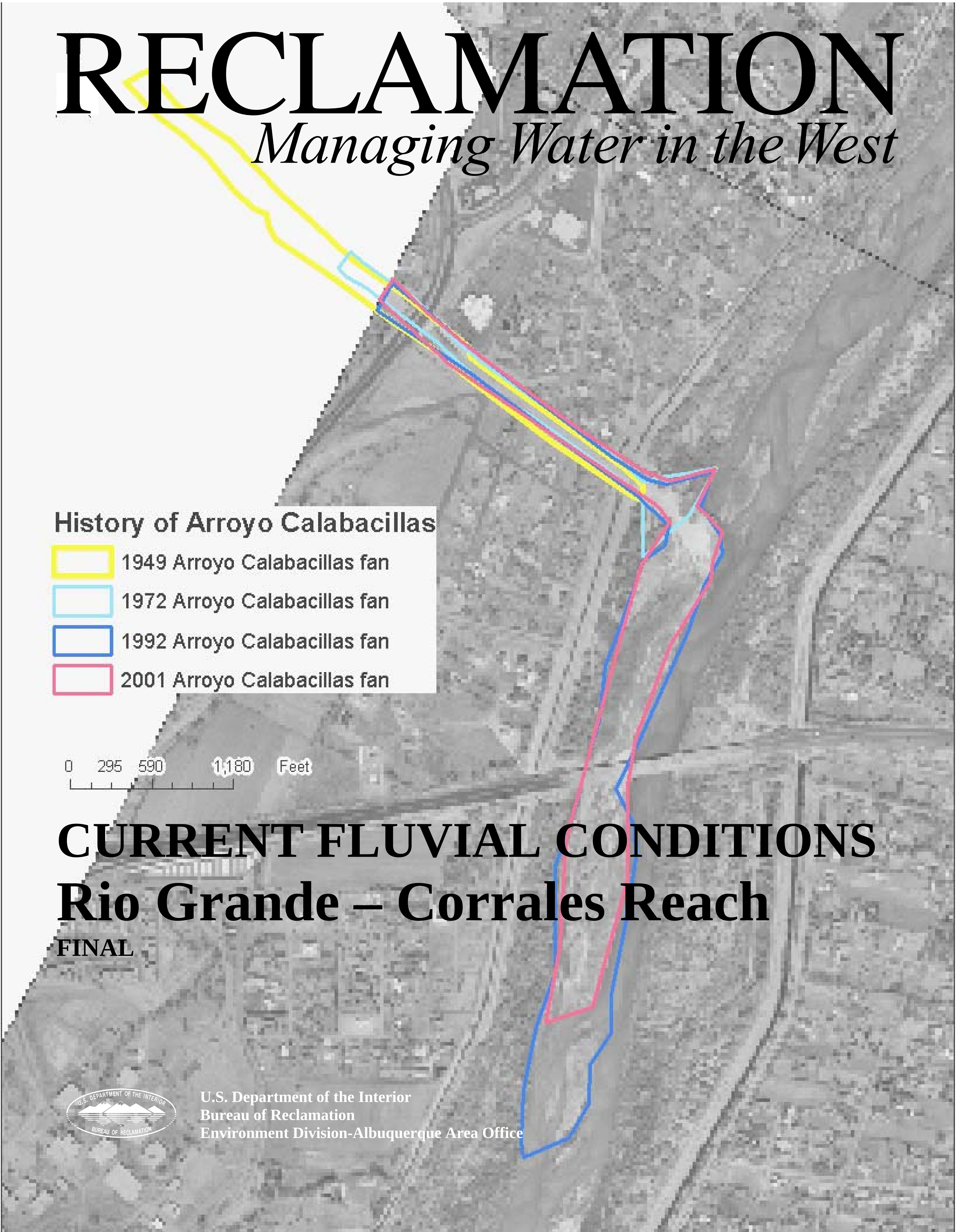
APPENDIX C

RECLAMATION

Managing Water in the West



CURRENT FLUVIAL CONDITIONS

Rio Grande – Corrales Reach

FINAL

U.S. Department of the Interior
Bureau of Reclamation
Environment Division-Albuquerque Area Office

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Rio Grande – Corrales Reach

FINAL REPORT
2005

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U.S. Department of the Interior
Bureau of Reclamation
Environment Division-Albuquerque Area Office

MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

TABLE OF CONTENTS

1.0 INTRODUCTION AND HISTORY OF REACH

The Corrales reach encompasses the Rio Grande at the northern end of the city of Albuquerque, extending from the Harvey Jones Channel/Arroyo de las Montoyas to the Montano Bridge crossing (Figure 1); a reach which is approximately 10.2 miles in length. This section of river flows through a heavily populated area, and hence the river and its floodplain have a long history of manipulation for public use and safety. The purpose of this report is to present the current physical conditions of the Rio Grande in the Corrales reach.

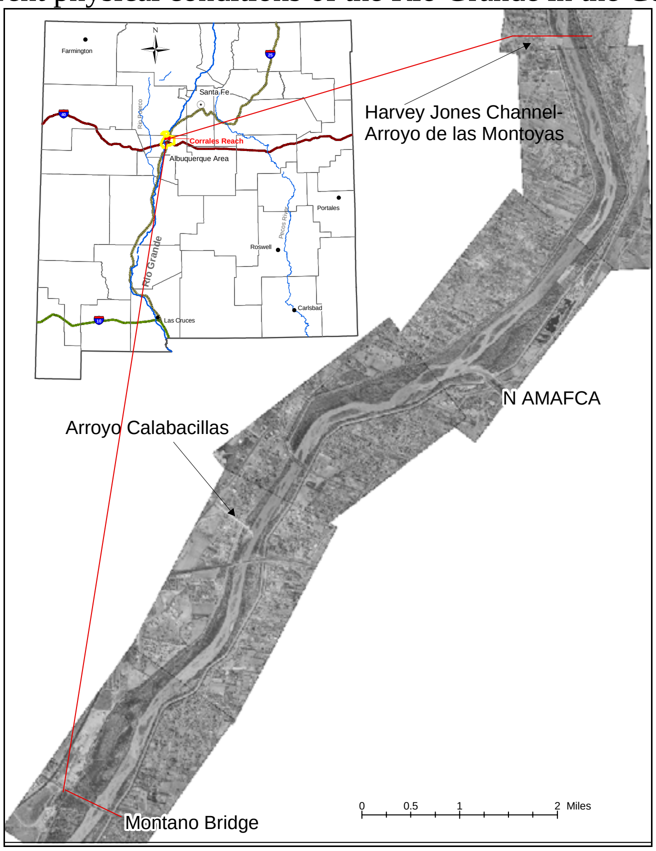

Figure 1: Location of the Rio Grande-Corrales reach, New Mexico. 2002 aerial photos source: Reclamation's aerial photography archives.

1.1 Review of Geologic History of the Reach/Area

(from Massong 2003)

Two geologic processes have controlled the geomorphic evolution of this section of the middle Rio Grande valley: extensional faulting that is mostly parallel to the valley, a.k.a. the Rio Grande rifting (Chapin 1988), and valley filling from both the ancestral and current Rio Grande. Extensional faulting, associated with the Rio Grande rifting has created a north-south extending valley, in which the valley bottom subsides relative to the sides of the rift which are uplifting and creating mountains. The rifting began 25-30 million years ago and continues to present day. The rifting has created a valley which is partially filled by debris (sediment) originating from both upstream sediment sources, and local sources such as the mountains. Several thousand feet of sediment (Hawley 1978) overlie the sinking bedrock in the study area.

1.2 Precipitation Patterns

(from Massong 2003)

Combining data from two climate gages, Bernalillo and Corrales climate gages (Hydrosphere, 2000), creates a nearly continuous precipitation record (1948-2000). Data was collected at the Bernalillo gage from 1948-1982 (elevation of 5,060 ft). The Corrales gage, elevation of 5,015 ft, began collecting data in 1983, and continues to date. Climate patterns dating back to the 1930's are available south of the study site at the Albuquerque airport (ALB-airport) climate gage (elevation of 5,310 ft). Although the Bernalillo and Corrales climate gages are very close to the study area, the ALB-airport data is more extensive thus this gage data is presented (Figure 2). Even though the ALB-airport gage generally received less precipitation than either the Bernalillo or Corrales gages, the general precipitation patterns are similar between the gages. Three distinct precipitation patterns emerge since the 1940s (Figure 2 and Table 1): 1) low precipitation (1942-1956) which is commonly referred to as the 1950s drought; 2) moderate precipitation (1957-1979); and 3) above average precipitation after 1979. Although the average precipitation was above average after 1979, several years of below average rain fall also occurred in this period (Figure 2).

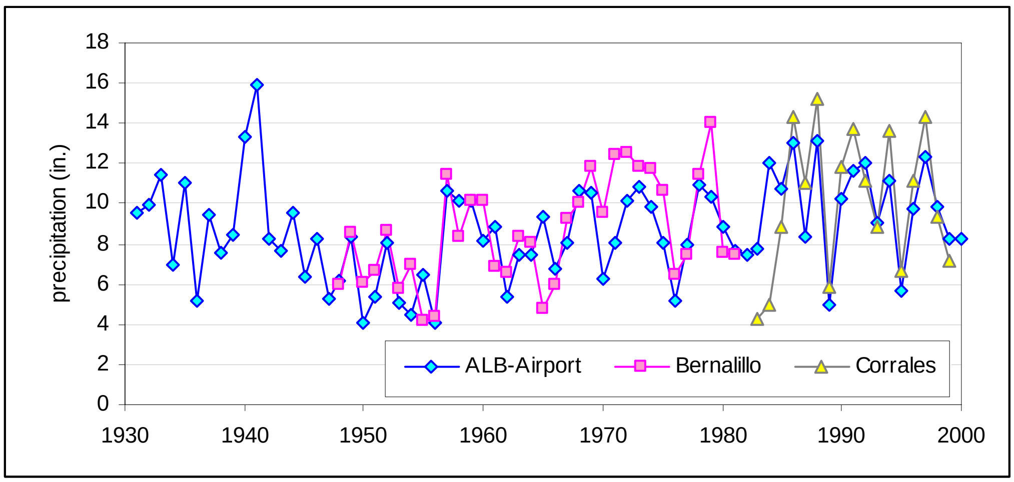

Figure 2: Yearly precipitation totals for the Albuquerque Area. Raw climate data supplied by Hydrosphere, 2000.

Table 1: Average yearly precipitation values for the Albuquerque Area. Raw climate data supplied by Hydrosphere, 2000.

	ALB-Airport	Bernalillo	Corrales	Bernalillo-Corrales
Yearly Average (whole record)	8.71	8.59	10.15	9.11
1984-1999	10.14	n/d	10.52	-
1957-1979	8.51	9.50	n/d	-
1942-1956	6.49	6.37	n/d	-

Although precipitation falls each month, the majority of the precipitation falls July-September (Figure 3). A cursory review of the daily records indicates that during the July-September period, storm events on individual days often supplied the recorded months' average precipitation.

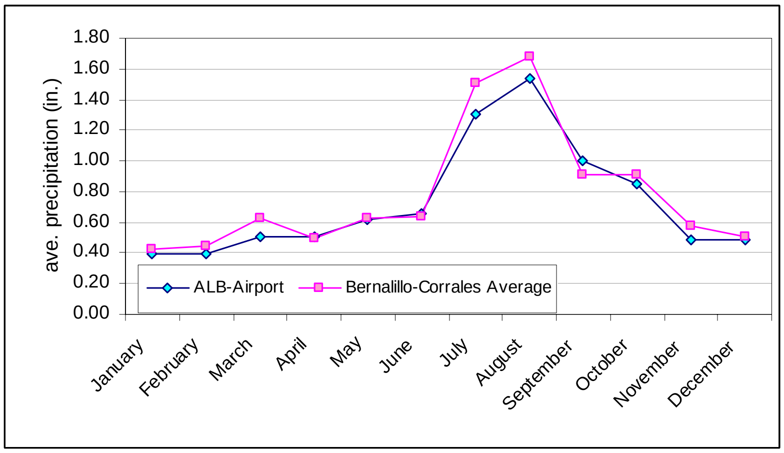

Figure 3: Average monthly precipitation totals for the Albuquerque Area; climate data supplied by Hydrosphere, 2000.

1.3 Monumental Historic Water and Sediment Events

(from Massong 2003)

Based on a report prepared by Scurlock (1998), nearly 60 floods were recorded in the Middle Rio Grande area (Velarde to Elephant Butte), 1822-1942. Of these 60 floods, 7 of the floods were described as very large or valley-filling type events. These events were estimated to be greater than 100,000 cfs. The last floods described by Scurlock (1998) were back-to-back high flows in 1941 and 1942. U.S. Geological Survey (USGS) river gage data indicate peaks near 20,000 cfs for each of these flows at San Felipe (Figure 4), with the 1941 peak at almost 23,000 cfs. Only two flows have exceeded 12,000 cfs since 1942, and no flows greater than 10,000 cfs have passed San Felipe since 1967 (Figure 4).

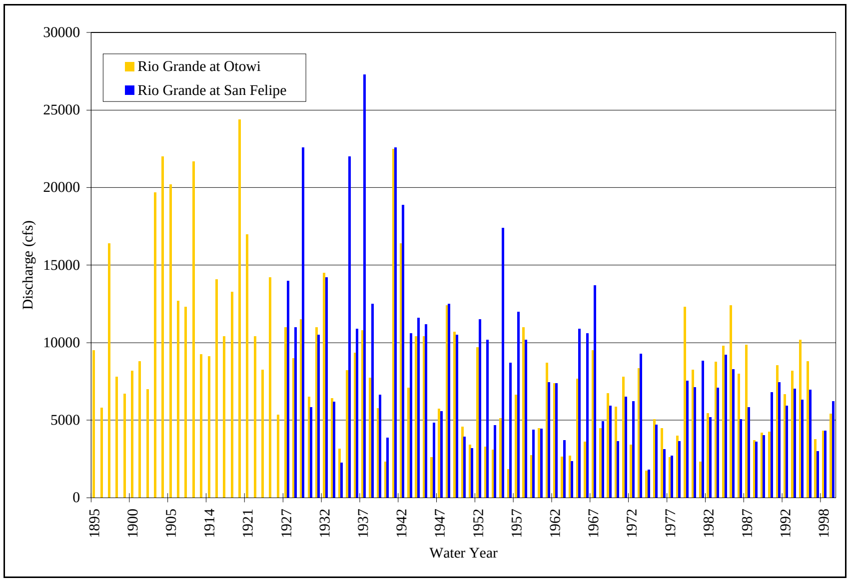

Figure 4: Peak discharge records measured; USGS Rio Grande gage data at Otowi Bridge (1895-1999) and San Felipe (1927-1999).

Although flows in 1941 and 1942 were large and extensive (throughout the middle Rio Grande valley), according to peak discharge data, the largest recorded instantaneous discharge was on June 26, 1937 (Figure 4), at just over 27,000 cfs (12,000 cfs mean daily discharge) for the USGS Rio Grande gage at San Felipe. Based on the hydrograph data (Figures 4 & 5), this flow was a summer thunderstorm event generated downstream of the Otowi gage. As typical with summer storm floods, this flow peaked and diminished quickly (Figure 5).

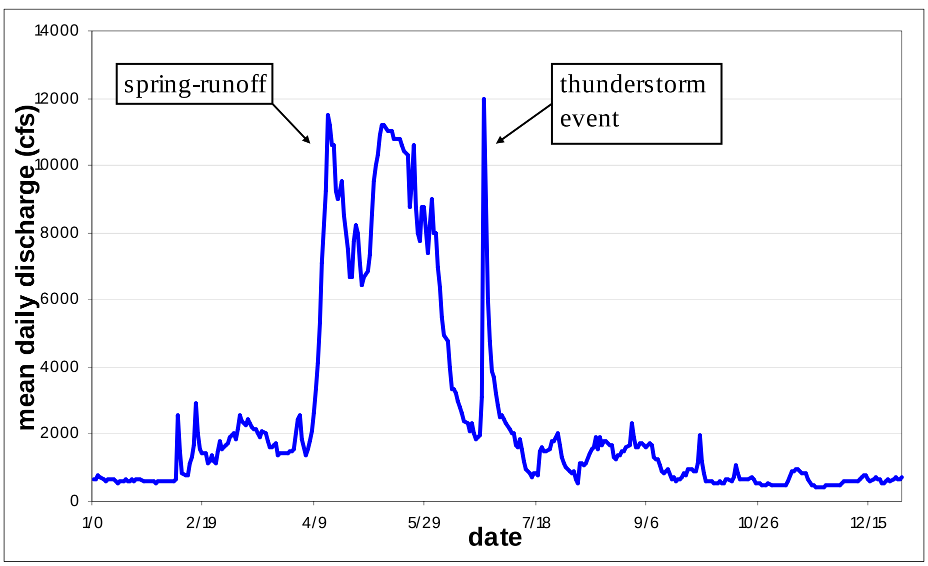

Figure 5: Mean daily discharge for 1937; USGS Rio Grande gage at San Felipe.

Suspended sediment data from the combination of two USGS river gages shows that the amount of suspended sediment decreased dramatically after 1958

(Table 2). The cause of this change in sediment supply is not clear but may be associated with upstream management. A decrease in the supply of sediment occurred again in 1973, which was the year that the Cochiti dam began operations and storing the upstream supply of sediment in the reservoir. A temporary increase in suspended sediment occurred between 1993 and 1995. Reviews of the precipitation record during 1993-1995 indicate that 1994 had an extensive thunderstorm season (May through October) and a higher than average yearly precipitation amount, over 13 inches (Hydrosphere, 2000). The higher than usual thunderstorm activity likely created the relative increase in sediment supply to the Rio Grande (Reclamation, 2003). The measured suspended sediment amounts decreased to levels similar to 1973-1993 after the temporary pulse in 1993-1995.

Table 2: Average yearly amount of suspended sediment collected at the USGS Rio Grande gages at Albuquerque and Bernalillo, NM.

Time Period	Average Suspended Sediment (million tons/yr)
1956-1958	10.8
1958-1972	3.0
1972-1973	7.6
1973-1985	1.2
1985-1993	0.3
(1989-1992)	(no data collected)
1993-1995	2.8
1995-1999	0.8

1.4 History of Channelization

Historically, the Middle Rio Grande was a relatively straight, braided and aggrading channel (Lagasse 1980, Leopold 1994, Leopold et al. 1964, Reclamation 2003). During the rehabilitation of the Rio Grande for mostly irrigation purposes, the Middle Rio Grande Conservancy District constructed a floodway along the river during the 1930 to 1936 period (Woodson and Martin 1962). Comparing the 1918 maps with the 1935 photos (Figure 6a), the most significant changes in the newly constructed floodway appears to have been an overall narrowing of the channel, while the general location of the river did not change significantly. Several bends were abandoned as well as existing side channels. An initial levee system was also constructed during this time period. By the 1950's, the Rio Grande occupied a wide shallow channel between the levees of the floodway which had little to no bank development (Leopold 1994). The average level of the channel bed, especially in the Albuquerque area, was above the elevation of the floodplain located outside of the levees (Woodson and Martin 1962). Continued flooding outside the levees prompted the U.S. Congress in 1948 and 1950 to authorize additional river modifications to control sedimentation and flooding along the Rio Grande. As part of this authorization, the Rio Grande was re-channelized, Keller jetty fields were placed along the floodway to control sedimentation, and an improved levee system was built. Since the river-work in the 1950's, the study reach appears stable in terms of locations (Figure 6b-6d). The most notable change since the 1950's river-work is the recent development of stable islands, which has been occurring since the 1980's.

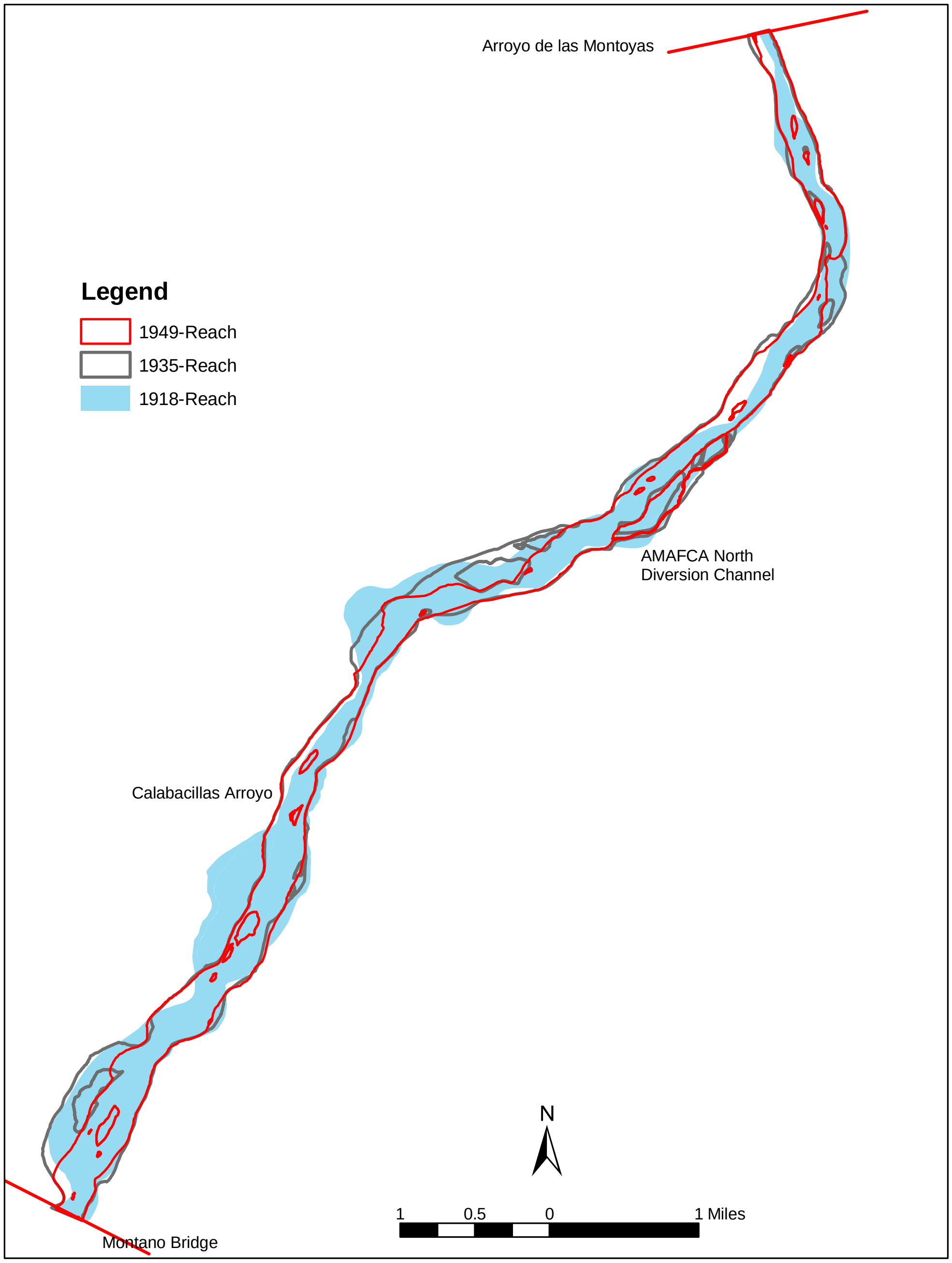

Figure 6a: Non-vegetated active channel of the Rio Grande, Corrales Reach; 1918, 1935, and 1949 channels. Modified product of the Bureau of Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

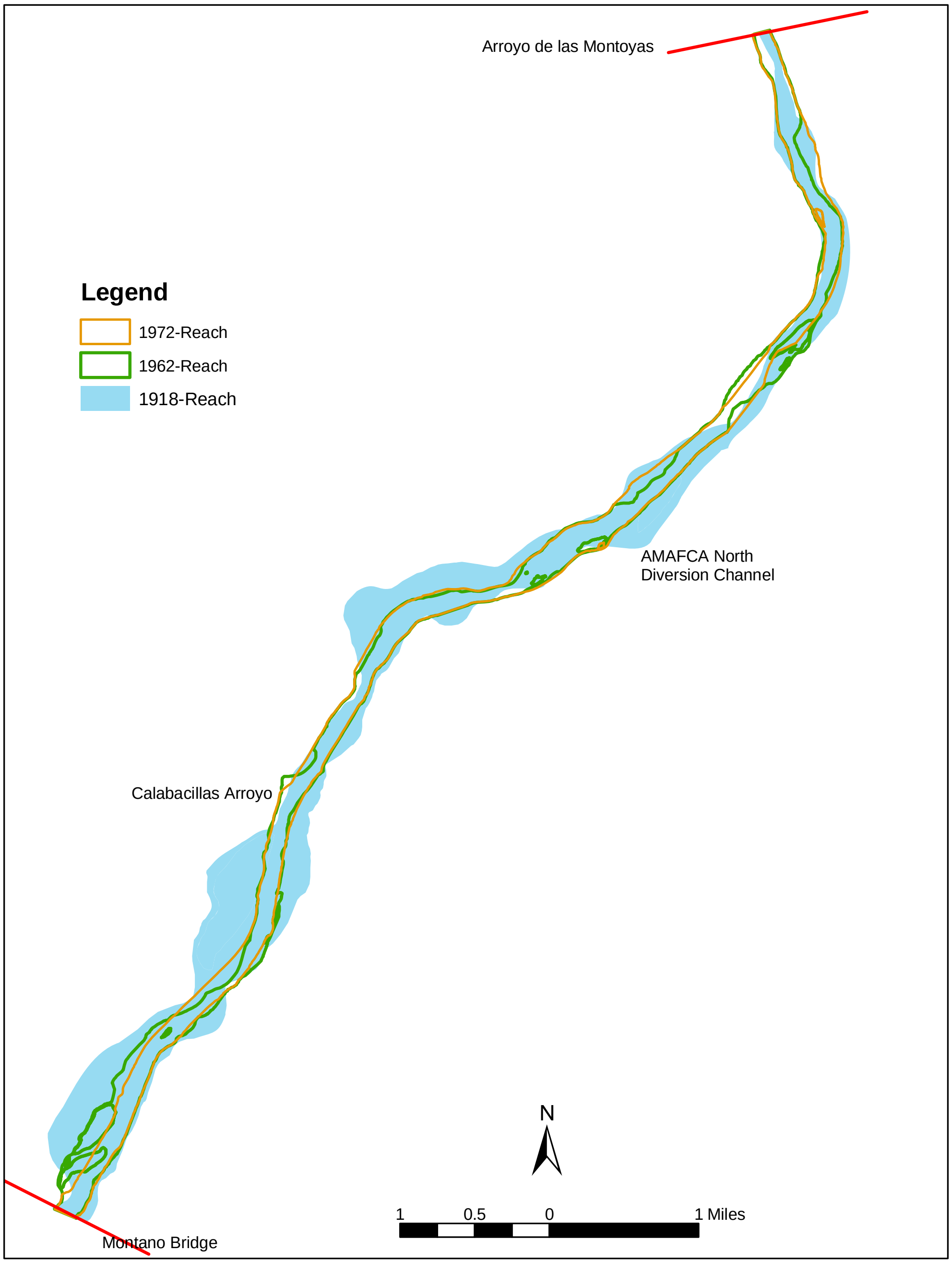

Figure 6b: Non-vegetated active channel of the Rio Grande, Corrales Reach; 1918, 1962, and 1972 channels. Modified product of the Bureau of Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

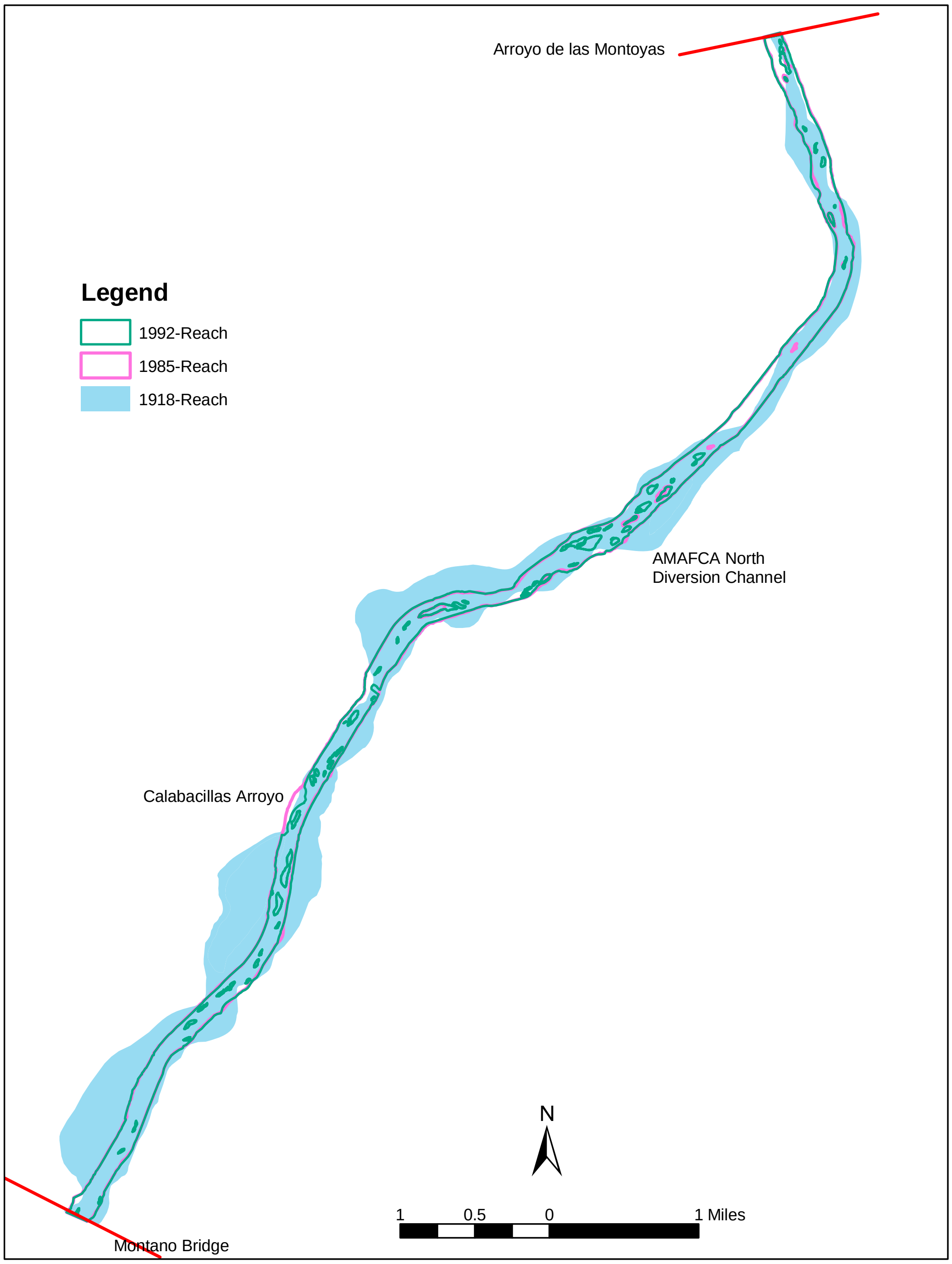

Figure 6c: Non-vegetated active channel of the Rio Grande, Corrales Reach; 1918, 1985, and 1992 channels. Modified product of the Bureau of Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

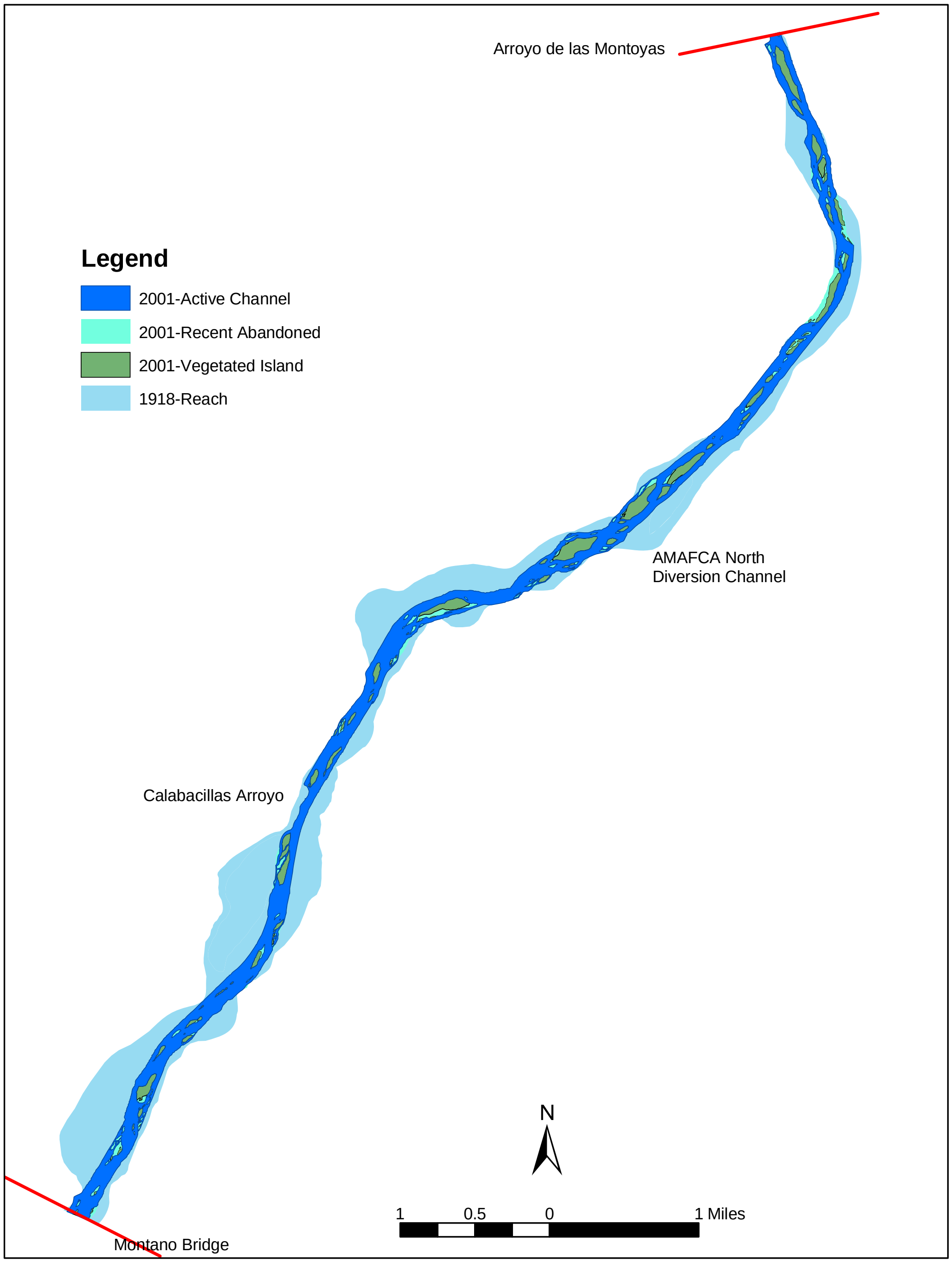

Figure 6d: Non-vegetated active channel of the Rio Grande, Corrales Reach; 1918 and 2001 channels. Modified product of the Bureau of Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

1.4 Channel forming flows

(from Massong 2003)

As defined by Knighton (1998), the flow that occurs approximately every 1.5-2 years is usually considered the channel forming flow. Unfortunately, no gage is currently located within the Corrales reach, and the closest gage (USGS gage-Rio Grande at Albuquerque) has a very short record. However, the USGS gage upstream, Rio Grande at San Felipe, which is approximately 16 miles north of the study area has a continuous peak discharge record dating back to 1927. After separating the data for pre- and post-Cochiti Dam (1973 water year), a simple flood frequency curve (Figure 7) was developed to assess the channel forming flow with a 1.5-2 year recurrence interval. Prior to the closing of Cochiti dam, the San Felipe gage received flows greater than 10,000 cfs approximately every 2 years. After flow modifications began at Cochiti dam (post-1973), the channel forming flow is estimated between 5,000-6,000 cfs.

The post-Cochiti dam channel forming flow values are consistent with estimated 2-year recurrence values found in other studies. Bullard & Lane (1993) reported that for the USGS Rio Grande gage at San Felipe the 2-year recurrence flows was 5,600. Richard (2001) reported a 2-year flow estimate for the USGS Rio Grande gages at Otowi and Cochiti at just over 5,100 cfs. The channel forming discharge at the San Acacia gage, located downstream of the study area, was estimated at 5,000 cfs for the post-Cochiti water years (Reclamation 2003). For the purposes of modeling channel characteristics in this report, 5,000 cfs will be used as the channel forming flow.

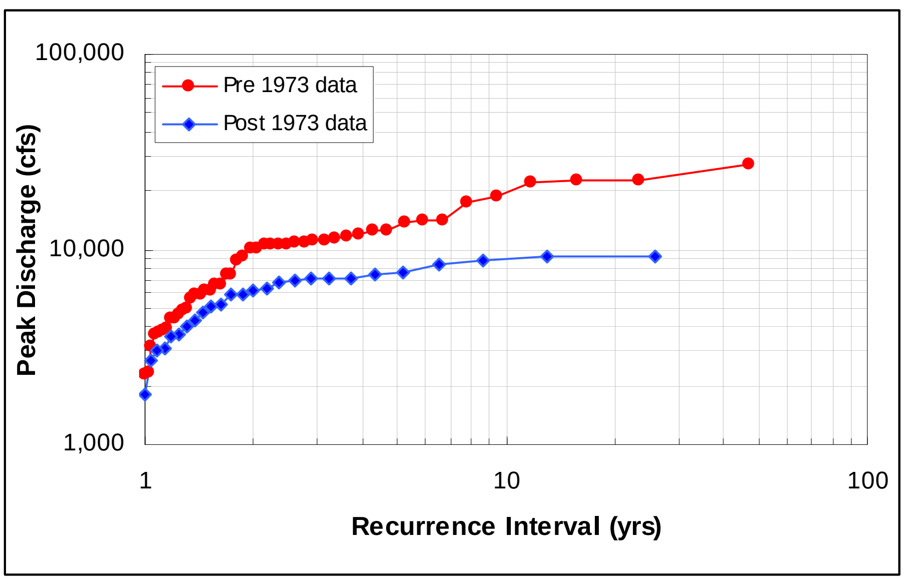

Figure 7: Flood frequency curve for the Rio Grande, using peak discharge data from the USGS gage station at San Felipe, NM.

1.6 Past Channel Patterns

Four sets of aerial photos were reviewed to describe past channel patterns throughout the Corrales reach; photos date between 1949 and 2001. In the oldest photos (1949), the active channel was wider with large, active, point bars (Figure 8). The wetted channel was also wider than the present channel (2001) but consisted of one dominant thalweg with side channels.

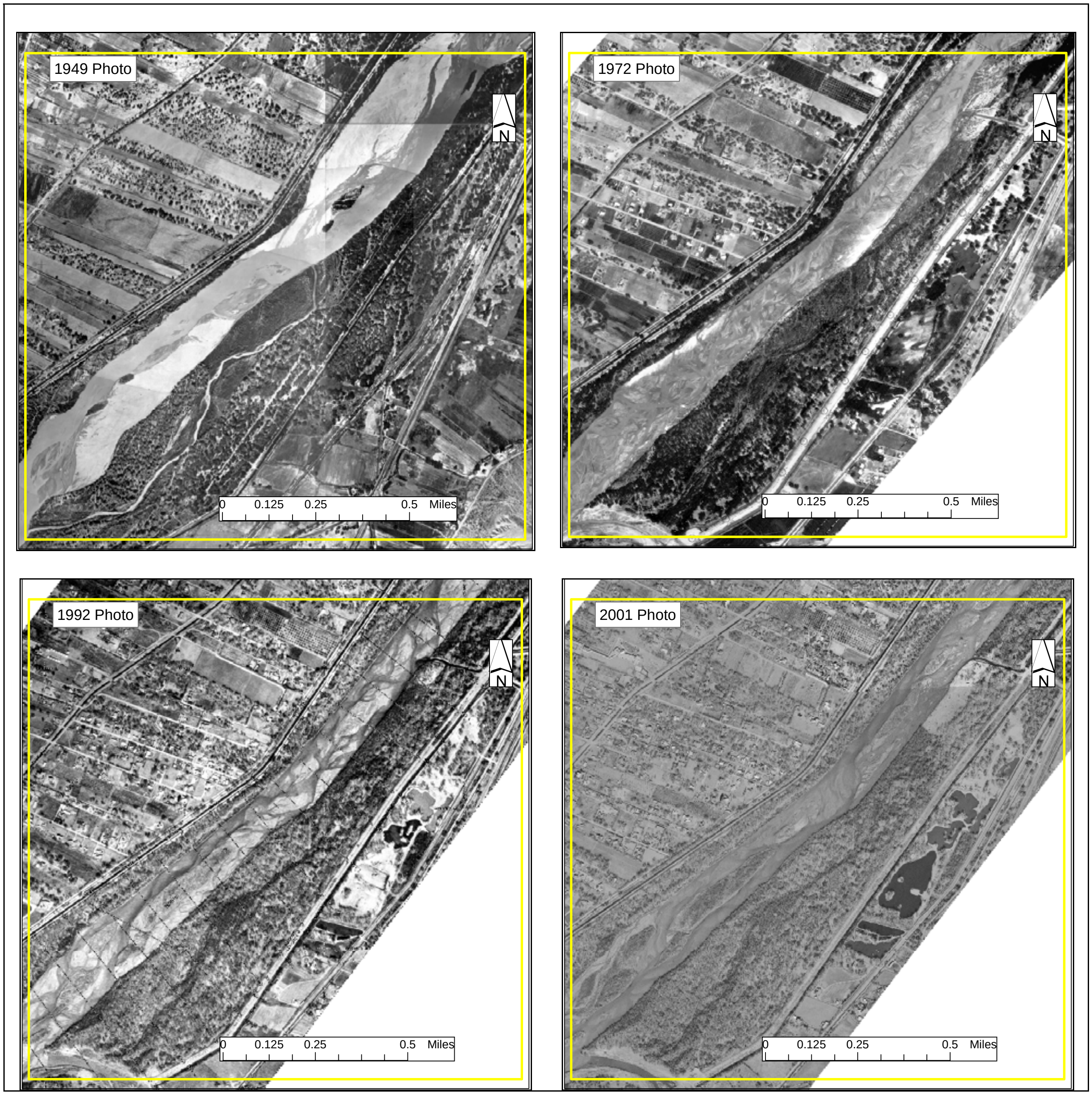

Figure 8: Historical aerial photographs (1949, 1972, 1992, and 2001) of the Corrales area. Photos source: Reclamation photo archives; all photos taken during low flow.

The 1949 bars appear low, as wetted side channels exist within the bars. Although islands were present in these early photos, the islands are quite small and fully vegetated (Figure 8). The best description of the 1949 morphology is a low sinuosity, meandering thalweg, as the exposed point bars are well developed on the inside of bends during low flows.

By 1972, the floodway re-construction appears to have reduced the active channel width (Figure 8), with the point bars viewed in 1949 becoming vegetated by 1972 or eroded. At low flows, the entire active channel is wet in 1972, with few bars exposed or vegetated. This morphology is best described as braided.

Although similar bank lines exist in 1992, the wetted proportion of the active channel is significantly reduced during low flows; within the active channel, many bars are exposed and several vegetated islands exist. Several channels convey the low flows, and these channels appear relatively deep as denoted by the darker colors of the channels; the morphology in 1992 is easily described as island/bar braided.

By 2001, the active channel is significantly filled with vegetated islands. Many of these islands appear to be bars that have become vegetated since 1992. One dominant channel has formed, however, the low flow side channels are well connected to the main channel. Exposed bars are predominantly absent in this photo series. The morphology of the 2001 channel appears to be island-braided.

2.0 CURRENT CONDITIONS

The Corrales reach current conditions assessment includes the delineation of the reach into sub-reaches, the current physical description of each sub-reach, analyses of the most current cross section data (2001), and a discussion of the larger bed material sizes and their potential mobility. The physical channel descriptions were observed in both the summer and winter months of 2000. Cross section and bed material data were collected by government contractor in the spring of 2001.

2.1 Delineation of Sub-Reaches and Descriptions

For analysis purposes, the Corrales Reach was subdivided into three sub-reaches (Figure 9): sub-reach 1 extends from Arroyo de las Montoyas to the AMAFCA North Diversion Channel (approximately 4.4 miles); sub-reach 2 extends from the AMAFCA North Diversion Channel to the Calabacillas Arroyo, approximately 2.6 miles in length; sub-reach 3 extends from the Calabacillas Arroyo downstream to the bridge at Montano Blvd. near Bureau of Reclamation range line CR-462. Since channel slope varies very little in this channel reach, the sub-reach boundaries were based primarily on the major tributary confluences.

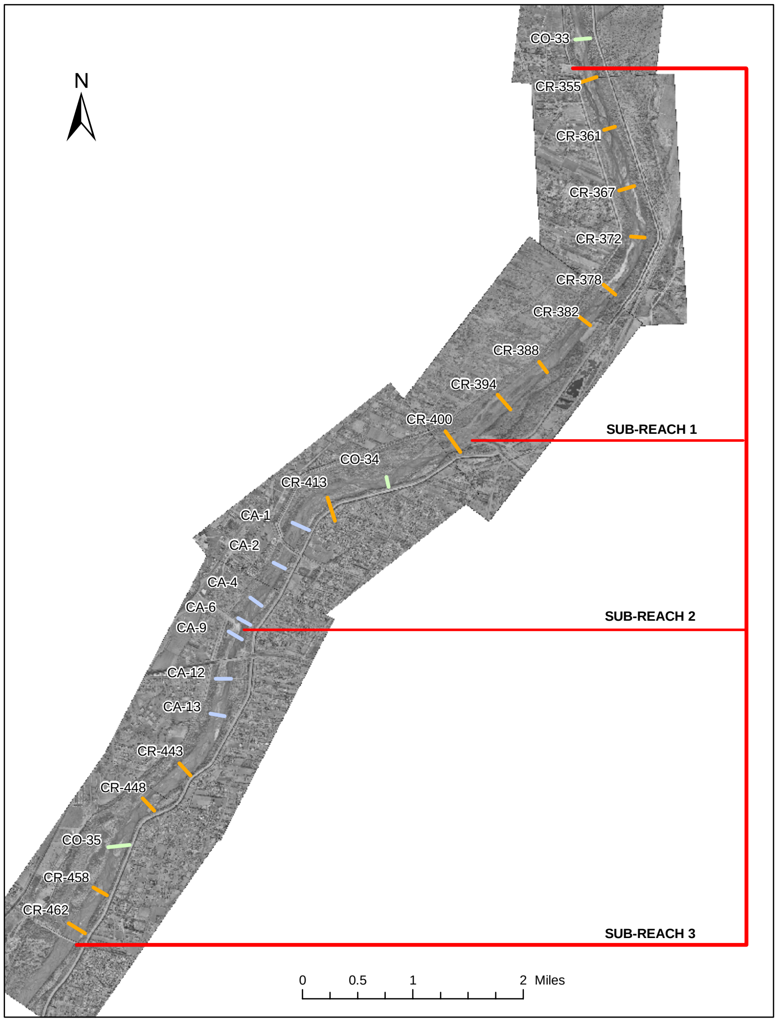

Figure 9: Corrales reach of the Rio Grande with cross sections and sub-reaches identified; 2001 aerial photographs.

During field visits, both sub-reach 1 and sub-reach 2 appeared similar in appearance. These sub-reaches have a modest amount of incision evidenced by the relatively high banks present. However, the incision does not appear active, as the banks are well vegetated and the bank edges are not necessarily abrupt (i.e., some weathering along the bank lines). These observations of incision are consistent with findings presented by Albert et al. (2003), where they found that incision in this area halted during the 1990's. The connected floodplain within the levees appears to be only inundated during very high flows, probably larger flows than the 2-year return period. Vegetated islands present in these two sub-reaches are well connected to the main river and are flooded at higher flows. The channel pattern is basically a braided morphology to an island-braided morphology at low flows, as the flows split around the vegetated islands. At higher discharges, the flow inundates the islands. Although gravel was present, its spatial extent is isolated. The dominant bed material is sand. Sand dunes are active at all flows observed (low and moderate flows).

Unlike sub-reaches 1 and 2, the channel in sub-reach 3 appeared to be filling slightly. The height of the vegetated bars and the channel bank lines were less in this reach than observed upstream. Especially the islands appeared to susceptible to high flow flooding. The bank lines are covered in dense riparian vegetation and appear stable. The channel pattern is similar to upstream: a braided morphology to an island-braided morphology at low flows, as the flows split around the vegetated islands. The channel bed is dominated by sand, and sand dunes are active at all flows observed (low and moderate flows).

2.2 Channel Dimensions

Channel dimensions include both the shape and size of the channel's cross section (e.g., width, depth, etc), but also the longitudinal characteristics such as channel slope. The application HEC-RAS, U.S. Army Corps of Engineers' Hydrologic Engineering Center-River Analysis System, version 3.1 (USACE, 2002) was used to estimate current channel characteristics from field collected cross section data at a flow of 5,000 cfs. HEC-RAS generated interpolated cross sections were added to the model at 300-500 foot intervals. Estimated channel features included channel width, maximum channel depth, average channel depth (hydraulic depth), average channel velocity, channel area, wetted perimeter of the channel, water surface elevations, and minimum bed elevations. Using the elevation results, bed slopes and water surface slopes were calculated between cross sections. Weighted averages were employed to calculate average sub-reach values. The last 3 cross sections, CO-35, CR-458 and CR-462 were not included in determining the average channel characteristics for sub-reach 3, due to model stability constraints.

HEC-RAS does not fully account for the many islands present in this reach nor does it account for the changing bed elevation due to the highly mobile sediment load. The Manning's n values, which account for channel roughness, were estimated mostly based on roughness due to grain size and in-channel characteristics at a cross section. However, this section of river has many islands. These islands are often partly flooded during higher flows, and split the flow into many side channels during the lower flows. Roughness due to flow interactions with the islands is not fully accounted for in the model. HEC-RAS also assumes a 'fixed-bed', such that the elevation of the channel bed does not change with discharge or mobile sediments. Along the Rio Grande, especially in the reaches with sandy substrates, a scour-fill cycle is well documented (Leopold 1994), indicating that bed elevation varies with sediment transport and discharge. This limitation in HEC-RAS overestimates the amount of overbank flooding and underestimates the flows at which flooding occurs (Reclamation, 2003).

2.2.1 Results

The hydraulic parameter results indicate that although sub-reach 2 is the widest reach (Table 3), the reach channel varies little along this reach length. The maximum channel depth is more than twice the average depth indicating that the thalweg is much deeper than the rest of the channel (Table 3). No overbanking appears to occur under 5,000 cfs. Sub-reach 3 has the lowest water surface slope, but has the steepest thalweg slope.

Table 3: Physical channel characteristics for the Rio Grande-Corrales reach, HEC-RAS estimates at 5,000 cfs.

	Sub-Reach 1	Sub-Reach 2	Sub-Reach 3	Reach Average
Width (ft)	590	680	600	610
Max Depth (ft)	5.10	4.90	5.10	5.00
Ave Depth (ft)	2.40	2.20	2.50	2.40
Velocity (ft/s)	3.70	3.50	3.40	3.60
Area (sq ft)	1,370	1,450	1,480	1,420
W. Perimeter (ft)	590	680	600	620
Water Surface Slope (ft/ft)	0.00101	0.00108	0.00091	0.00100
Thalweg Slope (ft/ft)	0.00099	0.00085	0.00105	0.00098

2.3 Bed Material Sizes

Generally, this reach has a sand bed, however the bed is at least partly gravel covered where the Arroyo de las Montoyas and the Arroyo Calabacillas join the Rio Grande. Based on the bed material sampled in 2001 (Table 4), large gravel is present both upstream and downstream of the Arroyo de las Montoyas (range lines CO-33 and CR-355). Although the sediment size data only indicates small gravel at the Calabacillas Arroyo (range line CA-1), field observations confirm large gravel is present in the Rio Grande at this confluence. However, the gravel material does not appear to extend completely across the channel.

Table 4: 2001 bed material grain sizes sampled in the Rio Grande – Corrales reach.

Reach	Cross Section	Sample Number	Date Collected	d_{84} (mm)	d_{50} (mm)	d_{35} (mm)
CO	33	2	04/11/01	34.25	12.44	4
CR	355	2	05/15/01	33.67	10.07	3.58
CR	361	1	05/16/01	1.47	0.5	0.42
CR	367	2	05/16/01	6.88	2.58	1.13
CR	372	1	05/16/01	1.86	0.72	0.53
CR	378	1	05/16/01	1.12	0.57	0.46
CR	382	1	05/16/01	0.98	0.48	0.38
CR	388	1	05/17/01	0.86	0.45	0.36
CR	394	1	05/17/01	1.22	0.53	0.41
CR	400	1	05/18/01	0.99	0.49	0.41
CO	34	1	04/10/01	1.99	0.84	0.63
CR	413	1	05/18/01	1.37	0.69	0.55
CA	1	6	04/10/01	4	0.81	0.66
CA	6	1	08/19/01	1.18	0.59	0.46
CA	12	1	08/19/01	1.5	0.66	0.5
CR	443	1	08/30/01	0.72	0.36	0.28
CR	448	1	08/30/01	1.08	0.48	0.39
CO	35	2	04/10/01	1.11	0.59	0.48
CR	458	1	08/30/01	0.86	0.46	0.38
CR	462	1	08/30/01	0.7	0.38	0.31

2.4 Sediment Movement Model

Incipient motion calculations allow a cursory assessment of the stability of the channel's bed material. This method assumes that the channel bed is more stable if the calculations indicate a high flow to initially move the channel material and less stable if lower flows move the material present. Although there are several methods that assess initial motion of grains on a channel bed, the most simple analytical tool is comparing shear stresses, which is the method employed for this study.

2.4.1 Shear Stress Comparison Methods

A shear stress comparison method (Knighton, 1998) assumes that a grain on the bed of a channel will move only when the overriding pressures (τ_o - weight of the water on top of the particle) over comes the resistance to motion or the critical shear stress (τ_c) of the particle. Two limitations to this method are: 1) it over estimates the shear stress necessary to initiate mobilization because it ignores lift due to both the velocity differences in the basal laminar flow, and the turbulence or eddying effects that breaks through the basal laminar flow, and 2) it ignores grain packing on the channel bed and the effects of grain-grain interaction which could prevent all grain movement if well packed. Based on field observations, the bed material in the channel of this reach is not well packed, and therefore grain packing is not considered a limitation. However, the first limitation reported above, unaccounted lift due to velocity differences and turbulence is not addressed; therefore the results are likely underestimates for the 'true' mobility of the bed material.

Equations:

$\boldsymbol{\tau_o}=\gamma Rs$ (general equation)

γ is the specific weight of water (9.807 kN/m^3 for water at 5C, or 9807 kg/m^2s)

R is the hydraulic radius (m)

s is the channel slope

$\boldsymbol{\tau_c}=kg(\rho_s-\rho)d$ (Shields equation)

k ranges from 0.03-0.06, 0.045 accepted as a good approximation (Komar, 1988) which is lower than Shields' value of 0.06.

d is grain size (m)

g is gravity (m/s)

ρ_s is density of sediment (2650 kg/m^3)

ρ is density of water (1000 kg/m^3 for water at 5C)

Initial motion was calculated using the physical conditions for six different flows: 2,000 cfs, 3,000 cfs, 4,000 cfs, 5,000 cfs, 7,000 cfs and 10,000 cfs. Physical parameters were estimated from the 2001 cross section data with the HEC-RAS (v. 3.1) model. Distances between each cross section were estimated using 2001 aerial photos in the GIS application, ARCMAP 8.1. Bed material was collected along each cross section. Both the d_{84} and d_{50} grain sizes were used to assess initial motion.

2.4.2 Sediment Movement Results

The grains present in nearly all the reach, downstream of Reclamation range line CR-355, are expected to be mobile at all flows greater than 2,000 cfs (Tables 5 & 6). However, the model results indicated that the armoring bed material (d_{84}) at CO-33 and CR-355 is not mobile at flows up to 10,000 cfs while the average bed material present is expected to move in high flows.

Table 5: Estimated mobility of d50 grain sizes for the Rio Grande - Corrales reach.

Cross Section	*Grain Size (mm)*	*2000 cfs*	*3000 cfs*	*4000 cfs*	*5000 cfs*	*7000 cfs*	*10,000 cfs*
CO-33	12.44	**no**	**no**	**no**	**no**	**no**	yes
CR-355	10.07	**no**	**no**	yes	yes	yes	yes
CR-361	0.5	yes	yes	yes	yes	yes	yes
CR-367	2.58	yes	yes	yes	yes	yes	yes
CR-372	0.72	yes	yes	yes	yes	yes	yes
CR-378	0.57	yes	yes	yes	yes	yes	yes
CR-382	0.48	yes	yes	yes	yes	yes	yes
CR-388	0.45	yes	yes	yes	yes	yes	yes
CR-394	0.53	yes	yes	yes	yes	yes	yes
CR-400	0.49	yes	yes	yes	yes	yes	yes
CO-34	0.84	yes	yes	yes	yes	yes	yes
CR-413	0.69	yes	yes	yes	yes	yes	yes
CA-1	0.81	yes	yes	yes	yes	yes	yes
CA-2	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CA-4	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CA-6	0.59	yes	yes	yes	yes	yes	yes
CA-9	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CA-12	0.66	yes	yes	yes	yes	yes	yes
CA-13	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CR-443	0.36	yes	yes	yes	yes	yes	yes
CR-448	0.48	yes	yes	yes	yes	yes	yes
CO-35	0.59	yes	yes	yes	yes	yes	yes
CR-458	0.46	yes	yes	yes	yes	yes	yes
CR-462	0.38	N/D	N/D	N/D	N/D	N/D	N/D

Table 6: Estimated mobility of d84 grain sizes for the Rio Grande - Corrales reach.

Cross Section	*Grain Size (mm)*	*2000 cfs*	*3000 cfs*	*4000 cfs*	*5000 cfs*	*7000 cfs*	*10,000 cfs*
CO-33	34.25	**no**	**no**	**no**	**no**	**no**	**no**
CR-355	33.67	**no**	**no**	**no**	**no**	**no**	**no**
CR-361	1.47	yes	yes	yes	yes	yes	yes
CR-367	6.88	no	no	yes	yes	yes	yes
CR-372	1.86	yes	yes	yes	yes	yes	yes
CR-378	1.12	yes	yes	yes	yes	yes	yes
CR-382	0.98	yes	yes	yes	yes	yes	yes
CR-388	0.86	yes	yes	yes	yes	yes	yes
CR-394	1.22	yes	yes	yes	yes	yes	yes
CR-400	0.99	yes	yes	yes	yes	yes	yes
CO-34	1.99	yes	yes	yes	yes	yes	yes
CR-413	1.37	yes	yes	yes	yes	yes	yes
CA-1	4	yes	yes	yes	yes	yes	yes
CA-2	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CA-4	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CA-6	1.18	yes	yes	yes	yes	yes	yes
CA-9	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CA-12	1.5	yes	yes	yes	yes	yes	yes
CA-13	n/d	N/D	N/D	N/D	N/D	N/D	N/D
CR-443	0.72	yes	yes	yes	yes	yes	yes
CR-448	1.08	yes	yes	yes	yes	yes	yes
CO-35	1.11	yes	yes	yes	yes	yes	yes
CR-458	0.86	yes	yes	yes	yes	yes	yes
CR-462	0.7	N/D	N/D	N/D	N/D	N/D	N/D

3.0 ESTIMATED FUTURE CONDITIONS

The future conditions of four river characteristics are assessed in this section: sediment supply, sediment size, channel pattern and channel bed elevation. Sediment supply and sediment size are intimately linked therefore they are discussed together. Channel pattern changes and the inception of channel bed incision appeared to be co-incident in upstream reaches, hence these two subjects will be discussed together as well for this reach.

3.1 Estimated Future Sediment Characteristics

Although the Corrales reach receives sediment from upstream sources which is mostly sand-sized sediment, sediment received from the tributaries have a significant component of gravel sized material. As the Bernalillo Bridge reach continues to evolve towards a gravel bed (Massong, 2003), the upstream supply of sediment will also increase in size to gravel. Based on Rio Grande sediments observed at each of the tributaries, the North AMAFCA channel appears to be supplying fine sediment, sand or smaller sized sediment, while the two west-side tributaries are delivering gravel. The Rio Grande channel at Arroyo de las Montoyas has already converted to a gravel bed, presumably due to the availability of gravel sized material. Based on the observations at Arroyo de las Montoyas confluence, the Rio Grande near Arroyo Calabacillas will likely convert to gravel due to the current supply of large sized sediment.

The shear stress assessment/model results indicated that the sand-sized bed material is not stable. In fact, the model showed ample potential for the sand to move at flows as low as 2,000 cfs, a finding consistent with field observations. Other field observations indicate that sand is mobile at much lower flows than 2,000 cfs. The model, used in a predictive mode, indicates that except at Arroyo de las Montoyas confluence, significantly larger grain sizes are required to stabilize the channel bed (Table 7). In several locations (e.g., CA-6 & 9), the estimated stable sediment size is as large as coarse gravel (16-32 mm), but most stable sizes estimated are medium gravel (7-11 mm).

Table 7: Current grain sizes and the estimated stable grain size at 5,000 cfs for the Rio Grande-Corrales reach.

Cross Section	*Current d_{50} Grain Size (mm)*	*Current d_{84} Grain Size (mm)*	*Estimated Stable Grain Size (mm)*
CO-33	12.44	34.25	8.9
CR-355	10.07	33.67	12.6
CR-361	0.5	1.47	10.9
CR-367	2.58	6.88	7.9
CR-372	0.72	1.86	10.4
CR-378	0.57	1.12	8.5
CR-382	0.48	0.98	9.9
CR-388	0.45	0.86	10.0
CR-394	0.53	1.22	7.6
CR-400	0.49	0.99	7.7
CO-34	0.84	1.99	8.0
CR-413	0.69	1.37	10.6
CA-1	0.81	4	7.2
CA-2	n/d	n/d	4.5
CA-4	n/d	n/d	4.6
CA-6	0.59	1.18	23.9
CA-9	n/d	n/d	16.5
CA-12	0.66	1.5	14.8
CA-13	n/d	n/d	9.9
CR-443	0.36	0.72	6.6
CR-448	0.48	1.08	10.7
CO-35	0.59	1.11	8.7
CR-458	0.46	0.86	10.9
CR-462	0.38	0.7	0.0

With this significant disparity between current grain sizes and predicted stable grain sizes, the Corrales reach is expected to coarsen to a gravel-bed morphology. Since there is a source for gravel sized material at the confluences, these locations may coarsen the quickest. The downstream movement (sediment transport) of gravel from upstream sources is a slower process, however, since the Bernalillo Bridge reach is currently converting to gravel (Massong, 2003), the gravel conversion will likely continue to proceed downstream through this entire reach. The exact rate of coarsening is not predicted in this study.

As noted by Massong (2003) for the Bernalillo Bridge reach, the higher suspended sediment recorded at the Albuquerque USGS gage for 1993-1995, summer thunderstorms could greatly influence the amount of suspended sediment received in this reach. However, this same process that increases the fine sediment supply will also increase the delivery of coarse sediment from the tributaries which may augment the propagation of the conversion process over the long-term.

In summary, this reach of the Rio Grande has physical characteristics similar to a gravel bed channel (a.k.a. 'graded' for gravel size sediment) which makes sand as a bed material unstable. Also, the channel has local supplies of gravel sized sediment from the tributaries. Hence, future conversion from a sand bed to a gravel bed is expected for this reach.

3.2 Estimated Future Channel Elevation

Simply stated, incision is the river bed eroding because the river has excess transport capacity; excess transport capacity is usually caused by either a decrease in sediment supply, or by a small sediment size present on the channel bed that does not prevent bed erosion. For the Rio Grande in the Corrales area, both causes of incision, lack of sediment supply and lack of a coarse armour layer, appear to be the likely causes of the recent channel incision trend.

Since the operations at Cochiti dam began in 1973, the supply of fine sediment has decreased dramatically. Albert et al. (2003) reports that the channel bed in the Corrales reach appears to have been slightly aggrading between 1962 and 1972; however after 1972, the channel bed generally degraded about 2.5 feet. In conjunction with these data, the shear-stress analysis indicated that the sand sized sediment is unstable and that larger sediment sizes are required to create a stable bed. With the continued decrease in sediment supply of fine sediment (sand size material), and no armour layer present on the channel bed, this reach of the Rio Grande is expected to experience more bed erosion/incision.

Two ongoing processes may hinder future channel bed incision: 1) growth of Arroyo Calabacillas fan deposits in the Rio Grande, and 2) wide-spread introduction of gravel to the reach that forms an armour layer. As seen at other confluences on the Rio Grande (Massong, 2003; Reclamation, 2003), tributaries, such as Arroyo de la Barranca, Arroyo de la Parida and Arroyo Calabacillas, deliver large quantities of mixed coarse sediment to the Rio Grande, which the Rio Grande does not readily transport downstream. As these deposits grow, they can influence the Rio Grande's location (Figure 10 and Massong 2003) as well as the channel profile (Reclamation 2003). In the case of affected profile, the arroyo deposit can create a 'natural' grade control which reduces the upstream sediment transport potential; these grade control features would also reduce potential for upstream bed scour. Although the deposits of Arroyo Calabacillas are not yet acting as a 'natural' grade control, the fan is already influencing the Rio Grande. The deposits have partially filled the existing Rio Grande channel, 'pushing' the river towards the eastern portion of the floodway. Although not transported a long distance, the Rio Grande has transported part of the arroyo deposits downstream a short distance (<0.5 miles).

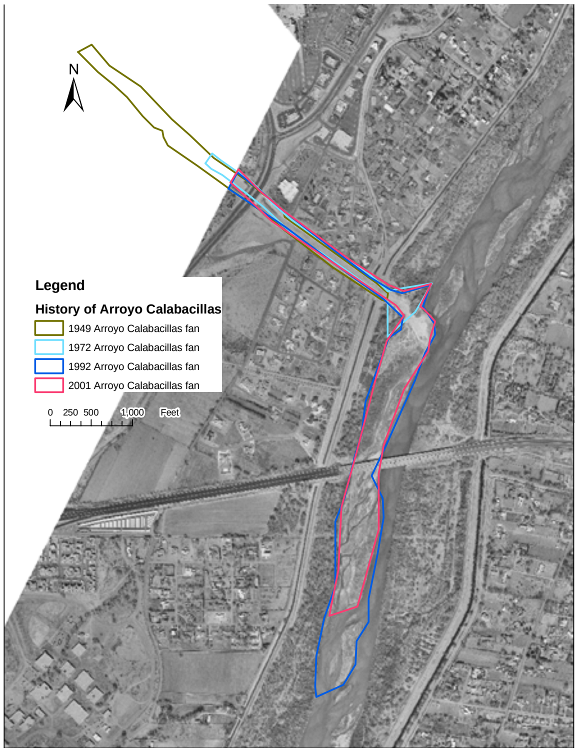

Figure 10: Historic fan deposit locations at the Arroyo Calabacillas-Rio Grande confluence.

The formation of an armour layer is dependent on a supply of coarse sediment to the river channel. Coarse sediment in the Corrales reach originates from two sources: the two west side tributaries and sediment transported into the reach by the Rio Grande from upstream sources. Along with the grade control, the coarse sediments delivered by the arroyos can supply the larger sediment sizes required for the development of an armour layer. Therefore it is likely that together, bed degradation/incision will be less prevalent at the tributary confluences.

3.3 Estimated Future Channel Pattern

The current channel pattern in the Corrales reach has evolved in the last 30 years from bar-braided to a vegetated, island-braided morphology, as side channels are abundant at all flows. However, with additional incision, the low-flow side channels will likely evolve into high flow side channels and could eventually become abandoned; a channel pattern process found in the Bernalillo Bridge reach (Massong, 2003). This potential evolution of side channel abandonment will likely create a single-threaded channel as found upstream in the Bernalillo Bridge reach. The single-threaded channels in the Bernalillo Bridge reach consist of gravel/cobble riffles flowing into planebed morphologies (runs). The channel morphology of the Corrales reach is expected to follow this evolution path and convert to a single channel with abandoned side channels.

4.0 CONCLUSIONS

- Climate data indicates three distinct precipitation periods during 1942-1999, and that the latest period, 1984-1999 has been the wettest with an average of over 10 in/yr.
- Based on peak discharge records from the Rio Grande USGS gage at San Felipe, the pre-1973 2-year recurring event was just over 10,000 cfs, but only 5,000-6,000 cfs post 1973. In fact, no flows greater than 10,000 cfs have passed San Felipe since 1967.
- The supply of sediment has decreased significantly.
- The general channel location was 'set' during the channelization activities in the early 1930's.
- The channel pattern has evolved from slightly meandering in the 1940s to bar-braided in the 1970s and 1990s to island-braided in 2001.
- Sub-reaches 1 and 2 appear to have a modest amount of incision visible by the high banks and are dominated by a sand bed. Sub-reach 3 did not appear to be incising in the field.
- Vegetated islands/bars are less connected to the river in sub-reaches 1 and 2, but still receive high flow waters.
- Sub-reach 2 is the widest channel and has the shallowest depth; however, physical characteristics between the sub-reaches vary little.
- At present, gravel has only been sampled near the west-side arroyo confluences.
- Initial motion calculations indicate that the bed material downstream of CR-355 (Arroyo de las Montoyas fan) is mobile for all flows greater than 2,000 cfs.
- A continued low supply of suspended sediment is expected.
- The size of the sediment found on the channel bed is expected to increase throughout the reach, except at CR-355 and CO-33, which are already coarse.
- Incision is expected throughout the reach, but may be hindered by the development of a channel armoring bed material and/or the growth of the Arroyo Calabacillas fan.
- The channel pattern is expected to convert towards a single-threaded channel with abandoned side channels.

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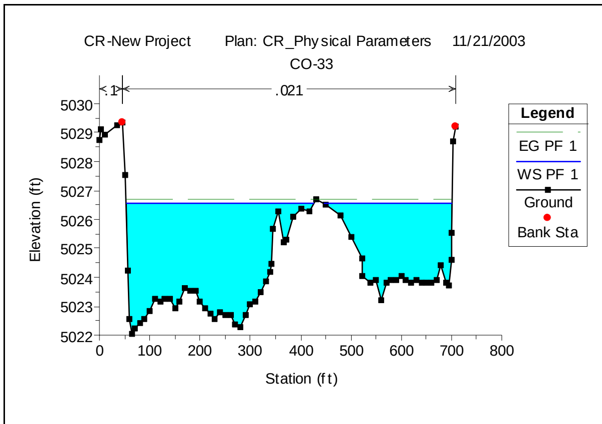
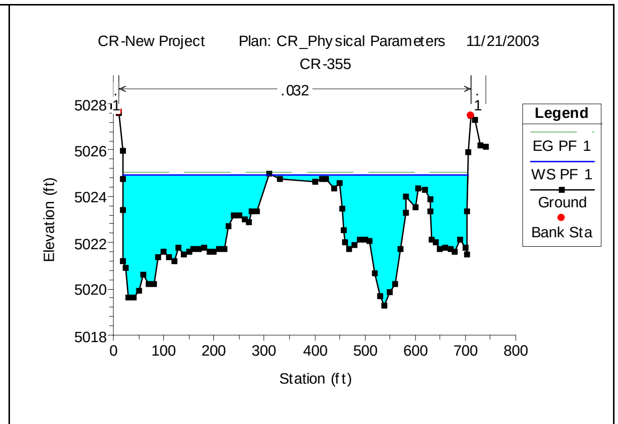
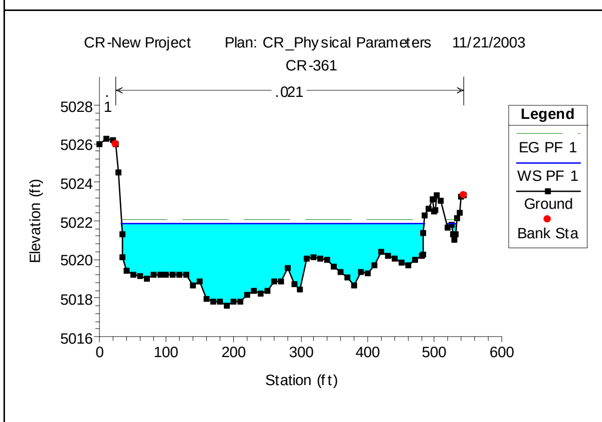
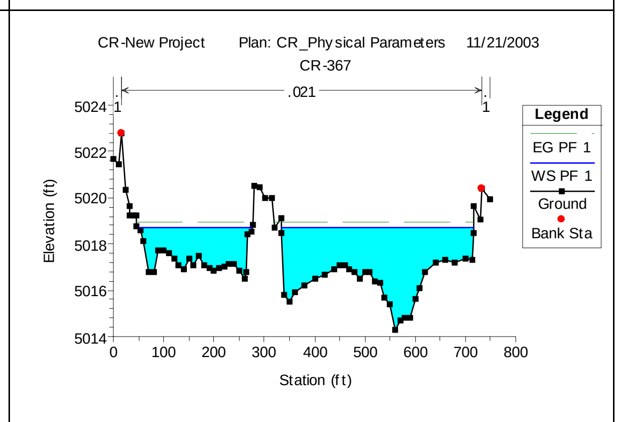
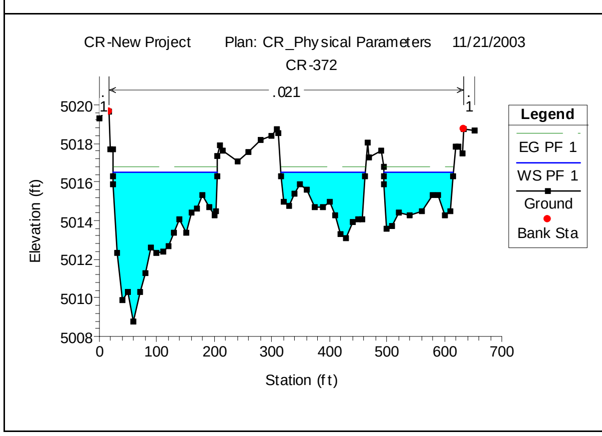
APPENDIX A – Cross Sections from HEC-RAS with a flow of 5,000 cfs

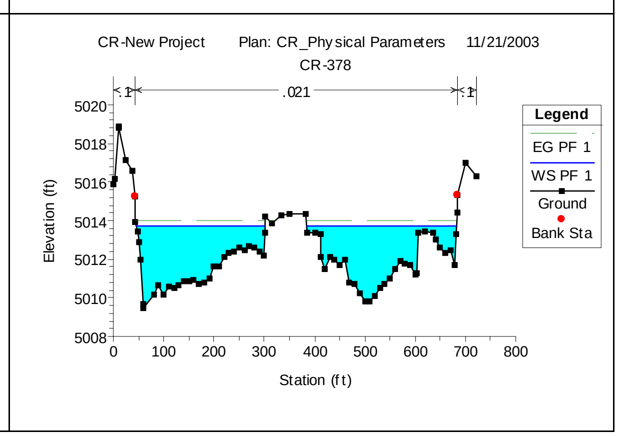


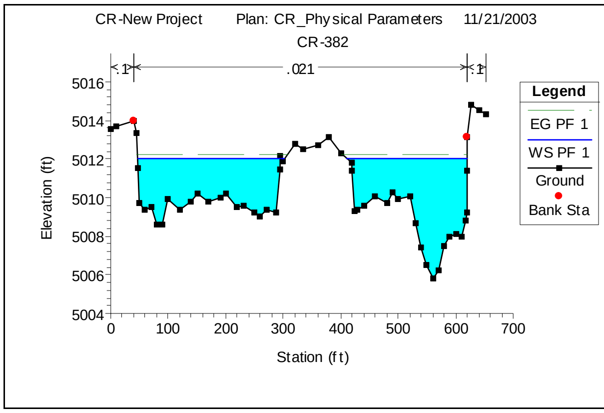








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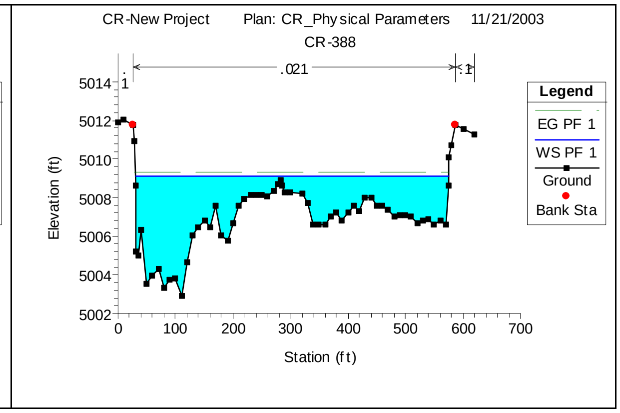
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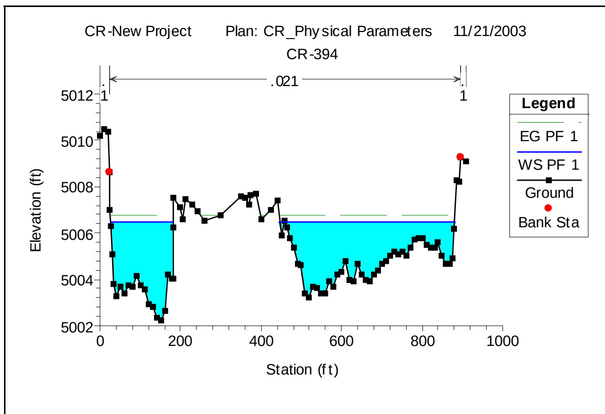
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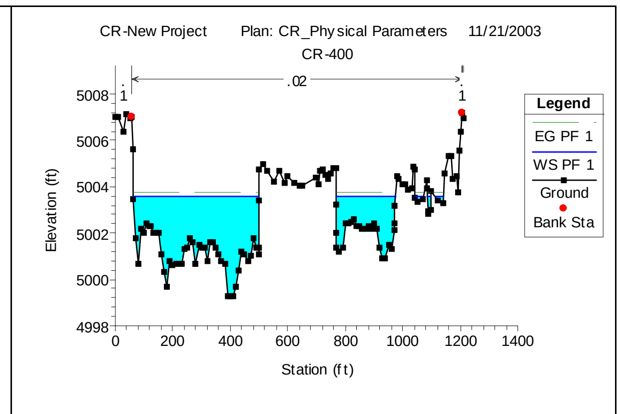
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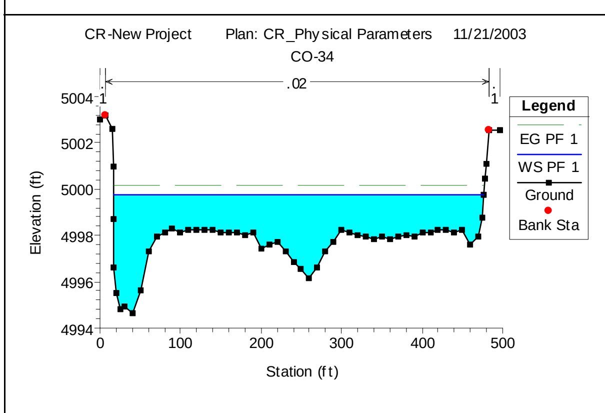
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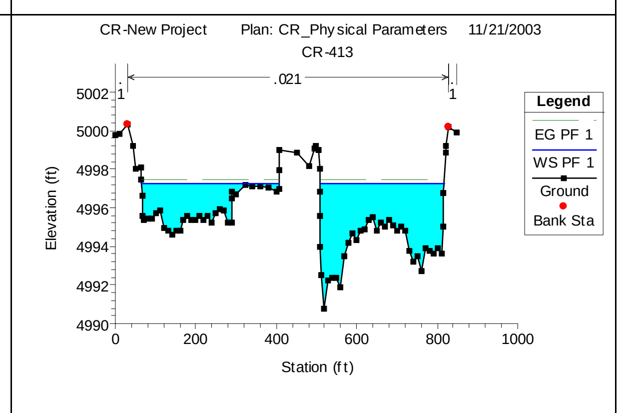
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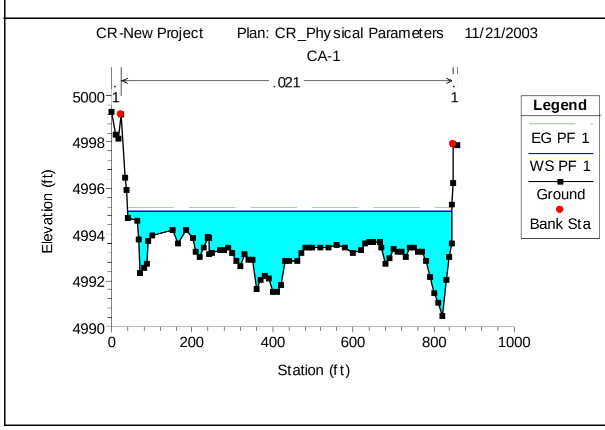
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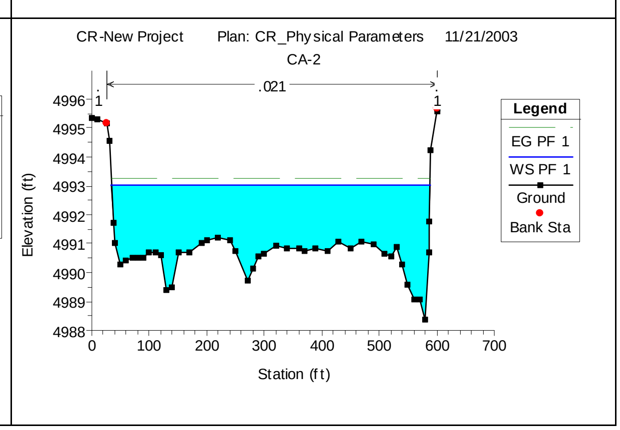
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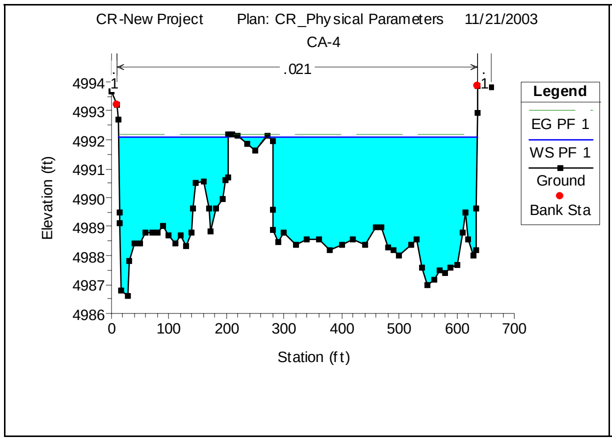
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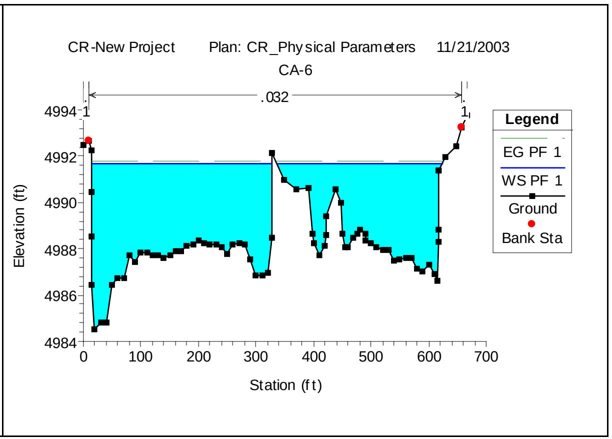
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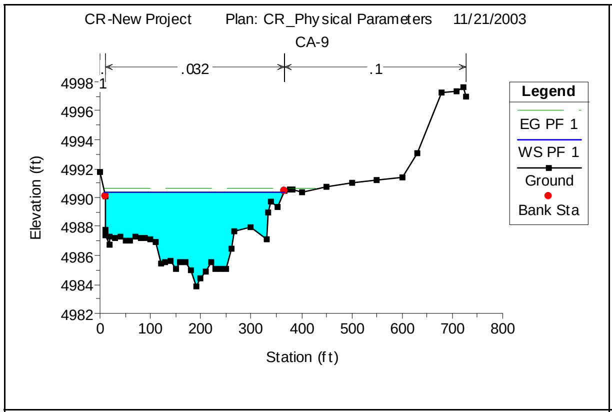
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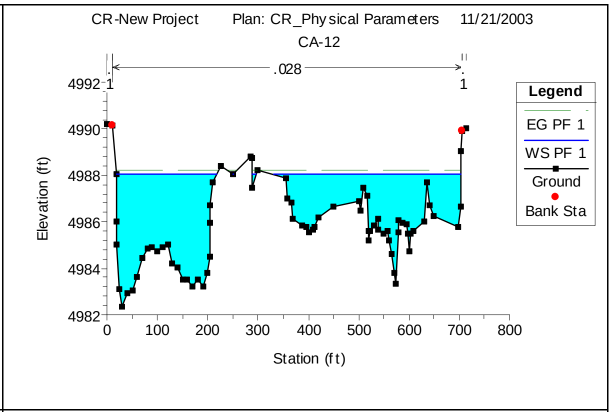
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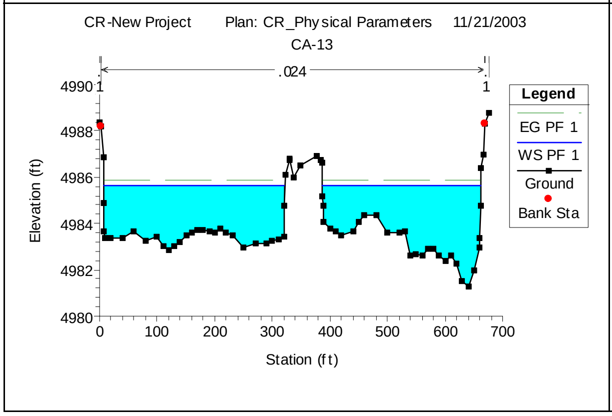
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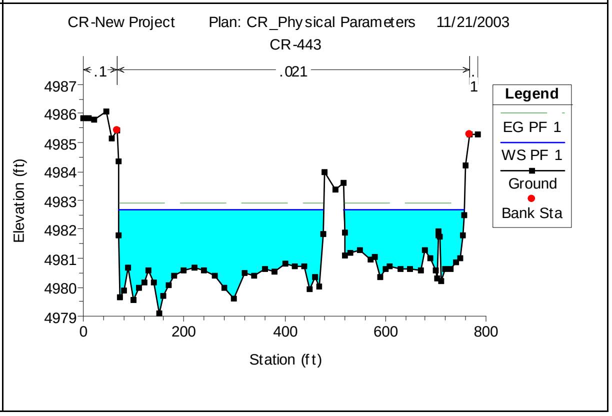
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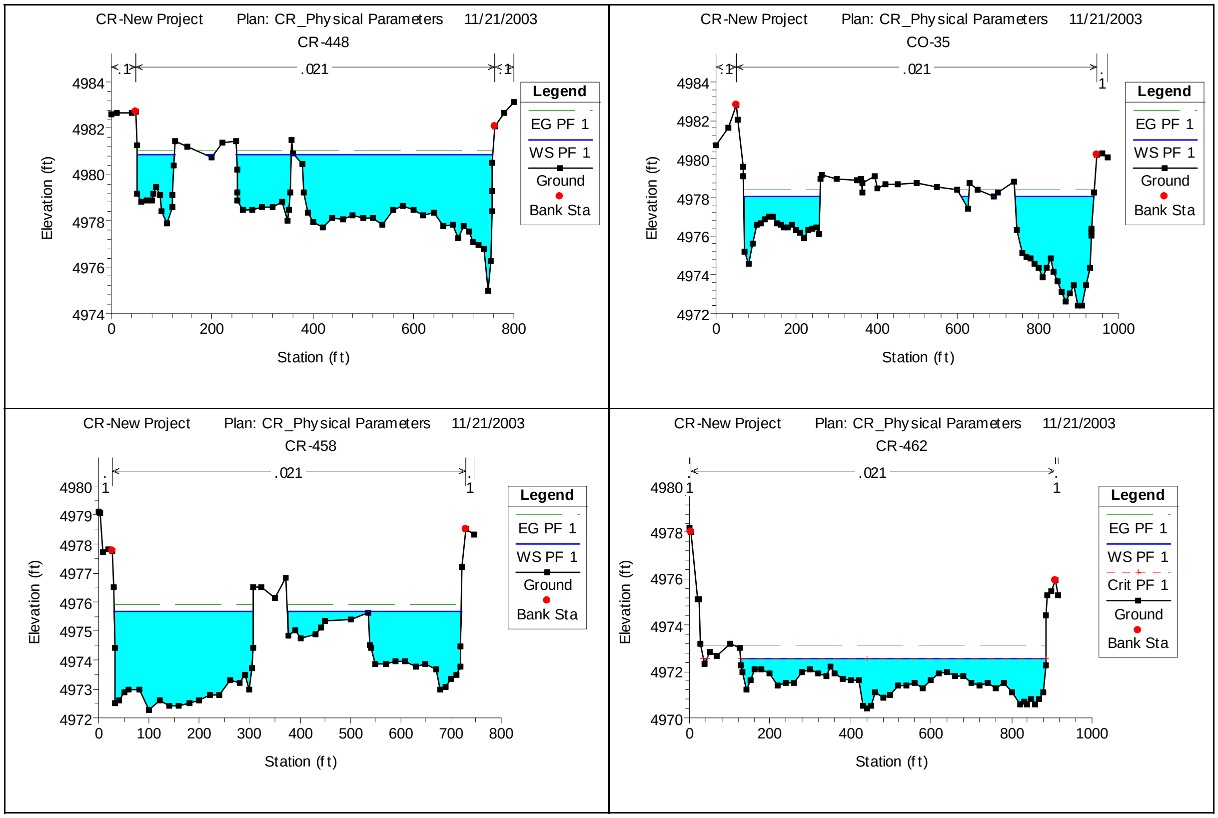
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