EVALUATION OF LANDSCAPE STRUCTURE USING AVIRIS QUICKLOOKS AND ANCILLARY DATA

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1. INTRODUCTION

Large scale earth system processes, like those likely to be affected by global climate change, result from a multitude of interactions between physical, chemical and biological systems operating over a variety of spatial and temporal scales (Hall et al., 1988; and many others). These processes taken together influence the configuration or structure of the landscape in which they are acting (Dunn, et al., 1991; Forman and Godron, 1988). Landscape structure is defined as the spatial relationships between distinctive ecosystem components and includes both the number of various patch types and their arrangement in space (Turner and Gardner, 1991; Turner, 1989). Because this configuration interacts with atmospheric conditions, both responding to and influencing climate as well as other ecological processes, we hypothesized that landscape structure might be used an integrated indicator of climate change at the landscape scale (Hunsaker et al, 1994; Norton and Slonecker, 1990). We use a number of commonly accepted landscape metrics to summarize the landscape structure (Turner et al., 1991; Riitters et al., 1995).

Currently the best tool for examining landscape structure is remote sensing, because remotely sensed data provide complete and repeatable coverage over landscapes in many climatic regimes. Many sensors, with a variety of spatial scales and temporal repeat cycles, are available. The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) has imaged over 4000 scenes from over 100 different sites throughout North America. For each of these scenes, one-band "quicklook" images have been produced for review by AVIRIS investigators. These quicklooks are free, publicly available over the Internet, and provide the most complete set of landscape structure data yet produced.

Quicklooks have several advantages for a survey of landscape structure. They are small (0.5 Mb) and easy to manipulate, yet retain a pixel size (40 m) which approximates the spatial resolution of current land observation satellite systems like Landsat -TM, -MSS and SPOT. Unlike panchromatic SPOT, they are free and easily available over the Internet; other free data (e.g. AVHRR) have much coarser spatial resolution. The single quicklook band is centered at approximately 700 nm (nominally 10 nm wide), which avoids major atmospheric absorbtions (Lillesand and Kiefer, 1994), yet is in a region where basic terrestrial materials, like water, soil/rock, vegetation, and snow/ice can generally be distinguished (Lillesand and Kiefer, 1994). Simple image processing techniques (contrast stretching, level slicing) allow the scenes to be classified into spectrally distinct landscape components for analysis. Though only a crude approximation of the landscape, these methods allow each scene to be analyzed in terms of the same component classes while retaining the spatial heterogeneity of the landscape.

A broad range of ecosystems representing a variety of climatic, geological and ecological conditions are represented in the quick look dataset. The dataset spans locations from 18° N to 56° N latitude and from 68° W to 126° W longitude, from boreal forest to tropical uplands, from coastal British Columbia to Key West, Florida. Eighteen of the twenty-seven North American vegetation types identified by Barbour and Billings (1988) and eleven of the fourteen North American physiographic regions identified by Vankat (1979) are represented in the dataset, including several examples each of montane conifer forest, boreal forest, temperate deciduous forest, desert scrub, Mediterranean scrub, prairie grasslands and tidal marshes. Though the dataset contains sites outside the United States, for this study we include only sites within the continental United States where ancillary data for comparison are available. Nevertheless, a short list of sites includes Mt. Rainier, WA, Biscayne Bay, FL, Los Angeles, CA, Rocky Mountain National Park, CO, Dismal Swamp, VA, Organ Pipe, AZ, Indian Pines, IN, and Suncook, NH. For most archive locations, several scenes are available, and for a few locations, multiple dates as well. Each scene is considered an independent sampling of that landscape type.

Climate interacts with landscape structure by influencing the amount of vegetation cover and the distribution of physiognomic types across the landscape (Prentice et al., 1993). Different plant communities have distinct spatial arrangements which form particular structures. Climate may also influence landscape structure through landforming processes like erosion and fluvial geomorphology. For this study we represented climate using the climate water balance diagram which integrates the temperature and moisture requirements of plants (Stephenson, 1990). By examining the seasonal timing of water supply vs. evapotranspiratory demand, we calculate expressions for the average, annual water surplus and deficit.

Climate is not the only influence on landscape structure however, and in many cases not the dominant one. Human land use and topography often have dominant influences on landscape pattern. Human land use breaks up vegetation patterns, creates new ones (e.g. agriculture), and is relatively indifferent to climatic effects. Topographic variation interacts with regional climate to create local climatic zones which in turn influence vegetation distributions. Mountainous terrain dissects the landscape, creating more complicated and variable landscape structures. River basins and channels influence the kind and structure of nearby vegetation. Inter-correlations between climate, land use and topography are subtle and complicated, yet important for understanding the large scale causes of landscape structure.

Because of the important influence of land use and topography, these variables have also been included in our analysis. Fortunately, for the contiguous United States, free, publicly available datasets are available over the Internet. We downloaded the appropriate land use and topographic geographic information system (GIS) coverages and clipped out the portion of the coverage corresponding to the quicklook. For land use we summarized the percentage land use for several major categories: urban, agriculture, range, forest, wetland and barren. For topographic variation, we calculated mean and standard deviations of elevation, slope and aspect, as derived from 1:250,000 scale Digital Elevation Models (DEMs).

This paper describes the methodologies used to evaluate the landscape structure of quicklooks and generate corresponding datasets for climate, topography and land use. A brief discussion of preliminary results is included at the end. Since quicklooks correspond exactly to their parent AVIRIS scenes, the methods used to derive climate, topography and land use data should be applicable to any AVIRIS analysis.

2. METHODS

Analysis of landscape structure required integrating data from many sources over a common geographic location. This integration was accomplished using a combination of ARC/INFO (Environmental Systems Research Institute, Redlands, CA), perl (Larry Wall, Mountain View, CA) and shell programming. The data sources are summarized in Table 1 and described in the text below. An example for an AVIRIS scene acquired over Jasper Ridge, CA is illustrated in Figure 1. Figure 1a indicates the local area and approximate boundaries of this quicklook image.

2.1 AVIRIS Quicklooks

For the analysis, we wanted to obtain the greatest variation in landscape structure, climate, land use and topography possible within the constraints of the AVIRIS quicklook dataset. Although a large number of scenes were available, we were restricted to choosing scenes which were complete, entirely cloud free, and where position and time of acquisition data were available. Further, because most images are acquired in flightlines, to insure independent sampling, we restricted ourselves to only selecting one image per flightline and avoided using multiple flightlines over the same location. The final number of quicklooks used for analysis was 109. The center and corner coordinates of each quicklook were calculated from the beginning and ending flightline coordinates and reported number of lines in the flightline. Coordinates were projected to an Albers Conic Equal-Area projection, with central meridian at –95° longitude, and standard parallels at 29° 30' and 45° 30' latitude. This projection is commonly used for the continental United States and has a maximum scale distortion of 1.25% for the 48 states.

The selected quicklooks were downloaded either as raw data files or gif format from the AVIRIS Internet homepage, then uploaded into IDL (Research Systems Inc., Boulder, CO) for manipulation and analysis. Each quicklook was given a numeric code, 1-109, and a longer name composed of the date of acquisition, and flight, run and scene number (e.g. 940815B06.02). Flightline names provided by the AVIRIS staff were also retained (e.g. Jasper Ridge).

Table 1. Data Sources

Landscape Structure data – Remotely sensed AVIRIS quicklooks and selected full AVIRIS scenes (ftp://ophelia.jpl.nasa.gov/pub/docs/html/pub.htm)

Quicklooks are one band (typically band 35 about 700 nm), grayscale images (0.5 Mb) derived from AVIRIS images. They are not atmospherically calibrated and are stretched so that colors range 0 to 255. Quicklook scenes are available in gif format from 1992 through 1996. Scenes are indexed by flight, run and scene, with six scenes per quicklook strip. Approximately 4000 scenes are available between 1992-1996, of which 109 were analyzed. All scenes were from the continental United States, though scenes are also available from Alaska, Canada, Mexico and Brazil. Additional scenes were acquired prior to 1992 and after 1996, but were not used in this analysis.

Landscape Structure Metrics: Contagion, Perimeter to Area Ratio ("Compaction"), Perimeter to Area Ratio Normalized to a Square ("Shape"), Fractal Dimension, Angular Second Moment, Inverse Difference Moment, Spatial Autocorrelation ("Scale")

Climate data (http://www.ncdc.noaa.gov/homepg/online.html)

Soils data (ftp://ftp.ftw.nrcs.usda.gov/pub/statsgo/unix/data).

Historical climate data providing mean monthly average temperature and precipitation for a over 4000 sites worldwide, with concentration in North America and Europe. These data are used to calculate climatic water balance diagrams as described Stephenson (1990) and Eagleman (1976) for each site. Besides the temperature and precipitation data, this calculation requires having available soil water capacity, which is estimated from the STATSGO soils database (National Resource Conservation Service), with complete coverage for the contiguous USA.

Topographic data (http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html)

1:250,000 scale digital elevation models (DEM) are available for most of the contiguous United States from the US Geological Service. Minimum, maximum and average elevation, slope and aspect are derived from elevation data coinciding with the quicklook.

Land use/land cover (ftp://ftp.epa.gov/pub/EPAGIRAS – ARC/INFO export coverages)
(http:// edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html – GIRAS format)

Land use data mapped at the 1:250,000 scale by the USGS including descriptions of both human land use and vegetative cover. Data coincident with quicklook polygon are summarized by land use and vegetation type, on an area weighted basis.

Each scene was stored in both continuous and nominal representations. Remote sensing images are useful for landscape analysis because they provide, without modification, a continuous measure of the landscape structure, but can be easily classified into nominal measures as well. Landscape structure metrics typically apply either to continuous or nominal data, but not both. As presented, quicklooks have a continuous range of gray levels from 0 to 255. These represent non-atmospherically corrected, upwelling radiance from the ground surface. To classify the scenes, we used a simple density slice technique to roughly identify patches of soil and vegetation in the image. Typically vegetation is darker than soil in the quicklook band (~700 nm). We confirmed this pattern by taking five calibrated AVIRIS data cubes, for which quicklooks and field data were available. These five scenes (Jasper Ridge, CA; El Dorado National Forest, CA; Santa Monica Mountains, CA; Winters, CA; Petaluma Marsh, CA) were deliberately chosen from different climate types and vegetation communities in California. The data cubes were classified into vegetation, soil or water using the Spectral Angle Mapper algorithm implemented in ENVI (Research Systems Inc., Boulder, CO) and image derived endmembers for those classes. The AVIRIS scene classifications were qualitatively verified by field work conducted by the CSTARS Laboratory (Department of Land, Air and Water Resources, University of California, Davis) at these sites. These classified images were compared to their corresponding quicklooks to derive gray level thresholds which distinguished vegetation from soil, with a small intermediate class. Although initially we had also planned to classify open water, there was sufficient variability in the quicklook band to make the identification of water unreliable. Because the quicklook classifications have not been rigorously confirmed by field reconnaissance, they are referred to as Class-V, Class-S and Class-I, so that it is clear they are based only on a simple remote sensing interpretation. An example of a quicklook and its classified product are shown in Figures 1c and 1d.

2.2 Landscape Structure Metrics

Landscape structure metrics fall into two broad classes: those which operate on nominal data (i.e. discrete classes) and those which operate over continuous data. We used landscape structure metrics recommended by Riitters et al. (1995) which represented in their analysis the main axes of landscape structure variation with a minimum of cross-correlation. These metrics all operate on nominal data and were applied to the classified quicklooks using algorithms programmed in IDL. These metrics are perimeter-area ratio, perimeter-area ratio normalized to a square ("shape"), fractal dimension, and contagion. We also recorded the number of patches, the number of patches less than four contiguous pixels (considered "small patches"), and the proportions of each class in each scene. Small patches were not used in calculating other landscape metrics (see discussion). We decided to supplement these measures with three which operate on the continuous image. These are scale based on an autocorrelation threshold, and two texture measurements (angular second moment, inverse difference moment) (Musick and Grover, 1991). We also examined histograms of gray levels where appropriate.

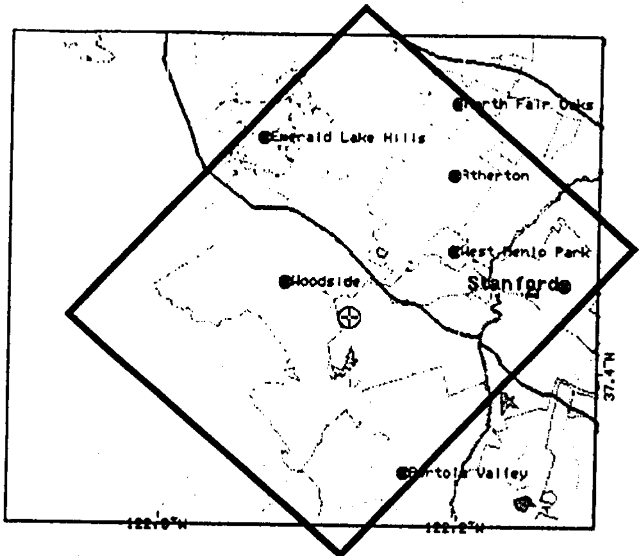
2.3 Climatic Water Balance

To estimate the climate, we decided to follow the practice of many ecologists in calculating the average, long term, climatic water balance for each site. Vegetation at the regional scale has been shown to be strongly influenced by the amount of water surplus, water deficit and their seasonal timing (Stephenson, 1990; Major, 1977). The climate water balance diagram is based on comparison of the potential evapotranspiration (based on temperature and latitude of the site) with actual evapotranspiration (based on potential evapotranspiration and available water from the soil and precipitation). Water surpluses occur when available water is greater than potential evapotranspiration; water deficits when there is insufficient water to meet potential evapotranspiratory demand (i.e. the difference between potential and actual evapotranspiration). Potential and actual evapotranspiration are calculated at monthly time steps based on long term averages of temperature and precipitation at each site.

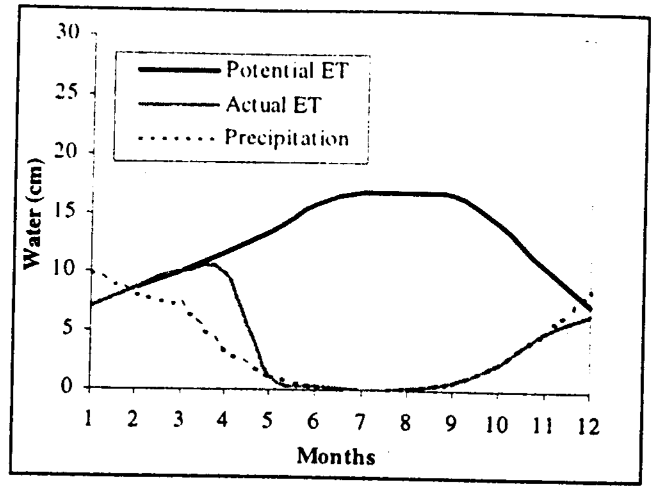
We obtained mean monthly temperatures and total precipitation from the Global Historical Climatological Network (Petersen et al., 1997), available for free over the Internet. This database has over 6000 precipitation stations and over 4000 temperature stations, with a large concentration of stations in North America, each with a historical record of at least 10 years. For each weather station, we averaged their long term records, then found the five closest stations within 100 km of each site. These five stations were averaged to estimate monthly temperature and precipitation at the quicklook site. Stations were reviewed to remove potentially unrepresentative data from the means (e.g. a weather station on the other side of a mountain range from the quicklook site).

Potential evapotranspiration at each site was calculated using the method of Thornthwaite and Mather (1955), which requires knowledge of only the mean monthly temperature, latitude and available soil water capacity of the site. Though more sophisticated methods are available, it is unclear whether the results are significantly better for large extent studies like this one (Milly, 1994). Using this method and the average precipitation, we used mass balance to calculate actual evapotranspiration, annual water deficit and surplus, given an estimate of the available soil water capacity.

In the past scientists have often assumed a uniform level of available soil water capacity for all sites (Eagleman, 1976; Major, 1977), but today it is possible to get a geographically specific estimate using the Natural Resources and Conservation Service State Soil Geographic (STATSGO) database (USDA, 1994). The STATSGO database provides 1:250,000 scale maps of soils and soil properties for the continental United States with a minimum mapping unit of about 625 ha. By overlaying each quicklook polygon on the appropriate soil coverage (each available for an entire state), we calculated an area-weighted average available water capacity for each site. Soil water capacity has a strong influence on the annual water deficits and surpluses because it determines both the amount of water stored in the soil and the proportion of actual to potential evapotranspiration, making estimations of this parameter an important step in accurate water balance calculations. A representative water balance diagram is shown in Figure 1b.



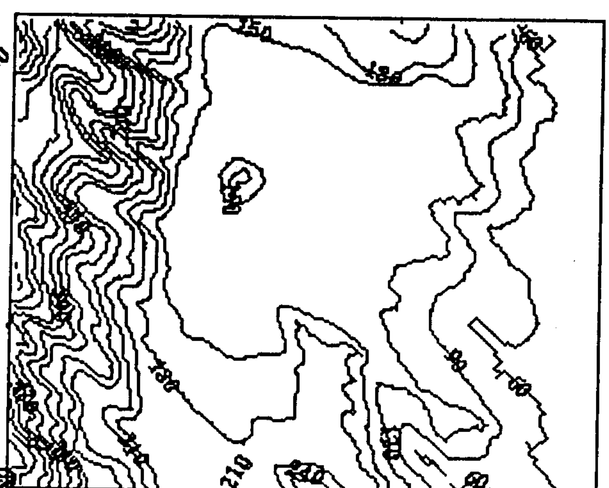
a. Map of quicklook acquisition site.



b. Climate water balance diagram.

c. AVIRIS quicklook.

d. Classified AVIRIS quicklook.



e. Topographic contour map. Interval 30 m.

f. Land use / land cover map.

Figure 1. Quicklook and Ancillary Data for AVIRIS image acquired August 15, 1994 over Jasper Ridge, California.

2.4 Topographic Data

Topographic data were acquired in the form of 1° digital elevation models (1:250,000 scale DEMs) from the USGS EROS Data Center for free over the Internet (USDI, 1994). These DEMs were developed by the Defense Mapping Agency from digitized topographic maps and photographic data sources, then interpolated to provide a lattice of elevation measurements at 3 arc-second spacing (approximately every 75 x 90 m in the continental United States, depending on latitude). The absolute horizontal accuracy of the resulting DEM is 130 m; the vertical accuracy is 30 m. For each site, the appropriate DEM was identified using an on-line map by state and county, downloaded, uncompressed and delimited, then imported into ARC/INFO. The DEM lattice was converted to a grid, then projected to an Albers Equal Area projection where x, y, and z dimensions were all expressed in meters. The corresponding quicklook area was clipped from the grid. Slope and aspect grids were derived from the DEM and then summarized by determining the minimum, maximum, mean and standard deviation for elevation, slope and aspect at each site. An example of the topographic data available is shown in Figure 1e.

2.5 Land Use Data

Land use data were acquired from the Land Use and Land Cover (LULC) database, which describes the vegetation, water, natural surface and cultural features of the land surface for the United States at 1:250,000 scale (USDI, 1990). The LULC coverages are distributed by the USGS EROS Data Center in the Geographic Information Retrieval and Analysis System (GIRAS) format, though for this study, we used ARC/INFO export coverages prepared by the US Environmental Protection Agency (see Table 1). The LULC maps are polygon coverages which were manually interpreted from high altitude aerial photography from NASA and other sources with a minimum polygon size of 4 ha (though for some non-urban, non-manmade land use types, the minimum polygon size is 16 ha.) Each polygon is coded with a Level 1 land use/land cover type, for example urban or built-up land, agricultural land, rangeland, forest land, water, wetland, barren land, tundra, or perennial snow and ice. Each of these codes is further divided into more specific, Level 2 land cover/land use codes, for example, forest land is further described as either deciduous forest, evergreen forest or mixed forest. The LULC data are presented in an Albers Equal Area Conic projection.

Land use coverages are identified by using an on-line map to find the appropriate 1:250,000 quadrangle. Each quadrangle has a corresponding EPA code which identifies the appropriate coverage to download and then import into ARC/INFO. The quicklook area of interest is clipped from the LULC coverage and summarized by proportional area of the Level 1 land use/land cover type. The LULC data have been used for several past landscape structure studies (e.g. Riitters et al., 1995; Hunsaker et al., 1994), but provide a much different sense of the landscape than remotely sensed data because they have been interpreted into homogenous polygons. An example of the land use data is shown in Figure 1f.

2.6 Analysis of Landscape Structure and Ancillary Data

Preliminary analysis of the landscape structure and ancillary datasets has consisted of univariate statistical summaries and calculation of Pearson correlation coefficients. Latitude and longitude of the scene centers were included in the correlation analysis. Only correlation coefficients significant at the 0.05 level or better were considered. Summary statistics are presented in Table 2. The correlation matrix among the analysis variables is shown in Table 3. Statistical analyses were all performed using SAS (SAS Institute, Cary, NC).

3. RESULTS AND DISCUSSION

3.1 Synopsis of the Landscape Structure and Ancillary Datasets

Substantial variation in landscape structure, climate, land use and topography is represented in this continental scale dataset. Landscape structure metrics show a large amount of variation; all coefficients of variation are greater than 0.25 except for fractal dimension and the fraction of small patches. The number of patches is quite

Table 2. Summary Statistics for landscape structure, climate, topography and land use/land cover data.

	Mean	Coefficient of Variation	Minimum	Maximum	Count
Landscape Structure					
Number of Patches	3986	0.37	679	8552	109
Number of Small Patches	3031	0.37	594	6696	109
Percentage of Small Patches	76.23%	0.05	67.18%	87.48%	109
Percentage of Class -V	49.63%	0.50	4.10%	88.98%	109
Percentage of Class -M	20.61%	0.50	1.63%	64.45%	109
Percentage of Class -S	29.76%	0.69	6.28%	94.27%	109
Perimeter - Area Ratio	0.4516	0.18	0.0410	0.7526	109
"Shape"	0.1353	0.20	0.0736	0.2529	109
Fractal Dimension	1.3383	0.05	1.2168	1.5429	109
Contagion	0.3628	0.38	0.1384	0.8354	109
Scale, by autocorrelation (pixels)	5.05	1.01	1.45	45.96	109
Texture: Angular Second Moment	3.72E-04	0.94	5.33E-05	1.95E-03	109
Texture: Inverse Difference Moment	0.1128	0.41	0.0489	0.2435	109
Climate Water Balance					
Annual Actual Evapotranspiration (cm)	59.63	0.56	9.19	135.75	106
Annual Water Deficit (cm)	51.10	1.00	0.00	170.36	106
Annual Water Surplus (cm)	50.14	0.89	0.00	185.19	106
Soil Water Capacity (cm)	10.33	0.65	0.07	28.79	109
Topography					
Mean Elevation (m)	822.02	1.13	-0.50	3429.50	109
Standard Deviation of Elevation (m)	90.84	1.05	0.20	355.40	109
Mean Slope (degrees)	5.30	1.12	0.01	21.49	109
Standard Deviation of Slope (degrees)	3.72	0.87	0.04	11.28	109
Mean Aspect (degrees)	174.57	0.21	77.03	270.00	109
Standard Deviation of Aspect (degrees)	91.59	0.26	0.00	143.02	109
Land use / land cover					
Percentage of Urban	6.44%	2.37	0.00%	88.69%	107
Percentage of Agriculture	18.99%	1.46	0.00%	99.37%	107
Percentage of Range	26.42%	1.23	0.00%	96.39%	107
Percentage of Forest	39.58%	0.97	0.00%	100.00%	107
Percentage of Open Water	1.71%	2.65	0.00%	32.18%	107
Percentage of Wetland	2.65%	3.54	0.00%	64.69%	107
Percentage of Barren	1.08%	3.24	0.00%	21.85%	107

high in comparison to landscape analyses of interpreted data (like the LULC maps) because the remotely sensed images capture the heterogeneity of the landscape that interpreted data tends to smooth. The proportion of small patches (defined as less than four contiguous pixels) was unexpectedly high, varying between 67-87% of all patches. Because small patches have a relatively small range of landscape structures, these patches were not used for calculating the other landscape structure metrics. However removing them from the analysis means that the other metrics are calculated over only 15-33% of the total patches.

The proportions of classes V, M and S (representing vegetation, mixed and soil, approximately) varied dramatically across the quicklook datasets. The proportion of vegetated surface varied from 4-89% and the proportion of bare soil varied from 6-94%. The scale, as estimated from the autocorrelation function, varied from 1-

46 pixels (40-2020 m), indicating that the quicklooks have an appropriate grain (40 m) for capturing variation of these landscapes. Scale was positively correlated with the proportion of class S in a scene and negatively correlated to the number of patches.

Variation in texture measures (angular second moment and inverse difference moment) were strongly positively correlated with contagion, since these metrics measure the homogeneity of the landscape, though from the perspective of continuous and nominal data, respectively. These measures were positively correlated with the proportion of class V in a scene, and negatively correlated with classes M and S.

The climatic water balance annual totals show significant variation site to site. Annual water surpluses vary from 0 at many sites in the western United States to over 185 cm, and deficits from 0-170 cm. Interestingly, highest surpluses and deficits were both recorded in Washington. Estimates of annual actual evapotranspiration and deficit are in similar ranges to those calculated by Eagleman (1976) and range over values that Stephenson (1990) associated with vegetation types from deciduous forest to desert scrub. Substantial variation in the available soil water capacity (from 0.07 – 28.79 cm) indicates how important this parameter is to the climatic water balance. Many earlier authors assumed constant available soil water capacities of 10 cm (Major, 1977) or 15.24 cm (Eagleman, 1976), which although good approximations can lead to serious errors.

Quicklook sites varied in elevation from sea level to over 3400 m. Slopes also varied from near flat to over 20%. The variation in slope and elevation within a quicklook scene (measured by the standard deviation of those variables) tended to increase with elevation, since most high elevation sites were in mountainous terrain.

Land use also varied widely across the sites. Agricultural, rangeland and forest land use types were the most prominent in the dataset overall, though urban and wetland land use/land cover types were locally dominant in some scenes. Agricultural land use is strongly, positively correlated with available soil water capacity.

3.2 Correlative Hypotheses between Landscape Structure and Climate, Topography and Land Use

Analysis of the correlation matrix between the various landscape structure metrics and the presumptive landscape forming elements of climate, topography and land use shows an intricate pattern of inter-correlation (Table 4). Analysis of this correlation matrix is leading to hypotheses which will be tested using path analysis.

For example, there is a strong positive correlation between annual actual evapotranspiration and the proportion of forestland in the scene, as predicted by Stephenson (1990). The proportion of forestland is in turn positively correlated with the proportion of Class V (roughly vegetation), and the proportion of Class V is correlated with homogenous, contagious landscapes as measured by angular second moment, inverse difference moment and contagion. Simultaneously, however, mean elevation is negatively correlated with both actual evapotranspiration and the proportion of Class V. Does elevation drive the pattern of actual evapotranspiration which then drives the amount of vegetation and the homogeneity of the landscape, or do actual evapotranspiration and elevation both act independently on the amount of vegetation? A similar set of hypotheses can be formulated for the relationship between elevation, rangeland, proportion of class S, and heterogeneous landscapes. Forest and range land uses may express climate derived landscape structure more clearly than other land uses because they are based on potential vegetation types which are largely climate driven.

Another set of hypotheses involves factors governing the compactness of patch shape. The available soil water capacity is positively correlated with the proportion of agricultural land use in a scene. However agriculture is negatively correlated with mean elevation, variation in elevation and mean slope. Agriculture is also positively correlated with the more compact shapes (indicated by perimeter-area ratio and fractal dimension) and negatively correlated with the fraction of small patches in the landscape.

Table 3. Correlation Matrix between Landscape Structure Metrics, and Climate, Land Use and Topography Variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1. No. of Patches	1.00																															
2. Perimeter-Area Ratio	[illegible]	1.00																														
3. Shape	-0.04	[illegible]	1.00																													
4. Fractal Dimension	[illegible]	-0.18	0.18	1.00																												
5. No. of Small Patches	[illegible]	-0.20	-0.11	[illegible]	1.00																											
6. % Small Patches	-0.13	[illegible]	[illegible]	[illegible]	-0.03	1.00																										
7. Contagion	[illegible]	[illegible]	-0.24	[illegible]	[illegible]	[illegible]	1.00																									
8. % Class - V	0.02	-0.15	-0.03	0.17	0.06	[illegible]	[illegible]	1.00																								
9. % Class - M	[illegible]	[illegible]	0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.00																							
10. % Class - S	-0.18	0.01	0.02	0.03	-0.20	-0.18	-0.14	[illegible]	0.21	1.00																						
11. Scale	[illegible]	0.01	0.00	0.18	[illegible]	-0.08	0.08	[illegible]	-0.03	[illegible]	1.00																					
12. Angular Second Moment	[illegible]	[illegible]	-0.14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.07	1.00																				
13. Inverse Difference Moment	[illegible]	[illegible]	-0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.04	[illegible]	1.00																			
14. Annual Actual ET	-0.03	-0.05	0.12	0.17	0.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.00																		
15. Annual Deficit	[illegible]	-0.14	-0.09	0.18	[illegible]	0.06	-0.22	-0.17	-0.17	[illegible]	[illegible]	0.08	0.08	-0.23	1.00																	
16. Annual Surplus	0.15	-0.09	-0.17	-0.14	0.16	0.04	-0.13	-0.01	0.16	-0.07	-0.19	-0.07	-0.09	-0.18	[illegible]	1.00																
17. Soil Water Capacity	-0.14	-0.01	0.15	0.24	-0.16	-0.12	0.06	0.11	-0.07	-0.10	-0.07	0.22	[illegible]	0.16	-0.06	0.01	1.00															
18. % Urban	[illegible]	0.07	-0.04	[illegible]	[illegible]	0.06	-0.18	0.06	0.05	-0.10	-0.02	-0.08	-0.11	0.14	0.02	-0.14	0.07	1.00														
19. % Agriculture	-0.14	[illegible]	[illegible]	[illegible]	-0.19	[illegible]	-0.16	-0.08	0.08	0.05	-0.07	0.12	[illegible]	0.00	-0.16	0.12	[illegible]	-0.06	1.00													
20. % Rangeland	-0.07	0.03	-0.09	-0.17	-0.09	-0.13	-0.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.01	0.12	-0.15	-0.15	-0.22	1.00												
21. % Forest	0.07	[illegible]	[illegible]	-0.04	0.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.23	-0.25	0.12	[illegible]	0.04	0.01	-0.18	-0.20	[illegible]	[illegible]	1.00											
22. % Water	-0.16	0.00	0.07	[illegible]	-0.16	0.11	0.17	0.06	-0.16	0.01	0.07	0.13	0.24	0.11	0.02	-0.13	0.02	0.10	0.01	0.04	-0.19	1.00										
23. % Wetland	-0.15	-0.01	0.08	0.12	-0.15	0.02	0.08	0.12	-0.13	-0.07	0.13	0.07	0.09	0.16	0.05	-0.18	0.02	-0.05	-0.08	-0.07	-0.09	0.04	1.00									
24. % Barren	0.01	0.17	0.11	-0.11	-0.01	-0.05	-0.02	[illegible]	0.10	[illegible]	0.15	-0.15	-0.13	-0.04	-0.01	-0.08	-0.07	-0.02	-0.05	[illegible]	[illegible]	-0.05	-0.02	1.00								
25. Mean Elevation	0.14	0.00	-0.17	[illegible]	0.12	-0.13	[illegible]	[illegible]	[illegible]	0.23	0.08	[illegible]	[illegible]	[illegible]	0.16	-0.04	[illegible]	[illegible]	[illegible]	0.21	0.13	-0.18	-0.20	0.00	1.00							
26. Std. Dev. Elevation	0.14	-0.14	[illegible]	-0.24	0.16	0.13	-0.04	0.06	-0.03	-0.06	0.06	-0.20	[illegible]	[illegible]	[illegible]	0.05	[illegible]	-0.16	[illegible]	-0.10	[illegible]	-0.13	-0.22	-0.12	[illegible]	1.00						
27. Mean Slope	0.10	-0.19	[illegible]	-0.21	0.12	0.20	0.05	0.13	-0.10	-0.10	-0.03	-0.13	-0.23	-0.19	[illegible]	0.06	[illegible]	-0.19	[illegible]	-0.14	[illegible]	-0.13	-0.19	-0.13	[illegible]	[illegible]	1.00					
28. Std. Dev. Slope	0.18	-0.19	[illegible]	[illegible]	0.20	0.17	-0.03	0.01	-0.03	0.01	0.03	-0.21	[illegible]	[illegible]	[illegible]	0.10	[illegible]	-0.16	[illegible]	-0.05	[illegible]	-0.12	-0.21	-0.07	[illegible]	[illegible]	[illegible]	1.00				
29. Mean Aspect	-0.06	0.05	0.11	0.05	-0.06	-0.03	0.09	0.03	-0.10	0.02	-0.06	-0.04	-0.03	0.04	0.09	0.04	-0.08	-0.09	0.02	-0.07	0.13	-0.10	-0.11	-0.02	-0.02	0.01	0.08	0.04	1.00			
30. Std. Dev. Aspect	-0.04	-0.06	0.06	-0.04	-0.05	0.01	0.16	0.18	[illegible]	-0.08	-0.07	0.13	0.07	0.13	0.06	-0.10	-0.17	-0.09	-0.15	-0.12	0.22	0.00	0.04	0.01	0.08	0.11	0.17	0.16	-0.03	1.00		
31. Latitude	-0.23	-0.15	-0.21	0.07	-0.23	-0.02	0.15	0.08	-0.04	-0.07	-0.01	0.17	0.14	-0.22	0.13	0.24	0.05	-0.19	-0.05	-0.16	[illegible]	-0.24	-0.04	-0.21	0.21	[illegible]	[illegible]	[illegible]	0.07	0.11	1.00	
32. Longitude	-0.09	-0.01	0.17	0.16	-0.08	0.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.20	0.14	0.05	0.04	-0.23	0.13	0.02	0.19	0.01	[illegible]	[illegible]	[illegible]	[illegible]	-0.02	0.11	-0.21	1.00

Pearson Correlation Coefficient Matrix.

Colored by significance levels: [illegible] [illegible] [illegible]

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