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ABSTRACT

Researchers at the Information Center for the Environment (ICE) are using ArcGIS to inventory and monitor environmental risks to California's north, coastal watersheds. In collaboration with state agencies, ICE has created a comprehensive GIS for selected watersheds in which water quality improvement and endangered species recovery is paramount. ICE has leveraged hyperspectral imagery, extensive field data, and framework datasets to provide resources managers with single source content to make decisions concerning the environmental risk of landslide potential; alterations in aquatic habitat; and land use change, among many. Our results indicate that a geospatial framework for information brokerage is critical for assessing land use decisions at a watershed scale.

INTRODUCTION

Many of California's coastal watersheds have been identified as requiring the need for Total Maximum Daily Load (TMDL) allocations for non-point source pollution such as temperature and sediment under section 303(d) of the Clean Water Act. The Information Center for the Environment (ICE) at the University of California, Davis and the North Coast Regional Water Quality Control Board have teamed up to develop new methods, in conjunction with existing ones, for inventorying and monitoring disturbance patterns at the watershed scale in support of TMDL development. This paper will present an overview of past, present and potential future research being conducted in the Gualala, Mattole and Navarro River watersheds (Figure 1).

The following entities contributed to this study in the form of project and material support: North Coast Regional Water Quality Control Board, California Department of Forestry and Fire Protection, USDA-Forest Service, California Department of Transportation, Center for Spatial Technologies and Remote Sensing, NASA-Jet Propulsion Laboratory, John Muir Institute of the Environment, and the Information Center for the Environment at the University of California, Davis.

MASS WASTING FEATURE MAPPING

The first objective of our work involved identifying mass wasting features in order to develop a sediment budget for each watershed. In addition to the mass wasting features a 1:24,000 scale DEM with a cell resolution of 10 meters and road coverages were used in the analyses. The entire Gualala River watershed was mapped and 550 mass wasting features were identified (Figure 2.). In the interest of time, only two representative subwatersheds were mapped in the Mattole River watershed. The sub-basins mapped were Rainbow and Squaw Creeks with 396 mass wasting features identified (Figure 3). In the Navarro River watershed, the North Fork of the Navarro was chosen for mapping because of available aerial photograph coverage and access for validation of the features. A total of 1064 mass wasting features were identified in the North Fork subwatershed alone (Figure 4). Timber harvesting, steep terrain and roads are all likely candidates for the high number of landslides in this sub-basin. In the remainder of this section we will examine the three methods we explored in the Navarro River watershed.

For the Navarro watershed stereo-paired aerial photographs and photogrammetric tools were used to identify active landslides for the years 1984, 1996, & 2000. All photos were at a scale of 1:12000 or better. Landslides that were greater than 0.1 hectares were drawn on acetate overlays and sequentially numbered; several attributes were also cataloged, such as natural or anthropogenic source. Each landslide was then transferred to GIS using Digital Orthophoto Quarter Quadrangles (DOQQs), at 1-meter pixel resolution, as the visual and spatial anchor. In total, 1064 landside features were identified in the North Fork Navarro watershed. Additionally, roads were identified and mapped from 1:24000 USGS Digital Raster Graphics and from the aerial photographs. The new digitized roads were combined with existing road data from the California Department of Forestry and Fire Protection and 1:100,000 scale county roads. Fieldwork was employed as a means of verification and accuracy assessment; approximately ten percent of all features were examined in the field and measured for spatial calibration of the features as well as updating attributes as needed. Similar methods were used in both the Gualala and Mattole watersheds.

The second method used was the implementation of SHALSTAB (Dietrich et al. 1999), a GIS-based, shallow-stability landslide model. SHALSTAB was run for a spatial subset of the North Fork Navarro River watershed to facilitate multi-method comparisons. We configured SHALSTAB to use a

Digital Elevation Model (DEM) created by the USGS at a nominal ground cell size of 10-meters, resampled to 5-meters. The DEM was resampled to facilitate comparisons with the AVIRIS imagery. The default values for friction angle (45 degrees) and soil bulk density (1700 kg/m^3) were used for the input parameters. The output of SHALSTAB is a landslide stability ratio (q/T ratio) grid ranging from stable (10) to chronic instability (–10) (Figure 5).

Ancillary attributes, such as elevation, curvature, slope, aspect, and proximity to hydrographic features, were generated in ESRI's GRID module from the DEM and used in subsequent analyses. We created a GRIDSTACK of these ancillary data to facilitate multivariate and zonal statistics. A total of ten random runs were generated in SHALSTAB; these randomly placed "landslides" were then analyzed against actual landslides in terms of the q/T ratio and ancillary information. These random site areas were generated using an even distribution and numeric bounds calculated from direct observations. All statistics were calculated in JMP 5.0 (SAS Institute – Cary, NC) and attributed to the random site features within the GIS. The SHALSTAB landslide analysis was a comparison of direct observations, identified on aerial photos and mapped within the GIS, to random landslide sites generated in SHALSTAB for a total of ten runs.

The AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) instrument was used to collect data for the watershed. Of the 29 flightlines that were proposed, only 26 were actually flown. The 26 AVIRIS flightlines represent 90-95% of the total watershed area and remains as of the largest single

AVIRIS collections. AVIRIS collects 224 contiguous bands of approximately 10-nm bandpass from 374 to 2500 nanometers (Green et al., 1998). The nominal size of the pixels at nadir ranged from 3.6 to 4.2 for the flightlines. The data received at ICE consisted of the uncorrected, calibrated radiance images. The geo-orthorectification of each flightlines was accomplished with the Parametric Geocoding (PARGE) program (Schläpfer 2000). Atmospheric correction was performed to remove the influence of atmospheric water vapor and aerosols using ATCOR4 (Richter 2000). For a more detailed explanation of the preprocessing sequence for the AVIRIS data see Viers et al (2002).

After calibration and correction, the AVIRIS data were transformed using the Tasseled Cap transformation and bisected at the first standard deviation below the mean to indicate pixels with exposed soil. This process allows us to restrict pixels with a significant amount of vegetation from further processing. Figure 6 shows an AVIRIS false-color composite over terrain features; spectral signatures and terrain analysis allowed further discrimination of our AVIRIS data to identify potential locations of mass wasting in Flightline 24.

Some interesting results have come out of this mapping and analysis exercise in the Navarro. One, is a comparison of source data for roads throughout the Navarro River watershed, we found significant differences in the density of road features on a planning watershed basis (Calwater 2.2).

In an analysis of road densities (km road per km^2 of watershed), photo enhanced road densities were greater than both 1:100000 and 1:24000 scale data. The closest pair-wise comparison was the enhanced roads and 1:24000 generated roads (Table 1); distributions are shown in Figure 7.

Results of the SHALSTAB analysis showed that the majority of our observed landslides fall in the domain between unstable and unconditionally unstable (Figure 8). In comparison, the log q/T ratio, or the ratio of effective precipitation to down slope transmissivity, resulted in significant differences between randomly generated sites and mapped sites.

A total of 1,064 erosional features were identified in the NF Navarro basin related to land uses such as logging and associated road networks. Preliminary estimates of the volume of debris produced (product of mapped area and depth) ranges from ~1,605,000 and 8,562,000 (m^3) for depth ranging from 0.75 to 4.0 m. Field reconnaissance suggests that about 65% of this debris is delivered to the stream network The second compelling finding from this exercise is the difference between landslide features in their source. Of the total features mapped for the NF Navarro basin, 887 were analyzed for differences in natural log transformed areas by their source of initiation: natural or anthropogenic. In this analysis of variance, there was no significant difference between the two in distributions of mapped areas (Figure 9). Anthropogenic slides, however, were more numerous (607 vs. 280).

Although we have extracted bare soil from the imagery (Figure 10), it still remains to be verified how effective this information is when combined with GIS data at detecting landslides. It is likely that the same information required for this exercise could be extracted from high spatial imagery, such as IKONOS or Quickbird, without the high storage and processing overhead required by hyperspectral imagery

RIPARIAN HABITAT MAPPING

The second objective of our study was to map riparian vegetation for the entire spatial extent of the Navarro watershed. We have taken three different approaches to do this: 1. photogrammetric methods, 2. extraction from Digital Raster Graphics, and 3. remotely sensed imagery.

Our first approach to mapping riparian extent proved to be labor and time intensive. We delineated vegetation cover on 1:24,000 scale USGS quad maps. The delineation was accomplished by viewing stereo pairs of 1:12,000 ,or better, scale aerial photographs from 1984, 1996, and 2000 and transferring the extant vegetation to the quad maps. The riparian vegetation was then on-screen digitized for all thirteen quads spanning the entire watershed. In total, the digitizing took approximately three months to complete.

An alternate approach was taken for mapping existing riparian vegetation in the Mattole watershed. Green pixels, denoting vegetation, were extracted from Digital Raster Graphics of the 1:24000 USGS georeferenced quads. The vegetation was then clipped to a buffered stream coverage. This method typically overestimates the amount of riparian vegetation and doesn't account for any recent changes in the vegetation, however, it is cost effective and does not require advanced image processing knowledge.

The last approach that was examined was the use of mapping riparian vegetation using image processing techniques and GIS in the Navarro watershed. The advantage of using spectral data is that it gives us the ability to map communities and individual species along riparian corridors based on each species spectral characteristics. The Riparian Extent data grid was created as a combination of two inputs. The first input is a Euclidean distance from streams data grid that was natural log transformed and rescaled from 1-100. A break point of 37.4 was chosen; it represents one standard deviation less than the mean. The second input represents the least cost path away from streams where Degree Slope is the cost. The results were natural log transformed and rescaled 1-100. A break point of 76.6 was chosen; it represents one standard deviation less than the mean. The Riparian Extent Mask represents the intersection of these two grids. This Riparian Extent Mask was then used to limit the influence of upslope vegetation on the spectral classification of the AVIRIS data and the Tasseled Cap Greenness plane was used as a mask to restrict the spectral classification to vegetation solely. Riparian vegetation in AVIRIS flightline 18 was extracted using the Tasseled Cap Transformation by segmenting the greenness plane such that only vegetation spectral signatures were analyzed. For a more detailed explanation of techniques used and results see Viers et al (2002). This method results in a detailed map of species and communities but comes at the expense of large images, 1.5GB and larger, along with specialized knowledge of imaging spectroscopy and digital image processing. Further processing of the data would be required for more conclusive results.

STREAM SHADING (RipTopo)

The spatially explicit, riparian-topographic stream shading model RipTopo uses readily available geodata and existing algorithms to provide a simple surrogate measure for stream shading (Viers 2003). All of our geographic information system coding and computation was implemented in the ArcInfo 8.1 GRID raster module (ESRI 2002). The RipTopo model calculates the effective shade for a stream channel based on sun position, topography, stream location and orientation, the unvegetated channel width, the distribution of vegetation types in the watershed, and the adjusted potential height of mature vegetation (Viers 2003). RipTopo is a macro-scale surrogate measure model for stream shading and, thus, stream temperatures on a spatially explicit basis.

The summary method of RipTopo is to summarize hourly sun angles on a surface depicting riparian cover and topography, less streams at bankfull width (Figure 11). We performed this modeling exercise for the Navarro and Mattole watersheds with comparable results shown in Table 2 for the

Navarro. To verify the stream shading estimates predicted from RipTopo, monthly Solar Pathfinder field measurements (June – August) were regressed against RipTopo estimates for corresponding dates of interest (0622, 0727, 0826). Individual shading measurements for stream segment estimates of shade resulted in significant linear relationships ($P < 0.10$) and explained greater than 50% of the variance in two of the three cases tested, June and July (Table 2). RipTopo results for August explained 45% of the variance and the beta estimate was significant ($P < 0.0001$).

CONCLUSION

We feel that each method of analysis presented here provides needed information in detecting disturbance patterns at a landscape scale. Remote methodologies will become increasingly important to land use managers of landscape scale areas as these technologies develop. Land use change in north, coastal California has resulted in detrimental impacts on anadromous salmonids and their spawning and rearing habitats. The use of aerial photography, terrain based modeling (SHALSTAB), and hyperspectral data (AVIRIS) analysis are each worthwhile in their own respects; however, it is the ability to use these media and methods in concert which allow researchers to gain added insight. We feel that future analyses of these data will help ongoing efforts aimed at the conservation and restoration of habitats supportive of continued salmonid presence in the north coastal watersheds of California.

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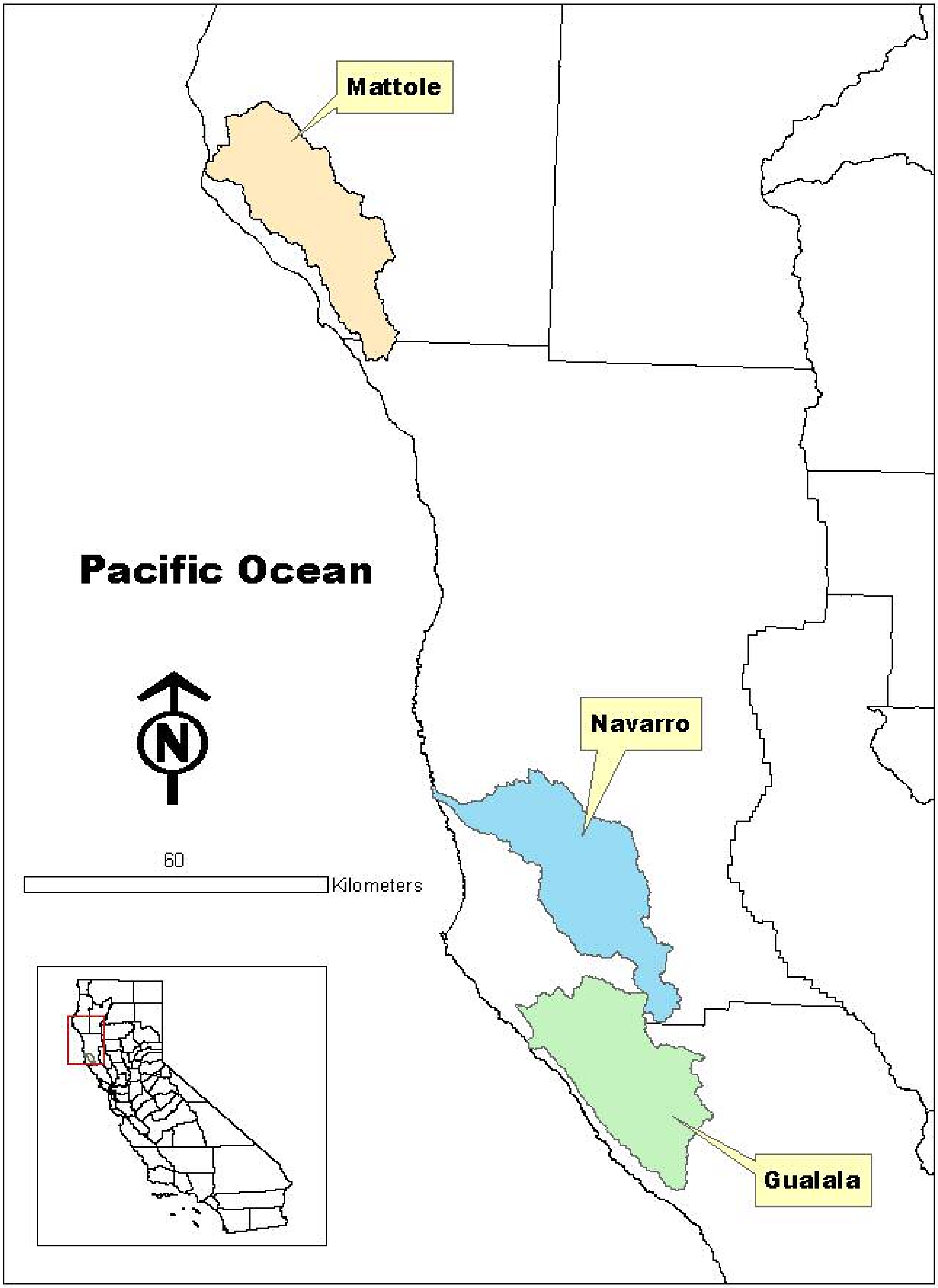


1. Northern California watersheds requiring TMDL development.

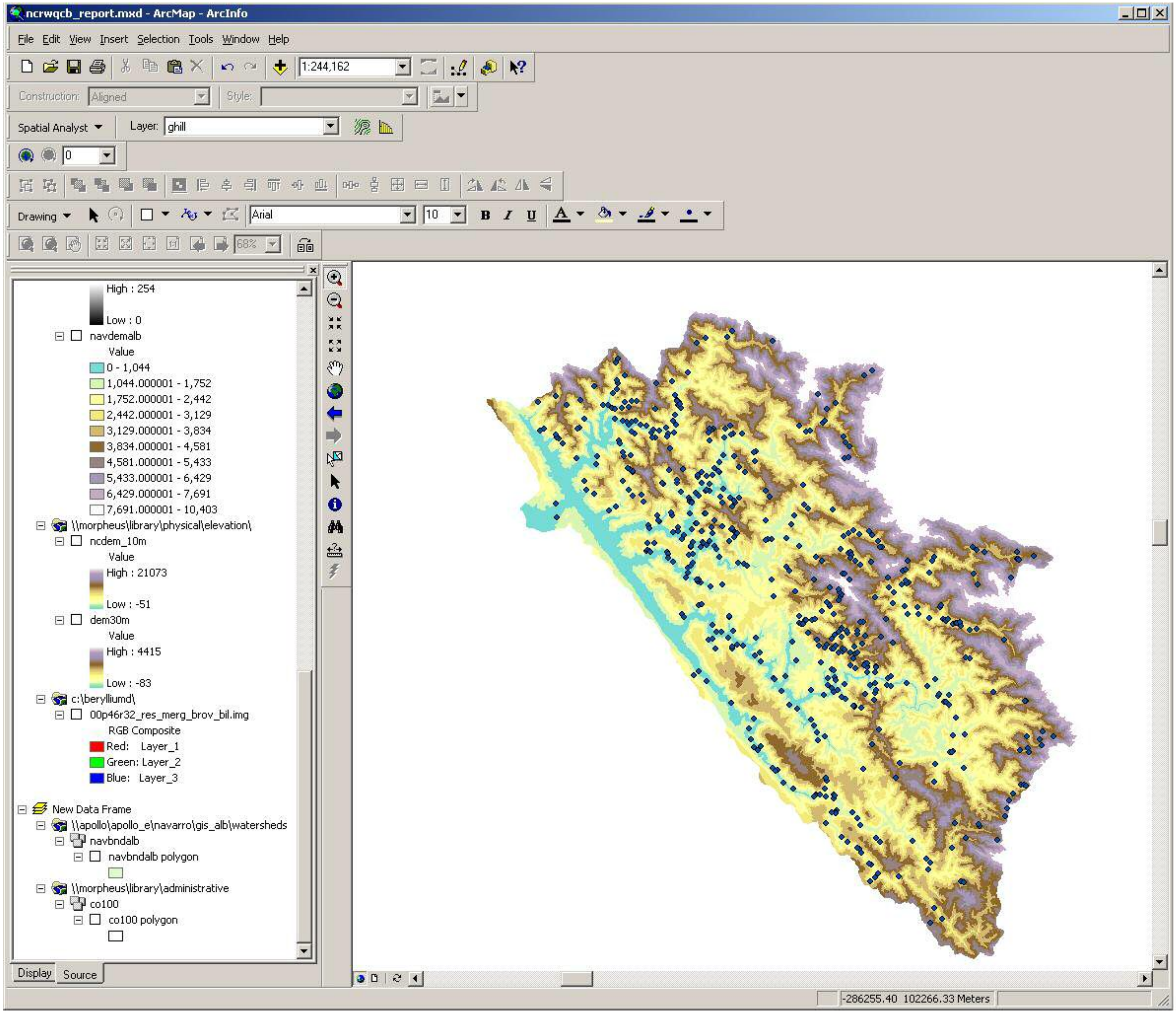


Figure 2. Mass wasting features identified in the Gualala River watershed, Mendocino and Sonoma County, California.

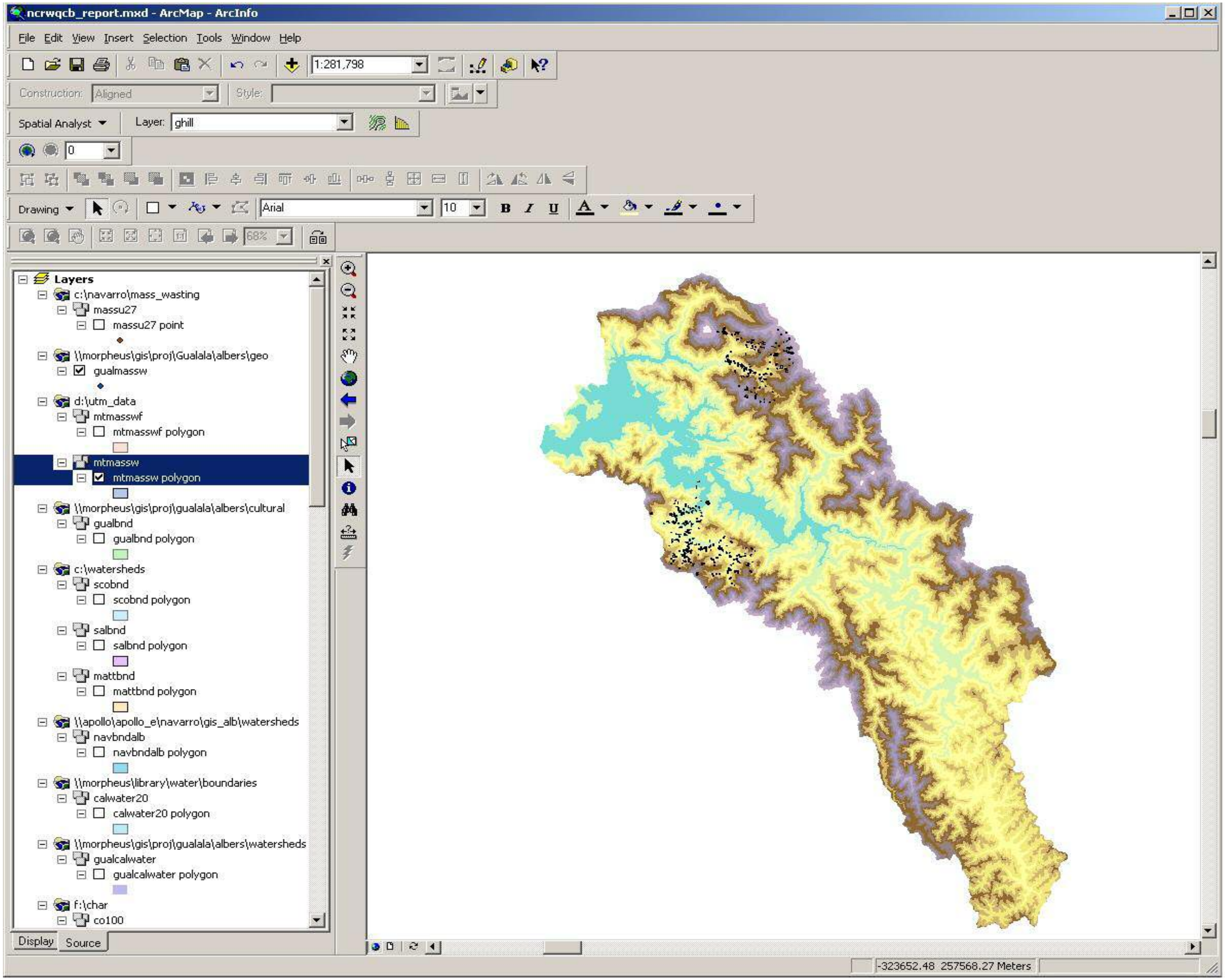


Figure 3. Mass wasting features identified in the Mattole River watershed, Mendocino and Humboldt County California.

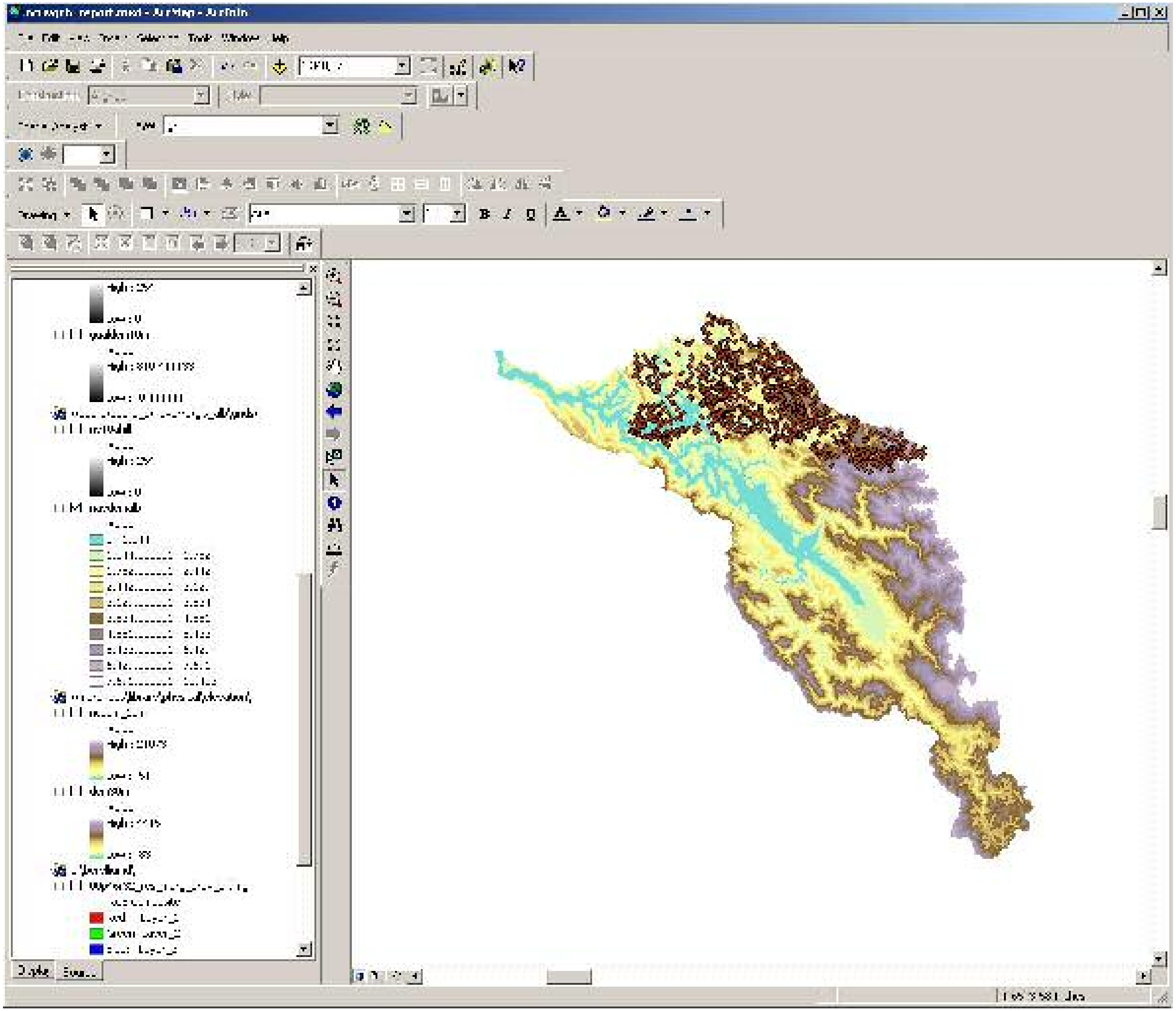


Figure 4. *Mass wasting features identified in the Gualala River watershed, Mendocino County, California.*

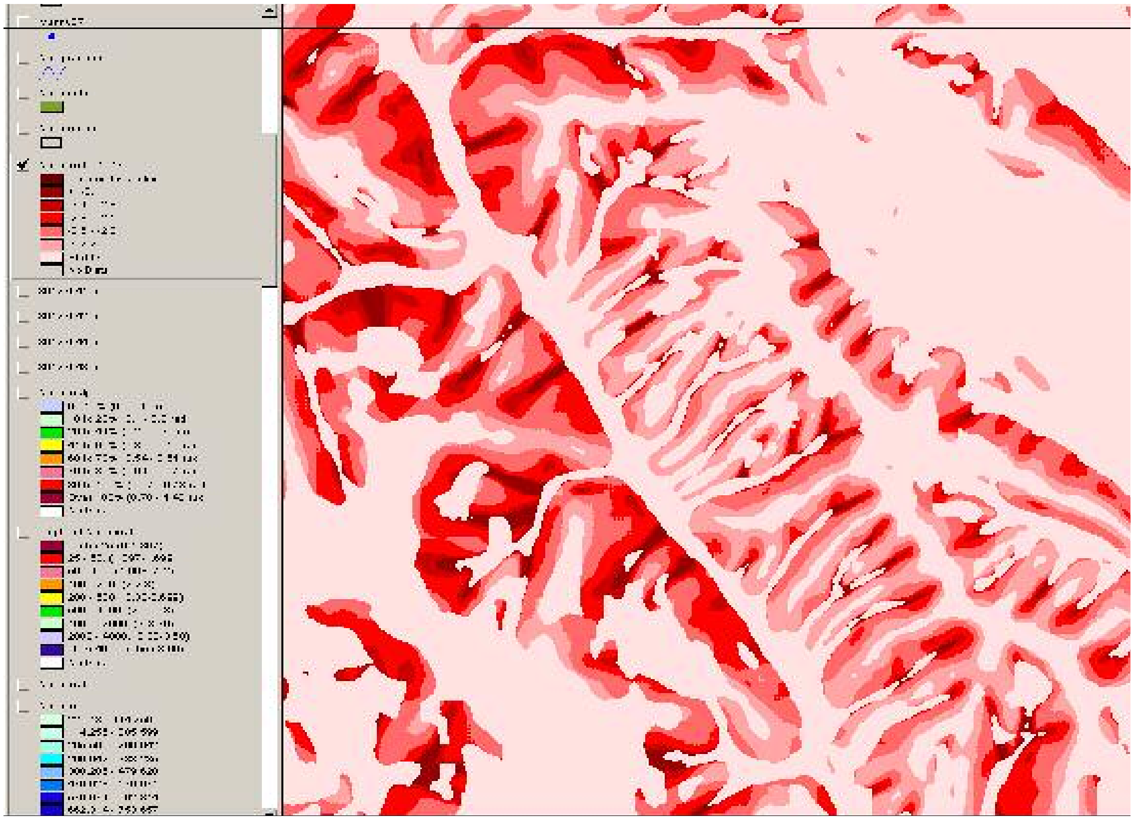


Figure 5. SHALSTAB generated grid; dark areas are more unstable.

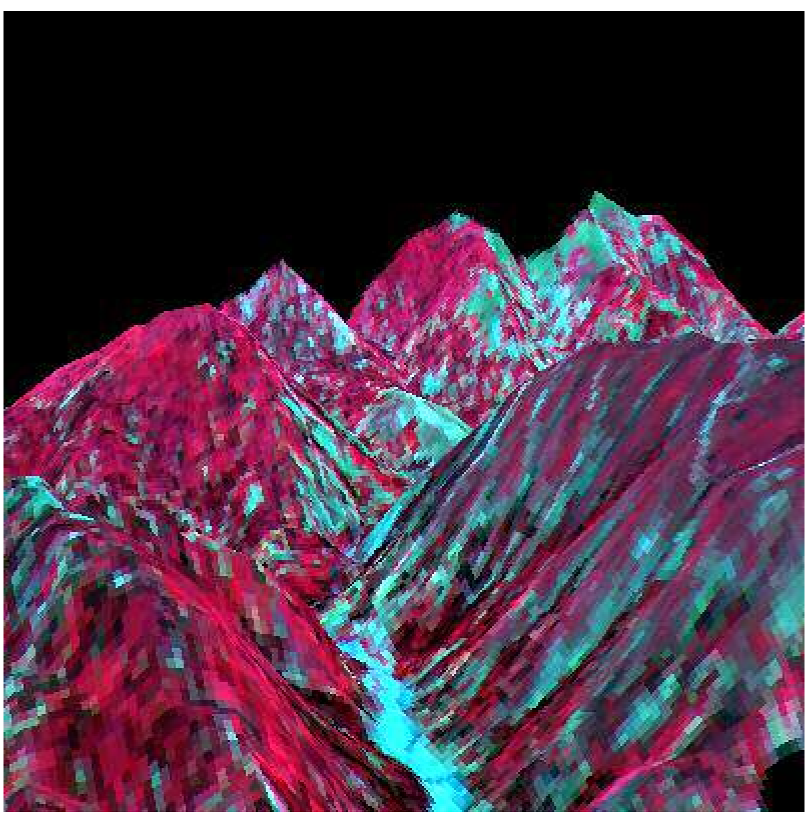
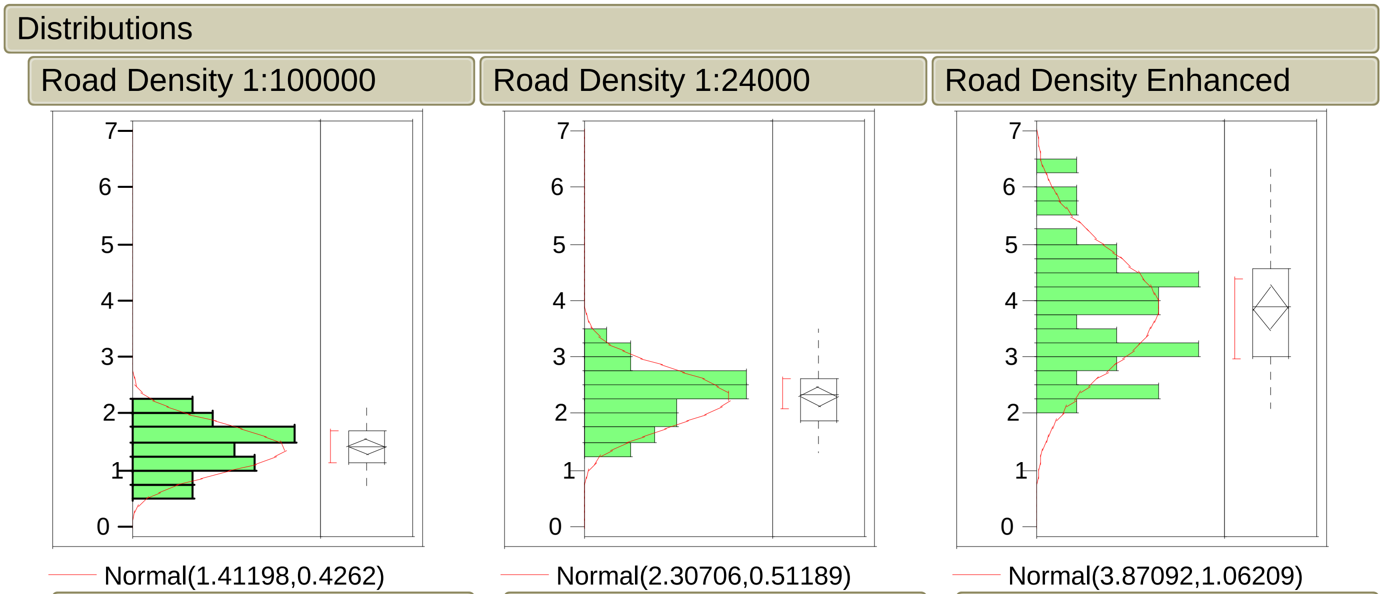


Figure 6. Digital elevation model with AVIRIS false-color composite image overlay



Moments

	Road Density 1:100000	Road Density 1:24000	Road Density Enhanced
Mean	1.4119781	2.3070574	3.8709234
Std Dev	0.4262005	0.5118882	1.0620875
Std Err Mean	0.0753423	0.0904899	0.1877523
upper 95% Mean	1.5656398	2.4916128	4.2538468
lower 95% Mean	1.2583164	2.122502	3.488
N	32	32	32

Figure 7. Road densities for 1:100,000, 1:24,000 and Enhanced roads coverages.

Road Density Enhanced	3.87092		t-Ratio	8.551209
Road Density 1:24000	2.30706		DF	31
Mean Difference	1.56387		Prob > |t|	<.0001
Std Error	0.18288		Prob > t	<.0001
Upper95%	1.93686		Prob < t	1.0000
Lower95%	1.19087			
N	32			
Correlation	0.2941			

Table 1. Pair-wise comparison of Enhanced roads and 1:24,000 roads.

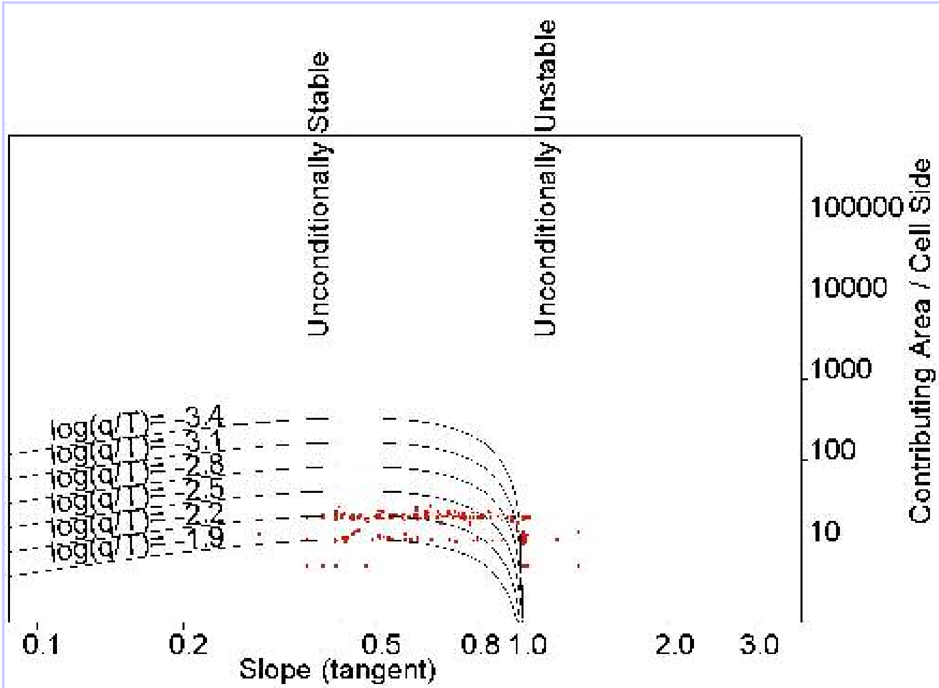


Figure 8. Results of SHALSTAB analysis.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Source	1	0.94430	0.944300	2.2359	0.1352
Error	885	373.76095	0.422329		
C. Total	886	374.70525			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Anthropogenic	607	7.41889	0.02638	7.3671	7.4707
Natural	280	7.48909	0.03884	7.4129	7.5653

Std Error uses a pooled estimate of error variance

Figure 9. ANOVA results of anthropogenic vs. natural slides.

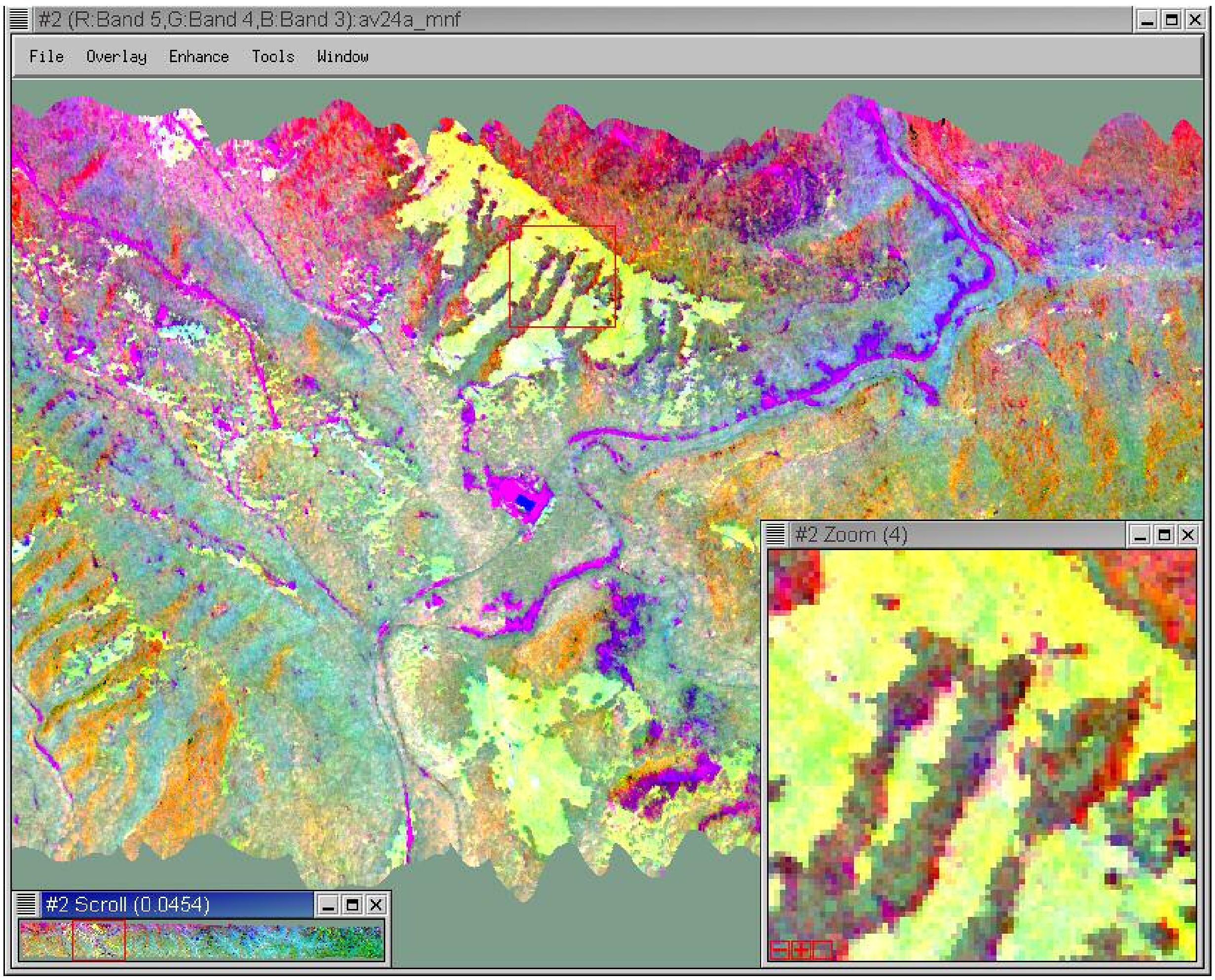


Figure 10. AVIRIS image showing close up of exposed soil.

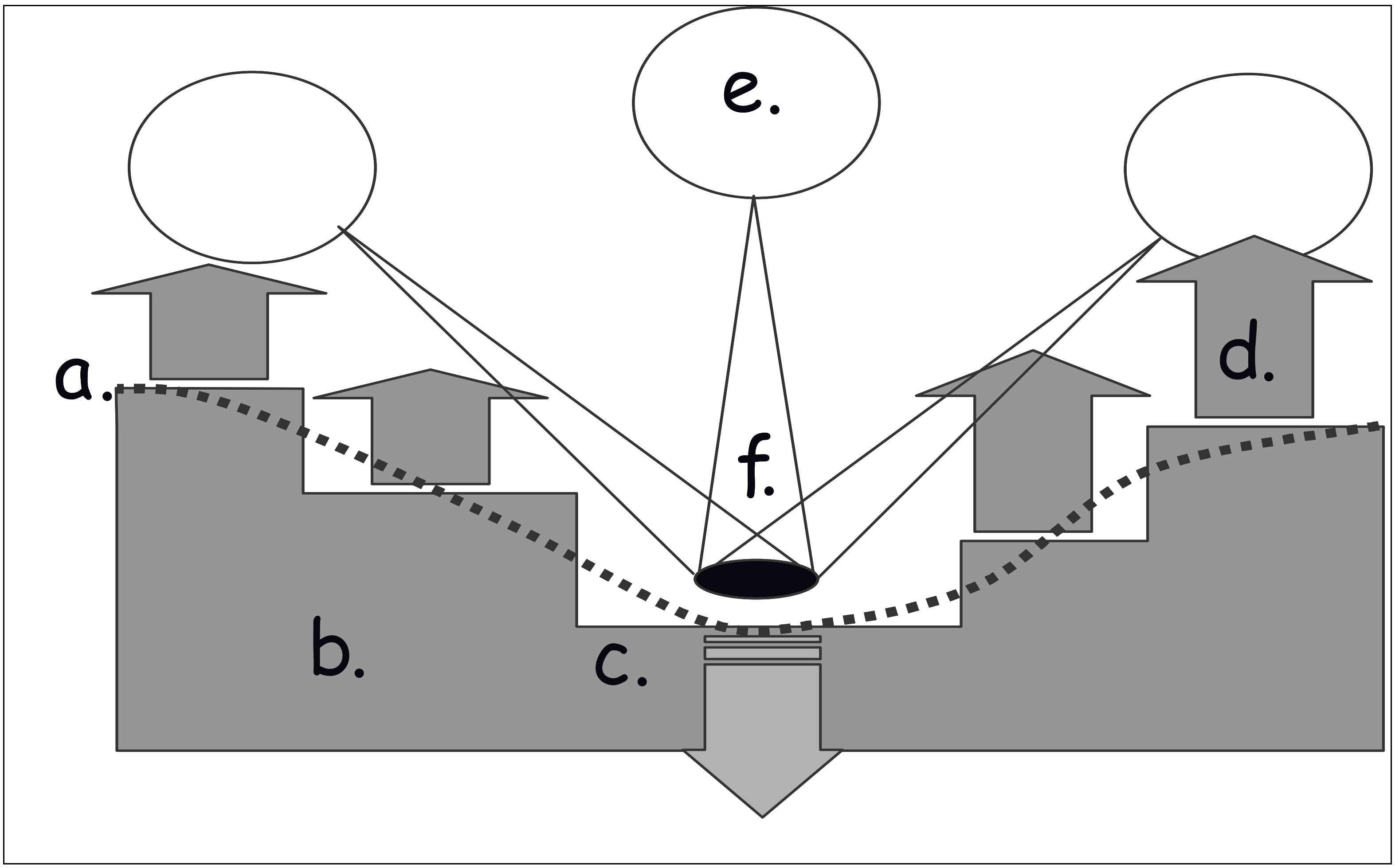


Figure 11. Schematic of RipTopo: a.) Cross-section of stream valley as characterized by b.) a Digital Elevation Model and c.) adjusted for stream bankfull width is the basis for d.) adding tree height from vegetation cover data to screen e.) hourly sun angles, which are f.) summed for each cell and summarized for each stream segment. Taken from Viers (2003).

RipTopo Run Date	Tukey-Kramer HSD Groups														RipTopo Mean Shade (%)
0831	A														71.3
0826		B													68.6
0821			C												65.6
0816				D											62.8
0811					E										60.4
0806						F									58.6
0801							G								56.7
0727								H							54.8
0722									I						53.0
0717										J					51.7
0712										J	K				50.6
0602										J	K	L			50.5
0707											K	L	M		49.8
0607											K	L	M	N	49.7
0702												L	M	N	49.2
0612													M	N	49.0
0627													M	N	48.7
0617													M	N	48.6
0622														N	48.5

Table 2. Comparison of RipTopo runs for different dates, HSD Groups, and mean predicted shade in the Navarro River watershed. Taken from Viers (2003).