DATA BASE MODELING TO DETERMINE IMPACT OF DEVELOPMENT SCENARIOS IN SAN BERNARDINO COUNTY

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ABSTRACT

The San Bernardino County project, completed in May, 1982, is one of four projects sponsored by NASA as part of the California Integrated Remote Sensing System effort. The project is a joint effort of NASA's Ames Research Center, the Environmental Systems Research Institute, the San Bernardino National Forest, and the San Bernardino County Planning Department. A major goal of the project was to demonstrate that Landsat data could be a useful component of a data base by functioning in unison with other elements to extract new and useful information. The project acquired and integrated a diverse range of data including Landsat-derived land cover, photointerpreted land use, terrain, soils, and geology. Models oriented towards County applications were developed to provide maps of areas suitable for urban growth, and to generate historical information on past growth through comparison of various data elements. Models oriented towards Forest Service applications were designed to generate and compare the impact of allowing unrestricted urban development around the National Forest fringe versus the impact of developing a fire protection zone (greenbelt) with restricted urban development. This application of the data base was developed partly as a result of a 1981 National Forest fire that consumed about 700 homes in the city of San Bernardino. The scenarios were compared through the use of fire hazard, erosion, water runoff, and urban and agriculture capability/suitability models.

INTRODUCTION

The San Barnardino County (SBC) Vertical Data Integration Study is one of four approaches to Landsat data integration studied by the California Integrated Remote Sensing System (CIRSS) Task Force. One objective of the SBC study was to examine the effectiveness of using private industry to aid local governments in their efforts to integrate geographic data. Towards this end, the San Bernardino project involved two government agencies and a private contractor, the Environmental Systems Research Institute (ESRI), in the construction and utilization of a data base. NASA's Ames Research Center maintained control of the project direction and of work involving classification of the Landsat data subsequently incorporated into the project's data base.

A major goal was to demonstrate that Landsat data could be a useful component of a data base by functioning in unison with other elements to extract new and useful information. A cornerstone of the CIRSS efforts was the concept of Vertical Data Integration. This concept refers to the integration of a range of separate data sets covering a single geographic area, as opposed to horizontal integration or the mosaicking of spatially adjacent data. The vertical integration concept stresses that the integration of data sets for a given area – data often held unshared by a variety of agencies – will have beneficial synergistic effects.

Both the San Bernardino National Forest (SBNF) and the San Bernardino County Planning Department (SBCPD) provided significant input and personnel time. A major test for this demonstration effort was to develop a data base that could be effectively used in yielding information important to these two agencies.

STUDY AREA

The project study area consists of the southwest corner of San Bernardino County, California. This area of roughly 750,000 acres (1200 mi. sq.) consists of the urban San Bernardino Valley, the brush and forest covered San Bernardino Mountains, and a portion of the Mojave Desert (Figure 1). Portions of the mountains are undisturbed wilderness, while much of the valley has experienced rapid development of residential and commercial properties. Natural land cover varies from valley grassland to hillside chaparral to mountain coniferous forest.

DATA BASE DESCRIPTION

In the project, a 39-layer data base (Table 1) covering the full study area was created. Some of these data were in digital polygonal and grid form, while others existed as unautomated map sheets. The data were all coregistered to the local state plane coordinate system and gridded into four-acre cells, with data being automated as required. Additionally, small area data bases were generated using components of the full area data base (Tables 2 and 3). The small area data bases were gridded into one-acre cells and used for localized applications analyses. 1976 and 1979 Landsat land cover data were components of each of the data bases. The Landsat data classification decisions were influenced by a number of the data base elements. The rationale is that Landsat data cannot only be useful within a data base, but that a data base can also be useful in categorizing the Landsat data (Likens and Maw, 1981.) It should also be noted that the full and small area data bases each contained photointerpreted 1974 and 1979 land use data. Land use is context oriented and fundamentally different from (though similar to) land cover; these data should not be confused as to origin and type.

Table 1. Elements of full study area data base.

1. Row
2. Column
3. Subarea
4. Valley Terrain Unique Number
5. SBNF Terrain Unique Number
6. Valley Map Module Number
7. Valley Terrain Unit Number
8. Valley Land Cover
9. Valley Geologic Type
10. Valley Slope
11. Valley Landform
12. Valley Soils
13. Valley Geologic Hazards
14. Valley Flood-Prone Areas
15. Valley Ground Water
16. SBNF Map Module Number
17. SBNF Terrain Unit Number
18. SBNF Land Cover
19. SBNF Geology
20. SBNF Slope
21. SBNF Landform
22. 1974 Land Use
23. 1979 Land Use
24. General Plan
25. Census Tracts
26. Valley Roads
27. Valley Railroads
28. Valley Streams
29. Valley Fault Lines
30. 1976 CDF Landsat
31. Elevation (DMA)
32. Slope Aspect (from elevation)
33. Slope (from DMA elevation)
34. 1976 Landsat Land Cover
35. Change Mask (Landsat)
36. 1979 Landsat Spectral Classes
37. 1979 Landsat Land Cover
38. Valley Soils
39. Valley Soils K Values

Table 2. Yucaipa Area Data Base

1. Row
2. Column
3. Study Area
4. Valley Terrain Unique Number
5. Valley Map Module Number
6. Valley Terrain Unit Number
7. Valley Land Cover
8. Valley Geologic Type
9. Valley Slope
10. Valley Landform
11. Valley Soils
12. Valley Geologic Hazards
13. Valley Flood-Prone Areas
14. Valley Groundwater
15. 1974 Land Use
16. 1979 Land Use
17. General Plan
18. Census Tracts
19. Valley Roads
20. Valley Railroads
21. Valley Streams
22. Valley Fault Lines
23. 1976 CDF Landsat
24. Elevation (DMA)
25. Slope Aspect (from elevation)
26. Slope (from DMA elevation)
27. 1976 Landsat Land Cover
28. Change Mask (Landsat)
29. 1979 Landsat Spectral Classes
30. 1979 Landsat Land Cover
31. Valley Soils
32. Valley Soils K Values

Table 3. Fire Buffer Greenbelt Data Base.

1. Row
2. Column
3. Study Area
4. Valley Terrain Unique Number
5. SBNF Terrain Unit Unique Number
6. Valley Map Module Number
7. Valley Terrain Unit Number
8. Valley Land Cover
9. Valley Geologic Type
10. Valley Slope
11. Valley Landform
12. Valley Soils
13. Valley Geologic Hazards
14. Valley Flood-Prone Areas
15. Valley Groundwater
16. SBNF Map Module Number
17. SBNF Terrain Unit Number
18. SBNF Land Cover
19. SBNF Geology
20. SBNF Slope
21. SBNF Landform
22. 1974 Land Use
23. 1979 Land Use
24. General Plan
25. Census Tracts
26. Valley Roads
27. Valley Railroads
28. Valley Streams
29. Valley Fault Lines
30. 1976 CDF Landsat
31. Elevation (DMA)
32. Slope Aspect (from elevation)
33. Slope (from DMA elevation)
34. 1976 Landsat Land Cover
35. Change Mask (Landsat)
36. 1979 Landsat Spectral Classes
37. 1979 Landsat Land Cover
38. Valley Soils
39. Valley Soils K Values
40. SBNF Soils
41. SBNF Soils K Values
42. SBNF Soils

YUCAIPA SMALL AREA STUDY - COUNTY ORIENTED ANALYSIS

The Yucaipa area is on the relatively rural fringe of the more densely populated east San Bernardino Valley. Pressure to develop the Yucaipa area has resulted in tentative approval for a waste treatment facility which will allow the denser development as well as the conversion of presently unimproved acreage. Since the Yucaipa area is unincorporated, it is one of the areas where the County has a mandate to ensure orderly development.

To determine which areas are more likely to be developed in the future, an urban development capability/suitability model was used with the integrated Geographic Information System (GIS) data base to identify those areas most capable of supporting construction. Landsat data was not used in this initial model. The resulting data file and map output rank each cell according to its relative capability/suitability to support development (Figure 2). The major geographic constraints such as steep slopes, flood-prone areas and high fire hazards are rated very low capability/suitability for urbanization. The presence of existing urban land use (photointerpreted) indicates the presence of infrastructure (roads, water service, etc.). Increasing distance from 1979 existing urban land use was therefore used to decrease the suitability of land for development.

Areas which the model designated "high capability/ suitability" are without major constraints, on gently sloping land, near existing urban uses, and are consistent with those areas designated for moderately dense development by County planning documents.

The non-Landsat or GIS only model generated above was used as a base for comparison to an identical model that incorporated only one other data layer, namely, 1979 Landsat land cover data. The GIS + Landsat model map displays several significant differences when compared to the output of the GIS-only model. The most apparent difference is the presence of "very high" capability/suitability assignments on the integrated (GIS + Landsat) model. The development in the area consists of structures fronting on streets (1/4 to 1/2 mile long) and large acreage of grassland within the residential block. The higher resolution of the Landsat land cover data (1 acre vs. 10-acre minimum mapping units, despite the quantization of all data into one-acre grid cells) allowed the undeveloped lands surrounded by residential development to be pinpointed as prime areas for development infill.

A correlation analysis between the two models was used to determine that the Landsat data in the second model accounted for about 10% of the variance in the model output. In other words, the inclusion of Landsat data added about 10% more variance over that present in the GIS model.

The land cover and land use data were also used to conduct change analyses within the Yucaipa area. However, these are not discussed in detail here because they did not involve modeling efforts utilizing major portions of the data base. The reader is directed to Likens et al. (1982), and Hodson and Christenson (1982), for in-depth descriptions of change detection efforts undertaken.

GREENBELT SMALL AREA STUDIES – FOREST SERVICE ORIENTED APPLICATIONS

In the summer and fall months, the brush and grass lands of the San Bernardino National Forest become very susceptible to fires. Such fire hazards are exacerbated by the large number of people in and about the forest. Fires within the SBNF are a hazard not only to the forest, but also to the extensive urban areas along its southern fringe. As a case in point, a 1981 fire moved out of the National Forest to destroy about 700 homes in the city of San Bernardino. Consequently, the SNBF has examined the possibility of establishing a fire protection zone, or "Greenbelt," along the forest fringe.

NASA determined that an evaluation of the impacts of greenbelt and non-greenbelt development strategies would be a useful demonstration of data base utility. This resulted in ESRI working with the SBNF to evaluate the fire hazard, erosion, and runoff results of each strategy using data base modeling. An initial task generated a small area data base for an area within which greenbelt policies might be established. Using a broad interpretation of SBNF guidelines [described by Bridges (1982)], we extracted a strip roughly one mile wide along most of the length of the slope break between the southern extent of the Mountains and the Valley floor. The resulting data base was gridded into one-acre cells.

The greenbelt and non-greenbelt management strategies were evaluated through the projection of two development scenarios: a continuation of present development trends (non-greenbelt scenario), and that of restricted urban development and increased agricultural use (greenbelt scenario). Initially, the small area data base was used to model fire hazard, erosion, and runoff conditions as of 1979, or before any scenario was hypothesized (also before the 1981 fire). Concurrently, the greenbelt scenario was formulated as an agriculture capability/suitability model that hypothesized no further urban expansion, and a non-greenbelt scenario formulated as an urban development capability/suitability model. The output from the two capability/suitability models were applied as modifiers to the outputs from the fire hazard, erosion, and runoff models to yield their projections. A diagram of the overall process is shown in Figure 3, with summaries of model inputs in Table 4 and output acreages in Table 5.

Table 4. Greenbelt model inputs.

Fire Hazard	1979 Landsat Land Cover, Slope
Runoff	Soil Capability Class, Slope
Erosion	Soil K Value, Slope

Table 5. Impact Comparisons.

	Non-Greenbelt	Greenbelt
Fire Hazards		
Very high	27,080	2,340
High	7,747	23,227
Moderate	6,766	5,400
Low	7,182	5,665
Very low	5,995	18,138
Runoff		
Low	6,422	11,027
Moderate	10,859	10,681
High	11,582	8,123
Very high	25,829	24,861
Water	78	78
Erosion		
Very low	7,668	16,157
Low	7,442	4,287
Moderate	5,329	3,174
High	9,718	7,805
Very high	24,535	23,269
Water	78	78

As expected from the intent of greenbelt designation, application of agricultural use significantly reduces fire hazards for the area (Figures 4 and 5). A few areas of high slope remain designated as high fire hazard. If no greenbelt buffer is designated, urbanization of the area will extend fire hazard conditions southward into the valley areas. As expected, little runoff difference is calculated on the steeper slopes, as these areas are not projected to support dense development.

Designation of a greenbelt fire buffer along the steeper slopes and to the valley would have little impact on existing runoff rates, but could increase runoff on moderate slopes. Urban development in the valley would also increase runoff in those locations, while agriculture would reduce runoff. Increases in erosion are expected to occur in areas of low and moderate density urbanization. Increased erosion presents a control problem in these locations, and could be addressed by appropriate grading and runoff controls. Erosion also presents a hazard to development along the base of the steeper slopes where mud flows often occur during rainfall following a burn. This hazard could be reduced by locating the greenbelt fire buffer in these locations.

A critical need to have good slope data was noted in the generation of the model products. The Landsat land cover data was used as inputs into only the urban and agriculture capability/suitability models, and the fire hazards model. In contrast, slope information was a critical input into all five of the greenbelt-oriented models. In the greenbelt small area data base there are two slope data layers, one created through slope calculation Defense Mapping Agency (DMA) digital elevation data quantitized (after processing by the Jet Propulsion Laboratory for Ames for an earlier project) into 40 foot elevation increments, and the other from slope polygonal data digitized from maps, and converted into 1-acre grid cell format. In testing two slope data sets as inputs into the calculation of fire hazard, it was noted that the DMA based data (Figure 6) introduced a significant amount of artificial terracing or contour effect into the product that was not present with the polygonally based data. Artificially abrupt slopes resulting from 40-foot elevation differences between adjacent grid cells in near level areas resulted in this contour effect in the DMA based slope data.

The impact model outputs provide graphic illustration of the location and severity of impacts expected to result from designation or non-designation of a fire buffer greenbelt within the mapped study area. These models provide information useful to the planning of activities and location of boundaries of the proposed greenbelt. While the models used are one of several possible methods for impact evaluation, their results are consistent with known conditions and historic concerns within the study area.

CONCLUSION

Vertical data integration allows a variety of data types to be evaluated simultaneously and provides a depth of analysis capability not possible with single data sets. Inconsistencies between data sets can become apparent and can be dealt with effectively, producing a more consistent data base. It was demonstrated that Landsat land cover data could be successfully used with other data to derive important planning information. The Landsat data was found to have higher spatial resolution than other data elements found in the data base (one-acre pixels versus 10 to 40+ acre minimum mapping units). Also, the Landsat data easily encompassed the full geographic extent of the study area, while most other data sets used were found to be significantly smaller in geographic extent. This was in part a result of focussed interest of individual agencies on specific portions of the study area, rather than the whole. The small data size of many other GIS data bases leads to the conclusion that many planning agencies and other data base users are accustomed to working with either smaller geographic areas or with courser resolution data than those in the remote sensing field. The use of Landsat data as a component in data base modeling can make possible the generation of products covering larger geographic areas, as products with greater spatial detail, than might be possible through the sole use of other geographic data base elements.

REFERENCES

Bridges, Jo Anne, 1981. Greenbelt: A Cooperative Approach. U.S. Forest Service, San Bernardino National Forest, San Bernardino, California.

Hodson, W. and Christenson, J.; 1982. CIRSS Vertical Data Integration - San Bernardino Study. NASA Contractor Report.

Likens, W. and Maw, K., 1981. Hierarchical Modeling for Image Classification. Proceedings of the Pecora VII Symposium, Sioux Falls, S. Dakota, p. 290-300. American Society of Photogrammetry, Falls Church, Va., 1982.

Likens, W., Maw, K. and Sinnott, D, 1982. Final Report - Landsat Land Cover Analysis Completed for CIRSS/San Bernardino County Project. NASA Technical Memorandum 84244.

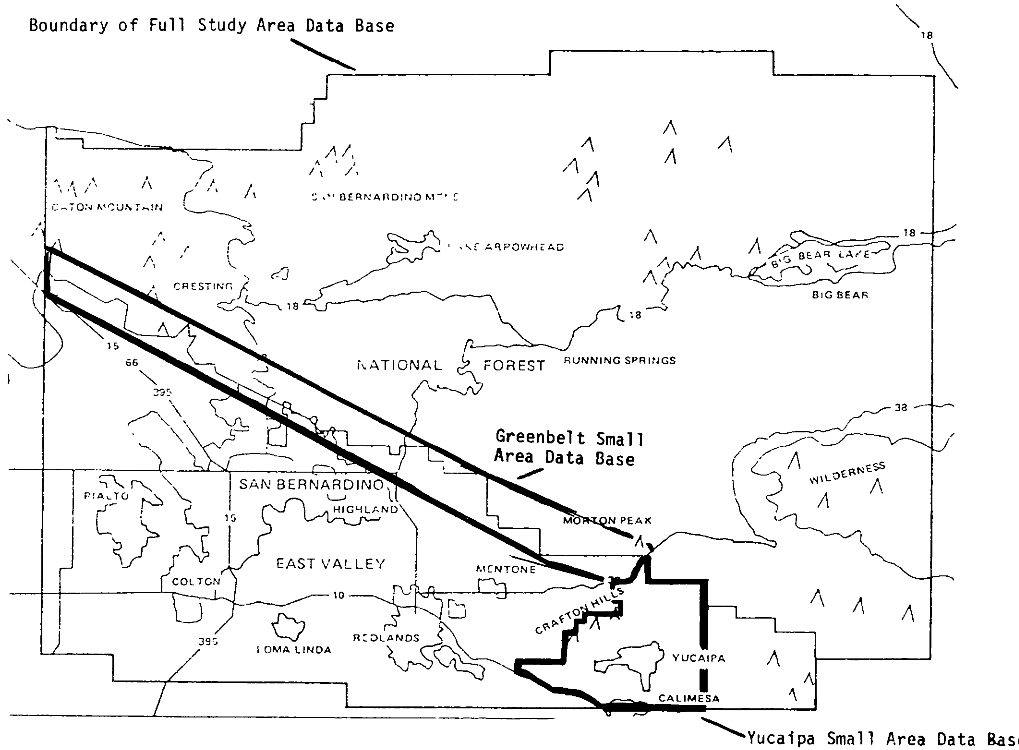

Figure 1. Study Area

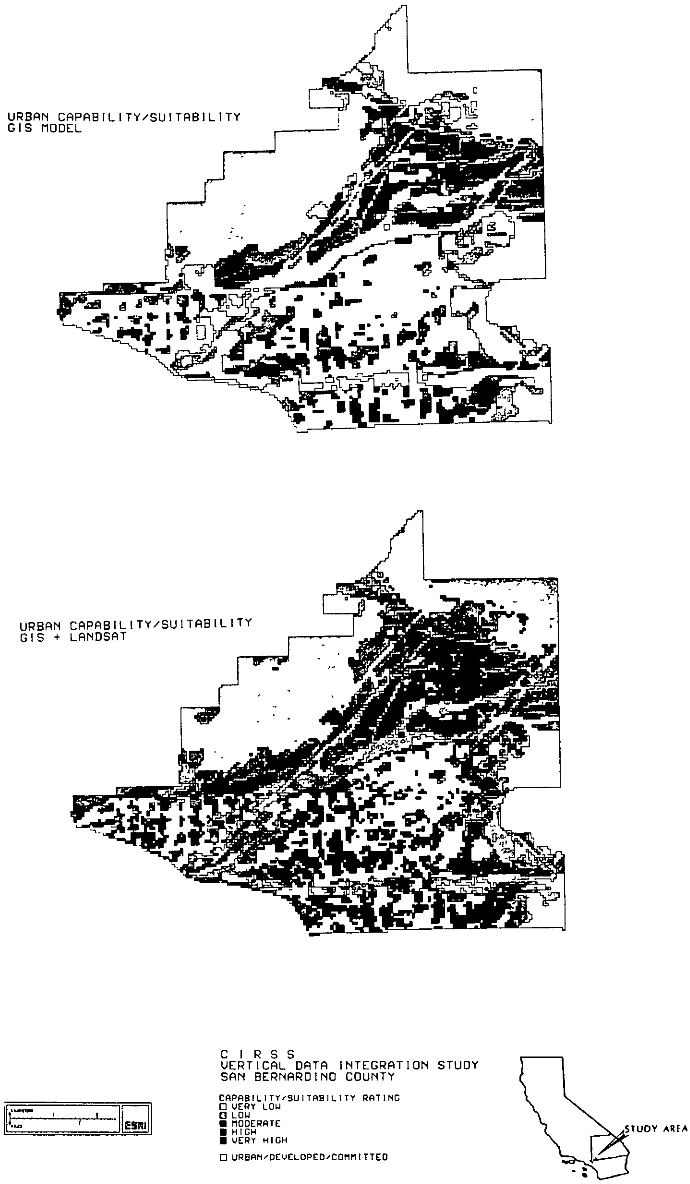

Figure 2. Yucaipa area urban capability/suitability.

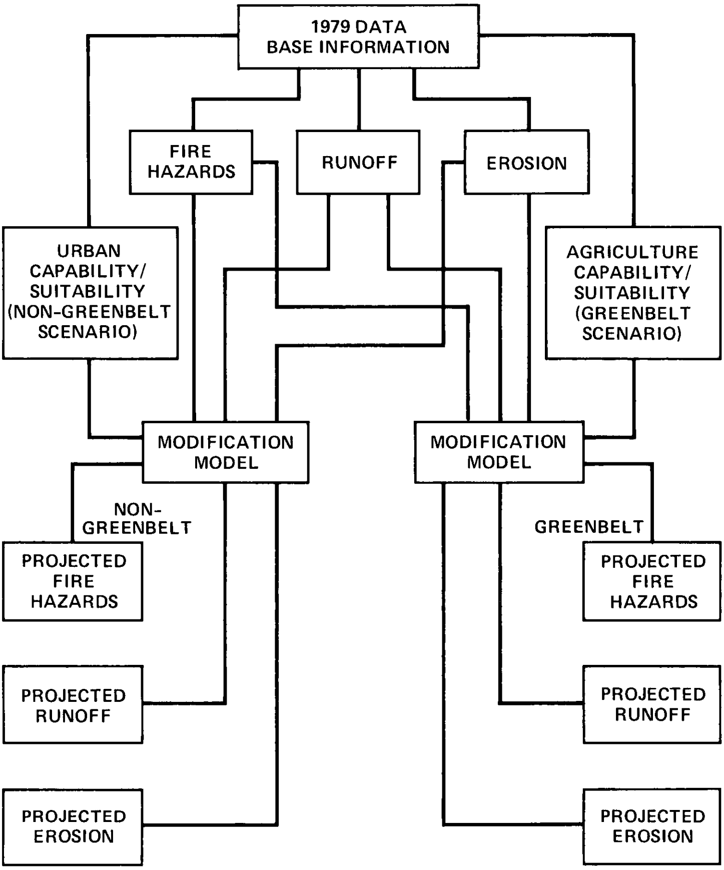

Figure 3. Greenbelt analysis flow.

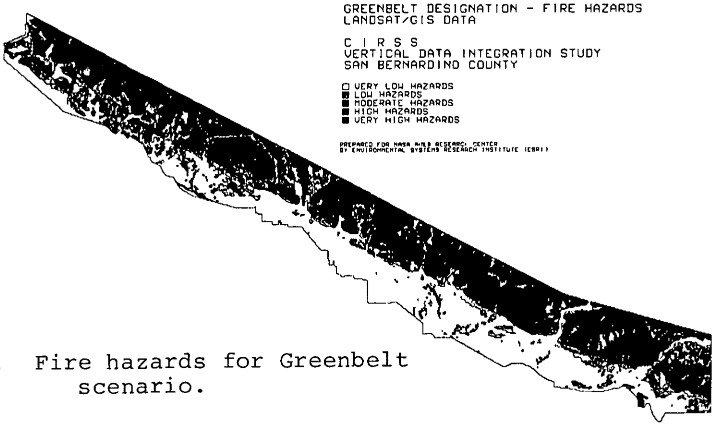

Figure 4. Fire hazards for Greenbelt scenario.

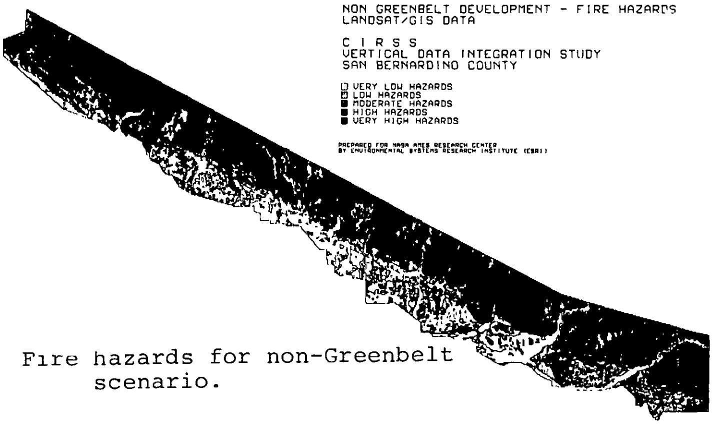

Figure 5. Fire hazards for non-Greenbelt scenario.

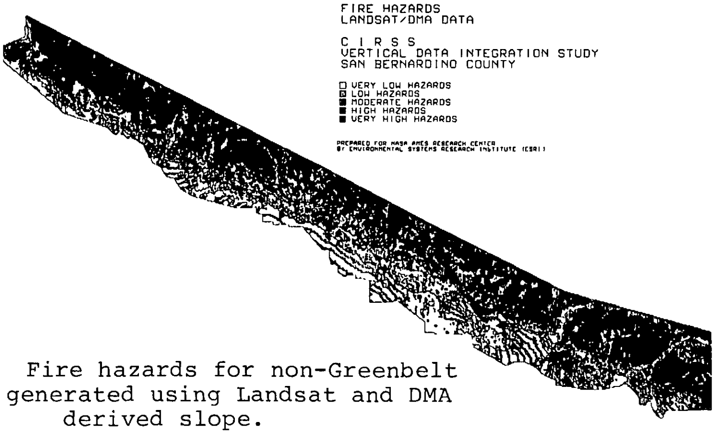

Figure 6. Fire hazards for non-Greenbelt scenario generated using Landsat and DMA derived slope.