Surficial Geologic Map of the Middle Rio Grande Valley Floodplain, From San Acacia to Elephant Butte Reservoir, New Mexico

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By

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TECHNICAL MEMORANDUM

SURFICIAL GEOLOGIC MAP OF THE MIDDLE RIO GRANDE VALLEY, SAN ACACIA TO ELEPHANT BUTTE RESERVOIR, NEW MEXICO

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1.0 INTRODUCTION

This memo summarizes our surficial geologic mapping of the Middle Rio Grande Valley between the towns of San Acacia and San Marcial, New Mexico. This river reach extends approximately 50 miles (80 km) from the San Acacia Diversion Dam on the north to the upstream high-water elevation of Elephant Butte Reservoir. It includes the entire reach of the Rio Grande where it passes through the Bosque del Apache National Wildlife Refuge, as well as private and public lands north and south of the refuge. The extent of the map area is shown on Figure 1.

Significance

This mapping provides detailed geologic data along the central part of the Rio Grande, which has been only generalized during previous mapping efforts. This mapping shows the distribution of various geologic deposits, landforms, and vegetation patterns derived from analysis of recent (2001) aerial photography, and thus documents nearly current conditions within the inner Rio Grande valley. The maps can be used to assess potential linkages between the stratigraphic deposits, vegetation patterns, and soil salinity. In addition, delineating the surficial geologic framework of the Middle Rio Grande Valley is important for understanding basic geologic and geomorphic processes of the fluvial system, and surface processes within the valley. These processes control or influence the location and magnitude of sediment input, transport, erosion, deposition, flooding, and stream channel migration. These processes, in turn, may influence river morphology, vegetation characteristics, and riparian and aquatic habitats. Thus, this effort is an important step in understanding historical geomorphic changes that have occurred in the valley, and in understanding the likely responses of the river system to possible future natural or anthropogenic changes.

Our mapping involved delineation of surficial geologic units and associated vegetation patterns, using aerial photography taken in 1935 and in 2001. Delineating the deposits, landforms, and vegetation on both the 1935 and 2001 data sets allows assessment of temporal changes in the floodplain of the Middle Rio Grande Valley. Comparing the distribution and extent of the channel deposits from the two time windows enables: 1) documentation of changes that have occurred to the fluvial system over a span of 65 years, and 2) characterization of fluvial processes that operate within the river system. The results of this project help document the characteristics of the Rio Grande prior to substantial engineering modification, and help show how the Rio Grande and its tributaries responded in time and space to land-use changes, hydrologic changes (e.g., regulated discharge), channel modification, and/or the presence of engineered structures.

Purpose

The primary purpose of this effort was to produce 1:24,000-scale surficial geologic maps of the Rio Grande floodplain between San Acacia Diversion Dam and Elephant Butte Reservoir. These maps depict the floodplain landforms and deposits associated with former river channels, bars, and crevasse splays. The maps also show the distribution of alluvial-fan deposits derived from tributary arroyos from the east and west, as well as older (Pleistocene) deposits that flank the inner Rio Grande Valley. The map was constructed in a GIS (Geographic Information System) format, and will be available as a downloadable file using standard Internet browsers. A secondary purpose of this effort was to provide a database for digital analysis of fluvial changes in the Middle Rio Grande Valley during the time period from 1935 to 2001. We anticipate that this database will enable identification of the areas of net deposition and net erosion during the 65-year interval, and from that interpret areas of likely long-term aggradation and degradation, respectively. Ultimately, such an analysis can provide a basis to interpret the dominant geomorphic processes that have acted within the Rio Grande fluvial system, and to help address the relative influences of hydrologic changes and channel modifications on present-day aggradation or degradation. Lastly, another secondary purpose of this mapping effort was to provide a basis for depicting and interpreting vegetation changes associated with geologic processes in the inner Rio Grande valley.

Approach and Methods

Our approach in delineating the surficial deposits in the Middle Rio Grande Valley was to analyze two sets of aerial photography (1935 and 2001), conduct a field reconnaissance of the area, input the geologic interpretation into a GIS, and identify substantial changes in the system through analysis of the two geologic map sets. The maps extend from the San Acacia Diversion Dam on the north to the upstream end of Elephant Butte Reservoir on the south.

We utilized black-and-white, stereo-pair images of the river valley taken in 1935, which were obtained from the Earth Data Analysis Center (EDAC) in Albuquerque. We chose to use these images because they are the earliest set of high-quality stereo-pair imagery available for the Middle Rio Grande Valley. In addition, these images pre-date substantial incursion of salt cedar vegetation (which tends to obscure geologic relations) throughout much of the valley, and thus allow for better delineation of surficial geologic units. The 1935 images are montages consisting of four separate images, and thus have noticeable distortion. To rectify this distortion and to increase the accuracy of the map unit boundaries, we manually transferred geologic boundary lines from overlays on the photographs to mylar USGS topographic base maps. These mylar sheets were then scanned and digitized by the New Mexico Bureau of Geology and Mineral Resources, and imported to our ArcView GIS software. The files were then manually checked and revised to be consistent with known topographic and cultural features, in order to minimize areal distortion.

Aerial photography taken in 2001 also was analyzed to provide an interpretation of comparatively up-to-date channel and valley characteristics. This analysis used digital imagery provided by the U.S. Bureau of Reclamation, with map units being input directly into a digital database via manual tracings on the computer screen (i.e. on-screen, or "head-up", digitizing). Because this imagery is not available in stereo (and thus provides no depth perception of topographic relief), we delineated map units through interpretation of planform patterns and tonal contrasts. Vegetation types, alignments, and densities also provided information from which to differentiate map units from the 2001-vintage imagery.

For delineation of the surficial geology from both the 1935 and 2001 images, we developed map units on the basis of recent similar mapping projects in the inner Rio Grande Valley, and refined these units on the basis of deposits identified during the course of this effort. Based on previous mapping of the Bosque del Apache National Wildlife Refuge (BDANWR) from 1935 photography by Hendrickx and Harrison (2000), as well as mapping of the inner Rio Grande Valley from Bernalillo to Isleta by Kelson et al. (1999), we developed a workable stratigraphic framework to delineate geologic map units for the purposes of this project. In addition to delineating surficial geologic deposits, we classified the vegetation characteristics of each map polygon through a nine-division scheme similar to that used by Hendrickx and Harrison (2000). The geologic and vegetation map units are described in detail in the Results section of this technical memorandum.

Acknowledgements

This study was completed by Keith Kelson and Justin Pearce of WLA, in collaboration with Dr. Bruce Harrison of New Mexico Tech and Dr. Paul Bauer of the New Mexico Bureau of Geology and Mineral Resources. Pearce completed the analysis of aerial imagery and digitization of 2001-vintage geologic data, under the supervision of Kelson. Harrison provided geologic data from 1935 photography of the BDANWR, and Ms. Lisa Majkowski/Taylor digitized these and additional mapping data for incorporation in the GIS database. Mr. Adam Read (NMBGMR) digitized the 1935 data in collaboration with Pearce and Bauer. Kelson and Pearce authored this report. We acknowledge the help of Ms. Tamara Massong and Mr. Drew Baird of the U.S. Bureau of Reclamation for providing the 2001 imagery, and Ms. Laura Gleasner of the Earth Data Analysis Center in Albuquerque for helping us acquire the 1935 imagery. Lastly, this project would not have been possible with the support and guidance of Ms. Page Pegram and Mr. Nabil Shafike of the New Mexico Interstate Stream Commission.

2.0 GEOLOGIC/GEOMORPHIC SETTING OF THE MIDDLE RIO GRANDE VALLEY

The Middle Rio Grande Valley is located in the Rio Grande rift in central New Mexico (Figure 1), which is an elongate, north-south topographic and structural depression. The present-day course of the Rio Grande flows from north to south through this depression, transporting sediments derived from northern New Mexico and southern Colorado. The eastern margin of the Rio Grande valley is bordered by active and potentially active faults adjacent to the Manzano, Joyita, and Fra Cristobal uplifts. These normal faults (e.g., West Joyita, Cliff, Walnut Springs; Machette et al., 1998) have primarily down-to-the-west vertical separation, and have exposed Proterozoic rocks in the footwall uplifts. Tertiary and Quaternary sediments derived from these uplifts consist primarily of alluvial-fan and eolian deposits that interfinger with fluvial and lacustrine sediments deposited by the Rio Grande. The western margin of the Rio Grande rift near the map area is characterized by down-to-the-east normal faults, including the Loma Blanca, Loma Pelada, and Socorro Canyon faults from San Acacia to Socorro, and the Milligan Gulch fault, Black Hill fault, and unnamed faults adjacent to the San Mateo Mountains between Socorro and Elephant Butte Reservoir (Machette et al., 1998). The western margin of the Rio Grande valley is bordered by the Magdalena and San Mateo Mountains, which have substantial topographic relief. The Magdalena Mountains are a primary source of sediments to tributary arroyos draining to the Rio Grande from the west.

The area encompassed by this mapping effort is the inner valley of the Rio Grande in central New Mexico, which flows within the Rio Grande rift in a generally north-south orientation. As shown on Figure 1, this mapping focused on the inner valley between the villages of San Acacia and San Marcial. The maps included in this report (Plates 1, 2, and 3) focus on the surficial geology of the inner valley within 13 7.5-minute USGS quadrangles (San Acacia, Lemitar, Mesa del Yeso, Socorro, Lomas de las Canas, Luis Lopez, San Antonio, Indian Well Wilderness, San Antonio SE, San Marcial, Fort Craig, Paraje Well, and Lava). The phrase “inner Rio Grande valley” is used herein to refer to the relatively flat valley floor of the Rio Grande, with the eastern and western margins of the inner valley defined by topographic escarpments that are as much as 100 m high. For the purposes of this report, we define the margins of the inner valley as the bases of these topographic escarpments on both sides of the valley. The floor of the inner valley slopes gently to the south and is underlain by sandy Holocene alluvium deposited by the Rio Grande. Geologic mapping by several workers in the inner Rio Grande Valley near Albuquerque, including Lambert (1968), GRAM/William Lettis & Associates, Inc. (1995), Connell (1996, 1997, 1998a, 1998b), and Kelson et al. (1999) show that this alluvium is inset into Pleistocene alluvium, alluvial-fan deposits and Tertiary bedrock that comprise the adjacent piedmont slopes. Holocene and alluvial-fan deposits derived from arroyos draining the piedmonts west and east of the inner valley interfinger with Rio Grande fluvial deposits, and have westerly or easterly slope gradients that contrast with the southerly gradient of the valley floor. In general, shallow groundwater in the inner valley is less than 12 m (40 ft) deep, and is substantially deeper beneath the Pleistocene and older deposits bordering the inner valley (Kelson et al., 1999).

Historical documents provide information on the extent of past flooding in the inner Rio Grande valley. Burkholder (1928) summarized the largest floods prior to construction of river levees in the 1930s, as measured at gaging stations upstream (at Bucknam) and downstream (at San Marcial) of Albuquerque. The majority of these floods occurred during the months of May and June, as a result of rapid snowmelt runoff in the mountains of northern New Mexico and southern Colorado. The largest historical flood in Albuquerque occurred in May 1874, prior to installation of the gaging stations along the Rio Grande. Burkholder (1928) notes that the 1874 flood probably was considerably greater than the largest measured discharge of 33,000 cubic ft per second (cfs) at the San Marcial gaging station in October 1904. Hosea (1927) and Kelley (1982) estimate that the 1874 flood probably exceeded 100,000 cfs near Albuquerque. Kelson et al. (1999) used this information on historical flooding in the inner Rio Grand valley near Albuquerque to help delineate historical floodplain deposits and thus to help identify areas that are potentially underlain by very young deposits. It is likely that the 1874 flood had a strong influence on the distribution of young surficial deposits in the inner valley, although we do not herein attribute any deposits or landforms specifically to this event because of an absence of deposit age control.

Mussetter (2003) summarized the annual maximum flood peaks for the periods of record from gaging stations throughout the Middle Rio Grande Valley, including records from Cochiti (1927–1996), San Felipe (1927–1996), Bernalillo (1929–1969), Albuquerque (1942–1996), Bernardo (1937–1964), San Acacia (1936–1964), and San Marcial (1925–1991). For the San Marcial gage, the six highest annual peaks all equaled or exceeded 15,000 cfs and occurred in 1929, 1933, 1935, 1937, 1941, and 1942, and the highest (in 1929) was about 47,000 cfs. Construction of several flood-control and flow regulation dams upstream of our study reach in the 1950s, 1960s, and 1970s attenuated the magnitude of high-discharge flows and increased the duration of moderate- and low-discharge flows (Mussetter, 2003). Therefore, it is likely that the deposits and landforms associated with the active channel shown on the 1935 imagery were associated with either the 1929, 1933, or 1935 flood events. In addition, the flood events that occurred in 1937, 1941, and 1942 probably substantially affected the pattern of surficial floodplain deposits and landforms (Happ, 1948). These post-1935 changes may be only partially documented on the 2001 imagery, because of other processes acting on the river system (i.e., construction of additional levees, construction and flow diversion into the Rio Grande Low Flow Conveyance Channel, channelization, encroachment of non-native plant species, or surface water extractions for agricultural purposes).

3.0 SURFICIAL GEOLOGIC MAPPING

As noted above, we delineated surficial geologic deposits in the inner Rio Grande valley between the San Acacia Diversion Dam and the upstream end of Elephant Butte Reservoir (Figure 1). We classify the deposits on the basis of both genetic origin and age, as best interpreted from the two sets of aerial photography (Table 1). On the 1935 imagery, we identify deposits and landforms that reflect active fluvial processes, as well as deposits and landforms that are late Holocene in age (within the past few thousand years old). Because we have only relative age information for these features (as opposed to numerical age), we identify the late Holocene deposits as "pre-1935". However, some of these deposits may be the products of historical deposition; for instance, some of the paleochannel landforms or deposits delineated on Plates 1 to 3 may have formed during the 1874, 1929, or other large, historic floods.

3.1 Definition of Map Units

Our definition of map units allows for identification of fluvial changes that occurred during the time period between 1935 and 2001. As shown on Table 1 and on Plates 1, 2, and 3, we identify deposits and landforms that pre-date 1935, are active in 1935, and are active in 2001. For example, the water surface in 1935 is shown as map unit "W35" and is light blue; whereas the water surface in 2001 is shown as map unit "W00" and is dark blue. On Plates 1C, 2C, and 3C, the active channels are shown on a separate map to illustrate the differences in channel location, width, pattern and geometry. The active channel is defined as the mapped water surface plus adjacent deposits that are covered with bare soil or grass. For both the 1935 and 2001 vintage maps, we identify Artificial Fill as levees, embankments and other man-made accumulations of sediment.

Fluvial deposits directly associated with historic or paleo-channels of the Rio Grande are grouped into five map units for each deposit-age group (Table 1). These five groups include deposits associated with: channels, scroll (bank) bars, instream (mid-channel) bars, channel (outside) bends, and crevasse splays. The channels are readily identified features that have distinct, roughly subparallel margins and, commonly, longitudinal tonal contrasts that likely represent predominant flow directions. These channels typically are curvilinear and in many cases have a slightly darker color on the images than surrounding deposits. Channel deposits that clearly pre-date 1935 are designated "Hch" (Holocene channel; Plates 1, 2, and 3). Channel deposits that are clearly related to the Rio Grande active channel in 1935 are designated "Rch35" (Recent channel, 1935), and channel deposits that are related to the Rio Grande active channel from post-1935 and in 2001 are designated "Rch01" (Recent channel, 2001; Plates 1, 2, and 3). Similarly, scroll bars, instream bars, channel bends and crevasses splay deposits associated with the active river system in 1935 are designated "Rsb35", "Rib35", "Rcb35", and "Rcs35", respectively (Plates 1, 2, and 3). Similar deposits associated with the active system from post-1935 and in 2001 are designated similarly, except with “01” as the age-indicative suffix. This system allows for flexibility in future mapping efforts if map units are identified on additional image vintages. In addition to the deposits described above, we also classified deposits that we interpreted to comprise the “active” channel zone in 1935 and in 2001. For this project we define “active” channel to include the mapped water surface, instream bars, and scroll bars that are adjacent to the water surface. Because active channel zone is a function of river discharge stage, we used vegetation patterns as criteria to help identify the active channel zone. For instance, bare soil or grass covering an “Rsb01” would be considered part of the 2001 active channel zone, whereas an “Rsb01” deposit that had dense shrubs or cottonwood vegetation would be interpreted as a previous, pre-2001, active channel zone. The attribute “Active channel (1935)” and “Active channel (2001)” were added to the “Comment” field in the GIS database for query and/or visualization purposes. Based on our field reconnaissance and literature review, these Recent/Holocene alluvial deposits consist primarily of sand, silt, and clay transported by the Rio Grande or locally derived by eolian processes (Kelson et al., 1999).

In many locations within the map area, the genetic origin of individual alluvial deposits is not easily distinguished, as a result of indistinct signatures on the imagery, dense vegetation, or cultural modification. These undifferentiated Holocene alluvial deposits are designated “Hal” (Table 1). Where these undifferentiated deposits have been modified by agricultural activities, we designate them “Hala”. Throughout much of the map area, deposits that are identifiable on the 1935 imagery as either Hch (Holocene paleo-channel deposits) or other Holocene fluvial deposits (Hsb, Hib, Hcb, or Hcs) are difficult to identify on the 2001 imagery. This is particularly valid in the areas west of the primary riverside levees, where land use in the inner valley is now primarily agricultural. Notably, however, there are rare areas (i.e., in the BDANWR) that have reverted from an agricultural land use in 1935 to a non-modified use in 2001 (Plate 2). Because most of the land-use changes that substantially affect our interpretation of deposit characteristics have occurred in the areas outside of the flood-protection levee system, it is likely the deposits shown as “Hal” and “Hala” on the 2001 map (Plates 1B, 2B, and 3B) have not changed since 1935.

Deposits derived from tributary arroyos draining into the inner Rio Grande valley are designated either “Rat”, “Hfy”, or “Hfo” (Table 1; Plates 1, 2, and 3), which consist of sand, silt, and gravel derived from bedrock or Pleistocene deposits in the adjacent mountain ranges or along the mountain-front piedmont. Map unit “Rat” reflects the active arroyo washes or alluvial deposits on the floodplain during either 1935 or 2001. Map unit “Hfy” reflects young alluvial-fan deposits within the inner valley, and unit “Hfo” reflects older alluvial-fan deposits, which tend to be larger in areal extent. The relative ages of these two alluvial-fan units are based on the relative areal extent of the fans, as well as cross-cutting relationships commonly present at the mouths of tributary arroyos in the inner Rio Grande valley (Kelson et al., 1999).

The younger alluvial fans commonly are inset into the older alluvial fans, and have prograded toward the axial channel of the Rio Grande, except in a few cases where the axial channel has migrated laterally toward the arroyo mouth and eroded the younger and older fans. An example of this lateral erosion of tributary fans is on the eastern side of the valley, across the valley from the mouth of Tiffany Canyon Arroyo on the San Marcial quadrangle, where the 1935 imagery shows the presence of older and younger tributary fans, and the 2001 mapping shows that these fans were removed. This area is underlain by Recent alluvial deposits in 2001 (map unit Rch01, Plate 2B).

Notably, most tributary arroyos are associated with deposition of both the Hfy and Hfo map units. Throughout the map area, the younger alluvial fans (unit Hfy) usually are inset into the older alluvial fans (unit Hfo). This suggests that the tributary alluvial fans have not experienced a rise in base level, and thus that over the long term (i.e., the past few hundreds years or so) the axial Rio Grande channel has not aggraded substantially. The incision of the younger fans into the older fans suggests, instead, that the local tributary base level has lowered or remained stable, implying that the Rio Grande elevation over the long term may have degraded or remained stable. Alternatively, the presence of younger alluvial fans that have prograded onto the Rio Grande floodplain may be a function of hydrologic or sedimentologic changes in the tributary arroyo systems, and have little or no linkage to long-term aggradation or degradation along the axial Rio Grande.

Older map units flanking the inner Rio Grande valley are mapped on Plates 1 to 3 as Pleistocene terrace alluvium (unit Pta), Pleistocene tributary fan alluvium (unit Pfa), and undifferentiated Quaternary and Tertiary bedrock (unit QTu). The terrace surfaces associated with the Pta deposits generally are several tens of feet higher than the adjacent valley floor, and have gentle southerly gradients. These sand, silt, and gravel deposits are inset into either the Pleistocene alluvial-fan deposits or bedrock (Plates 1 to 3). The alluvial-fan deposits (unit Pfa) consist of sand, silt, and gravel derived from the mountain ranges bordering the Rio Grande rift or from adjacent bedrock on the mountain-front piedmont. Bedrock units include volcanic rocks (i.e., basalt, andesite), as well as semiconsolidated and consolidated sandstone, siltstone, and conglomerate of the Santa Fe Group. Our mapping effort did not focus on delineating these units in detail.

3.2 Definition of Vegetation Classes

In addition to delineating surficial geologic deposits within the inner Rio Grande valley, we note the generalized characteristics of vegetation within each map polygon. As noted above, we base this simple characterization on the type and density of vegetation land cover determined from the 1935- and 2001-vintage imagery. Our vegetation classes are defined as follows:

Class 0	Water
Class 1	Bare soil
Class 2	Bare soil / grasses
Class 3	Grasses
Class 4	Grasses / Shrubs
Class 5	Mixed Grass / Shrubs / Cottonwood
Class 6	Low-density (Scattered) Cottonwood
Class 7	High-density Cottonwood
Class 8	Agricultural lands

Our intent with this classification scheme is to (1) differentiate geologic map units associated with distinct vegetation types and densities, and (2) provide a relative numerical scale that reflects a general succession of vegetation development on fluvial deposits in the inner valley. For example, cross-cutting fluvial relationships in the inner valley suggest that relatively younger deposits are associated with Classes 1, 2, or 3, and relatively older deposits are associated with Classes 5, 6, or 7. Our intent in developing this numerical classification is that the database will be used for identifying any possible correlations between vegetation characteristics and geologic map units, and for analyzing progressive changes in vegetation through time. This effort refines a similar classification completed by Hendrickx and Harrison (2000) for the inner valley in the BDANWR, and may or may not be similar to previous vegetation classifications conducted by the USBR based on the 1935 imagery (USBR, 1997). We have not quantitatively compared these previous data sets with our map polygons, and at this time make no quantitative or qualitative comparisons with the previous efforts.

3.3 Pre-1935 and 1935 Surficial Geology Map Units

Analysis of the 1935 aerial photography provides an excellent snapshot of the geologic characteristics of the inner Rio Grande valley at the time the photographs were taken. Because the Rio Grande fluvial system is dynamic, the map units shown on Plates 1A, 2A, and 3A represent a geologically instantaneous condition in the inner valley. This section briefly describes some initial observations and primary characteristics of the fluvial system at the time of the 1935 photography.

The 1935 photography shows that the active, water-filled Rio Grande channel below San Acacia Diversion Dam was confined on the west by riverside levees system and on the east by the eastern margin of the valley. For the purposes of this study, we define the “1935 active channel” as the water-filled channel and adjacent areas containing little or no vegetation (vegetation classes 0 and 1). Although there are areas of bare soil (Class 1) that were not occupied by the Rio Grande at the time of the 1935 photography, we interpret that these areas were very recently occupied, and thus represent the active Rio

Grande channel during the most-recent substantial discharge event. Given that the substantial discharges were recorded at the San Marcial gage in the southern part of the study area in 1933 and 1935 (Mussetter, 2003), we interpret that this active channel probably represents the areas occupied during flows of approximately 15,000 to 21,000 cfs. This active channel is shown on Plates 1C, 2C, and 3C.

The 1935 imagery also shows the presence of several pre-1935 paleochannels and associated fluvial deposits throughout the inner Rio Grande valley (Plates 1A to 3A). For example, the inner valley directly west of the San Acacia Diversion Dam contains a large paleochannel along the northern and western valley margin (Plate 1A), and this paleochannel can be mapped along the western valley margin for several kilometers south of the diversion dam. Various channel-bend and crevasse splay deposits are present in the valley between this paleochannel and the present-day (2001) position of the river. Similarly, the western part of the inner valley between Highway 180 (near the town of San Antonio) on the north and Tiffany Canyon Arroyo on the south contains several paleochannels and associated crevasse-splay deposits. The pattern of these paleochannels, particularly within the BDANWR, demonstrates that the inner Rio Grande valley at some time prior to 1935 was dominated, in this area, by a meandering fluvial system. The presence of the crevasse splay deposits shows that substantial sediment deposition occurred during flood events that overtopped the natural channel banks and natural levees, and laid down sediments on the adjacent floodplain. Long-term sediment transport likely was related to intermittent erosion of these sediments via lateral migration and down-valley sweep of meander bends. The mapping in the BDANWR area suggests that the meander wavelengths of these paleochannels are on the order of about 1 to 4 km, and meander amplitudes are about 1 to 3 km (Plate 1A). This pattern of surficial deposits and landforms is in stark contrast with the Recent (post-1935) pattern of deposits and landforms (Plate 1B), which show a generally braided fluvial system that is confined between artificial levees and the eastern valley margin. The age of the pre-1935 paleochannels is poorly constrained, although we interpret that they are probably older than about 1917, based on the absence of large meander bends shown on planform maps surveyed in 1917/1918 (U.S. Reclamation Service, 1922, cited in Mussetter, 2003).

Sediments derived from west- or east-flowing tributary arroyos flank both sides of the inner Rio Grande valley (units Rat, Hfy, and Hfo; Plates 1, 2, and 3). Along the reach from the San Acacia Diversion Dam to Highway 180, these alluvial deposits are derived from both large and small arroyos and, as noted in the section above, consist primarily of younger alluvial-fan deposits and Recent alluvium inset into the older alluvial-fan deposits. Most of the tributaries draining to the inner valley from the east (i.e., the west-flowing arroyos) are associated with relatively small alluvial fans, because either they deposit material directly to the active Rio Grande channel or the Rio Grande has eroded the fan deposits. Based on our mapping, it appears that the primary arroyos contributing sediment to the Rio Grande valley from the east are Arroyo de la Parida, Arroyo de la Presilla, Arroyo de las Canas, and San Pedro Arroyo (Plate 1). In general, this eastern valley margin contains relatively few younger fans between these arroyos (Plate 1). In contrast, the alluvial fans bordering the western valley margin typically are larger and have been preserved on the now-abandoned Holocene fluvial deposits on the valley floor. Large alluvial fans are present along the western valley margin at the mouths of Nogal Arroyo, Arroyo de la Matanza, Red Canyon Arroyo, Walnut Creek Arroyo, and Tiffany Canon Arroyo, and smaller fans are present along the valley margin between these arroyos (Plate 1A).

Along the reach from Highway 180 to southern map border, the sediments derived from the tributary arroyos have a different distribution. Most of the tributaries draining to the inner valley from the east (i.e., the west-flowing arroyos) are associated with little or no remaining alluvial deposits in 1935. There are very few alluvial-fan deposits preserved along this eastern margin south of Highway 180, and those present are generally very limited in extent (Plates 1A and 2A). It appears that the absence of substantial tributary fans on the eastern side of the inner valley is probably related to the presence of the most-recent channel of the Rio Grande, which likely transported away the sediments derived from the ephemeral arroyos. In contrast, the tributary arroyos draining into the inner Rio Grande valley from the west are associated with relatively large alluvial fans deposited in the inner valley (Plate 2A). These fans probably are preserved because the Rio Grande has been located on the eastern side of the inner valley. In fact, the presence of older alluvial-fan deposits, which may be several hundred to several thousand years old, suggest that the Rio Grande has been located on the eastern side of the inner valley for a substantial period of time, and thus that the paleochannels in this reach of the valley may also be pre-historic.

3.4 2001 Surficial Geology Map Units

Analysis of the 2001 aerial photography also provides an excellent snapshot of the recent pattern of surficial deposits in the inner Rio Grande valley and, in conjunction the analysis of 1935 photography, provides a means to characterize the changes that have occurred in the inner valley within the past 65 years. Although the photography taken in 2001 represents only an instantaneous view of the dynamic river system, comparison with the 1935 photography yields interesting and important information on the pattern of fluvial deposits and on river processes. This section summarizes the major observations on the surficial deposits in the inner Rio Grande valley based on our analysis of the 2001 imagery.

The 2001-vintage photography shows that the active, water-filled Rio Grande channel below San Acacia Diversion Dam was confined on the west by riverside levees system and on the east by the eastern margin of the valley. As with the 1935 active channel, we define the “2001 active channel” as the water-filled channel and adjacent areas containing little or no vegetation (vegetation classes 0 and 1). Although there are areas of bare soil (Class 1) that were not occupied by the Rio Grande at the time of the 2001 photography, we interpret that these areas were very recently occupied, and thus represent the active Rio Grande channel during the most-recent substantial discharge event. Given that the discharges on the Rio Grande are regulated, this active channel probably represents the areas occupied during flows of approximately 5,000 to 10,000 cfs.

In general, the 2001 active channel is narrow and well defined (Plates 1C, 2C, and 3C), with very few areas that are bare soil (vegetation class 1). In northern part of the map area (between San Acacia and the BDANWR), the levees bordering the river channel are similar to those present in 1935, with only a few modifications. In this area, the active channel is confined to a 1000- to 3000-ft-wide floodplain between the levee and the eastern margin of the valley. However, in the southern part of the map area (between the BDANWR and San Marcial), the river lies within a confined valley between the levee system and the eastern valley margin, because of the presence of the Low Flow Conveyance Channel (LFCC). This confined valley is much narrower in 2001 than in 1935 (Plates 1 and 2). The location of the active channel in 2001 is along the eastern valley margin, whereas in 1935 the active channel was located along the western valley margin (Plate 2C).

Because the Rio Grande was confined in 2001 by the levee system and the Low Flow Conveyance Channel, the distribution of channel deposits east of the levees and the conveyance channel is greatly changed from the 1935 distribution (Plates 1B, 2B, and 3B). In this area, the Rio Grande has eroded fluvial deposits present in 1935, and laid down Recent alluvium. For example, in the central part of Plate 2 (east of Tiffany Canyon Arroyo), there was considerable erosion of 1935 floodplain alluvium, tributary alluvial fans, and valley-margin Pleistocene alluvium. The 2001 photography shows the presence of Recent alluvium in the same locations as these 1935 deposits. Also, the 2001 photography shows the predominance of channel point bars, scroll bars, and in-stream bars associated with the 2001 active channel, and an absence of crevasse splay deposits (Plates 1B, 2B, and 3B).

However, the distribution of channel deposits outside of the levees and the conveyance channel is essentially unchanged from the 1935 distribution (Plates 1B, 2B, and 3B). Plate 3B shows the presence of Recent channel alluvium (unit Rch00) in the area west of the LFCC, which is essentially the deposits left in the 1935 active channel after it was abandoned. Most other areas west of the levee system are mapped on the 2001 imagery as unit Hal or unit Hala, rather than the more-detailed map units shown on the 1935 imagery (Plates 1B, 2B, and 3B). There are three primary reasons for the lesser amount of detail shown on the 2001 map. First, large areas have been modified by agricultural practices, and the signature of the various deposits and landforms has been obscured by the tilling and other practices, making identification of detailed map units difficult. Second, where areas are unmodified by cultural practices, the density of vegetation appears to have increased between 1935 and 2001, which also makes identification of subtle fluvial landforms more difficult. Third, the 1935 photography was viewed stereoscopically, whereas the 2001 photography was not, and thus relied more on tonal contrasts than on perceived topographic relief to identify map units. As a result, we identify most areas west of the levee system on the 2001 imagery as undifferentiated alluvium (unit Hal) or agriculturally modified alluvium (unit Hala).

Lastly, alluvial fans contributed from the tributary arroyos to the Rio Grande valley commonly show evidence of either deposition or erosion between 1935 and 2001. Where the Rio Grande did not migrate laterally to the eastern margin of the inner valley, small alluvial fans (unit Hfy, Plates 1B, 2B, and 3B) accumulated sediment. In other locales, alluvial fans present in 1935 were completely or partially eroded, and the shapes of the Hfy fans are considerably different. In the areas along the western valley margin, there is only limited areal coverage of the 2001 photography compared to the 1935 photography. Thus, there is only very limited information from 2001-vintage imagery on the distribution of alluvial-fan deposits derived from tributaries draining from the west. Because these east-draining tributaries generally are not hydrologically connected with the Rio Grande, we speculate that from 1935 to 2001 there may have been substantial alluvial-fan sedimentation on the floodplain between the levee system (including the LFCC) and the western margin of the inner valley.

3.5 Fluvial Changes Between 1935 and 2001

The documentation of surficial deposits present in the inner Rio Grande valley on both the 1935 and 2001 vintage aerial photography sets provides a means to evaluate the changes in the fluvial system during this 65-year time period. On the basis of our analysis, several significant changes have taken place over this period. According to Mussetter (2003), the present-day hydrology of the Middle Rio Grande has been significantly changed as a result of water importation, wastewater discharge, irrigation, irrigation return flows, and development of several dams. Our analysis confirms that there have been substantial changes in the planform pattern and channel width of the active Rio Grande channel between 1935 and 2001, as suggested by several previous investigators (Lagasse, 1980; Leon, 1998; Bauer, 2000; Richard, 2001; Baird, 2001; Smith et al., 2001; Mussetter, 2003). In addition, we show that there have been substantial changes in the type of fluvial deposits (and, by inference, the process of deposition) along the active channel, and in the distribution of sediments derived from tributary arroyos.

The most obvious change in the Rio Grande system between 1935 and 2001 is in the channel width. Comparison of map units W35 and W00 shows that the 1935 water surface is substantially wider than the 2001 water surface (Plates 1C, 2C, and 3C). Because the width of the water-filled channel is dependent upon discharge, we also compare the 1935 active channel with the 2001 active channel, defined as the water-filled channel and the adjacent bare soil (vegetation class 1). As shown on Plates 1C, 2C, and 3C, the 1935 active channel is substantially wider than the 2001 active channel. In addition, our aerial reconnaissance of the map area on July 23, 2003 showed that the present-day channel generally is bordered by dense vegetation, reflecting a channel that probably has undergone little lateral migration.

Another obvious difference between the 1935 and 2001 fluvial system is that the 2001 channel generally is straighter and contains fewer in-stream bars than the 1935 channel. In the northern part of the study area (upstream of the BDANWR), the 2001 channel typically lies within the larger 1935 channel, but has a considerably lower sinuosity. South of the BDANWR, the 2001 channel is artificially confined between the LFCC and the eastern valley margin, and is considerably straighter than the 1935 channel. In addition, both the 1935 and 2001 channels are straighter than the pre-1935 paleochannels present in the inner Rio Grande valley, which is consistent with the presence of confining levees on both the 1935 and 2001 photography. Because both the 1935 and 2001 channels are confined by levee systems, neither of these channels represent the original, natural planform of the Rio Grande. Instead, the original pattern of the Rio Grande is better approximated by the pattern of paleochannels preserved in the areas west of the present-day levees. These paleochannels have substantially greater sinuosity than the 1935 and 2001 channels (Plates 1 to 3), and represent a meandering fluvial system.

In addition, the 1935 and 2001 channels are associated almost exclusively with in-stream bar and local point bar deposits, whereas the pre-1935 paleochannels are almost exclusively associated with crevasse splay deposits (Plates 1 to 3). In conjunction with the changes in channel width and channel sinuosity between the pre-1935, 1935, and 2001 channels, this change in depositional style represents very different floodplain processes in the inner Rio Grande valley. These data suggest that prior to 1935 (and perhaps prior to 1917), a meandering channel dominated the fluvial system. Deposition occurred primarily during overbank flooding via overtopping of channel banks and development of crevasse splay deposits that fanned out across the floodplain away from the channel breach. Deposition also apparently occurred along relatively large point bars, in-stream bars, and scroll bars, as the channel migrated across and down the valley. In contrast, the more-recent channels shown on the 1935 map represent a moderately confined, moderately braided channel (or “wandering channel”, Mussetter, 2003), and the 2001 channel represents a highly confined, regulated braided system.

Although we do not know the age of these paleochannels, we suspect that they are older than the initiation of substantial irrigation abstractions and cultural modification in the 1880s (Mussetter, 2003), because the 1917/1918 U.S. Reclamation Service maps show an overall braided fluvial system that lacked large meander bends. Thus, we interpret that many of the large, meandering paleochannels shown on the western parts of Plates 1A, 2A, and 3A likely represent a relatively unmodified, natural Rio

Grande planform pattern. Because the overall gradient of the inner Rio Grande valley likely has not changed within the past several hundred or even thousand years, these relationships suggest that the change from a meandering channel to the present-day braided channel may be associated with an increase in the channel thalweg gradient within the map area.

As noted above, the alluvial fans derived from tributary arroyos commonly show evidence of either deposition or erosion between 1935 and 2001. In some locations along the eastern valley margin, small alluvial fans grew as a result of local deposition. In general, we note that where the Rio Grande did not impinge upon the eastern valley margin, the young tributary alluvial fans grew slightly in size. Where the Rio Grande did impinge upon the eastern valley margin, young alluvial fans present in 1935 were completely or partially eroded, and the shapes of the young alluvial fans are considerably different. In the areas along the western valley margin, there is limited information from 2001-vintage imagery on the distribution of alluvial-fan deposits derived from tributaries draining from the west. Because these east-draining tributaries generally are not hydrologically connected with the Rio Grande, we speculate that from 1935 to 2001 there may have been substantial alluvial-fan sedimentation on the floodplain between the levee system (including the LFCC) and the western margin of the inner valley.

4.0 CONCLUSIONS

The primary purpose of this effort was to develop surficial geologic maps of the inner Rio Grande valley, showing the distribution of floodplain deposits and landforms present during 1935 and 2001 along the Middle Rio Grande from San Acacia Diversion Dam to Elephant Butte Reservoir. These maps show the active channels during these two time windows, as well as the presence of fluvial deposits (i.e, point bars, in-stream bars, crevasse splays, paleochannels) and tributary alluvial fans (Plates 1 to 3). From initial analysis of these maps, we conclude that between 1935 and 2001 the active channel of the Rio Grande is substantially narrower and straighter, as concluded previously by other investigators. These maps show the overall pattern and location of this narrowing and straightening.

In addition, the surficial geologic mapping on Plates 1 to 3 shows that the pre-1935 paleochannels preserved locally throughout the inner valley are much more sinuous than both the 1935 and 2001 channels, and that the floodplain associated with these channels is dominated by crevasse splay deposits. The floodplain directly associated with the 1935-vintage channel is characterized by point bars, in-stream bars, and local scroll bars on the insides of substantial channel bends. The floodplain associated with the 2001-vintage Rio Grande channel is dominated by local point bars and small in-stream bars. This change from a meandering system dominated by crevasse-splay deposition (prior to 1935) to a braided system dominated by local in-stream and point bars (in 2001) represents a fundamental difference in the fluvial processes acting on the floodplain. We interpret that the "wandering" channel system present in 1935 is transitional between the pre-1935 meandering system and the highly controlled, braided channel in 2001, and likely represents a river response to an intermediate level of planform control, discharge regulation, and other human interventions. Because the overall gradient of the inner Rio Grande valley likely has not changed within the past several hundred or even thousand years, these relationships suggest that the change from a meandering channel to the present-day braided channel may be associated with an increase in the channel thalweg gradient within the map area. Collectively, these data suggest that the Rio Grande channel since at least 1935 has been strongly affected by channelization, construction of riverside levees, and changes in the amounts and durations of discharge.

Lastly, our mapping delineates the distribution of alluvial-fan sediments deposited by tributary arroyos draining from the east and west into the Rio Grande. Several of these arroyos have deposited alluvial fans on the Rio Grande floodplain and represent a substantial amount of stored sediment, whereas others contribute sediment directly to the Rio Grande channel. As a result of lateral migration of the Rio Grande through time, some of these alluvial fans were eroded between 1935 and 2001, and some arroyos now contribute sediment directly to the channel rather than to the floodplain. In contrast, other arroyos that previously flowed directly into the active channel in 1935 are now developing alluvial fans because the main channel has migrated away from the arroyo mouth. On the western side of the inner valley, the construction of riverside levees and other structures have essentially isolated most, but not all, of the tributaries from the Rio Grande. Most of the east-flowing tributaries are associated with alluvial fans that are deposited on the western part of the floodplain, and do not directly contribute sediment to the active channel. A few major arroyos that are channelized through the levee system and to the Rio Grande, and these arroyos likely contribute substantial amounts of sediment to the active channel.

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Table 1. Surficial Geologic Units within the inner Rio Grande Valley, San Acacia to Elephant Butte Reservoir, NM

Geologic Age	Map Unit	pre-1935	1935	2001
Recent	Water		W35	W01
Recent	Artificial Fill		Af	Af
Recent/Holocene	Channel	Hch	Rch35	Rch01
Recent/Holocene	Channel Scroll Bar	Hsb	Rsb35	Rsb01
Recent/Holocene	Channel Instream Bar	Hib	Rib35	Rib01
Recent/Holocene	Channel Bend	Hcb	Rcb35	Rcb01
Recent/Holocene	Crevasse Splay	Hcs	Rcs35	Rcs01
Recent/Holocene	Alluvium - undifferentiated	Hal	Hal	Hal
Recent/Holocene	Alluvium - undifferentiated (agriculture)	Hala	Hala	Hala
Recent/Holocene	Tributary Channel Alluvium		Rta	Rta
Recent/Holocene	Tributary Fan Alluvium - Younger	Hfy	Hfy	Hfy
Recent/Holocene	Tributary Fan Alluvium - Older	Hfo	Hfo	Hfo
Pleistocene	Terrace Alluvium	Pta	Pta	Pta
Pleistocene	Tributary Fan Alluvium	Pfa	Pfa	Pfa
Neogene	Bedrock (sandstone, basalt, other)	Q Tu	Q Tu	Q Tu

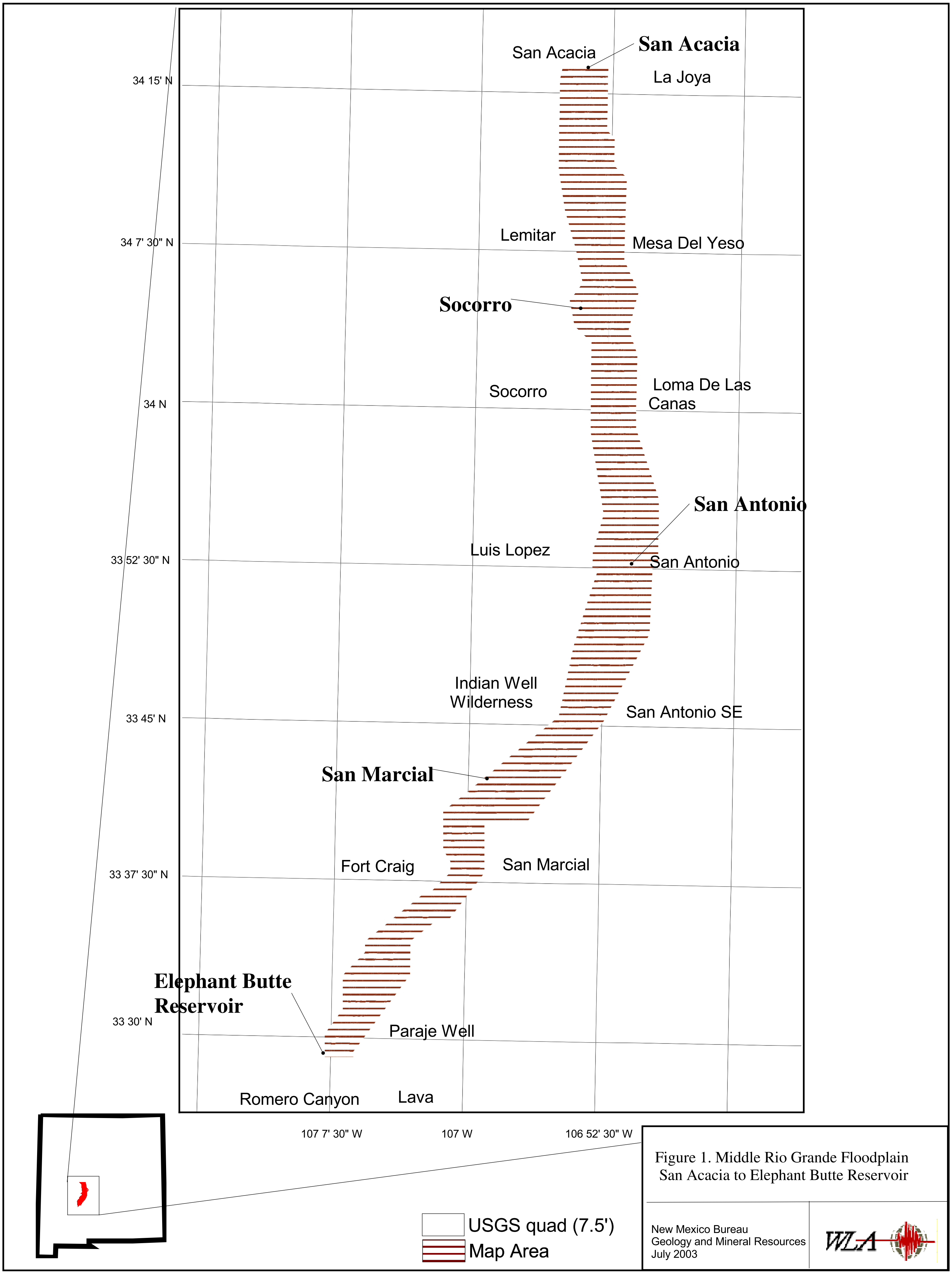

Figure 1. Middle Rio Grande Floodplain
San Acacia to Elephant Butte Reservoir

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