HYDROGEOMORPHIC EVALUATION OF ECOSYSTEM RESTORATION AND MANAGEMENT OPTIONS FOR ALAMOSA NATIONAL WILDLIFE REFUGE

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May 2013

Greenbrier Wetland Services
Report No. 13-06

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Publication No. 13-06

Suggested citation:

Heitmeyer, M. E., and C. M. Aloia. 2013. Hydrogeomorphic evaluation of ecosystem restoration and management options for Alamosa National Wildlife Refuge. Prepared for U. S. Fish and Wildlife Service, Region 6, Lakewood, CO. Greenbrier Wetland Services Report 13-06, Blue Heron Conservation Design and Printing LLC, Bloomfield, MO.

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EXECUTIVE SUMMARY

This report provides a hydrogeomorphic (HGM) evaluation of ecosystem restoration and management options for Alamosa National Wildlife Refuge (NWR) in the central portion of the San Luis Valley (SLV) in south-central Colorado. Alamosa NWR contains 12,026 acres and was established in 1962. Most of the refuge is located within the historic Rio Grande floodplain; Hansen's Bluff, an outcrop of Pleistocene-age Alamosa Formation upland hills, forms the east boundary of the refuge. Floodplain wetlands, wet meadows, riparian woodland, and salt desert shrub vegetation communities historically, and currently, compose refuge habitats.

Many land and water changes have occurred throughout the SLV, and at Alamosa NWR, since European settlement. Agricultural irrigation systems were extensively developed in the SLV beginning in the late-1800s, and included diversion of water from the Rio Grande and other rivers/creeks, exploitation of groundwater, and various use and diversion of prior-used water drained from agricultural fields after irrigation. Use and allocation of both surface and groundwater in the SLV have been regulated through many complex water right agreements. Water available for wetland management on Alamosa NWR has become more limited over time. In addition to the extensive alterations in land and water uses in the SLV region, the U.S. Fish and Wildlife Service (USFWS) also modified landform and water distribution on Alamosa NWR after it was established. These modifications included the construction of extensive water management infrastructure and the conversion of former meadow and shrub areas to artificially flooded wetlands. The ecological consequences of long-term diversion of water and consistent flooding of areas formerly in salt desert shrub habitats have included increased soil salinity in some areas, alterations to the presence and distribution of native vegetation species, altered resource availability to native animal species, and invasion and establishment of non-native plants, especially tall whitetop (*Lepidium latifolium*).

In 2003, a Comprehensive Conservation Plan (CCP) was prepared for Alamosa and Monte Vista NWRs. Since that time, management of Alamosa NWR has sought to implement CCP goals, but also recognized constraints of water availability and the need for more holistic management approaches. In 2011, the USFWS initiated a new CCP planning process for the SLV NWR Complex, including Alamosa NWR. This HGM report provides information to support the new CCP and subsequent management of Alamosa NWR with the following objectives:

1. Describe the pre-European settlement (hereafter Presettlement) ecosystem condition and ecological processes in the Alamosa NWR region.
2. Document changes in the Alamosa NWR ecosystem from the Presettlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.
3. Identify restoration and management options and ecological attributes needed to restore specific habitats and conditions within the Alamosa NWR region.

Information was obtained on historical and contemporary geology and geomorphology, soils, topography, climate and hydrology, and plant/animal communities of the Alamosa NWR region. The surficial geomorphology of Alamosa NWR is dominated by Quaternary-age alluvial deposits of the Rio Grande floodplain. Lateral migrations of the Rio Grande and three major tributaries, La Jara and Rock Creeks and the Alamosa River, that enter the Rio Grande near the east side of Alamosa NWR created many geomorphic surfaces on the refuge including split river channels, abandoned channel sloughs and oxbows, natural levees, scroll bars, and terraces. Three major soil-landform associations with 29 distinct soil types are present on the refuge and the distribution of soil types reflects historical deposition and movement of floodplain sediments. The majority of Alamosa NWR contains Alamosa-Vastine-Alluvial Association soils that are deep loams commonly flooded in spring.

The climate of the SLV is semi-arid, with cold winters and moderate summers. Alamosa NWR receives about seven inches of precipitation per year, with 60% occurring as rain in July and August. Long-term precipitation data suggest that alternating low and high yearly precipitation patterns recur at about 20- to 30-year intervals. Generally, the long-term trend for total water year precipitation is increasing over time. Historically, Alamosa NWR received surface water inputs from the Rio Grande and its tributaries and the relatively limited onsite precipitation. Annual variation in mountain snowpack historically influenced Rio Grande and tributary discharge, sediment transfer and deposition, and duration of flood events on Alamosa NWR. Historically, the high Rio Grande discharges in spring following snow melt caused at least some overbank and/or backwater flooding into and through its floodplain at Alamosa NWR in most years. Groundwater seeps along the base of Hansen's Bluff also formerly were common. Two main aquifers, the shallow unconfined and the deeper confined, underlie the SLV.

Historically, Alamosa NWR contained predominantly herbaceous wetland and wet meadow plant communities in the Rio Grande floodplain, narrow riparian woodland 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 areas adjacent to the floodplain. An HGM matrix of relationships of major plant communities to geomorphic surface, soil, general topographic position, and hydrology at Alamosa NWR was developed. The ecological attributes identified in the HGM matrix were used to make a model map of the potential distribution of historical vegetation communities at Alamosa NWR to provide some guidance to future community restoration activities.

The many changes to the Alamosa NWR ecosystem are chronicled in the report including discussion of early settlement and land use changes, contemporary hydrologic and vegetation community changes, and refuge development and management. The primary change to the ecosystem structure, function, and processes at Alamosa NWR since the late-1800s has been the extensive alterations of SLV-wide, and refuge-specific, distribution, chronology, and abundance of surface and groundwater. The history of water diversion, use, and management throughout the SLV, both prior to, and after refuge establishment is complex. Past management objectives for Alamosa NWR promoted increased wetland area with relatively consistent annual water management, mostly for breeding ducks, and has exacerbated certain local ecosystem changes. For example, the annually consistent diversion of water to irrigate extensive areas including many former shrub and seasonal meadow habitats has: 1) converted meadow and shrub sites to more persistent tall emergent habitats; 2) modified and/or eliminated natural surface water flow pathways and patterns across the refuge; 3) facilitated invasion and expansion of non-native plant species; and 4) altered basic soil and topographic characteristics of the system.

Based on information obtained and evaluated in this HGM study, we believe that future restoration and management of Alamosa NWR should consider the following goals where possible:

1. Restore and manage natural hydrologic flow patterns and regimes throughout the Rio Grande floodplain.
2. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes.
3. Encourage management strategies that can emulate natural disturbance events including flooding, drought, fire, and herbivory.

Specific recommendations for each of the above ecosystem restoration and management option goals are provided in the report. For goal #1 they include:

- Restore water distribution to historical drainages by routing surface water north to south and west to east to allow for gravity-fed sheetflow throughout the Rio Grande floodplain.
- Remove or modify water delivery infrastructure to allow flow through natural drainages.
- Remove islands and associated borrow ditches that artificially impound water.

- Replace water-control structures that do not have adequate capacity or are restricting water flows.
- Provide water delivery through ditches, levees, and roads that will allow water to flow through natural drainage areas.
- Prevent artificial ponding of water along roads and levees where it prevents water flow through drainages and sheetflow across the area.
- Manage water regimes in wetland units to emulate natural seasonal and interannual dynamics.
- Prevent impounding water in former salt desert shrub areas in the northern portions of the refuge.
- Further evaluate the New Ditch Diversion site and structures related to refuge restoration potentials.
- Develop a strategic water management plan that identifies specific objectives for the distribution, timing, and extent of water resources.

Specific recommendations for Goal #2 include:

- Restore and manage semipermanently flooded wetlands in Marsh and Vastine soil types within or adjacent to abandoned river channels and near historic seeps along Hansen's Bluff.
- Restore seasonal wetlands in Vastine soils paralleling the Rio Grande riparian corridor and along old drainage pathways.
- Restore wet meadow communities on Loamy and Wet Alluvial Lands, Alamosa, Vastine, and La Jara soil types with short duration spring and early summer flooding regimes.
- Provide water conditions in and near Sandy Alluvial Land soils to promote regeneration of existing cottonwood and willow.
- Restore salt desert shrub communities on Hapney-Hooper-Corlett Association soils.
- Control invasive plant species throughout the refuge, especially in native wetland locations.

Specific recommendations for Goal #3 include:

- Allow or mimic natural overbank flood events if possible by providing the Rio Grande access to its historic floodplain.
- Provide vegetation and soil disturbance events at more natural intervals.
- Mimic historical river/floodplain scouring events through mechanical or chemical treatments.
- Consider use of fire, grazing, mowing, and haying to manage succession stage and composition of vegetation communities based on plant phenologies in seasonal wetland and wet meadow communities.

Future management of Alamosa NWR should include regular monitoring and directed studies to determine how ecosystem structure and function are changing, regardless of whether restoration and management options identified in this report are undertaken. Management activities on Alamosa NWR should be done in an adaptive management framework where: 1) predictions about community response and water issues are made relative to specific management actions and 2) follow-up monitoring is conducted to evaluate ecosystem responses to the action. Especially important categories of information and monitoring needs for Alamosa NWR include:

- Surface and groundwater quantity and quality
- Restoring natural water flow patterns and water regimes
- Long-term changes in vegetation and animal communities

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INTRODUCTION

Alamosa National Wildlife Refuge contains 12,026 acres in the central portion of the San Luis Valley in south-central Colorado (Fig. 1). The refuge was established in 1962 under authority of the Migratory Bird Treaty Act with the authorizing purpose "… for use as inviolate sanctuary or for any other management purpose, for migratory birds." Acquisition of lands for Alamosa NWR incorporated an area once referred to as the "Island Ranch" including seven river miles of the Rio Grande (U. S. Fish and Wildlife Service (USFWS) 2003). The first funds for acquiring the refuge were available in 1962-64 with fee-title acquisition of private lands. Other lands included in the refuge were obtained by withdrawal of public lands administered by the U.S. Bureau of Land Management (BLM) and lease of Colorado state lands.

Most of Alamosa NWR is located within the historic Rio Grande floodplain where Rock and La Jara Creeks and the Alamosa River entered the Rio Grande from the west (Fig. 2). Hansen's Bluff forms the eastern boundary of the Rio Grande floodplain on the refuge. Historically, the Rio Grande had two split active channels in the lower half of the refuge and movement of the river across its floodplain over time created an extensive system of abandoned channel sloughs, oxbow lakes, and wet meadow depressions, some of which are still present today. Riparian narrowleaf cottonwood (*Populus angustifolia)* and willow (*Salix* spp.) woodland historically was present along the main stem and western branch of the active Rio Grande channel. Salt desert shrub occupied higher elevations on floodplain terraces and uplands.

Many land and water use changes have occurred throughout the SLV, including at Alamosa NWR, since European settlement. Following major expansion of

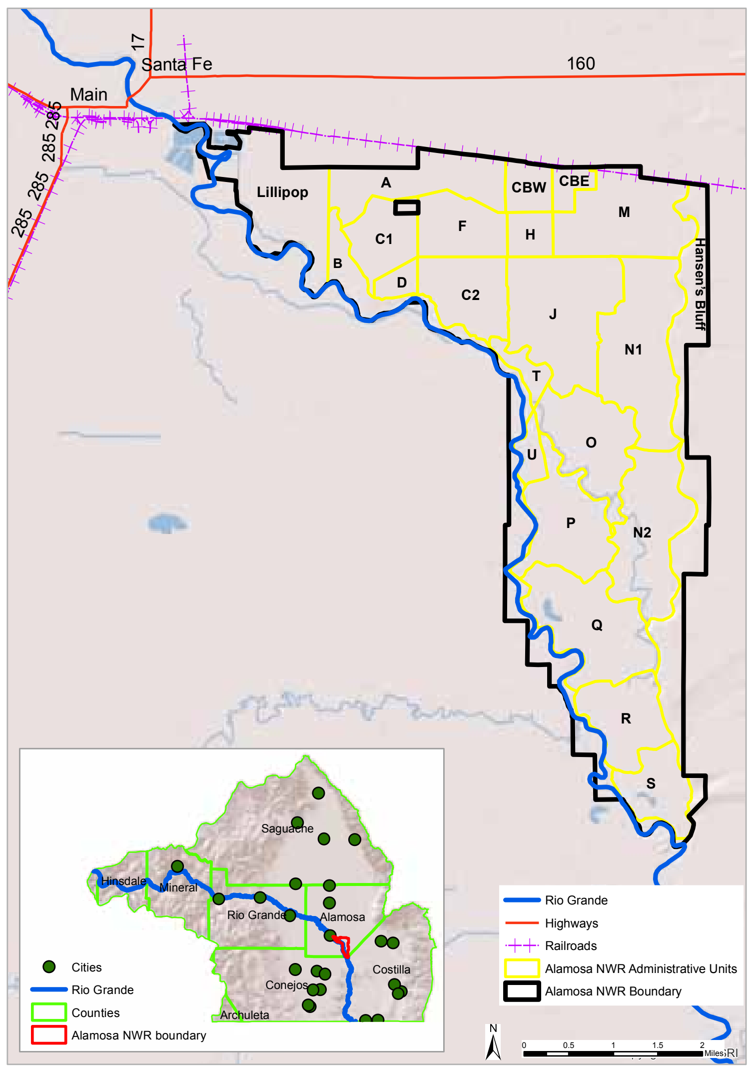

Figure 1. General location of Alamosa National Wildlife Refuge in southern Colorado.

settlements in the SLV in the mid-1800s, agricultural production increased greatly, but was limited by the availability of surface and groundwater. To support a growing agricultural economy, agricultural irrigation "systems" were extensively developed in the SLV and included diversion of water from the Rio Grande and other rivers/creeks, conveyance of diverted river water through an elaborate system of ditches and canals, exploitation of groundwater using pumped wells from shallow unconfined aquifers and pumped and free-flowing deeper artesian water, and various use and diversion of prior-used water drained from agricultural fields after irrigation (locally called "drainwater", see Buchanan 1970, Athearn 1975, Hanna and Harmon 1989, Emery 1996 and others). Use and allocation of both surface and groundwater in the SLV have been regulated through many complex water right agreements beginning with the Embargo of 1896 and Mexican Treaty of 1906 (Natural Resource Committee 1938). The interstate Rio Grande Compact (Compact) was ratified in 1939 and stipulated water use and diversion among states, local irrigation districts, and individual water source/diversion legalities.

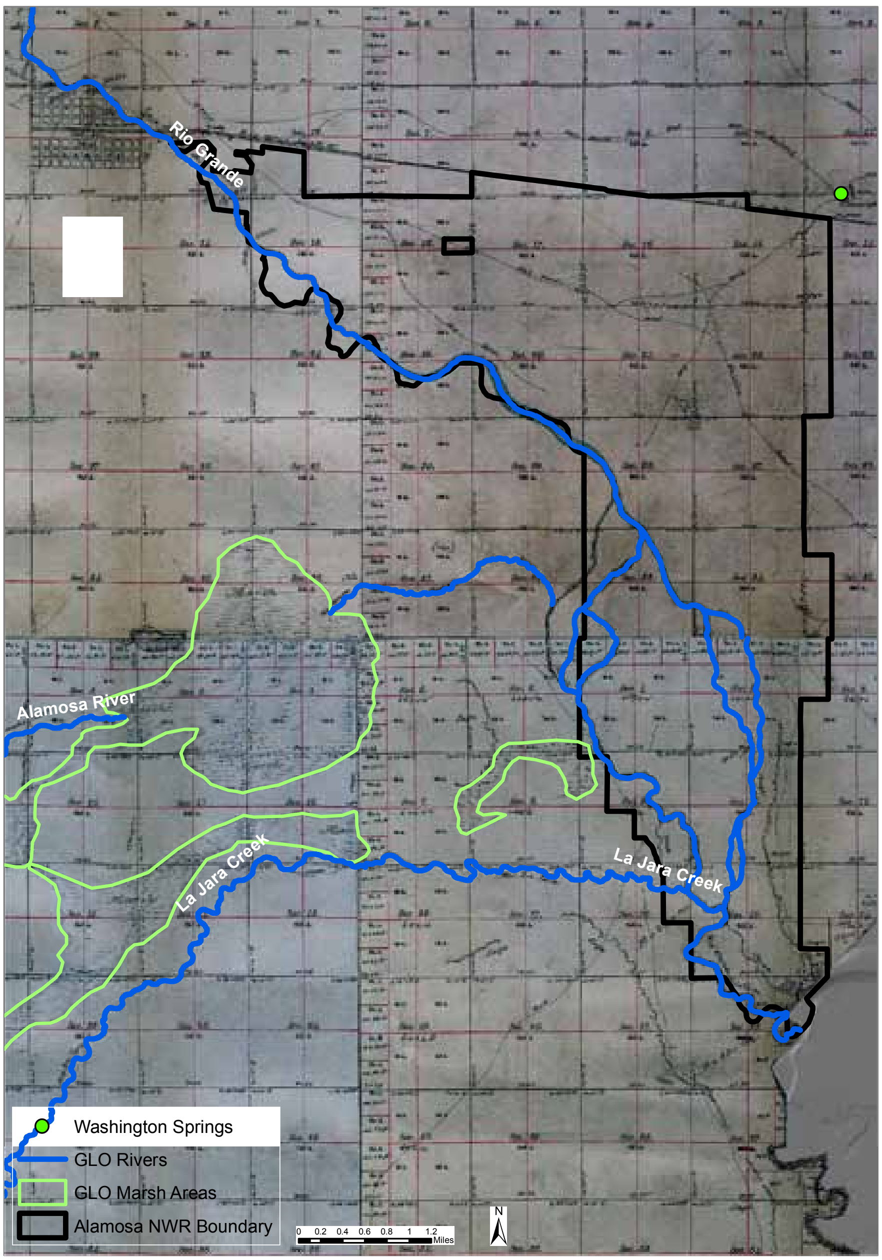

Figure 2. Historic floodplain of the Rio Grande showing marsh areas, rivers, and creeks in relation to the Alamosa National Wildlife Refuge (adapted from late-1800s GLO survey maps).

Water available for wetland management on Alamosa NWR has become more limited over time because of reduced natural river and stream flows, decreases in groundwater-levels and discharges, and many local and SLV-wide water and land use issues (Emery et al. 1973, Cooper and Severn 1992, Ellis et al. 1993, Emery 1996, refuge annual narratives). For example, water in Rock and La Jara Creeks and the Alamosa River no longer reach the refuge except sometimes through drains or return flow from upstream ditches. Future efforts to regulate over-appropriated and limited groundwater in the SLV (and the entire Rio Grande system) is being directed by the Colorado State Engineer, pursuant to Colorado General Assembly SB 04-222, subsection 4, rules Governing the Withdrawal of Groundwater in Water Division No. 3. SB 04-222 requires full replacement of all new or increased withdrawals from the confined aquifer system and maintenance of artesian pressures and SB 04-222 requires an "Augmentation Plan", or replacement plan for new groundwater withdrawals. Alamosa NWR will need to develop an augmentation plan for groundwater used from the Mumm Well based on response functions from the Rio Grande Decision Support System (Striffler 2013).

In addition to the extensive alterations in land and water uses in the larger SLV region, the USFWS also modified landform and water distribution on Alamosa NWR after it was established. These modifications included the construction of extensive water management infrastructure (levees, ditches, and water-control structures) and the conversion of former native wet meadow and salt desert shrub communities to artificially irrigated and inundated meadows and wetlands (USFWS 2003). The ecological consequences of long-term diversion of water and seasonal inundation of areas formerly in salt desert shrub and extended annual flooding of wet meadow habitats have included increased soil salinity in many areas, alterations to the presence and distribution of native vegetation species, altered natural resource availability to native animal species, and invasion and establishment of non-native plant species, especially tall whitetop (*Lepidium latifolium*).

In 2003 a Comprehensive Conservation Plan (CCP) was prepared for Alamosa NWR and Monte Vista NWR, to identify habitat and public use goals (USFWS 2003). Since that time, management has sought to implement CCP goals, but also has recognized constraints of water availability and the need for more holistic system-based approaches to design and implement future restoration and management efforts. In 2011 the USFWS initiated a new CCP planning process for SLV NWRs including Alamosa NWR. This new CCP is being facilitated by Hydrogeomorphic Methodology (HGM) evaluation. Recently, HGM has been used to evaluate ecosystem restoration and management options on many NWR's in Region 6 of the USFWS (e.g., Heitmeyer and Fredrickson 2005; Heitmeyer et al. 2009; Heitmeyer et al. 2010a,b; Heitmeyer et al. 2012; Heitmeyer and Aloia 2013). The HGM process obtains and collates historical and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) aerial photographs and maps, 6) land cover and plant/animal communities, and 7) physical anthropogenic features of ecosystems (Heitmeyer 2007, Klimas et al. 2009, Theiling et al. 2012, Heitmeyer et al. 2013). HGM information provides a context to understand the physical and biological formation, features, and ecological processes of lands within a NWR and surrounding region. This historical assessment provides a foundation, or baseline condition, to determine what changes have occurred in the abiotic and biotic attributes of the ecosystem and how these changes have affected ecosystem structure and function. Ultimately, this information helps define the capability of the area to provide key ecosystem functions and values and identifies options that can help to restore and sustain fundamental ecological processes and resources.

This report provides HGM evaluation of Alamosa NWR with the following objectives:

1. Describe the pre-European settlement (hereafter Presettlement) ecosystem condition and ecological processes in the Alamosa NWR region.

2. Document changes in the Alamosa NWR ecosystem from the Presettlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.

3. Identify restoration and management options and ecological attributes needed to restore specific habitats and conditions within the Alamosa NWR region.

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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";

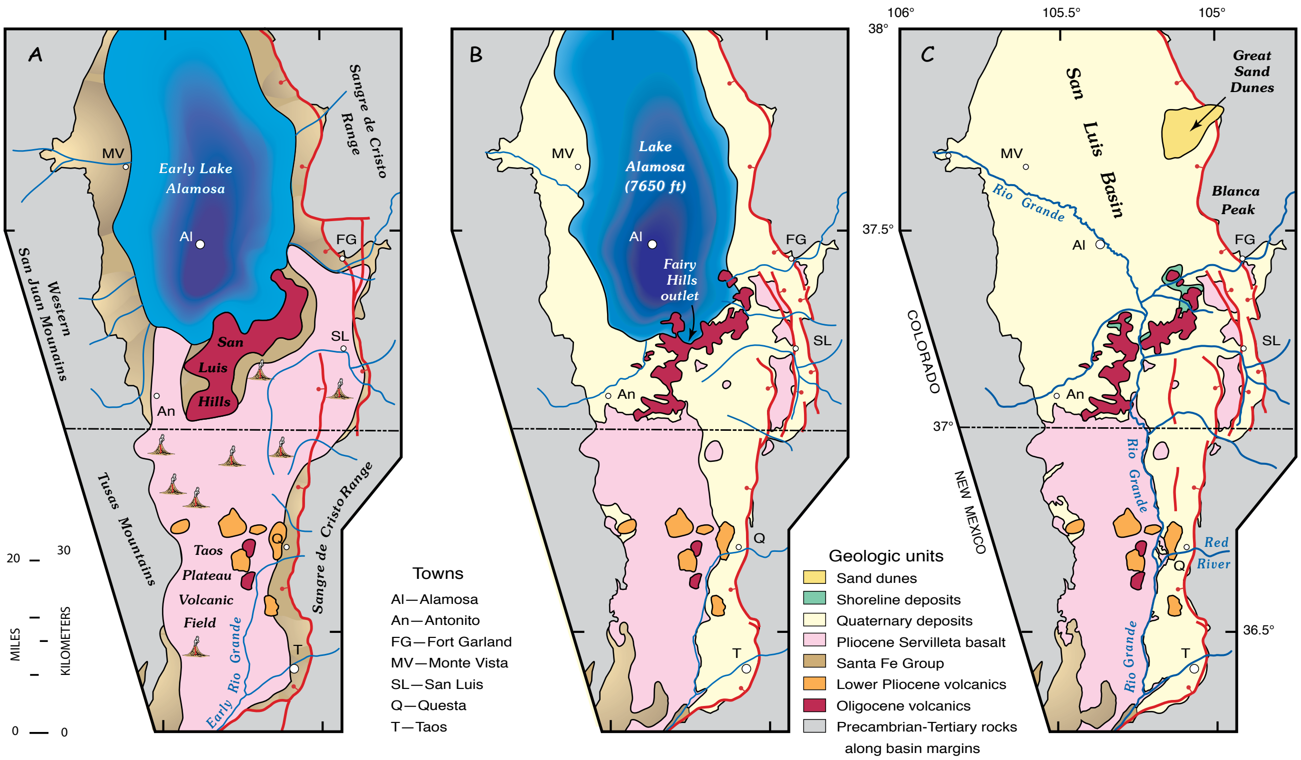

Figure 3. Simplified geological map of the San Luis Basin showing generalized geology and drainage patterns for the time intervals: A) 3.5-5 million years before the present (BP), B) 440,000 years BP, and C) current (from Machette et al. 2007).

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

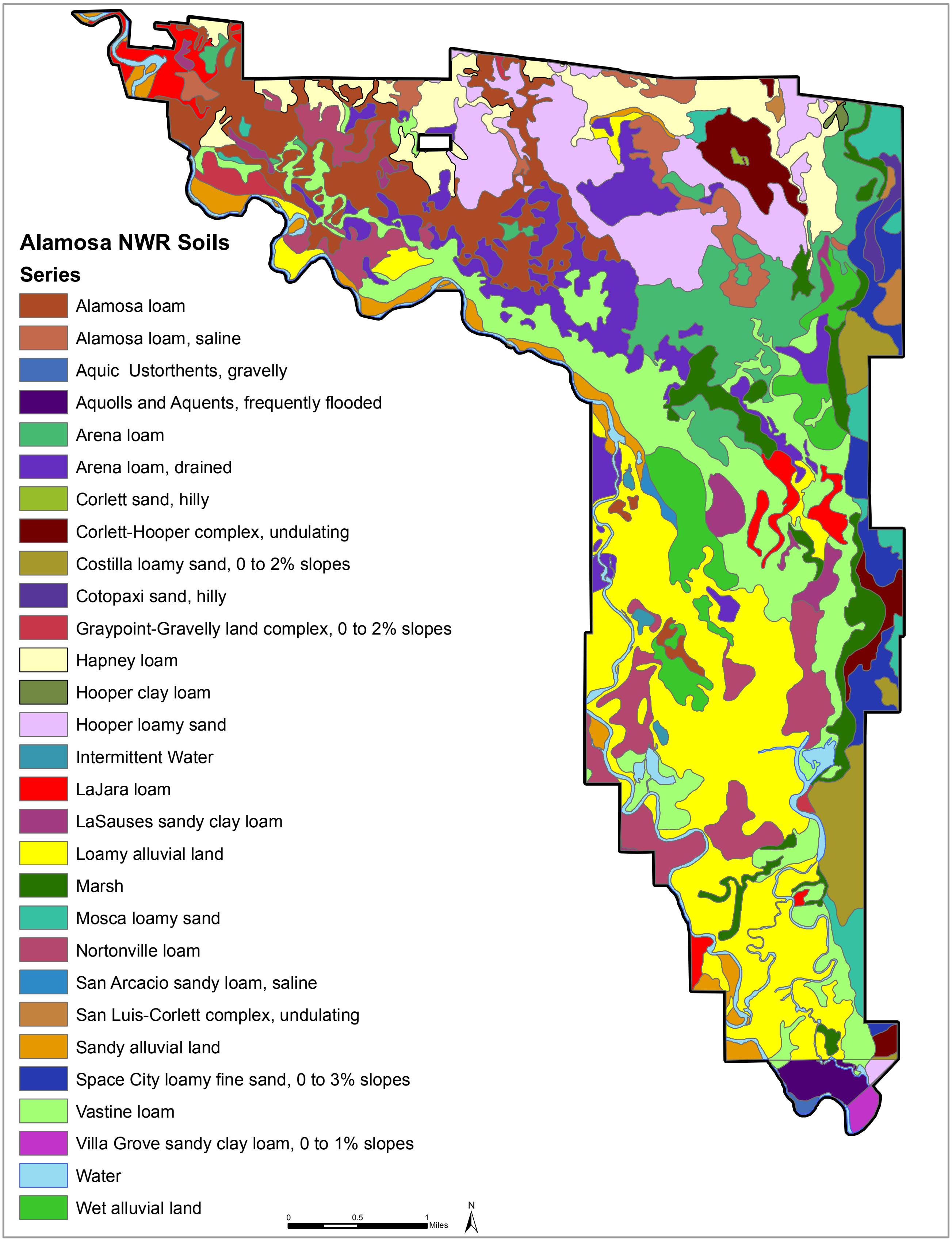

Figure 5. Soil series and location on Alamosa National Wildlife Refuge (USDA SSURGO data, http://websoilsurvey.nrcs.usda.gov).

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° Fahrenheit (F) at Del Norte, Colorado. Temperatures of -20 to -30° 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.

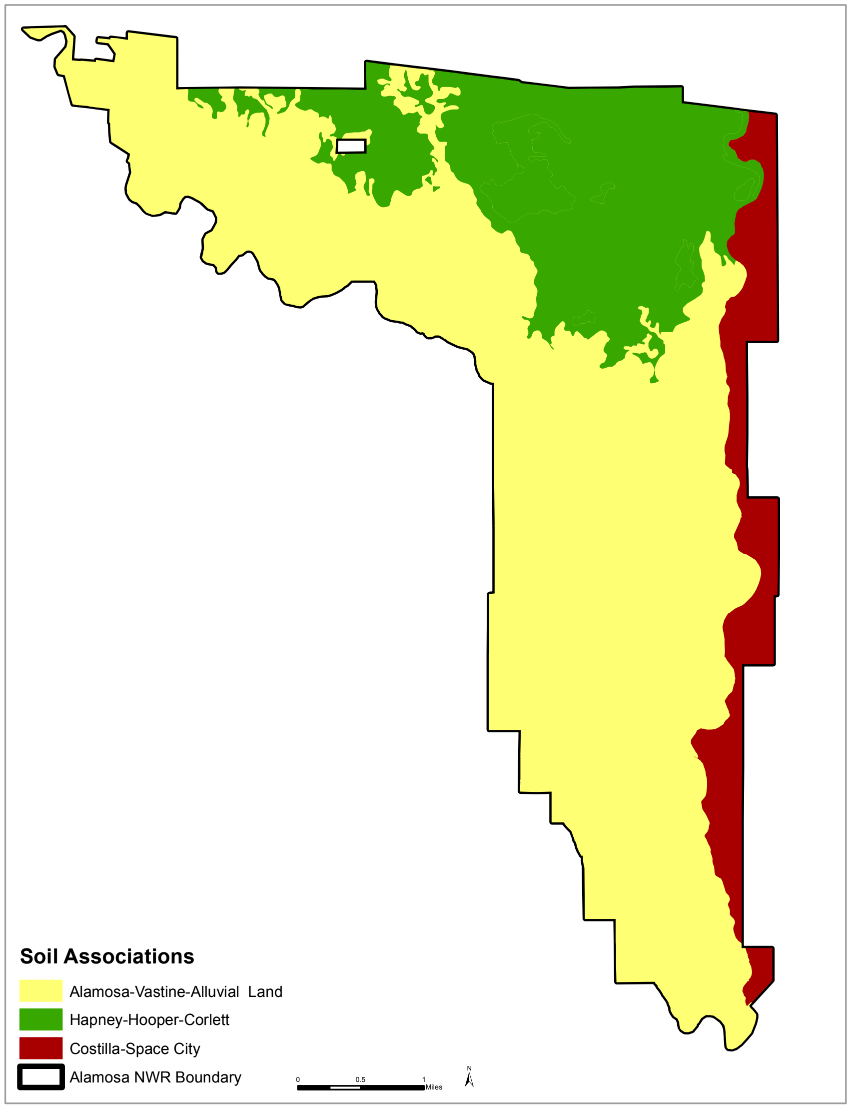

Figure 6. Soil associations on Alamosa National Wildlife Refuge (from SCS 1973).

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

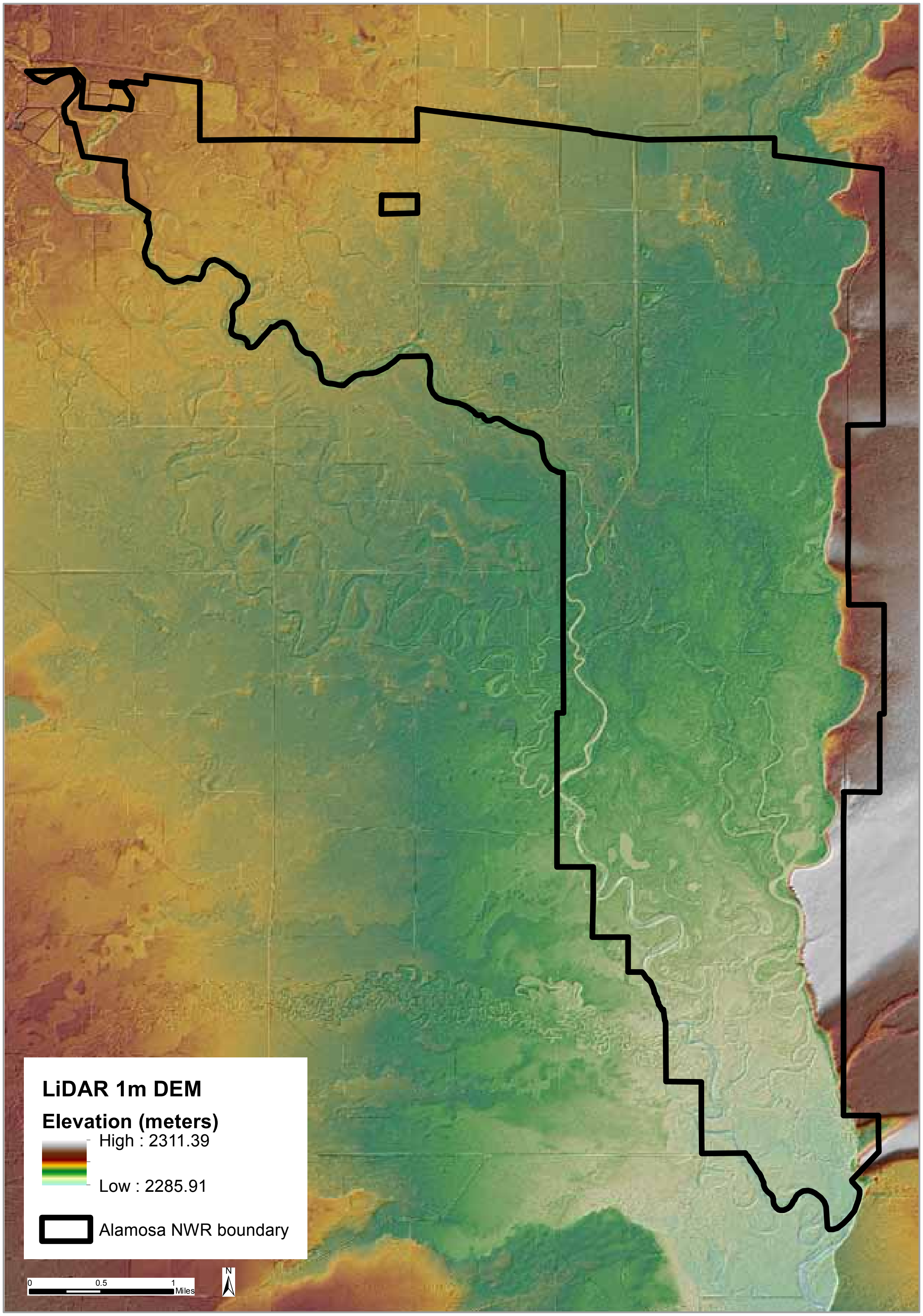

Figure 7. Elevations calculated from LiDAR 1 m DEM of Alamosa National Wildlife Refuge.

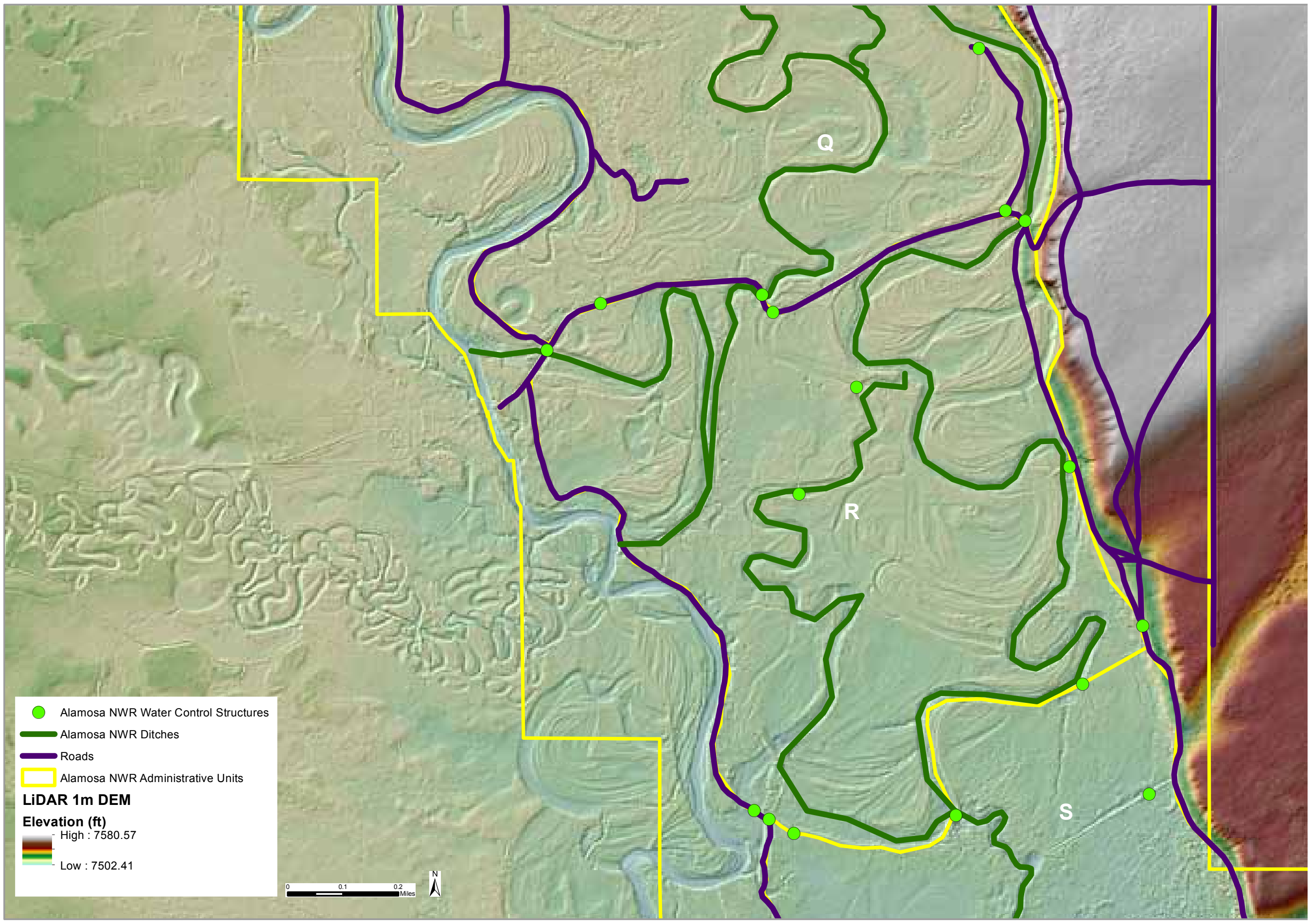

Figure 8. Natural floodplain features shown by LiDAR elevation contours on Alamosa National Wildlife Refuge in relationship to existing roads and ditches in Units Q, R, and S.

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

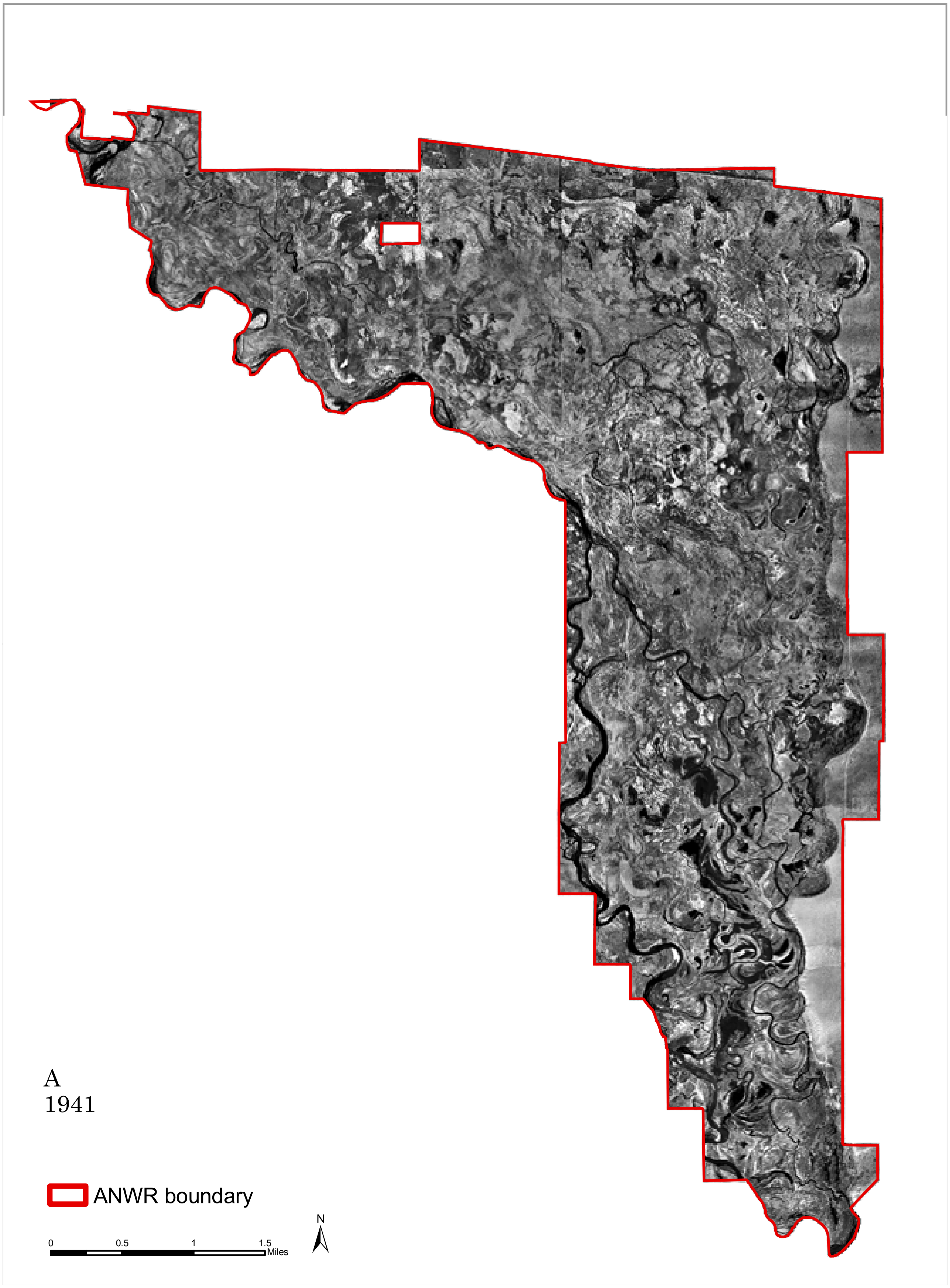

Figure 9. Aerial photographs of the Alamosa National Wildlife Refuge for: A) 1941, B) 1953, and C) 1988.

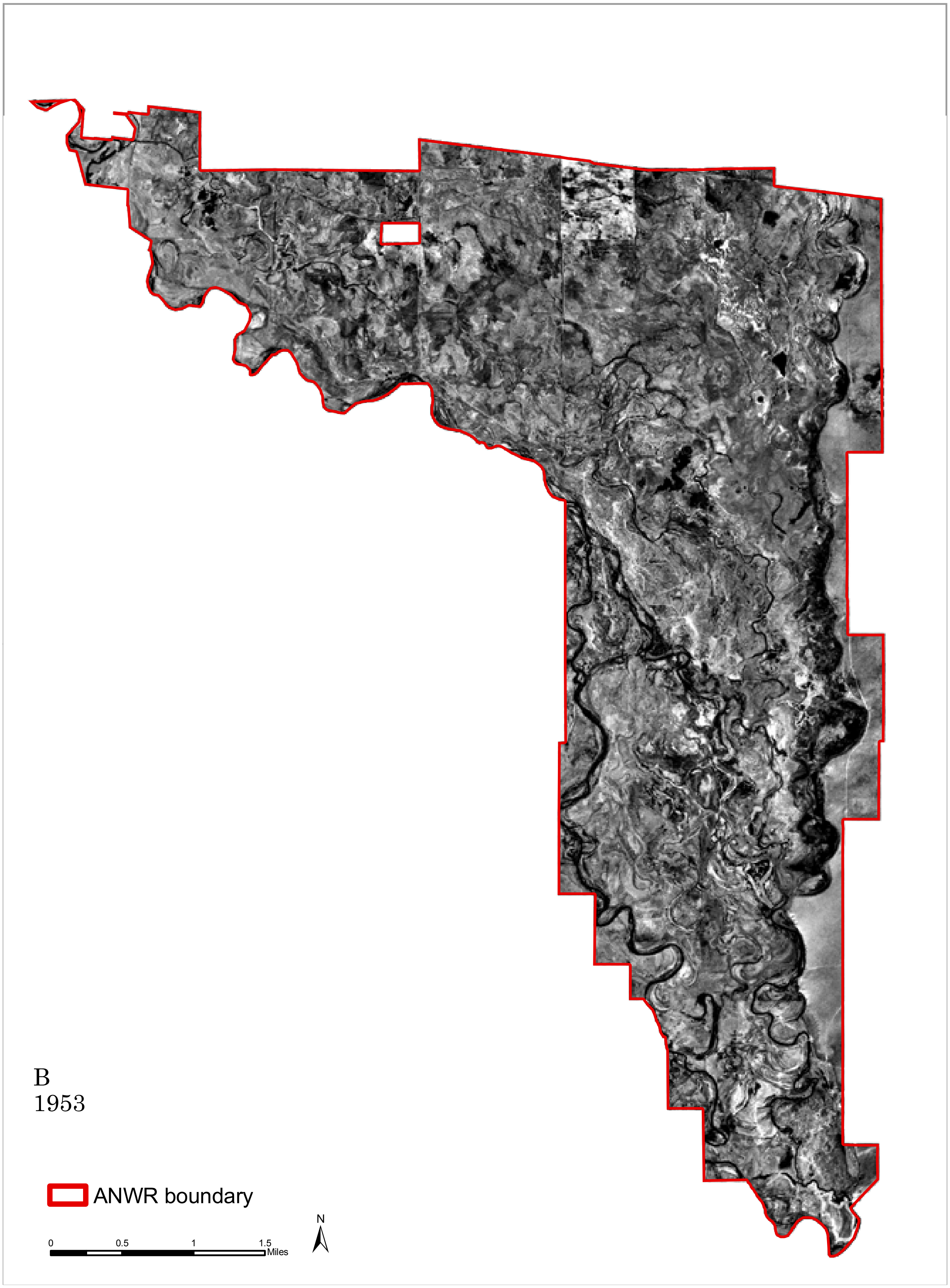

Figure 9, continued. Aerial photographs of the Alamosa National Wildlife Refuge for: A) 1941, B) 1953, and C) 1988.

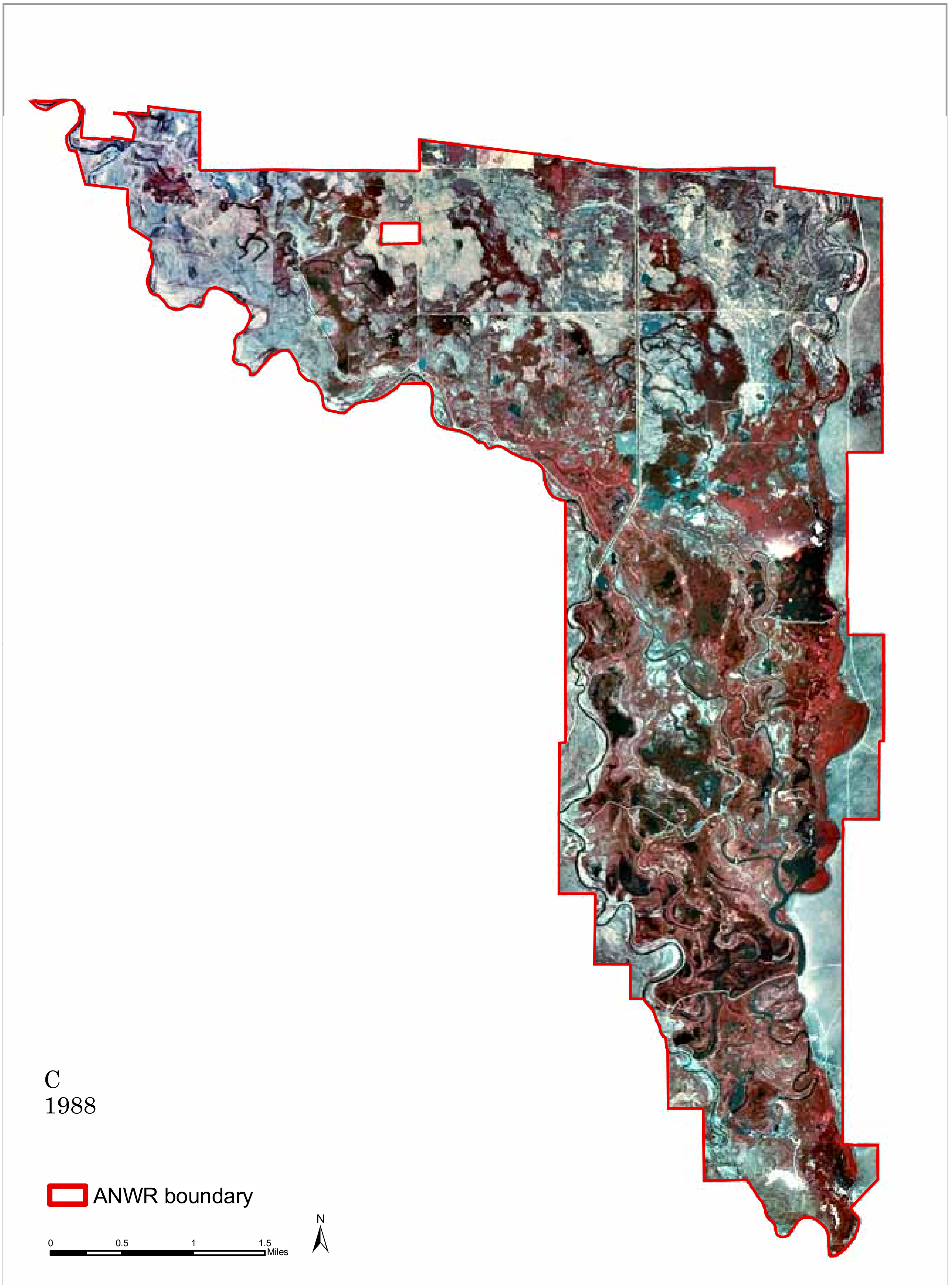

Figure 9, continued. Aerial photographs of the Alamosa National Wildlife Refuge for: A) 1941, B) 1953, and C) 1988.

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

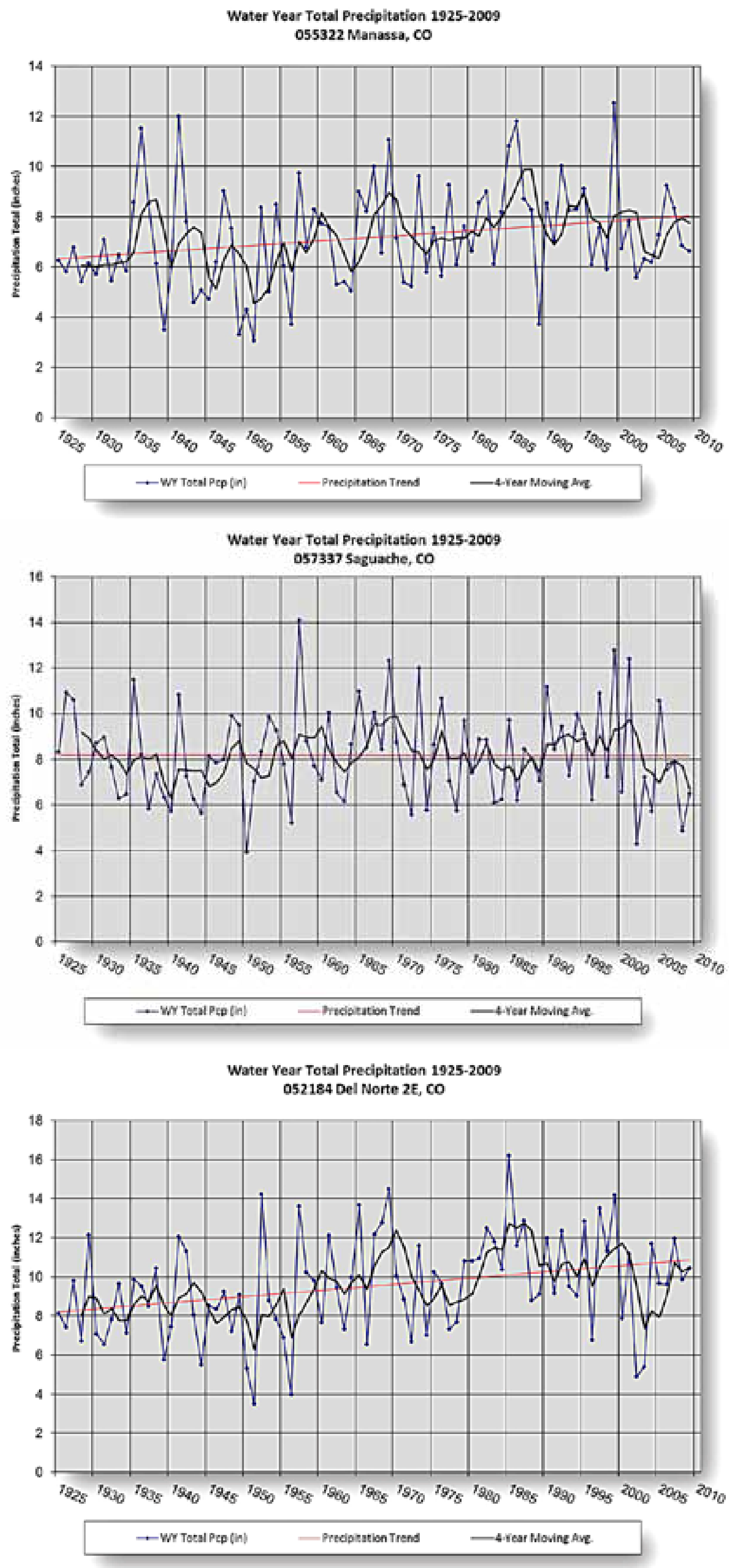

Figure 9 Total Precipitation from 1925 to 2010 at Manassa, Saguache, and Del Norte, CO (U.S. Historical Climatology Network data, taken from Striffler 2013).

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).

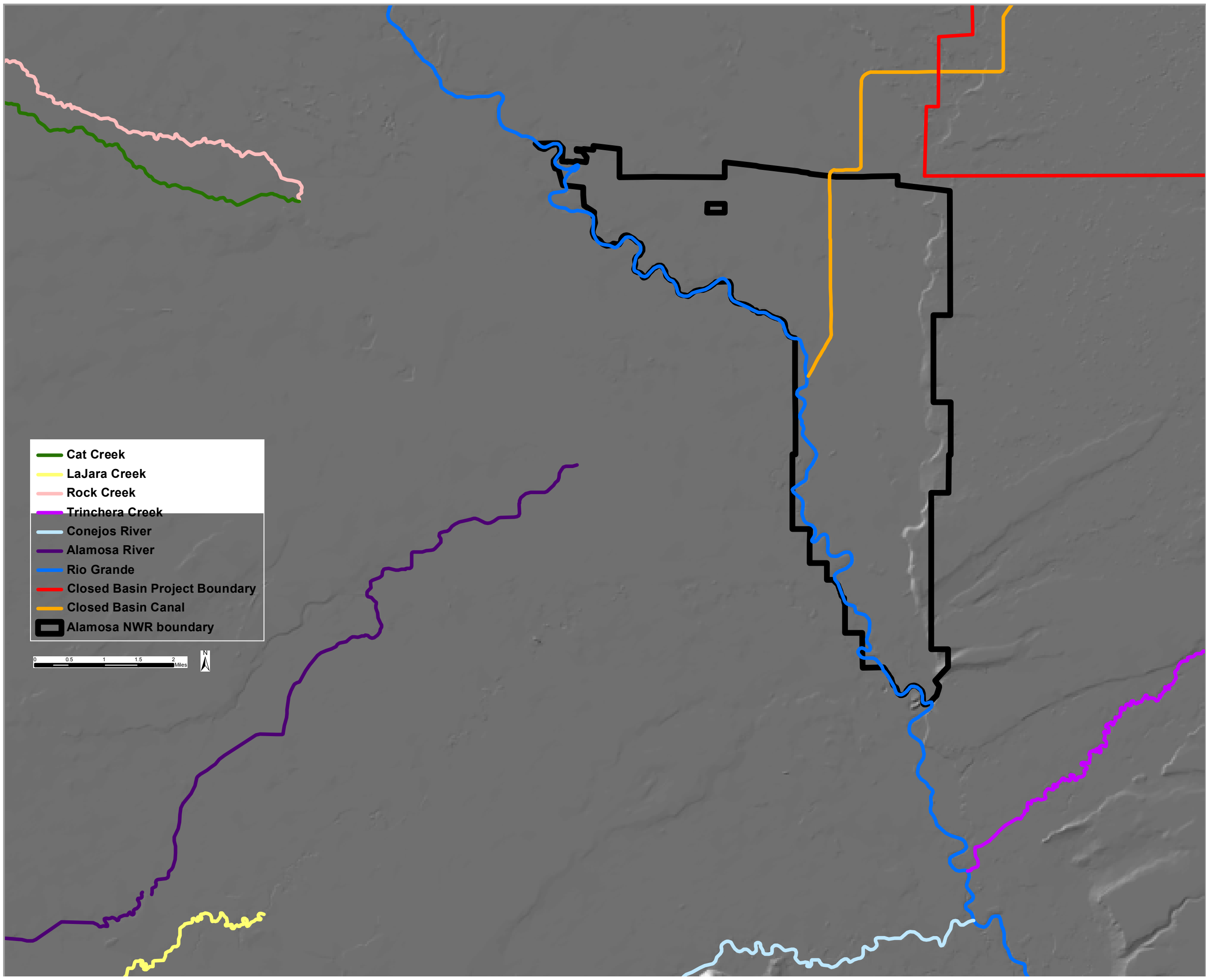

Figure 11. Current location of rivers and creek drainages near Alamosa National Wildlife Refuge.

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

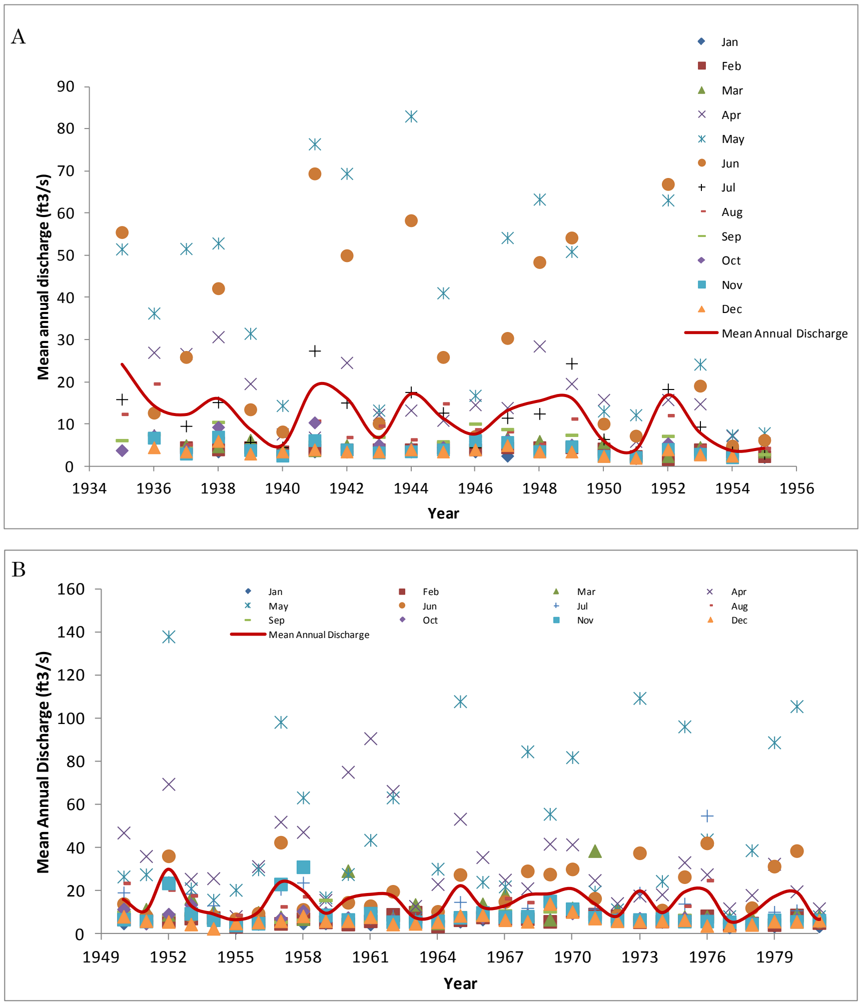

Figure 12. Mean monthly discharge: a) Rock Creek 1935 to 1955 and b) La Jara Creek 1950-1980 (USGS data).

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

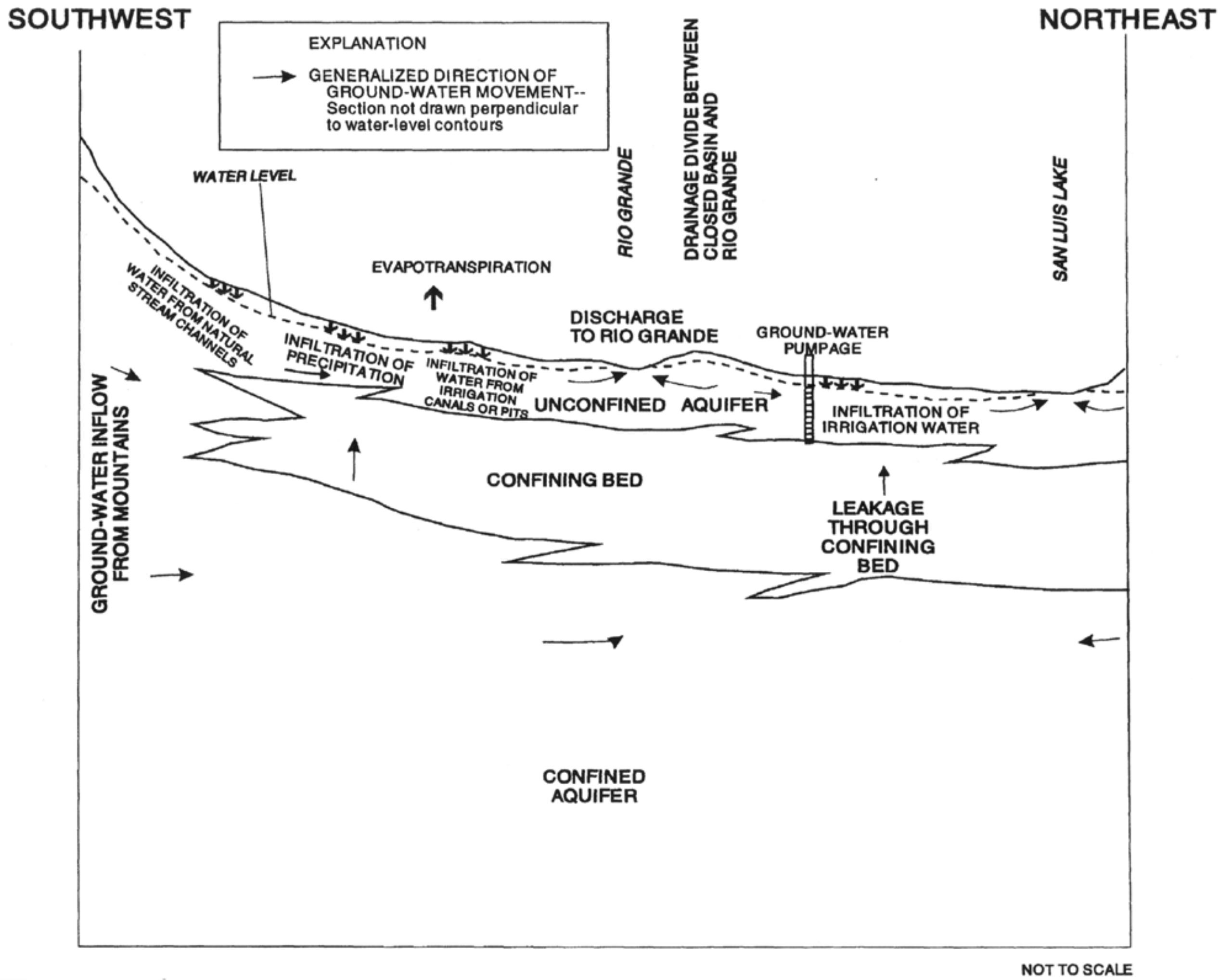

Figure 13. Schematic cross-section of groundwater movement in relation to the unconfined and confined aquifers in the San Luis Valley (modified from Hanna and Harmon 1989).

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

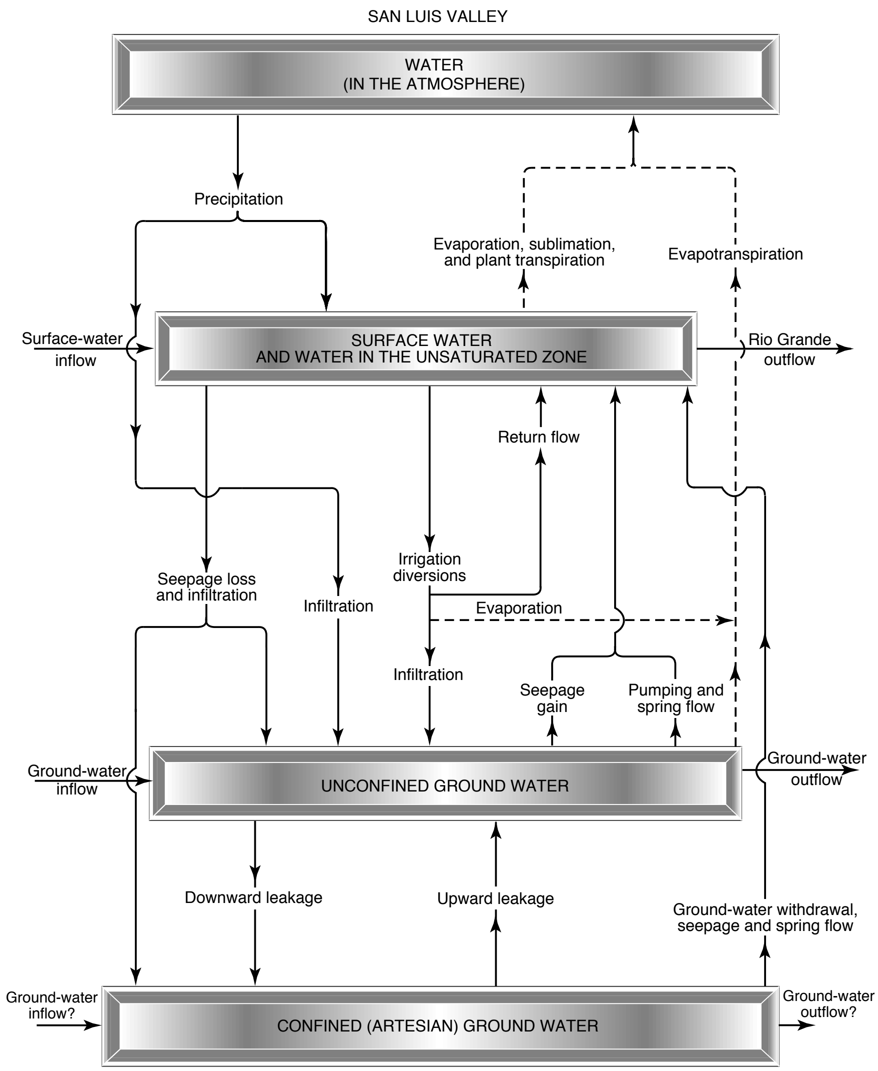

Figure 14. Generalized hydrological flow diagram of the San Luis Valley (modified from U.S. Bureau of Reclamation 1995 and Wilkins 1998).

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-

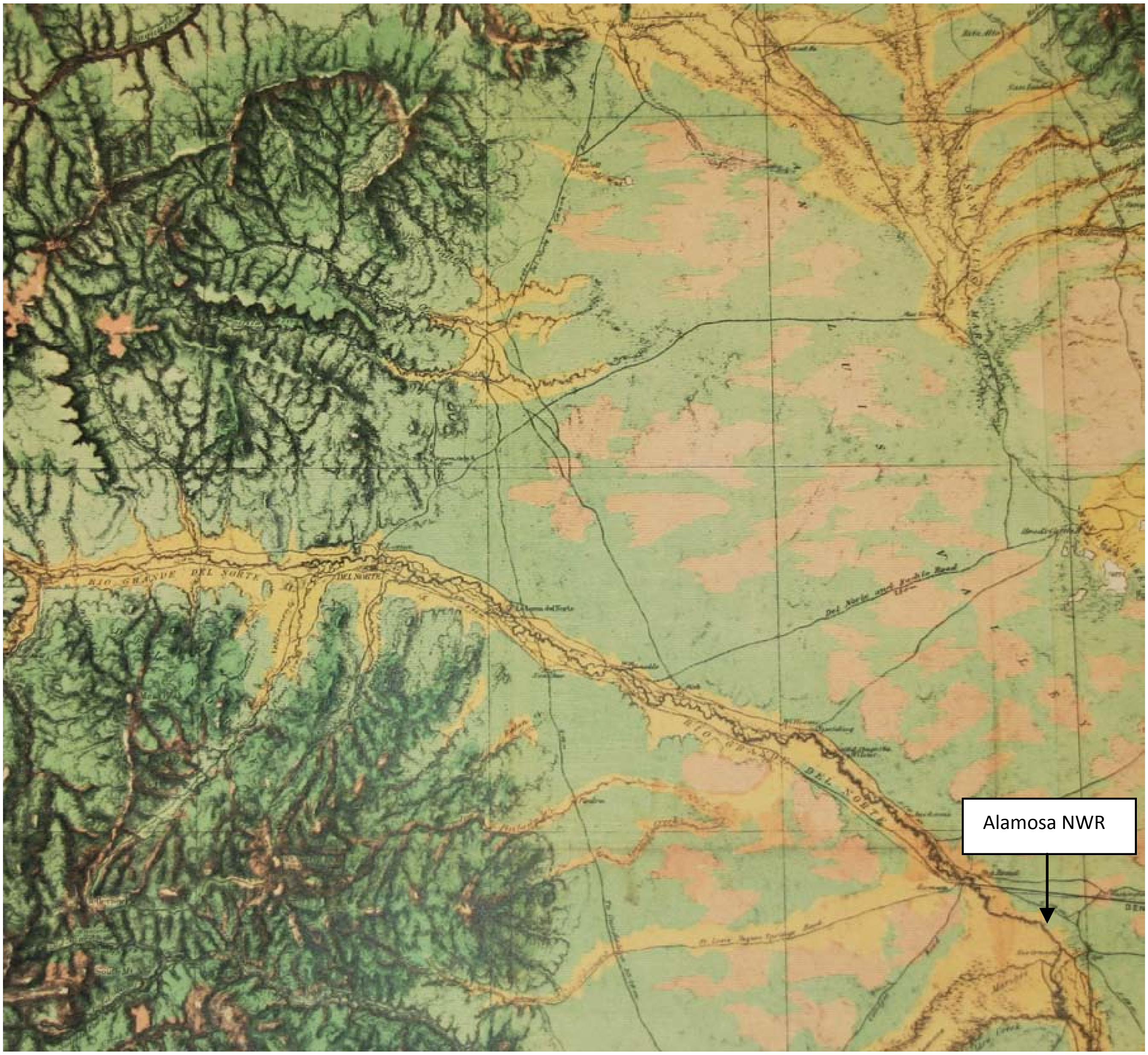

Figure 15. Wheeler Geologic Map of the San Luis Valley depicting land coverages. Yellow= Agricultural (irrigated); Pink= Arid and barren; Light green= Grazing; and Dark green= Timber. From U.S. Geological Surveys West of the 100th Meridian Land Classification Map of Southwestern Colorado: Expeditions 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

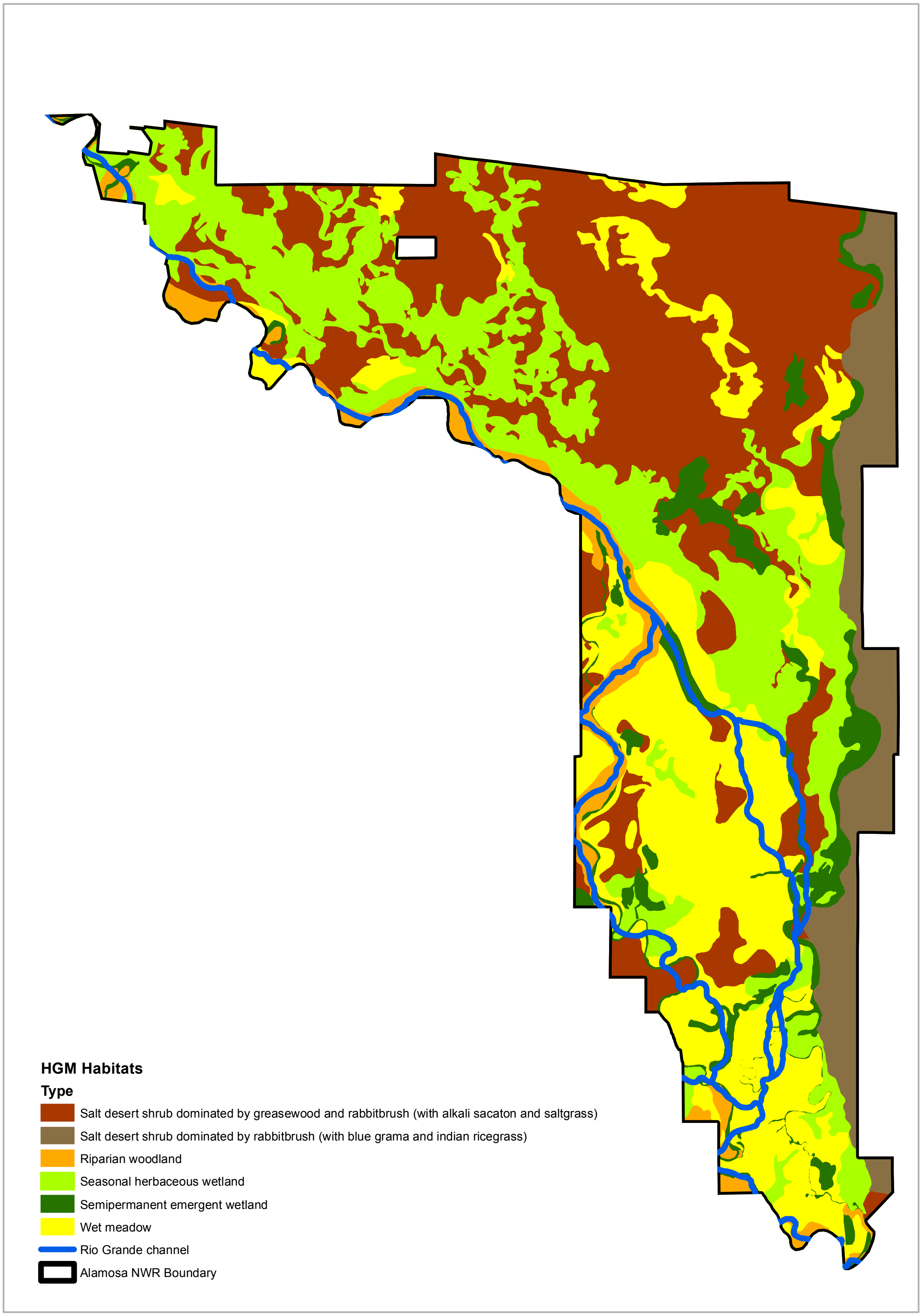

Figure 16. Potential historical vegetation community distribution on Alamosa National Wildlife Refuge (mapped using HGM attribute relationships in Table 5).

CHANGES TO THE ALAMOSA ECOSYSTEM

SLV SETTLEMENT AND LAND USE CHANGES

Native people apparently first occupied the SLV 10,000 to 12,000 years before the present (BP) (e.g., Jodry et al. 1989). These people had a highly mobile lifestyle that depended largely on big game hunting. Native people continued to occupy the SLV thereafter, but populations apparently were relatively small with localized and often seasonal settlements. Many of these camp sites and population centers were along the Rio Grande and former lakes, rivers, and wetlands of the SLV because of the more predictable availability of water, wildlife, and shelter. Inhabitants of the area collected wild plants, hunted large and small animals, and created chipped and ground tools. By about 2,000 BP, human populations in the SLV appear to have increased and small villages were established; evidence of early agriculture is found along some waterways. Pueblo people were attracted to the SLV and they, along with the Comanche, Utes, and other tribes, maintained some occupation of the region through the mid-1800s. Spanish explorers in 1540 found evidence that Pueblo people were diverting water from the Rio Grande in "acequias" or irrigation ditches.

Spanish settlers first entered the SLV between 1630 and 1640 and several Spanish expeditions to the SLV occurred in the 17th and 18th centuries, although extensive settlement did not occur until the 1800s. An excellent summary of European settlement and history in the SLV is provided in Athearn (1975) and Simmons (1999), as excerpted from USFWS (2003). The following historical information comes from these sources unless cited.

The historic territory of "New Mexico" was claimed for Spain in 1598 and Juan de Onate established a base near the confluence of the Rio Grande and Rio Chama. Shortly thereafter, hunting and exploratory expeditions into the SLV occurred and by the 1700s some mining had begun in the mountains around the valley. Bison were hunted in the valley at that time and native people were present (Fitzgerald et al. 1994). Santa Fe was established in 1610 and became the capital of Spain's Northern Province. No permanent town-settlements occurred in the SLV until the 1800s, but the region was controlled by Spain and then the Republic of Mexico until 1860.

Conflicts between the Spanish, Pueblo, and Ute peoples accelerated in the early- to mid-1600s. After the expulsion of Spanish people from New Mexico in 1680, Spain retaliated in 1694, when Don Diego de Vargas reestablished control of Santa Fe. Later Vargas traveled through and established camps in the SLV to hunt bison and elk. Many place names in the SLV came from early Spanish expeditions and people. By the mid-1700s, the Comanche gained power in the Rio Grande Valley and displaced the Ute who lived in the SLV. During the mid- to late-1700s, the controlling government of New Mexico attempted to curtail Comanche raiding parties in the region, including the SLV. The Utes joined the Spanish in combating the Comanche and in 1786, the Comanche were defeated and signed a peace treaty with the Spanish.

From 1780 to the early-1800s, the Utes were the principal claimants to the SLV and Colorado mountains. Other tribes, including the Navajo, Apache, Comanche, Kiowa, Arapaho, and Cheyenne, also visited the valley. Spanish and native people began to trap furs in the nearby mountains at this time and the fur trade expanded markedly after the U.S. gained control of much of the western U.S. via the Louisiana Purchase. Zebulon Pike was dispatched to explore the Rocky Mountain region in 1806. His party established a winter camp along the Conejos River, but was later detained by the Spanish. This was the last U.S.-sponsored expedition into the SLV until 1848, when John Fremont came through the valley in search of a route through the Rocky Mountains.

In 1821, revolution created the independent Republic of Mexico, seceding from Spain. At this time, the former New Mexico territory became a free province and American and Mexican trappers regularly used the SLV as a resting and staging location. While the buffalo trade developed across the West in the 1830s, the SLV was less affected because it had few bison and the Utes defended their hunting territory. Hispanic settlement of the SLV began on Mexican land grants in the late-1840s and early-1850s; most settlers were Spanish missionaries and sheep men (Buchanan 1970). Mexican farmers soon learned that the rivers and creeks were the only areas that could be cultivated and these riparian and floodplain areas also provided the most dependable forage for livestock, which dominated the economy of the area at the time (Holmes 1903). By the late-1840s, scattered settlements were present throughout the SLV. In 1846, war occurred between Mexico and the U.S., which culminated in the Treaty of Guadalupe-Hildalgo in 1848 when the U.S. obtained control over Colorado and other western areas. After the U.S. occupied the southwestern region, settlement, farming, and ranching expanded rapidly in the late-1850s after a network of army posts were established. The Homestead Act of 1862 and the arrival of roads and railroads in the 1860s and 1870s facilitated substantial population growth and influence thereafter (Denver Daily Tribune 1878). During the 1860s, a series of roads were built in the SLV to provide travel north from Fort Garland, Colorado. In 1879 a narrow gauge rail line was constructed to Alamosa, Colorado and agricultural goods were shipped to Denver, Colorado and eastern cities. By the late-1800s, sheep and cattle grazing were extensive in the Valley and valley farms were producing large quantities of potatoes, hay, and peas.

Following major expansion of settlement into the SLV in the mid-1800s, farmers decided that irrigation was necessary for the valley agricultural commerce to survive. The history of efforts to develop means to irrigate SLV lands for agricultural production is extensive and is a classic example of efforts (that occurred repeatedly throughout the Western U.S. where water is limited) to acquire, divert, and use limited surface and groundwater (Siebenthal 1910, Follansbee et al. 1915, Brown 1928, Powell 1958, Buchanan 1970, Emery et al. 1973, Athearn 1975, Hanna and Harmon 1989, Leonard and Watts 1989, BLM 1991, Ellis et al. 1993, Emery 1996, Jodry and Stanford 1996, McGowan and Plazak 1996, Wilkins 1998). This report does not attempt to chronicle the complex water developments, laws and regulations, and past and current attempts to plan and manage irrigation water supplies and diversions throughout the SLV. However, the following is a brief account of some of the major events that ultimately affected water supplies, movement, and uses on Alamosa NWR based on the above references.

The first ditch to move water from local rivers to the interior of the SLV occurred in 1852 with the construction of the San Luis Peoples Ditch. The first large ditch to move water from the Rio Grande, the Silva Ditch, was constructed in 1866 (Holmes 1903). The "Ditch Boom" hit the SLV in the 1880s when many British and eastern investors sponsored construction of canals to provide irrigation water to valley agriculture. Many canals, ditches, and drains now flow to or through the current Alamosa NWR, most notably the Closed Basin Canal (CBC), Chicago Ditch, New Ditch, and San Luis Valley Ditch (Fig. 17). Many of the large canals (excepting the Closed Basin Canal) were completed in the 1880s and 90s, such that 8,000 cfs of surface water was adjudicated by 1890 on the Rio Grande, Alamosa River, La Jara Creek, Conejos River, and San Antonio River. Alamosa NWR, along with the entire SLV, was transformed into an agricultural production region as a result of this infrastructure. Expansion of surface irrigation, an increase in the unconfined aquifer water table, and increases in the amount of salts brought to the soil surface created a need for the development of eight drainage ditches which were established by 1921 (Natural Resource Commission 1938, Thomas 1963). These drains were designed to help prevent salts from accumulating on the soil surface in addition to lowering the artificially raised groundwater table.

The substantial diversion of water from the Rio Grande in the SLV in the late-1800s led to the "embargo" of 1896 and the Rio Grande Convention Treaty of 1906 between the United States and Mexico. The "embargo" ordered by the U.S. Secretary of the Interior prevented further irrigation development of any magnitude in the Rio Grande Basin of Colorado and New Mexico by suspending rights of way across public lands for use of Rio Grande water; the embargo was not lifted until 1925. Under terms of the Treaty of 1906, the U.S. guaranteed an annual delivery in perpetuity of 60,000 acre-feet of water in the Rio Grande at the head of the Mexican Canal near El Paso, Texas. In 1929, a temporary compact for water use and delivery in the Rio Grande was ratified by Colorado, New Mexico, and Texas and in 1938-39 these states ratified the Rio Grande Interstate Compact, which provides for apportionment of the water of the Upper Rio Grande Basin on the basis of specified indexes of flow at key gauge stations (Rio Grande Compact Commission 1939). This Compact greatly influenced diversion of water from the Rio Grande in the SLV and subsequent development of surface and groundwater infrastructure that has affected Alamosa NWR.

The active channel of the Rio Grande has been, and continues to be, altered by in-stream structures and diversions of river water to many irrigation canals and ditches. Many portions of the Rio Grande channel in the SLV have been straightened and stabilized to ensure use of various water rights. Around 1925, the Rio Grande channel was stabilized by a couple of high water events that have caused avulsions since that time (Jones and Harper 1998). River structures and diversions that specifically impact Alamosa NWR include the Chicago and New Ditch Diversions that have decrees from 1896 and 1903, respectively (Colorado Decisions Support System, accessed at http://cdss.state.co.us/onlineTools/Pages/WaterRights.aspx). These specific structures, along with many others along the Rio Grande have altered the rate, timing, and distribution of river flows (see, e.g., Zeedyk and Clothier 2009); changed the velocity, sediment load, and water quality in the river (MWH 2005); and altered the distribution of vegetation communities associated with historical and current floodplain wetlands and uplands (Siebenthal 1910, Ramaley 1942, Bunting 2012).

Agricultural production in the SLV also was enhanced by drilling thousands of wells into both the shallow unconfined and the deeper confined aquifers underlying the area. Wells in the unconfined aquifer are subject to annual variation related to variable recharge rates from infiltration of local precipitation and runoff. By 1980 about 2,300 pumped wells existed in the unconfined aquifer in the SLV (Emery 1996). In contrast, wells drilled into the confined aquifer are artesian and not subject to highly variable annual climate and precipitation fluctuations. Artesian water under the SLV was

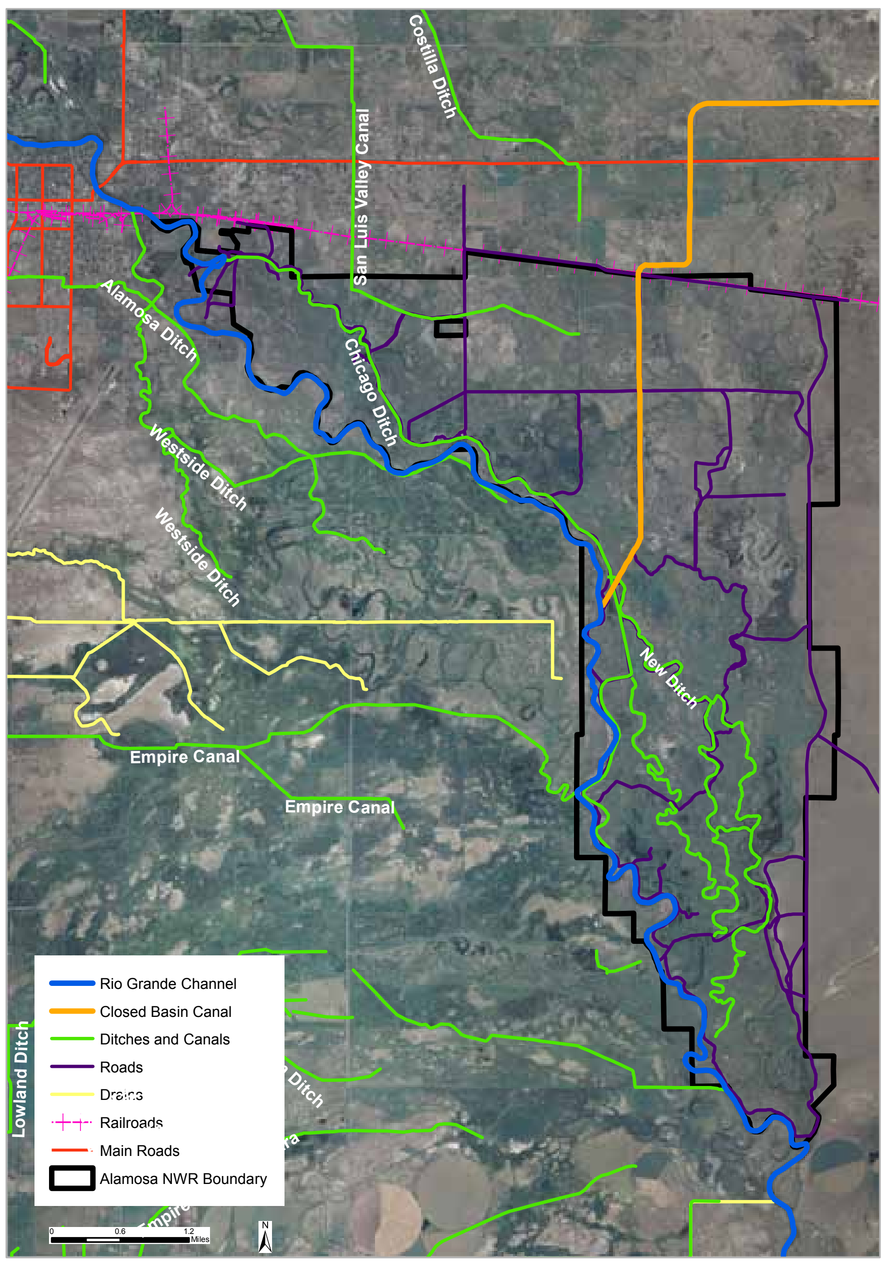

Figure 17. Location of roads, canals, ditches, drains, and rivers in and around Alamosa National Wildlife Refuge.

discovered about 1887 and within four years about 2,000 flowing wells had been developed (Emery 1996). By 1904 more than 3,200 artesian wells had been drilled and by 1916 about 5,000 artesian wells were present and flowing in the SLV (Follansbee et al. 1915). By 1970 that number had increased to over 7,000 wells. Well pumping typically causes the unconfined aquifer to be seasonally lowered; the last time this aquifer was at or near capacity was between the mid-1980s and the mid-1990s, which coincides with one of the wettest periods in the last 1,000 years (Grissino-Mayer et al 1998). Pumping from the confined aquifer has continually depleted aquifer storage which has not been at capacity since the early-1950s (http://www.waterinfo.org/taxonomy/term/1620). Over time and through 2012, many wells have declined in artesian pressure or have completely stopped flowing due to mining of the aquifer and continued drought conditions.

CONTEMPORARY HYDROLOGIC AND VEGETATION COMMUNITY CHANGES AT ALAMOSA NWR

Water Sources

Alamosa NWR was established in 1962 under authorization of the Migratory Bird Treaty Act (USFWS 2003). Immediately prior to establishment, the refuge area was predominantly used for pasture and hay by private owners and ranchers (USFWS 1962). At that time, ditches and drains connected to the Rio Grande were used to flood-irrigate pastures in the spring and to remove water in summer for haying. Upon acquisition of refuge lands, several permittee reservations existed for haying and grazing that prevented immediate changes in water and land management (refuge annual narratives). As the reservations expired, refuge managers began upgrading ditches and water-control structures to change the timing and periodicity of irrigation (Table 6).

With the onset of meeting Compact regulations in the late-1960s, major changes occurred in the timing, distribution, and availability of water resources throughout the SLV, which impacted Alamosa NWR (e.g., Emery 1996), as less water was diverted from the Rio Grande in Colorado so that agreed water discharges could reach the New Mexico state line. Although more water was left in the river after the Compact was being enforced, the timing and amount of river flows have been altered from historical patterns as the state of Colorado releases, or diverts, river water in different amounts based on the total amount of water to be sent to New Mexico and Texas and the timing of irrigation season. A series of reservoirs near the headwaters of the Rio Grande control downstream river flows and Colorado's senior and junior surface water right appropriations divert much of the river upstream of the Alamosa NWR. At times, the Rio Grande itself has discontinuous flows resulting from the large diversions of river water upstream for irrigation.

Water in tributaries of the Rio Grande on or near Alamosa NWR also have been diverted such that water from Rock Creek, La Jara Creek, and the Alamosa River no longer directly reach the Rio Grande due to diversions on those systems. As an example of these changes, the Alamosa River with headwaters near the Continental Divide, is regulated by Terrace Reservoir completed in the 1920s within the Alamosa Canyon in the San Juan Mountains. Surface water from the Alamosa River is diverted into many different ditches with surface and subsurface flow into La Jara Creek and Rock Creek. The Alamosa River contains 38 diversion structures and is considered fully allocated at its intersection with the Empire Canal at Hwy 285 south of Alamosa NWR, with little or no current stream flow past this point (Ford and Skidmore 1995, Figs. 11, 17). A total of 113 water right priority numbers on the Alamosa River incorporate 1,354 cfs, but there is only enough water to fill roughly half of the water right diversions annually (MWH 2005). Throughout the irrigation season, the Alamosa River has inconsistent flows and variable chemistry resulting from return flows from ditches, runoff, and inputs from tributaries. Operation of the Summitville Mine from 1986 to 1992 included open pit and cyanide leach methods, which led to a settlement over impacts to the Alamosa River and the mine's designation as a Superfund Site (MWH 2005). Since that time, contamination from the effects of the mine tailings has diminished, but irrigation return flows and drains may still alter water chemistry. For example, pH increases as the Alamosa River moves east of Hwy 15 towards the Alamosa NWR (Ford and Skidmore 1995).

In 1936, the "Closed Basin Project" was proposed (Natural Resource Committee 1938), but was not authorized for construction until the 1970s to help the state of Colorado meet Rio Grande

Table 6. Summary of water developments and management of Alamosa NWR 1962-2011 taken from refuge annual narratives and conversations with refuge staff.

Year	Location	Development Activities
1965	New Ditch	Head gates and crossing installed
	Rio Grande	10 missile tubes installed with canal checks
	Tract 14	Installed a dike and water-control structures
1966	Tract 11, 15, and 21	New structures installed
	Chicago, Lowry, New Ditches, and Rio Grande	Installed water-control structures
1967	Stewart Tract	Water level control established in old channel along the bluff
	Costilla Ditch	3 way water-control structure installed
	New Ditch	Flume installed near water recorder clock house
1968	Rio Grande	5 missile tubes installed at New Ditch diversion
	New Ditch	Breached in June, repaired to allow water to be diverted to Tracts 10, 11, and 13
	New Ditch	Overflow bypass installed
	Chicago Ditch	New head gate installed
	Tracts 10, 11, and 20	Dike and roadway built up
	Tract 14	1700' of roadway was raised and repaired with 2 new water-control structures
1969	Costilla Ditch	Installed 3 new structures and a lateral ditch
	Chicago Ditch	Breached dam twice
	Chicago Ditch	Dam repaired and 30 new tubes were installed, 5 with screw gates at the east end, 2' too high
	Tracts 11, 14, 14a, and 17	Installed 6 new water-control structures
	Tract 17	Dug a new ditch
1970	Chicago Ditch	8 new structures installed to check water for diversion in Bagwell-Sowards lateral
	New Ditch	Dam breached, repaired and spillway tripled in size
1971	Chicago Ditch	Installed 6 check structures
	Mumm lateral	Installed 2 new structures
1972	Bagwell-Sowards Tract	Installed 12 new water-control structures
	Chicago Ditch	Installed a check and crossing with 3 30" missile tubes
	Rio Grande	Hauled 17 loads of concrete chunks to a bend north of Parking area #3 that was washed out
1973	Lillipop Ranch	Two old water-control structures combined into one
1975	Chicago Ditch	Installed a 6' bypass in the dam
1977	Rio Grande	3 sections of river bank were stabilized however contractor took out 10 times the amount of material needed
1979	Chicago Ditch	Rehabilitation of the ditch and construction of a lateral as well as leveling an 80 ac parcel that will be irrigated with this water
	Rio Grande	Stabilization of the river along 1300' of bank
	New Ditch	Removed and rebuilt the diversion
	Mumm Ditch	Rehabilitation of the ditch
1980	Chicago Ditch	Installed 25 new structures
	Artesians	Potholes dug around the artesians
1981	Mumm Ditch	Construction of a 3,000' dike, 12' to and 24 water-control structures
	Lowry Ditch	7,300' of dike and ditch rebuilt
1983	Closed Basin	Construction
	Andrews lateral	3 way diversion added in first lateral to the south
	Costilla Ditch	New diversion at lower end
	Farm field	Construction of 1,580' of 15" pvc pipe in a raised ditch to the field
1984	Closed Basin	Continued construction; 8 new borrow areas with structures for diversion
	New Ditch	3 to 4" thick cement cap poured on overflow spillway

Cont'd. next page

Table 6., cont'd

Year	Location	Development Activities
	Farm field	Construction of 1,580' of 15" pvc pipe in a raised ditch to the field
1984	Closed Basin	Continued construction; 8 new borrow areas with structures for diversion
	New Ditch	3 to 4" thick cement cap poured on overflow spillway
1985	New Ditch	Installation of new water-control structures in headwall
	New Ditch	Overflow bypass rebuilt after high water
1986	Closed Basin	Lateral ditch reconstructed to deliver water to the east
	Chicago ditch dam	Reconstructed with river bottom sediments
1987	Lillipop Ranch	10 water-control structures replaced
1988	Lillipop Ranch	250' dike reconstructed and water-control structure installed
	Chicago Ditch	Installation of new water-control structure
	South end of refuge	5 dikes were reconstructed
1990	Pumping plant moist soil unit	30 ac moist soil unit developed next to Closed Basin Pump
1991	Pumping plant moist soil unit	Dike constructed to divide 30 ac moist soil unit
1992	Closed Basin	BOR constructed emergency spillway near the end of canal
1998	Auto Tour loop?	DU project
2000	Units C and D	DU project with new dikes and water-control structures
2005	Unit N	Burned and herbicided for phragmites and tall whitetop control
2011	Unit O	9 water-control structures replaced
2011	Rio Grande	Relocation of Rio Grande active channel and diversion for the New Ditch and installation of J hooks

Compact requirements for water flow into New Mexico and Texas. As part of the Closed Basin Project, a series of shallow groundwater wells were drilled to provide "salvage" water through the CBC constructed within the Closed Basin along the eastern portion of the SLV to the Rio Grande. To mitigate for wetland loss caused by decreases in water tables near these wells and for the construction of the CBC, Alamosa NWR receives an average of 1,613 acre-feet/year of water from the CBC (Striffler 2013). The CBC enters the refuge at the northern boundary and bisects the refuge terminating at a pump station on the Rio Grande in the west-central portion of the refuge (Fig. 17). The following three diversion points on the CBC distribute water to the refuge; 1) the pumping station, 2) Mumm ditch Constant Head Orifice (CHO), and 3) Chicago ditch CHO (Striffler 2013).

Water from the Rio Grande currently is diverted through Alamosa NWR by four major ditches: 1) Chicago, 2) New, 3) Costilla, and 4) San Luis. Total average diversion from the Rio Grande to Alamosa NWR is about 15,000 acre-feet/year with most water delivered through the Chicago Ditch. Water delivery and distribution on the refuge currently is facilitated by approximately 51 miles of ditches, canals, and levees with 234 water-control structures consisting mostly of flashboard risers and corrugated pipes (Striffler 2013). The Costilla and San Luis Ditches often do not provide water in dry years because of their location in the ditch network and a junior appropriation status. For example, the Costilla ditch did not provide any water to the refuge in 5 of the last 15 years (Striffler 2013).

The last point of water diversion on the Rio Grande in Colorado is the New Ditch Diversion on the Alamosa NWR (Fig. 18). This New Ditch Diversion was initially an earthen dam installed across the active channel of the Rio Grande (Striffler 2013). Head gates and water-control structures on this diversion and ditch system were installed in 1965 by the USFWS. Some of this installation was new, and some were replacements of old infrastructure (refuge annual narratives, Table 6). Breaches and repairs of the New Ditch Diversion infrastructure occurred in 1968, 1970, 1979, 1985, 2000, and 2010 (Table 6; refuge annual narratives; Scott Miller, personal communication). Other repairs also may have occurred between 1994 and 2000, however, limited information exists for this time period. In 2000, the diversion was damaged and inoperable until repaired in 2010. Recent modification of the New Ditch Diversion system included moving the diversion downstream from its old location, rerouting the active channel of the Rio Grande, and placing cross-vein and weir in-stream structures in the river (Fig. 18). These new structures were intended to slow river flow, promote deposition of sediment, increase the bed level of the active channel over time, allow fish passage, and allow for diversion of the refuge water right (Alamosa NWR staff, personal communication). Average to low spring river flows in 2010 and 2011 damaged the in-stream structures and required extensive repairs. Current water rights associated with this diversion include four different appropriations, ranging from 2.61 to 20 cfs (Simpson 2013).

In addition to water diversions of rivers and creeks, groundwater resources in the SLV also began to diminish in the mid-1900s because of the expansion of center-pivot irrigation systems (Emery et al. 1973, Emery 1996). In the early-1970s, the Colorado State Engineer placed a moratorium on new wells drilled into the confined aquifer in the SLV. Since 1981, no well construction permits for new water appropriations, other than exempt domestic wells, have been issued in the SLV. When the USFWS acquired Alamosa NWR, it received appurtenant water rights. A maximum of 1,541 acre-feet of water/year is supplied from groundwater, almost entirely from the Mumm Well (USFWS 2003). In the 1980s, the Mumm Well had a court "change-of-case" to allow this water to be used year-round (refuge annual narratives), which is an exception to most other wells in the SLV that are subject to an irrigation season use.

The Colorado State Engineer currently is in the process of promulgating new rules and regulations that will affect future groundwater use throughout the SLV, including on Alamosa, Monte Vista, and Baca NWRs. At this time only one groundwater sub-district has been officially formed, with other sub-districts waiting for more information from the state before moving forward. Of great importance is the determination of groundwater depletions caused by wells given their depth and location. This information is still being analyzed, thus, it is difficult to project exactly how water resources on Alamosa NWR will be impacted. Regardless, local water tables and aquifer levels in the SLV continue to diminish as groundwater pumping overdrafts aquifers. For example, current groundwater-levels have been described as below normal and much below normal at a monitoring well

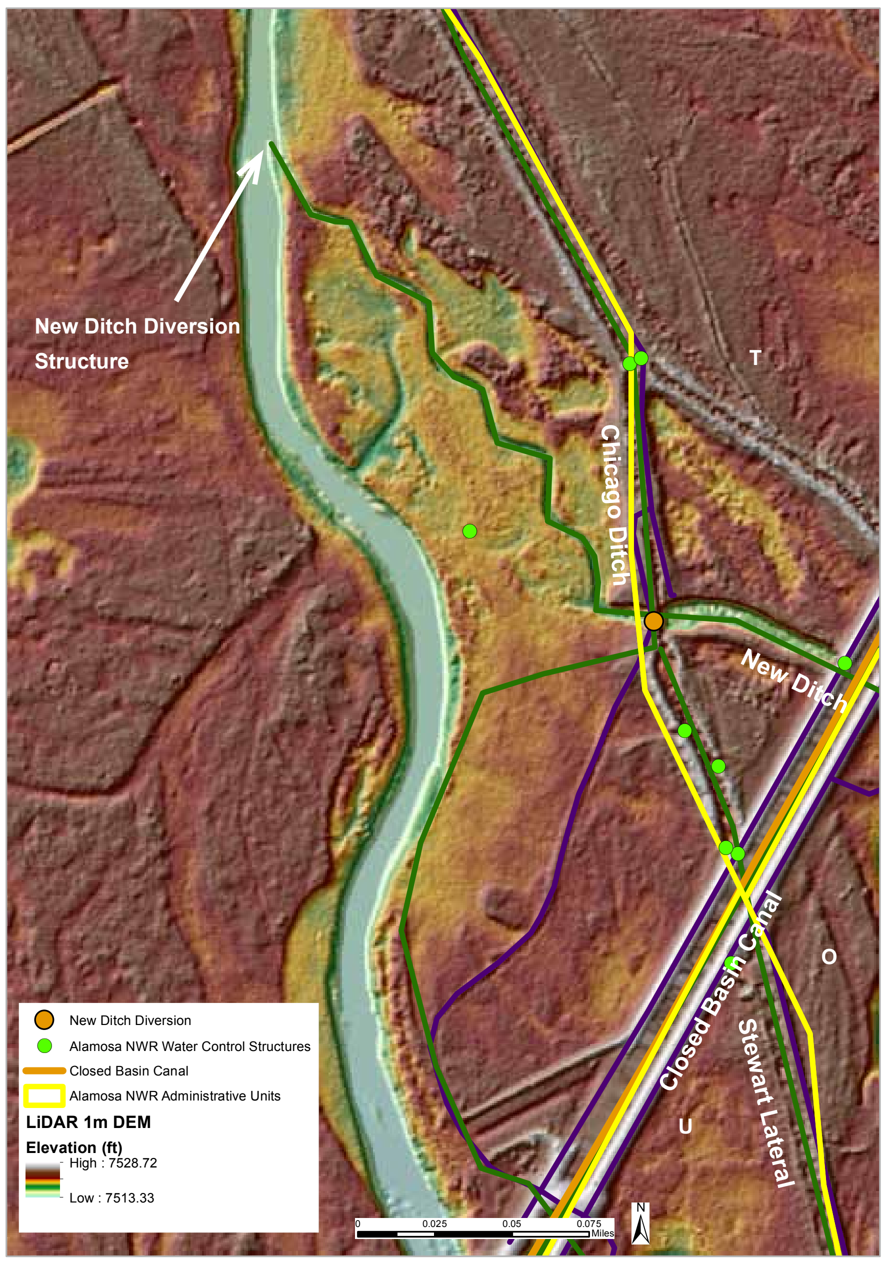

Figure 18. Location of the New Ditch Diversion that diverts water from the Rio Grande River onto Alamosa NWR.

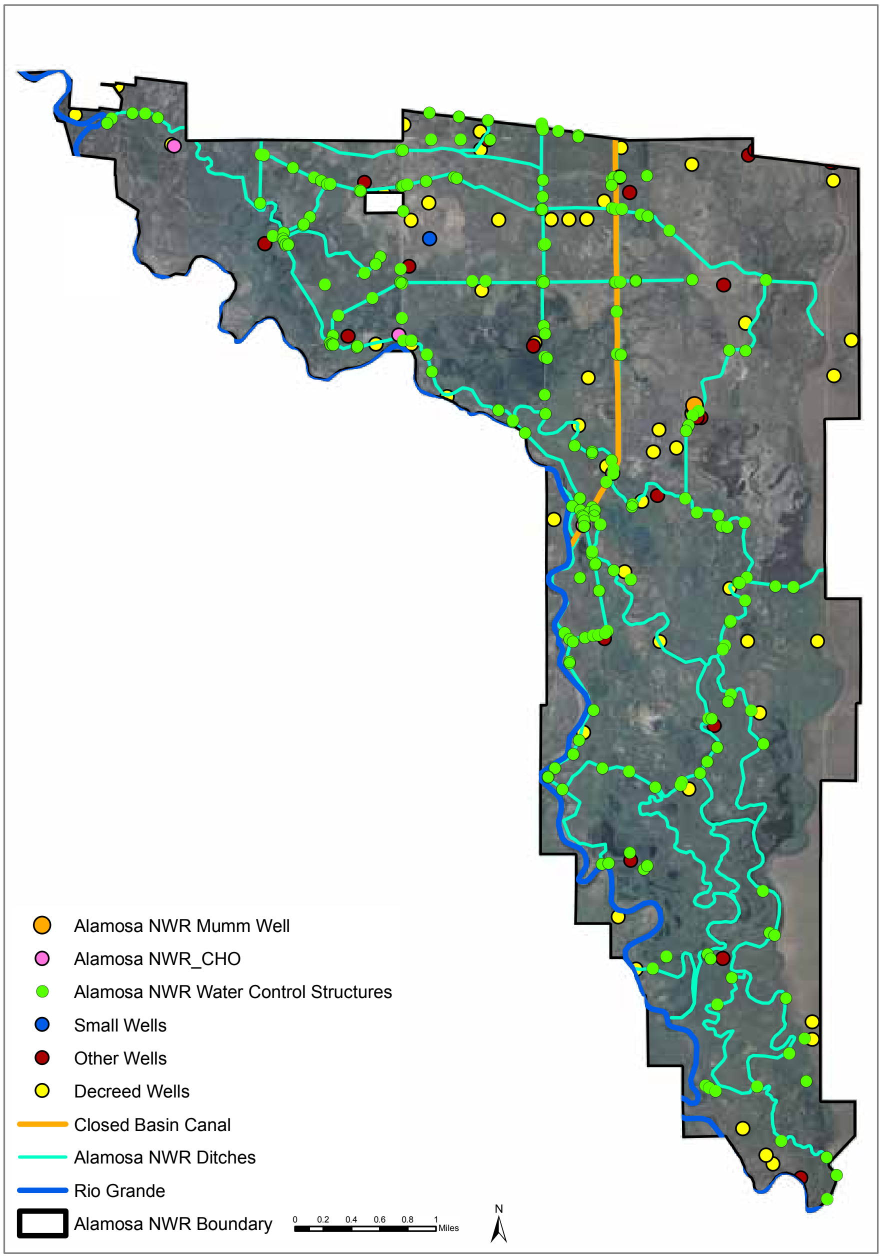

Figure 19. Water delivery infrastructure and wells on Alamosa NWR.

located on the Alamosa NWR (USGS groundwater watch website, Site Number: 372550105455001 – NA03701122CC1 ALA 4). This overdraft has been exacerbated by drought conditions over the past ten years, when little to no recharge into the aquifer has occurred. A recent study documented that aquifer levels in the west-central part of the unconfined aquifer dropped by approximately 450,000 acre-feet in 2012 (Rio Grande Water Conservation District and Davis Engineering Service, Inc. 2013). For example, groundwater Sub-District #1 in the Closed Basin area just north of Alamosa NWR lost approximately 120,000 acre-feet of water in the aquifer despite reducing groundwater pumping by 250,000 acre-feet in that area in 2012 (Steve Vandiver, personal communication). Many of the wells throughout the SLV have seen large reductions in flow or have completely stopped flowing because of the extreme low levels of the unconfined aquifer. Upon promulgation of new groundwater rules, options will exist as to how groundwater depletions may be augmented on Alamosa NWR. For example, use of the Mumm Well may require augmentation by reduction of surface water use on one or more of the SLV NWR's (Striffler 2013).

Currently, Alamosa NWR has 74 groundwater wells (Fig. 19), most of which are artesian wells that discharge less than 50 gallons/minute (gpm). The large Mumm Well produces discharges up to 2,865 gpm. The Mumm Well is a warm-water well that can reach 85° F, which helps provide some open water habitat on the refuge in winter. The refuge water right for the Mumm Well is limited to 1,541 acre-feet/year (Striffler 2013). Six wells that are appropriated for over 50 gpm are present on the refuge, but they are un-metered and currently do not flow. Sixteen of the small artesian wells are strictly for monitoring purposes and do not contribute water to the refuge. Total annual water use (surface and groundwater) on Alamosa NWR has varied from less than 1,500 to more than 26,000 acre-feet over the last 42 years (Fig. 20).

A detailed summary of the quality of water entering Alamosa NWR is provided in the recently completed Water Resources Inventory Assessment (WRIA) for the refuge (Striffler 2013). Generally, water quality at Alamosa is good. Potential sources of contamination include surface water diverted from the Rio Grande, groundwater from the confined and unconfined aquifers, and "salvage" water from the CBC (Striffler 2013). For example, Environmental Protection Agency (EPA) assessment data for the Rio Grande lists impaired conditions from cadmium and zinc below Willow Creek and copper from Del Norte to Monte Vista; the sources of these contaminants is likely abandoned mine lands (EPA 2008). Mean concentrations of beryllium cobalt, iron, and manganese measured in the Rio Grande immediately upstream of Alamosa NWR and in ditch water on the refuge can exceed sediment guidelines and mean boron concentration has exceeded dietary levels for waterbirds (Archuleta 1992). Water in wetlands studied at Alamosa NWR that receive Alamosa River water has higher concentrations of copper and zinc than wetlands receiving water from other sources, and accumulation rates of copper and zinc that receive Alamosa River water are two to four times higher than wetlands that receive Rio Grande Water (Archuleta 1997). Shallow groundwater quality is degraded in many areas of the San Luis Valley (Anderholm 1996); however contamination is not likely at the Mumm Well because of its relative isolation (Striffler 2013). Water in Closed Basin Project salvage water has an historical trend of high total dissolved solids (TDS) and water in the CBC must meet a water standard of 350 ppm TDS to be delivered to the Rio Grande (U.S. Bureau of Reclamation 2003).

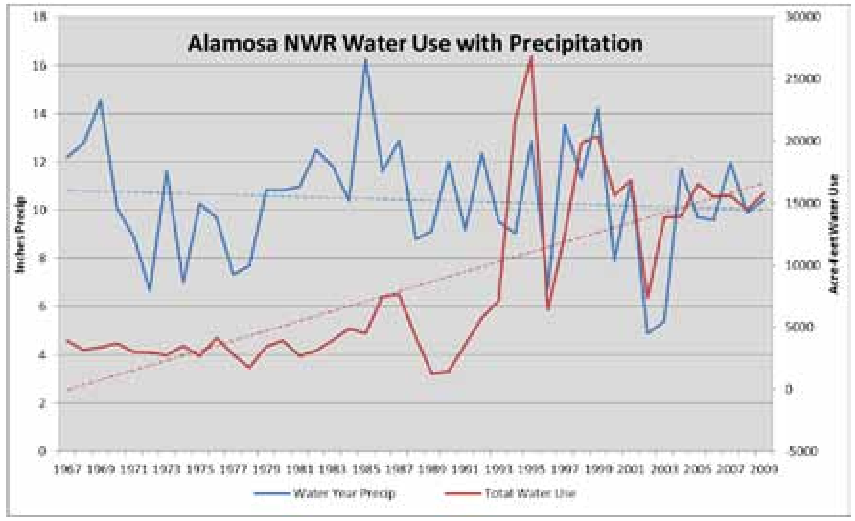

Figure 20. Alamosa National Wildlife Refuge water use and annual precipitation from 1967 to 2009 (from Striffler 2013).

Refuge Water and Habitat Management and Ecosystem Changes

Annual narratives for Alamosa NWR chronicle the many water management issues on the refuge through 1994 (Table 6). Water delivery infrastructure existed on the refuge prior to acquisition, however, much of the system was in a poor to failed condition. Replacement or installation of new water-control structures began in 1965 soon after the refuge was established. Missile tubes in combination with canal checks were some of the first water-control structures used within the active channel of the Rio Grande. Through the years missile tubes were installed in various other locations such as the Chicago and New Ditches (Table 6). Many other types of structures, ditches, roads, and levees/dikes were built throughout the tenure of the refuge to facilitate water management. Generally, since the late-1960s, priorities for water management on the refuge have been to provide water and cover resources for breeding ducks. This management emphasis was fostered by the attraction of high numbers and densities of breeding dabbling ducks to flooded wetlands on the newly established nearby Monte Vista NWR in the 1950s (Gilbert et al. 1996). Long-term studies of nesting ducks indicated generally good nesting success and recruitment of young from Monte Vista NWR. These studies encouraged annual flooding of wetland units and expansion of Baltic rush and other short emergent wetland species on both Monte Vista and Alamosa NWRs. Some areas on Alamosa NWR also were planted to small grains, and predator control occurred on the refuge to improve duck nesting success (refuge annual narratives).

The typical water management on Alamosa NWR has not changed since the mid-1960s. Generally, artesian groundwater flows from the Mumm Well and CBC water has been diverted throughout the eastern and southern portions of the Alamosa NWR in February and March (Striffler 2013, refuge annual narratives). This early water provides roosting and loafing habitat for waterfowl, foraging and pair habitat for breeding waterbirds, and irrigation of nesting cover, especially Baltic rush. During April through mid-June, over 6,000 acres of wetland units on Alamosa NWR traditionally have been irrigated using surface water diverted from the Rio Grande through the Chicago, Costilla, New, and San Luis Ditches; the CBC; and the Mumm Well. This water is diverted to units via lateral diversion

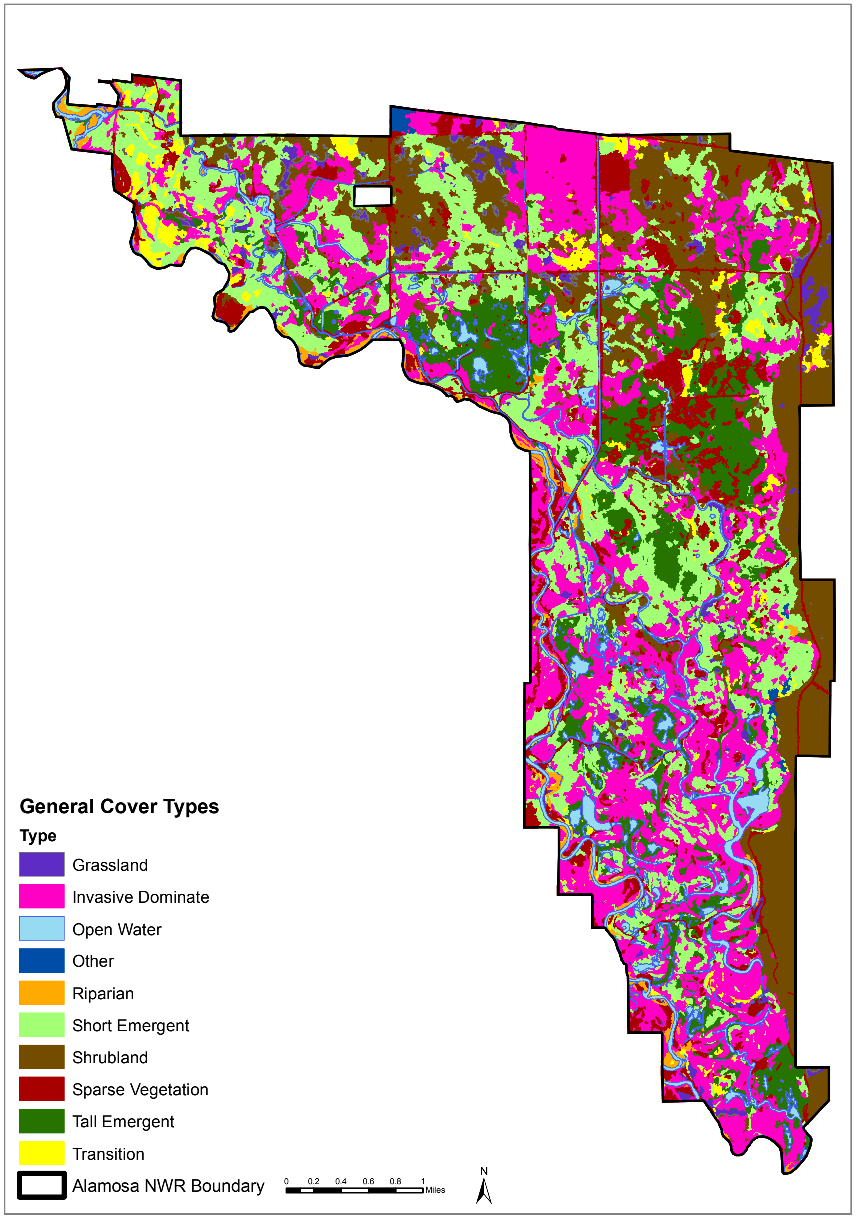

Figure 21. Current general vegetation type coverage on Alamosa National Wildlife Refuge.

ditches and water-control structures (Figs. 17, 18) and is used to provide nesting and foraging habitat for breeding ducks and waterbirds and irrigation of nesting cover. From mid-June to August, about 4,600 acres of wetland units are shallowly inundated similar to water diversions conducted in April and May to provide nesting and brood rearing habitat. During September and October about 5,500 acres are flooded using Rio Grande water through the Chicago Ditch, the CBC, and the Mumm Well. This water provides loafing, roosting, and foraging habitat for fall migrant sandhill cranes, waterbirds, and waterfowl, along with providing some hunting opportunity. From November through January, some water may be used from the CBC or Mumm Well to provide open water for wintering waterfowl or to create sheet ice that will contribute to surface flooding for early migrants the following spring.

The many changes to the natural hydrologic regime (timing, distribution, duration, and frequency) at Alamosa NWR have negatively affected the distribution and extent of native vegetation communities. As early as 1910, Siebenthal (1910) noted that lands in the SLV that were "broken out" for agricultural production were left fallow and had begun to revert back to upland shrub, namely greasewood. The 1938 Natural Resource Joint Investigation Report (Natural Resources Committee 1938) indicates that the amount of land being sub-irrigated in the SLV had increased substantially by that time, which was altering native vegetation communities while simultaneously increasing the water table and alkalinity. Similar changes in the vegetation community on Alamosa NWR were observed and documented in refuge annual narratives in the mid-1960s. For example, extensive expansion of cattail and soft-stem bulrush was noted on the refuge in 1967 within abandoned channels along Hansen's Bluff. Greasewood in Tract 14 (most of which is in Unit M) was flooded and transitioned to sedges and rushes in 1968 with expansion of cattail into this area by 1970. Phragmites (*Phragmites arundinaceae*) had taken over in two areas which were aerially sprayed with herbicide dating to 1970. The spread of invasive weeds on Alamosa NWR continued in the 1990s. Over time, invasive weed species including tall whitetop, Canada thistle (*Circium arvense*), knapweeds (*Centaurea* spp. and *Acroptilon repens*), and phragmites have become widely distributed throughout the refuge (Fig. 21).

The development of wetland management infrastructure and the redistribution and timing of flooding reduced some of the greasewood and rabbitbrush shrub land habitat on Alamosa NWR and shifted communities toward baltic rush, cattail, and invasive species. National Wetland Inventory (NWI) maps of the refuge from the mid-1980s indicate that a majority of the area was emergent wetland at that time (Fig. 22). Native upland desert shrub habitat still exists in the northern portion of the refuge, along Hansen's Bluff, and in some small isolated areas throughout the refuge. Invasive weeds have become a major concern as tall whitetop covers a majority of the areas designated as wetlands and adjacent upland areas (Figs. 21, 22). The combination of increased spring and summer irrigation flooding to promote baltic rush and other seasonal wetland plants in areas with soils that historically did not have regular or extended spring-summer flooding has promoted expansion and establishment of weed species, especially tall whitetop (Gardner 2002). Photographs taken along the Hansen's Bluff road from two locations looking out onto the refuge in June 1967 were replicated in July 2012 and identify a distinct decrease in shrub habitat and a corresponding increase in seasonal habitat from Point A (Figs. 23, 24). This comparison also chronicles the conversion of open water with willows and adjacent shrubland or wet meadow to tall emergent and tall whitetop from Point B. In more permanent water areas, cattail and phragmites developed relatively monotypic stands over this time period.

The decline of the riparian cottonwood gallery along the Rio Grande was first noted on the refuge in 1980 (refuge annual narratives). Subsequently, cottonwood "poles" were planted in 1987 and riparian fencing was initiated in 1992 to discourage herbivory (Table 6). Since that time the cottonwood and willow galleries on the refuge have continued to decline in extent and health. Root development of cottonwood is related to the depth of the underlying water table (e.g., Scott et al. 1999), and historically, water regimes along the Rio Grande at Alamosa NWR provided adequate groundwater-levels to support cottonwood survival and regeneration. Severe fluctuations in water tables cause large scale mortality of cottonwood, especially young saplings that have not developed root systems at various depths to offset large fluctuations (Shafroth et al. 2000, Anderson 2005). During times of low flow in the Rio Grande, water is often discharged from adjacent floodplain wetlands to the river or lower elevation ditches which function as a drain (Powell 1958), consequently lowering the water table of these adjacent areas. Currently, low flows in the Rio Grande caused by diversions and groundwater use contribute to decreases in local water tables and undoubtedly

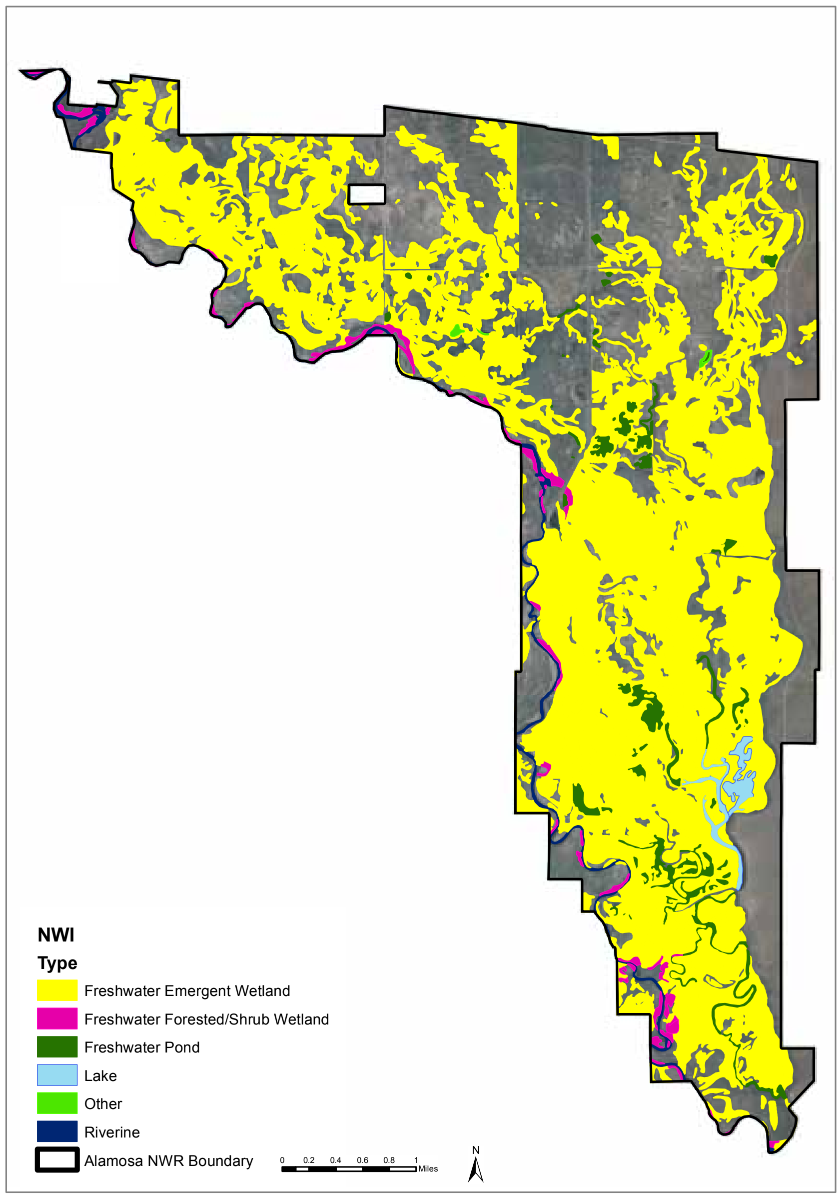

Figure 22. National Wetland Inventory categories on Alamosa National Wildlife Refuge (data 9/1984, from www.fws.gov/wetlands/data).

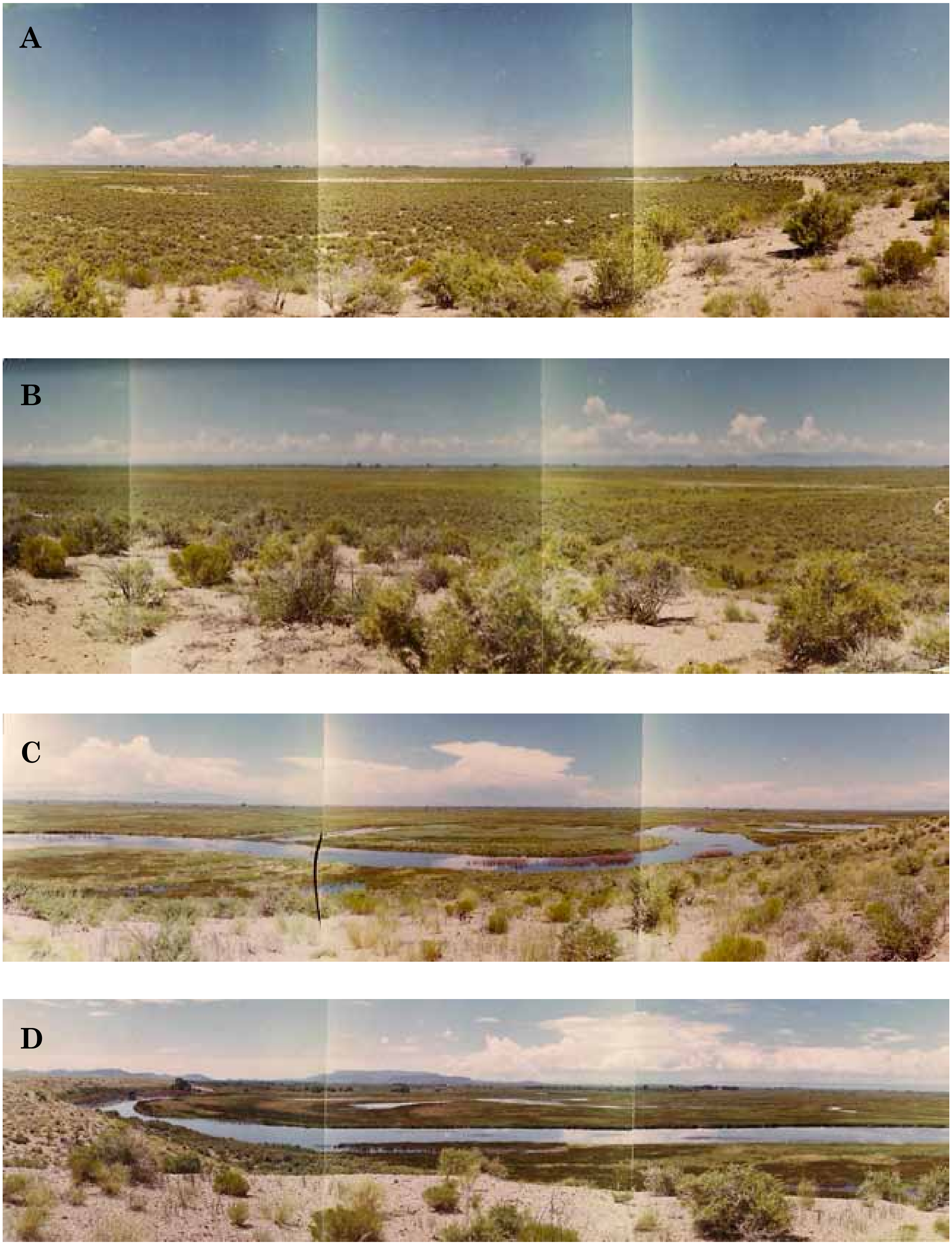

Figure 23. Panoramic photos of Alamosa National Wildlife Refuge in 1967: A) Point A on Bluff Road near units M and N1 looking north in 1967; B) Point A on Bluff Road near units M and N1 looking southwest in 1967; C) Point B on Bluff Road near overlook looking north in 1967; and D) Point B on Bluff Road near Overlook looking southwest in 1967.

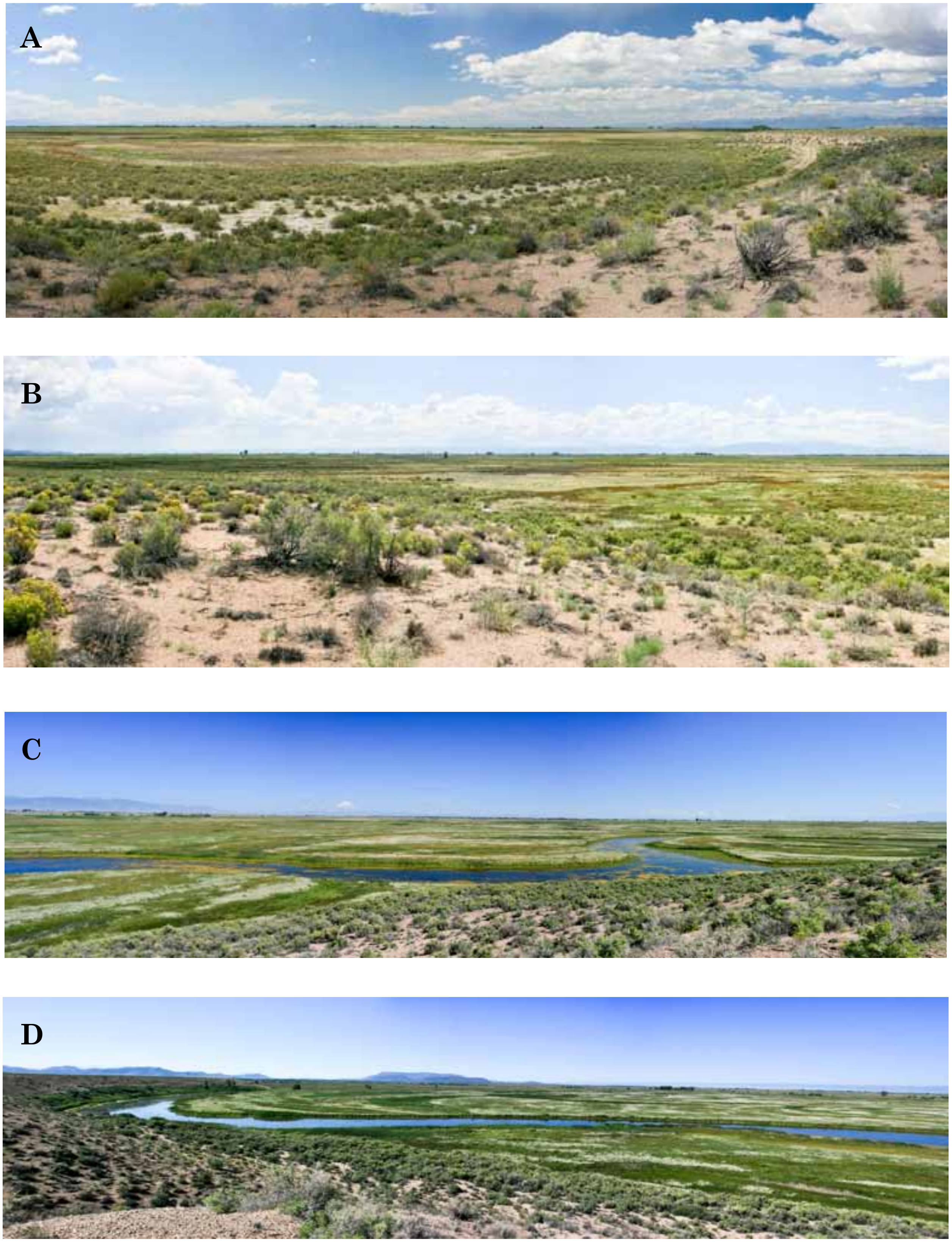

Figure 24. Panoramic photos of Alamosa National Wildlife Refuge in 2012: A) Point A on Bluff Road near units M and N1 looking north in 2012; B) Point A on Bluff Road near units M and N1 looking southwest in 2012; C) Point B on Bluff Road near overlook looking north in 2012; and D) Point B on Bluff Road near Overlook looking southwest in 2012.

affect survival of riparian woodland. Also, annually consistent grazing, especially in newly established cottonwood and willow communities, impacts the diversity and complexity of riparian woodland stands and the wildlife communities that depend on them (Shafroth et al. 2000). Grazing on the Alamosa NWR has occurred over time at various intensities, durations, and seasons incorporating some of the riparian habitat types; trespass cattle also have been problematic at times.

In addition to the extensive management of water on Alamosa NWR, other habitat management activities have occurred at various intensities, times, and rates including: 1) physical manipulation of vegetation using grazing, burning, tillage, and chemical treatments; 2) a short-term farming operation for small grain production; and 3) chemical and mechanical control of invasive plant species (USFWS 2003, Table 6). Cattle grazing occurred on Alamosa NWR from establishment to 1994 under several different strategies (USFWS 2003). In 1994 a federal court ruling postponed grazing on the refuge and the USFWS initiated a five-year study to assess the effectiveness of different habitat management techniques (Diebboll 1999). Concerns about grazing were in part derived from a long-term study of dabbling duck nesting on the Monte Vista NWR that indicated nest density was negatively affected by grazing (Gilbert et al. 1996) although many other factors such as vegetation characteristics, hydrology, and location were never considered. Grazing was discontinued on the refuge through the late-2000s when some grazing was re-established, as was haying. Over time, burning became infrequent on the refuge although some has occurred in the mid- to late-2000s. The refuge began farming 80 acres in 1978 to provide small grain foods to wintering waterfowl, cranes, upland birds, and deer (refuge annual narratives). By early 1991, farming was discontinued due to difficulties with encroaching weeds and poor soil conditions for small grains. Lands removed from crop production were planted to perennial grasses and legumes.

CHANGES IN ANIMAL POPULATIONS

The historical riparian, wetland, wet meadow, and shrub/grassland habitats on Alamosa NWR and other areas along the Rio Grande traditionally provided resources for populations of many animal species associated within the Rocky Mountain Ecoregion (USFWS 2010). As mentioned above, the development of water diversion infrastructure that moved water from the Rio Grande allowed floodplain and upland areas on Alamosa NWR to be irrigated for longer durations and depths than historically occurred. With the wetland developments that occurred after the refuge was established (Table 6), breeding dabbling ducks were attracted to the area to nest, and the refuge became an important contributor to local waterfowl populations (Szymczak 1986, Gilbert et al. 1996). Duck production on Alamosa NWR averaged about 5,000 fledglings annually until the 1990s, but annual numbers fluctuated greatly depending on the amount of water available on the refuge and the overall wetness of the previous winter in the Rio Grande watershed (refuge annual narratives). Avian cholera outbreaks throughout the SLV NWR complex have killed up to 6,500 ducks in some years (USFWS 2003). The USFWS Partner's for Fish and Wildlife Program began private lands wetland restoration and enhancement projects in the SLV to help provide wetland habitats off of Monte Vista and Alamosa NWRs to distribute birds over the larger landscape to help reduce avian cholera from occurring on the refuge. Wetlands and meadows on Alamosa NWR also formerly supported substantial populations of waterfowl in winter and waterfowl hunting harvest in the SLV traditionally was among the highest in Colorado, mainly supported by locally produced ducks (Szymczak 1986).

The natural, artificial, and enhanced riparian, wetland and wet meadow habitats on Alamosa NWR also attracted and supported relatively large populations of many waterbirds, such as white-faced ibis, egrets, and shorebirds (D'Errico 2006). Alamosa NWR provides resources for several species of concern, including the white-faced ibis, bald eagle (*Haliaeetus leucocephalus*), american bittern (*Botaurus lentiginosus*), black tern (*Chlidonias niger*), and ferruginous hawk (*Buteo regalis*) along with the endangered southwestern willow flycatcher (*Empidonax traillii extimus*) (SWFL). Population trends for bald eagles (Fig. 25) and sandhill cranes (Fig. 26) indicate annually variable numbers. Wintering waterfowl and bald eagle population numbers have decreased over time on Alamosa NWR (USFWS 2003). In contrast, it is generally believed that wetland-associated animal species, especially waterbirds, have increased on Alamosa NWR compared to pre-irrigation and pre-wetland development periods (USFWS 2003). Several species of shorebirds, wading birds, and over-water nesters such as pied-billed grebes commonly nest on the refuge. In contrast to waterbirds, populations of other animals that are associated with the salt desert shrub habitat likely have declined as this habitat was converted to irrigated meadow and seasonally flooded wetland units. In particular, species such as burrowing owl (*Athene cunicularia*), prairie dog (*Cynomys* spp.), raptors, plateau lizard (*Sceloporus tristichus*), and shrub and grassland birds now are rare, reduced in number and distribution, or absent (USFWS 2003).

Riparian cottonwood and willow woodland along the Rio Grande support a wide variety of neo-tropical migrants including the SWFL (Knopf et al. 1988). SWFL surveys were conducted on Alamosa NWR in 1996 and 1997 (refuge staff, personal communication) and in 2003 and 2004 (Hawk's Aloft 2004). Many individual SWFL were observed in all years with 10 confirmed breeding pairs found in 1997 (USFWS 2003) and 4 territories discerned in 2004. Nests were not located in 2004, and breeding was probable but not certain (Hawk's Aloft 2004). Since that time, the extent and health of riparian woodland has diminished on the refuge. Habitat requirements for SWFL at this elevation along the northern boundary of their range have not been thoroughly researched. Some work indicates that willows of various heights and structure, potentially with an overstory of cottonwood, more than 10 m wide, and adjacent to water through the breeding season (e.g. July) is necessary (Sogge et al. 2010). Currently, these habitat types in juxtaposition to one another are at a minimum on Alamosa NWR. A San Luis Valley Regional Habitat Conservation Plan (ERO Resources Corporation 2012) has been finalized covering the six counties within the SLV providing habitat protection for the SWFL and yellow-billed cuckoo (*Coccyzus americanus*) while allowing for common activities associated with agriculture and community infrastructure through local working partnerships. The SWFL Recovery Plan (USFWS 2002) required a minimum of 50 pairs be maintained throughout the region. Past surveys have established consistent use of specific publicly owned riparian areas including McIntire/Simpson and Rio Grande State Wildlife Area (ERO Resources Corporation 2012).

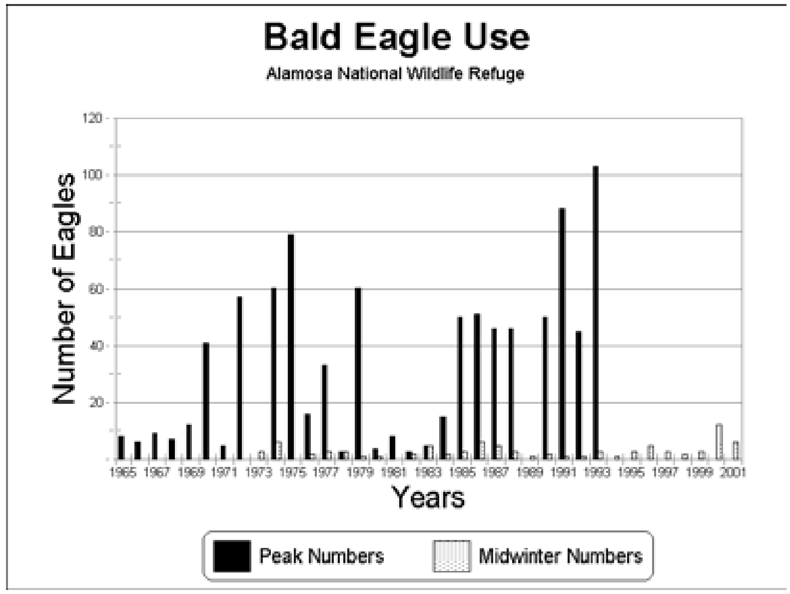

Figure 25. Population trends for bald eagles on Alamosa National Wildlife Refuge (USFWS 2003).

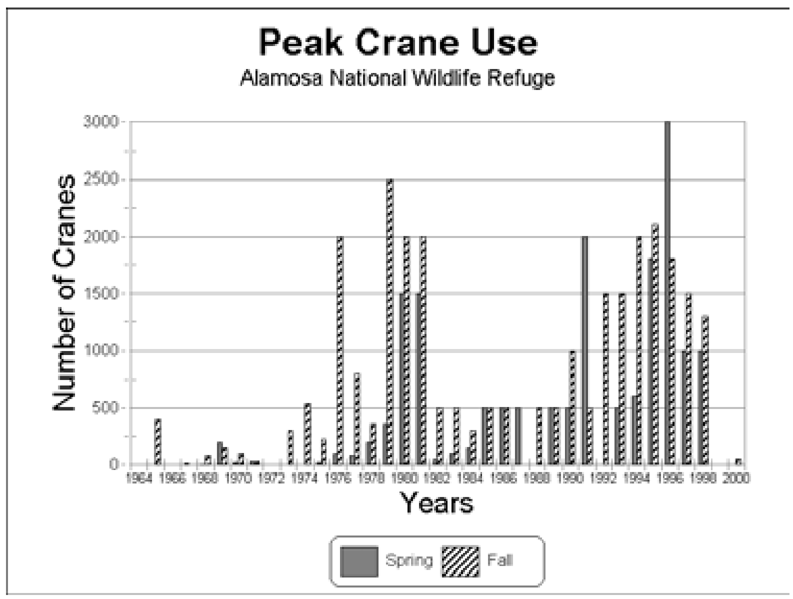

Figure 26. Population trends for sandhill cranes on Alamosa National Wildlife Refuge (USFWS 2003).

Cary Aloia

OPTIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

This report and a similar HGM evaluation for Monte Vista NWR (Heitmeyer and Aloia 2013) have helped describe the historical ecosystem structure and processes within the southern SLV NWR complex region and have chronicled the many changes to this ecosystem over time, both before and after refuge establishment. Alamosa NWR provides unique, yet highly modified, ecosystem conservation lands along the Rio Grande and its floodplain. This area provides critical resources to help support populations of many animal species associated within the Rocky Mountain Ecoregion (USFWS 2010).

The primary change to the ecosystem structure, function, and processes at Alamosa NWR since the late-1800s has been the extensive alterations of SLV-wide, and refuge-specific, distribution, chronology, and abundance of surface and groundwater. The history of water diversion, use, and management throughout the SLV, both prior to and after refuge establishment, is complex. This history reflects attempts by man, common throughout the arid Western U.S., to obtain water for agricultural and community uses where surface water is limited. A wide range of modifications to the SLV landscape have resulted in many ecological consequences; most of which have been detrimental to the long-term sustainability of native communities and resources. Many of the modifications on Alamosa NWR have resulted from off-site changes such as the complete diversion of Rock and La Jara Creeks and the Alamosa River, along with continued declines in local groundwater tables. Past management objectives for Alamosa NWR, which promoted relatively consistent annual water management exacerbate certain local ecosystem changes. For example, the annually consistent use of ground and surface water to irrigate extensive areas on the refuge to increase wetland habitats has: 1) converted shallowly flooded wet meadows and seasonal wetlands to more permanent tall emergent habitats; 2) modified and/or eliminated natural surface water flow pathways and patterns across the refuge; 3) facilitated invasion and expansion of invasive plant species, especially tall whitetop; and 4) altered basic soil and topographic characteristics of the system. Most of the system modifications on Alamosa NWR after it was established were motivated by a desire to increase annually consistent dabbling duck production and also was promoted by USFWS perceptions about the need to use available water resources during the irrigation season to maintain refuge-specific water rights through use. This paradigm promoted the development of water diversion and storage infrastructure that allowed managers to move water unnaturally to higher floodplain elevations, which caused alteration and conversion of some native habitats and led to more permanent water regimes in many areas.

While past planning efforts for Alamosa NWR were largely based on the desire to continue previous water management among the developed wetland sub-units for breeding ducks (see refuge annual narratives and discussion in USFWS 2003), current refuge planning is considering a more system-based and holistic approach for future management strategies and desired states for the refuge. Considerations for a more "system-based" management approach requires that managers address basic questions about how to, and if they can realistically, restore more natural and sustainable communities and resources on Alamosa NWR. This HGM report provides an evaluation of existing hydrogeomorphic information to help understand potential general options for restoration efforts and certain management actions that will be needed to sustain and support restorations. Assuming that at least some restoration of native communities is desired on Alamosa NWR, then the paramount issue influencing future management and restoration is the need to change how management addresses the timing, distribution, and movement of water on the refuge. Future management decisions will require a careful focus on changing the artificial water diversion and management on the refuge.

GENERAL RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

As previously stated, the physical form, hydrology, and plant and animal communities at Alamosa NWR are highly modified from the historical condition. Despite the many artificial alterations to the ecological integrity and character of the refuge, opportunities exist to restore some natural vegetation community types if changes can be made to the natural hydrological flow pattern, timing and distribution of water management, and invasive weed management. This evaluation does not address where, or if, the many sometimes competing uses of the refuge can be accommodated, but rather it provides information to support the National Wildlife Refuge System Improvement Act of 1997, which seeks to ensure that the biological integrity, diversity, and environmental health of the (eco)system (in which a refuge sits) are maintained (USFWS 1999, Meretsky et al. 2006, Paveglio and Taylor 2010). Administrative policy that guides NWR goals includes mandates for: 1) comprehensive documentation of ecosystem attributes associated with biodiversity conservation, 2) assessment of each refuge's importance across landscape scales, and 3) recognition that restoration of historical processes is critical to achieve goals (Mertetsky et al. 2006). Most of the CCP's completed for NWR's to date, including the 2003 Alamosa NWR CCP, have highlighted ecological restoration as an objective. Generally, historical conditions (those prior to substantial human related changes to the landscape) are considered the benchmark condition to guide restoration efforts (USFWS 2002, Meretsky et al. 2006). General USFWS policy, under the Improvement Act of 1997, directs managers to assess not only historical conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, USFWS guidance documents for NWR management "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s)" (USFWS 2001).

Given the above USFWS policies and mandates for management of NWR's, the HGM approach used in this study can assist decisions about future management of Alamosa NWR, at least where some restoration of historical communities and ecological processes is desired. The HGM approach objectively seeks to understand: 1) how this ecosystem was created, 2) the fundamental physical and biological processes that historically "drove" and "sustained" the structure and functions of the system and its communities, and 3) what changes have occurred that have caused degradations and that might be reversed and restored to historic and functional conditions. This HGM approach also helps understand restoration opportunities for the Alamosa NWR within the context of appropriate regional and continental landscapes, and helps identify the "role" of refuge lands in meeting larger conservation goals and needs at different geographical scales. In many cases, restoration of functional ecosystems on NWR lands can help an individual refuge serve as a "core" of critical, sometimes limiting, resources that can complement and encourage restoration and management on adjacent and regional private and public lands.

HGM evaluations are not species-based, but rather seek to identify options to restore and maintain system-based processes, communities, and resources that ultimately will help support local and regional populations of endemic species, both plant and animal, and other ecosystem functions, values, and services. Management of specific land parcels and refuge tracts should identify key resources used and needed by a variety of native species. Increased availability and health of resources should meet the needs of species of concern as habitats are restored. The development of specific management strategies for Alamosa NWR requires an understanding of the historic context of the Alamosa area relative to what communities naturally occurred, the seasonal and interannual dynamics and thus availability of community resources, and when and where (or if) species of concern actually were present and what resources they used. Contemporary management also is based on understanding the regional context of the site, both historic and present, by understanding how, or if, the site historically, or currently, provided dynamic resources to species of concern – and attempt, where possible, to continue to provide key resources in naturally occurring times and distribution consistent with meeting life cycle requirements necessary to sustain populations. Consequently, recommendations from the HGM evaluation in this study are system-based first, with the goal of maintaining the ecosystem itself, with the assumption that if the integrity of the system is maintained and/or restored, that key resources for species of concern can/will be accommodated. This approach is consistent with recent recommendations to manage the NWR system to improve the ecological integrity and biodiversity of landscapes in which they sit (Fischman and Adamcik 2011). Obviously, some systems are so highly disrupted that all natural processes and communities/resources cannot be restored, and key resources needed by some species may need to be replaced or provided by another habitat or resource.

Based on the HGM context of information obtained and analyzed in this study, it appears that future management of Alamosa NWR can address the following ecosystem restoration and management goals:

1. Restore and manage natural hydrologic flow patterns and regimes throughout the floodplain of the Rio Grande.
2. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes (topography, soils, etc) where possible.
3. Encourage management strategies that can emulate natural disturbance events, including flooding, drought, fire, and herbivory.

The following general recommendations are suggested to meet these goals.

1. Restore and manage natural hydrological flow patterns and regimes throughout the floodplain of the Rio Grande where possible.

The historical distribution and extent of surface and groundwater flow on Alamosa NWR was related to geomorphology, soil type, elevation, and seasonal and interannual climatic conditions tied most directly to the fluvial dynamics of the Rio Grande. This report identifies the major changes that have occurred in the natural hydrology of the SLV, and at Alamosa NWR specifically. The many studies cited in this report, along with refuge annual narratives, and personal observations have been central to understanding direct and indirect effects of hydrological changes on the ecological character and integrity of the region. Of particular note are the extreme modifications to the landscape on- and off-refuge resulting from various types of infrastructure, including roads, canals, ditches, drains, and diversions. If the goal of restoring at least some natural flow of water throughout the historic Rio Grande floodplain at Alamosa NWR is adopted, then changes to water management is needed. As such, topography, water-control infrastructure, water rights, and refuge water management plans must be evaluated for possible beneficial changes.

First, the topography and natural water flow and drainage patterns of Alamosa NWR are greatly altered from the historic condition. The establishment of roads throughout the Rio Grande floodplain began as early as the late-1800s (e.g., GLO maps, Fig. 2). Continued development of the railroad, roads, cattle trails, and channelization of the Rio Grande largely disconnected the river from its floodplain, prevented sheetflow of surface water onto the floodplain, and created artificial drainage patterns that cut through topographic features (Zeedyk and Clothier 2009). Canals, ditches, and drains have further bisected the floodplain and prevented water from flowing through natural topographic features (Fig. 17). Continued groundwater pumping has negatively impacted water table levels, artesian and spring flows, and reduced surface water resources. Collectively these modifications have altered hydrologic flow patterns and prevented Rio Grande water from accessing the floodplain through natural channels that flowed from north to south and west to east.

Given the promulgation of new Groundwater Rules and Regulations by the Colorado State Engineer, more efficient use of all water resources will be of great importance on Alamosa NWR in the future. Future water resources (both surface and groundwater) may be limited as unconfined and confined aquifer levels decrease and lower the water table, and artesian free-flowing wells are reduced. Potentially reduced groundwater availability may suggest that water management on Alamosa NWR should attempt to prioritize water delivery within natural historical channels, which would increase water use efficiency, promote the type of native vegetation that soils naturally can support, and help control the spread of invasive species. Managing water using natural gradients and flow paths, and not attempting to move water uphill to former upland shrub habitat types, would reduce costs and time to maintain certain ditches, levees, and water-control structures. Many water-control structures on Alamosa NWR are not within natural drainages, set at wrong invert elevation, or lack the capacity to convey flows through the system. By using relict abandoned channels to carry water through the system, and by reactivating the secondary channel that existed in the late-1800s (Figs. 2, 16), natural topographic features can aid in the distribution of water to promote sheetflow and native vegetation (Fig. 27).

Many of the areas in the north portion of Alamosa NWR have been divided by roads and ditches with water-control structures placed outside of natural drainage pathways (Figs. 27a, 28). Specifically, impoundments in areas that were historically dominated by shrubland such as Units A, C, CBE, CBW, H, M, and parts of J and N2 (Figs. 1, 16, 27b) have been converted to semi-permanent and seasonal wetlands that now are heavily infested by invasive species (Figs. 21-24). Currently, water-control structures move water between Units F and H, CBW and CBE, A and F, A and CBW, and C2 and J (Figs. 27a, 28). These inter-unit structures are not within historic drainage channels and generally seek to move water artificially to former shrub habitats. Some natural drainage patterns do exist between a few of these units, but these natural channels are not currently being used to the extent possible.

Artificial water delivery infrastructure that affects Alamosa NWR, such as the CBC and other ditches that bisect many of the natural historic flow patterns, now restrict restoration of specific areas and habitats. Water-control structures are present that allow water to pass from one side of the CBC to the other (Figs. 17, 27a). However, based on aerial photography and LiDAR analysis (Figs. 9, 27a, 28), these structures appear to be placed outside of natural drainage pathways and promote the diversion of water to the east onto the HHC soil-land association where several artificial, semi-permanently flooded impoundments now exist (Figs. 6, 22). Moreover, areas in units A and CBW have been compartmentalized with a series of levees, ditches, and water-control structures; these units historically were mostly shrub land and some small areas of seasonally flooded wet meadows (Fig. 29). Development of nesting islands throughout Units D, C2, and J also has disrupted the natural flow and dispersal of water throughout this northern area of the refuge (Fig. 30). Despite the continued presence of these hard infrastructure features, restoration of historic flows and habitats may be possible in certain locations if key water-control structures, nesting islands, levees, roads, and minor ditches can be removed or modified (Figs. 27, 30). Locations indicated for removal of water-control structures in Figs. 28 and 29 represent potential sites for restoration but are not all-inclusive and may not be viable given a variety of factors. Each structure should be assessed to determine if its location, height, capacity, etc. are practical and realistic given future management objectives.

Management of water flow through natural channels and across the Rio Grande floodplain on Alamosa NWR could help promote a more natural distribution of natural wetland habitat types. By moving water through natural channels, seasonal and wet meadow habitats could occur in juxtaposition to semipermanently flooded wetlands within relict abandoned channels and oxbow lakes. The loamy and wet alluvial soils that dominate the lower two-thirds of the refuge (Fig. 5) are well-suited to seasonal and wet meadow habitats (Fig. 16). The return to a north-south gravity-flow of surface water across these sites should help promote a more shallowly flooded habitat type with a diversity of native vegetation based on slight changes in elevation or topographic features. An assessment of current infrastructure in the southern part of Alamosa NWR indicates that existing floodplain features have been bisected by roads, ditches, and levees that prevent natural surface water sheetflow. Removal or re-alignment of infrastructure would facilitate more efficient use of water resources. These areas are currently dominated by invasive species (Fig. 21), but historically supported wet meadow habitats with short duration flooding interspersed with shrublands (Fig. 16).

Other areas such as in Unit U and surrounding areas have been significantly altered due to ditches like the Stewart Lateral and New Ditch which have cut through natural features and compartmentalized wetlands near the active channel of the Rio Grande (Figs. 18, 31). This area would have historically been impacted annually by over bank flood events with continuous scouring and deposition events occurring to promote riparian cottonwood galleries on natural levees. Over time, the extent of these galleries has decreased based on the presence of remnant and residual stands, topography, and soil distribution suited to willow and cottonwood (Fig. 21).

If future water management strategies seek to restore natural flow through historic topographic features, water resources should then be distributed based on annual climatic conditions to provide flooding and drying periods in order to further promote the re-establishment of native vegetation. During years of high spring runoff, application of water throughout the floodplain could occur. Past refuge annual narratives and accounts indicate that the lower two-thirds of the refuge was commonly inundated by spring

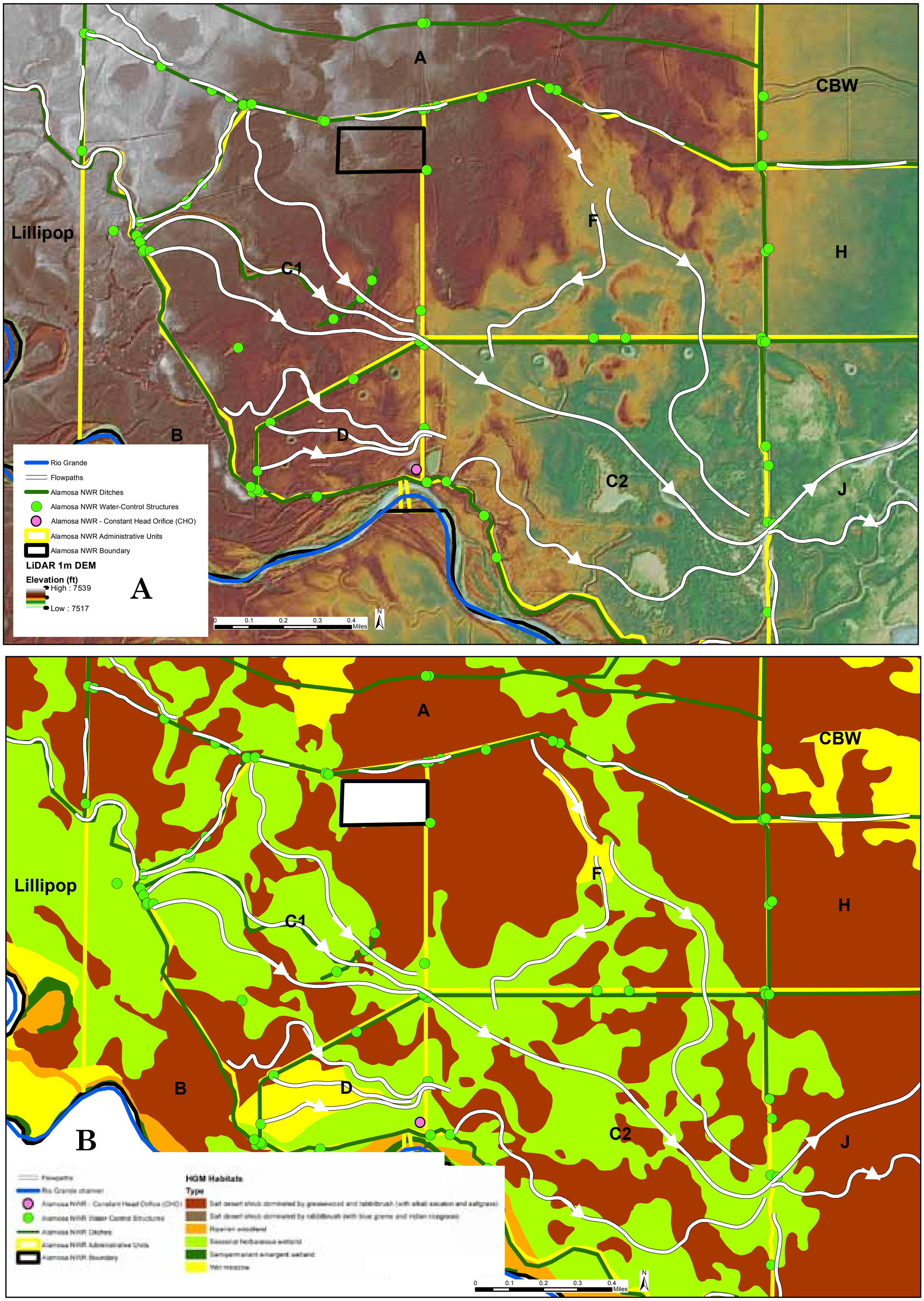

Figure 27. Natural drainage pathways on the north part of Alamosa National Wildlife Refuge overlain on: A) LiDAR 1 m DEM and B) potential historical vegetation from Fig. 16.

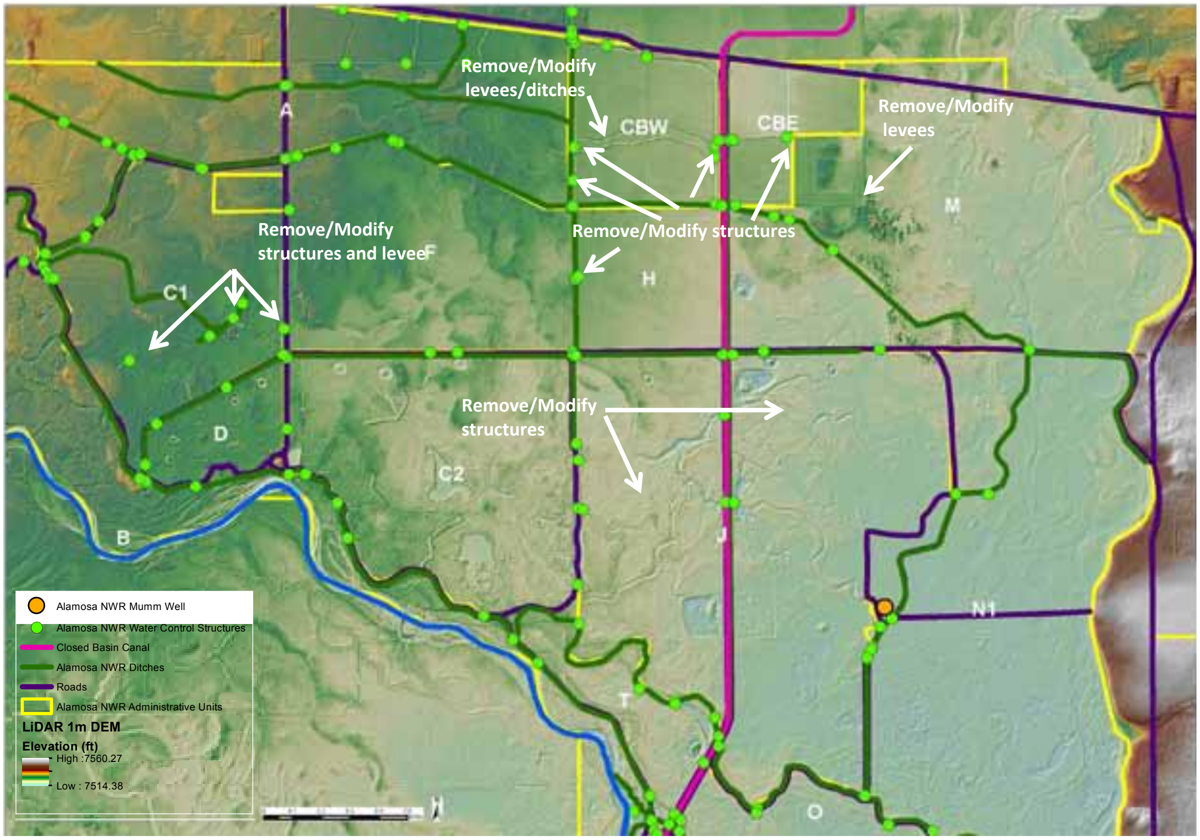

Figure 28. Location of water delivery infrastructure in the northern portion of the Alamosa National Wildlife Refuge that could be removed or modified to improve restoration potential.

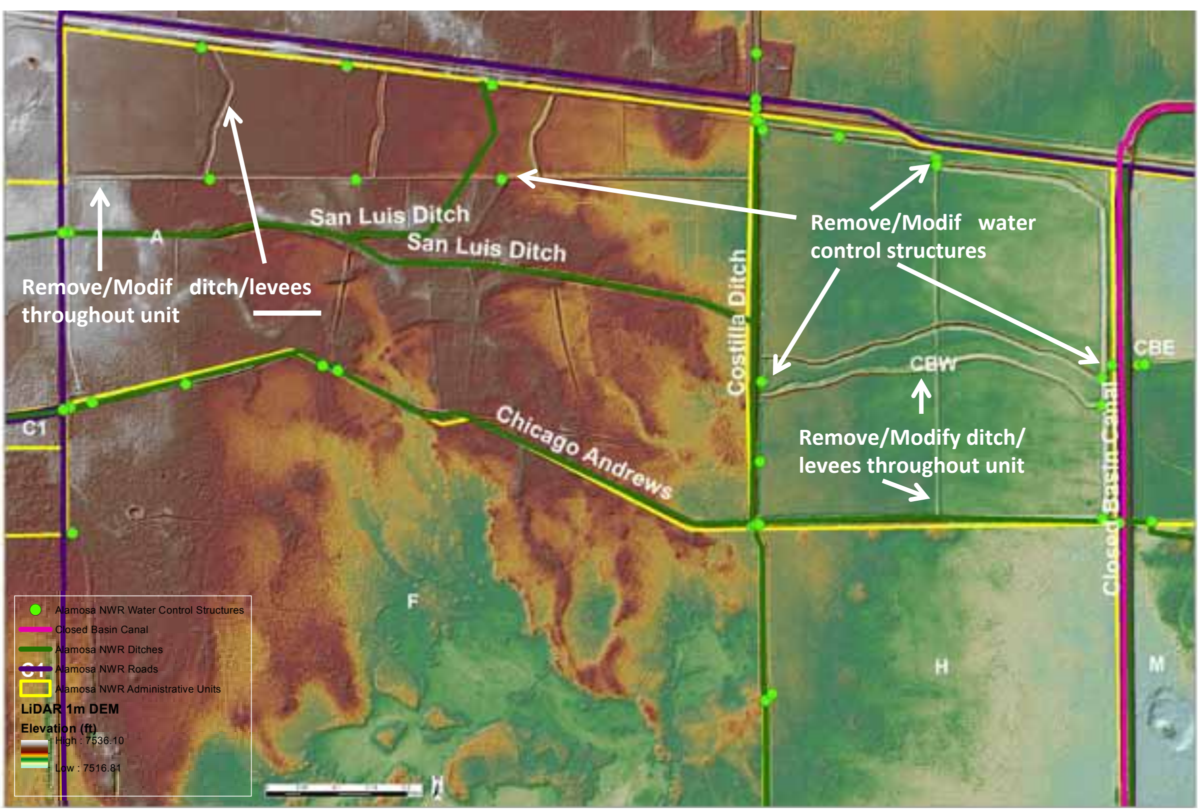

Figure 29. Location of ditches and levees in Administrative Units A and CBW outside of natural drainage pathways and in historic shrublands on Alamosa National Wildlife Refuge that could be removed or modified to improve restoration potential.

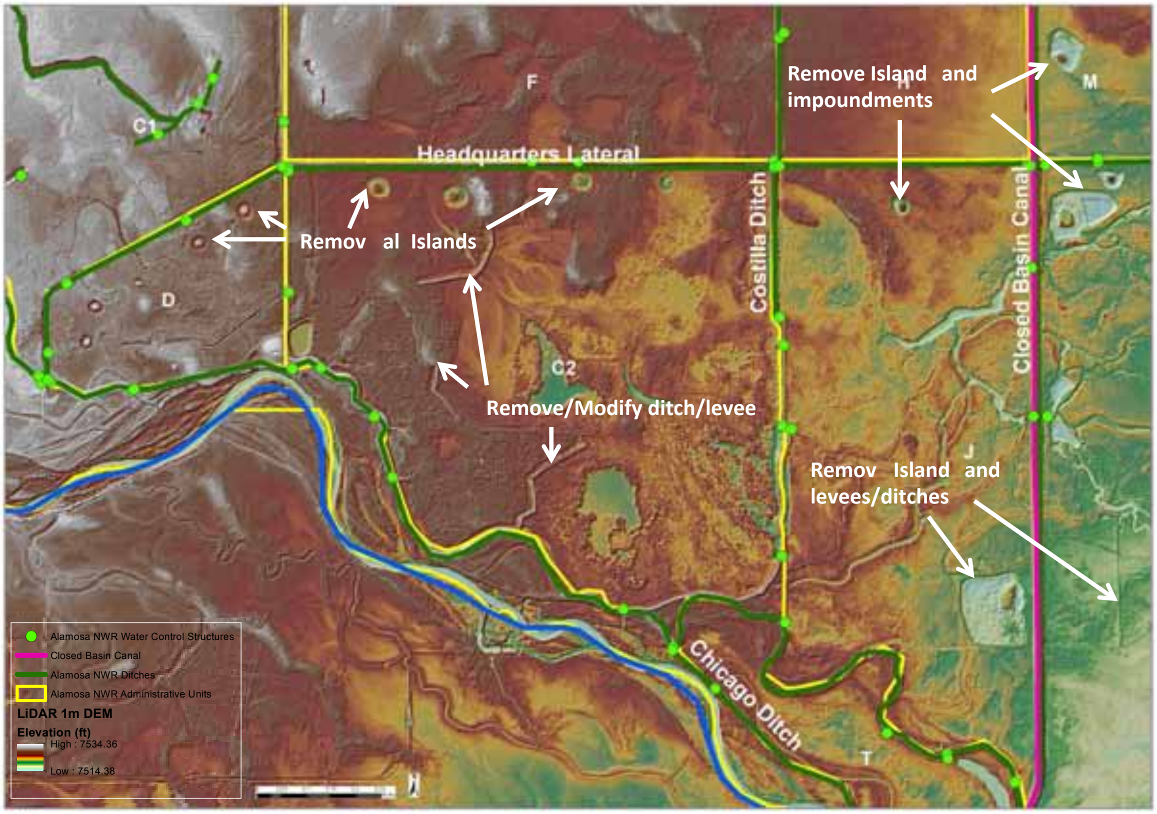

Figure 30. Location of islands and other infrastructure in Administrative Units C2 and J which could be removed to facilitate natural surface water flow across the floodplain on Alamosa National Wildlife Refuge.

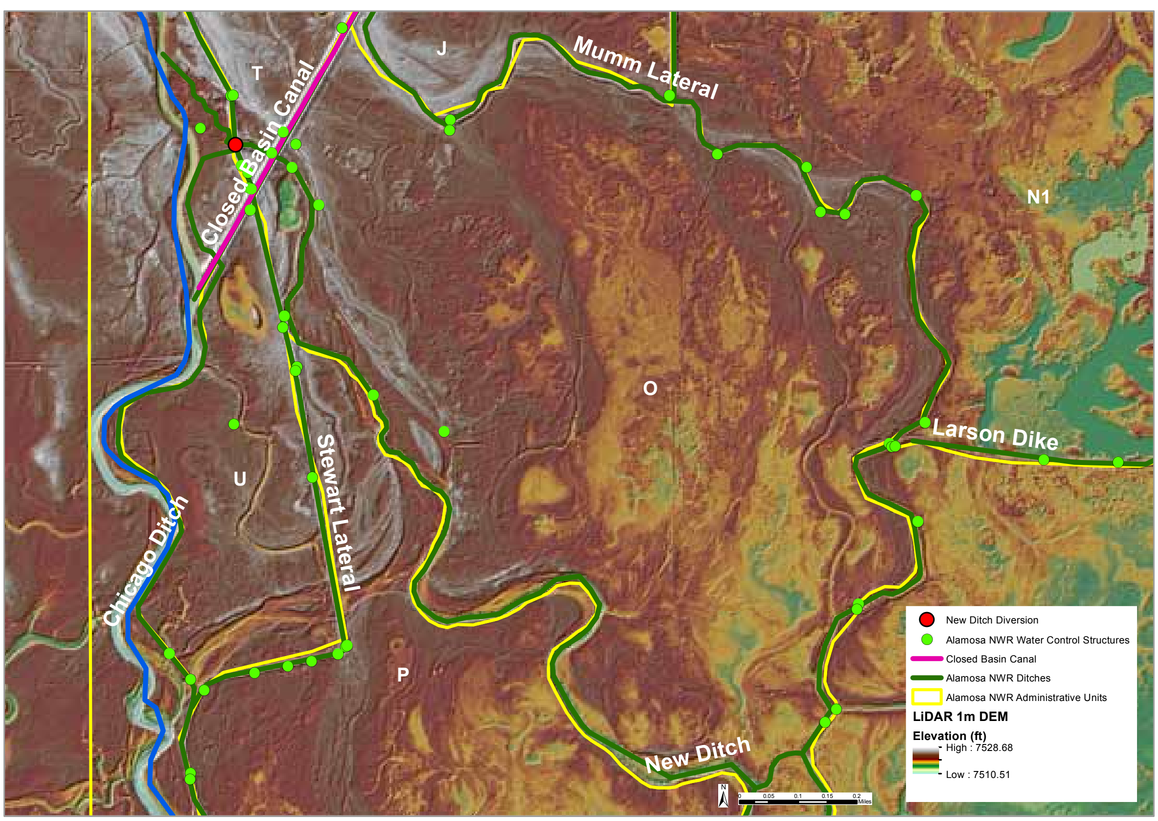

Figure 31. Location of infrastructure in Administrative Units O and U in relation to natural topography on Alamosa National Wildlife Refuge.

floods; this observation is consistent with the distribution of soils mapped on the area and by the distribution of flood water during the last large overbank flooding event on the Rio Grande that occurred in 1988. In high water years, some areas on Alamosa NWR could be allowed to remain flooded in the summer such as deeper abandoned channels and oxbow lakes. Conversely, in dry years when spring snow runoff is low many of these wetland areas would remain dry. By providing wet and dry cycles that mimic natural climatic dynamics, the abiotic and biotic characteristics of the floodplain may be restored. Current infrastructure on Alamosa NWR may not allow for the complete drawdown of certain wetland units due to ineffective or misplaced water-control structures, levees, or roads (Figs. 27-31). Relocation of water-control structures to allow for the release of water through impoundments such that drying occurs annually or at some point in a dry cycle can improve the productivity of wetlands. The relocation or placement of different types of water-control structures to allow for sheetflow, while preventing artificial "ponding" or the impoundment of water next to levees and roads is important to re-establish natural hydrologic regimes and vegetation communities. Flow through natural topographic features that allow subsurface flow and dispersal of water across the floodplain can be increased with the correct placement of water-control structures, moving roads to side slopes, and eliminating lead-in and lead-out ditches from water-control structures in wet meadow locations where sheet-water flow is desired (Zeedyk 1996). Preventing artificial impoundment of water in areas where soils are not suited to a more prolonged inundation also will help prevent further invasion of weeds and promote conditions where control-treatments can help reduce current stands. Changes in water management coupled with changes in water delivery infrastructure should assist staff in managing these habitats to promote plant species adapted to drier conditions and allow for invasive weed management activities during drought periods.

2. Restore and manage the distribution, type, and extent of native vegetation communities in relation to hydrogeomorphic attributes where possible.

The distribution and extent of former riparian, wetland, and shrub habitats on Alamosa NWR was related to geomorphology, soil type, elevation, and seasonal hydrological regimes of the active Rio Grande and its tributaries. The HGM matrix (Table 5) and map predicting former distribution and extent of these habitats (Fig. 16) provided in this report offers a guide to the appropriate spatial location of these habitat types that can be used to plan future restoration and management of communities. The changes in habitat distribution, type, and extent from the late-1800s to the current time on Alamosa NWR document the: 1) conversion of former salt desert shrub to artificial wetland units, 2) alteration of seasonal wet meadow habitats to more prolonged flooded regimes, 3) the expansion and spatial closure of persistent emergent vegetation in deeper floodplain sloughs and former channels, 4) reduced extent and health of riparian woodland, and 5) expansion of invasive weeds into all habitat types.

Historically, the distribution of native community/habitat types at Alamosa NWR was heterogeneous and temporally and spatially dynamic with riparian woodland, floodplain wetlands, and shrub uplands occurring in close juxtaposition. Long-term fluvial dynamics of the Rio Grande and its local tributary confluences caused the specific location of river and creek channels and associated wetland depressions to shift over time across the floodplain. Historic information and maps indicate that seasonal wetlands and wet meadow habitats were present throughout the Rio Grande floodplain extending to Hansen's Bluff. Relict abandoned river channels on the refuge along with GLO maps and studies done by Jones and Harper (1998) indicate that the historic flow of water across the floodplain on the refuge was from the north and west to the east and south and that extensive wetlands historically existed in the lower two-thirds of Alamosa NWR. By the time Alamosa NWR was established in the early-1960s, considerable parts of the refuge were in irrigated pasture and hay land. Soon thereafter, dikes, ditches, drains, and water-control infrastructure were repaired, replaced, or enhanced mostly with the intent of creating wetlands and irrigated meadows for waterfowl (Table 6). When larger numbers of breeding ducks were attracted to the more extensively flooded area, refuge management began to prioritize water and land management for nesting cover, brood habitat, and fall migration habitats for ducks. However, long-term prolonged flooding of wetland compartments that formerly were seasonal meadow or upland shrub habitats was not consistent with former community distribution and sustaining processes. Continued maintenance of artificial wetland units, especially in higher elevations, likely runs the risk of long-term degradation of soil salinity, increased invasive species occurrence, decreased vegetation diversity, increased density and monocultures of certain emergent species such as cattail, and gradual decreases in wetland productivity. Generally, future wetland management should more closely align water distribution, timing, depth, and duration to match former wetland locations.

The active channel and fluvial dynamic of the Rio Grande has been drastically modified as a result of reductions in flow, in-stream structures, multiple points of river water diversion, channelization, and armoring of channel banks since the 1800s (Jones and Harper 1998). The most significant changes in channel movement and discharge occurred after 1925 (Jones and Harper 1998, Mix 2010, Table 6). In addition, roads, levees, and ditches parallel the Rio Grande within the Alamosa NWR, many of which prevent overbank flood events, lateral hydrologic flow, sediment and nutrient transfer, and scouring. Generally the natural dynamic functions of the Rio Grande have been reduced or do not occur at all, which prevents scouring of floodplain depressions and channels while increasing the amount of organic material present on the soil surface. Consequently, conditions for regeneration of riparian cottonwood galleries and willow often do not occur. For example, canals, ditches, laterals, and other infrastructure have been located and constructed in such a way that floodplain features have been bisected, leveled, modified, and ultimately changed the way water moves through the area (Figs. 18, 27-31). Historically, riparian woodland probably occurred near the point of Rio Grande diversion in Unit U and adjacent areas given the soils, natural features, and location of the active channel (Figs. 16, 21, 31). Over time, the riparian cottonwood and willow gallery has declined with the eventual death of willow stands and little to no regeneration. A heterogeneous age class and structure within riparian woodland is essential to the survival and maintenance of most wildlife species that use these habitats for winter shelter, forage, migration, and movement corridors (Scott et al. 2003, Skagen et al. 2005, Shafroth et al. 2000). Riparian woodlands correspond to the natural distribution of the Sandy Alluvial Land soil series (Fig. 5), which parallel the active channel of the Rio Grande on Alamosa NWR (Fig. 16). Although this soil series is restricted to a few areas along the current active channel, topographic features such as historical natural levees exist along historic secondary channels of the Rio Grande on Alamosa NWR and may be sites that now are suitable for the regeneration of cottonwood and/or willow if natural water regimes can be restored.

A majority of the refuge was historically dominated by wet meadow habitats that contained diverse grasses, sedges, and rushes (Fig. 16). Restoration of these communities will require restoration of dynamic seasonal water regimes. Future water management that can emulate natural water flow regimes (see previous section) will help promote establishment and productivity of native wet meadow plant assemblages and a dynamic interspersion of communities. For example, short duration seasonal flooding followed by drying in early summer promotes the germination of annual herbaceous plants and also accelerates decomposition of organic detritus (Fredrickson and Taylor 1982). Studies in the SLV have shown that prolonged and annually consistent impoundment of water in former wet meadows decreases plant and invertebrate productivity and waterbird use while simultaneously increasing sedimentation and aggradation of wetlands (Cooper and Severn 1992). Conversely, water management that provides for natural seasonal hydroperiods creates more favorable conditions for many endemic wildlife species. During dry periods, the opportunity to apply management strategies that reduce the cover and density of invasive weeds is increased working in combination with physiological stress to the plant (Gardner 2002).

Salt desert shrub habitats formerly located in the northern portions of the refuge have been extensively modified due to the construction of ditches, levees, roads, and water-control structures (Figs. 17, 27-30). If the water management recommendations provided above are adopted to provide a more natural distribution of water resources throughout this portion of the refuge then restoration of many areas of salt desert shrub can occur. Removal of certain levees and ditches (Figs. 28, 29) that restrict natural water flow and artificially impound water in historic shrub land promote the re-establishment of drier plant species such as greasewood and alkali sacaton and also help reduce invasive weed distribution and cover. Many islands and borrows have been constructed throughout

Units D, C2, J, and M (Fig. 30) that restrict sheet-water flow across the units, impounds water in deep borrow areas, and tends to encourage establishment of tall emergent plant species.

3. Encourage management strategies that can emulate natural disturbance events including flooding, drought, fire, and herbivory.

Historically, wetlands and uplands located within the Alamosa NWR were temporally and spatially dynamic because of the natural fluvial dynamics of the Rio Grande and its tributaries. The Rio Grande avulsed and meandered across the floodplain and was bounded by Hansen's Bluff, which restricted movement further to the east. The Alamosa River and La Jara Creek also occasionally shifted their courses and scoured and deposited sediments at their confluences with the Rio Grande. Consequently the topography, soils, and vegetation communities at Alamosa NWR were constantly changing in response to climatic conditions and the amount of water flowing through the system each year. These dynamic conditions were intrinsic to the maintenance of different types of vegetation communities. With the development of water diversion infrastructure and increased extraction of groundwater aquifers, the dynamic nature of the Rio Grande and its tributaries and their connection to floodplains were reduced or effectively eliminated.

It seems unlikely that the Rio Grande will ever be able to naturally provide the system-driving dynamics that historically occurred. Consequently, to restore intrinsic values associated with the river and its floodplain habitats, management strategies should seek to emulate natural processes with active water management to provide disturbances that invigorate growth, provide abiotic conditions to promote germination and survival of native vegetation, and supply nutrients to the soil (e.g., Molles et al. 1998, Opperman et al. 2010). Since the Rio Grande has been mostly disconnected from its floodplain at Alamosa NWR since the late-1920s (Jones and Harper 1998), the position of the river channel has been mostly static and soil/topography landforms on the refuge also have been stable. Although current vegetation communities in the Rio Grande floodplain on Alamosa NWR have been greatly altered from former periods and now are dominated by invasive weeds, implementation of the previous recommendations in conjunction with emulating natural disturbance regimes or processes will further promote the restoration of wetland and upland habitats on the Alamosa refuge. The important historical disturbance events in SLV wetlands included river overbank and backwater flooding, drought, fire, and herbivory; these disturbances helped recycle nutrients and biomass, regenerate communities, and volatilize salts and minerals. Reintroduction of these disturbance mechanisms into the Alamosa NWR system will be important to restoration of native communities.

Management to provide the above disturbance events will depend on specific management objectives and the appropriate timing, periodicity, intensity, and application of the event. For example, creating conditions to mimic overbank flood events could occur where water delivery infrastructure has the capacity to allow a flooding event during years with greater spring snowmelt. Likewise, management strategies could variously incorporate fire and herbivory in selected areas to help promote nutrient cycling. Each of the different habitats on the refuge will require different rates and types of disturbance to achieve desired results. For example, grazing strategies in wet meadows may differ from those in seasonal wetlands.

Natural herbivory by wildlife such as elk on Alamosa NWR probably would have occurred in large herds for short time intervals as they moved to other sites with available resources, returning when the forage they consumed had recovered. This strategy allowed plant species to recover without being defoliated to the point that they could not regrow (Halbritter 2007). Currently, this type of natural grazing by wildlife species is not possible due to a number of factors including competition from cattle, hunting pressure, and a fragmented landscape to name a few. However, management strategies that incorporate knowledge of elk and livestock preferences for different forage species as well as potential competition conflicts will help direct the type of strategies that will promote sustainable habitat resources. A study by Hansen and Reid (1975) in the SLV indicated that diets overlapped most for elk and cattle with some overlap with mule deer. Sedge, fescue, and bluegrass plant species were the most common meadow species that were utilized by all three herbivores. Elk may try to avoid habitat utilized by cattle during the summer, as they may prefer rested pastures (Yeo et al 1993; Chaikina and Ruckstuhl 2006; Halbritter 2007), and select areas that were winter grazed by cattle as new plant growth is more easily accessible (Halbritter 2007).

Therefore, the type of grazing strategy utilized will depend on refuge objectives for specific habitat types and at times specific plant species growth. Livestock grazing on Alamosa NWR has been controversial, but effective grazing strategies can incorporate rest-rotation and short duration/high intensity grazing depending on the objectives, the type of vegetation, and availability of cattle, time, and labor (Sayre 2001). Long-term grazing affects the physiology and morphology of plant species and community structure generally by promoting the growth of shorter stature plants that are less accessible or less nutritious to grazers such as sandberg bluegrass (*Poa secunda*) (Fahnestock and Detling 2000; Yeo 2005). If livestock grazing is used, strategies should take into consideration plant community structure, phenology, and climatic conditions to promote the growth and survival of native plant species that provide optimal palatability and nutrition.

Grazing management, coupled with other treatments (e.g. flooding, fire, herbicide, etc), can assist in weed control, specifically for tall whitetop (Diebboll 1999, Gardner 2002). Rosettes and early stems may be eaten by cattle, although later growth stages are avoided. The specific timing of grazing will dictate the type of disturbance or effect that cattle would have on this weed based on growth stage. Cattle are able to digest these lower palatable plant species compared to some ungulates such as deer which select higher quality browse species (Chaikina and Ruckstuhl 2006). Thus, utilizing cattle or other livestock which can process lower quality forage may be a viable strategy to reduce conflicts with wildlife and reduce weeds. Recently some landowners on the Rio Grande floodplain have changed their grazing management from one or two large pastures where cattle were held for long periods to many smaller pastures with short duration/high intensity grazing. This system appears to have been successful in decreasing invasive weeds such as wild iris (*Iris missouriensis*) and tall whitetop while also increasing cover, density, and the health of a wide diversity of plant species (Ruth Lewis and Cynthia Villa, personal communication). A reduction in the extent and density of tall whitetop will improve the health of wetlands, increase resources for waterfowl and waterbirds, and increase nutritional content of the forage for cattle or elk grazing on the refuge in subsequent years (Young et al 1995). Grazing within the riparian cottonwood and willow areas will require different management strategies including fencing or exclusion areas, longer-term rest, timing, changes in rate, and age class of livestock. Some plant and tree species in riparian areas may be more sensitive to browsing and grazing during specific plant growth periods or seasons (Leonard et al. 1997). For example, selecting specific associations of age classes such as cow-calf pairs or yearlings will impact different plant species based on the time of year and their unique nutritional needs.

The use of fire within various habitat types also could help restore native vegetation communities at Alamosa NWR. Fire removes some, or at times all, of the vegetation and other organic matter that has built up on the soil surface. This removal and processing of biomass returns nutrients to the system and promotes growth of existing or new plants. Historical frequency of fire in the Rio Grande floodplain is not entirely known and likely depended on dynamic climatic conditions, hydroperiods, and habitat type. Riparian areas with historically high water tables probably had a longer fire return interval. Fire frequency generally increases away from river channels and wetland areas such that the shrub and grassland communities with lower water tables would have a higher fire frequency (Reardon et al. 2005). Variability in fire frequency may have been higher in riparian areas and could have been influenced more by fires in adjacent habitat types than fuel loads within the riparian habitat itself or through lightning strikes (Stone et al. 2010). Overall, fire may be used as a substitute for other natural disturbance events that removed residual vegetation and in some way returned nutrients to the system.

SPECIFIC RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

1. Restore and manage natural hydrologic flow patterns and regimes throughout the floodplain of the Rio Grande where possible.

Managing water resources to promote variations in the hydrologic regime in conjunction with restoring natural flow patterns through the floodplain will help re-establish native vegetation and increase water use efficiency at Alamosa NWR. Wetland habitat types within the floodplain environment have adapted to the dynamic nature of riverine processes. Restoring hydrologic regimes which mimic climatic conditions and vary through time will help to create a productive and healthy ecosystem. Specific management actions that can assist this restoration include:

- Restore water distribution to historical drainages by routing surface water north to south and west to east to allow for gravity fed sheetflow throughout the Rio Grande floodplain. Currently, Mumm Well water is one of the water sources used to provide water in the winter and late fall to Unit N1 (Striffler 2013; Fig. 28). This unit is north of the Mumm Well head and at a slightly higher elevation. Pushing water to the north is contradictory to efforts to restore natural floodplain water flow patterns, which flow north to south.

- Remove water delivery infrastructure such as water-control structures, ditches, levees, and roads that cannot be repaired or enhanced to allow flow through drainage. Specifically remove ditches and levees which exist in the northern portions of the refuge which impound water and prevent natural sheetflow (Figs. 28-30)

- Remove islands and associated borrow ditches that artificially impound water from Units D, C2, J, and M (Fig. 30)

- Replace water-control structures which do not have the capacity or are restricting water flows (e.g., are placed outside of natural drainage pathways) (Figs. 28-30).

- Provide water delivery through ditches, levees, and roads that will allow water to flow through natural drainage areas. Specifically assess flow patterns through the northern portions of the refuge which currently utilize structures that lie outside natural drainage pathways or do not meet flow capacities. The CBC bisects this area and prevents natural flow from west to east and north to south (Figs. 17, 27, 28). Structures which provide some flow across this area appear to be misplaced and do not meet the needs (e.g., capacity to mimic high water flow events).

- Prevent ponding of water along roads or levees where it prevents flow through drainage and sheetflow across the area. Specifically assess infrastructure in Units Q, R, S, and U that prevent sheetflow and bisect natural topography.

- Manage water regimes in semi-permanently flooded PEM wetlands to emulate strong spring seasonal inputs of water and inter-annual wet vs. dry regimes. Vary annual flooding regimes of wetland impoundments among years to emulate periods of natural drought or more extended flooding at about 4 to 5 year intervals of peak-to-peak and low-to-low patterns.

- Vary the duration, timing, and depth of flooding in seasonal wetlands to follow climatic conditions and allow the wetland to dry out in the summer and for longer durations to mimic natural drought conditions.

- Manage wet meadows for shallow short duration sheetwater flooding in spring to help re-establish grasses and sedges, allowing the meadows to be dry for long periods of time especially in the southern two thirds of the refuge (Fig. 16).

- Prevent impounding water in areas mapped to the HHC soil-land association (Fig. 6), which are best suited for restoration of salt desert shrub habitats in the northern portion of the refuge (Figs. 16, 27b, 28). Prolonged flooding of this soil-land association promotes establishment of tall whitetop and baltic rush along with other seasonal wetland vegetation that is not suited to these soils. Several of the largest infestations of phragmites occur in and near these soil types in the northeast portion of the refuge. Restricting prolonged flooding in soils adapted to precipitation driven or sub-irrigation flooding will help to reduce the maintenance and expansion of this tall emergent invasive species.

- Remove (if possible) all unnecessary dikes, ditches, and water-control structures in areas that promote long-term flooding, ponding, or prevent sheetflow through the system especially in areas which have been converted from one habitat to another (e.g., prevent long-term flooding in areas in the HHC land association outside of topographic features such as abandoned channels). Specifically remove ditches and levees in Units A and CBW which compartmentalize and artificially impound water in historic shrublands (Fig. 29).

- Prevent conversion of transition areas (Fig. 21) to seasonal or semipermanent wetlands through prolonged flooding. Tall whitetop is often established and maintained through changes in hydrologic patterns such as flooding which may act as a disturbance and/or carry seeds. Management strategies which promote the growth of baltic rush or seasonal wetland vegetation commonly incorporates flooding which has often occurred in soils unsuited to long-term flooding regimes, thereby providing tall whitetop a competitive edge. The diversion and impoundment of water into upland areas carries seeds and provides conditions for establishment of the weed in these areas as roots can then grow in subsequent years to several meters dependent upon depth of the water table.

- The past problems at the New Ditch Diversion site suggest that further evaluation of the site related to ecosystem restoration potentials on the refuge is needed including evaluation of the point of diversion, relocation of the diversion ditch that currently bisects the floodplain, continued use of the refuge water right, and distribution of water resources from this diversion.
- Develop a strategic water management plan that identifies specific objectives for the distribution, timing, and extent of water resources.

2. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes where possible.

Restoration of at least parts of the historically diverse vegetation communities on Alamosa NWR is an important goal. The distribution and extent of these habitats was determined by hydrogeomorphic attributes and restoration of the specific types should match appropriate geomorphology, soils, topography, and hydrology regimes (Table 5, Fig. 16). Specific locations and recommendations to restore the native communities are listed below:

- Restore and manage semi-permanently flooded PEM wetlands in Marsh and Vastine soils types (Fig. 5) within or adjacent to abandoned channels and near historic seeps along Hansen's Bluff.
- Restore former seasonal wetlands in Vastine soil types paralleling the riparian corridor and along old drainage pathways with short duration spring and early summer flooding.
- Restore former wet meadow communities on Loamy and Wet Alluvial lands, Alamosa, Vastine, and La Jara soil types (Fig. 5) with short duration spring and early summer flooding.
- Provide water conditions in and near the Sandy Alluvial Land soils (Fig. 5) to promote regeneration or suckering of existing cottonwood and willows. Early succession riparian woodland typically supports narrowleaf cottonwood and sandbar willow in areas not more than 3 to 6 ft above the high water table marks (Carsey et al 2003). Assess placement of ditches in Unit U and surrounding areas, which historically had some riparian habitats but that now are dominated by invasive weeds. Current infrastructure bisects topographic features and prevents natural hydrologic regimes from existing in these areas.
- Restore former salt desert shrub habitats on HHC soil-land association (Fig. 6) and allow precipitation events to drive temporary wetland distribution and hydrology in upland shrub community types. See recommendations above for water management in northern refuge units.
- Control invasive plant species in wetlands to promote re-establishment of native species composition, diversity, and distribution.
- Identify soil type, texture, and stratigraphy within natural levees along the historic secondary channel to help determine appropriate locations for re-establishing native vegetation communities.

3. Encourage management strategies that can emulate natural disturbance events including flooding, drought, fire, and herbivory.

Natural ecological processes along the Rio Grande and its floodplain were suspended beginning with the construction of irrigation canals in the late-1800s. Little to no movement of the river channel, or regular overbank flooding, has occurred since the 1920s because of channelization of the river and diversion of river water for agricultural purposes. Important disturbance processes at Alamosa NWR historically were river overbank and backwater flooding, drought, fire, wind, and herbivory. Specific management actions that can partly restore or replace these disturbances include the following:

- Allow or mimic natural overbank flood events (if possible) to occur by providing the river access to its historic floodplain or gathering water resources for release in one large pulse. Water-control structures may need to be moved or replaced in order to facilitate this event.
- Provide vegetation and soil disturbance events at more natural intervals (every 5-10 years) within all of the habitat types to emulate natural cycles of vegetation decomposition, nutrient recycling, and soil aeration.
- Mimic historic scouring events through mechanical (e.g., disking) or chemical treatments that exposes mineral soils through removal of vegetation and organic matter and provide appropriate hydrologic conditions in the spring to promote regeneration of cottonwoods and willow.
- Consider use of fire, grazing, mowing, and haying to manage succession stage and composition of vegetation communities based on plant phenologies in seasonal wetland and wet meadow communities. Past grazing at Alamosa NWR has been controversial, especially in affecting density of dabbling duck nests, but at least some information suggests that grazing can improve the integrity of wet meadow habitats, improve habitats for other species, and also provide important resources used for non-nesting life cycle events of waterfowl (Diebboll 1999). Grazing and haying also can help control tall whitetop (Gardner 2002).
- If fire can be used, late winter burns may be used to remove residual vegetation and allow new growth of vegetation in the spring. Fire may be used in winter to artificially impact vegetation communities to promote a more native assemblage of plants despite plants adaptations to fire in the spring and summer. Winter burning also would allow for greater coverage of target invasive weeds in relation to herbicide application in the summer.
- If fire can be used and conditions allow, spring and summer burns could be planned based on the vegetation community objectives. For example, cool and warm season grasses respond differently to spring and summer burns based on their phenologies. These burns could also be used to help prevent certain invasive weeds from producing seed depending on season and growth stage.
- Promote a grazing management strategy that incorporates knowledge of different plant life history characteristics to allow for growth and recovery in relation to the current climatic conditions. Prevent disturbance and herbivory of new cottonwood seedlings by cattle and elk using small exclusions or permanent fencing to prevent browse. Potential sites located near abandoned channels containing necessary resources for cottonwood regeneration may be successful if combined with the construction of exclusions to help prevent herbivory. Some information suggests that the time and duration of potential herbivory are important factors in preventing overgrazing of cottonwoods; however, other studies indicate that the diversity and complexity of newly established cottonwood and riparian forests are negatively impacted by any grazing (Scott et al. 2003) regardless of stand age.
- Mowing or haying may be done to mimic natural herbivory if grazing is not an option. Mowing of habitats that will be flooded will allow residual vegetation to provide the necessary structure for invertebrate communities. Removal of the residual structure may increase soil temperatures and promote the growth of other species. Both strategies may be utilized to help prevent the expansion of tall whitetop, reduce cover and density, and allow other native species to out-compete the weed.

MONITORING AND EVALUATION

The current understanding of the SLV and the Alamosa NWR ecosystem has been greatly enhanced by documentation of system attributes and management actions (such as in former annual narratives of the refuge) and past monitoring and evaluation studies of vegetation and animal communities, water quality and quantity, and specific management actions. Future management of the system should incorporate key monitoring studies and direct research as needed (Paveglio and Taylor 2010). Monitoring will be determined primarily by refuge objectives, but some measures should be collected that indicate how factors related to ecosystem structure and function are changing, regardless of whether the restoration and management options identified in this report are undertaken. Ultimately, the success in restoring and sustaining communities and ecosystem functions and values at Alamosa NWR will depend on how well the physical integrity and hydrological processes and events within the refuge can be restored, maintained, and emulated by management actions as well as the relative resiliency of different habitat types. Therefore, monitoring and evaluation of the management strategies employed at Alamosa NWR must be long enough to account for the spatial and temporal rate of change for different abiotic and biotic characteristics that are altered (Michener and Haeuber 1998). The availability of future water amounts, timing, and type (groundwater vs. surface water source) is a major item that must be carefully monitored and considered as future management for the refuge is considered. Uncertainty exists about the future of some important water issues and the ability of the USFWS to make some system changes because they are not completely under the control of the USFWS. Also, specific techniques for certain management actions, such as controlling and reducing introduced plant species and the efficacy of restoring native composition and integrity of wetland and desert shrub habitats are not entirely known.

Whatever future management actions occur on Alamosa NWR, activities should be done in an adaptive management framework where: 1) predictions about community response and water issues are made (e.g., decreased invasive weed dominated habitats) relative to specific management actions (e.g., restoration of seasonal sheetwater flow) in specific locations or communities (e.g., Vastine soils) and 2) follow-up monitoring is conducted to evaluate ecosystem responses to the action. Information and monitoring needs for Alamosa NWR related to the hydrogeomorphic information evaluated in this report are identified below:

GROUNDWATER AND SURFACE WATER QUALITY AND QUANTITY

The recent WRIA for Alamosa NWR (Striffler 2013) identified several important future monitoring and information needs related to water. These and other needs include:

- Protect water rights for the refuge through careful monitoring and reporting of water use and ecosystem benefits. This will include updating well-meter calibrations, restoring and maintaining points of water diversion, and use of appropriated water rights.
- Evaluate potential alternatives to existing water sources and supplies to augment water supplies in the advent of decreased availability of some sources.

- Initiate a baseline water monitoring program to document long-term changes in surface and groundwater quality and quantity.
- Conduct routine monitoring of water quality and contaminant issues in relation to water source and routing. Regular monitoring of surface, ground, and soil salinity in key reference locations related to HGM-determined communities should be established.
- Install water flow metering stations at key points on the refuge if/when historic drainage pathways are utilized to allow water to more naturally flow through the system.
- Continue to participate in SLV water monitoring and management activities and determine potential effects of various climate change scenarios.

RESTORING NATURAL WATER FLOW PATTERNS AND WATER REGIMES

This report identifies several potential physical and management changes that could help restore natural topography, water flow, and flooding/drying dynamics in managed wetlands. These changes include restoring sheetflow through natural drainages across the floodplain and managing impoundments (that are retained) for more natural spring-flooded seasonal flooding regimes. Further, restoring inter-annual dynamics of flooding and partial drying of the impoundments managed for seasonal and semi-permanent water regimes and persistent emergent vegetation is desired. The following monitoring will be important to understanding effects of these changes if implemented:

- Evaluate current water-control infrastructure to determine if current and future water management needs (e.g. capacity and placement) are being met or if changes to the system are warranted.
- Evaluate current hydrologic flow patterns in relation to HGM recommendations to restore some historical flow through natural channels.
- Evaluate surface and groundwater interactions and flow. Development of an annual water budget which incorporates both surface and groundwater based on predictions and actual conditions could help in creating future Augmentation Plans and maintaining water rights.
- Document and monitor timing, duration, and extent of surface water across habitat types. Observations of how water flows through current water-control structures in, for example, wet meadow habitats will help guide the modification of existing structures and the placement of new ones in appropriate locations, both vertically and horizontally, to distribute water in a sheetflow pattern without causing head-cuts or other water delivery-induced impacts to the system (Zeedyk 1996).
- Monitor groundwater changes within features such as natural levees where revegetation activities occur, such as pole plantings of cottonwood.

LONG-TERM CHANGES IN VEGETATION AND ANIMAL COMMUNITIES

The availability of historic vegetation information coupled with regularly documenting changes in general and specific vegetation communities is extremely important to understand the long-term changes and management effects on Alamosa NWR. Also, regular monitoring of at least some select animal species or groups helps define the capability of the Alamosa NWR ecosystem to supply key resources to, and meet annual cycle requirement of, animals that use the refuge and regional area. Important survey/monitoring needs include:

- Mapping the cover, density, and diversity of invasive species over time in relation to management strategies.
- Success of cottonwood and willow regeneration on Sandy Alluvial Land soil series areas and in other areas such as natural levees where this habitat type is being promoted.
- Changes in extent of different wetland and upland habitats as hydrologic changes occur in relation to timing, duration, periodicity, and source of water resources utilized
- Occurrence, timing, and habitat use of key migratory and breeding birds, including Neotropical songbirds, secretive marsh birds, waterfowl, and colonial waterbirds.

- Rates and occurrence of fire in riparian areas, wetlands, and shrublands in relation to invasive weeds and native vegetation cover and diversity.
- Vegetation response to grazing strategies, including the rate, timing, and intensity of grazing (e.g., warm vs. cool season plant response to various strategies).
- Vegetation response to mowing and/or haying in relation to season
- Vegetation response to mechanical manipulations mimicking natural processes such as scouring events.
- Occurrence, distribution, and abundance of amphibians and reptiles in relation to different hydrologic regimes, wetland types, and management strategies.
- Occurrence, distribution, and abundance of invertebrates in relation to different hydrologic regimes, wetland types, and management strategies.

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ACKNOWLEDGEMENTS

This project was supported by IDIQ Contract No. F10PD77659 between the USFWS and Blue Heron Conservation Design and Printing LLC. Mike Blenden, Project Leader, of the San Luis Valley NWR Complex sponsored the project and assisted with all field visits, planning meetings, gathering of information for the refuge, and review of report drafts. Floyd Truetken, Ron Garcia, Pat Gonzales, and Scott Miller provided important information and review of past refuge management activities and current conditions. Wayne King, USFWS Regional Biologist, helped initiate the project and provided administrative support and review of the report. Pete Striffler and Meg Estep helped obtain and analyze the hydrological data for the study, kindly provided early drafts WRIA and allowed use of select figures in it, and provided important review of the draft report. Meg VanNess provided information and assistance with information pertaining to the history of the SLV. Murray Laubhan and Mike Artmann assisted with developing current vegetation maps for the refuge, assisted in developing recommendations, and provided important review of the draft report. Leigh Fredrickson kindly provided information on past studies of the SLV NWRs and offered important insights into ecosystem attributes and management effects. Karen Kyle of Blue Heron Conservation Design and Printing LLC administered the contract for the project and provided assistance with analyses of data and geographical information, preparation of report drafts, and publication of the final report.

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