# Appendix: Modeling Flow and Erosion Sensitivity for Rio Rancho, New Mexico

## Study Area and Background

Rio Rancho is situated within the Middle Rio Grande Basin and is northwest of Albuquerque. Figure A1 illustrates the city's relationship to the Rio Grande to the east, and to Albuquerque to the south and southeast. A visual inspection shows that the city's incorporated boundary includes an area comparable to that for Albuquerque (in fact, the incorporated area is one square mile larger than the Albuquerque area). Current Rio Rancho population is approximately 50,000, while the current Albuquerque population is approximately 500,000.

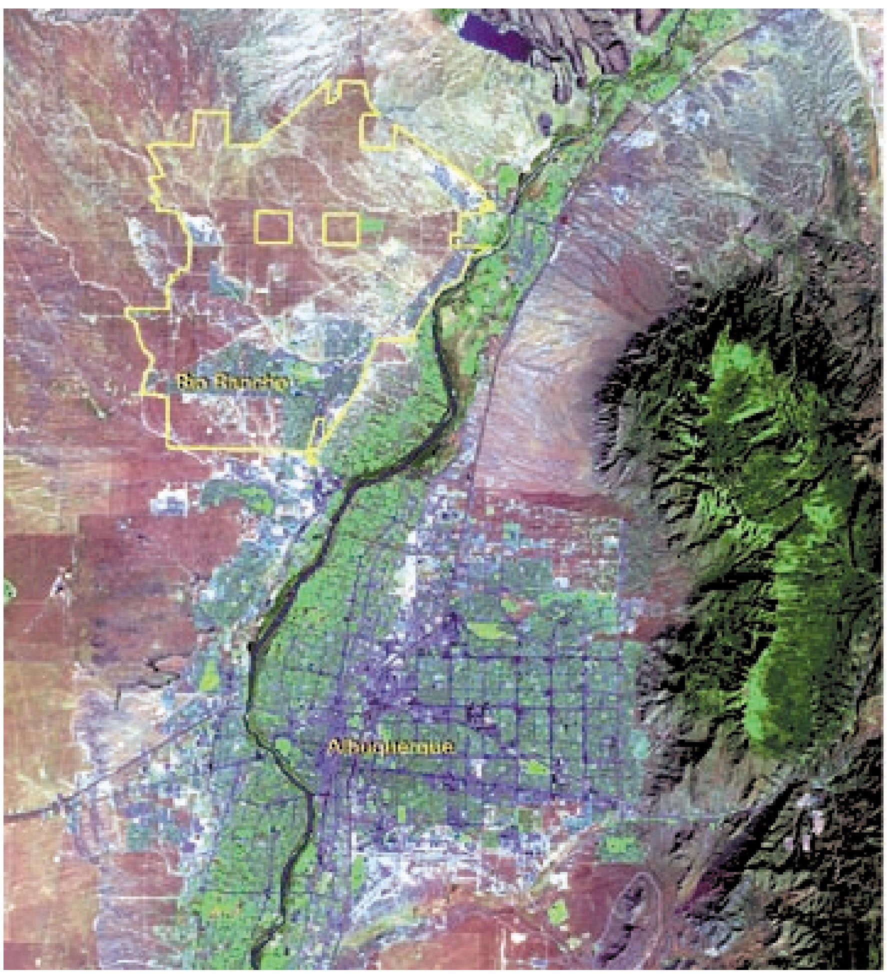


Figure A1. Rio Rancho is outlined in yellow in this September 1999 Landsat 7 ETM+ image, with Bands 5, 4, and 2 displayed in Red, Green, and Blue, respectively. The Rio Grande flows from the northeast to the southwest, the City of Albuquerque is south and southeast of Rio Rancho, and the Sandia Mountains are east of Albuquerque.

The study area encompasses the Rio Rancho drainage area, as constrained to the west by the Landsat imagery coverage (Figure A2). Several factors mark its complexity: urban area, urban/disturbed natural fringe, natural shrub and grass lands, arroyos, riparian area, agriculture, and an elevational gradient of 1353 feet (from 4999 ft to 6352 ft). This semi-arid environment receives approximately ten inches of rain per year from a highly season-dependent weather regime, often with heavy rain accumulation and run-off from individual storms. Greatest amounts and intensity of rainfall occur during the summer "monsoon" season and the early autumn. Rio Rancho is in a transition area at the edge of the Great Basin physiographic region. Plant types are characteristic of those found in the Great Basin.

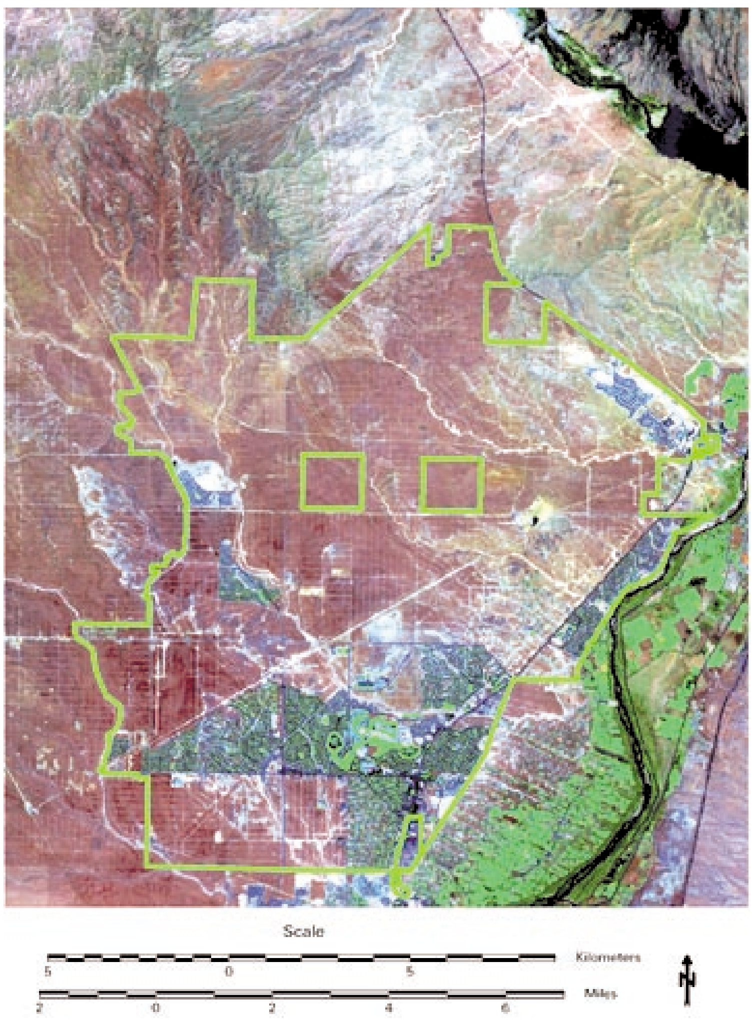


Figure A2. This 9 May 2000 Landsat 7 ETM+ image is displayed with Bands 5 (mid-infrared), 4 (near infrared), and 2 (visible green) in Red, Green, and Blue, respectively. The bright green boundary is for the Rio Rancho, New Mexico incorporated area. Unpaved roads from the 1960's are still visible.

Rio Rancho was originally intended as a land subdivision for the purpose of land sales, rather than for the creation of a healthy and sustainable community. Population growth has corresponded to city growth that has generally been characterized by sprawling development. The Planning Division recognizes these problems and is directing new activity and remedying past actions where possible. Future growth and development will be guided by the city's 20-year comprehensive plan, which emphasizes master-planned communities sensitive to the natural environment rather than unplanned individual residences.

The City originated in the 1960's as a Large Land Subdivision, with ½-acre properties being platted without an essential infrastructure, such as in-place or nearby utilities. Usually, the physical layout of the plats did not take into consideration the natural terrain, and the predetermined grids were superimposed upon rolling hills and branching arroyos. Half-mile-long blocks were created with graded roads that bisected arroyos, compromising natural drainage for those and "downstream" areas. These roads are still visible in the May 2000 Landsat 7 image (Figure A2). Subsequent housing developments have artificially channeled arroyos or drastically altered their flow path, resulting in large areas and high rates of soil erosion and in channels clogged with vegetative litter.

Erosion and construction obstacle sensitivity images/maps were developed through this study to provide the Planning Division with information for planning and deciding upon such issues as community growth, parcel size, and construction permits.

## Soil Erosion

Soil erosion occurs by water and by wind, and results in loss of soil. Arid and semi-arid areas face greater soil loss, especially where human practices have disturbed the topsoil, and during times of drought. Erosion is a complicated process that is influenced by weather patterns, especially those for rain, intense storms, and winds, and by topographic features, vegetation cover, and soil conditions. It is a natural process, but one that is accelerated by human activities such as grazing cattle, destroying vegetation, and disturbing the soil surface by cultivation, construction, or with vehicles. In addition to soil loss, erosion affects human property. Deposited soil buries structures, covers roads, and blocks drainages, and the act of erosion can wash away roads and foundations.

The Revised Universal Soil Loss Equation, RUSLE, estimates rates of soil erosion caused by rainfall and the associated overland flow, and was developed as a tool to identify areas and degree of erosion and to develop conservation plans to control erosion. RUSLE represents the relationship between climate, soil, topography, and land use with soil loss caused by raindrop impact and surface runoff. In general, erosion depends upon the amount and intensity of rainfall and runoff, the land cover protection offered the soil from those rain factors, the landscape topography, and the intrinsic soil susceptibility to erosion. These influences are described in the equation

$$A = R * K * L * S * C * P, \tag{A.1}$$

where A is the predicted average sediment yield measured in tons per acre-year. R is the rainfall-runoff factor and is computed from historical climatological values; K is the soil erodibility factor derived from field measurements. LS factors represent effects from slope length, steepness, and shape; C is the cover-management factor and P is the supporting practices factor. Each of these factors quantifies one or more processes and their interactions, and each factor is combined in RUSLE to yield an estimate of soil loss.

## Data and Sensor Description

### Satellite Sensors

The Landsat 7 satellite is a joint venture between the USGS and NASA, and was launched in April 1999. It carries the Enhanced Thematic Mapper Plus (ETM+) instrument, a nadir-viewing radiometer with eight multispectral bands (Table 1). The swath width is 185 km, and repeat coverage occurs at 16-day intervals.

Table 1 Landsat ETM+ Bands, Spectral Ranges, and Resolutions

| Band Number | Spectral Range (μm) | Ground Resolution (m) |
|---|---|---|
| TM1 (Vis Blue) | 0.450 – 0.515 | 30 |
| TM2 (Vis Green) | 0.525 – 0.605 | 30 |
| TM3 (Vis Red) | 0.630 – 0.690 | 30 |
| TM4 (NIR) | 0.750 – 0.900 | 30 |
| TM5 (Mid-IR) | 1.550 – 1.750 | 30 |
| TM6 (TIR) | 10.40 – 12.50 | 60 |
| TM7 (Mid-IR) | 2.090 – 2.350 | 30 |
| TM8 (Pan) | 0.520 – 0.900 | 15 |

Space Imaging's IKONOS is a commercial Earth observing satellite and was launched in September 1999. The sensor is capable of in-track and cross-track pointing, and has four multispectral bands that are comparable to the VNIR bands on the Landsat satellites (Table 2). Its nominal swath width is 11 km at nadir, and the combination of nadir and off-nadir viewing allows for almost-daily imaging of most sites.

Table 2 IKONOS Bands, Spectral Ranges, and Ground Resolutions

| Band Number | Spectral Range (µm) | Ground Resolution (m) |
|---|---|---|
| 1 (Vis Blue) | 0.45 – 0.52 | 4 |
| 2 (Vis Green) | 0.52 – 0.60 | 4 |
| 3 (Vis Red) | 0.63 – 0.69 | 4 |
| 4 (NIR) | 0.76 – 0.90 | 4 |
| Panchromatic | 0.45 – 0.90 | 1 |

### Raster Image Data

Landsat 7 ETM+ data for Path 33 Row 36 in the Landsat Worldwide Reference System were acquired on 9 May 2000. The image was initially obtained from the USGS EROS Data Center in Sioux Falls, South Dakota. This image was contributed to Earth Data Analysis Center (EDAC) in mid-July 2000, through the Evapotranspiration Project of the Hydrogeoecology Group at the University of New Mexico, in cooperation with the USDA Agricultural Research Service.

IKONOS 4-m Multispectral Image (MSI) data were acquired on 23 July 2000. These data were collected from a viewing angle of 33.9° off-nadir and for an area of approximately 12 km x 12 km. NASA Stennis Space Center provided the image to EDAC for the original project, in early August 2000.

Digital Elevation Model (DEM) data for the study area were obtained from the EDAC archive. USGS 7.5-minute, 10-m DEM data sets describe terrain elevation in raster form and are derived from stereo aerial photographs. The DEMs used in this project were created in 1999.

### Digital Vector Data

The digital Soil Survey Geographic (SSURGO) database was produced by the USDA Natural Resources Conservation Service and cooperating agencies for the 21 June 2000 Soil Survey of Sandoval County Area, New Mexico. These data were distributed in ARC interchange file format (an ESRI® GIS format) from the Internet site www.ftw.nrcs.usda.gov/ssur_data.html. The 1:20,000-scale map of soil boundaries is intended for planning and management purposes, and includes feature attribute data for major soil layers, soils features and properties, and soils use and management. Attributes for the SSURGO database included entries for soil features and physical and chemical properties, such as soil component name, texture, drainage, corrosion-concrete, erodibility, and permeability.

## Data Processing

Landsat 7 ETM+ data were imported into ERDAS® IMAGINE as an 8-bit continuous-data image, and IKONOS MSI data were imported as a 16-bit continuous-data image. These images were geocorrected and projected to Universal Transverse Mercator (UTM), Zone 13, with Geodetic Reference System of 1980 (GRS 1980) Spheroid and North American Datum of 1983 (NAD 83). (All images used in this study were in the same projection.)

Composite DEM data were imported as a 16-bit continuous-data image with 10-m pixel size (and elevation in units of feet). IMAGINE Topographic Enhancement functions were used to create aspect, percent slope, and shaded relief images. The aspect and percent slope data sets were converted to 8-bit thematic-data types. DEM, aspect, and percent slope images were then subset to the study area. The aspect values were re-assigned to wind factors that were extrapolated from the percentage of time that winds blew from each direction.

A CURVATURE Surface Function was performed on the DEM, using the ARC/INFO GRID module. The computation yielded an output with values ranging from negative to zero to positive. Negative curvature indicated the degree of surface concavity, while positive curvature indicated degree of surface convexity. Flat surfaces had a value of zero. The GRID-formatted output was imported into IMAGINE as an image file. Each pixel value was summed with 100 so that all values were zero or positive. Flat surfaces had a value of 100 in the resulting 8-bit thematic-data image. Concave and convex surfaces had values less than and greater than 100, respectively.

Next, a FLOWACCUMULATION Hydrologic Function was performed on the DEM, using the ARC/INFO GRID module. The GRID-formatted output was imported into IMAGINE as an image file. A linear relationship was determined between channel width (from shaded relief analysis) and flow accumulation values, using the Microsoft Excel Linear Regression function.

The equation for channel width against flow accumulation values generated data to compute a flood zone data file in IMAGINE Spatial Modeler. The linear equation (b + a*flow_accum)/2 was applied to the flow accumulation file, resulting in an unsigned 16-bit, thematic-type data file. This file was then used with the ARC/INFO GRID GRIDLINE and BUFFER functions to create flow line and flow buffer files. The GRID flow buffer output was imported into IMAGINE as an image that delineated the buffered flood zone for arroyos and other drainages. The flood zone buffer image was an unsigned 8-bit, thematic-data type.

Sandoval County SSURGO data were imported into IMAGINE image format and subset to the Rio Rancho study area, with 4-m pixel size and as an unsigned 8-bit, thematic-data image. There were 30 distinct soil areas for 13 different component soils, and one water component. Pertinent soil attribute values were for component name, frost action, drainage, corrosion-concrete, corrosion-uncoated steel, texture, K factor (soil erodibility), permeability, shrink/swell action, and the wind erosion index (WEI).

## Analysis

### Supervised Classification

Land cover/land use supervised classifications were derived for the Landsat 7 and IKONOS images with a maximum likelihood parametric decision rule. IMAGINE Classification functions were used to perform these image classifications. Field descriptions were collected in the Rio Rancho area, and located using hard-copy maps of the images. Points representative of the major surface features and land covers were collected for classification training. Classes represented by these points included water, natural vegetation, urban structures and vegetation, and natural and urban barren features.

Each resulting image classification contained ten map units. IKONOS data did not classify accurately for shrubland, natural grassland, and juniper when compared to the Landsat classification and to knowledge of the study area, and so the two land cover classifications were combined in IMAGINE Spatial Modeler. This resulted in an unsigned 8-bit, 4-m-pixel, thematic-type image with 11 map units. A column was added to the image attribute table for Erosion Factor, designating the soil protection properties for each map unit. Figure A3 shows the 11 map units in the combined classification image.

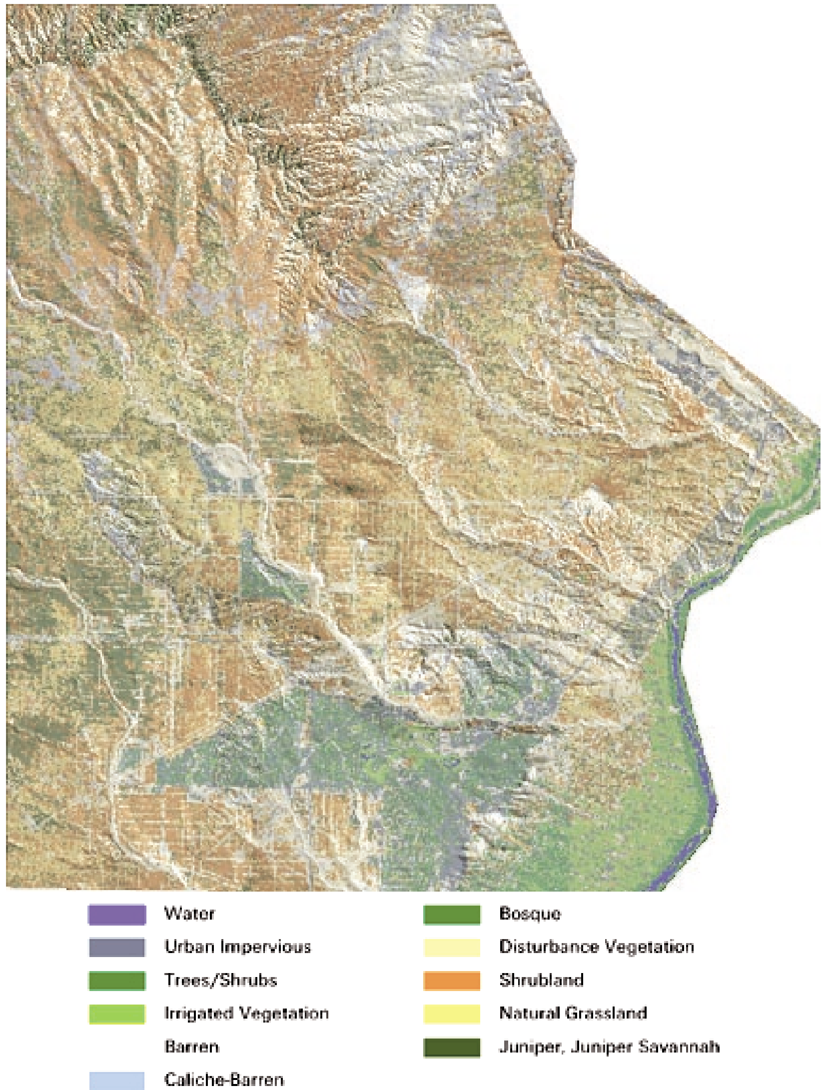

Figure A3. The combined Landsat and IKONOS land cover classification has been overlaid on the shaded relief for the area. There are 11 map units in this final classification, as indicated in the legend.

## Erosion Sensitivity

RUSLE computes amount of soil loss in tons/acre/year. Field measurements necessary for such quantitative results were not available, and so this study attempted to qualify soil erosion sensitivity using RUSLE concepts as a guide toward determining parameters and models that characterized the erosion potential.

Since the study area was small and with no significant interruptions in terrain, the rainfall-runoff factor R had the same value throughout and so was not used in the analysis. K, the soil erodibility factor, was the K factor attribute in the SSURGO database; in the wind erosion model, K was replaced with the WEI. Slope length, L, is a field measurement and had not been computed; but curvature values were used to model shape, one of the slope length components. Percent slope values were used for the S variable; slope was replaced by an aspect wind factor for the wind erosion model. C and P, cover-management and supporting practices, were combined as erosion factor attributes to the land cover classification map units.

Erosion sensitivity was computed as an average, rather than as a product, so that the result would be of the same scale as the inputs. All values were defined to be without units, giving each input equal weight. Input values/factors were integers that had been normalized to 100, where highest sensitivity or influence took the value 100 and no sensitivity/influence was indicated by the value 0. Percent slope values had a maximum of 130 and curvature values had a maximum of 115. These two data sets were used without modification, resulting in exceptions to the normalization process. Sensitivity models were developed for soil erosion due to water and to wind.

Soil erosion due to water was modeled using DEM-derived values for curvature and percent slope, the soil survey K factor, and the map unit erosion factors. Flat and concave/depositional curvature values were considered insensitive to erosion by water, and so values from 0 through 100 were set to 0. Otherwise, curvature was defined as the file value minus 100.

Soil erosion due to wind was modeled using DEM-derived values for curvature, aspect-wind, the soil survey WEI, and the map unit erosion factors. Concave/depositional surfaces were considered insensitive to erosion by wind, and so curvature values less than 100 were assigned 0 value. Flat and convex surface sensitivities were represented with values of 75 and 100, respectively.

The Water/Wind Erosion Sensitivity models were created in IMAGINE Spatial Modeler with conditional functions to give unsigned 8-bit, thematic-type image outputs for erosion sensitivity. Each algorithm incorporated Boolean, conditional, and relational functions with the input values. The following were the (generalized) statements for the Water Erosion Sensitivity model.

IF curvature LE 100, THEN curvature_factor EQ 0
IF curvature GT 100, THEN curvature_factor EQ (curvature – 100)
IF classification_mapunit EQ water, THEN water_erosion EQ 100
IF classification_mapunit EQ urban impervious, THEN water_erosion EQ 150
OTHERWISE
water_erosion EQ (curvature_factor + percent_slope + erosion_factor + K_factor) / 4

Statements for the wind erosion model were similar.

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IF curvature LT 100, THEN curvature_factor EQ 0
IF curvature EQ 100, THEN curvature_factor EQ 75
IF curvature GT 100, THEN curvature_factor EQ 100
IF classification_mapunit EQ urban impervious, THEN wind_erosion EQ 150
OTHERWISE
wind_erosion EQ (curvature_factor + aspect_wind_factor + erosion_factor + WEI) / 4
```

## Construction Sensitivity

Sensitivity to construction hazards and obstacles was computed as an aid to be used with the erosion sensitivity products. Percent slope, flood zone, and SSURGO values for drainage, shrink/swell action, and corrosion-concrete were modeled to qualitatively illustrate those areas that are least desirable for construction. As with the erosion sensitivity models, values were normalized to 100 (highest sensitivity/influence) and defined to be without units. Averages of the input values were computed, resulting in an output that was of the same scale as the inputs.

Variables for percent slope, flood zone, and soil characteristics such as drainage, shrink/swell action, and corrosion risk for concrete were considered pertinent to issues such as movement of footings and ease of excavation and construction. Corrosion risk for uncoated steel was High for the soil types in the study area, and although this was a pertinent construction variable, its consistency would not have influenced the output and so it was not used in the model. Frost action had varying values in the study area, but shrink/swell was considered a more important variable for the construction model since footings, by code, should be placed below the freeze zone. Large stone size was also a consideration for ease and cost of construction, but none of the soils in the study area had rocks greater than 10 inches in size (the largest size category in the SSURGO database). And, the Sandy Riverwash soil component was the only one in the study area that had rocks greater than 3 inches in size (only 5% of the soil area, and outside of Rio Rancho boundaries). Other pertinent factors were depth to bedrock or cemented pan and a high water table. These values were not listed in the soils database, or else insufficient information was available to model their influences.

Percent slope values had a maximum of 130, and were the same as those used in the erosion sensitivity models. According to the University of Rhode Island *Rapid Site Assessment Guide* (www.edc.uri.edu/cewq/rapid/slope.html), slopes up to eight percent are optimal for development, as they require only slight grading and cause minimal land disturbance. Also, slopes greater than eight percent are more susceptible to erosion by water and extra efforts must be made to prevent the post-construction erosion. Slopes less than two percent can pond when the surrounding area is graded. Road construction is substantially more expensive for slopes greater than eight percent; and building construction becomes more expensive for slopes greater than fifteen percent. Information from the University of Rhode Island was used to model the influence of percent slope on construction hazards sensitivity.

The Construction Obstacles/Hazards Sensitivity model had six input rasters: percent slope, flood zone buffer, classification map unit, drainage, corrosion-concrete, and the shrink/swell factor. These were used in Spatial Modeler with Boolean, conditional, and relational functions (similar to those used in the erosion models) to give an unsigned 8-bit, thematic-type image output for construction obstacles sensitivity.

### Rainwater Flow

The DEM for the study area was resampled to 2-m pixels and subset to the urban impervious map unit, using the IMAGINE Spatial Modeler. Pixels not coincident with the map unit were assigned the value of 1, and coincident pixels retained their values. FLOWDIRECTION and FLOWACCUMULATION were computed for the DEM with ARC/INFO GRID functions and the conditional statement, con(grid_in>1, flowdirection(grid_in)). These files were then imported into IMAGINE as images. Flow accumulation values ranged from 0 to 502. The flow accumulation image was then used as an overlay to the erosion and construction sensitivity images to identify areas of heightened or additional concern with respect to potential erosion.

## Results

This project resulted in numerous image and map products that can be used in Rio Rancho's GIS program, and at EDAC and the University of New Mexico. These include the geocorrected Landsat and IKONOS images and their respective land cover classification images. The combined Landsat and IKONOS classification provides Rio Rancho's Planning Division with a good, general land cover characterization. Some of the incorporated area includes healthy natural grasslands that the city might choose to preserve, and the classification identifies their locations. Much of the city is represented in the IKONOS image, and the 4-m pixel resolution results in a crisp classification for barren areas, such as unpaved roads, arroyos, and graded construction areas. Arroyos and unpaved roads are visually distinguished in the classification, even though they are both contained in the same map unit. Traffic and ground conditions in some areas have resulted in unpaved roads that have eroded into drainages. The various stages of erosion can be identified in the classification and monitored or, if possible, repaired. Small drainages and offshoots to main arroyos have developed recently, and so might not be included in Rio Rancho's drainage GIS data set. As with the eroded roads, these features can be identified and monitored as the surrounding areas are developed. Various GIS coverages, such as those for roads, drainages, and parcels, can be layered with the land cover classification.

Features were extracted for soil erosion due to water and to wind and for construction obstacles/hazards, and each of these extraction processes resulted in a sensitivity image. As with the land cover classification, these thematic images can be used as layers within a GIS. Categories, or sensitivity "map units," for each image were determined through a density slice on the histogram peaks—a clustering method applied to the image data. These show high sensitivity relative to lower degrees of sensitivity, with user-defined groupings and colors. Figures A4 and A5 show the categorized sensitivity images. The DEM-derived flow accumulation image can be overlaid with any of the sensitivity images.

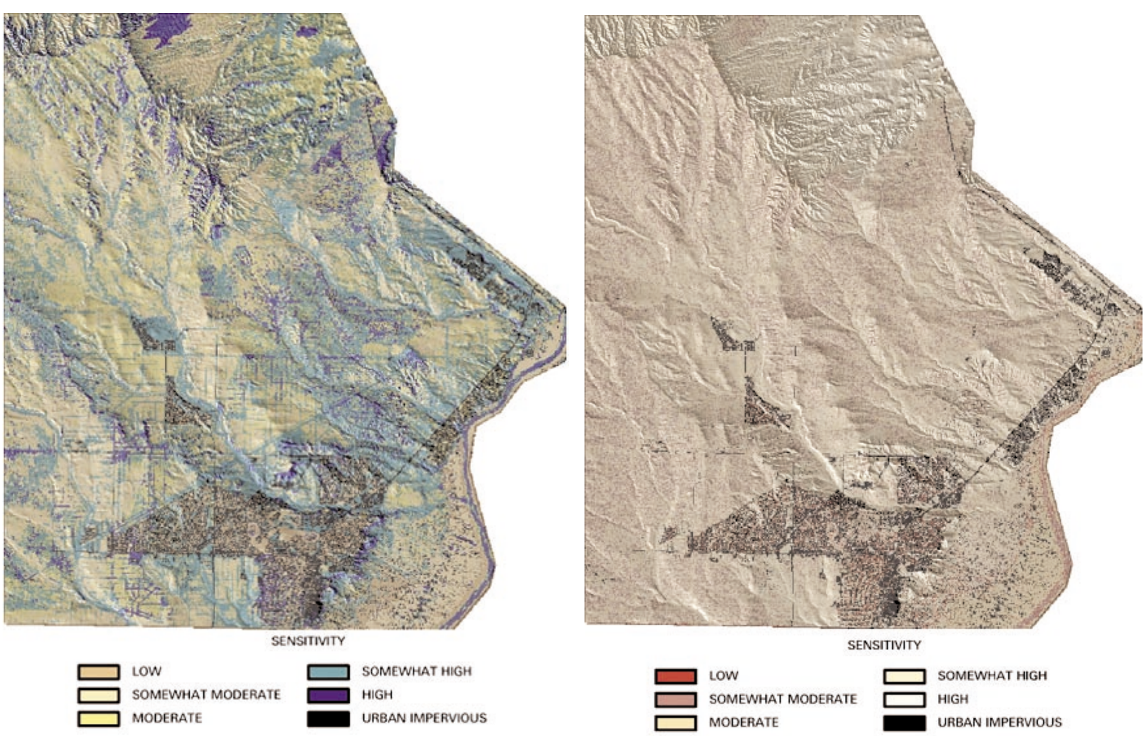


Figure A4. Water Erosion Sensitivity is shown in the left-hand image, overlaid on the shaded relief. Wind Erosion Sensitivity is shown overlaid on the shaded relief to the right. Five categories of sensitivity, plus an urban impervious category, are defined in each legend.

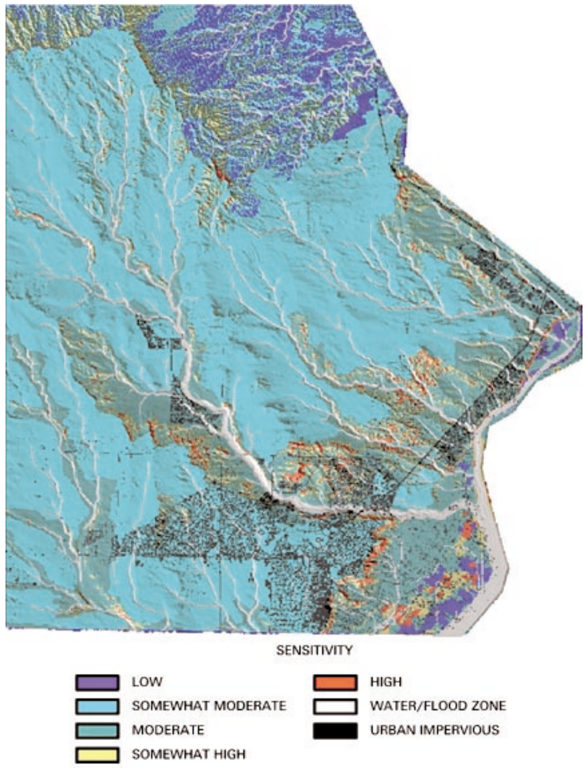


Figure A5. Construction Obstacles/Hazards Sensitivity, overlaid on the shaded relief, shows categories for water/flood zones and urban impervious features, and shows five sensitivity categories, as defined in the legend.

## Conclusions and Synopsis

This study focused on developing models and thematic image products that addressed the important issues of soil erosion for an area in the semi-arid Southwest. Image feature extractions were performed as land cover and sensitivity classifications for Rio Rancho, a city that faces rapid growth and development. These feature extractions included a land cover/land use classification, sensitivity to soil erosion by water and by wind, and construction obstacles/hazards sensitivity.

Landsat and IKONOS satellite images were processed and analyzed, as were images for topography and soils. Processing was performed with ERDAS® IMAGINE and ESRI® ARC/INFO GRID software, and resulted in numerous base image products for the Rio Rancho study area. These included the geocorrected satellite images, USGS DEM and derived topographic images, and images for the USDA soils and attributes data.

The study was an extension to a NASA project that was carried out as an evaluation of new ERDAS® IMAGINE functions. Because the project emphasized image processing, minimal ground measurement data have been used, leading to qualitative images and products rather than to quantitative results. It should be noted that the USDA soils data were derived from field experiments, although they were used in the analyses as image data.

Landsat and IKONOS images were geocorrected and subset to the study area. Supervised image classification is a commonly used feature extraction technique, and both satellite images were classified for land cover features using the conventional maximum likelihood parametric decision rule. This process used the computed statistical values for each image layer for the training sites to allocate each pixel to a specific class. The Landsat and IKONOS classifications were combined, resulting in one thematic classification image with 4-m pixel size and with eleven "simple" map units.

Features for erosion and construction obstacles sensitivity were derived in the IMAGINE Spatial Modeler function, with user-defined models. Erosion models were based upon concepts in the Revised Universal Soil Loss Equation (RUSLE) developed by USDA agencies. RUSLE quantitatively computes the annual amount of soil loss due to water erosion, and the measurements required to compute the equation were not available for this study. The modeled erosion features are qualitative rather than quantitative, but the variables derived from the terrain and land cover images were approximate counterparts to the RUSLE variables.

Erosion depends upon the amount and intensity of rainfall and runoff, land cover protection offered the soil from those rain factors, landscape topography, and intrinsic soil susceptibility to erosion. This study area was small with no terrain disruptions to weather events, and so the climatic variable in RUSLE was not considered in the model development. Erosion factors were derived for the land cover categories, and the soil erodibility variable was provided in the soil survey database, as was the wind erosion index. Percent slope, curvature, and aspect variables were derived from the USGS DEM data to characterize the topography.

Soil survey data also included parameters for soil properties that were used to model the area's sensitivity to construction hazards and obstacles. This model incorporated the DEM-derived data sets, including one for buffered flood zones, with the soil property data. All three sensitivity products resulted in qualitative characterizations for the Rio Rancho study area.

A flow accumulation image for the impervious map unit was created with GRID functions. This image can then be overlaid on the other images from the study to further identify areas of erosion concern.

The land cover and sensitivity classifications are thematic image products that are readily used in a Geographic Information System (GIS). They provide Rio Rancho's Planning Division with data layers that can be integrated into planning and decision-making with respect to development and zoning. Areas that are known to be problematic are well modeled in these images, and the Planning Division can use the image information to support the decisions made for those areas. Other areas that show high sensitivity had not been determined as problem areas, and they can be further assessed through ground surveys now that they have been identified. Rio Rancho can also use the models developed in this study for ongoing assessment. The models can be easily updated or modified as additional or more current data become available. As with the image products, the models can be incorporated, and analyses performed, in a GIS.

An important feature of this project is that the results can be used for a larger or different area than that chosen for the study. Many communities in the semi-arid and arid regions of the United States are addressing erosion problems. The problems arise from natural environmental characteristics and from human activity, such as grazing or premature platting. For example, there are an estimated one million acres of prematurely-platted properties in New Mexico, alone. Arizona, Colorado, and California also face problems with large numbers of platted properties, and with the ensuing erosion. Complex features such as erosion have been qualitatively represented through this study with straightforward models. These models are portable to other communities that have incorporated spatial data analysis into their planning programs.

Future research into the erosion feature classification methods developed for this study will yield more information through better characterization of the soils in the study area. Image-derived data layers that would improve soil description are those for soil moisture, principal components, and (Landsat) band ratios. These data sets, combined with soil texture information and the image data, will allow better assessment of areas that have a high potential for soil erosion. Further analyses will also provide a more accurate delineation of those areas that have the highest rates of erosion. Refined soil characterization will also allow image-derived erosion modeling for areas that do not have access to soil survey data.