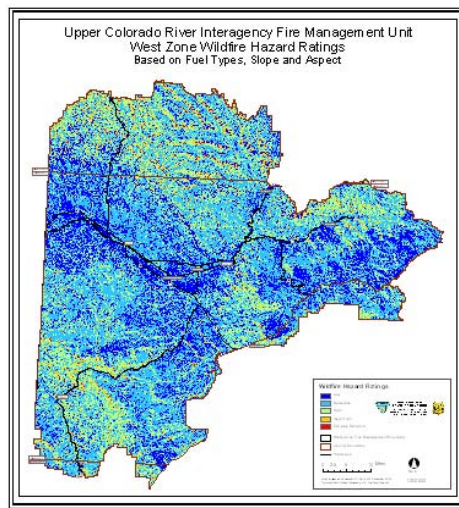


PROJECT REPORT

Calculating Wildfire Hazard Levels: Algebraic Raster Construction using Spatial Analyst



PREPARED FOR

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AND

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Abstract

Arc GIS Spatial Analyst, one tool in the ArcGISv.8.3 software suite, was used to develop a raster grid predicting hazard levels in wildfires within a western Colorado fire management zone. The term hazard refers to dangers related to fire behavior rather than risk of ignition. This layer was constructed using the Reclassify and Raster Calculator utilities within Arc GIS Spatial Analyst and ESRI extension Raster Clipper. Spatial Analyst evaluated hazard factors such as slope, aspect and fuels. Reclassify assigned break and integer values to analyzed hazards. Map Algebra expressions derived output cell values based on summed integers and included the condition that a zero score in the fuel model must return a zero value to the output cell.

Tested for correct function in ArcGIS, the map will be evaluated further both electronically and in the field. Wildfire management agencies are using electronic versions of the project, as well as paper maps constructed from it, to anticipate fire behavior, safety concerns and resource allocations during the 2005 wildfire season. Analysis based on comparisons of the new map with historic fire perimeters is proceeding and development may include weighted calculations of reclassified fuel models within such boundaries.

Introduction and Purpose

Whether lightning or human caused, wildfires are now and have always been common occurrences across western Colorado. Before Colorado was settled, frequent fires helped maintain open, healthy forest structures, sometimes replacing forested lands with grass and shrublands. Fire is a natural process, often driving functions integral to ecosystem evolution. The term 'fire regime', used most simply, refers to the patterns of fire frequency that occur over long periods of time (Grahame and Sisk, 2002). Frequency is determined largely by ecosystem characteristics, duration and character of precipitation patterns and ignition sources. The intensity of a fire is affected by the inherent combustibility, moisture content and quantity of a fuel, combined with existing weather conditions. Interactions between frequency and intensity are influenced by other factors such as aspect, topography and fuel complex characteristics.

Topography exerts a major influence on local weather and fire conditions, especially in areas of complex terrain. It is a major factor in determining type and amount of fuels. It also influences ignition, direction, intensity and rate of fire spread. Aspect, the direction a slope faces, directly affects fire danger and behavior because the amount of solar radiation a site receives in turn affects the amount of moisture in a given fuel, whether the fuel is litter or actively growing vegetation. Slope, meaning steepness or percent of incline, is an important factor in determining how fires ignite and spread. On sharper gradients, flame lengths are longer because the slope has the same effect as an increasing wind, effectively preheating upslope fuels, which in turn contributes to more rapid fire spread. Also, when slopes are steep, heat rising from the fire generates convective winds which subsequently carry more air, heat and flame upslope.

Fire has played a major role in shaping the composition, structure, and function of the vegetative communities throughout Colorado. Particularly effected are those of the Ponderosa pine, pinyon juniper woodland, mountain shrublands, and sagebrush grasslands at lower elevations (Covington and Moore 1994) and the high-elevation sub-alpine forests, composed mainly of subalpine fir, Engelmann spruce, Douglas fir, lodgepole pine, and aspen (Grahame and Sisk, 2002). However, since the threat of fire led to an approximately 60-year history of fire suppression on the public lands, these historic vegetative communities are now considerably altered (Grahame and Sisk, 2002). Changes include increased density of trees, invasion of trees into formerly shrub or grass-dominated areas, increased abundance of saplings, fewer large trees, increased fuel accumulations, dominance of older age shrubs, and fewer native bunchgrasses and forbs (Lewis, 2001).

Mild winters, warm, dry summers, and consecutive years of severe drought have continued to place added pressure on Colorado's already stressed wildlands. Large fire incidents burned approximately 675,000 acres in 2002, leaving many critical watersheds in need of both emergency and long-term rehabilitation (Lewis, 2003). Lower elevation pinyon-juniper and ponderosa pine forests characterize much of the state's high-risk wildland-urban interface. These are the forests that have been most affected by previous decades of fire exclusion and changing land management objectives. These and other lands across Colorado offer great opportunities for diverse stakeholders to work together at the local level on projects that increase community protection while improving forest conditions on the ground (Lewis, 2003).

Stakeholders in this project include the author, Mesa State College, the Bureau of Land Management, Grand Junction Field Office, the West Zone of the Upper Colorado River Interagency Fire Management Unit (UCR) and anyone who might be affected by wildfire in western Colorado.

It was conceived by the author, an undergraduate GIS minor at Mesa State College in Grand Junction, Colorado. Development of the project was encouraged and supported by Verner C. Johnson, PhD, director of Mesa State College's GIS program and W. Timothy Foley, West Zone Colorado Fire Management Officer (FMO).

The UCR came into existence as a result of the 1995 Federal Wildland Fire Policy. It required the integration of fire management with forest and resource management objectives, and the full involvement of interagency partners and the public in fire management (USDOJ, 2001). The UCR consists of the West, Central and East Fire Management Zones and the Grand Junction Air Center. The West Zone covers over 1,900,000 acres (2,960 square miles) of national forest and other public lands in western Colorado (Fancher, 2004). Agencies supporting West Zone operations are the Bureau of Land Management's Grand Junction and Glenwood Springs Field Offices and the U.S. Forest Service's Grand Valley and White River Ranger Districts. Cooperating agencies include the Mesa County Sheriff, Colorado State Forest Service, and the Colorado National Monument, part of the National Park Service.

The project was conceived with the purpose of developing an electronic data file, of the grid type known as a raster dataset, which would calculate and display wildfire hazard ratings anywhere in the West Zone. The software package ArcGIS v.8.3, a product of Environmental Systems Research Institute (ESRI), was employed to produce it. Factors included in the analysis and design were aspect, slope, vegetation and other land surface covers. This raster file is currently being used to produce printed maps for purposes of presentation and at-a-glance assessment of area hazards, but its real strengths should be proven during its use as an electronic resource for further GIS analysis during upcoming wildfire seasons.

Methods

The electronic file that provided the foundation for much of the project is a Digital Elevation Model (DEM) of part of western Colorado that includes the West Zone (Fig 1.). A DEM is a representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. It is typically used to represent terrain relief electronically, as part of a Geographic Information System (GIS). Projected coordinate system of the file is North American Datum (NAD), 1983, Universal Transverse Mercator (UTM), Zone 13 North. Format is a single band ESRI grid. All outputs were saved in the same coordinate systems. A vector dataset, West Zone Boundary, was used to clip the DEM, using the ESRI extension Raster Clipper (Fig. 2). The tool Spatial Analyst, part of the ArcMap software package, was used extensively throughout the remainder of the project, to analyze and reclassify the clipped DEM and other raster datasets produced during spatial analysis. Spatial Analyst options were set, for all raster output, as follows:

Analysis Mask: None
Extent: Same as west_zone polygon
Cell Size: Same as gjdem83
Analysis cell size: 9.152311952
Number of rows: 14952
Number of columns: 14908
Number of cells: 222,904,416 cells

ArcMap's Spatial Analyst tool was first used to analyze the clipped DEMs for percent slope and aspect, producing two more raster datasets (Fig. 3, 4). Each of the raster datasets was then reclassified, using Spatial Analyst tool Reclassify. Each reclassification created a new raster layer. When reclassifying slope, break values were set at 20, 40 and 818.4482422, the highest value in the percent slope dataset. For purposes of fire spread and hazard analysis, slopes of less than 20% are least dangerous. Slopes of over 40% are most hazardous in terms of fire behavior and fire fighting. After reclassification, each of the three new classes was assigned a new integer value that would later be used in calculating hazard ratings. Integer values for slope classes were set at 0, 1 and 2, respectively (Fig. 5). The aspect raster was reclassified next. Southwest facing slopes, the most

dangerous in terms of fire behavior, were assigned the highest integer value of 3. South and west-facing slopes were assigned a value of 2, slopes with southeastern aspects were assigned the integer value of 1. All other aspects were assigned a value of 0, being of least concern in terms of fire hazards. Compass bearings were given directional labels, with an eye toward user-friendliness (Fig. 6).

The next step was to develop a fuel model of vegetation and land surface cover. A statewide raster delineating all cover types was available. 103 cover types of all kinds were mapped and documented by class name (Fig. 7). They included urban and rural uses, vegetative communities and areas of rock and water. Examples of class names: Urban/Built-up, Irrigated Agriculture, Sparse Juniper/Shrub/Rock Mix and Disturbed Rangeland. Again, Raster Clipper was employed to clip the statewide raster to West Zone boundaries, bringing the number of classes down to 70 (Fig. 8). W.T. Foley, West Zone FMO, manually assigned numbers to the classes such that integer values ranged from 0-3. Values of 0 were assigned to non-combustible surfaces such as Water, Rock, Soil and Barren Land. Zero values were also assigned to areas usually included in the mandates of other types of firefighting agencies, though UCR resources could be made available to them if necessary. Examples of these classes include Commercial and Residential. Least flammable vegetative classes such as Aspen/ Mesic Mountain Shrub Mix and Irrigated Ag were assigned integer values of 1. Classes receiving values of 2 included Herbaceous Riparian and Sub-Alpine Shrub Community. Highest values of 3 were assigned to most dangerous vegetation communities, such as Sagebrush/ Rabbitbrush Mix and Grass/ Forb Rangeland. As fuels, these are most likely to contribute to fire spread or intensity. Again, a new raster layer with reassigned integer values for cover types was created using the Reclassify tool (Fig. 9).

Three rasters had been created and named to be understandable at a glance: Reclassification of Slope Raster, Reclassification of Aspect Raster and Reclassification of Colorado Vegetation, which acted as the fuel model. It was time to write an expression to calculate, using the recently assigned integer values, the wildfire hazard ratings for the lands in the West Zone. To this purpose, another tool in Spatial Analyst, Raster Calculator, was used to design an expression, or algorithm, using arithmetic, Boolean and relational operators.

Raster Calculator was used to design an expression to calculate, using the assigned integer values, the wildfire hazard ratings for the West Zone. Spatial Analyst, through the Map Algebra language, provides tools to perform operations, conditional statements, and local, focal, zonal, global, and application functions (ArcGIS Desktop Help). One such local function is the Conditional or Con function, written as a statement that is evaluated on a cell-by-cell basis. This specifies which computing action to take, depending on the conditions. Specifications include conditions that must be evaluated as True before an action can be taken, as well as actions to be taken when the conditions are evaluated as False. The traditional If-Then-Else statement is an example of a conditional statement.

The syntax of the Con function is:

CON (condition, true expression, condition, true expression, false expression)

where 'condition' is a conditional expression that is evaluated for each cell in the analysis extent (ArcGIS Desktop Help). If the condition is True, 'true_expression' identifies the value to be used to compute the output cell value. If none of the results of the evaluations of the conditional statements is True, a value or expression can be applied to the cells through the 'false_expression' optional argument. When syntax rules are violated, no result is created and Spatial Analyst returns an error message.

The hazard rating was to be assigned based upon addition calculations of the integer values assigned to the three layers. For example, should the fuel model return a value of 3, the aspect a value of 2 and the slope a value of 1, the sum of 6 would fall into a created hazard category with that value. These calculations would be performed for all cells in each designated raster, so that all surfaces in a landscape would be assigned numbers from 0-8. Simple in concept to this point, another condition had to be applied to the expression. If the fuel model returned a value of 0, and the other layers contributed integer values greater than 0, a moderately high hazard rating could be assigned to a non-combustible surface. For example, if the fuel layer returned a zero value for a rock outcrop, but it faced southwest and had a slope in excess of 40%, the hazard rating of 5 would be assigned to cells meeting those conditions. The Map Algebra statement had to be designed to return a zero value for the calculated result every time that the vegetative fuel model scored a zero value.

As there were two functions to be performed within the algorithm, it was designed in two steps. The first was to return a 0 value for appropriate areas, according to fuel model values. The expression that was used to accomplish this was:

$$\text{Grid Layer1} = \text{CON}([\text{Reclassification of Colorado Vegetation}] < 1, 0)$$

The raster that was created with this conditional statement correctly identified and displayed the zero-valued cells in the vegetative layer as a single class with a value of zero (Fig. 10).

The second step in writing the expression was to sum the values of all three layers. The expression which performed this operation was:

$$\text{Grid Layer2} = ([\text{Reclassification of Colorado Vegetation}] + [\text{Reclassification of Aspect Raster}] + [\text{Reclassification of Slope Raster}])$$

The resulting raster grid correctly summed the assigned integer values of the slope, aspect and vegetative/fuel layers, assigning them to new output grid cells. This generated nine classes with values from 0-8 (Fig. 11).

When combined and reconfigured, the final expression that was used to build the raster layer that successfully performed both functions was:

$$\text{Test} = \text{CON}([\text{Reclassification of Colorado Vegetation}] > 0, \\ ([\text{Reclassification of Colorado Vegetation}] + \\ [\text{Reclassification of Aspect Raster}] + [\text{Reclassification of Slope Raster}] , \\ ([\text{Reclassification of Colorado Vegetation}] < 1), 0)$$

Loosely translated, this says, “Create a raster layer named ‘Test.’ If the condition that the value of a cell in the grid Reclassification of Colorado Vegetation is greater than zero is True, then assign the output cell a value calculated by summing the associated cell values in the layers Reclassification of Colorado Vegetation, Reclassification of Aspect Raster and Reclassification of Slope Raster. If the previously specified condition is False, assign the output cell a value of zero.” The resultant raster file worked well to display the nine identified classes of hazard (Fig. 12).

Five ranges of hazard were desired, that could be assigned labels of Low, Moderate, High, Very High and Extreme. Again, using the Reclassify tool in Spatial Analyst, break values of the data were set at 2, 4, 6, 7 and 8, respectively. This newly generated raster successfully embodied the pinnacle of the project’s ambitions (Fig 13).

Results and Discussion

The project was relatively simple in concept and design. It was inspired by a class lecture and discussion that described the possibilities for spatial analysis and reclassification offered within the ArcGIS Spatial Analyst. The opportunity to explore such possibilities while combining them with interesting and useful data was hard to pass up. Steps of clipping and reclassification were

fairly straightforward, with progress being slowed only by the manipulation of large files and the author's unfamiliarity with the tools. Writing the sections of the algorithm in two steps was a good way to gain understanding of Map Algebra tools and syntax. Each of the first two layers successfully calculated was tested individually to determine whether it was functioning as intended (Fig. 14). The ArcMap Identify tool was used to check from which layers calculations were being derived, as well as whether correct cell values were reflected in the output grid. The final layers were tested in the same manner (Fig. 15).

Writing the single expression that combined both functions was a little more complicated. Beginning with two expressions, the first inclination was to use a Boolean operator like AND or OR to connect the two. Writing a simpler expression that included the addition section of the algorithm as the instruction to be followed should the condition be evaluated as False turned out to be the way to go. Research into Map Algebra, the CON function and correct syntax, as well as trial and error, eventually led to a functional expression. Often, a matter of a space or the placement of a parenthesis was of some import. Carefully documenting every successful and failed expression minimized confusion to some extent:

```
expgrid = [Reclassification of Aspect Raster] + [Reclassification of Colorado Vegetation] +
[Reclassification of Slope Raster]
Works: expgrid = ([Reclassification of Aspect Raster] + [Reclassification of Colorado Vegetation] +
[Reclassification of Slope Raster])
expgrid2 == CON((([Reclassification of Colorado Vegetation] == 0),0)
expgrid2 = CON((([Reclassification of Colorado Vegetation] = 0),0)
Works: expgrid2 = CON((([Reclassification of Colorado Vegetation] < 1),0)
Works, but didn't give me what I was after: expgrid2 = CON((([Reclassification of Colorado Vegetation] <
1),0) & ([Reclassification of Aspect Raster] + [Reclassification of Colorado Vegetation] + [Reclassification
of Slope Raster])
expgrid3 = ([Reclassification of Aspect Raster] + [Reclassification of Colorado Vegetation] + [
Reclassification of Slope Raster]) & CON((([Reclassification of Colorado Vegetation] < 1),0)
```

Conclusion

Immediate analyses of the map's accuracy can be pursued in GIS by imposing perimeters of previous fires on the new layer. If the patterns of these burns follow the expectations to which the map leads us, it may further lead us to expect real utility from it. Future development could conceivably include historic wildfire perimeters, weighted by age, being included in hazard calculations. For example, if an area has been substantially burned within a relatively recent time frame, it is reasonable to expect less hazardous fire behavior now than could be expected from the same area had it not burned. Or, if the area has been burned, then re-colonized by annual vegetation such as cheatgrass, more rapid spread might be expected due to the change in fuel complex.

The final product of this project, the calculated raster grid depicting combined wildfire hazard ratings for the West Zone, has yet to be proven in use during a wildfire season. A paper copy of the layer, developed as a map, entitled "Upper Colorado River Interagency Fire Management Unit: West Zone Wildfire Hazard Ratings Based on Fuel Types, Slope and Aspect," as well as the electronic file that is its foundation, will be distributed to participating and supporting agencies of the UCR. Each agency will be asked to utilize it to predict and manage wildfire behavior and firefighting resources during the upcoming 2005 fire season. For example, when an initial attack crew arrives at the scene of a newly reported fire, the crew immediately calls Grand Junction Dispatch with latitude/ longitude coordinates of the location, based on readings taken with handheld GPS receivers. These coordinates may then be immediately located on the West Zone Hazard Ratings map, both on the wall and in GIS, so that fire behavior, resources and safety needs for both the firefighters and the public might be better anticipated and planned. As the fire season progresses, it will remain to be seen whether the factors used to predict hazard values will prove to be appropriate.

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Douglas Diekman

GIS Coordinator, Bureau of Land Management, Grand Junction Colorado Field Office

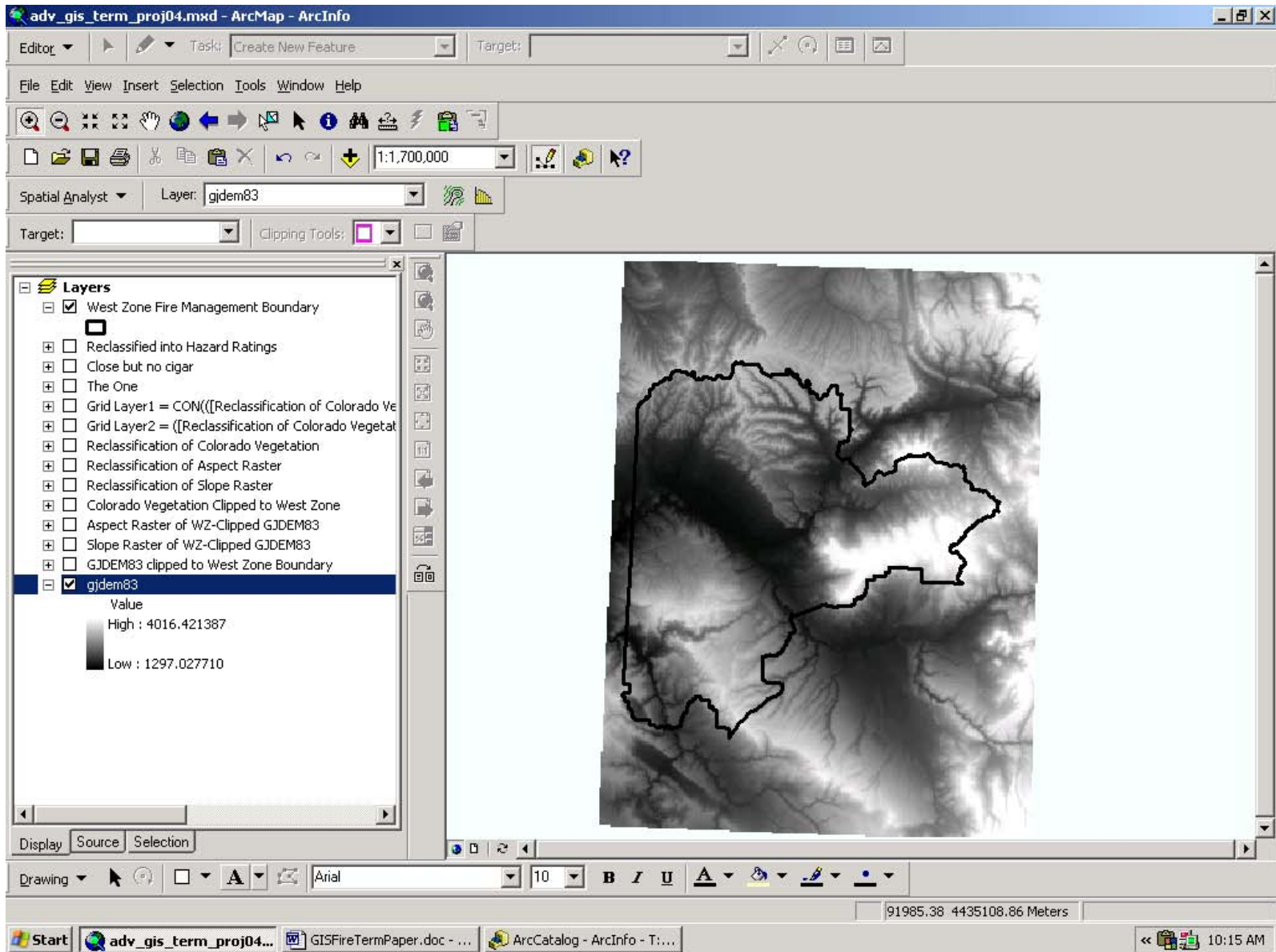


Fig. 1. West Zone Fire Management Boundary, superimposed on Grand Junction Digital Elevation Model (DEM)

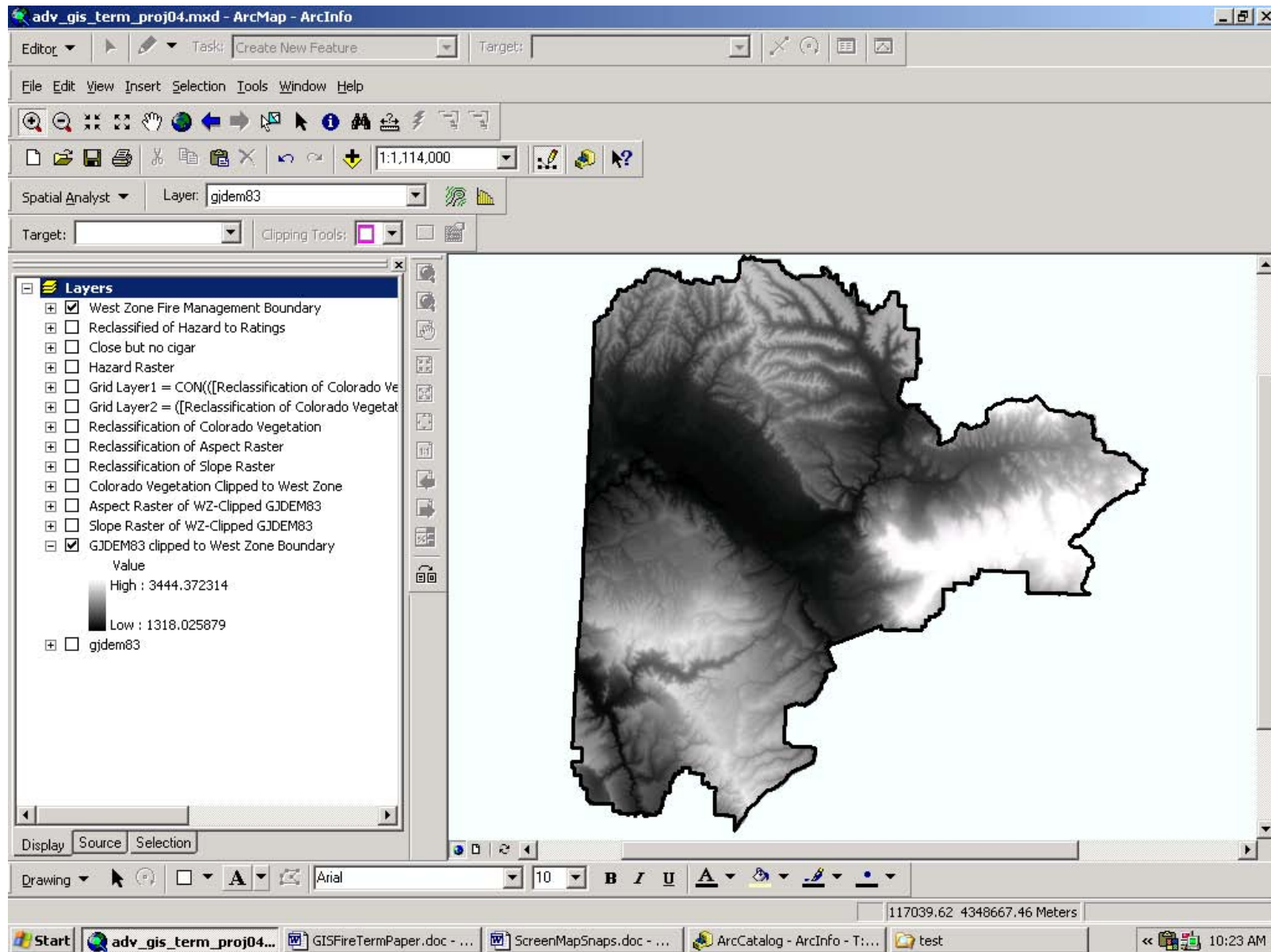


Fig. 2. Grand Junction DEM, clipped to West Zone Fire Management Boundary, using extension Raster Clipper

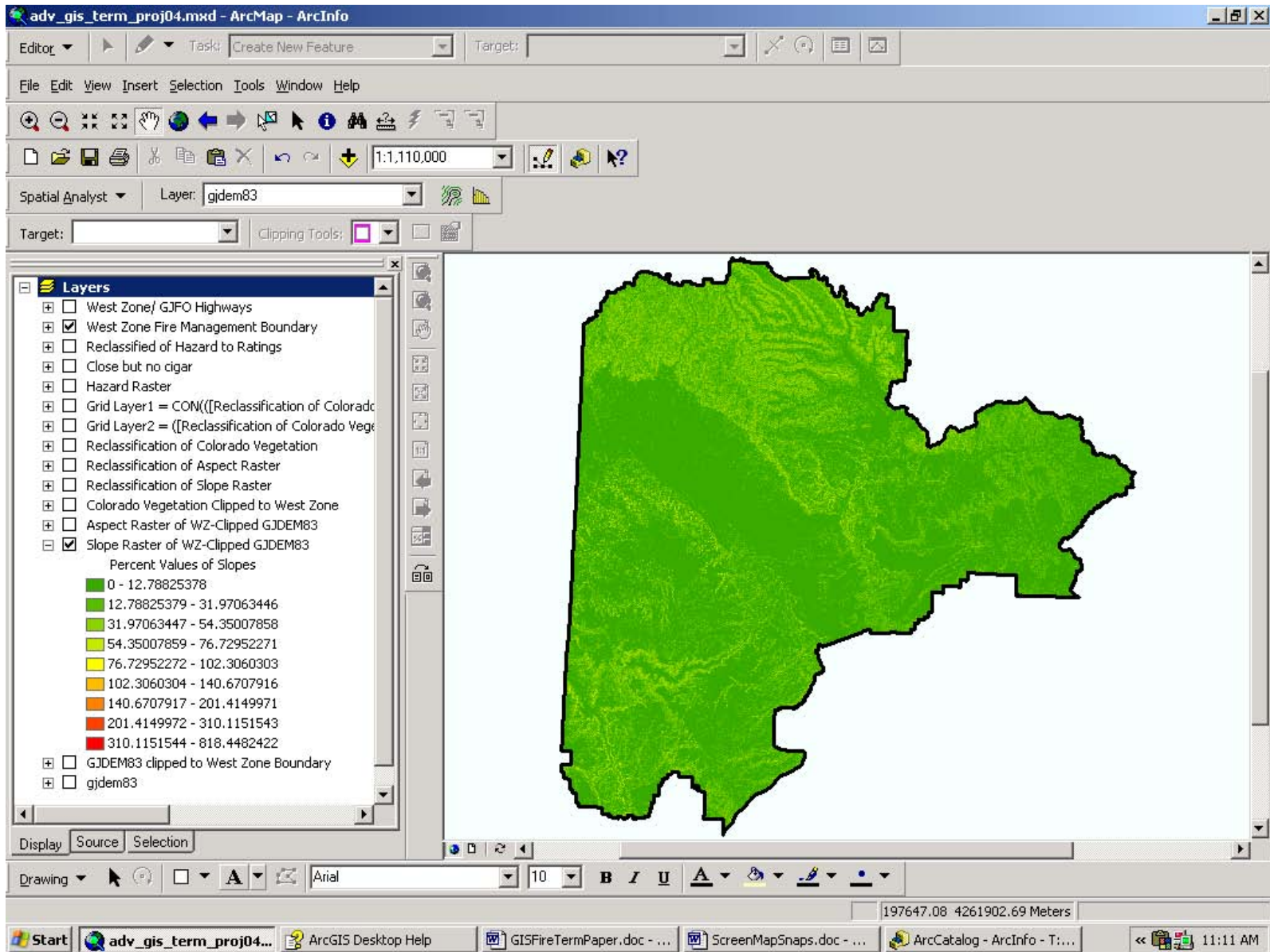


Fig. 3. Raster of percent slope, created from DEM, using Spatial Analyst: Slope

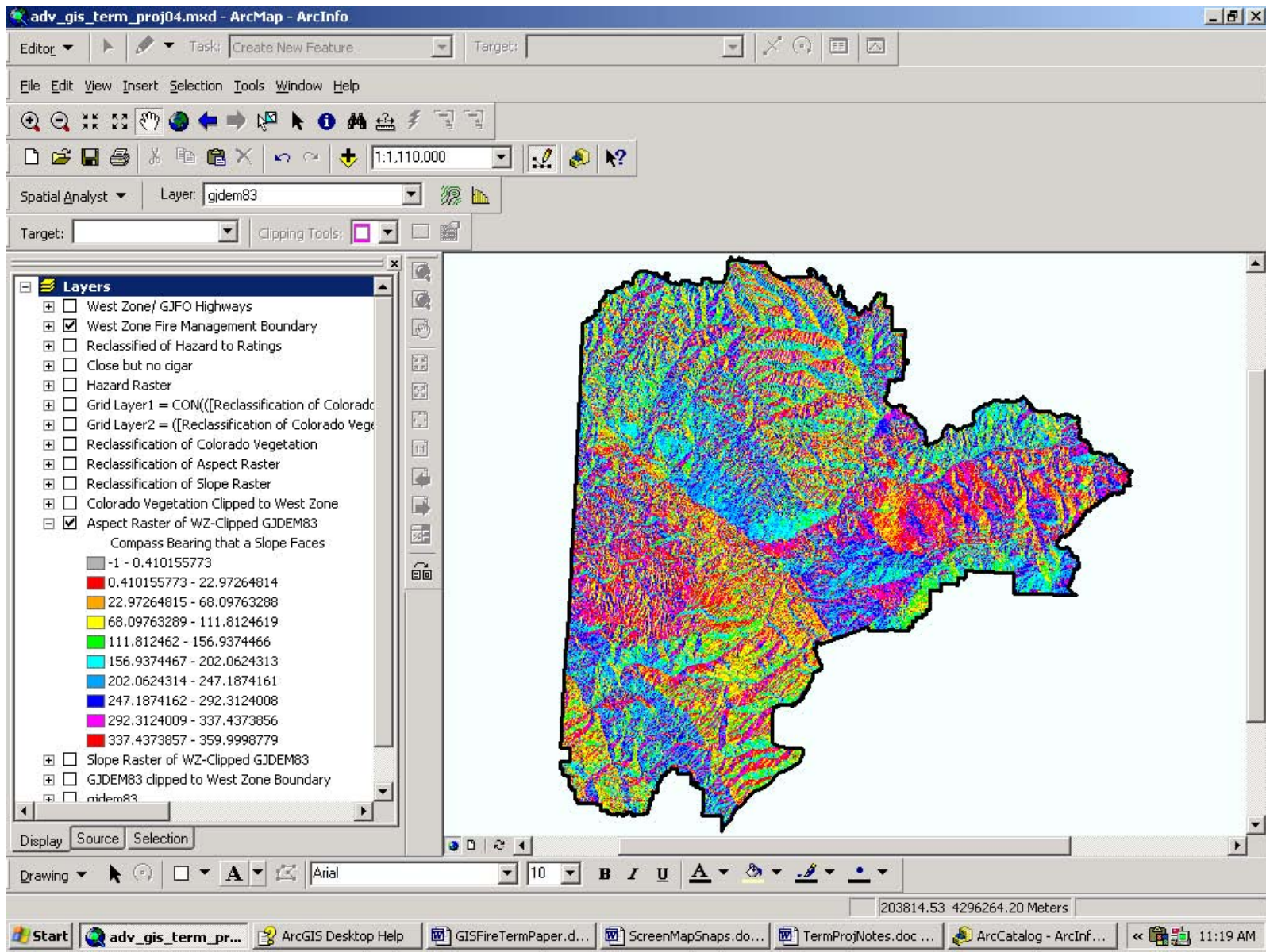


Fig. 4. Raster of Aspect, created from DEM, using Spatial Analyst: Aspect

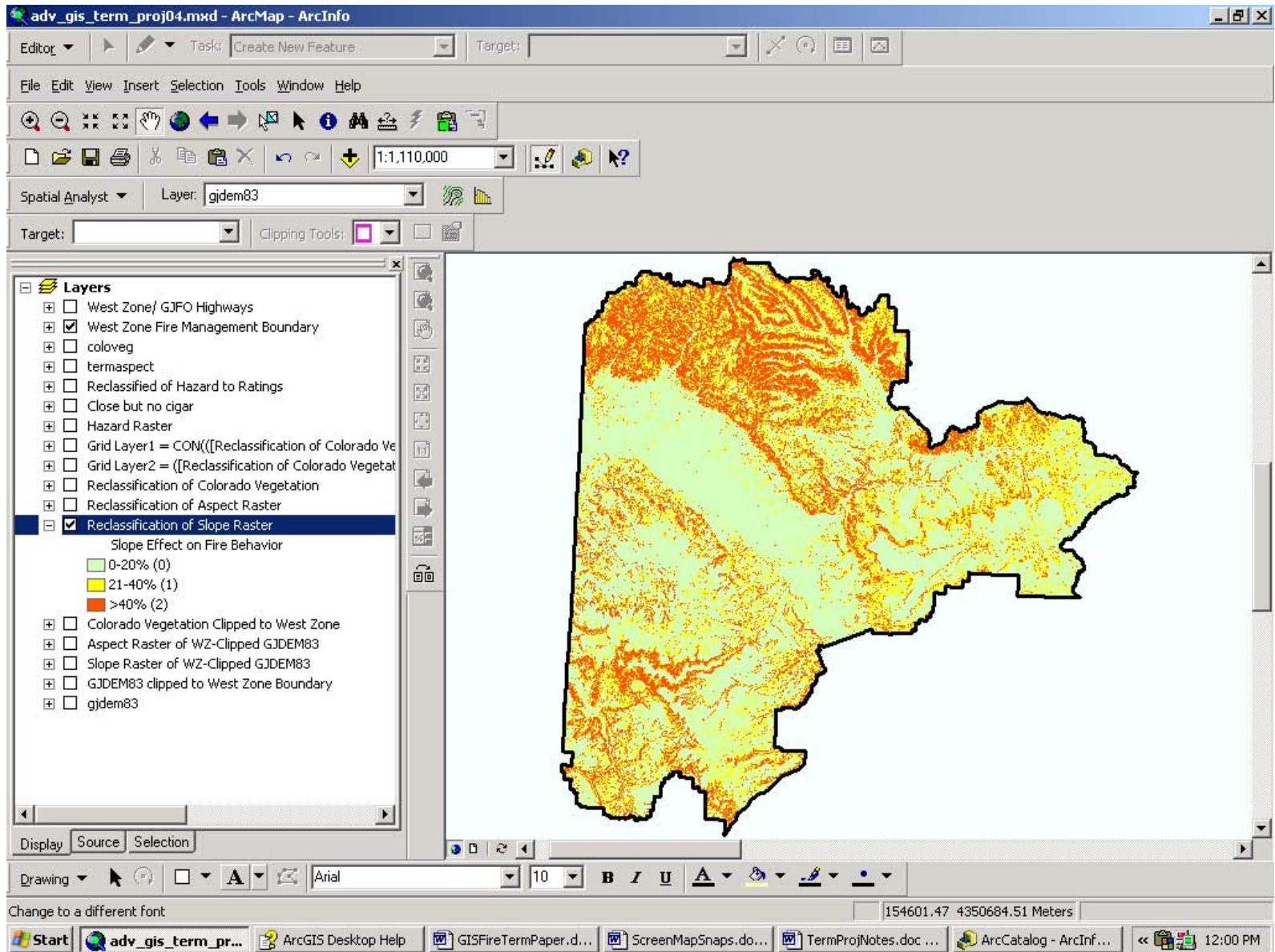


Fig. 5. Reclassification of percent slope raster, created using Spatial Analyst: Reclassify Break values set at 20, 40, >40

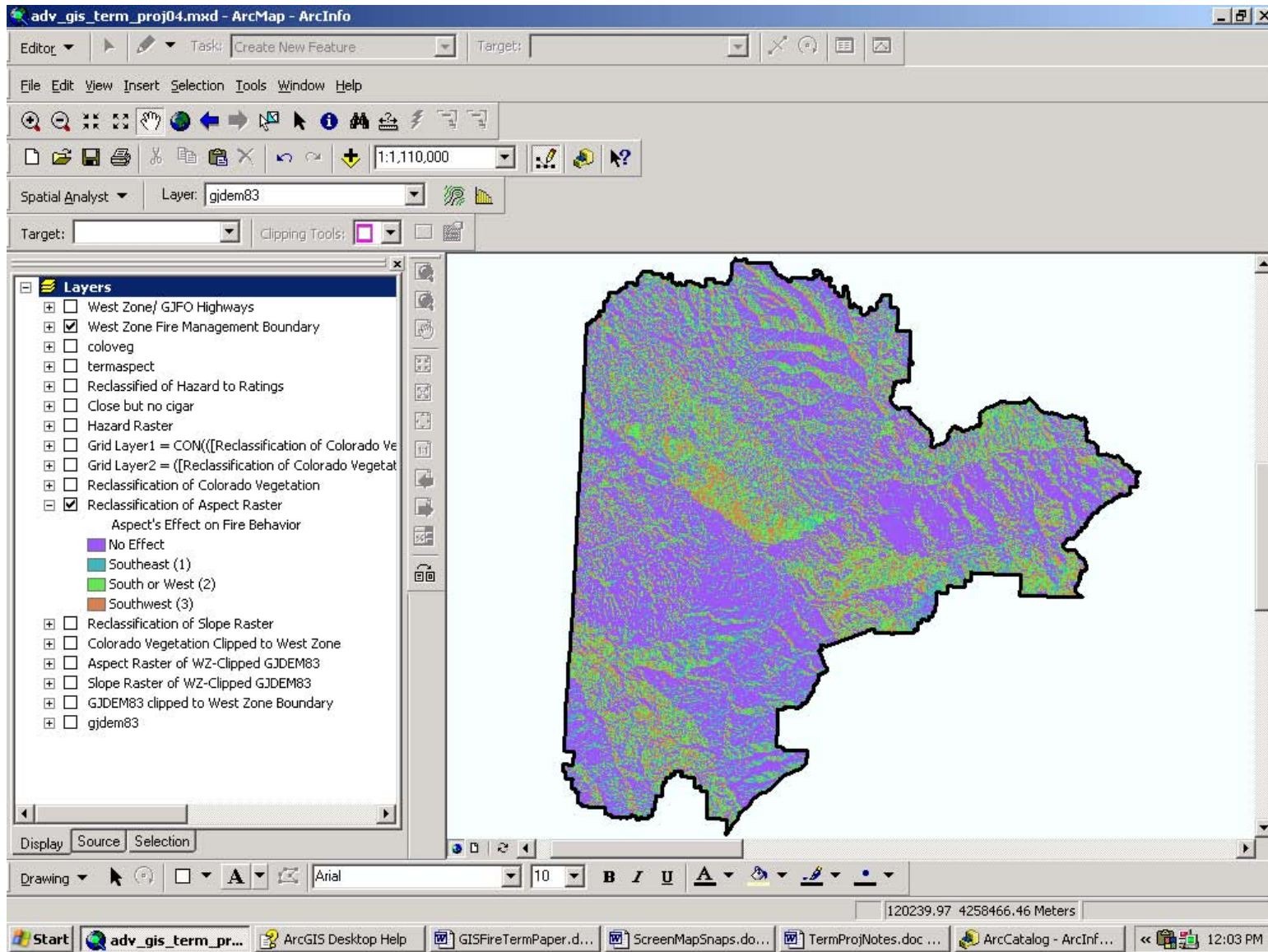


Fig. 6. Raster of reclassified aspects, created using Spatial Analyst: Reclassify
Compass bearings relabeled as directions

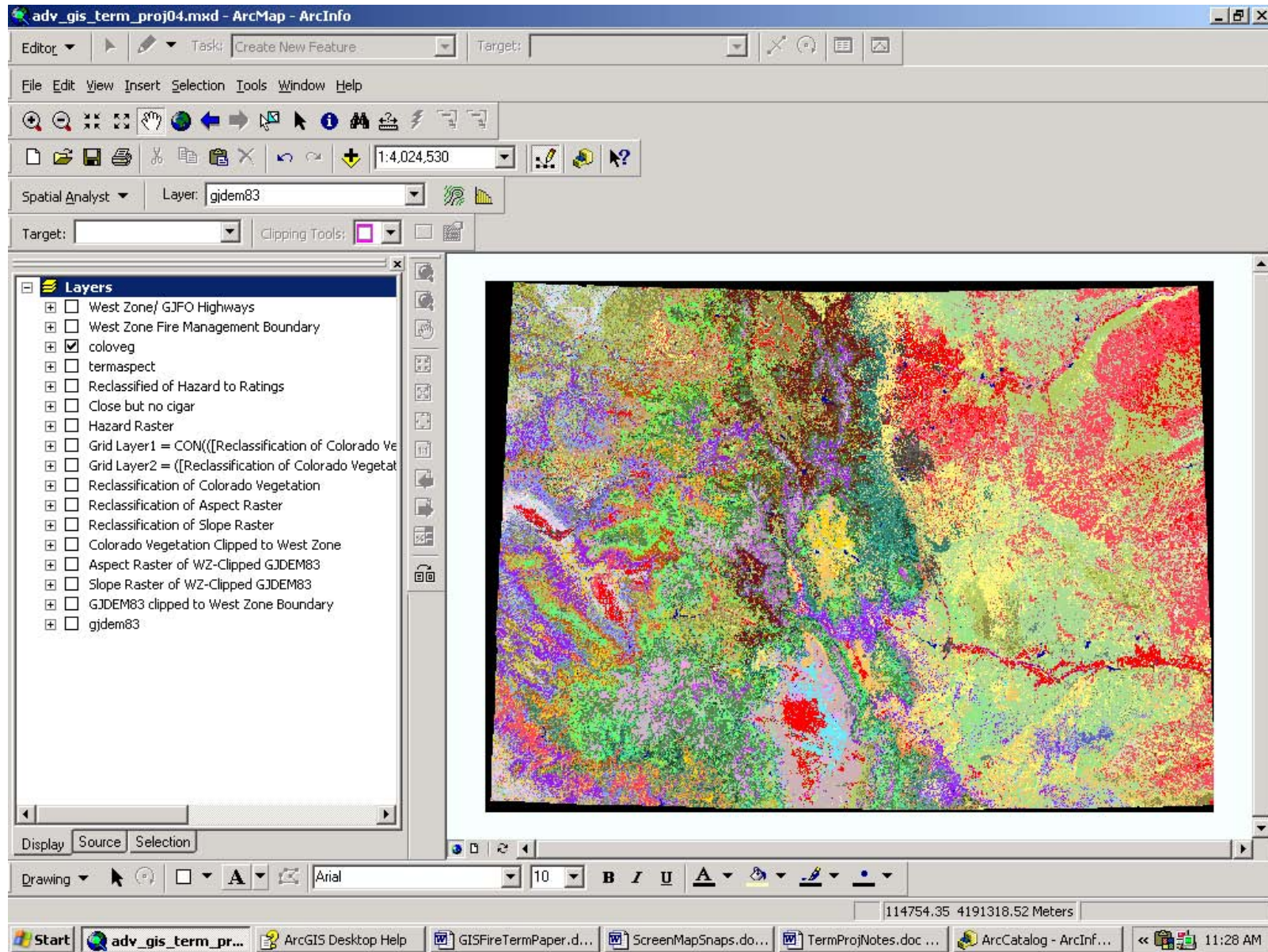


Fig. 7. Statewide raster layer of Colorado vegetation and other land cover types

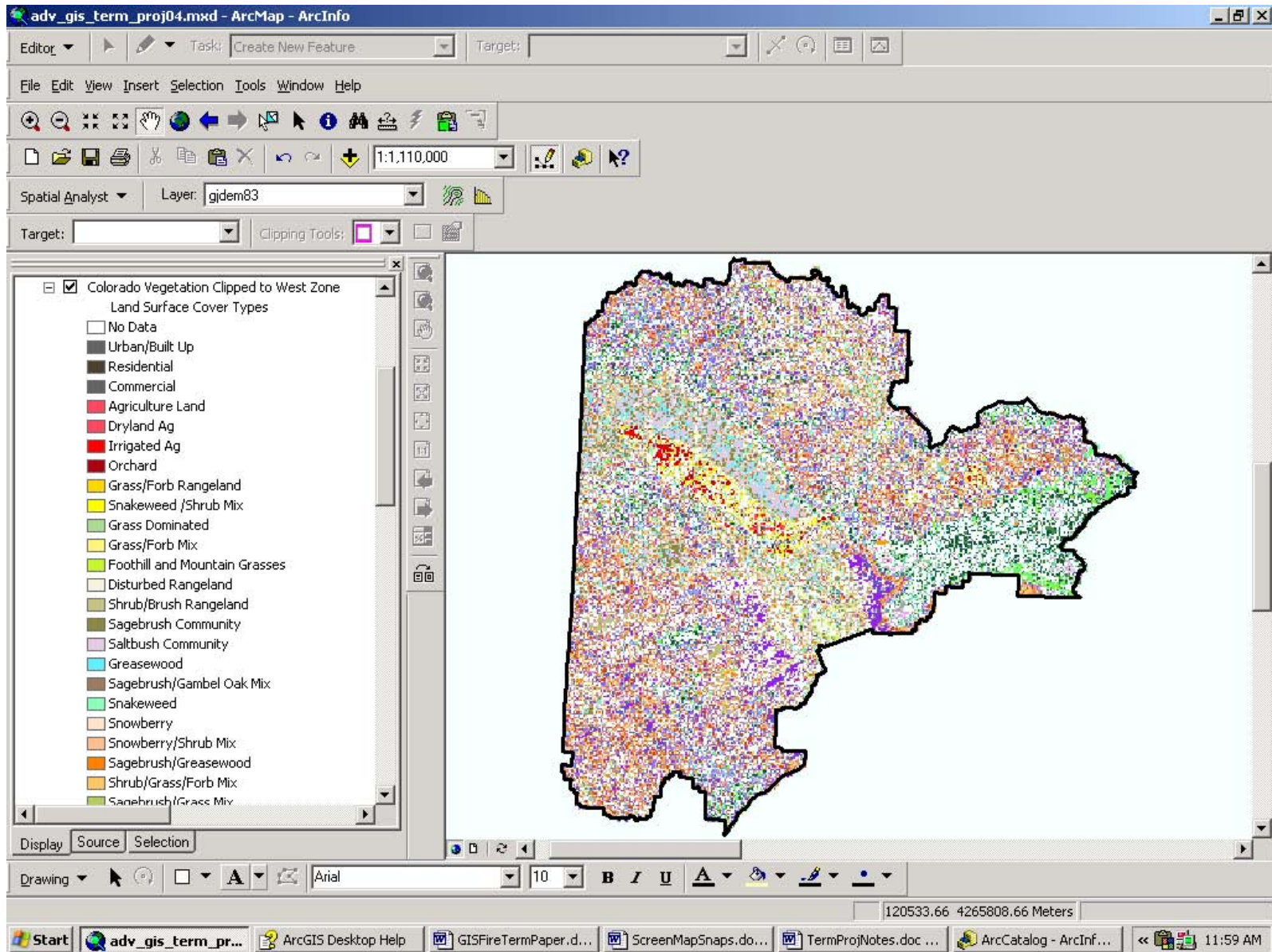


Fig. 8. Colorado vegetation and other land cover types, clipped to West Zone boundary, using extension Raster Clipper

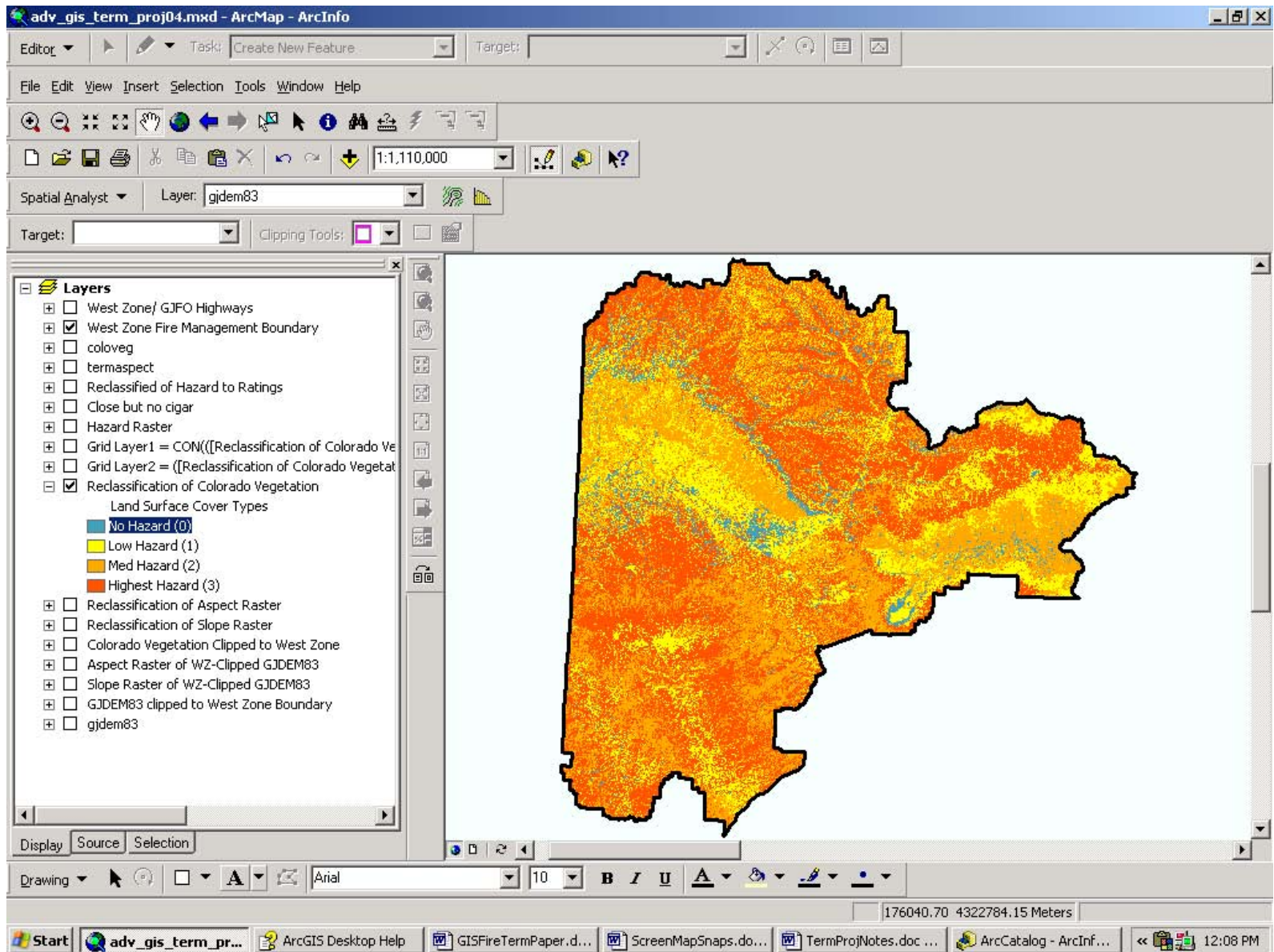


Fig. 9. Reclassification of Colorado vegetation and land cover types, created using Spatial Analyst: Reclassify. Values of vegetation and cover types were changed to integer values within a range of 0-3, effectively creating a West Zone fuel model.

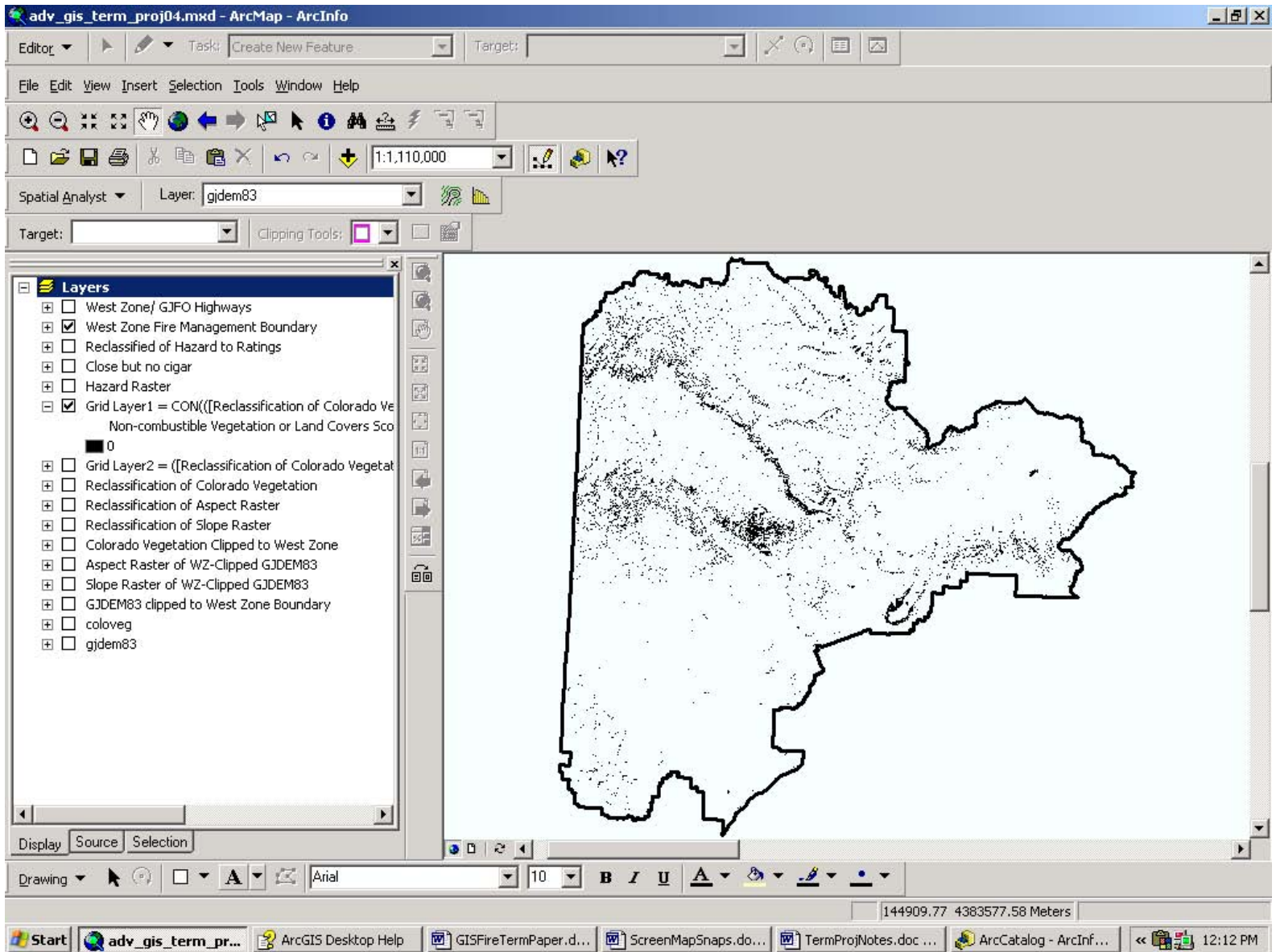


Fig. 10. Raster created using Spatial Analyst: Raster Calculator, to develop first stage conditional algorithm selecting non-combustible vegetation and ground covers.
 Map Algebra expression: Grid Layer1 = CON([Reclassification of Colorado Vegetation] < 1),0)

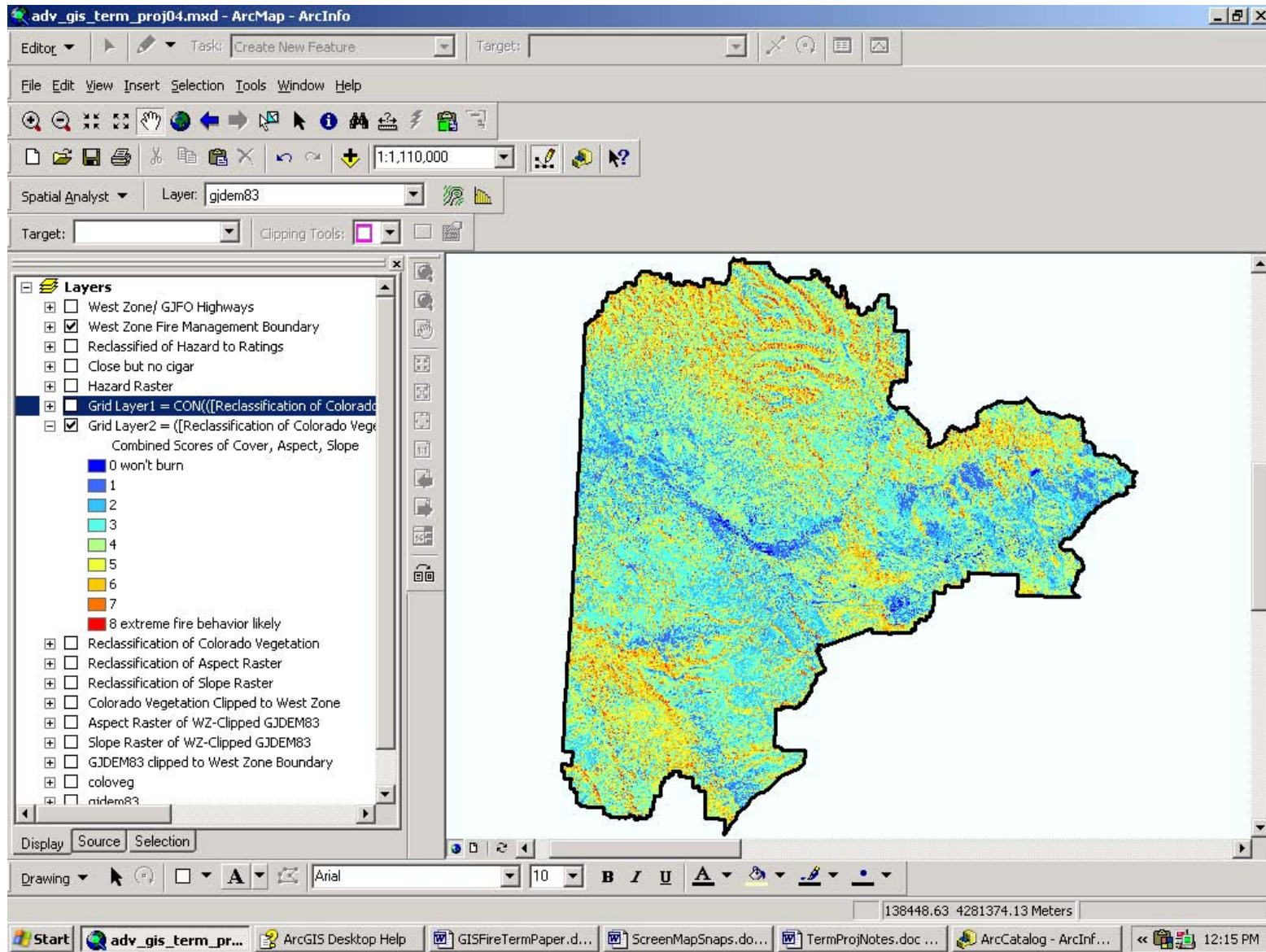


Fig. 11. Raster created using Spatial Analyst: Raster Calculator, to develop second stage addition algorithm to sum assigned integer values from three rasters of combustible vegetation and ground cover, aspect and percent slope. Map Algebra expression: $\text{Grid Layer2} = ([\text{Reclassification of Colorado Vegetation}] + [\text{Reclassification of Aspect Raster}] + [\text{Reclassification of Slope Raster}])$

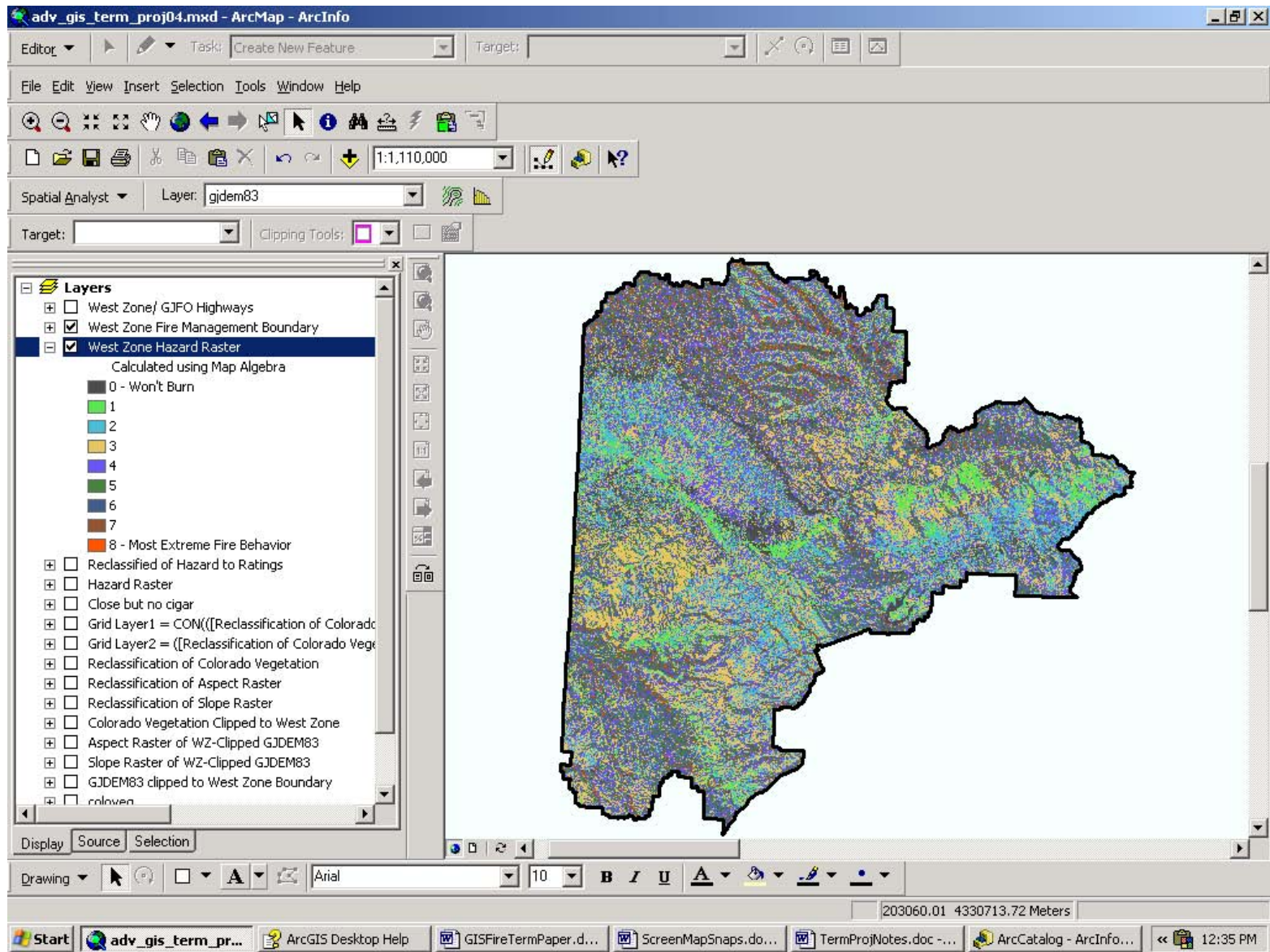


Fig. 12. Completed hazard raster, created using Spatial Analyst: Raster Calculator. Map Algebra expression:

$$\text{test} = \text{CON}(\left(\left[\text{Reclassification of Colorado Vegetation} \right] > 0 \right), \left(\left[\text{Reclassification of Colorado Vegetation} \right] + \left[\text{Reclassification of Aspect Raster} \right] + \left[\text{Reclassification of Slope Raster} \right] \right), \left(\left[\text{Reclassification of Colorado Vegetation} \right] < 1 \right), 0)$$

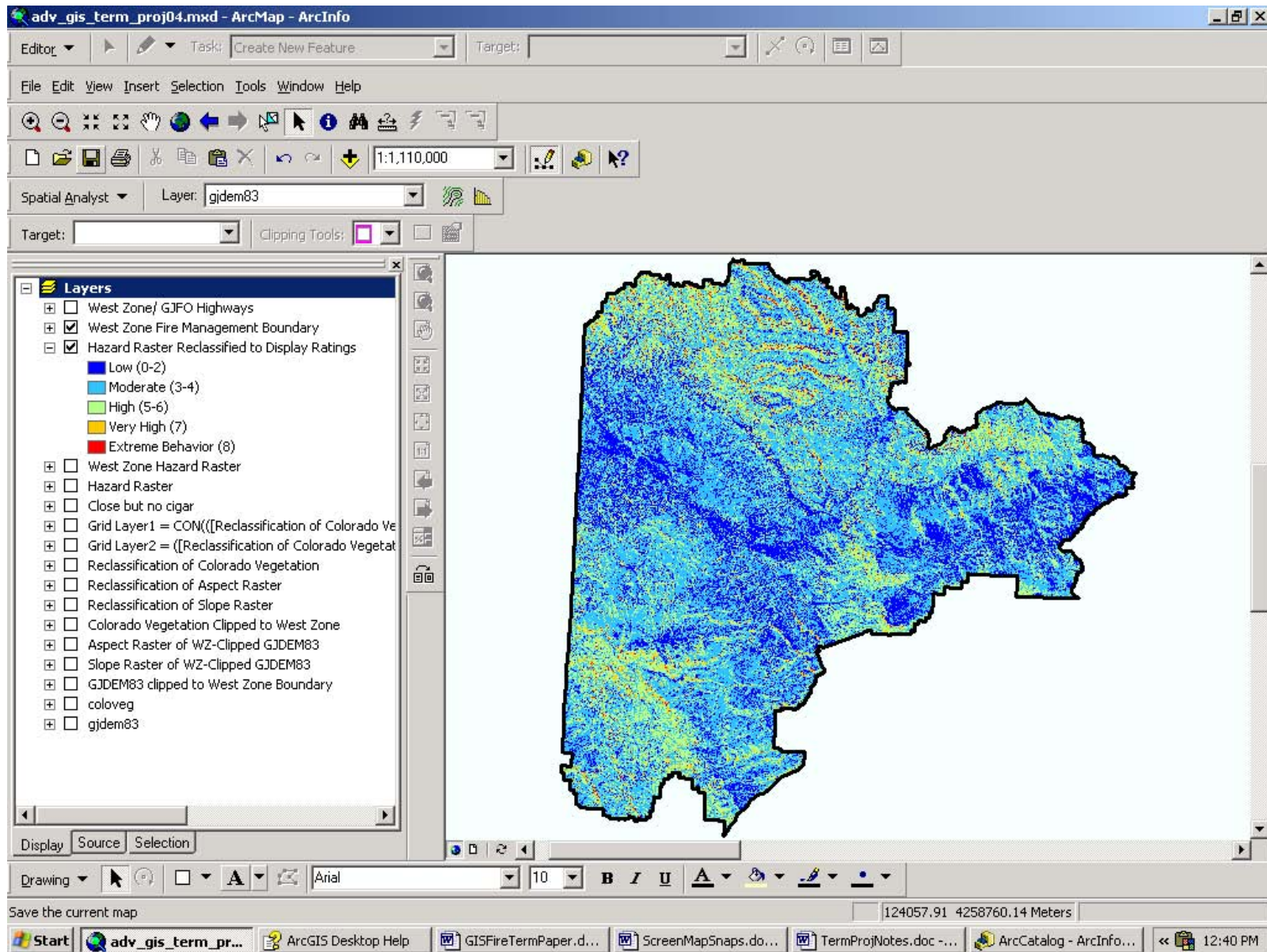


Fig. 13. Reclassified hazard raster, created using Spatial Analyst: Reclassify
Break values set at 2, 4, 6, 7, 8

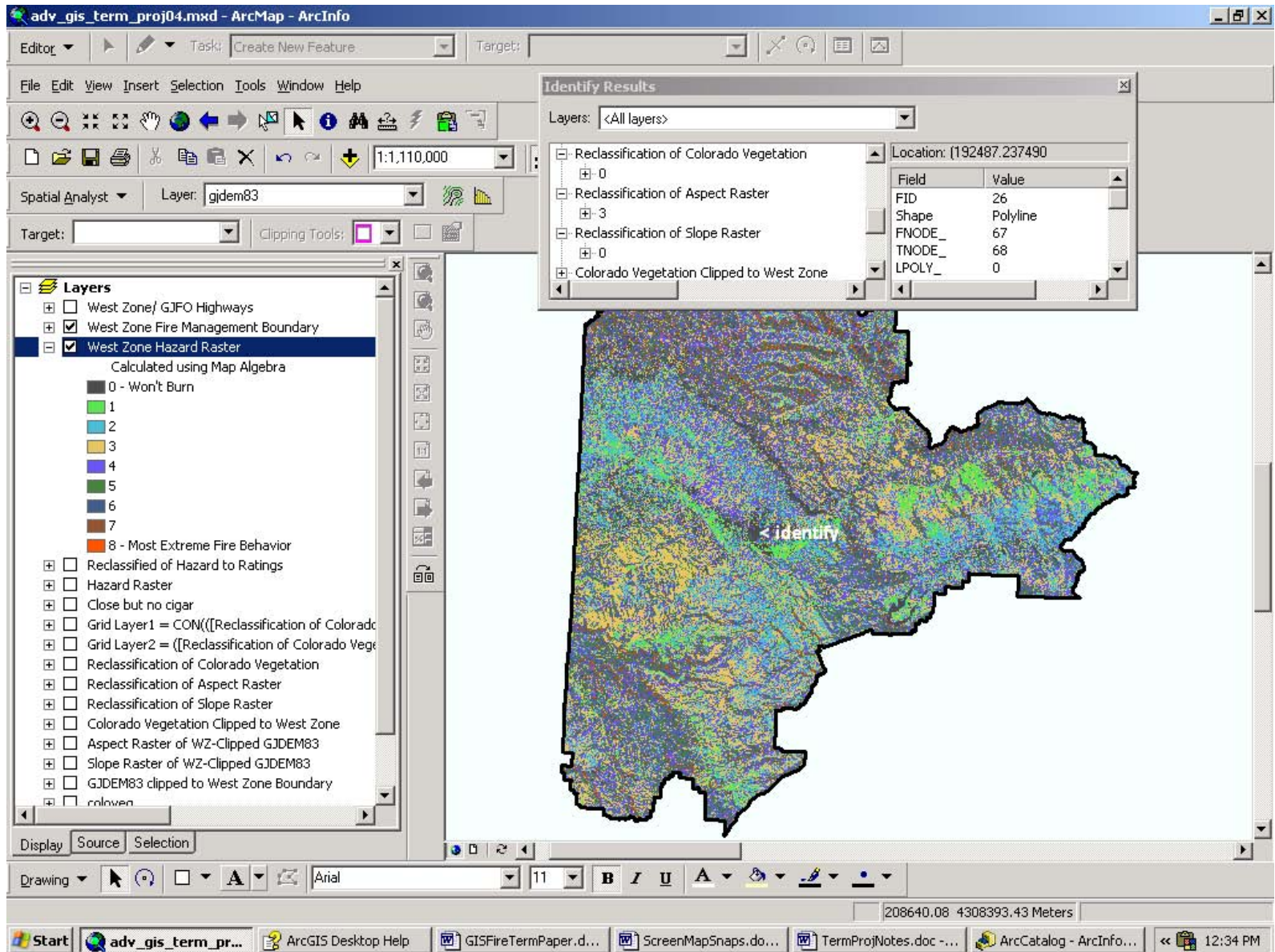


Fig.14. Testing initial calculated hazard raster to determine whether algorithm function is calculating as intended

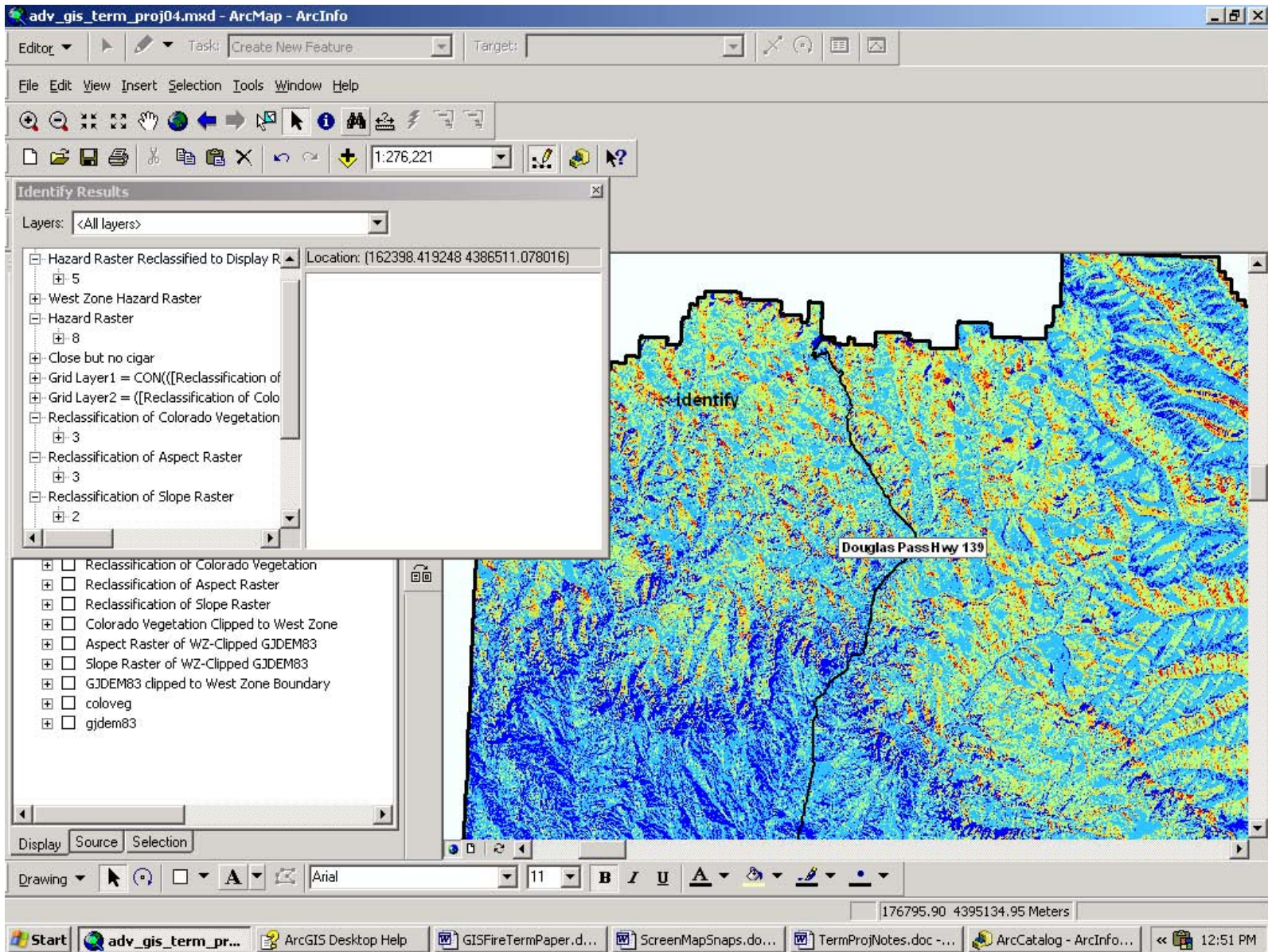


Fig.15. Testing reclassified hazard raster to double check algorithm calculations and range values