THE HISTORICAL ALAMOSA ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

The SLV is the largest of a series of high-altitude, inter-montane basins located in the Southern Rocky Mountains (Jodry and Stanford 1996) and is part of the much larger Rio Grande Rift Zone that extends from southern New Mexico north through the SLV to its northern terminus near Leadville, Colorado (Chapin 1971, Bachman and Mehnart 1978). The SLV is a compound graben depression that was down-faulted along the base of the Sangre de Cristo Mountains, which bounds the valley to the east, from extensive block faulting during the Laramide Orogeny. The San Juan Mountains, that bound the valley to the west, were created by extensive Tertiary volcanism about 22 to 28 million years before the present (BP) (McCalpin 1996). The Oligocene volcanic rocks of the San Juan Mountains slope gradually down to the SLV floor where they are interbedded with alluvial-fill deposits (BLM 1991). This volcanic rock layer extends over the Alamosa Horst, a buried ridge of a normal fault, which separates the SLV into the Monte Vista Graben to the west and the Baca Graben to the east (Bachman and Mehnart 1978). The normal fault line trends north from the San Luis Hills to the Sangre de Cristo Mountains near Medano pass. The Baca Graben contains almost twice as much alluvium (about 19,000 feet thick) as the Monte Vista Graben because of its juxtaposition to the Sangre de Cristo fault zone (Zeisloft and Sibbet 1985, Burroughs 1981, Brister and Gries 1994). Alamosa NWR lies at the boundary between the Baca Graben and the Alamosa Horst (Mackelprang 1983).

From the Pliocene to middle Pleistocene time, a large, high altitude lake, Lake Alamosa, occupied most of the SLV (Fig. 3, Machette et al. 2007). Lake Alamosa existed for about three million years when it overtopped a low wall of Oligocene volcanic rocks of the San Luis Hills and carved a deep gorge that flowed south into the Rio Grande, entering at what is now the mouth of the Red River. This ancient lake went through several cycles of drying and flooding which eroded and deposited sediments within the historic lakebed. These sediments have been designated as the Alamosa Formation (Siebenthal 1910. Pliocene and Miocene formations underlie the Alamosa Formation, which is in turn underlain by Echo Park alluvium and then Precambrian rocks.

The surficial geomorphology of Alamosa NWR is dominated by Quaternary alluvial deposits of the Rio Grande floodplain and Hansen's Bluff, which is an outcrop of the Alamosa Formation characterized by younger Quaternary age alluvium and surficial deposits overlaying the formation (Rogers et al 1992; Fig. 4). The Rio Grande enters the SLV near Del Norte, Colorado and flows to the south and east along the southern boundary of the Rio Grande alluvial fan. The entry of the Rio Grande into the SLV is bounded by a low elevation terrace on the south and west, which caused the channel to active migrate, or "avulse" to the northeast of the town of Monte Vista, Colorado, and created a river floodplain 200 to 300 times the width of the current average river channel (Jones and Harper 1998). The Rio Grande turns south near Alamosa, Colorado where a low topographical, and historically a hydrological, divide separates the Rio Grande floodplain from the SLV "Closed Basin" to the north. After turning south the Rio Grande floodplain is confined to the east by Hansen's Bluff, which is also the eastern boundary of Alamosa NWR (Jones and Harper 1998). The common lateral migration of the Rio Grande in the SLV created many geomorphic surfaces at Alamosa NWR including active, sometimes "split" or "braided" channels; abandoned channel "sloughs" and "oxbows";

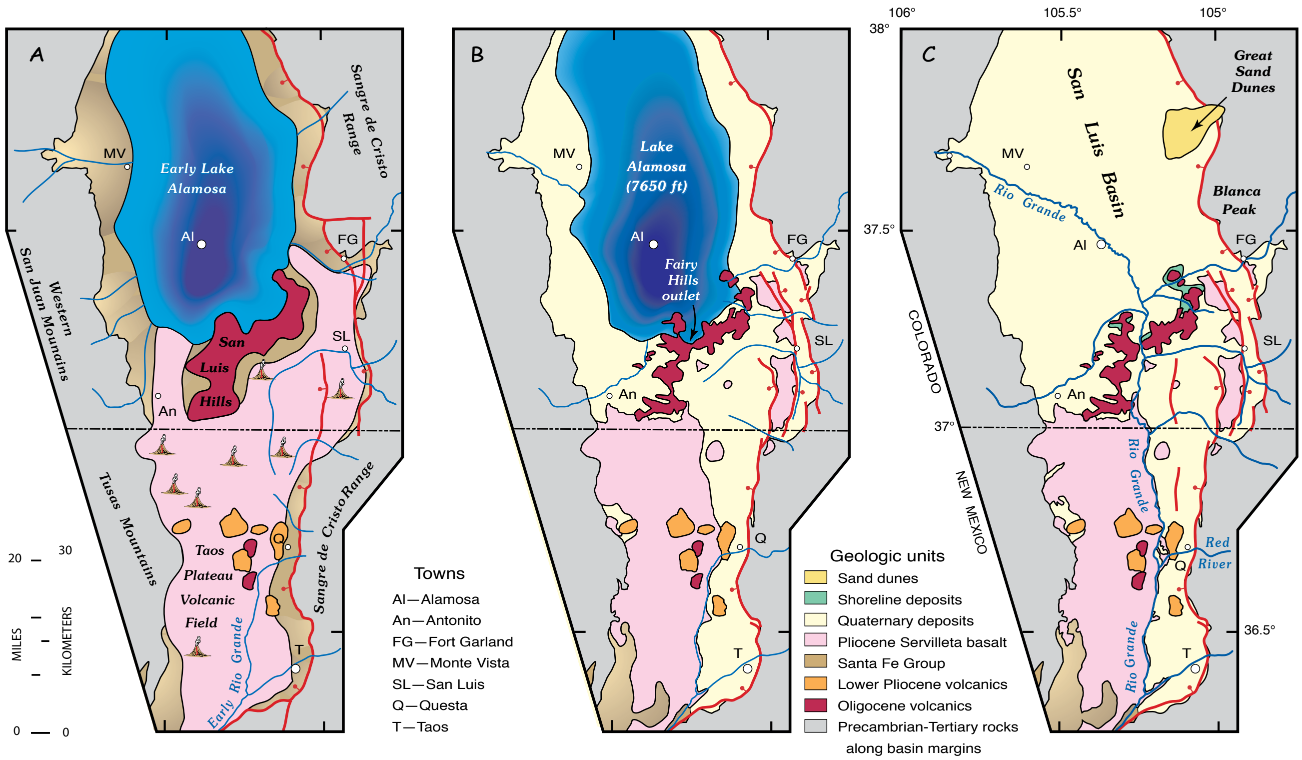

Figure 3. Simplified geological map of the San Luis Basin showing generalized geology and drainage patterns for the time intervals: A) 3.5-5 million years before the present (BP), B) 440,000 years BP, and C) current (from Machette et al. 2007).

natural levees, scroll bars, and terraces (see definitions in Lettis and Associates 2003). Most of the channel movement on the northern part of Alamosa NWR was west of its current channel position, while movements in the south part of the refuge occurred on both sides of the current channel (Jones and Harper 1998). Channels of the Alamosa River and La Jara Creek, which join the Rio Grande along the western boundary of the Alamosa NWR, also have shifted frequently over time and created diverse geomorphology in these confluence areas (MWH 2005).

SOILS

About 29 distinct soil types (Fig. 5), categorized in three major soil-landform associations (Fig. 6), are present on Alamosa NWR. Soil distribution across the refuge generally reflects historical deposition and movement of sediments caused by dynamics of the Rio Grande and its tributaries (Soil Conservation Service (SCS) 1973). The soil-land associations include the Alamosa-Vastine-Alluvial Association (AVA) on floodplains, Hapney-Hooper-Corlett Association (HHC) on hilly or dune areas, and the Costilla-Space City Association (CSC) on Hansen's Bluff (Soil Conservation Service (SCS) 1973). The majority of Alamosa NWR contains the AVA association, which is characterized by deep, dark textured soils that are commonly flooded in the spring or that have a high water table that creates somewhat saline conditions. The primary soil texture in the AVA association is loam, with minor components of sand and clay. The "Loamy Alluvial Land" soil series of the AVA association covers a majority of the central and southern portion of the refuge and covers 16.5% of the total refuge area. This soil series contains a wide range of structures and textures with variable stratification underlain by sand. The AVA Association also includes Vastine and Alamosa soil series, which comprise about 12.1% and 9.8% of the refuge, respectively. Loamy Alluvial Land, Vastine, and Alamosa soils typically are associated with seasonal wet meadows in floodplain margins (SCS 1973). Another AVA soil series is the Sandy Alluvial type that occurs on natural levees along the active channel of the Rio Grande and covers about 2.2% of the refuge area. "Marsh soils" also are within the AVA Association and occupy a small area along the toe of Hansen's Bluff and in a few areas throughout the floodplain.

The northeast section of Alamosa NWR contains part of the HHC association, which is characterized by moderately fine to coarse textured alkali soils on nearly level to hilly sites that are moderately well to somewhat excessively drained (SCS 1973). Dominant soil series in this association are calcareous and strongly alkaline. Sandy dunes also are present in scattered locations throughout this association. The eastern boundary of Alamosa NWR along Hansen's Bluff contains the CSC association, which has gently sloping topography comprised of coarse-textured soils that are well drained.

Figure 4. Geology of Alamosa NWR and surrounding area (http://datagateway.nrcs.usda.gov/).

TOPOGRAPHY

The SLV is a large high elevation mountain valley > 7,500 feet above mean sea level (amsl). Light Detection and Ranging (LiDAR) elevation surveys for the SLV region were flown in fall 2011 and data recently have been processed to produce 1m digital elevation model (DEM) maps for the refuge area. Elevations on Alamosa NWR range from 7,498 to 7,580 feet amsl and elevations decrease from the west and east toward the floodplain of the Rio Grande and generally decrease from north to south (Fig. 7). The LiDAR-DEM maps clearly identify Hansen's Bluff on the east side of the refuge (shown in gray to red shading) and many former channels of the Rio Grande and its tributaries. More subtle topographic features throughout the Rio Grande floodplain include many floodplain depressions created by sediment scouring and deposition related to historic fluvial dynamics of the rivers and creeks (Jones and Humphrey 1997, Jones and Harper 1998, Figs. 7, 8). Other topographic features include natural levees, abandoned channels, and oxbow lakes (as seen on 1941, 1953, and 1988 aerial photos in Fig. 9). The General Land Office (GLO) maps prepared from 1875 to 1880 also identify extensive wetland areas that historically occurred just west of the Alamosa NWR between the Alamosa River and La Jara Creek (Fig. 2).

CLIMATE AND HYDROLOGY

The climate of the SLV is semi-arid, with cold winters and moderate summers (Table 1). The Alamosa NWR region is in the rain shadow of the San Juan Mountains and receives about seven inches of precipitation per year (Table 2). About 60% of this precipitation occurs as rain in July and August. The source of this summer moisture is the Gulf of Mexico and Gulf of California derived from monsoonal flow from the desert southwest. This monsoonal air moves north through Arizona and New Mexico into the SLV where no mountains obstruct the flow. Wide seasonal and annual variation in precipitation can occur in the SLV. Long-term precipitation data from the region

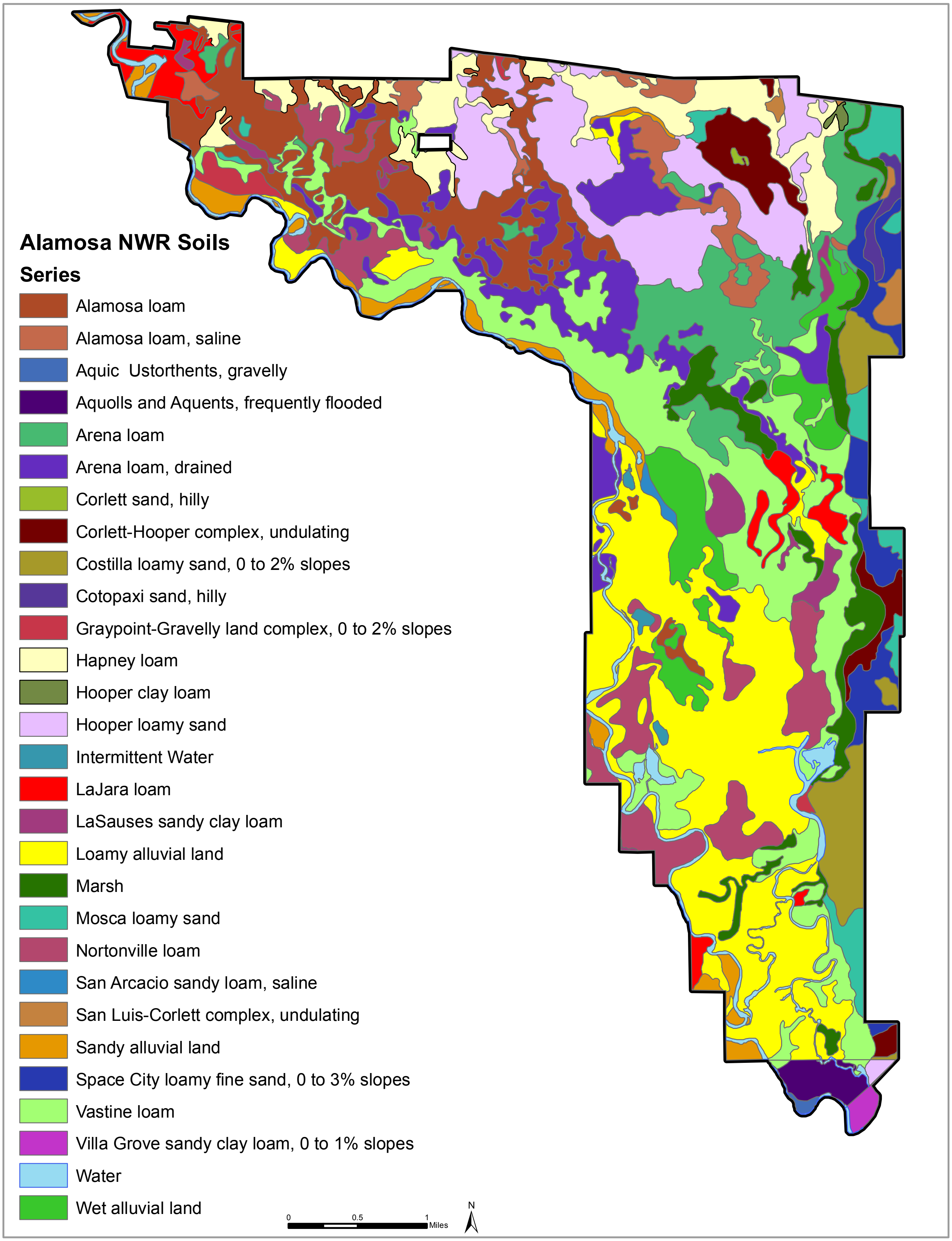

Figure 5. Soil series and location on Alamosa National Wildlife Refuge (USDA SSURGO data, http://websoilsurvey.nrcs.usda.gov).

suggest that alternating low and high yearly precipitation patterns recur (Fig. 10). Dry periods in the long-term precipitation pattern occurred in the 1930s, 1950s, mid-1970s, late-1980s, early-1900s, and early-2000s. Generally, the long-term trend for total water year precipitation is increasing over time (Striffler 2013). Long-term tree-ring data have been used to reconstruct streamflow throughout the Rio Grande Basin and suggest that the periodicity and duration of individual droughts has increased over the last 730 years (Correa 2007). Snow cover usually is sparse in the SLV and sometimes is completely lacking during much of the winter (BLM 1991).

Mean annual temperature is 42^o Fahrenheit (F) at Del Norte, Colorado. Temperatures of -20 to -30^o F can be expected each year. The annual frost-free growing season averages about 90-100 days ranging from late May through early September (Emery 1996), however wide annual variation occurs with July and August typically the only consistent completely frost-free months. Evapotranspiration (ET) rates in the refuge region typically are 45-50 inches per year (Leonard and Watts 1989, Ellis et al. 1993). A precipitation deficit (potential ET minus precipitation) occurs every month of the year; deficits are largest in June (Leonard and Watts 1989). Prevailing winds usually are from the south-southwest with wind speeds of 40 miles per hour common in spring and early summer.

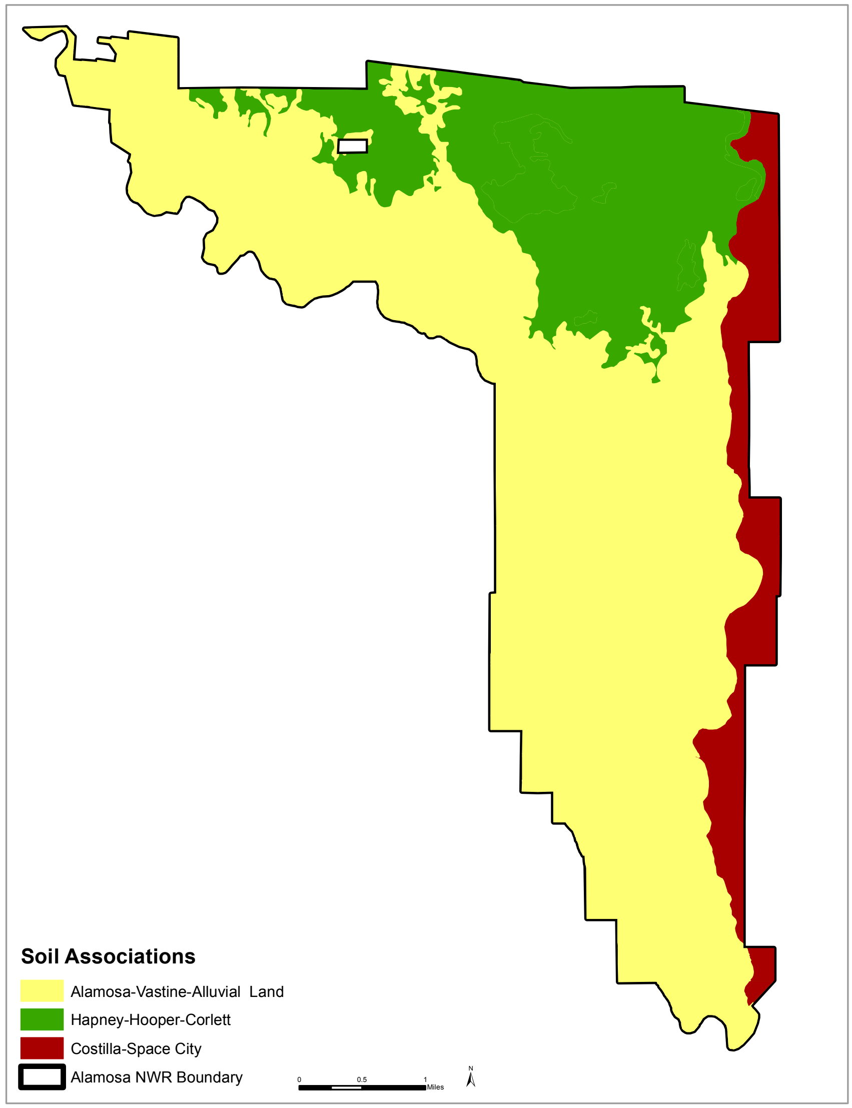

Figure 6. Soil associations on Alamosa National Wildlife Refuge (from SCS 1973).

Historically, Alamosa NWR received surface water inputs from the Rio Grande and its tributaries and the relatively limited onsite precipitation. Tributaries of the Rio Grande including the Alamosa River and La Jara Creek (Fig. 2) originate in the San Juan Mountains and are fed by snowmelt during the spring. These drainages historically also were supplied by some groundwater discharges associated with springs. The Alamosa River receives water from Spring and Rock creeks, while La Jara Creek received some discharge from Diamond Springs and the Alamosa River. Some surface water in La Jara Creek and the Alamosa River infiltrates to the underlying unconfined aquifer; historically their flows were discontinuous or dissipated in some years above their junction with the Rio Grande (Anderholm 1996, MWH 2005). The Alamosa River and La Jara and Rock Creeks now have been diverted so that currently they do not flow to the Rio Grande (Fig. 11).

Annual variation in mountain snowpack influences Rio Grande and tributary discharge, sediment transfer and deposition, and duration of flood events. Prior to the 1940s, Rio Grande flows had a strong seasonal peak that typically occurred during June (average flow of about 1,100 cfs, from USGS mean monthly streamflow from the Alamosa gage) followed by declines through winter, which

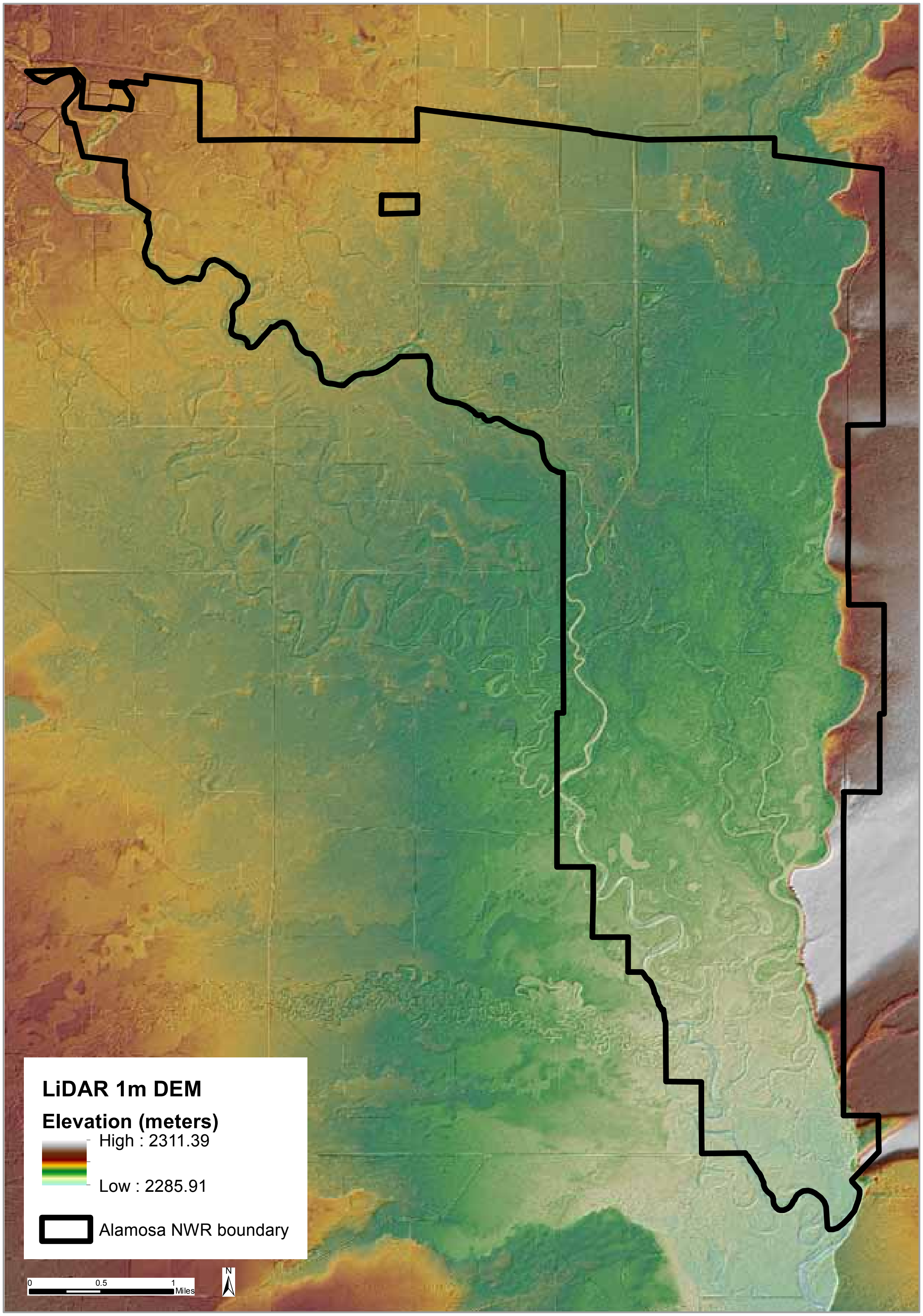

Figure 7. Elevations calculated from LiDAR 1 m DEM of Alamosa National Wildlife Refuge.

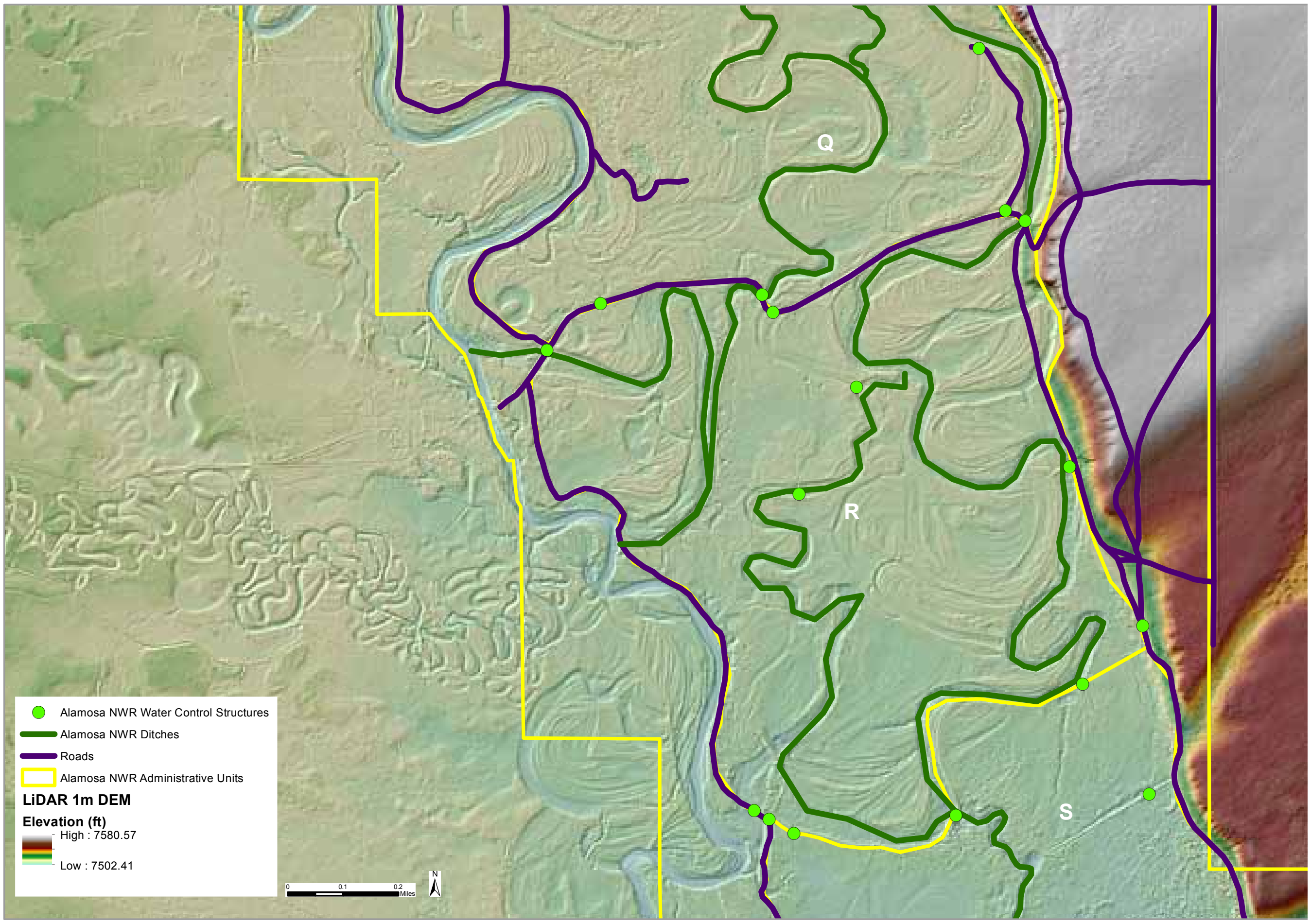

Figure 8. Natural floodplain features shown by LiDAR elevation contours on Alamosa National Wildlife Refuge in relationship to existing roads and ditches in Units Q, R, and S.

averaged between 200 and 300 cfs. Flows were slightly higher in Alamosa than Del Norte on average in December, February, and March (Table 3) prior to channelization of the river between 1925 and 1941 (Jones and Harper 1998). Long-term gauge data for Rock and La Jara Creeks indicate that peak flows occurred in May, which contributes to the peak in Rio Grande flows in June. Over the 20 year period from 1935 to 1955 when records are most continuous, an alternating wet-dry regional precipitation and river flow pattern occurred in Rock Creek about every two to three years (Fig. 12a). La Jara Creek follows a similar pattern based on USGS streamflow data from 1950 through 1980 although monthly and annual discharge rates are slightly higher for this creek (Fig. 12b).

Historically, the high Rio Grande discharges in spring caused at least some overbank and/or backwater flooding into and through its floodplain at Alamosa NWR in most years (Jones and Harper 1998). The Rio Grande split into two active channels near the west central portion of the refuge, converging into one main channel near the south end of the refuge. Alamosa NWR contains an area once owned by Governor Adams called the "Island Ranch", so named because of its position between two active branches of the Rio Grande that isolated lands between them, especially during wet periods (Fig. 4, refuge annual narratives). By the time the refuge was acquired, the main split secondary channel was no longer active. The general direction of high water "flood" flows was from north to south on Alamosa NWR, but more extensive floods occasionally inundated most, if not all, of the floodplain and water likely moved in different directions through natural abandoned channel and slough corridors. These seasonal flood events were the source of annual flooding for most wetlands on and around Alamosa NWR. For example, the area just west of Alamosa NWR, previously known as the "Alamosa Marshes", was created by annual water inputs from overbank and backwater flooding of the

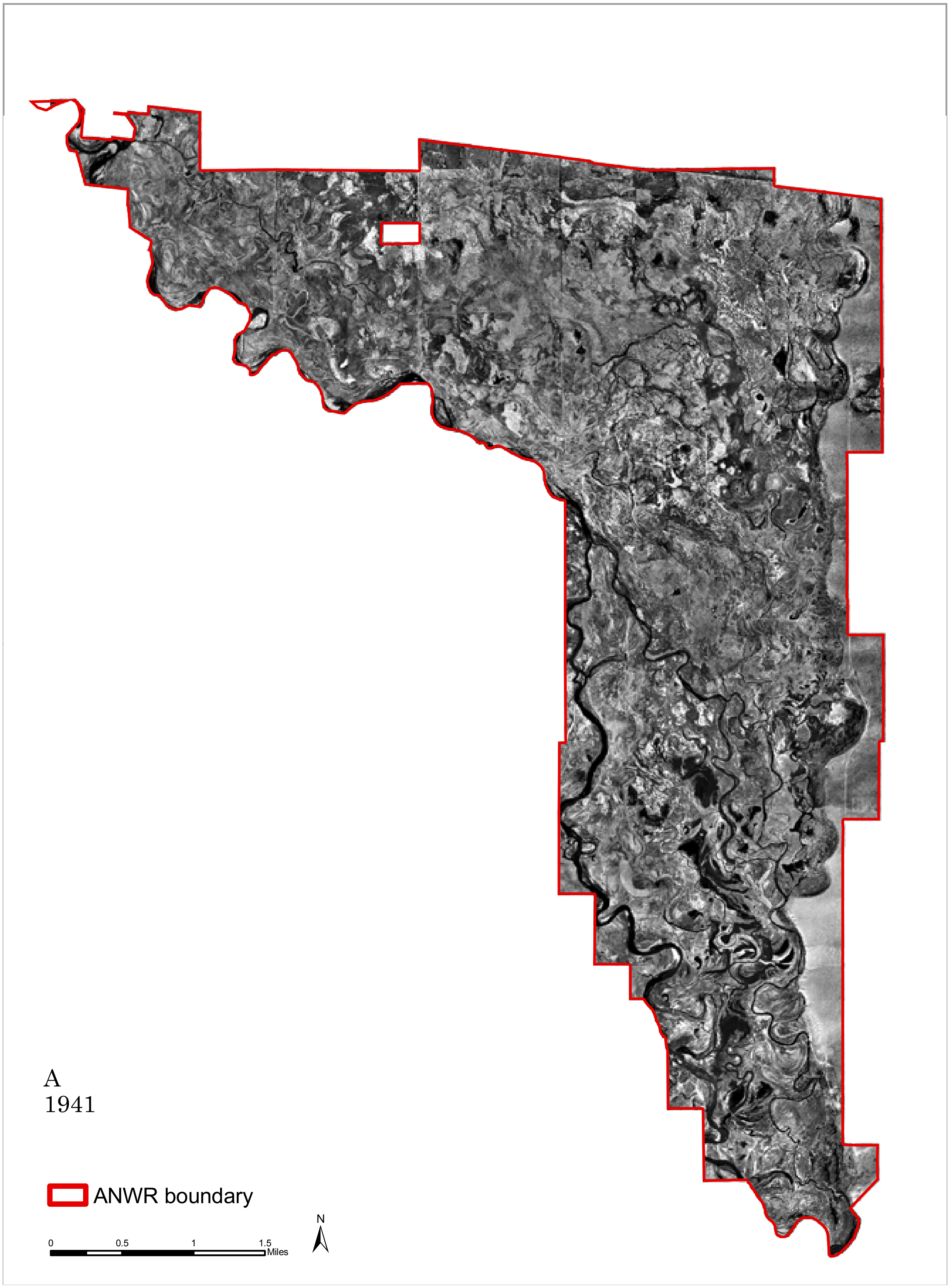

Figure 9. Aerial photographs of the Alamosa National Wildlife Refuge for: A) 1941, B) 1953, and C) 1988.

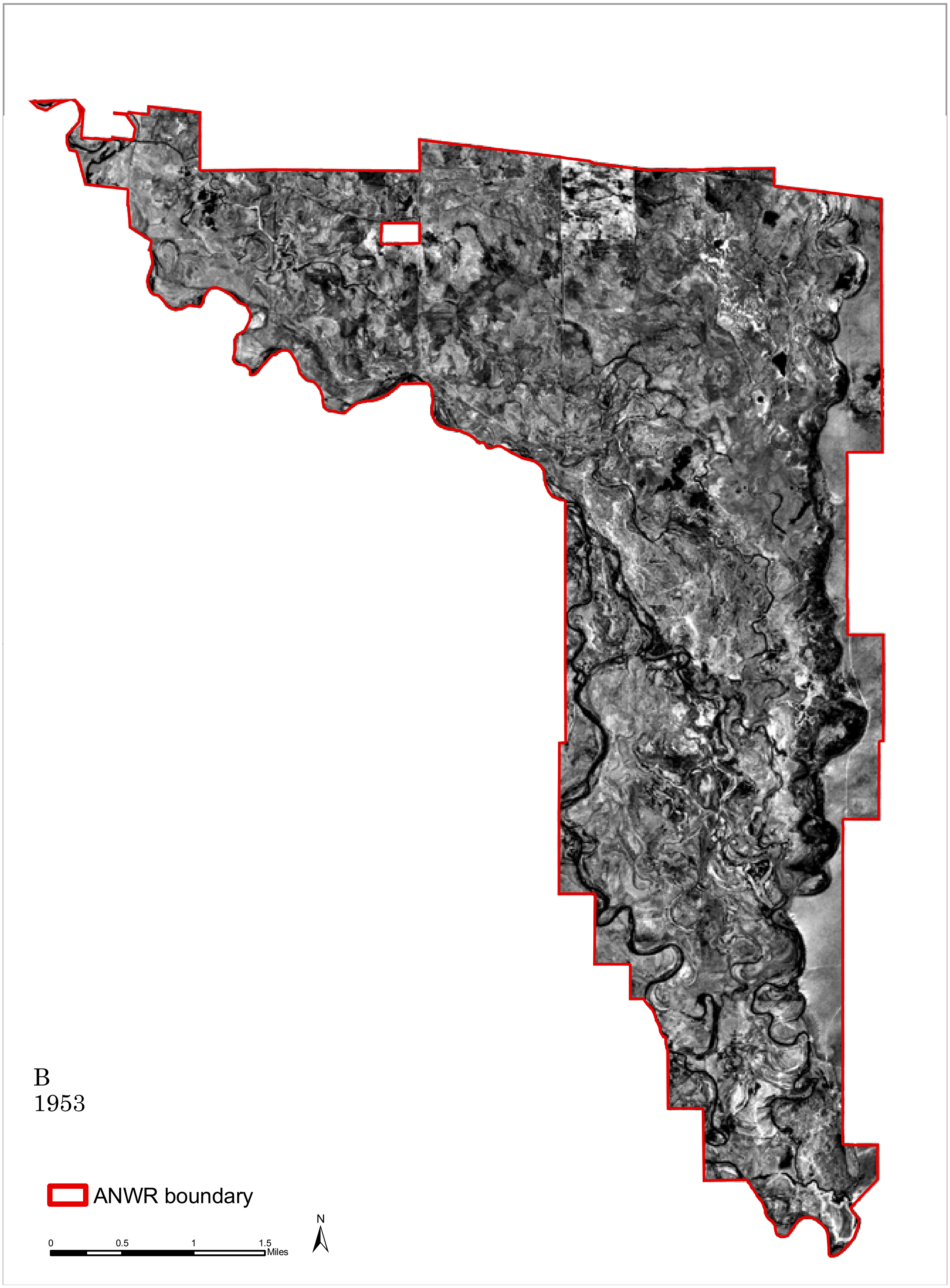

Figure 9, continued. Aerial photographs of the Alamosa National Wildlife Refuge for: A) 1941, B) 1953, and C) 1988.

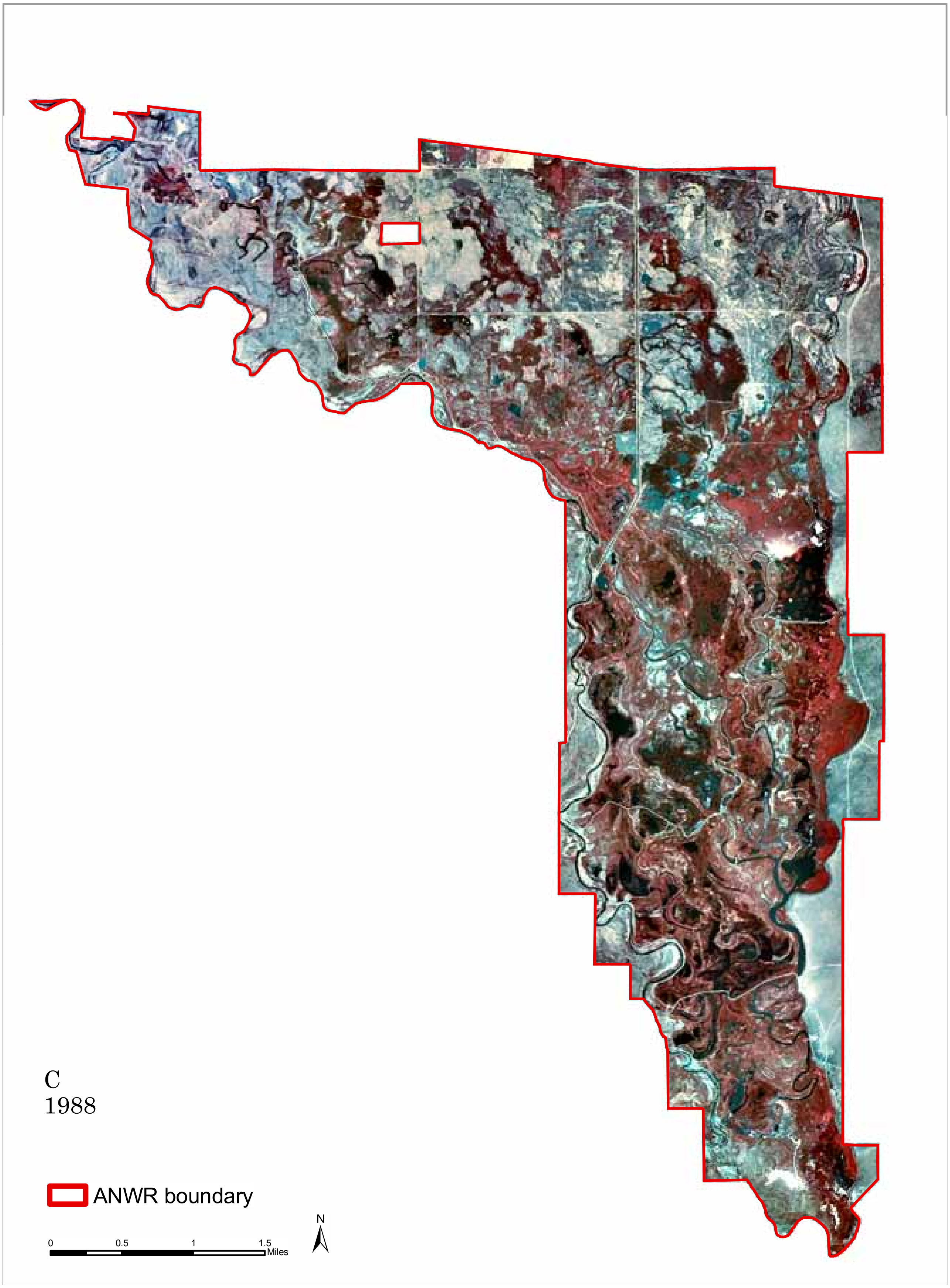

Figure 9, continued. Aerial photographs of the Alamosa National Wildlife Refuge for: A) 1941, B) 1953, and C) 1988.

Table 1. Mean monthly and annual temperature data from 1971-2000 at Alamosa Bergman Field, CO (from National Climatic Data Center, www.ncdc.noaa.gov).

Temperature (˚F)																					
Mean (1)				Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	33.1	-3.7	14.7	62	1971	20	25.6	1999	-41	1963	13	.6	1984	1551	0	.0	.0	2.0	13.7	31.0	18.5
Feb	40.2	4.7	22.5	66	1986	25	33.3	1995	-30+	1989	7	9.4	1979	1189	0	.0	.0	6.2	5.9	28.2	9.1
Mar	49.6	15.8	32.7	73+	1989	10	37.3	1999	-20	1964	4	26.1	1984	985	0	.0	.0	16.4	.8	30.6	1.0
Apr	58.7	22.8	40.8	80	1989	20	47.0	1992	-6	1973	8	35.5	1983	719	0	.0	.0	24.7	.1	27.0	.1
May	68.3	32.4	50.4	89	2000	29	55.2	1996	11	1967	1	46.2	1983	451	0	.0	.0	30.2	.0	13.7	.0
Jun	78.4	40.4	59.4	95	1994	26	62.4	1981	24	1990	2	56.0	1983	169	7	.0	.5	30.0	.0	1.8	.0
Jul	81.7	46.4	64.1	96	1989	5	66.7	1980	30	1997	2	62.1	1995	47	27	.0	.8	31.0	.0	@	.0
Aug	78.9	45.2	62.1	90	1977	7	64.7	1995	29	1964	21	58.3	1974	91	10	.0	@	31.0	.0	.1	.0
Sep	72.5	36.5	54.5	87+	1990	13	57.9+	1998	15+	1999	29	51.5	1985	302	0	.0	.0	29.9	.0	7.2	.0
Oct	61.7	23.9	42.8	81	1979	7	45.9	1992	-9	1991	31	39.1	1976	675	0	.0	.0	27.5	.3	27.0	.1
Nov	45.7	11.1	28.4	71+	1980	10	34.1	1998	-30	1952	27	17.8	1972	1082	0	.0	.0	12.2	3.9	29.5	4.3
Dec	34.8	-.7	17.1	61	1958	8	27.4	1980	-42+	1978	8	4.9	1991	1475	0	.0	.0	2.2	11.5	31.0	15.6
Ann	58.6	22.9	40.8	96	Jul 1989	5	66.7	Jul 1980	-42+	Dec 1978	8	.6	Jan 1984	8736	44	.0	1.3	243.3	36.2	227.1	48.7

Alamosa River and La Jara Creek as they approached the Rio Grande. Rio Grande and tributary creek and river flows have declined over time because of increased use and diversion of river/creek water and depletion of groundwater throughout the SLV (McGowan and Plazak 1996; 2004 CW 24; USFWS 2003). These factors, along with recent drought conditions, have effectively prevented flooding by the Rio Grande onto its floodplain at Alamosa NWR over the past 20 years.

Historically, water sources in addition to Rio Grande and tributary flows also directly or indirectly provided some water to the Alamosa NWR area. Groundwater seeps located along and near the toe of Hansen's Bluff formerly were common (e.g., Siebenthal 1910). For example, Washington Springs, located just north of the current refuge boundary (Fig. 2), provided some surface water and potentially subsurface irrigation to the shrub community located in that area. GLO survey maps and notes and geohydrology maps prepared by Siebenthal (1910) indicate that local springs were flowing in the late-1800s and early-1900s, but they apparently had stopped flowing by 1936 (Natural Resource Committee 1938).

The thick basin-fill deposits of interbedded clay, silt, gravel, and volcanic rock form groundwater aquifers under the SLV (Burroughs 1981, Wilkins 1998, Hanna and Harmon 1989). The two main aquifers, the confined and unconfined aquifers, are separated by a confining layer of discontinuous clay beds and volcanic rocks (Fig. 13, Emery et al. 1973). The unconfined alluvial aquifer underlies Alamosa NWR to a depth of about 40+ feet. This aquifer consists of sands and gravels of the Upper Alamosa Formation. Hydraulic conductivity of this unconfined aquifer can range from 35 to 235 feet/day, with the highest values near the western edge of the SLV (Hanna and Harmon 1989). Natural recharge to the unconfined aquifer occurs throughout the SLV from infiltration of precipitation, infiltration of surface water from natural stream channels (i.e., Rio Grande), inflow of groundwater from the San Juan Mountains and Sangre de Cristo Mountains, and upward leakage of groundwater through the confining bed (Mutz 1958, Powell 1958, McGowan and Plazak 1996, Stanzione 1996). Recharge of the unconfined aquifer is strongly affected by annual changes in runoff from the surrounding mountains, which is a function of annual snowpack and melting dynamics. Discharge from the unconfined aquifer includes ET, groundwater discharge to streams and creeks, and some groundwater flow to the south.

Deeper active and passive zone confined aquifers are present below the unconfined alluvial aquifer in the SLV (Fig. 13). Along the periphery of the SLV, the unconfined and active confined aquifers are directly connected hydraulically.

Table 2. Mean monthly and annual precipitation data from 1971-2000 at Alamosa Bergman Field, CO (from National Climatic Data Center, www.ncdc.noaa.gov).

Precipitation (inches)

	Precipitation Totals									Mean Number of Days (3)				Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Means/ Medians(1)		Extremes							Daily Precipitation				Monthly/Annual Precipitation vs Probability Levels. These values were determined from the incomplete gamma distribution										
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	.25	.23	.33+	1974	1	.75	1979	.00+	1998	3.8	.9	.0	.0	.00	.03	.08	.12	.16	.21	.26	.32	.40	.53	.66
Feb	.21	.21	.88	1963	10	.77	1997	.00	1999	3.8	.7	.0	.0	.01	.03	.06	.09	.12	.16	.21	.26	.34	.46	.59
Mar	.46	.38	1.15	1992	4	1.62	1992	.03	1971	5.4	1.5	.1	@	.05	.09	.15	.22	.29	.36	.45	.56	.71	.96	1.20
Apr	.54	.42	1.22	1952	20	1.72	1990	.00	1972	5.1	1.6	.2	@	.02	.07	.15	.22	.31	.40	.52	.66	.85	1.17	1.49
May	.70	.70	.86	1967	26	1.85	1973	.01+	1998	6.1	2.3	.3	.0	.03	.06	.14	.23	.34	.47	.63	.84	1.13	1.63	2.14
Jun	.59	.58	1.02	1969	16	1.26	1995	.00	1980	5.4	1.9	.1	.0	.05	.11	.20	.29	.38	.48	.59	.73	.92	1.22	1.51
Jul	.94	.77	1.56	1971	18	2.59	1971	.02	1994	8.5	2.6	.2	@	.10	.17	.30	.43	.57	.73	.92	1.15	1.47	2.00	2.52
Aug	1.19	.98	1.31	1993	27	5.40	1993	.21	1980	10.1	3.6	.4	.1	.25	.36	.54	.70	.85	1.02	1.22	1.45	1.75	2.23	2.69
Sep	.89	.81	1.77	1959	30	1.85	1982	.19	1978	6.4	2.8	.3	.0	.21	.30	.43	.54	.66	.78	.92	1.08	1.29	1.63	1.95
Oct	.67	.52	.89	1969	11	2.16	1972	.00+	1995	4.8	2.1	.3	.0	.00	.07	.18	.29	.40	.52	.66	.83	1.07	1.46	1.83
Nov	.48	.44	.71	1981	7	1.23	1991	.00+	1999	4.4	1.5	.1	.0	.00	.04	.12	.20	.28	.37	.47	.60	.77	1.06	1.34
Dec	.33	.19	.91	1964	3	.99	1983	.00+	1996	4.0	1.1	.1	.0	.00	.02	.06	.11	.17	.23	.31	.41	.54	.78	1.01
Ann	7.25	7.18	1.77	Sep 1959	30	5.40	Aug 1993	.00+	Nov 1999	67.8	22.6	2.1	.1	4.80	5.27	5.86	6.32	6.73	7.13	7.55	8.01	8.58	9.40	10.12

Snow (inches)

	Snow Totals														Mean Number of Days (1)								
	Means/Medians (1)				Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	4.6	3.3	2	1	6.4	1974	1	17.8	1974	10+	1992	31	10	1992	4.1	1.4	.4	.2	.0	16.2	8.6	6.0	.9
Feb	2.7	2.5	1	1	3.5	1971	3	7.0	1987	10+	1992	20	9	1992	3.6	1.1	.1	.0	.0	9.0	4.6	3.1	.4
Mar	5.9	4.1	#	1	12.0	1992	4	29.2	1973	11	1992	5	3	1992	4.9	2.0	.4	.2	.1	3.6	1.2	.6	@
Apr	3.7	3.2	#	0	9.0	1990	30	9.2	1990	5+	1987	13	#	2000	2.7	1.0	.4	.2	.0	.9	.2	.1	.0
May	2.1	.1	#	0	8.4	1973	6	13.5	1978	4	1978	5	#	2000	1.3	.7	.2	.1	.0	.3	@	.0	.0
Jun	.0	.0	#	0	.2	1983	13	.2	1983	#	1990	9	#	1999	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	#	0	.0	0	0	.0	0	#+	1990	26	#	1997	.0	.0	.0	.0	.0	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Sep	.1	.0	0	0	1.2	1971	18	1.2	1971	#	1973	26	0	0	.1	.1	.0	.0	.0	.0	.0	.0	.0
Oct	3.0	.5	#	0	13.1	1991	30	15.1	1991	12	1991	31	1	1991	1.3	.7	.3	.2	.1	.8	.2	.1	@
Nov	4.7	3.7	1	0	8.0	1985	14	19.8	1972	12	1972	1	4	1972	3.6	1.4	.5	.1	.0	5.4	2.6	.9	@
Dec	5.1	4.9	1	1	9.6	1978	6	12.1	1978	10+	1991	27	6	1991	4.3	1.6	.5	.2	.0	12.6	6.8	2.6	.2
Ann	31.9	22.3	N/A	N/A	13.1	Oct 1991	30	29.2	Mar 1973	12+	Oct 1991	31	10	Jan 1992	25.9	10.0	2.8	1.2	.2	48.8	24.2	13.4	1.5

Recharge to the active confined aquifer takes place, in part, through the unconfined aquifer at these locations. The active confined aquifer is up to 4,000 feet below the land surface. Recharge to the confined aquifer occurs along the margins of the SLV from infiltration of precipitation, infiltration of surface water, and inflow of groundwater from the San Juan Mountains and the Sangre de Cristo Mountains. Discharge from the confined aquifer occurs as groundwater flows to the south and upward leakage through the confining bed. A generalized schematic of hydrologic flow in the San Luis Valley (including current modifications and management) is provided in Fig. 14.

PLANT AND ANIMAL COMMUNITIES

Historically, Alamosa NWR contained predominantly herbaceous wetland and wet meadow plant communities in the Rio Grande floodplain, narrow riparian woodland corridors along the Rio Grande, small seep wetlands along the base of Hansen's Bluff, and salt desert shrub on higher elevation floodplain terraces and upland bluff areas adjacent to the floodplain (Hanson 1929; Ramaley 1929, 1942; Harrington 1954). Brief descriptions of these communities are provided below.

Floodplain Wetlands

The numerous historical creek and river corridors converging on Alamosa NWR formed labyrinths of active and former high- and low-water channels, sloughs, oxbows, and shallow scattered floodplain depressions that supported wetland communities. Late-1800s GLO maps (Fig. 2) and survey notes and a map of Wheeler's Expedition (Fig. 15) around the same time period indicate that herbaceous wetland and wet meadows were the dominant land cover over most of Alamosa NWR. Remnant floodplain and abandoned creek channel depressions were present throughout most of the refuge area and supported several wetland types with diverse communities of sedges (*Carex* spp.), rushes (*Juncus* spp.), grasses, cattail (*Typha* spp.), soft-stem bulrush (*Schoenoplectus tabernaemontani*), and aquatic species such as pondweeds (*Potamogeton* spp.) (Ramaley 1929, 1942; Carsey et al. 2003).

Vegetation in Rio Grande floodplain wetlands varies by topographic location, hydrology, and soils (Cooper and Severn 1992). Deeper floodplain depressions typically have more prolonged water regimes and contain persistent emergent wetland species such as soft-stem bulrush and cattail. These deeper wetlands are located in backwater sloughs, oxbow lakes, and seeps along Hansen's Bluff on Alamosa NWR. Historically, sloughs associated with creeks and rivers

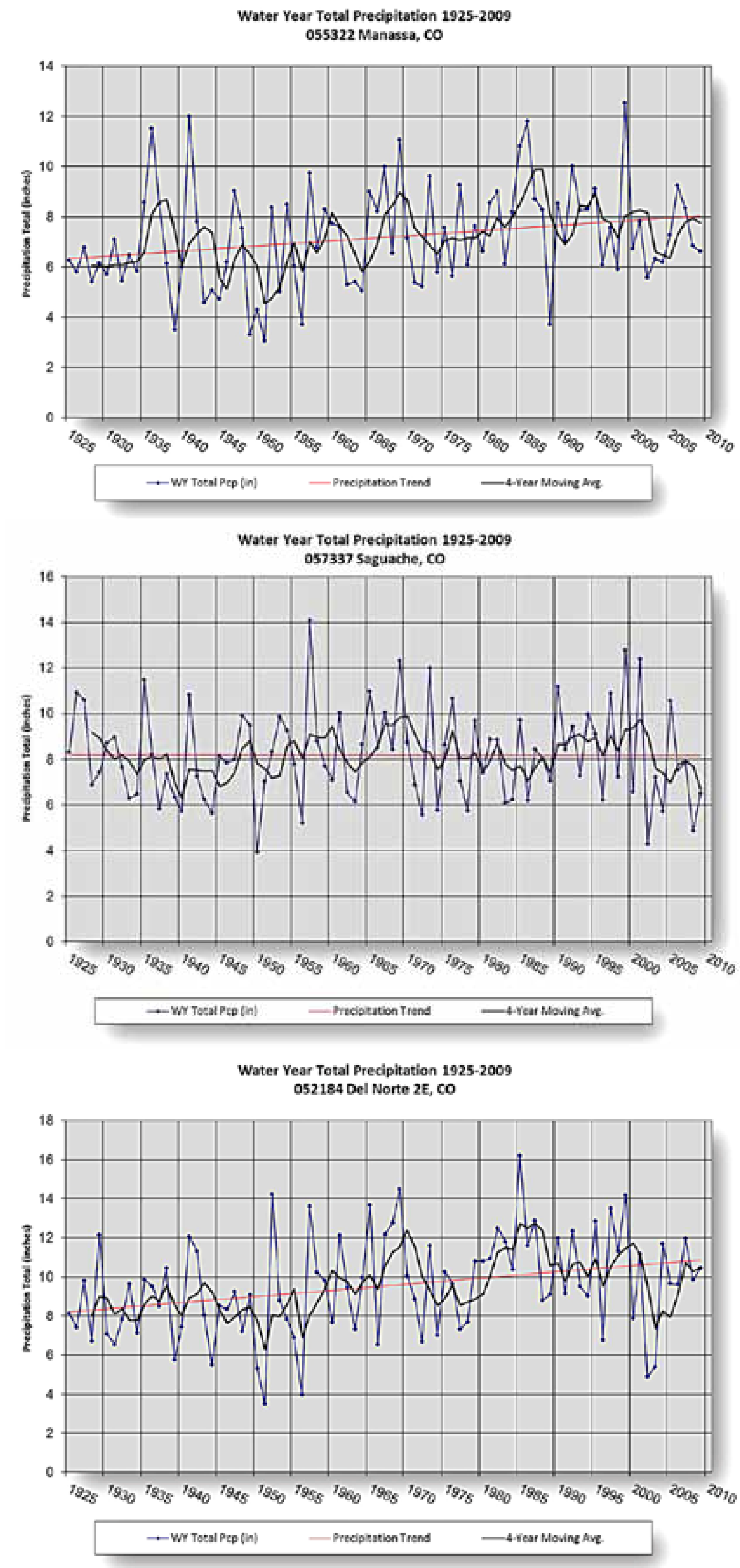

Figure 9 Total Precipitation from 1925 to 2010 at Manassa, Saguache, and Del Norte, CO (U.S. Historical Climatology Network data, taken from Striffler 2013).

at Alamosa NWR were seasonally flooded in late spring and early summer from snowmelt, spring rainfall, river and creek overflows, and groundwater discharge. Some of these deeper sloughs held water through June into July and in very wet years they may have held water year round (Ramaley 1929, 1942; Rees 1939, and aerial photographs from 1941 in Fig. 9). The deeper sloughs contain Marsh and Vastine soils (Fig. 5) that are highly impermeable and lose little water from seepage; most surface water loss occurs from the high ET rates during summer.

Shallow floodplain depressions and meadow flats at Alamosa historically were seasonally flooded by local surface water runoff and sheetflow; occasional backwater or overbank flood events in wet years also inundated these areas. These wetlands contained diverse herbaceous and grass-type wetland plants including emergent sedges, spikerush (*Eleocharis* spp.), rushes, dock (*Rumex* spp.), smartweed (*Polygonum* spp.), and millet (*Echinochloa* spp.). An increase in the water table and short duration shallow flooding would have promoted saltgrass meadows at the edges of seasonal wetlands and within depressions in the salt desert shrub area. The relative juxtaposition of wetland types likely was dynamic over time depending on fluvial dynamics of the Rio Grande and associated tributaries creating floodplain geomorphic features.

Riparian Woodland

Riparian forest species such as narrowleaf cottonwood and willow historically occurred adjacent to the active Rio Grande channel in bands up to one-half mile wide (Ramaley 1942). The distribution and extent of these woodlands likely varied over time in relationship to migration of the river channel and associated sediment scouring and deposition. Consequently, the exact historical extent of the woody riparian community along the Rio Grande at Alamosa NWR is unknown and likely was spatially variable. Sandy Alluvial Land soils on Alamosa (Fig. 5) that are seasonally hydrated are suited for cottonwood and willow survival and growth (see Cooper et al. 1999; Scott et al. 1993, 1999) and these soil areas along the Rio Grande probably supported this habitat. Despite little historical reference to cottonwood galleries in and around Alamosa NWR, the town of Alamosa was probably so named due to the prevalence of cottonwood trees in the area (the word 'Alamosa' means cottonwood, or many cottonwoods, in Spanish).

Salt Desert Shrub

Higher elevation areas adjacent to the Rio Grande floodplain at Alamosa NWR historically were, and currently still are in many places, dominated by a salt desert shrub community (Ramaley 1942, Cronquist et al. 1977). These areas occur mainly to the north and east of the Rio Grande although some higher elevation terraces support this community throughout the floodplain. Salt desert shrub communities were dominated by rubber rabbitbrush (*Ericameria nauseous*) and greasewood (*Sarcobatus vermiculatus*) with an understory of alkali sacaton (*Sporobolus airoides*) and saltgrass (*Distichlis spicata*). Areas along Hansen's Bluff and to the east transitioned to rabbitbrush and grass species such as Indian ricegrass (*Achnatherum hymenoides*) and blue grama (*Bouteloua gracilis*). Salt desert shrub vegetation historically was present on HHC association soils that typically are poorly drained with groundwater tables relatively close to the surface (Cronquist et al. 1977). Even slight differences in elevation of a few inches can alter drainage and can cause ephemeral or seasonal surface water "ponding", which creates significant variation in soil salinity and consequently heterogeneity in plant species occurrence. For example, excess alkali occurs when water tables are close to the ground surface, especially in shallow depression "pool" areas. As alkali concentrations increase, these small depressions typically become dominated by saltgrass, foxtail barley (*Hordeum jubatum)*, alkali muhly (*Mulhenbergia asperifolia*), and Douglas' sedge (*Carex douglassii*). Where alkali is extremely high, "chico slick spots" or barren salt flats occur within scattered greasewood clumps. Generally areas within salt desert shrub that have more salt-tolerant species can be determined by salinity of soils. At higher elevations, the desert shrub community is characterized by shrubs interspersed with substantial amounts of bare ground and scattered herbaceous species that include grasses, sedges, and legumes. The specific composition of species is determined by topography, soil aeration, surface hydrology, and depth to groundwater (Ramaley 1942). For example, in some areas dunes were formed as a result of wind erosion creating an undulating topography (SCS 1973) that support rabbitbrush where greater aeration of roots can occur. Near Washington Springs, inter-dune bare spaces often held water during spring snowmelt and the monsoonal season (Siebenthal 1910).

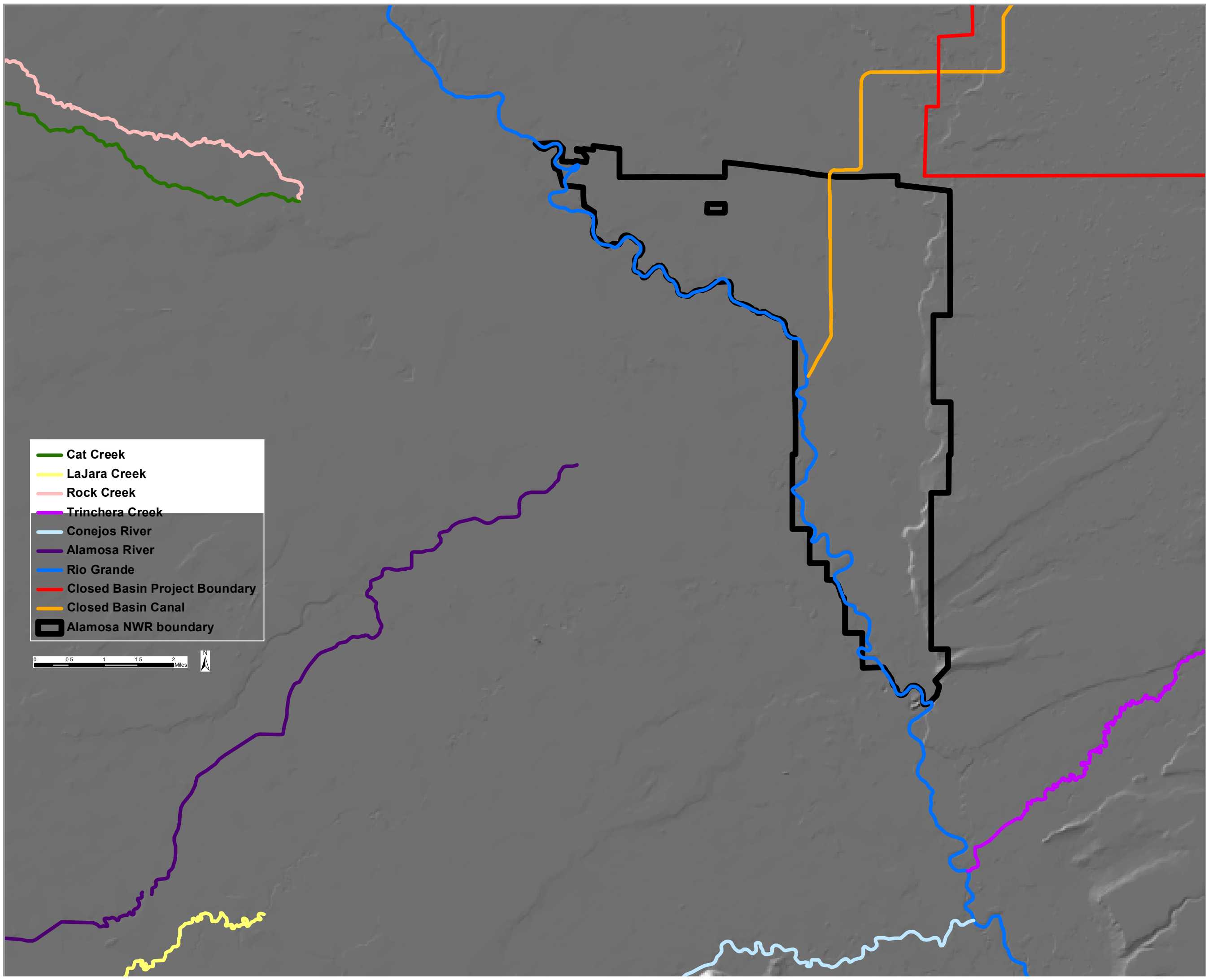

Figure 11. Current location of rivers and creek drainages near Alamosa National Wildlife Refuge.

Key Animal Species

A diverse assemblage of animal species historically occupied various habitat types at Alamosa NWR (Rocchio et al. 2000, Table 4). The majority of species were those adapted to floodplain wetlands and wet meadows with short emergent vegetation (Laubhan and Gammonley 2000), along with riparian corridors along the Rio Grande and salt desert shrub. The large areas of wet meadow and seasonal wetlands supported many waterbird, mammal, and

Table 3. Mean monthly discharge (cubic-feet/second) of the Rio Grande at the Alamosa and Del Norte gauge stations for various time intervals (data available at http://waterdata.usgs.gov/co).

Alamosa gauge	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1912-1995	182	207	228	194	392	748	241	112	119	155	203	204
1912-1925	238	258	335	374	895	1794	461	253	209	329	350	272
1926-1995	170	196	205	156	283	504	190	79	99	114	169	188
Del Norte gauge	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1890-1995	187	194	274	774	2,550	3,080	1,380	768	507	490	283	204
1890-1925	235	228	337	910	2883	3494	1516	869	576	654	357	258
1912-1925	240	239	309	747	2958	3949	1928	1115	613	604	357	248
1926-1995	171	184	246	716	2355	3054	1417	764	482	415	257	186

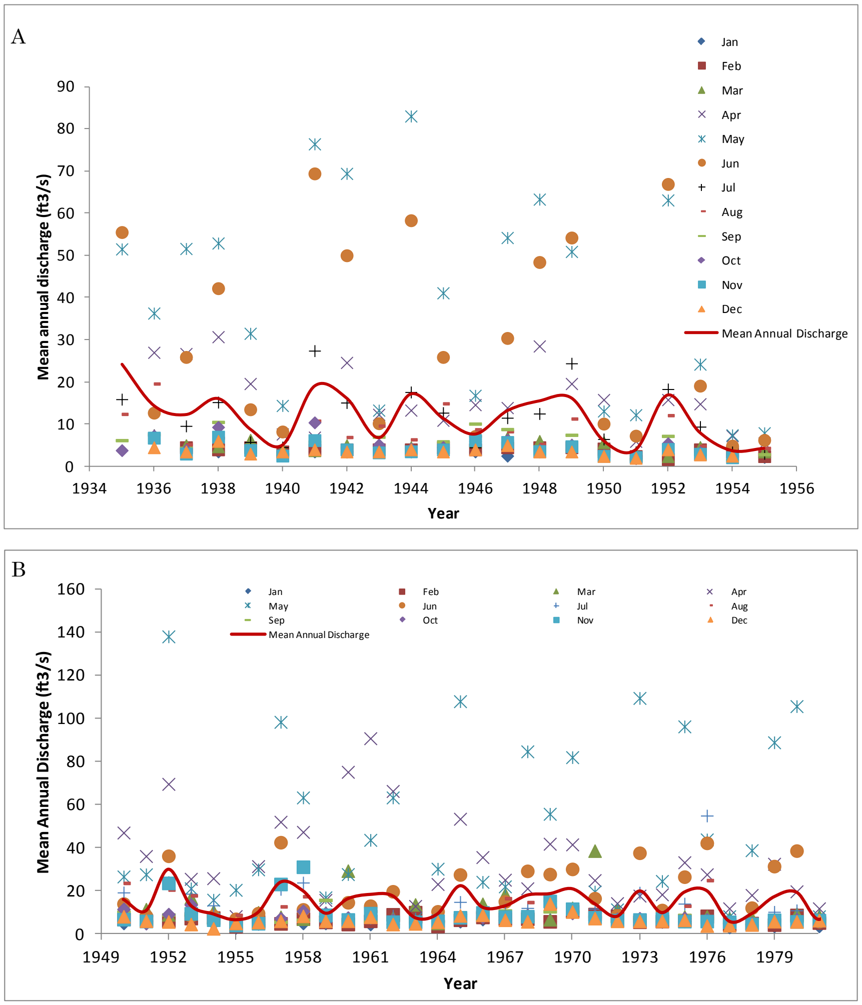

Figure 12. Mean monthly discharge: a) Rock Creek 1935 to 1955 and b) La Jara Creek 1950-1980 (USGS data).

amphibian/reptile species, especially during wet years when more stream flow and overbank flooding supported semi-permanent wetlands throughout the floodplain. The alternating wet vs. dry precipitation cycle in the SLV caused the availability of wetland habitat to be highly variable among years. Most waterbirds probably used the historic wetlands present on Alamosa NWR mainly during migration, especially in spring; these included many species of waterfowl, shorebirds, and wading birds such as dabbling ducks, common snipe (*Gallinego gallinego*), American avocet (*Recurvirostra americana*), sandhill crane (*Grus canadensis*) long-billed dowitcher (*Limnodromus scolopaceus*), various sandpipers (*Caldris* spp.), white-faced ibis (*Plegadis chihi*), pied-billed grebe (*Podilymbus podiceps*), sora (*Porzana carolina*), marsh wren (*Cistothorus palustris*), and yellow-headed blackbird (*Xanthocephalus xanthocephalus*). Grassland and upland shrub bird species such as Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), sage thrasher (*Oreoscoptes mantanus*), and western meadowlark (*Sturnella neglecta*) probably utilized many of the grassland and shrub habitats in the refuge area. Mammals such as the desert cottontail (*Sylvilagus auduboni*), white-tailed jackrabbit (*Lepus townsendii*), long-tailed weasel (*Mustela frenata*), beaver (*Castor canadensis*), mule deer (*Odocoileus menionus*), and elk (*Cervus canadensis*) were common. Amphibians and reptiles such as the western terrestrial garter snake (*Thamnophis elegans*), northern leopard frog (*Rana pipiens*), and various toads frequented wetland areas.

Historical Distribution and Extent of Plant Communities

A HGM matrix of relationships of major plant communities to geomorphic surface, soil, general topographic position, and hydrology at Alamosa NWR was generated (Table 5) from information on general plant communities described and mapped in the late-1800s by the GLO surveys (Fig. 2), plant species associations described in published literature (e.g., Ramaley 1929,1942; Harrington 1954; Cronquist et al. 1977), older maps (Wheeler 1887, Siebenthal 1906, Clason 1910, Fig. 15), aerial photographs (Fig. 9), and state-of-the-art understanding of plant species relationships (i.e., botanical correlation) to geomorphology, soil, topography and elevation, hydrological regimes, and ecosystem disturbances (e.g., Robbins 1910; Summers and Smith 1927; Ramaley 1929, 1942; Hanson 1929; Harrington 1954; SCS 1973; Carsey et al. 2003; Brown et al. 2007). Collectively, this information suggests that the type and distribution of historical vegetation communities at Alamosa NWR were defined by:

- The geomorphic and topographic surfaces created by the Rio Grande and its tributaries within Alamosa NWR, including historical wetland depressions associated with the

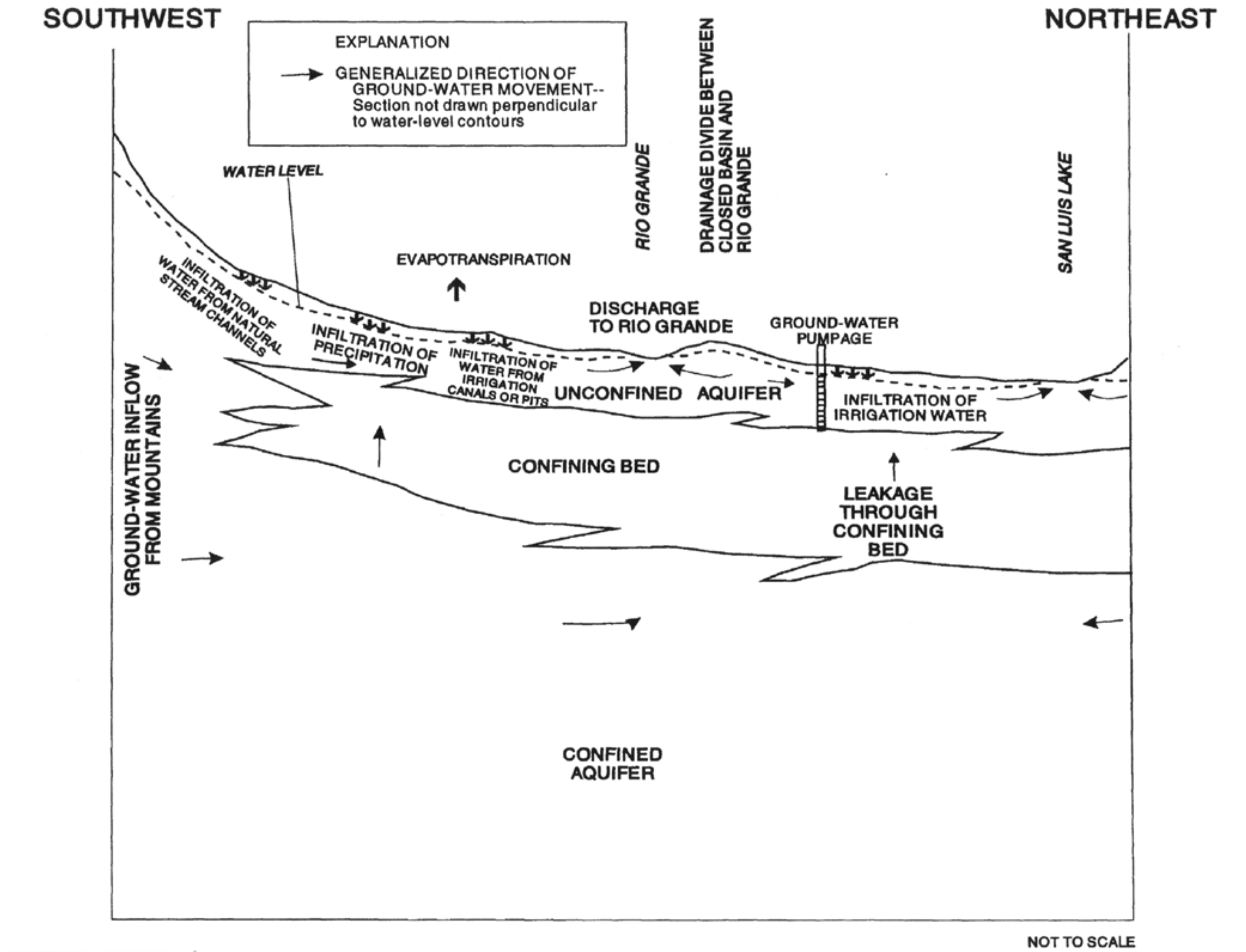

Figure 13. Schematic cross-section of groundwater movement in relation to the unconfined and confined aquifers in the San Luis Valley (modified from Hanna and Harmon 1989).

floodplain based on GLO maps and survey notes, historic maps, and aerial photographs (Figs. 2, 9, 15).

- Soil type and salinity (Fig. 5).
- On-site hydrology that is affected by type and input of surface and groundwater from the Rio Grande, precipitation, seeps, springs, and sub-irrigation.

The ecosystem attributes identified in the HGM matrix (Table 5) were used to make a model map of the potential distribution of historical vegetation communities at Alamosa NWR (Fig. 16). The first step in making the potential historical vegetation map was to determine the distribution of major vegetation/community types from GLO surveys (Fig. 2), early botanical accounts (e.g., Ramaley 1929), and older maps and aerial photographs (Figs. 9, 15). This information defines the locations of Hansen's Bluff, the historic Rock and La Jara Creeks, Alamosa River, and the Rio Grande along with descriptions of the location of salt desert shrub and larger wetland depressions such as abandoned river and creek channels. Aerial photographic mosaics taken during the 1940s and 1950s also identify vegetation communities present in various areas of Alamosa NWR and document relationships of vegetation to particular attributes such as the soils and topography. These major communities were overlaid on contemporary geomorphology, soil, and topography maps to determine correspondence. While older maps and accounts have limitations and may not be completely georeferenced, they do provide the opportunity to specifically define some areas, such as the historic Rock

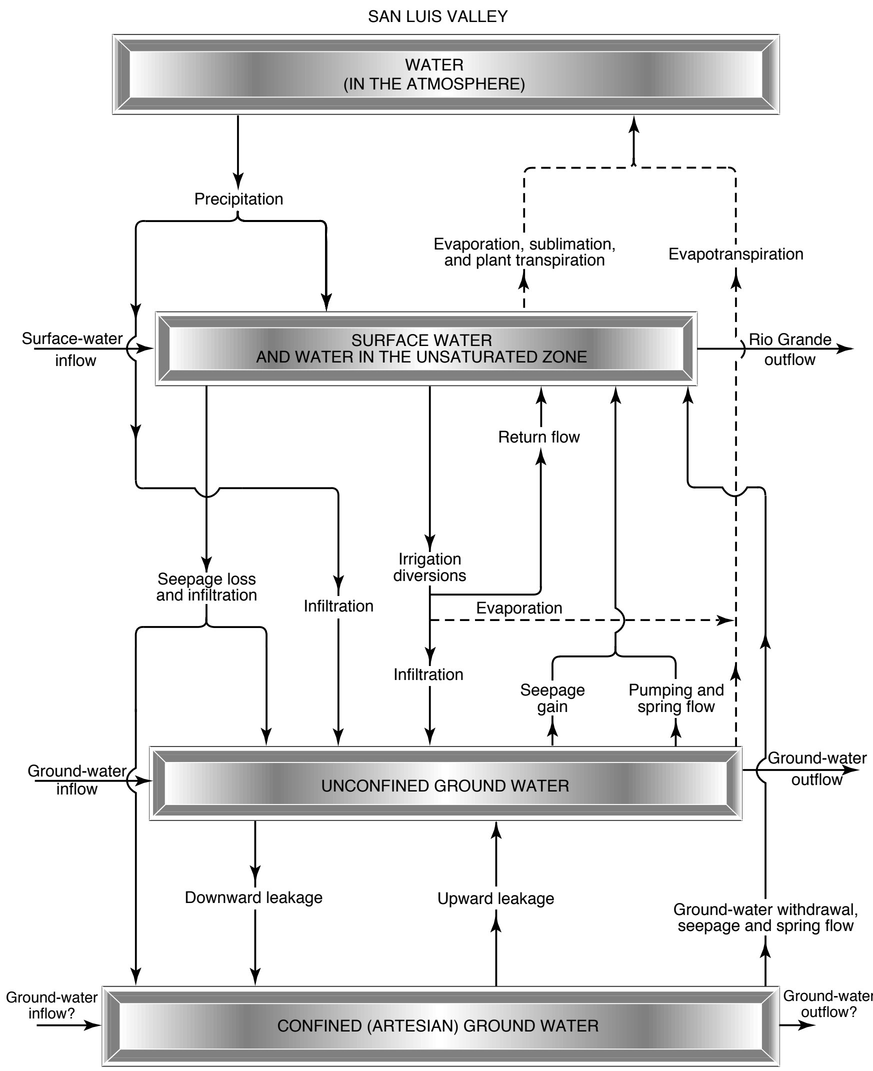

Figure 14. Generalized hydrological flow diagram of the San Luis Valley (modified from U.S. Bureau of Reclamation 1995 and Wilkins 1998).

and La Jara creek channels, the secondary active channel of the Rio Grande in the eastern part of the refuge, and the Hansen's Bluff area with Costilla-Space City association soils (SCS 1973). Once the major river, creek, wetland, and Hansen's Bluff areas were identified, the balance of Alamosa NWR was divided into potential historical communities/habitat types based on soil types and smaller geomorphic features. Information in the soil survey for Alamosa County was especially useful to distinguish major communities associated with specific soil types and series (SCS 1973).

We acknowledge that soil mapping in 1973 may have reflected changes in the soil chemistry and hydrologic characteristics that occurred since the late-1800s because of long-term extensive irrigation. However, even extended irrigation would not have substantially changed most soil textures (Soil Survey Division Staff 1993) with the exception that prolonged impoundment of water in some areas may have led surveyors to label some areas with a "Marsh" soil description given the depth of organic material present overlying historic soils.

Historical information is not available on site-specific hydrology of the many wetlands on Alamosa NWR, but general assumptions about hydrological regimes were made based on the information that could be obtained through historic maps, GLO survey notes, and the 1973 soil survey in relation to hydrologic regime and topography. For example, seasonally flooded wetlands and wet meadows are dominated by Loamy and Wet Alluvial soils, which have shallow seasonal flooding regimes and are dominated by soils with a loamy texture (Fig. 5). We assume the deeper wetland depressions in the Rio Grande floodplain, although not described in the GLO survey, historically were mainly semi-permanently flooded based on location and historical hydrological regimes of flooding along the Rio Grande during spring and early summer. These semi-permanent wetlands contain mostly Marsh soils or are located in abandoned or secondary channels or within seeps along Hansen's Bluff.

Riparian habitats depicted in Figure 16 are primarily associated with the Sandy Alluvial Land soil series and are located adjacent to the active main channel of the Rio Grande. Riparian woodland habitat is not well documented at Alamosa, but anecdotal accounts from early fur traders and explorers indicate that many areas along the Rio Grande had cottonwood and willow present (e.g., Ramaley 1929, Dolin 2010). It seems likely that narrow riparian woodland habitats may have existed along the secondary active channel of the Rio Grande prior to the 1900s as river migration and overbank flooding scoured riverbank surfaces, deposited silts on natural levees, and created sub-

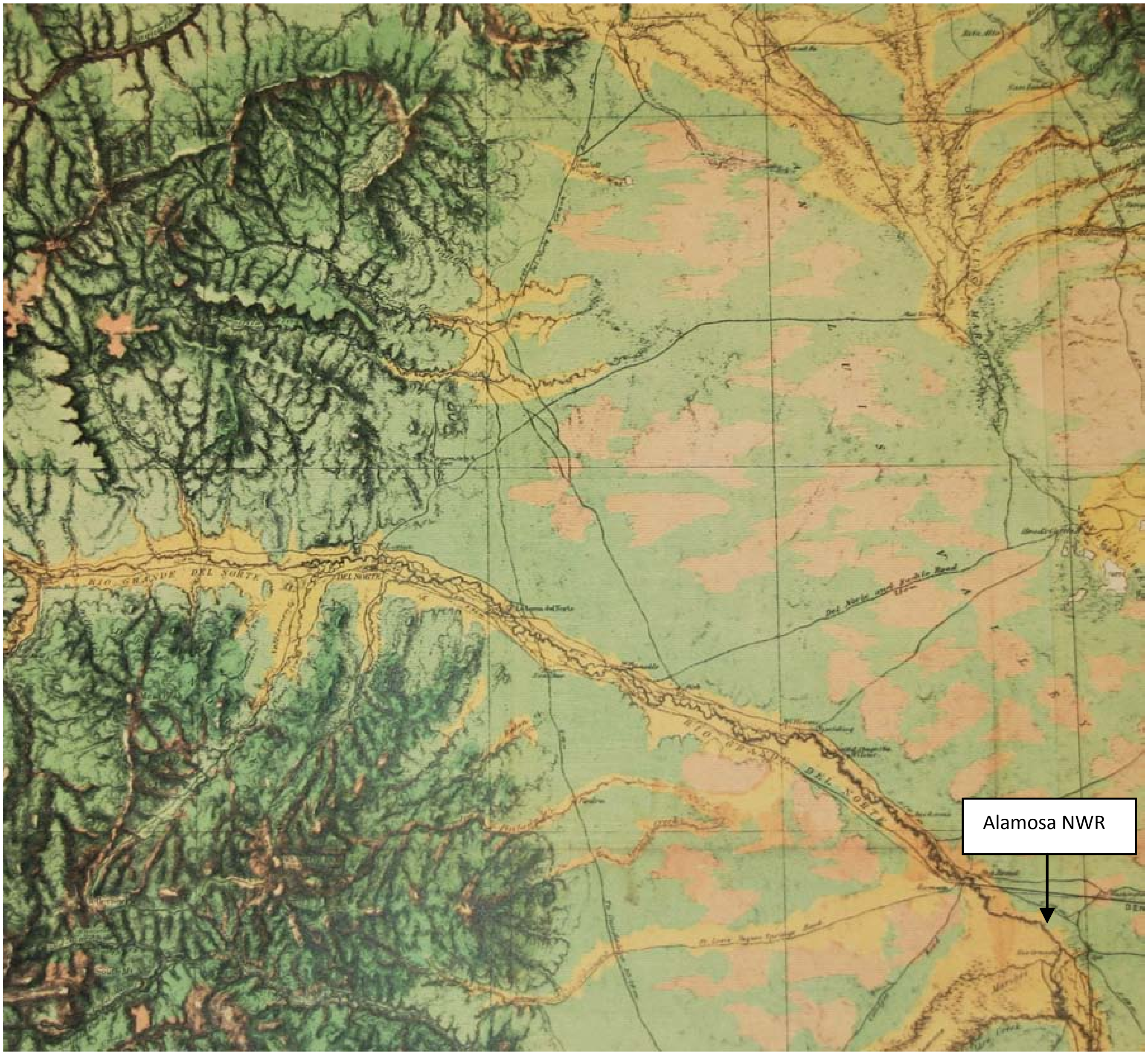

Figure 15. Wheeler Geologic Map of the San Luis Valley depicting land coverages. Yellow= Agricultural (irrigated); Pink= Arid and barren; Light green= Grazing; and Dark green= Timber. From U.S. Geological Surveys West of the 100th Meridian Land Classification Map of Southwestern Colorado: Expeditions of 1873, 74, 75, and 76. Atlas Sheet No. 61. Modified from Wheeler (1887).

strates suitable for cottonwood and willow regeneration, growth, and survival (Scott et al.1993, 1999).

We mapped the potential historical distribution of the salt desert shrub community at Alamosa NWR based on the strong relationship between this community and the CSC and HHC soil-land associations (Fig. 16). The salt desert shrub habitat at Alamosa NWR undoubtedly had considerable diversity in specific plant distribution related to site-specific soils, hydrology, and topography. For example, dune-like areas were formed in the northeastern portion of the refuge through wind erosion and deposition creating distinct conditions within the shrub community, given slight differences in hydrology, soil structure, and elevation. Many small topographic depressions apparently were adjacent to these sites. HHC soils are more alkaline than the CSC association and these salinity differences help distinguish the differences in the shrub community. The CSC association is dominated by rabbitbrush, blue grama, and Indian ricegrass, which are somewhat excessively drained

Table 4. Habitat types and utilization by select avian species on the Alamosa/Monte Vista NWR Complex.

Semiperm.(1'+)	Seasonal(<1')	Tall emergent	Short emergent	Saltgrass	Annuals	DNC	Riparian	Upland	Ag. Lands	Riverine
				Killdeer (ns.fo)						Killdeer (fo)
								Mountain plover(ns.fo)?		
	Black-necked stilt (ns.fo)			Black-necked stilt (ns.fo)						Black-necked stilt (fo)
	American avocet (ns.fo)		American avocet(fo)	American avocet (ns.fo)						American avocet(fo)
	Greater yellowlegs (fo)									Greater yellowlegs (fo)
	Lesser yellowlegs(fo)									Lesser yellowlegs(fo)
Solitary sandpiper (fo)	Spotted sandpiper(fo)									
	Long-billed curlew(lo,fo)		Long-billed curlew (fo)							
	Marbled godwit (fo)									
	Semi-palmated sandpiper (fo)									
	Western sandpiper(fo)									
	Least sandpiper(fo)									
	Baird's sandpiper(fo)									
	Pectoral Sandpiper(fo)									
	Stilt sandpiper(fo)									
	Long-billed dowitcher(fo)									
			Common snipe(ns,fo)							Common snipe(fo)
	Wilson's phalarope (fo)		Western phalarope (ns,fo)	Western phalarope (fo)						
	Red-necked phalarope (fo)									
Forster's tern (fo)	Forster's tern (fo)									
Least tern(fo)										
Black tern(fo)	Black tern(fo)	Black tern(fo)								
			Great Horned owl (fo)			Great Horned owl (fo)	Great Horned owl (ns)			
								Burrowing owl (ns,fo)		
			Short-eared owl(ns,fo)			Short-eared owl(ns,fo)				
							Willow flycatcher(ns,fo)			
		Marsh wren(ns,fo)								
								Sage thrasher (ns,fo)		
								Loggerhead shrike (ns,fo)		
							Yellow warbler (ns,fs)			

Cont'd. next page

Table 4, Cont'd.

Semiperm.(1'+)	Seasonal(<1')	Tall emergent	Short emergent	Saltgrass	Annuals	DNC	Riparian	Upland	Ag. Lands	Riverine
							Yellow-breasted chat (ns,fo)?			
							Blue grosbeak (ns,fo)?			
							Indigo bunting (ns,fo)			
								Brewer's sparrow (ns,fo)		
			Vesper sparrow (ns,fo)	Vesper sparrow (ns,fo)						
			Savannah sparrow (ns,for)	Savannah sparrow (ns,fo)						
			Western meadowlark (ns,fo)							
		Yellowheaded blackbird (ns,fo)								
		Brewer's blackbird (ns,fo)								
							Bullock's oriole (ns,fo)			
Eared grebe (ns,fo)										
Pie-billed grebe (ns,fo)										
Western grebe (fo)										
American White pelican (fo)										
		Am.Bittern (ns)	Am.Bittern (fo)							
	Snowy egret (fo)	Snowy egret (ns)								Snowy egret (ns)
	Cattle egret (ns)	Cattle egret (fo)								
	Black-crowned night. heron (ns)									Black-crowned night heron (fo)
	White-faced ibis (fo)	White-faced ibis(ns)	White-faced ibis(fo)	White-faced ibis(fo)						
Canada geese(mo)		Canada geese(ns)	Canada geese(ns)						Canada geese (fo)	Canada geese (ro)
	Mallard(fo)	Mallard(br,ns)	Mallard(ns,fo)	Mallard(fo)	Mallard(fo)	Mallard(ns)		Mallard(ns)	Mallard(fo)	Mallard(ro)
Gadwall(fo)		Gadwall(br)	Gadwall(ns)		Gadwall(fo)	Gadwall(ns)		Gadwall(ns)		Gadwall(ro)
		Pintail(br)	Pintail(ns)	Pintail(fo)	Pintail(fo)	Pintail(ns)			Pintail(fo)	Pintail(ro)
			Green-wing teal(ns,br)		Green-wing teal(fo)				Green-wing teal(fo)	Green-wing teal(ro)
	Blue-wing cinnamon teal(fo)		Blue-wing cinnamon teal(ns,br)	Blue-wing cinnamon teal(fo)	Blue-wing cinnamon teal(fo)					Blue-wing cinnamon teal(ro)
	Shoveler(fo)		Shoveler(ns,br)		Shoveler(fo)					
Redhead(fo)		Redhead(ns)	Redhead(fo)							Redhead(ro)
Ruddy(fo)		Ruddy(ns)								
										Common merganser (fo)

Cont'd. next page

Table 4, Cont'd.

Semiperm.(1'+)	Seasonal(<1')	Tall emergent	Short emergent	Saltgrass	Annuals	DNC	Riparian	Upland	Ag. Lands	Riverine
Bufflehead(fo)										
Ringneck(fo)										
Canvasback(fo)										
							Osprey(ro)			Osprey(fo)
Bald Eagle(fo)	Bald Eagle(fo)						Bald Eagle(ro)			Bald Eagle(fo)
			Northern harrier(ns,fo)			Northern harrier(ns,fo)				
			Swainson's hawk(fo)			Swainson's hawk(fo)	Swainson's hawk(ns,ro)			
			Red-tail hawk(fo)			Red-tail hawk(fo)	Red-tail hawk(ns,ro)			
			Rough-leg hawk(fo)			Rough-leg hawk(fo)	Rough-leg hawk(ro)			
								Ferruginous hawk(fo)		
							Golden Eagle (ro)	Golden Eagle (fo)		
			Prairie falcon(fo)			Prairie falcon(fo)		Prairie falcon(fo)		
Peregrine falcon(fo)	Peregrine falcon(fo)									
						Ring-necked pheasant(ns)			R.N.pheasant(fo)	
			Sora (ns,fo)							
		Virginia rail(ns,fo)	Virginia rail(ns,fo)							
American coot (fo)		American coot (ns)								
	Sandhill crane(ro)		Sandhill crane(lo,fo)		Sandhill crane(fo)				Sandhill crane(fo)	
	Whooping crane(ro)		Whooping crane(lo,fo)		Whooping crane(fo)				Whooping crane(fo)	
	Snowy plover(fo)			Snowy plover (ns,fo)?						
	Semipalmated plover(fo)									

Activity Code: ns=nesting, fo=foraging, mo=molting, ro=roosting, br=brood rearing, lo=loafing

and contain coarse textured soils, while HHC soils are dominated by greasewood, saltgrass, and alkali sacaton, which occur on more finely textured soils. Areas in the HHC near backwater sloughs and abandoned channels probably had higher groundwater tables that may have effectively sub-irrigated some sites. Older botanical accounts also indicate interspersion of highly saline barren "chico" flats and pans at Alamosa NWR along with ephemeral wetland basins (Ramaley 1929, 1942). Unfortunately, contemporary alteration of hydrology at Alamosa NWR make modeling of the historical distribution of small alkaline wetland "pans" difficult. Nonetheless, some of the attributes of the desert shrub habitat diversity are known and are articulated in the HGM matrix (Table 5) so that some guidance can be provided to future restoration activities.

Generally, the HGM matrix and potential historical vegetation map described above are based on known, or interpreted, correlations between plant communities and abiotic attributes in the Alamosa NWR area. This inference of plant biogeography (e.g., Barbour and Billings 1991, Bailey 1996) obviously depends on the availability of quality historical geospatial data and the accuracy of relationships (e.g., Allred and Mitchell 1955, Buck 1964) for the communities along the Rio Grande. Clearly, some relationships are less known and some data simply are not available. For example, mapping the precise distribution of riparian woodland is constrained by unknown temporal and spatial dynamics of the Rio Grande channel historically, and currently by major topographic alterations such as roads, levees, ditches, etc. that have obscured former topographic features. Hopefully, future studies can expand on the model matrix and map we produced and refine understanding about community distribution and extent.

Table 5. Hydrogeomorphic (HGM) matrix of historic distribution of vegetation communities/habitat types on Monte Vista National Wildlife Refuge. Relationships were determined from old aerial photographs (Fig. 9), plat and GLO maps (Fig. 2) geomorphology maps (Fig. 4), soil maps (Fig. 5) and survey publications (SCS 1980), various historical botanical accounts of the region (Hayden 1873, Hanson 1929, Ramaley 1929, 1942, Carsey et al. 2003), and land cover maps prepared by the U.S. Fish and Wildlife Service.

Habitat Type	Geomorphic surface	Soil Type	Flood Frequency[a]
Salt Desert Shrub	Alluvial fan, Floodplain, Bluff	Corlett, Hooper, Hapney, San Arcacio, Space City, Arena	OSL
Semipermanent wetland	Abandoned channels	Marsh	OBF
Seasonal Wet Meadow	Floodplain margins	Vastine, Alamosa, Loamy and Wet Alluvial Land, La Jara	OBF, SWF
Temporary wetland	Depressions in Salt Desert Shrub	Hooper	OSL
Cottonwood/willow galleries	Natural Levees along Active River Channel	Sandy Alluvial Land	OBF

[a] OSL – on-site local precipitation, OBF – overbank flows, SWF – surface sheetwater flow.

Cary Aloia

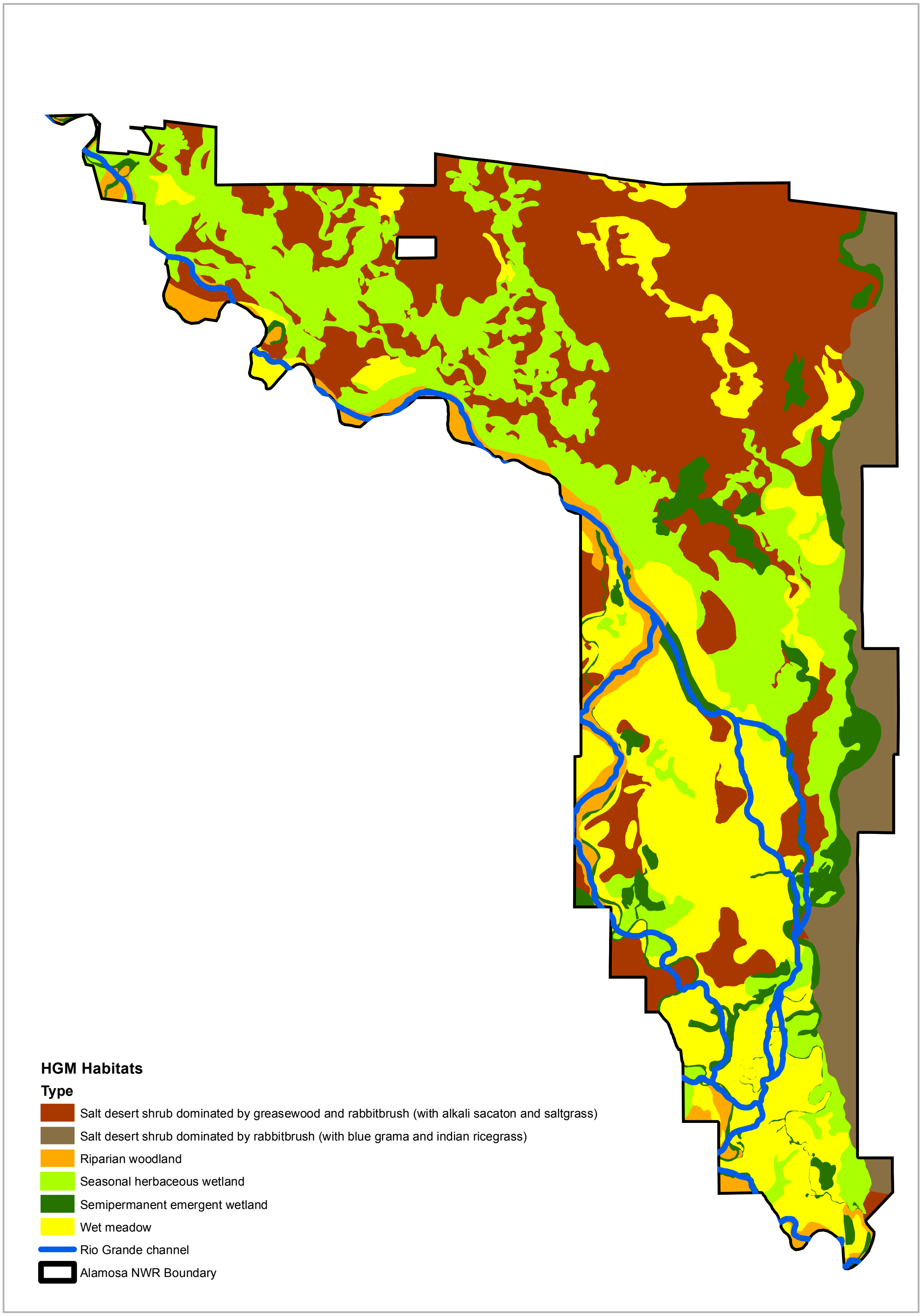

Figure 16. Potential historical vegetation community distribution on Alamosa National Wildlife Refuge (mapped using HGM attribute relationships in Table 5).