6 DISCUSSION

6.1 HISTORIC TREND ANALYSIS AND CURRENT CONDITIONS

Entire Bernalillo Bridge Reach

Discharge - Total annual water discharge at the Albuquerque gage increased from 1978 to 1987 by a factor of two (Figure 4-1). After 1987, the total annual water discharge declined to a value slightly higher than the total annual water discharge prior to 1978. Factors such as management of Cochiti Dam, climatic changes, irrigation and other water diversions could be responsible for these changes.

Suspended Sediment - The total annual suspended sediment discharge at the Albuquerque gage reveal a decreasing trend of suspended sediment load though time. This decreasing trend exacerbates after 1973, when Cochiti Dam started to impound water (Figure 4-2).

Bed Material – The median bed material size in the Bernalillo Bridge reach comprises fine sand in 1962, fine to medium sand in 1972, medium sand to very fine and medium gravel in 1992, and from medium sand to very coarse gravel in 2001.

The channel bed was composed of sand at all water discharges during the 1952 - 1969 period at the Bernalillo gage (Nordin and Beverage 1964, León C. 1998). Bed material surveyed during early summer in 2001, exhibit a bimodal size distribution (0.46mm < d_{50} < 18.13 mm) (Table 3-7). This conclusion is corroborated with recent field observations (Massong pers. comm. 2000). In summary, the bed material in the study reach has changed from sand to a bimodal sand and gravel bed material distribution from 1972 to 2001.

Channel Pattern – Qualitative observation of the GIS coverages of the non-vegetated active channel show that the greatest change in channel width occurred from 1918 to 1935. Channel width of the study reach has been controlled since the 1930's after the construction of the floodway during the 1930 to 1935 period (Woodson and Martin 1962). The floodway was built to contain the river in its channel and prevent avulsions from forming in the adjacent areas (Sanchez et. al 1997). According to the non-vegetated active channel widths computed from the GIS coverages, no significant change in width is observed between 1949 and 1992. Channel width decreased from 1992 to 2001 for subreaches 1 and 2, and increased for subreach 3 during this same time period.

The 1962, 1972 and 1992 aerial photos reveal a straight river with multiple channels at discharges below bankfull. Aerial photos of the river for 2001 reveal vegetated islands lateral to the low flow channel in the upper end of the study reach and several sediment bars within the low flow channel in other short reaches.

Channel Classification - Based on the results of the channel classification methods, the observed 2001 channel planform is represented best by Henderson's method, which predicts a braided channel. Other methods, such as Leopold and Wolman's and Schumm and Khan's methods, which all predicted straight channel planform at 5,000 cfs, illustrate the low sinuosity (<1.5) of the channel throughout the time period analyzed.

Vertical Movement - Analysis of the mean bed elevation indicates that the channel aggraded approximately 1.3 feet from 1962 to 1972 and degraded approximately 2.6 feet from 1972 to 1992 (Figure 3-8). The net change in channel elevation between 1962 and 1992 is approximately 1.3 feet. CO-line surveys show small degradation (about 1 foot) in the 1990's in the upper and middle part of the reach and almost constant thalweg elevation in the lower part of the reach (Figure 3-6). The apparent degradation trend observed in the upper and middle sections of the reach might be due to the fact that the bed material sediment is finer in those sections and therefore, more easily entrained by the spring runoffs. The 1972 to 1992 bed degradation trend continued until 2001, the bed degraded up to 2 feet in subreaches 1 and 2 and aggraded up to 1 foot in subreach 3 between 1992 and 2001.

Channel Geometry - General trends in channel geometry based on HEC-RAS results at 5,000 cfs from 1962 to 2001 include a decrease in width, width-depth ratio, wetted perimeter, and velocity and an increase in cross sectional area and depth. Water surface and energy slopes did not change. The changes in non-vegetated active channel width measured from the GIS coverages also show decreasing width since 1918 (Figure 3-13). Channel width remained almost constant between 1949 and 1992 and declined during the 1992-2001 period (Figure 3-13).

Overbank flow/channel capacity - Based on the results from HEC-RAS runs at 5,000 the overbank flow area is greater for the 1972 data than for 1962, 1992 and 2001. The 1972 channel had the largest cross sections in which the channel-forming discharges flowed out of the main channel into the overbank area. This illustrates the aggradational trend evident in the mean bed elevation profiles.

Subreach Trends

Channel Pattern - In general, the channel has maintained virtually the same width from 1949 to 1992. Channel width decreased from 1992 to 2001. The greatest change in width occurred between 1918 and 1935. Subreaches 1 and 2 have experienced almost the same changes in width. Subreach 3, which is the narrowest of the three subreaches, depicts the smallest change in width since 1918. The three subreaches are fairly straight and reflect a multi-channel configuration at flows below bankfull (< 5,000 cfs). Subreach 1 reflects a multi-channel configuration at high flows as well.

Vertical Movement – The three subreaches aggraded about 1.3 feet from 1962 to 1972 and degraded almost 2.5 feet from 1972 to 1992 (Figure 3-8, Table 3-5). Maximum changes in mean bed elevation occurred in subreaches 1 and 3 during 1972 and 1992 period. Minimum changes in mean bed elevation (< 2 ft) occurred in the transition from subreaches 1 to 2 and at the upper end of subreach 3 during the same time period. Subreaches 1 degraded while subreaches 2 and 3 aggraded during the 1992-2001 period (Figure 3-7).

Channel Geometry – Width, width/depth ratio, wetted perimeter, and velocity decreased while cross sectional area and flow depth increased in subreaches 1 and 2 between 1962 and 2001. Area, wetted perimeter and velocity decreased in subreach 3 while width, depth, and width-depth ratio increased. Energy and water surface slope did not change in subreach 1 and decreased in subreach 2. Energy slope decreased and water surface slope increased in subreach 3. Table 6-1 summarizes the net channel changes between 1962 and 2001 for all the subreaches and the entire reach. A plus (+) indicates an increase in the magnitude of the parameter, a minus (-) a decrease and the equal sign (=) indicates no change.

Table 6-1 Summary of channel changes between 1962 and 2001 based on reach-averaged main channel parameters from HEC-RAS modeling runs at Q = 5,000 cfs.

1962-2001 Period								
Reach	**W**	**EG-Slope**	**Velocity**	**Area**	**D**	**F =W/D**	**WP**	**WS slope**
1	-	=	-	+	+	-	-	=
2	-	-	-	+	+	-	-	-
3	+	-	-	-	+	+	-	+
Total	-	=	-	+	+	-	-	=

W = width, EG-Slope = energy grade line slope, D = depth, F = width/depth ratio, WP = wetted perimeter, WS slope = water surface slope

Table 6-2 summarizes the channel changes during 1962-1972, 1972-1992, and 1992-2001 periods. The active channel width slightly increased in all subreaches in the 1962-1972 period as a result of the aggradation of the river bed. Channel area increased and mean velocity decreased in subreaches 1 and 2. The opposite trends are observed in subreach 3. Active channel width, width/depth ratio and wetted perimeter decreased while mean velocity increased in all subreaches during the 1972-1992 time period. These changes are the result of the degradation trend after 1972. The increase in cross section area, flow depth, and wetted perimeter between 1992 and 2001 also reflect the effect of the degradation of the bed during that time period. The decrease in velocity is likely the primary result of the increase in roughness of the channel in 2001.

GIS coverage's reflect the same trends in channel width obtained from the HEC-RAS analysis. In summary, the overall reach-averaged changes are a decrease in width, width/depth ratio, wetted perimeter and flow velocity and an increase in area and depth in the 1962-2001 time period.

Table 6-2 Summary of channel changes during 1962-1972 and 1972-1992 periods based on reach-averaged main channel parameters from HEC-RAS modeling run at Q = 5,000 cfs.

1962-1972 Period								
Reach	**W**	**EG-Slope**	**Velocity**	**Area**	**D**	**F =W/D**	**WP**	**WS slope**
1	+	-	-	+	+	-	+	+
2	+	=	-	+	-	+	+	-
3	+	+	+	-	-	+	+	+
Total	+	-	-	+	+	+	+	=

1972-1992 Period								
Reach	**W**	**EG-Slope**	**Velocity**	**Area**	**D**	**F =W/D**	**WP**	**WS slope**
1	-	+	+	-	-	-	-	-
2	-	=	+	-	+	-	-	+
3	-	=	+	+	+	-	-	=
Total	-	+	+	-	-	-	-	=

1992-2001 Period								
Reach	**W**	**EG-Slope**	**Velocity**	**Area**	**D**	**F =W/D**	**WP**	**WS slope**
1	-	=	-	+	+	-	-	=
2	-	-	-	+	-	+	+	-
3	+	-	-	+	+	+	+	-
Total	+	-	-	+	+	-	+	-

W = width, EG-Slope = energy grade line slope, D = depth, F = width/depth ratio, WP = wetted perimeter, WS slope = water surface slope.

6.2 SCHUMM'S (1969) RIVER METAMORPHOSIS MODEL

Schumm's (1969) qualitative model of channel metamorphosis is based on the concept that the dimensions, shape, gradient and pattern of stable alluvial rivers are controlled by the quantity of water and sediment as well as the type of sediment moved through their channels. The application of this model is appropriate for rivers in semi-arid regions because they are usually more adjustable than rivers in humid regions due to their less cohesive and less developed bank vegetation. The following equations summarize Schumm's results. A plus exponent indicates an increase in the magnitude of a parameter and a minus indicates a decrease:

- Decrease in bed material load:

$$Q_s^{-} \sim \frac{W^{-}L^{-}S^{-}}{D^{+}P^{+}}$$

- Increase in bed material load:

$$Q_s^{+} \sim \frac{W^{+}L^{+}S^{+}}{D^{-}P^{-}}$$

- Increase in water discharge:

$$Q^{+} \sim \frac{W^{+}D^{+}L^{+}}{S^{-}}$$

- Decrease in water discharge:

$$Q^{-} \sim \frac{W^{-}D^{-}L^{-}}{S^{+}}$$

- Increase in water discharge and bed material load:

$$Q^{+}Q_t^{+} \sim \frac{W^{+}F^{+}L^{+}S^{\pm}D^{\pm}}{P^{-}}$$

- Decrease in water discharge and decrease in bed material load:

$$Q^{-}Q_t^{-} \sim \frac{W^{-}F^{-}L^{-}S^{\pm}D^{\pm}}{P^{+}}$$

Where,

Q = water discharge,

Q_s = bed material load,

Q_t = percentage of total sediment load that is bed-load or ratio of bedload (sand size or larger) to total sediment load x 100 at mean annual discharge,

W = channel width,

D = flow depth,

F = width/depth,

L = meander wavelength,

P = sinuosity, and

S = channel slope.

These equations are summarized in Table 6-3. Table 6-4 summarizes the trends in channel changes in the Bernalillo Bridge reach for the 1962 to 1972, 1972 to 1992, and 1992 to 2001 time periods in a similar manner as Table 6-3 for purposes of comparison.

Table 6-3 Summary of Schumm's (1969) channel metamorphosis model.

	W	D	S	W/D =F	P	L
Qs^-	-	+	-		+	-
Q^+	+	+	-			+
Qs^+	+	-	+		-	+
Q^-	-	-	+			-
Q^-Qs^-	-	+ -	+ -	-	+	-
Q^+Qs^+	+	+ -	+ -	+	-	+

Table 6-4 Summary of channel changes during 1962-1972, 1972-1992, and 1992-2001 periods.

1962-1972 Period					
Reach	W	D	F =W/D	EG-Slope	P
1	+	+	-	-	-
2	+	-	+	=	-
3	+	-	+	+	+
Total	+	+	+	-	-

1972-1992 Period					
Reach	W	D	F =W/D	EG-Slope	P
1	-	-	-	+	+
2	-	+	-	=	+
3	-	+	-	=	=
Total	-	-	-	+	+

1992-2001 Period					
Reach	W	D	F =W/D	EG-Slope	P
1	-	+	-	=	+
2	-	-	+	-	-
3	+	+	+	-	+
Total	+	+	-	-	=

According to Schumm's (1969) metamorphosis model, changes in channel geometry, slope and planform in the Bernalillo Bridge Reach from 1962 to 1972 were the response to increasing mean annual flood (Q^+) and increasing bed-material load (Q_s^+). The large suspended sediment concentration (Figures 4-2 and 4-3) observed at the Bernalillo and Albuquerque gages are in agreement with the modeled results, assuming that the bed-material load was also large during the 1962-1972 period. Conversely, annual peak flows appear to be lower between 1962 and 1972 than during previous years (Figure 2-8, Appendix C).

The 1972-1992 changes in channel geometry, slope and planform in the study reach are best explained by decrease in discharge (Q^-) and bed-material load (Q_s^-). The model results are supported by the decrease in suspended sediment concentration since 1973 (Figure 4-2 and 4-3). However, the decrease in annual peak flows at San Felipe and Albuquerque are not in agreement with the model prediction (Figure 2-8, Appendix C).

The channel width changed only from 501 ft to 504 ft from 1992 to 2001, which is not a

significant change. The channel depth increased during the same time period. Therefore, the width-depth ratio decreased. The changes in channel geometry between 1992 and 2001 are also best explained by the decrease in discharge (Q^-) and bed-material load (Q_s^-).

Schumm's (1969) model uses mean-annual flows instead of annual peak flows. The annual peak flows are more uniformly distributed after 1963 (Figure 2-8). There are fewer low and high flows and therefore, more frequent flows between 3,000 cfs and 7,000 cfs. It is possible that peak discharges are not indicative of the channel forming discharge regime. Additionally, changes in water regime could have been less significant than changes in sediment load and therefore, the channel could have been responding primarily to the changes in the sediment regime.

6.3 POTENTIAL FUTURE EQUILIBRIUM CONDITIONS

Sediment Transport Analysis

Sediment transport equations predict bed-material loads lower than the incoming sand-load (0.0625 mm to 2 mm) to the reach (21,672 tons/day) for 1992 and 2001. The incoming bed-material load (0.36 mm < d_s < 2 mm) to the reach (10,836 tons/day) is comparable to the sediment transport capacities estimated by most sediment transport equations for 1992 (Tables 5-7 and 5-9). The equation that yields closer results to the incoming bed-material load is Yang sand (d_{50} and size fraction) for all subreaches. The channel slope in 1992 seems appropriate to transport the incoming bed-material load of 10,836 tons/day. However, the degradation of the river bed between 1992 and 2001 indicates that the transport capacity of the stream is larger than the sediment supply and therefore, is not in agreement with the results of the sediment transport analysis for 1992.

The transport capacities computed for subreaches 1 and 2, based on the 2001 bed material gradation analyses, are much lower than the estimated bed-material load. It is likely that a layer of sand coming from tributaries and mined from the bed and banks of the channel upstream from the study reach overlay and move above a layer of coarser material (armor layer) that the river cannot transport. The averaged transport capacity of subreach 3 for 2001 is less than 50 % of the bed-material load (10,836 tons/day) and is about half of the capacity of that subreach in 1992, likely due to the reduction of flow velocity and friction slope from 1992 to 2001. In summary, the transport capacity of this reach has decreased from 1992 to 2001.

Equilibrium Channel Width Analysis

- Williams and Wolman (1984) Hyperbolic Model

Hyperbolic equations fit the historical data very well and therefore could be used to describe the past trends in channel width. Table 6-5 contains the 1991-1992 rate of decrease in channel width in feet per year, the 2001 active channel widths in feet from GIS and the 2001 channel widths in feet predicted with the hyperbolic functions. 1991-1992 rates of decrease in channel width were computed as the slope of the hyperbolic function between 1991 and 1992. These rates are very low and suggest that the channel widths are still decreasing at a slow rate. The active channel widths for 2001 from the digitized aerial photos are less than the 2001 widths calculated from the regression equations. The coarsening of the bed material between 1992 and 2001 might have caused the reduction of width during that period. This model indicates that the channel width did not change significantly between 1962 and 1992.

Table 6-5 1991-1992 rate of decrease in channel width according to the hyperbolic model and 2001 predicted and measured widths

Reach	1991-1992 rate of decrease in channel width (ft/yr)	Predicted 2001 width from hyperbolic equations (ft)	2001 non-vegetated width from GIS in ft
1	-0.6	536	418
2	-0.9	491	347
3	-0.3	401	371
Total	-0.6	485	378

- Richard (2001) Exponential Model

Exponential equations fit the historical data very well and therefore could be used to describe the past trends in channel width. Table 6-6 summarizes the 1985-1992 rate of change of width in feet per year, the predicted 2001 widths in feet from the exponential equations and the 2001 non-vegetated channel widths in feet from the digitized aerial photos. The exponential model produces lower rates of decreasing channel width with time than the hyperbolic model. The predicted 2001 widths are greater than the measurements. This model indicates that the channel width did not change significantly between 1962 and 1992.

Table 6-6 1985-1992 rate of decrease in channel width according to the exponential model and 2001 predicted and measured widths

Reach	1985-1992 rate of decrease in channel width (ft/yr)		Predicted 2001 width from hyperbolic equations (ft)		2001 non-vegetated width from GIS in ft
	Method 1	Method 2	Method 1	Method 2	
1	-0.011	-0.010	519	560	418
2	-0.008	-0.007	502	536	347
3	-0.002	-0.002	404	414	371
Total	-0.002	-0.002	490	518	378

Hydraulic Geometry

The hydraulic geometry equations do not predict the historical width values well. However, the predicted widths illustrate the nearly constant width of the channel between 1962 and 1992. The conditions of the Bernalillo Bridge reach are out of the range of applicability of Nouh's and Blench's equations. Lacey's, Simons and Albertson's, Julien-Wargadalam's and Klassen and Vermeer's equations under estimate the channel width for all the reaches and years.