MODELING FLOW AND EROSION SENSITIVITY FOR RIO RANCHO, NEW MEXICO

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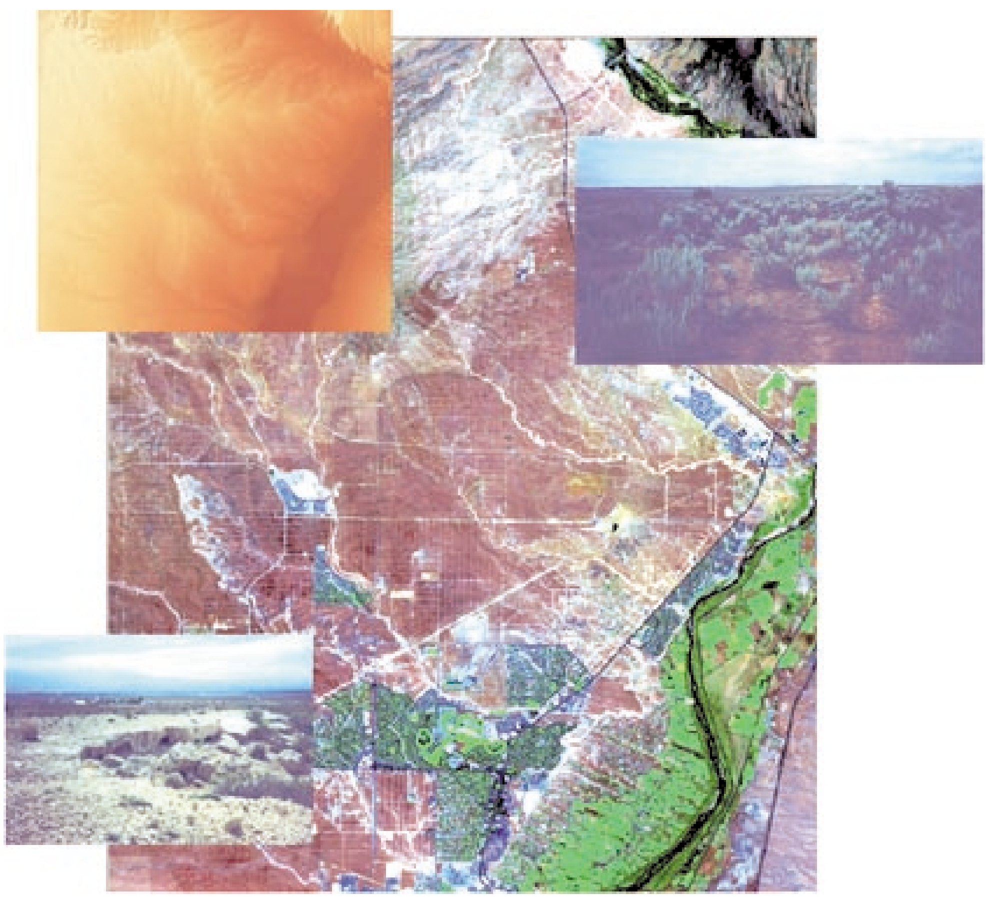
CE 547 GIS in Water Resources Engineering
Spring 2002



INTRODUCTION

This study focused on developing models for feature extraction using digital image processing supplemented with a Geographic Information System (GIS). It was an extension to a NASA-funded project that was carried out by Earth Data Analysis Center with the City of Rio Rancho, New Mexico. Rio Rancho's Planning Division identified soil erosion as a critical issue in their community planning and decision making. Features that characterized this urban environment and development issue were then modeled to create land cover and sensitivity images and maps, and water flow maps for the urban and natural surroundings interface in Rio Rancho.

Study Objective

The objective was to model and extract features for erosion sensitivity and for rainwater flow across impervious surfaces. In this study, features were extracted for land cover, sensitivity to erosion by water and by wind, and to construction obstacles/hazards using satellite, topographic, and soils imagery. The Revised Universal Soil Loss Equation (RUSLE), developed by the U.S. Department of Agriculture (USDA) Agricultural Research Service and Natural Resources Conservation Service, served as a guideline to the pertinent parameters for modeling erosion [1]. Rainwater flow was modeled for impervious surfaces and identified for paved/unpaved interfaces, using land cover and topographic imagery. Since the original project emphasized image-processing methods, these extraction models and assessments were based only upon image and soil survey data. Thus, the minimal amount of available ground data led to qualitative, rather than quantitative, results. The Appendix further describes the background, methods, and results for the study.

Study Area

Rio Rancho is situated in Sandoval County, New Mexico, in a semi-arid environment that receives less than a foot of rain annually (Figure 1). Rain events are often intense, to the point that arroyos are filled with fast-moving, eroding water. Also, elevational gradients in the area cause overland water run-off to be erosive, especially where the ground has been disturbed or is otherwise denuded of vegetation. Planning for future construction and city growth must consider drainage and erosion factors, both for more effective development and to preserve the existing arroyos.

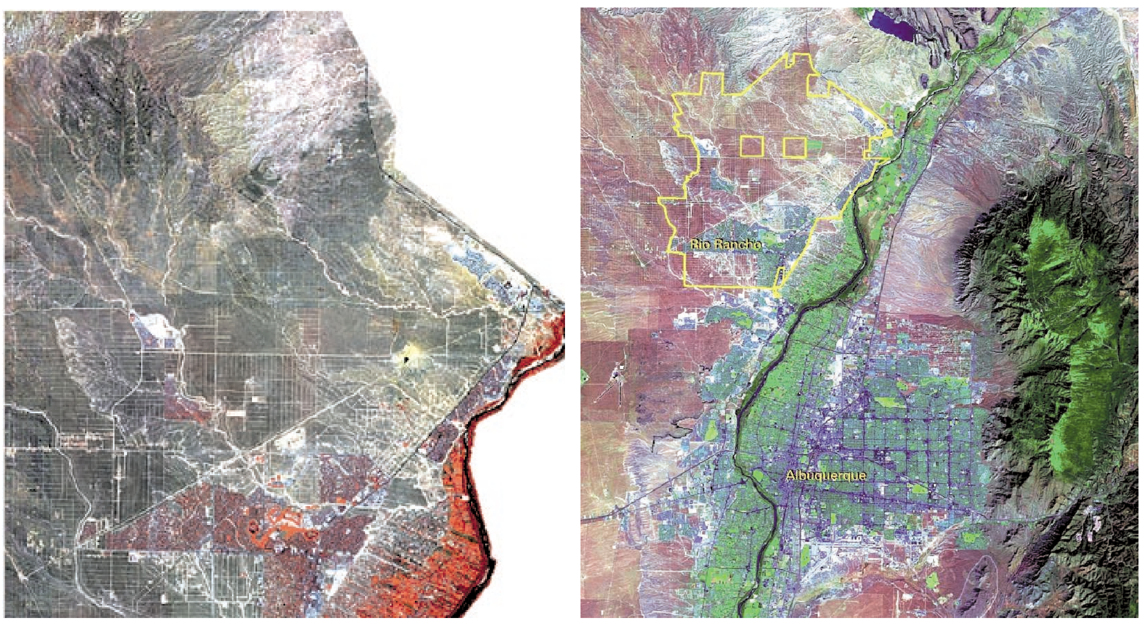


Figure 1. The left-hand image shows the study area as a merged Landsat 7-IKONOS image. Near Infrared, Visible Red, and Visible Green bands are displayed in Red, Green, and Blue, respectively. Irrigated vegetation is shown in red; unpaved roads are visible even 40 years after they were graded. The right-hand Landsat 7 image shows the City of Rio Rancho outlined in yellow. Albuquerque is south of Rio Rancho, the Rio Grande and Corrales are east, and the Sandia Mountains are southeast of the city. Mid-infrared, Near Infrared, and Visible Green bands are displayed in Red, Green, and Blue, respectively.

Analysis and Results

Images included satellite, elevation, and soil survey raster data sets. Since the study area was small (approximately 20 km x 25 km) and precise measurements were desirable, the images were used with the Universal Transverse Mercator Projection, Zone 13, Geodetic Reference System 1980 Spheroid, and North American Datum 1983. Landsat 7 30-m and IKONOS 4-m images were used for supervised classifications in ERDAS® IMAGINE image processing software. The two classifications were merged, resulting in one 4-m image with 11 map units for water, urban impervious, irrigated vegetation, natural grasslands and shrublands, and barren areas. These map units were then assigned erosion factors based on soil protection properties. Shaded relief, slope, aspect, curvature, flow accumulation, and flood zone image files were derived from U.S. Geological Survey (USGS) 10-m Digital Elevation Models (DEMs) using IMAGINE and the ESRI® ARC/INFO GRID module. The USDA soil survey database [2] included soil features and properties, and the soils raster data, at a 1:20,000-scale, that were imported as an image. Figures 2 and 3 show some of the input images for the study.

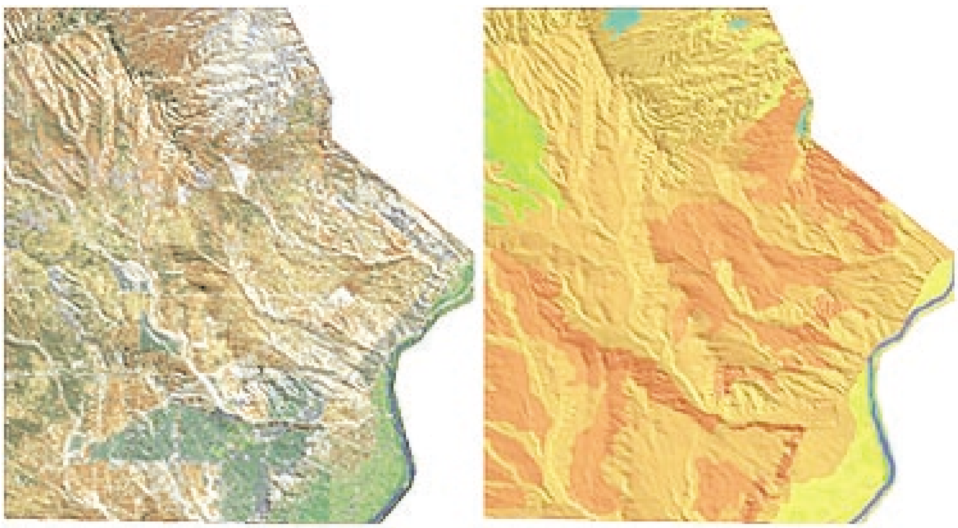


Figure 1. Eleven map units are represented in the image-derived land cover classification on the left. Thirty soil polygons and the river polygon are displayed in the soils image on the right.

Figure 3. The left image is of the study area DEM, with the lowest elevation displayed in blue and the highest in red. The elevation gradient for the area is 1353 feet. A colored shaded relief is shown in the middle. In the percent slope image on the right, blue indicates shallow slopes (the river bed is in black) and red indicates steepest.

Erosion and Construction Sensitivities

Erosion sensitivities were modeled for water and wind, and were computed as averages, rather than as products (as with RUSLE), so that results would be of the same scale as the inputs. All values were defined to be without units, giving each input equal weight. Input values 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. Soil erosion due to water was modeled as a function of curvature and percent slope, the soil survey K (erodibility) factor, and the classification-derived erosion factors. Soil erosion due to wind was modeled as a function of curvature, an aspect-wind-direction factor, the soil survey Wind Erosion Index, and the classification-derived erosion factors. Sensitivity for construction hazards and obstacles modeled the difficulty and costliness of construction and development, and the spatial model was a function of six input rasters: DEM-derived percent slope and flood zone, classification map unit, and soil survey drainage, corrosion-concrete, and shrink/swell factors. The model and parameters were computed in the same manner as for erosion. All of these sensitivity algorithms used Boolean, conditional, and relational functions with the above values.

The water erosion model was most sensitive to inputs for the classification erosion factor and percent slope, while the wind erosion model showed greatest sensitivity to inputs for curvature and percent slope. Much of the high response for water erosion occurred in areas of unpaved roads, and the results indicated that these areas were indeed breaking down and gullying. Sensitivity for the construction obstacles/hazards model was greatest for flood zone, percent slope, and corrosion-concrete inputs. Figures 4 and 5 illustrate the three image products.

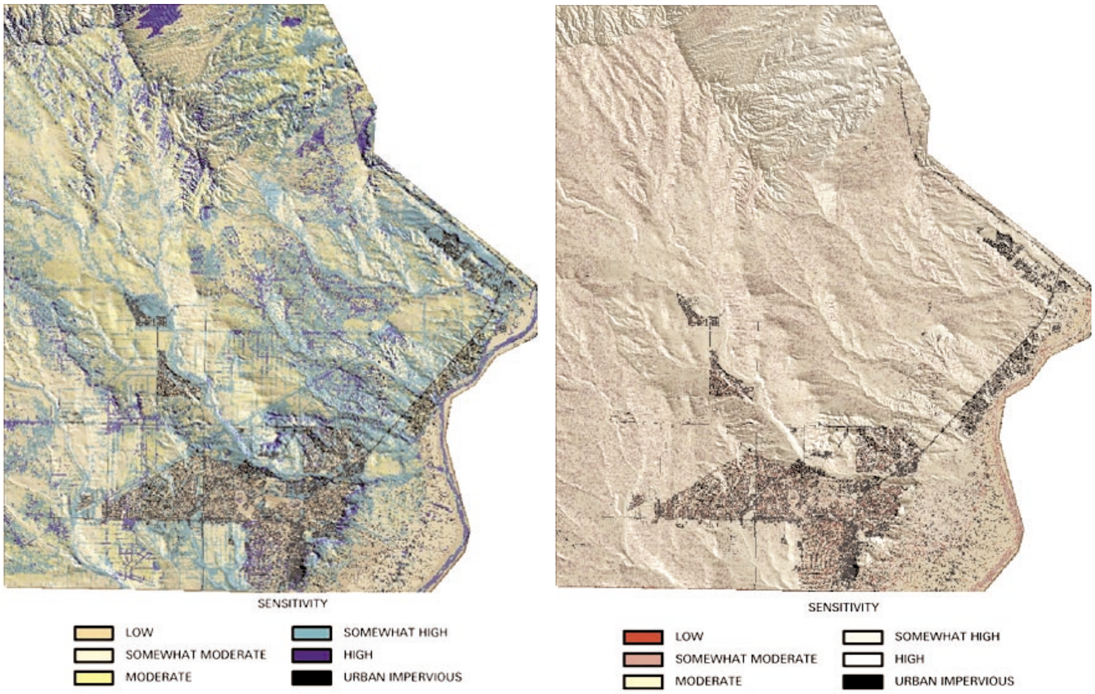


Figure 4. Water (left) and Wind (right) Erosion Sensitivity images, are overlaid on the shaded relief for the study area. Five categories of sensitivity, plus an urban impervious category, are defined in each legend.

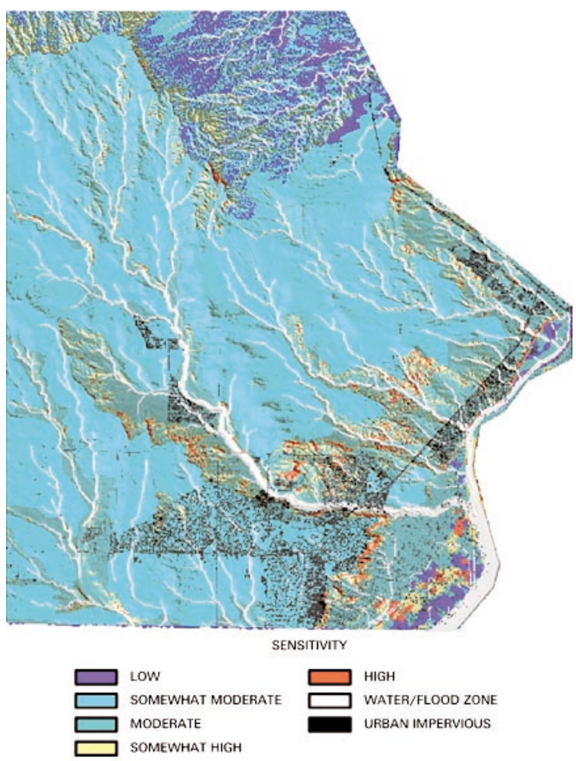


Figure 5. Construction Obstacles Sensitivity, overlaid on the shaded relief, shows categories for water/flood zones and urban impervious features, and shows five sensitivity categories, as defined in the legend.

Rainwater Flow

Rainwater flow across impervious surfaces was computed with a new DEM image that was created using the impervious map unit as a mask, and resampling to 2-m pixels (Figure 6). Flow direction and accumulation were derived for these paved surfaces in ARC/INFO GRID, with the assumption that the paved “terrain” followed the natural terrain. The resulting flow accumulation image was overlaid on the erosion and construction obstacle sensitivity images to identify interface areas with high water flow (Figure 7).

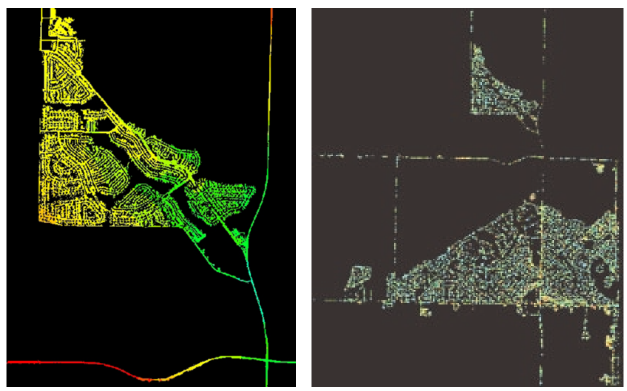


Figure 6. The left-hand image is an example of the resampled and masked DEM, with highest elevations in red. An example of the flow accumulation is on the right. Low values are displayed in blue, through high values in red.

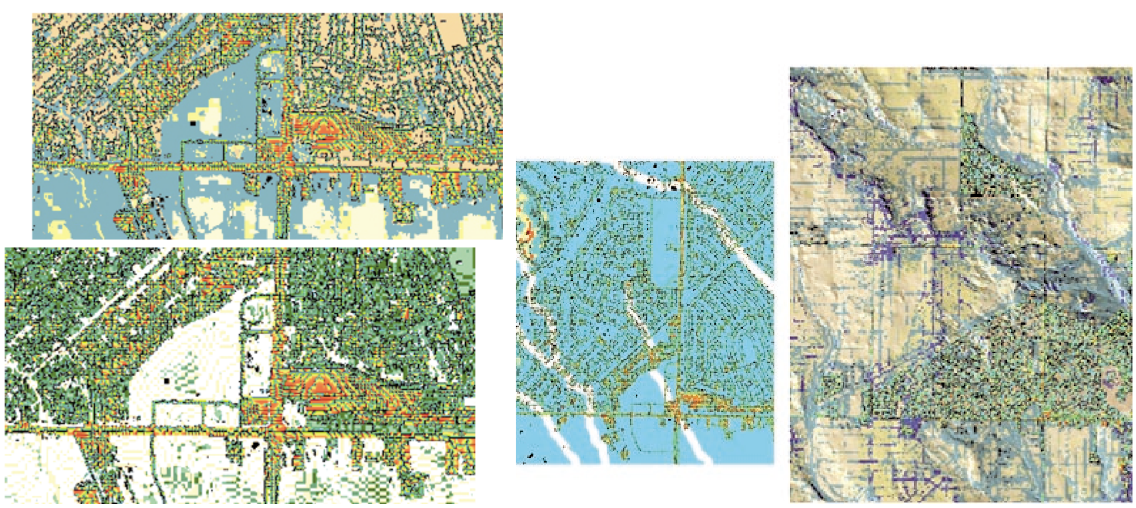


Figure 7. The top left image is an example of flow accumulation overlaid on water erosion sensitivity, with blue representing moderately high sensitivity to erosion and red and yellow representing high flow accumulation values. The bottom left image shows flow accumulation overlaid on combined water-wind erosion sensitivity. Here, light colors indicate high sensitivity and greens indicate low sensitivity. Flow accumulation is overlaid on construction obstacle sensitivity in the middle image. Cyan shows relatively low sensitivity and off-white shows flood zones. The right-hand image is a larger view of flow accumulation overlaid on water erosion sensitivity.

The highest flow accumulation value was 502, representing the number of pixels flowing into the given pixel. Such a 2-m x 2-m pixel resulted in accumulation from a 2000 m^2 surface area, and a 0.5” rain event would deliver 25 m^3 of water to that pixel. Flow accumulation at the paved/unpaved interface areas gives some indication of those places that should be of greater concern to the Planning Division because of co-existing high erosion or construction obstacle sensitivity. This information is limited, however, by the coarseness of the DEM data.

Conclusion

All of these sensitivity products will provide support for Planning Division decisions and plans regarding such issues as minimum parcel size, construction permits for lots on drainage beds, access to developing areas, and open space designation. Their utility is enhanced by the thematic nature of the raster images, as they add readily-used and pertinent information layers to Rio Rancho’s developed GIS program. These products and models can be easily updated in the GIS.

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, and therefore, sensitivity to erosion, include those for soil moisture, principal components, and band ratios (Figure 8). These data sets, combined with soil texture information and image data, will allow better assessment of areas that have a high potential for and high rate of soil erosion. Image-derived soil characterization would also make the sensitivity models applicable in areas for which a ground-based soil survey has not been performed.

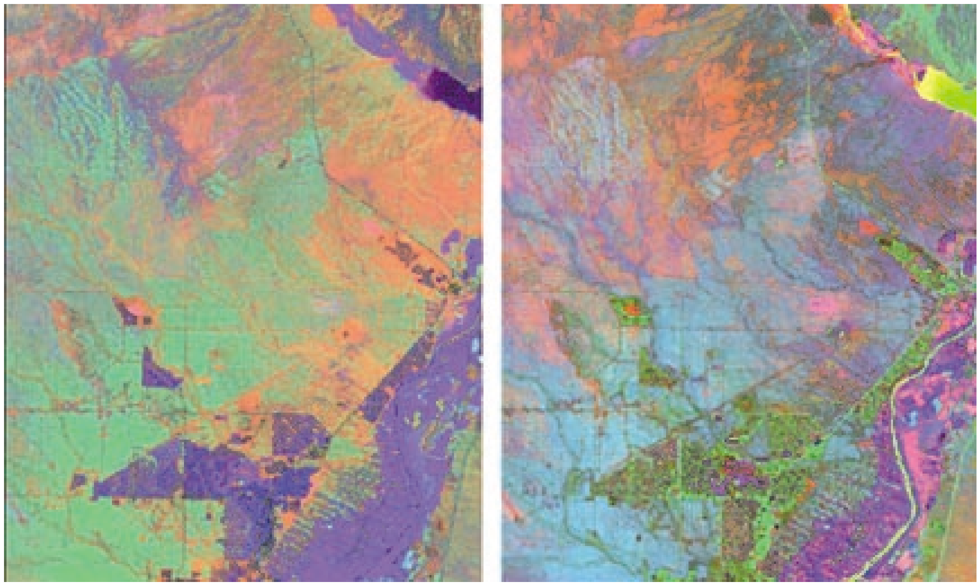


Figure 8. These images were derived from the Landsat image shown in Figure 1.
The left-hand image is a combination of three band ratios. Among the features illustrated in this image are soil content for iron oxide, and ferrous and clay minerals, displayed in Red, Green, and Blue, respectively. The right-hand image shows a combination of three principal components from a principal components analysis. These components illustrate such features as soil content for clay minerals, iron oxide, and ferrous minerals, displayed in Red, Green, and Blue, respectively.

Flow models for the impervious surfaces could be improved with high-resolution elevation data for those surfaces, such as 1-m LiDAR or aerotriangulation elevation data. In addition to providing true elevation information for non-natural surfaces, such data sets would allow for a more detailed, finer resolution land cover classification.

ACKNOWLEDGEMENTS

The author is grateful to the following people and programs: NASA Stennis Space Center Affiliated Research Center Program for funding the initial study and for providing IKONOS image data, through Cooperative Agreement Number NCC13-98002; the Evapotranspiration Project of the Hydrogeoecology Group, University of New Mexico, for their contribution of Landsat 7 image data; the staff of Earth Data Analysis Center, University of New Mexico; and the City of Rio Rancho Planning Division.

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1. U.S. Department of Agriculture, ARS National Sedimentation Laboratory. RUSLE. (November 2000). <http://www.sedlab.olemiss.edu/rusle/>
2. U.S. Department of Agriculture Natural Resources Conservation Service. *Soil Survey Geographic (SSURGO) Data Base*. Fort Worth, TX (1995). <http://www.ftw.nrcs.usda.gov/ssur_data.html>