "Hyperspectral Landcover Classification for Yakima Training
                  Center, Yakima, WA," 1998. Additional information about the
                  HYDICE sensor can be found at http;//rsd-
                  www.nrl.navy.mil/hydice/
      Time_Period_of_Content:
```

```
        Time_Period_Information:
              Single_Date/Time:
                    Calendar_Date: 19960712
        Currentness_Reference: Ground Condition
Status:
        Progress: Complete
        Maintenance_and_Update_Frequency: None planned
Spatial_Domain:
        Bounding_Coordinates:
              West_Bounding_Coordinate: -120.477000
              East_Bounding_Coordinate: -120.441000
              North_Bounding_Coordinate: +46.677300
              South_Bounding_Coordinate: +46.672200
Keywords:
        Theme:
              Theme_Keyword_Thesaurus: None
              Theme_Keyword: HYDICE
              Theme_Keyword: Hyperspectral
              Theme_Keyword: Army
              Theme_Keyword: NRL
              Theme_Keyword: DoD
        Place:
              Place_Keyword_Thesaurus: None
              Place_Keyword: Yakima Training Center
              Place_Keyword: Naval Research Laboratory
Access_Constraints: Official Project Use Only.
Use_Constraints: Official Project Use Only.
Point_of_Contact:
        Contact_Information:
              Contact_Person_Primary:
                    Contact_Person: Mr. Mike O'Brien
                    Contact_Organization: National Imagery and Mapping
                    Agency Terrain Modeling Project Office
              Contact_Position: Physical Scientist
              Contact_Address:
                    Address_Type: mailing address
                    Address: 12310 Sunrise Valley Drive
                    City: Reston
                    State_or_Province: VA
                    Postal_Code: 20191-3449
                    Country: USA
              Contact_Voice_Telephone: (703) 262-4578
Native_Data_Set_Environment:
              Presented below are the file names and corresponding titles
              for the data contained in this data set.
              ---
              crf06m008_bil.cub - HYDICE 1 m Raw Imagery for the
              Cantonement Area at the Yakima Training Center, WA (run 6
              frames 8-10)
              ---
              crf06m002_bil.cub - HYDICE 1 m Raw Imagery for the
              Cantonement Area at the Yakima Training Center, WA (run 31
              frames 2-4)
              ---
```

crf08m005_bil.cub - HYDICE 1 m Raw Imagery for the Cantonement Area at the Yakima Training Center, WA (run 8 frames 5-7)

---

crf08m008_bil.cub - HYDICE 1 m Raw Imagery for the Cantonement Area at the Yakima Training Center, WA (run 31 frames 8-10)

---

crf08m002_bil.cub - HYDICE 1 m Raw Imagery for the Cantonement Area at the Yakima Training Center, WA (run 31 frames 2-4)

Data_Quality_Information:
    Logical_Consistency_Report:
        This data set was derived from raw raster imagery. Therefore, no tests for graphical relationships or topology were performed.

Completeness_Report: Raw data.
    Lineage:
        Process_Step:
            Process_Description: Raw data.
            Process_Date: 19960712

Spatial_Data_Organization_Information:
    Direct_Spatial_Reference_Method: Raster
    Raster_Object_Information:
        Raster_Object_Type: Pixel
        Row_Count: 320
        Column_Count: 320 (per frame, some scenes have multiple frames)

Metadata_Reference_Information:
    Metadata_Date: 19971200
    Metadata_Contact:
        Contact_Information:
            Contact_Person_Primary:
                Contact_Person: Karen Steinmaus
                Contact_Organization: Pacific Northwest National Laboratory, Remote Sensing Group
            Contact_Position: Technical Group Manager
            Contact_Address:
                Address_Type: mailing address
                Address: P.O. Box 999, MS K9-55
                City: Richland
                State_or_Province: WA
                Postal_Code: 99352
                Country: USA
            Contact_Voice_Telephone: (509) 372-6288
    Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
    Metadata_Standard_Version: 19940608

```
Identification_Information:
      Citation:
            Citation_Information:
                  Originator: Pacific Northwest National Laboratory
                  Publication_Date: Unknown
                  Publication_Time: Unknown
                  Title: Yakima Training Center Chokepoint Classification
                  Geospatial_Data_Presentation_Form: map
      Description:
            Abstract:
                  The raster data contained in this data set entitled "Yakima
                  Training Center Chokepoint Classification" were developed
                  by the Pacific Northwest National Laboratory (PNNL) for the
                  National Imagery and Mapping Agency (NIMA), Terrain
                  Modeling Project Office (TMPO).  The spatial domain of this
                  data set is an area referred to as the "chokepoint"
                  (approximately 10 km east of the Cantonment Area) at the
                  Yakima Training Center, Yakima, WA.  Initially, the
                  landcover data were derived from a classified HYDICE 3-
                  Meter image. The following NIMA coverages--population
                  buildings, population obstacles, transportation roads,
                  surface drainage, vegetation area, and vegetation tree
                  points--are individually derived from specific spatial
                  models.
            Purpose:
                  The purpose of this data set is to evaluate the degree to
                  which automatic multisensor classification can be used to
                  derive landuse based on the NIMA Feature and Attribute
                  Coding Catalog (FACC).
            Supplemental_Information:
                  A detailed description of this data set and the process
                  steps to create it are in the document entitled, PNNL 11871
                  "Hyperspectral Landcover Classification for Yakima Training
                  Center, Yakima, WA," 1998.
      Time_Period_of_Content:
            Time_Period_Information:
                  Single_Date/Time:
                        Calendar_Date: 19960712
            Currentness_Reference: Ground Condition
      Status:
            Progress: Complete
            Maintenance_and_Update_Frequency: None planned
      Spatial_Domain:
            Bounding_Coordinates:
                  West_Bounding_Coordinate: -120.359977
                  East_Bounding_Coordinate: -120.309186
                  North_Bounding_Coordinate: +46.706194
                  South_Bounding_Coordinate: +46.674716
      Keywords:
            Theme:
                  Theme_Keyword_Thesaurus: None
                  Theme_Keyword: HYDICE
                  Theme_Keyword: Hyperspectral
                  Theme_Keyword: Chokepoint
```

Theme_Keyword: Army
Theme_Keyword: Yakima Training Center
Theme_Keyword: NRL
Theme_Keyword: DoD
Access_Constraints: Official Project Use Only
Use_Constraints: Official Project Use Only
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Mike O'Brien
Contact_Organization: National Imagery and Mapping Agency, Terrain Modeling Project Office (TMPO)
Contact_Position: Physical Scientist
Contact_Address:
Address_Type: mailing and physical address
Address: 12310 Sunrise Valley Drive
City: Reston
State_or_Province: VA
Postal_Code: 20191-3449
Country: USA
Contact_Voice_Telephone: (703) 262-4578
Native_Data_Set_Environment:
This data set was created using ERDAS Imagine 8.3 on a UNIX operating system. Below are the files names and corresponding titles for the data contained in this data set.
---
chkpt_bldg.img - Population Buildings Landcover Map for the Chokepoint Area at the Yakima Training Center, WA
---

chkpt_obstacle.img - Population Obstacles Landcover Map for the Chokepoint Area at the Yakima Training Center, WA

---

chkpt_roads - Transportation Dirt Roads for the Chokepoint Area at the Yakima Training Center, WA

---

chkpt_water.img - Surface Drainage Landcover Map for the Chokepoint Area at the Yakima Training Center, WA
---
chkpt_veg..img - Vegetation Area Landcover Map for the Chokepoint Area at the Yakima Training Center, WA
---
chkpt_tree_pt.img - Vegetation Trees Landcover Map for the Chokepoint Area at the Yakima Training Center, WA
Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report:

An error analysis of the final landuse classification at the NIMA coverage level yielded an overall classification accuracy of no less than 85%.

Logical_Consistency_Report:

As this map was derived from a raster image, no tests for graphic relationships or topology were performed.

Completeness_Report:

Fewer than 5% of the pixels in the footprint of the data set were not classified. Because the coverages (surface drainage, vegetation, etc.) were each generated from the same spectral classification but using separate spatial models, there are some missing pixels in the footprint of the data set. The missing pixels are generally a result of mixed pixels that were not easily classified or isolated patches of 2 or 3 pixels.

Positional_Accuracy:

Horizontal_Positional_Accuracy:

Horizontal_Positional_Accuracy_Report:

Because this data set is based on the file called "HYDICE 3-Meter Registered/Normalized Mosaic for the Chokepoint Area at the Yakima Training Center, WA," its Horizontal Positional Accuracy can be referenced in that file's corresponding metadata.

Lineage:

Source_Information:

Source_Citation:

Citation_Information:

Originator: Pacific Northwest National Laboratory

Publication_Date: Unknown

Publication_Time: Unknown

Title: HYDICE 3-Meter Registered/Normalized Mosaic for the Chokepoint Area at the Yakima Training Center, WA

Geospatial_Data_Presentation_Form: remote-sensing image

Type_of_Source_Media: Digital File

Source_Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 19960712

Source_Currentness_Reference: Ground Condition

Source_Citation_Abbreviation: None

Source_Contribution:

The information contributed by the source to the data set is a HYDICE 3-Meter Registered/Normalized Mosaic for the Cantonment Area at the Yakima Training Center.

Process_Step:

Process_Description:

A detailed description of the process steps to create the data in this data set are found in the document entitled "Hyperspectral Landcover Classification for the Yakima Training Center, Yakima, Washington." The following is a brief summary of these steps.

Reduction of 210 HYDICE bands to 44 representative bands based on expert judgement.

Unsupervised and supervised classifications to determine optimal landcover classification.

Spatial, multisource modeling to derive landuse categories from landcover. This step involves integration of supplementary data sets, such as terrain data, along with spatial modeling techniques.

```
                Process_Date: 19980100
Spatial_Data_Organization_Information:
      Direct_Spatial_Reference_Method: Raster
      Raster_Object_Information:
            Raster_Object_Type: Pixel
            Row_Count: 1123
            Column_Count: 1335
Spatial_Reference_Information:
      Horizontal_Coordinate_System_Definition:
            Planar:
                  Grid_Coordinate_System:
                        Grid_Coordinate_System_Name: Universal Transverse
                        Mercator
                        Universal_Transverse_Mercator:
                              UTM_Zone_Number: 10 North
                              Transverse_Mercator:
                                    Scale_Factor_at_Central_Meridian: .9996
                                    Longitude_of_Central_Meridian: -123.000000
                                    Latitude_of_Projection_Origin: +00.000000
                                    False_Easting: 500,000
                                    False_Northing: 0
                  Planar_Coordinate_Information:
                        Planar_Coordinate_Encoding_Method: coordinate pair
                        Coordinate_Representation:
                              Abscissa_Resolution: .61
                              Ordinate_Resolution: .61
                        Planar_Distance_Units: Meters
Entity_and_Attribute_Information:
      Overview_Description:
            Entity_and_Attribute_Overview:
                  A detailed description of the attribute information of this
                  data set are found in the document entitled "Hyperspectral
                  Landcover Classification for the Yakima Training Center,
                  Yakima, Washington."
            Entity_and_Attribute_Detail_Citation: None
Metadata_Reference_Information:
      Metadata_Date: 19980300
      Metadata_Contact:
            Contact_Information:
                  Contact_Person_Primary:
                        Contact_Person: Karen Steinmaus
```

```
                Contact_Organization: Pacific Northwest National
                Laboratory, Remote Sensing Group
            Contact_Position: Technical Group Manager
            Contact_Address:
                Address_Type: mailing address
                Address: P.O. Box 999, MS K9-55
                City: Richland
                State_or_Province: WA
                Postal_Code: 99352
                Country: USA
            Contact_Voice_Telephone: (509) 372-6288
    Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial
    Metadata
    Metadata_Standard_Version: 19940608
Identification_Information:
    Citation:
        Citation_Information:
            Originator: Pacific Northwest National Laboratory
            Publication_Date: Unknown
            Publication_Time: Unknown
            Title: Yakima Training Center Cantonment Area 1-Meter
            Vector Maps
            Geospatial_Data_Presentation_Form: map
    Description:
        Abstract:
            The vector data contained in this data set entitled "Yakima
            Training Center Cantonment Area 1-Meter Vector Maps" were
            developed by the Pacific Northwest National Laboratory
            (PNNL) for the National Imagery and Mapping Agency (NIMA),
            Terrain Modeling Project Office (TMPO). The spatial domain
            of this data set is the cantonment area of the Yakima
            Training Center, Yakima, WA.  These vector coverages were
            generated from the raster files contained in the metadata
            file "Yakima Training Center Cantonment Area 1-Meter
            Classification."  Polygon coverages (population buldings,
            surface drainage, transportation parking areas, and
            vegetation areas) were generated from the raster data using
            the Arc/Info GRIDPOLY command.  Line coverages
            (transportation roads) were generated from the raster data
            using the Arc/Info ARCSCAN module. Point coverage
            (vegetation tree points) was created by locating the
            centroid of the vectorized polygons.  One additional
            coverage, (transportation bridges) was created by
            intersecting the transportation roads and surface drainage
            coverages.
        Purpose:
            The purpose of this data set is to evaluate the degree to
            which automatic multisensor classification can be used to
            derive landuse based on the NIMA Feature and Attribute
            Coding Catalog (FACC) .
        Supplemental_Information:
            A detailed description of this data set and the process
            steps to create it are in the document entitled, PNNL 11871
```

```
        "Hyperspectral Landcover Classification for Yakima Training
        Center, Yakima, WA," 1998.

Time_Period_of_Content:
    Time_Period_Information:
        Single_Date/Time:
            Calendar_Date: 19960712
    Currentness_Reference: Ground Condition
Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: None planned
Spatial_Domain:
    Bounding_Coordinates:
        West_Bounding_Coordinate: -120.476588
        East_Bounding_Coordinate: -120.441422
        North_Bounding_Coordinate: +46.677327
        South_Bounding_Coordinate: +46.672216
Keywords:
    Theme:
        Theme_Keyword_Thesaurus: None
        Theme_Keyword: HYDICE
        Theme_Keyword: Hyperspectral
        Theme_Keyword: Cantonment
        Theme_Keyword: Classification
        Theme_Keyword: Army
        Theme_Keyword: Yakima Training Center
        Theme_Keyword: NRL
        Theme_Keyword: DoD
        Theme_Keyword: Land Use
Access_Constraints: Official Project Use Only
Use_Constraints: Official Project Use Only
Point_of_Contact:
    Contact_Information:
        Contact_Person_Primary:
            Contact_Person: Mike O'Brien
            Contact_Organization: National Imagery and Mapping
            Agency, Terrain Modeling Project Office (TMPO)
        Contact_Position: Physical Scientist
        Contact_Address:
            Address_Type: mailing and physical address
            Address: 12310 Sunrise Valley Drive
            City: Reston
            State_or_Province: VA
            Postal_Code: 20191-3440
            Country: USA
        Contact_Voice_Telephone: (703) 262-4578
Native_Data_Set_Environment:
        This data set was created using ESRI Arc/Info version 7.1.2
        on a UNIX operating system.  All files in this data set are
        in the Arc/Info version 7.1.2 interchange format. Below are
        the files names and corresponding titles for the data
        contained in this data set.
        ---
```

bldg_1m.e00 - Population Buildings Vector Map for the Cantonment Area at the Yakima Training Center, WA
---
water_1m.e00 - Surface Drainage Vector Map for the Cantonment Area at the Yakima Training Center, WA
---
bridge_1m.e00 - Transportation Bridges Vector Map for the Cantonment Area at the Yakima Training Center, WA
---
roads_1m.e00 - Transportation Roads Vector Map for the Cantonment Area at the Yakima Training Center
---
park_1m.e00 - Transportation Parking Area Vector Map for the Cantonment Area at the Yakima Training Center, WA
---
veg_1m.e00 - Vegetation Area Vector Map for the Cantonment Area at the Yakima Training Center, WA
---
tree_1m-pt.e00 - Vegetation Trees Point Vector Map for the Cantonment Area at the Yakima Training Center, WA

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report:
An error analysis of the final landuse classification at the NIMA coverage level yielded an overall classification accuracy of no less than 85%.
Logical_Consistency_Report:
As this map was derived from a raster image, no tests for graphical relationships or topology were performed.
Completeness_Report:
All classified areas contained in the metadata file "Yakima Training Center Cantonment Area 1-Meter Classification" were vectorized. Fewer than 5% of the pixels in the footprint of that data set were not classified and therefore were not converted to vectors.
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
Because this data set is based on the file called "HYDICE 1-Meter Registered/Normalized Mosaic for the Cantonment Area at the Yakima Training Center, WA," its Horizontal Positional Accuracy can be referenced in that file's corresponding metadata.
Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Originator: Pacific Northwest National Laboratory
Publication_Date: Unknown
Publication_Time: Unknown
Title: Yakima Training Center Cantonment Area 1-Meter Classification
Geospatial_Data_Presentation_Form: map

Type_of_Source_Media: Digital File
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 19960712
Source_Currentness_Reference: Ground Condition
Source_Citation_Abbreviation: None
Source_Contribution:
The raster source data provided the basis for the vector coverages.

Process_Step:
Process_Description:
A detailed description of the process steps to create the data in this data set are found in the document entitled "Hyperspectral Landcover Classification for the Yakima Training Center, Yakima, Washington." The following is a brief summary of these steps.

ERDAS Imagine 8.3 raster files were imported into Arc/Info version 7.1.2 using the IMAGEGRID command
---
Polygon coverages (population buldings, surface drainage, transportation parking areas, and vegetation areas) were generated from the raster data using the Arc/Info GRIDPOLY command. Attributes were transfered from the raster image to the polygons using an aml that reads an Imagine Export File and assigns attributes to the polygons.

Line coverages (transportation roads) were generated from the raster data using the Arc/Info ARCSCAN module. Attributes were subsequently assigned to the vectors.

Point coverage (vegetation tree points) was created by locating the centroid of the vectorized polygons.

One additional coverage (transportation bridges) was created by intersecting the transportation roads and surface drainage coverages.

Process_Date: 19980200

Spatial_Data_Organization_Information:

Direct_Spatial_Reference_Method: Vector
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: Universal Transverse Mercator
Universal_Transverse_Mercator:

```
                              UTM_Zone_Number: 10 North
                              Transverse_Mercator:
                                    Scale_Factor_at_Central_Meridian: .9996
                                    Longitude_of_Central_Meridian: -123.000000
                                    Latitude_of_Projection_Origin: +00.000000
                                    False_Easting: 500,000
                                    False_Northing: 0
                  Planar_Coordinate_Information:
                        Planar_Coordinate_Encoding_Method: coordinate pair
                        Coordinate_Representation:
                              Abscissa_Resolution: .61
                              Ordinate_Resolution: .61
                        Planar_Distance_Units: Meters
Entity_and_Attribute_Information:
      Overview_Description:
            Entity_and_Attribute_Overview:
                  A detailed description of the attribute information of this
                  data set are found in the document entitled "Hyperspectral
                  Landcover Classification for the Yakima Training Center,
                  Yakima, Washington."
            Entity_and_Attribute_Detail_Citation: None
Metadata_Reference_Information:
      Metadata_Date: 19980300
      Metadata_Contact:
            Contact_Information:
                  Contact_Person_Primary:
                        Contact_Person: Karen Steinmaus
                        Contact_Organization: Pacific Northwest National
                        Laboratory, Remote Sensing Group
                  Contact_Position: Technical Group Manager
                  Contact_Address:
                        Address_Type: mailing address
                        Address: P.O. Box 999, MS K9-55
                        City: Richland
                        State_or_Province: WA
                        Postal_Code: 99352
                        Country: USA
                  Contact_Voice_Telephone: (509) 372-6288
      Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial
      Metadata
      Metadata_Standard_Version: 19940608
```

Appendix C

AML and Associated Control Files for Vectorization

Appendix C

AML and Associated Control Files for Vectorization

Aml vectorize.aml

```
/* ---------------------------------------------------------
/* File vectorize.aml
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/* Created by Signe K. Wurstner
/* <sk_wurstner@pnl.gov>
/*
/* Pacific Northwest National Laboratory
/* (509) 372-6115
/* Created on Jan 8, 1998
/* Last Change: Fri Feb  6 14:34:00 1998 by Signe K. Wurstner
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/*
/*  This aml converts an imagine raster file to an arc/info grid,
/*  creates a polygon coverage and adds the attribute information
/*  from an imagine export file, using attribute definitions from
/*  a specified lookup table.  The coverage names are then written
/*  to an ascii file for use in export.aml which will convert the
/*  files to arc/info interchange (or export) format (e00.)
/*
/*
/*  Arguments:  asciilist - name of an ascii file containing
/*                 the names of the imagine files and their
/*                 corresponding attribute files and
/*                 lookup tables
/*  format:
/*  line 1 - imagine filename (including path)
/*  line 2 - attribute filename (including path)
/*         this file should be in Imagine export format
/*  line 3 - attribute lookup table (including path)
/*         this file should be an ascii file corresponding to
/*         the above attribute file, with the following format
/*         line 1 - number of columns to skip in attribute file,
```

```
/*          line 2 - attribute name, type (c for character,
/*                i for integer,f for floating point, or b for boolean),
/*                internal item width (4 or 8 for int and float,
/*                = output width for char), output width,
/*                number of decimal places (if type = float)
/*          etc...
/*          for example: 4
/*                   f_code,c,32,32
/*                   wid,i,4,5
/*                   ohc,f,4,12,2
/*   line 4 - imagine filename (including path)
/*   etc...
/*
/*            outlist - name of output file to which coverage
/*                   names will be written (default is export.txt)
/* ------------------------------------------------------------
/* ------------------------------------------------------------
/*
&args asciilist outlist skipflag flag2
/*
/* error checking for arguements
/*
&if [null %asciilist%] &then &do
 &type Usage:&run vectorize <ascii file name> <output filename>
 &return
&end
/*
/* read file names from a file called %asciilist%
/*
/* file format:
/*
/*   format:
/*   line 1 - imagine filename (including path)
/*   line 2 - attribute filename (including path)
/*   line 3 - attribute lookup table (including path)
/*   line 4 - imagine filename (including path)
/*   etc...
/*
/*  open ascii file and output file
/*
&sv fileunit = [open %asciilist% openstat -read]
&sv outfil := [open %outlist% openstatus -write]
/*
/*  Loop through files listed in ascii file
```

```
/* (102 is status for EOF)
/*
&sv string = [read %fileunit% readstat]
&do &until %readstat% eq 102
 /*
 &sv imgfilname = %string%
 &do &until [null %save%]
  &sv save = [after %imgfilname% /]
  &if ^ [null %save%] &then
   &sv imgfilname = %save%
  &else
   &sv imgpath = [before %string% %imgfilname%]
 &end
 &sv imgfilname = [before %imgfilname% .]
/*
 &sv string = [read %fileunit% readstat]
/*
 &sv attfilname = %string%
 &do &until [null %save%]
  &sv save = [after %attfilname% /]
  &if ^ [null %save%] &then
   &sv attfilname = %save%
  &else
   &sv attpath = [before %string% %attfilname%]
 &end
 /*
 &sv string = [read %fileunit% readstat]
 &sv lutable = %string%
 &do &until [null %save%]
  &sv save = [after %lutable% /]
  &if ^ [null %save%] &then
   &sv lutable = %save%
  &else
   &sv lupath = [before %string% %lutable%]
 &end
 /*
 /*
 /* error checking - check if files exist
 /*
 &if ^ [exists %imgpath%%imgfilname%.img -file] &then &do
   &type Imagine file %imgfilname%.img does not exist in %imgpath%
   &return
  &end
 /*
```

```
&if ^ [exists %attpath%%attfilname% -file] &then &do
  &type Attribute file %attfilname% does not exist in %attpath%
  &return
&end
/*
&if ^ [exists %lupath%%lutable% -file] &then &do
  &type Lookup table %lutable% does not exist in %lupath%
  &return
&end
/*
&if [null %imgfilname%] &then &do
  &type Done Processing
  &stop
&end
/*
&sv covername = [substr %imgfilname% 1 12]
/*
/*
&type imgfilname = [value imgfilname]
&type attfilname = [value attfilname]
&type lutable = [value lutable]
/*
/* copy attribute file and lookup table to current directory
/*
&sys cp %attpath%/%attfilname% %attfilname%
&sys cp %lupath%/%lutable% %lutable%
/*
/* read attribute names from lookup table
/*
&type Reading attributes and their types from %lutable%
/*
/*
&sv fileunit2 = [open %lutable% openstat -read]
/*
&sv nskip = [read %fileunit2% readstat]
&sv natt = 0
&sv string = [read %fileunit2% readstat]
&do &until %readstat% eq 102
  &sv natt = %natt% + 1
  &sv item%natt% = [extract 1 %string%]
  &sv type%natt% = [extract 2 %string%]
  &sv inwid%natt% = [extract 3 %string%]
  &sv outwid%natt% = [extract 4 %string%]
  &sv decimal%natt% = [extract 5 %string%]
```

```
 &sv string = [read %fileunit2% readstat]
&end
/*
&type %natt% attributes read from lookup table
&sv closefil1 := [close %fileunit2%]
/*
/*
/*
&if [null %flag2%] &then &do
/*
&if [null %skipflag%] &then &do
/*
/*  convert imagine file to arc/info grid
/*
   &type Converting Imagine file %imgpath%%imgfilname%.img to arc/info grid
/*
   &if [exists %covername%g -grid] &then
    kill %covername%g all
/*
   imagegrid %imgpath%%imgfilname%.img %covername%g
/*
 &end
/*
/*  convert grid to polygon coverage
/*
   &if [exists %covername% -cover] &then
    kill %covername% all
/*
   gridpoly %covername%g %covername%

/*
/*  add items to polygon coverage based on attribute names
/*
&type Adding the following items to the coverage:
&do step = 1 &to %natt% &by 1
 &type step = %step% item = [value item%step%]
 &if [value item%step%] ne row &then &do
    &type [value item%step%] with [value inwid%step%] [value outwid%step%] [value type%step%]
[value decimal%step%]
    &if [null [value decimal%step%]] &then
      additem %covername%.pat %covername%.pat [value item%step%] [value inwid%step%] [value
outwid%step%] [value type%step%]
    &else
```

```
    additem %covername%.pat %covername%.pat [value item%step%] [value inwid%step%] [value
outwid%step%] [value type%step%] [value decimal%step%]
  &end
&end
/*
 &end
&sv cover = [upcase %covername%]
/*
/*  read in attributes from export file
/*
&sv fileunit3 = [open %attfilname% openstat -read]
/* skip first record - row 0
&sv string = [read %fileunit2% readstat]
/*
&sv nrec = 0
&sv string = [read %fileunit3% readstat]
&do &until %readstat% eq 102
 &if %nskip% ne 0 &then &do
   &do dumloop = 1 &to %nskip%
    &sv dummy = [extract %dumloop% %string%]
   &end
  &end
 &sv nrec = %nrec% + 1
 &do loop = 1 &to %natt%
  &sv att%loop%r%nrec% = [extract %loop% %string%]
  &end
 &sv string = [read %fileunit3% readstat]
&end
/*
&sv closefil2 := [close %fileunit3%]
/*
/*  assign values to items
/*
 &type Populating attributes with proper values
/*
/*
ae
&do loop2 = 1 &to %nrec%
 edit %cover%
 ef poly
 &type att1r%loop2% = [value att1r%loop2%]
 sel grid-code = [value att1r%loop2%]
 &if [show number select] eq 0 &then
  &type No features present in this class, skipping grid-code = [value att1r%loop2%]
```

```
 &else &do
 &type Selected grid-code =  [value att1r%loop2%]
 &do loop3 = 2 &to %natt%
 &if [value type%loop3%] eq c &then &do
   CALC [value item%loop3%] = [quote [value att%loop3%r%loop2%]]
   &type Assigned [quote [value att%loop3%r%loop2%]] to [value item%loop3%]
   &end
 &else &do
   &type
   CALC [value item%loop3%] = [value att%loop3%r%loop2%]
   &type Assigned [value att%loop3%r%loop2%] to [value item%loop3%]
  &end
 &end
 &end
&end
/*
save
q
/*
/*  for all coverages except tree point coverages, assign polygon area
/*  to attribute ARA
/*
&if %covername% nc tree &then &do
  &data ARC INFO
    ARC
    SEL [UPCASE %covername%].PAT
    ALTER ARA
    ~
    12
    F
    2
    ~
    ~
    ~
    ~
    CALC ARA = AREA
    Q STOP
  &end
 &end
/*
/*  write coverage name to output file
/*
&sv writkey := [write %outfil% %covername%]
/*
```

```
/*  read next string
/*
&sv string = [read %fileunit% readstat]
/*
&end
/*
/*  close output file and ascii list file
/*
  &sv closefil3 := [close -all]
/*
```

Example control file vectorize.ctl - specified as argument asciilist in vectorize.aml

```
/net/io/files1/dma/signe/ytc/gregg/park_3m.img
/net/io/files1/dma/signe/ytc/attribute_files/park_3m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/parking.lut
/net/io/files1/dma/signe/ytc/gregg/veg_3m.img
/net/io/files1/dma/signe/ytc/attribute_files/veg_3m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/veg.lut
/net/io/files1/dma/signe/ytc/gregg/water_3m.img
/net/io/files1/dma/signe/ytc/attribute_files/water_3m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/water.lut
/net/io/files1/dma/signe/ytc/eileen/chkpt_bldg.img
/net/io/files1/dma/signe/ytc/attribute_files/chkpt_bldg_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/bldg.lut
/net/io/files1/dma/signe/ytc/eileen/chkpt_veg.img
/net/io/files1/dma/signe/ytc/attribute_files/chkpt_veg_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/veg.lut
/net/io/files1/dma/signe/ytc/eileen/chkpt_obstacle.img
/net/io/files1/dma/signe/ytc/attribute_files/chkpt_obst_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/obstacle.lut
/net/io/files1/dma/signe/ytc/eileen/chkpt_water.img
/net/io/files1/dma/signe/ytc/attribute_files/chkpt_water_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/water.lut
/net/io/files1/dma/signe/ytc/eileen/chkpt_tree_pt.img
/net/io/files1/dma/signe/ytc/attribute_files/chkpt_tree_pt_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/tree_pt.lut
/net/io/files1/dma/signe/ytc/harlan/veg_1m.img
/net/io/files1/dma/signe/ytc/attribute_files/veg_1m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/veg.lut
/net/io/files1/dma/signe/ytc/harlan/water_1m.img
/net/io/files1/dma/signe/ytc/attribute_files/water_1m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/water.lut
```

```
/net/io/files1/dma/signe/ytc/harlan/bldg_1m.img
/net/io/files1/dma/signe/ytc/attribute_files/bldg_1m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/bldg.lut
/net/io/files1/dma/signe/ytc/harlan/park_1m.img
/net/io/files1/dma/signe/ytc/attribute_files/park_1m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/parking.lut
/net/io/files1/dma/signe/ytc/harlan/tree_1m.img
/net/io/files1/dma/signe/ytc/attribute_files/tree_1m_att.dat
/net/io/files1/dma/signe/ytc/lookup_tables/tree_pt.lut
```

Example lookup table veg.lut

```
0
row,f,4,12
f_code,c,10,10
ara,f,4,12
bud,c,10,10
ftc,c,10,10
hgt,f,4,12
sd1,c,10,10
sd2,c,10,10
str,f,4,12
tre,c,10,10
ts1,c,10,10
ts2,c,10,10
veg,c,10,10
vh1,c,10,10
wtr,c,10,10
zv1,f,4,12
zv2,f,4,12
label,c,40,40
```

Aml add_stat_attributes.aml

```
/* ------------------------------------------------------------
/* File add_stat_attributes.aml
/* ------------------------------------------------------------
/* ------------------------------------------------------------
/* Created by Signe K. Wurstner
/* <sk_wurstner@pnl.gov>
/*
/* Pacific Northwest National Laboratory
/* (509) 372-6115
```

```
/* Created on July 22, 1997
/* Last Change: Tue Feb 10 14:49:44 1998 by Signe K. Wurstner
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/*
/* This aml assigns a value (e.g. elevation) from a value grid
/* (e.g. DEM) to an attribute in a polygon coverage based on
/* some statistical calculation (e.g. min, mean or max). This
/* value is divided by a conversion factor.
/*
/* Arguments:  asciilist - name of an ascii file containing
/*                the names of the polygon coverages
/*                to which the value will be added
/*
/* format:
/* line 1 - path to value grid
/* line 2 - name of calue grid (imagine)
/* line 3 - conversion factor, cellsize on which polygon coverage was based
/*        (default 3 meters)
/* line 4 - path to coverages
/* line 5 - coverage name, item name, stat type (eg. min, max, etc.)
/* line 6 - coverage name, item name, stat type (eg. min, max, etc.)
/* etc...
/*
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/*
&args asciilist skipflag
/*
/*
&if [null %asciilist%] &then &do
 &type Usage:&run add_stat_attributes <ascii file name>
 &return
&end
/*
/* read file names from a file called %asciilist%
/*
/* file format:
/*
/* line 1 - path to value grid
/* line 2 - name of value grid (imagine)
/* line 3 - conversion factor, cellsize on which polygon coverage was based
/*        (default 3 meters)
/* line 4 - path to coverages
```

```
/*   line 5 - coverage name, item name, stat type (eg. min, max, etc.)
/*   line 6 - coverage name, item name, stat type (eg. min, max, etc.)
/*   etc...
/*
/*
&sv fileunit = [open %asciilist% openstat -read]
&sv string = [read %fileunit% readstat]
/*
&sv dempath = [extract 1 %string%]
/*
&sv string = [read %fileunit% readstat]
/*
&sv demname = [extract 1 %string%]
/*
&sv string = [read %fileunit% readstat]
&sv cnvrt = [extract 1 %string%]
&sv csize = [extract 2 %string%]
&if [null %csize%] &then
  &sv csize = 3
/*
&sv string = [read %fileunit% readstat]
/*
&sv covpath = [extract 1 %string%]
/*
/*  Loop through files listed in ascii file
/*  (102 is status for EOF)
/*
&sv string = [read %fileunit% readstat]
&do &until %readstat% eq 102
/*
  &sv covname = [extract 1 %string%]
  &sv itemname = [extract 2 %string%]
  &sv stattype = [extract 3 %string%]
/*
  &if [null %covname%] &then &do
      &type Done Processing
      &stop
    &end
  /*
  &sv covername = [substr %covname% 1 12]
/*
/*  convert imagine files to arc/info grids
/*
  &if [null %skipflag%] &then &do
```

```
&if [after %demname% .] = img &then &do
  &sv demname1 = [trim %demname% -right g]
  &sv demname2 = [trim %demname1% -right m]
  &sv demname3 = [trim %demname2% -right i]
  &sv demname4 = [trim %demname3% -right .]
  &sv demname = %demname4%
  &type %demname%
  &end
/*
&sv demshort = [substr %demname% 1 12]
 &if [exists %demshort%g -grid] &then
  kill %demshort%g all
/*
 imagegrid %dempath%/%demname%.img %demshort%g
 &end
&else
  &sv demshort = [substr %demname% 1 12]
/*
 /* convert coverage to a grid based on cover-id to create
 /* a unique zone for each polygon
/*
&if [exists %covername%d -grid] &then
 kill %covername%d all
/*
polygrid %covername% %covername%d %covername%-id
[value csize]
y
/*
/*
/* Use zonalstats function to create an info file containing
/* the mean value for each zone (polygon)
/*
describe %demshort%g
&severity &error &ignore
&sv junk = [delete meanval.inf -info]
&severity &error &fail
grid
meanval.inf = zonalstats (%covername%d,%demshort%g,%stattype%)
q
/*
&sv itstring = [iteminfo %covername% -poly %covername%-id -definition]
&sv in = [extract 1 %itstring%]
&sv out = [extract 2 %itstring%]
&sv typ = [extract 3 %itstring%]
```

```
&type adding item to meanval.inf
/*
additem meanval.inf meanval.inf %covername%-id %in% %out% %typ%
ae
edit meanval.inf info
sel all
calc %covername%-id = value
save
q
/*
joinitem %covername%.pat meanval.inf %covername%.pat %covername%-id %itemname%
/*
ae
edit %covername%
ef poly
sel all
calc %itemname% = %stattype% / %cnvrt%
save
q
/*
dropitem %covername%.pat %covername%.pat %stattype%
dropitem %covername%.pat %covername%.pat value
dropitem %covername%.pat %covername%.pat count
/*
&sv string = [read %fileunit% readstat]
&sv skipflag = 1
  &end
```

Example control file elevations_3m.ctl - specified as argument asciilist in add_stat_attributes.aml

```
/net/triton/files5/data/yakima/dtm
ytc_1arc_wgs84_filled.img
1.0,3.0
/net/io/files1/dma/signe/ytc/final_vectors
water_3m,zv1,min
water_3m,zv2,max
veg_3m,zv1,min
veg_3m,zv2,max
park_3m,zv1,min
park_3m,zv2,max
```

Example control file slopes.ctl - specified as argument asciilist in add_stat_attributes.aml

```
/net/io/files2/data/dma_phase_iii/ytc/working/eileen/choke_pt_class
chkpt_alm_slope
1.0,3.0
/net/io/files1/dma/signe/ytc/final_vectors
chkpt_obstac,sgc,mean
```

Aml add_elevation_points.aml

```
/* ---------------------------------------------------------
/* File add_stat_attribues_points.aml
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/* Created by Signe K. Wurstner
/* <sk_wurstner@pnl.gov>
/*
/* Pacific Northwest National Laboratory
/* (509) 372-6115
/* Created on July 22, 1997
/* Last Change: Wed Jan 21 11:09:30 1998 by Signe K. Wurstner
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/*
/*  This aml assigns a value (e.g. elevation) from a value grid
/*  (e.g. DEM) to an attribute in a point coverage by sampling
/*  the value grid at each point. This value is divided by a conversion
/*  factor.
/*
/*  Arguments:  asciilist - name of an ascii file containing
/*                the names of the point coverages
/*                to which the value will be added
/*
/*  format:
/*  line 1 - path to value grid
/*  line 2 - name of calue grid (imagine)
/*  line 3 - conversion factor
/*  line 4 - path to coverages
/*  line 5 - coverage name, item name
/*  line 6 - coverage name, item name
/*  etc...
/*
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/*
&args asciilist skipflag
```

```
/*
/*
&if [null %asciilist%] &then &do
 &type Usage:&run add_stat_attributes_points <ascii file name>
 &return
&end
/*
/* read file names from a file called %asciilist%
/*
/* file format:
/*
/*   line 1 - path to value grid
/*   line 2 - name of value grid (imagine)
/*   line 3 - conversion factor
/*   line 4 - path to coverages
/*   line 5 - coverage name, item name
/*   line 6 - coverage name, item name
/*   etc...
/*
/*
&sv fileunit = [open %asciilist% openstat -read]
&sv string = [read %fileunit% readstat]
/*
&sv dempath = [extract 1 %string%]
/*
&sv string = [read %fileunit% readstat]
/*
&sv demname = [extract 1 %string%]
/*
&sv cnvrt = [read %fileunit% readstat]
/*
&sv string = [read %fileunit% readstat]
/*
&sv covpath = [extract 1 %string%]
/*
/* Loop through files listed in ascii file
/* (102 is status for EOF)
/*
&sv string = [read %fileunit% readstat]
&do &until %readstat% eq 102
/*
  &sv covname = [extract 1 %string%]
  &sv itemname = [extract 2 %string%]
/*
```

```
&if [null %covname%] &then &do
  &type Done Processing
  &stop
 &end
/*
&sv covername = [substr %covname% 1 12]
/*
/* convert imagine files to arc/info grids
/*
&if [null %skipflag%] &then &do
  &if [after %demname% .] = img &then &do
    &sv demname1 = [trim %demname% -right g]
    &sv demname2 = [trim %demname1% -right m]
    &sv demname3 = [trim %demname2% -right i]
    &sv demname4 = [trim %demname3% -right .]
    &sv demname = %demname4%
    &type %demname%
    &end
/*
&sv demshort = [substr %demname% 1 12]
 &if [exists %demshort%g -grid] &then
  kill %demshort%g all
/*
 imagegrid %dempath%/%demname%.img %demshort%g
 &end
&else
  &sv demshort = [substr %demname% 1 12]
/*
 /* convert coverage to a grid based on cover-id to create
 /* a unique zone for each polygon
/*
&severity &error &ignore
dropitem %covname%.pat %covname%.pat spot
&severity &error &fail
latticespot %demshort%g %covname%
ae
edit %covname%
ef point
sel all
cursor open
cursor first
&do &while %:edit.AML$NEXT%
 &if %cnvrt% eq 1 &then
  calc %itemname% = [quote [value :edit.SPOT]]
```

```
  &else
    calc %itemname% = [value :edit.SPOT] / %cnvrt%
  cursor next
 &end
 cursor close
 save
 q
 dropitem %covname%.pat %covname%.pat spot
/*
&sv string = [read %fileunit% readstat]
&sv skipflag = 1
  &end
```

Example control file trees_elev.ctl - specified as argument asciilist in add_elevation_points.aml

```
/net/io/files1/dma/signe/ytc/lidar
tree_height_cm
100.0
/net/io/files1/dma/signe/ytc/final_vectors
chkpt_tre-pt,vh1
```

Aml arc_to_export.aml

```
/* ----------------------------------------------------------
/* File arc_to_export.aml
/* ----------------------------------------------------------
/* ----------------------------------------------------------
/* Created by Signe K. Wurstner
/* <sk_wurstner@pnl.gov>
/*
/* Pacific Northwest National Laboratory
/* (509) 372-6115
/* Created on May 9, 1997
/* Last Change: Mon Oct  6 21:47:23 1997 by Signe K. Wurstner
/* ----------------------------------------------------------
/* ----------------------------------------------------------
/*
/*  This aml converts arc/info coverages to export
/*  (arc interchange) format
/*
/*  Arguments:  asciilist - name of an ascii file containing
/*                    the names of the coverages to convert
/*
/*  format:
```

```
/*  line 1 - cover name
/*  line 2 - cover name
/*  etc...
/*
/* -----------------------------------------------------------
/* -----------------------------------------------------------
/*
&args asciilist
/*
/*
&if [null %asciilist%] &then &do
 &type Usage:&run arc_to_export <ascii file name>
 &return
&end
/*
/*
/* read file names from a file called %asciilist%
/*
/* file format:
/*
/*  line 1 - cover name
/*  line 2 - cover name
/*  etc...
/*
/*  filenames must be seperated by commas
/*
&sv fileunit = [open %asciilist% openstat -read]
/*
/*  Loop through files listed in ascii file
/*  (102 is status for EOF)
/*
&sv cover = [read %fileunit% readstat]
&do &until %readstat% eq 102
/*
 &if [exists %cover%.e00 -file] &then
  &sys rm %cover%.e00
/*
 export cover %cover% %cover%
/*
  &sv cover = [read %fileunit% readstat]
/*
&end
/*
```

Example control file export.ctl - specified as argument asciilist in arc_to_export.aml

```
park_3m
veg_3m
water_3m
chkpt_bldg
chkpt_veg
chkpt_obstac
chkpt_water
chkpt_tre-pt
veg_1m
water_1m
bldg_1m
park_1m
tree_1m-pt
```

Aml convert_trees.aml

```
/* ---------------------------------------------------------
/* File convert_trees.aml
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/* Created by Signe K. Wurstner
/* <sk_wurstner@pnl.gov>
/*
/* Pacific Northwest National Laboratory
/* (509) 372-6115
/* Created on Feb 6, 1998
/* Last Change: Fri Feb  6 17:06:41 1998 by Signe K. Wurstner
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/*
/*  This aml converts a polygon coverage to a point coverage
/*  and transfers over the attribute information
/*
/*  Arguments:  asciilist - name of an ascii file containing
/*                 the names of the polygon coverages
/*                 to be converted
/*  format:
/*  line 1 - polygon coverage name
/*  line 2 - polygon coverage name
/*  etc...
/*
```

```
/*            outlist - name of output file to which coverage
/*                    names will be written (default is export.txt)
/* ----------------------------------------------------------
/* ----------------------------------------------------------
/*
&args asciilist outlist
/*
/* error checking for arguements
/*
&if [null %asciilist%] &then &do
 &type Usage:&run convert_trees <ascii file name> <output filename>
 &return
&end
/*
/* read file names from a file called %asciilist%
/*
/* file format:
/*
/*   format:
/*   line 1 - polygon coverage name
/*   line 2 - polygon coverage name
/*   etc...
/*
/*  open ascii file and output file
/*
&sv fileunit = [open %asciilist% openstat -read]
&sv outfil := [open %outlist% openstatus -write]
/*
/*  Loop through files listed in ascii file
/*  (102 is status for EOF)
/*
&sv string = [read %fileunit% readstat]
&do &until %readstat% eq 102
 /*
 &sv pcovname = %string%
 /*
 /*  error checking - check if files exist
 /*
  &if [null %pcovname%] &then &do
    &type Done Processing
    &stop
   &end
/*
  &if ^ [exists %pcovname% -cover] &then &do
```

```
    &type Polygon coverage %pcovname% does not exist
    &return
   &end
  /*
  &sv covername = [substr %pcovname% 1 9]-pt
/*
/*
/*  convert polygon coverage to point coverage
/*
   &type Converting Polygon coverage %pcovname% to point coverage
   /*
   copy %pcovname% %covername%
   dropfeatures %covername% poly
   build %covername% point
   additem %covername%.pat %covername%.pat %pcovname%# 4 5 b
   ae
   edit %covername%
   ef points
   sel all
   calc %pcovname%# =  %covername%#
   save
   q
   joinitem %covername%.pat %pcovname%.pat %covername%.pat %pcovname%# %pcovname%#
   /*
   /*
/*  write coverage name to output file
/*
&sv writkey := [write %outfil% %covername%]
/*
/*  read next string
/*
&sv string = [read %fileunit% readstat]
/*
&end
/*
/*  close output file and ascii list file
/*
 &sv closefil3 := [close -all]
/*
/*
```

Example control file trees.ctl - specified as argument asciilist in convert_trees.aml

```
chkpt_tree_p
```

tree_1m

Aml mak_bridges.aml

```
/* -----------------------------------------------------------
/* File mak_bridges.aml
/* -----------------------------------------------------------
/* -----------------------------------------------------------
/* Created by Signe K. Wurstner
/* <sk_wurstner@pnl.gov>
/*
/* Pacific Northwest National Laboratory
/* (509) 372-6115
/* Created on Jan 8, 1998
/* Last Change: Fri Feb 13 10:16:19 1998 by Signe K. Wurstner
/* -----------------------------------------------------------
/* -----------------------------------------------------------
/*
/*  This aml intersects a roads coverage with a water coverage
/*  creating a coverage representing bridges. The attributes wid,
/*  zv1 and zv2 are maintained from the roads coverage, and
/*  transfered to the bridge coverage. Other attributes are dropped
/*  and the bridge attributes are added from a lookup table.
/*
/*
/*  Arguments:  asciilist - name of an ascii file containing
/*                 the names of the coverages and
/*                 lookup tables
/*  format:
/*  line 1 - roads coverage name (including path)
/*  line 2 - water coverage name (including path)
/*  line 3 - name to call bridge coverage
/*  line 4 - attribute lookup table for roads (including path)
/*       this file should be an ascii file corresponding to
/*       the above attribute file, with the following format
/*       line 1 - number of columns to skip in attribute file,
/*       line 2 - attribute name, type (c for character,
/*            i for integer,f for floating point, or b for boolean),
/*            internal item width (4 or 8 for int and float,
/*            = output width for char), output width,
/*            number of decimal places (if type = float)
/*       etc...
/*       for example: 4
```

```
/*                  f_code,c,32,32
/*                  wid,i,4,5
/*                  ohc,f,4,12,2
/*  line 5 -  attribute lookup table for water (including path)
/*         (same format as above)
/*  line 6 -  attribute lookup table for bridges (including path)
/*         (same format as above)
/*  etc...
/*
/*           outlist - name of output file to which coverage
/*                  names will be written (default is export.txt)
/* ---------------------------------------------------------
/* ---------------------------------------------------------
/*
&args asciilist outlist
/*
/* error checking for arguements
/*
&if [null %asciilist%] &then &do
 &type Usage:&run mak_bridges <ascii file name> <output filename>
 &return
&end
/*
/* read file names from a file called %asciilist%
/*
/* file format:
/*
/*  format:
/*  line 1 - roads coverage name (including path)
/*  line 2 - water coverage name (including path)
/*  line 3 - name to call bridge coverage
/*  line 4 - attribute lookup table for roads (including path)
/*  line 5 - attribute lookup table for water (including path)
/*  line 6 - attribute lookup table for bridges (including path)
/*  etc...
/*
/*  open ascii file and output file
/*
&sv fileunit = [open %asciilist% openstat -read]
&sv outfil := [open %outlist% openstatus -write]
/*
/* Loop through files listed in ascii file
/*  (102 is status for EOF)
/*
```

```
&sv string = [read %fileunit% readstat]
&do &until %readstat% eq 102
 /*
 &sv rdcover = %string%
 &do &until [null %save%]
  &sv save = [after %rdcover% /]
  &if ^ [null %save%] &then
   &sv rdcover = %save%
  &else
   &sv rdpath = [before %string% %rdcover%]
 &end
 /*
 &sv string = [read %fileunit% readstat]
 &sv wtrcover = %string%
 &do &until [null %save%]
  &sv save = [after %wtrcover% /]
  &if ^ [null %save%] &then
   &sv wtrcover = %save%
  &else
   &sv wtrpath = [before %string% %wtrcover%]
 &end
 /*
  &sv brdgcover = [read %fileunit% readstat]
 /*
 &sv string = [read %fileunit% readstat]
 &sv rdlutable = %string%
 &do &until [null %save%]
  &sv save = [after %rdlutable% /]
  &if ^ [null %save%] &then
   &sv rdlutable = %save%
  &else
   &sv rdlupath = [before %string% %rdlutable%]
 &end
 /*
 &sv string = [read %fileunit% readstat]
 &sv wtrlutable = %string%
 &do &until [null %save%]
  &sv save = [after %wtrlutable% /]
  &if ^ [null %save%] &then
   &sv wtrlutable = %save%
  &else
   &sv wtrlupath = [before %string% %wtrlutable%]
 &end
 /*
```

```
&sv string = [read %fileunit% readstat]
&sv brdglutable = %string%
&do &until [null %save%]
 &sv save = [after %brdglutable% /]
 &if ^ [null %save%] &then
  &sv brdglutable = %save%
 &else
  &sv brdglupath = [before %string% %brdglutable%]
&end
/*
/*  error checking - check if files exist
/*
&if ^ [exists %rdpath%%rdcover% -cover] &then &do
   &type Coverage %rdcover% does not exist in %rdpath%
   &return
 &end
/*
&if ^ [exists %wtrpath%%wtrcover% -cover] &then &do
   &type Coverage %wtrcover% does not exist in %wtrpath%
   &return
 &end
/*
 &if ^ [exists %rdlupath%%rdlutable% -file] &then &do
   &type Lookup table %rdlutable% does not exist in %rdlupath%
   &return
  &end
 /*
 &if ^ [exists %wtrlupath%%wtrlutable% -file] &then &do
   &type Lookup table %wtrlutable% does not exist in %wtrlupath%
   &return
  &end
 /*
 &if ^ [exists %brdglupath%%brdglutable% -file] &then &do
   &type Lookup table %brdglutable% does not exist in %brdglupath%
   &return
  &end
 /*
 &if [null %rdcover%] &then &do
   &type Done Processing
   &stop
  &end
 /*
/*  copy lookup tables to current directory
/*
```

```
  &sys cp %rdlupath%/%rdlutable% %rdlutable%
  &sys cp %wtrlupath%/%wtrlutable% %wtrlutable%
  &sys cp %brdglupath%/%brdglutable% %brdglutable%
/*
/*  read attribute names from lookup tables
/*
&type Reading attributes and their types from %rdlutable%
/*
/*
 &sv fileunit2 = [open %rdlutable% openstat -read]
 /*
&sv nskip = [read %fileunit2% readstat]
&sv rdnatt = 0
&sv string = [read %fileunit2% readstat]
&do &until %readstat% eq 102
 &sv rdnatt = %rdnatt% + 1
 &sv rditem%rdnatt% = [extract 1 %string%]
 &sv rdtype%rdnatt% = [extract 2 %string%]
 &sv rdinwid%rdnatt% = [extract 3 %string%]
 &sv rdoutwid%rdnatt% = [extract 4 %string%]
 &sv rddecimal%rdnatt% = [extract 5 %string%]
 &sv string = [read %fileunit2% readstat]
&end
/*
&type %rdnatt% attributes read from lookup table
&sv closefil1 := [close %fileunit2%]
/*
&type Reading attributes and their types from %wtrlutable%
/*
/*
 &sv fileunit2 = [open %wtrlutable% openstat -read]
 /*
&sv nskip = [read %fileunit2% readstat]
&sv wtrnatt = 0
&sv string = [read %fileunit2% readstat]
&do &until %readstat% eq 102
 &sv wtrnatt = %wtrnatt% + 1
 &sv wtritem%wtrnatt% = [extract 1 %string%]
 &sv wtrtype%wtrnatt% = [extract 2 %string%]
 &sv wtrinwid%wtrnatt% = [extract 3 %string%]
 &sv wtroutwid%wtrnatt% = [extract 4 %string%]
 &sv wtrdecimal%wtrnatt% = [extract 5 %string%]
 &sv string = [read %fileunit2% readstat]
&end
```

```
/*
&type %wtrnatt% attributes read from lookup table
&sv closefil1 := [close %fileunit2%]
/*
&type Reading attributes and their types from %brdglutable%
/*
/*
 &sv fileunit2 = [open %brdglutable% openstat -read]
 /*
&sv nskip = [read %fileunit2% readstat]
&sv brdgnatt = 0
&sv string = [read %fileunit2% readstat]
&do &until %readstat% eq 102
 &sv brdgnatt = %brdgnatt% + 1
 &sv brdgitem%brdgnatt% = [extract 1 %string%]
 &sv brdgtype%brdgnatt% = [extract 2 %string%]
 &sv brdginwid%brdgnatt% = [extract 3 %string%]
 &sv brdgoutwid%brdgnatt% = [extract 4 %string%]
 &sv brdgdecimal%brdgnatt% = [extract 5 %string%]
 &sv string = [read %fileunit2% readstat]
&end
/*
&type %brdgnatt% attributes read from lookup table
&sv closefil1 := [close %fileunit2%]
/*
/*  Intersect coverages to create bridge coverage
/*
   &type Intersecting roads with water to create bridges
/*
   &if [exists %brdgcover% -cover] &then
    kill %brdgcover% all
/*
   intersect %rdpath%%rdcover% %wtrpath%%wtrcover% %brdgcover% line
   /*
   build %brdgcover% line
/*
/*  drop unnecessary items
   /*
   &do step = 1 &to %rdnatt% &by 1
     &if [value rditem%step%] ne wid and [value rditem%step%] ne zv1 and [value rditem%step%] ne
zv2 and [value rditem%step%] ne row and [value rditem%step%] ne label and [value rditem%step%] ne
f_code &then
      dropitem %brdgcover%.aat %brdgcover%.aat [value rditem%step%]
   &end
```

```
  /*
  &do step2 = 1 &to %wtrnatt% &by 1
    &if [value wtritem%step2%] ne wid and [value wtritem%step2%] ne zv1 and [value
wtritem%step2%] ne zv2 and [value wtritem%step2%] ne row and [value wtritem%step2%] ne label and
[value wtritem%step2%] ne f_code &then &do
       &severity &error &ignore
       dropitem %brdgcover%.aat %brdgcover%.aat [value wtritem%step2%]
       &severity &error &fail
     &end
  &end
/*
/* add items to bridge coverage
/*
&type Adding the following items to the coverage:
&do step = 1 &to %brdgnatt% &by 1
 &type step = %step% item = [value brdgitem%step%]
 &if [value brdgitem%step%] ne row and [value brdgitem%step%] ne label and [value
brdgitem%step%] ne f_code and [value brdgitem%step%] ne wid and [value brdgitem%step%] ne zv1
and [value brdgitem%step%] ne zv2 &then &do
    &type [value brdgitem%step%] with [value brdginwid%step%] [value brdgoutwid%step%] [value
brdgtype%step%] [value brdgdecimal%step%]
    &if [null [value brdgdecimal%step%]] &then
      additem %brdgcover%.aat %brdgcover%.aat [value brdgitem%step%] [value brdginwid%step%]
[value brdgoutwid%step%] [value brdgtype%step%] 0 f_code
    &else
      additem %brdgcover%.aat %brdgcover%.aat [brdgvalue item%step%] [value brdginwid%step%]
[value brdgoutwid%step%] [value brdgtype%step%] [value brdgdecimal%step%] f_code
  &end
&end
/*
/* assign correct f_code and set other attributes to null
/*
&sv bridgecode = AQ040
&sv nullcode = -9999
ae
edit %brdgcover%
 ef arc
 sel all
 CALC f_code = [quote %bridgecode%]
 CALC label = 'Bridge'
 &do stepx = 1 &to %brdgnatt% &by 1
  &if [value brdgitem%stepx%] ne wid and [value brdgitem%stepx%] ne zv1 and [value
brdgitem%stepx%] ne zv2 and [value brdgitem%stepx%] ne row and [value brdgitem%stepx%] ne label
and [value brdgitem%stepx%] ne f_code &then &do
```

```
 &if [value brdgtype%stepx%] eq c &then &do
   CALC [value brdgitem%stepx%] = [quote [value nullcode]]
   &type Assigned  [quote [value nullcode]] to [value brdgitem%stepx%]
   &end
 &else &do
   &type
   CALC [value brdgitem%stepx%] = [value nullcode]
   &type Assigned  [value nullcode] to [value brdgitem%stepx%]
  &end
   &end
 &end
/*
save
q
/*
/*  write coverage name to output file
/*
&sv writkey := [write %outfil% %brdgcover%]
/*
/*  read next string
/*
&sv string = [read %fileunit% readstat]
/*
&end
/*
/*  close output file and ascii list file
/*
 &sv closefil3 := [close -all]
/*
/*
```

Example control file bridge.ctl - specified as argument asciilist in mak_bridges.aml

```
/net/io/files1/dma/signe/ytc/roads/roads_3m
/net/io/files1/dma/signe/ytc/final_vectors/water_3m
bridge_3m
/net/io/files1/dma/signe/ytc/lookup_tables/roads.lut
/net/io/files1/dma/signe/ytc/lookup_tables/water.lut
/net/io/files1/dma/signe/ytc/lookup_tables/bridge.lut
```

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