HUMAN MODIFICATION OF THE UPPER MIDDLE RIO GRANDE: USING GIT TECHNIQUES TO MEASURE CHANGE BETWEEN ALBUQUERQUE AND COCHITI DAM, NEW MEXICO

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Humans have always modified the natural environment in which they live. Many people of the past have lived near waterbodies or waterways for various reasons, including the abundance of wildlife, availability of food and water, and the relatively cooler temperatures. The human population has increased at an astounding rate over the last 200 years as a result of technological and medical advances. We have also become world travelers, selecting species, both plant and animal, to introduce to areas where they were never native.

The Rio Grande valley is no different. Local inhabitants, including Native Americans, Spanish explorers, Hispanics, and Anglos, have intensely modified the waterway over the past 400 years. According to Spanish explorers, Native Americans in the central Rio Grande valley were practicing irrigated agriculture as early as 1591, and diversion of waterways most likely has been occurring since the Pueblo people arrived in the Rio Grande valley during the 1300s (Schroeder and Matson 1965; Scurlock 1998). Modifications have included changes in land use, riparian vegetation, and channel morphology, as well as the construction of fluvial alterations such as dams, canals, and levees. Each of these changes is interconnected with the environment upstream and downstream, including the native flora and fauna.

Modification of the riparian area along the Rio Grande has allowed invasive species such as tamarisk (*Tamarix ramosissima*) and Russian olive (*Elaeagus angustifolia*) to take advantage of a fragmented ecosystem. Under natural conditions, where human modification is absent or minimal, the invasive species have difficulty competing with native deciduous vegetation such as cottonwood (*Populus* spp.) and willow (*Salix exigua;* Everitt 1998). But within an altered and damaged ecosystem such as along the Rio Grande, invasive species have an enhanced capability to compete (Crawford et al. 1993; Earick 1999). Dams, especially Cochiti Dam, land use changes, including agricultural practices, and grazing allotments contribute to fragmentation, ultimately having a dramatic impact on the vegetation, hydrology, and channel morphology of the river.

Fluvial alterations that have occurred along the Rio Grande since Native Americans moved into the valley (Scurlock 1998) include large-scale and diversion dams, irrigation ditches, drainage ditches, levees, and jetty jacks. The most dramatic impacts may have come from the construction of impoundment dams during the second half of the twentieth century, but ditches, canals, and levees assist in channeling the waters of the Rio Grande to areas that normally would not have water flowing through them. These human-made waterways allow invasive vegetation to proliferate in previously dry areas (Rood and Mahoney 1990; Howe and Kopf 1991; Stromberg 1998).

This study used GIS and image processing techniques to document patterns of change in channel and vegetative area, vegetative island formation, and vegetation cover along the Rio Grande from Albuquerque to Cochiti Dam, in New Mexico. Change was measured over four time periods: 1935, 1954, 1975, and 1996. This research is part of an ongoing research project that analyzes riparian change using GIT techniques throughout the Rio Grande watershed.

STUDY AREA

The study was conducted within the middle Rio Grande riparian area in north-central New Mexico, along a reach of the Rio Grande approximately 50 miles long, starting directly downstream from Cochiti Dam and ending in Albuquerque. The Rio Grande is perennial throughout the reach, although the river has been known to become dry in the Albuquerque area. Six study sites were estab-

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lished (Figure 1). The first was located on the south side of the city of Albuquerque, the second on the north side of Albuquerque, the third in Bernalillo, the fourth near San Felipe Pueblo, the fifth near Santo Domingo Pueblo, and the sixth near Cochiti Dam. Each study site was 1200 m wide and 900 m long to accommodate the use of GIS. The area of the study sites was selected because it was large enough to include the river channel, adjacent vegetation, and riparian land use, which was essential for analyzing and interpreting changes in the data. The 1200 x 900 m study areas provided 30 x 30 m cells, creating an overall appearance of 40 cells wide and 30 cells long (1200 total cells) for each grid overlay.

MATERIALS AND METHODS

Image Processing

All data were derived from aerial photographs using GIS and image processing techniques. Aerial photographs of the study area, purchased in the form of georectified images and un-rectified aerial photos, were collected for 1935, 1954, 1975, and 1996. The georectified images had associated real-world coordinates and map projections, whereas the aerial photos needed to be georectified to conform to the same format. The images from Albuquerque to Bernalillo were georectified, and the images from Bernalillo to Cochiti needed georectification. Satellite images from sources such as Landsat 7 were available for the study area, but not for the earlier time periods of 1935 and 1954. For this reason, aerial photographs were used instead of satellite imagery.

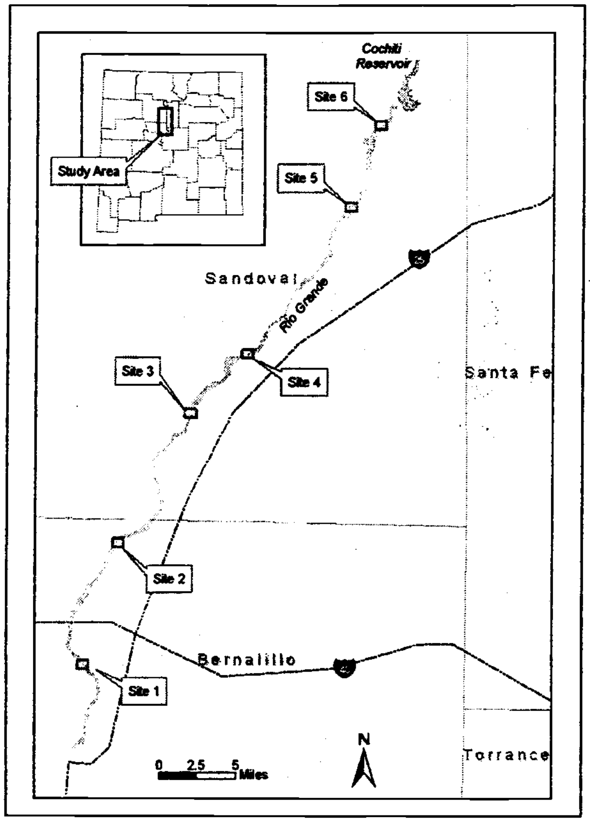

Figure 1. Location map of the six study sites from Albuquerque to Cochiti Dam.

Most of the image processing was accomplished using the Image Analysis extension in ArcView 3.x, although the images were initially viewed and manipulated using PCI Geomatics software and some mosaicking was accomplished using the Raster Calculator in ArcGIS 8.x. The image processing methods included mosaicking, masking, and georectification.

Digital orthophoto quadrangles (DOQs) are a common source of remotely sensed data. DOQs are aerial photographs that have had the distortion caused by the tilting of the camera and topography removed. Standard DOQs are based on 7.5' topographic quadrangles. They are generally available in gray-scale or color-infrared images with 1 m ground resolution; all of the DOQs used in this project were gray-scale images. The images are available in their native format or as TIF compressed files, which can then be imported into a GIS environment.

The images needed to be mosaicked to preserve space and to create a continuous surface. Before mosaicking, the images had to be georectified so they displayed in the correct geographic location. Georectification was attempted using the ArcView Image Analysis extension, but the root mean square (RMS) error was extremely high. The RMS error is measured in cells (pixels) of the source image. It is up to the user to determine an acceptable RMS error for the images; the lower the better.

The masking technique was also used. Polygon shapes can be used to mask, or subset, portions of images. A mask limits the final mosaicked image to facilitate digitizing and measuring change at each site. For every study site, a polygon shapefile was created as the boundary for the 1200 x 900 m area, and a subsequent mask was made from the polygon shapefile. Masks of the images were made at each of the six study sites, and for each interval year; there were thus 24 masks.

Geographic Information Systems

Human activities generate changes in the natural environment. Detecting such changes is important in understanding the past as well as what may occur in the future. These changes can be detected by comparing two images with different temporal coverage and similar spatial coverage. For this project the temporal interval for detecting change was 20 years, from 1935 to 1996.

When features are drawn in a view using a reference or background, it is called on-screen digitizing. This type of digitizing does not require a digitizing board. The reference theme for on-screen digitizing can be image layers or feature layers; image layers were used for this research. Features can be digitized and then saved as shapefiles, or coverages, and used for further analysis.

Features were digitized at the six study sites using the masked aerial photographs that were previously mosaicked together, creating 24 layers for each constituent. The digitizing was completed using both ArcView 3.x and ArcGIS 8.x. The layers were saved as shapefiles, and then converted into coverages using the Shapearc command in ArcInfo 8. This conversion was completed to compile area statistics.

Point values were spread across the surface in each of the cells that were created in a grid format; a density value was then assigned to each cell. Spatial analyses of the data set were accomplished using GIS to determine vegetative cover at the site. The cover calculations were completed using the kernal method (as opposed to the simple calculation method). In a simple calculation, points that fall within the search area are summed and then divided by the search area size to get a cell's density value. In a kernal density calculation, the points lying near the center of a raster cell's search area are weighted more heavily than those near the edge. The resulting raster output has a smoother distribution of values.

Vegetative cover was measured using both ArcView 3.x and ArcGIS 8.x. A point layer was created based on a value classification scheme in the attribute field DEN_NUM. Before creating point layers, a polygon grid was created in Arc View 3.x. The polygon grid is exactly the same size as the study site, 1200 x 900 m, with each polygon in the grid being 30 x 30 m. The polygon grid was then laid over the top of the masked aerial photograph, and vegetation was measured for each polygon. The attribute table was populated at the same time as the polygons were being classified. The fields in the attribute table, ID, Year, Density, Den_Num, and Site, were populated with alphanumeric values. The classification for Density and Den_Num is 0–25 percent density = Den_num of 1; 26–50 percent density = Den_num of 2; 51–75 percent density = Den_num of 3; and 76–100 percent density = Den_num of 4.

The values for the polygons of each study area were populated, and point shapefiles were created in ArcView 3.x. Point values were then assigned only to polygon cells with vegetative cover values (aerial photos showing the presence of vegetation). An attribute table was created for each of the point shapefiles with ID, Density, and Den_Num fields being populated using the same classification scheme as mentioned above. Point shapefiles representing vegetation were completed for each of the six study sites for 1935, 1954, 1975, and 1996, totaling 24 point shapefiles.

The next step was to create raster grids of the vegetative cover vector shapefiles. The point shapefiles created in ArcView 3.x were brought into ArcGIS 8.x, and vegetative cover density was calculated using the Spatial Analyst extension. Kernal calculation was the selected density type, Density was the selected population field, and the output cell units were generally around 3.5. A raster output grid of vegetative cover density was then produced and reclassified. The vegetative cover density grids were reclassified to match the original classification scheme.

RESULTS

Channel Area and Vegetative Area

All but one of the six sites from Albuquerque to Cochiti Dam experienced an increase in vegetative area (Table 1). The largest change was at Site 5 with an increase of 361,751.25 sq m between 1935 and 1996. Site 1 had an increase of 191,953.82, Site 3 had an increase of 12,777.54, Site 4 had an increase of 65,500.13, and Site 6 had an increase of 136,611.79. Site 2, however, had a decrease of 82,788.32 sq m in vegetative area. Analysis of the change in channel area over the same time was the exact opposite. As vegetative area increased, channel area decreased. Figure 2 compares the vegetative area and channel area at the two selected study sites. The increasing vegetative area and decreasing channel area created smaller riparian sites with more vegetation, or an area with greater vegetation density.

Table 1. Vegetative area in square meters and percent of the total area (1.2 sq km).

	1935		1954		1975		1996	
	sq m	%	sq m	%	sq m	%	sq m	%
Site 1	142,235.74	13.20	271,421.00	25.10	277,400.52	25.70	334,189.56	31.00
Site 2	349,428.68	32.40	212,600.71	19.70	336,940.64	31.20	266,640.36	24.70
Site 3	169,994.42	15.70	222,615.31	20.60	162,816.02	15.10	182,771.96	16.90
Site 4	138,429.23	12.80	176,753.22	16.40	147,754.94	13.70	203,929.36	18.90
Site 5	26,989.96	2.50	202,139.97	18.70	321,302.34	29.80	388,741.21	36.00
Site 6	152,852.93	14.20	155,284.63	14.40	131,004.57	12.10	289,464.72	26.80

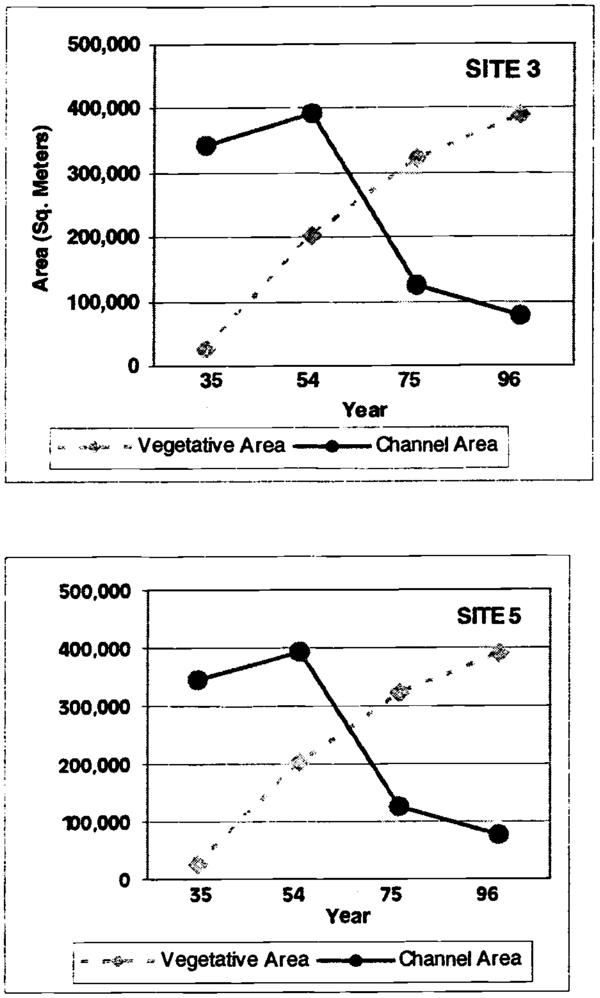

Figure 2. A comparison of vegetative and channel area change at two sites.

Vegetative Cover Density

The vegetative cover, overall, increased at each of the six sites. It is important to look at the relationship between the 25 percent and 100 percent data classes. At each of the six sites the 25 percent data class decreased in percent of total raster cells, whereas the 100 percent data class increased at each of the six sites (Table 2). Over time, as human modification has increased, vegetative cover density has increased. Figure 3, Site 1, indicates that from 1935 to 1996 there was a large decrease in the percent of raster cells in the 25 percent data class, from 47.3 to 18.4 percent. During the same time, there was an increase in the 100 percent data class, from 20.9 to 54.7 percent. This indicates that there has been a shift from sparse vegetative and low-density sites to high-density sites. The other five sites show similar trends in vegetative cover density. These trends indicate that the changes along the Rio Grande during the twentieth century have led to an increase in vegetation density between Albuquerque and Cochiti Dam.

Vegetative island area has also increased since the construction of Cochiti Dam. Figure 4 shows the formation of vegetative islands over time. Similar results were found at the other six sites.

CONCLUSIONS

Channel and Vegetative Area

The first set of data illustrates vegetative area at the six study sites. Overall, vegetative area has increased along the Rio Grande, especially since the construction of Cochiti Dam in the early 1970s. As vegetative areas were increasing in size, total channel area was decreasing in size. This suggests a correlation between the expansion of vegetative communities and the constriction of the river channel. At sites exhibiting a large increase in vegetative area there was a large decrease in channel area, whereas at sites with a small increase in vegetative area there was a small decrease in channel area. Also, the vegetation in this area has changed substantially from what Watson (1912) and others described before the 1950s. Instead of

Table 2. Vegetative cover density at each site in percent by year.

	1935	1954	1975	1996
Site 1				
25	47.3	31.3	25.4	18.4
50	15.9	22.8	16.8	13.2
75	15.9	23.6	23.9	13.5
100	20.9	22.2	33.8	54.7
Site 2				
25	31.4	26.8	16.8	21.0
50	25.6	25.3	14.5	13.3
75	30.0	28.4	26.8	12.4
100	12.9	19.5	41.8	53.3
Site 3				
25	31.6	25.0	23.2	20.4
50	29.8	20.4	21.3	18.8
75	23.6	31.6	24.6	26.7
100	14.9	22.9	30.3	34.1
Site 4				
25	39.1	39.1	30.4	26.3
50	34.2	26.5	16.8	20.3
75	21.8	20.4	18.3	23.0
100	5.0	20.3	34.4	30.4
Site 5				
25	59.0	48.3	37.6	28.3
50	35.9	25.6	18.5	12.2
75	5.1	18.5	11.0	19.9
100	0.0	12.2	32.8	39.6
Site 6				
25	33.0	54.3	43.9	21.1
50	21.8	19.6	20.9	18.8
75	26.0	19.1	11.8	19.9
100	19.1	7.0	23.5	40.2

the monotypic cottonwood and willow forests, there is now a mixture of invasive Russian olive and tamarisk trees along with native cottonwoods and willows. Future research will analyze the distribution of each species at the selected study sites.

Vegetative Cover Density

Vegetative cover density at each of the six sites has increased, due to the lack of natural spring flooding that occurred before the construction of levees and dams, and before the Rio Grande became a heavily controlled river. The increase in vegetation density is related to the intermediate disturbance hypothesis, where a flood of small or no magnitude will do little damage to the existing vegetation, a moderate flood will remove some vegetation and there will be an addition of new vegetative communities, and a large flood will remove most of the vegetative communities, resulting in low density and new vegetative communities (Bendix 1997). Thus, the elimination of natural flooding has resulted in greater vegetative density along the Rio Grande between Albuquerque and Cochiti Dam. The same natural flooding regimes that have been eliminated also have the capability to control the diffusion of invasive species.

Streamflow rate has also changed within the study area from 1935 to 1996. Streamflow measures the average rate of flow and does not take into consideration cycling flooding. Within a controlled river system there is not much fluctuation in streamflow, and large flow regimes are absent.

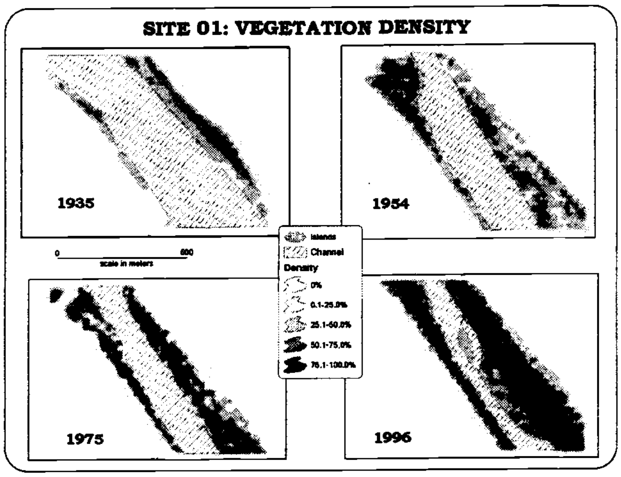

Figure 3. Changes in vegetative cover density. The lighter colors represent less density, whereas the darker colors indicate greater density values.

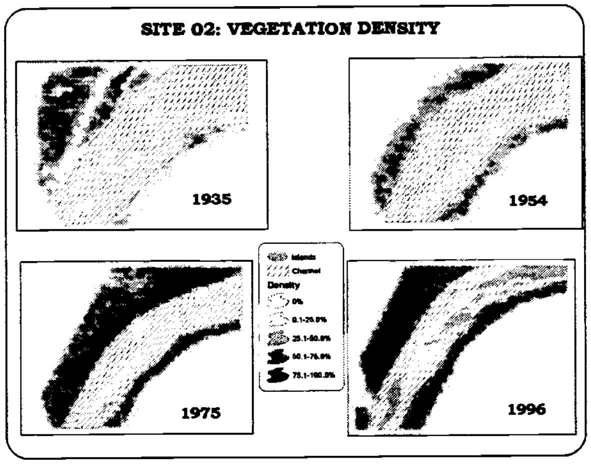

Figure 4. An example of the change in vegetative island formation. Note the number of islands in 1935 versus the number of islands in 1996.

GIT Techniques

GIT techniques are important in analyzing environmental change over time. Both image processing and GIS techniques were used successfully in this research. Further research related to this project will look at satellite imagery to document changes in the composition of vegetation at the study sites. GPS units may also be used to define vegetative community boundaries at the sites. There has been no known documentation of researchers using similar GIT techniques to measure vegetation density and vegetative area change. Other vegetation density measurements are done entirely in the field, taking more resources, money, and time. Increased analyses of environmental change using GIT techniques are needed in scientific research, and can be helpful in analyzing many environmental issues.

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