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

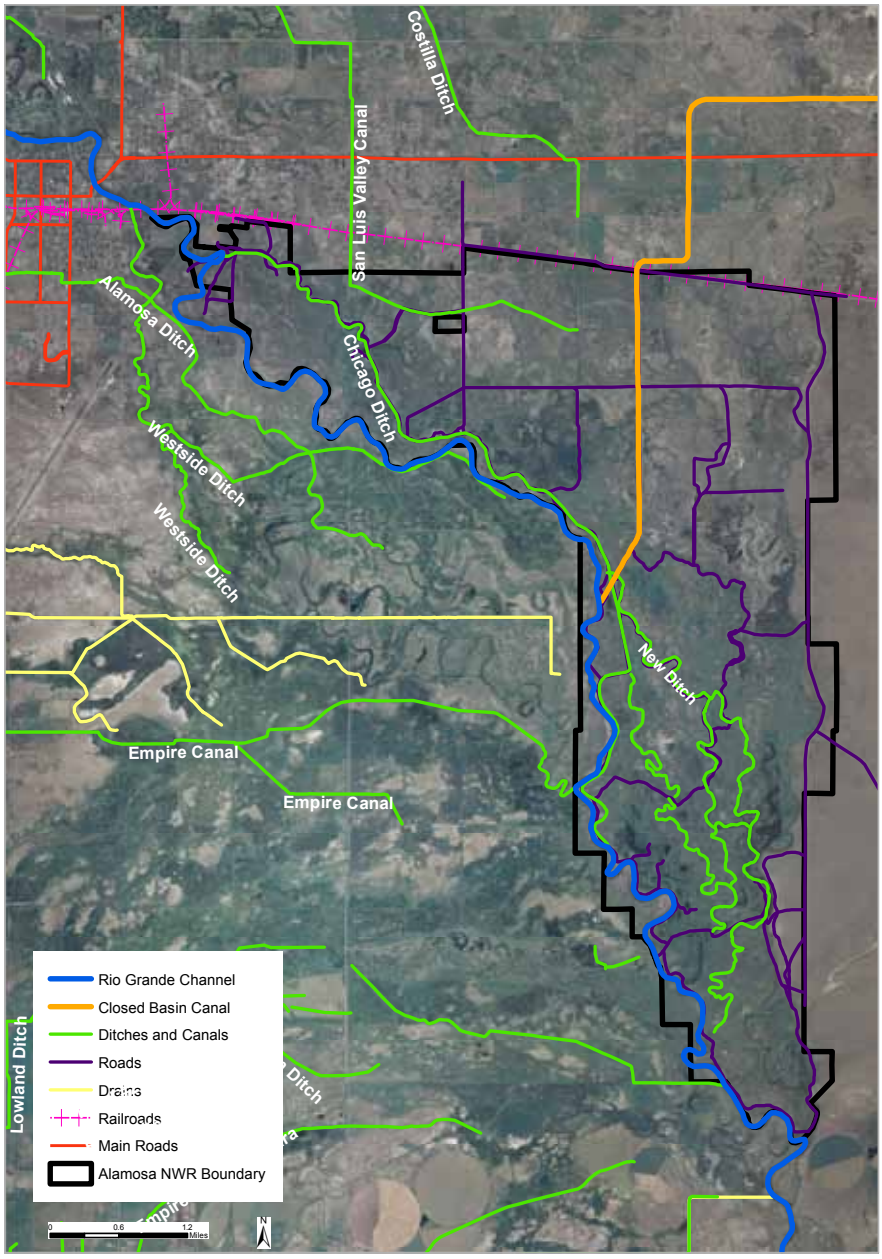

Figure 17. Location of roads, canals, ditches, drains, and rivers in and around Alamosa National Wildlife Refuge.

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

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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, re-

routing 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

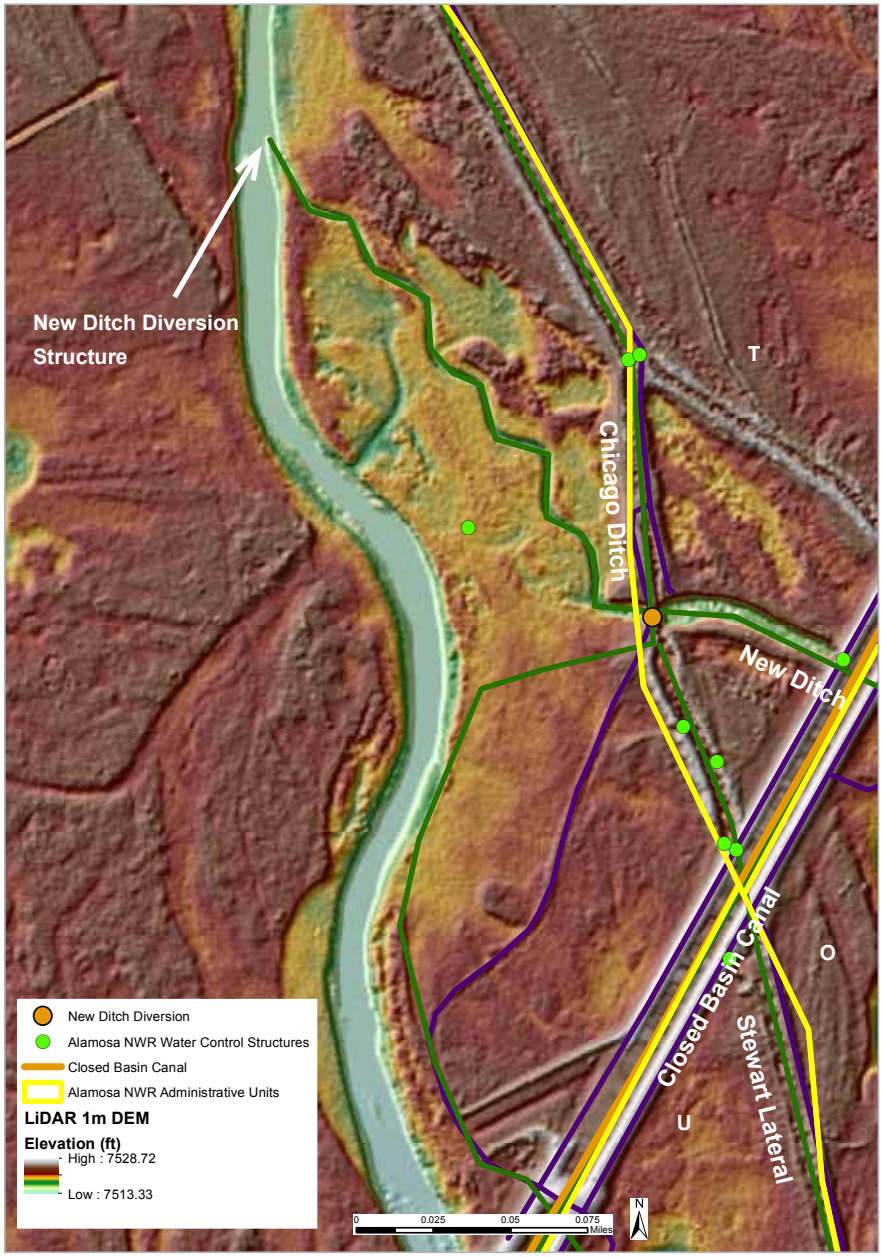

Figure 18. Location of the New Ditch Diversion that diverts water from the Rio Grande River onto Alamosa NWR.

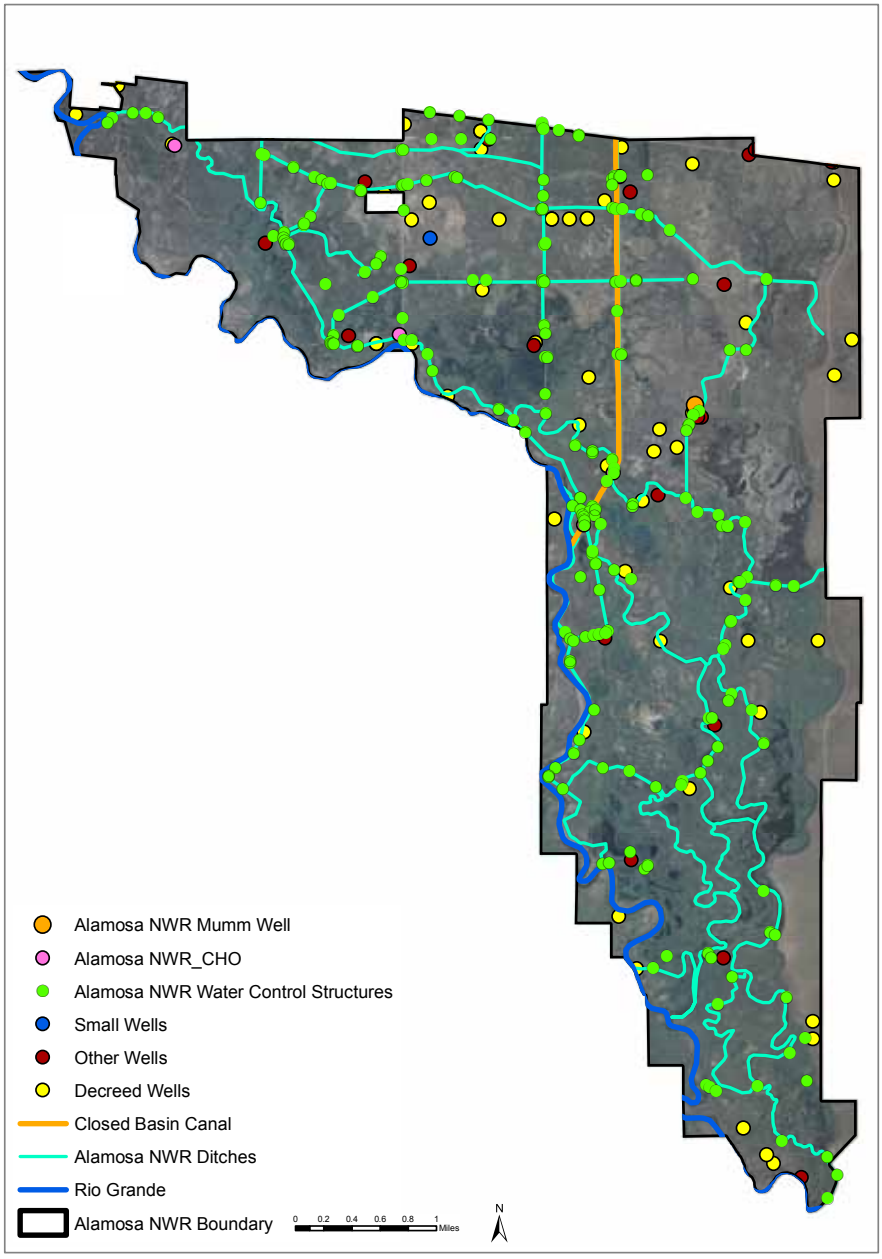

Figure 19. Water delivery infrastructure and wells on Alamosa NWR.

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, Environ-

mental 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).

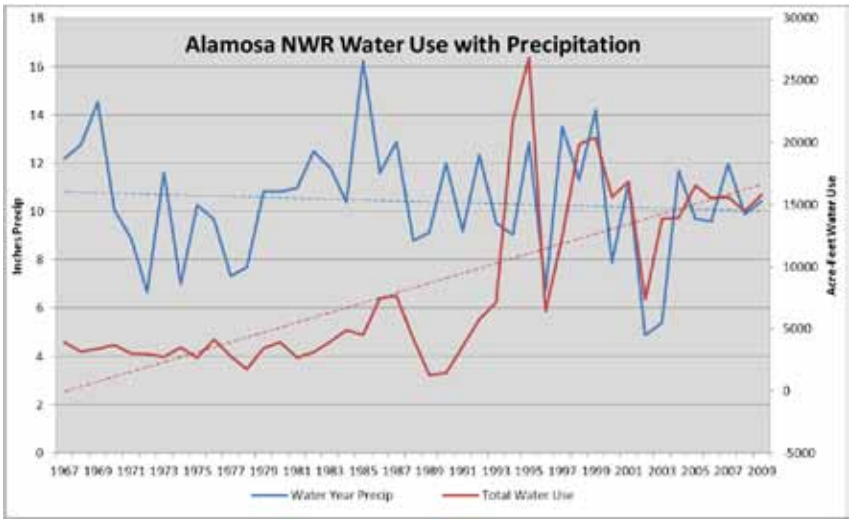

Figure 20. Alamosa National Wildlife Refuge water use and annual precipitation from 1967 to 2009 (from Striffler 2013).

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

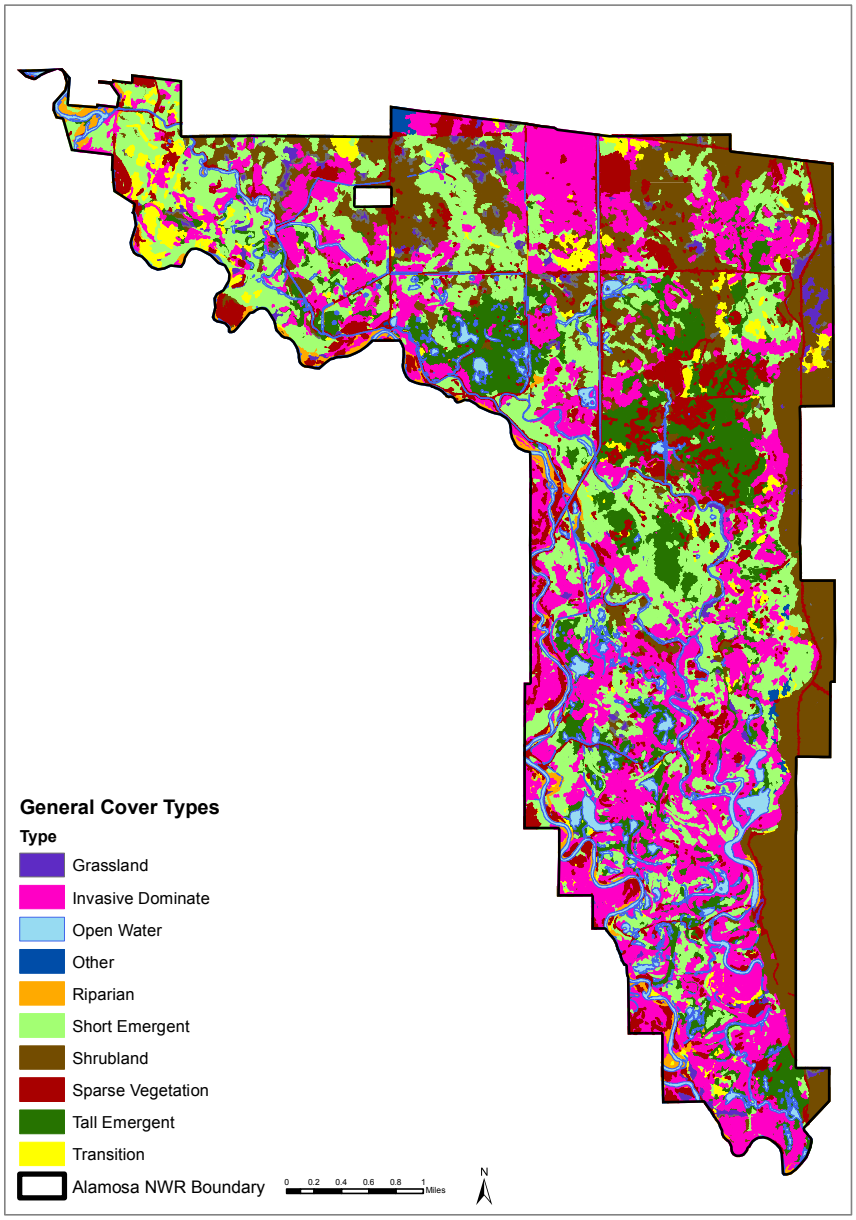

Figure 21. Current general vegetation type coverage on Alamosa National Wildlife Refuge.

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

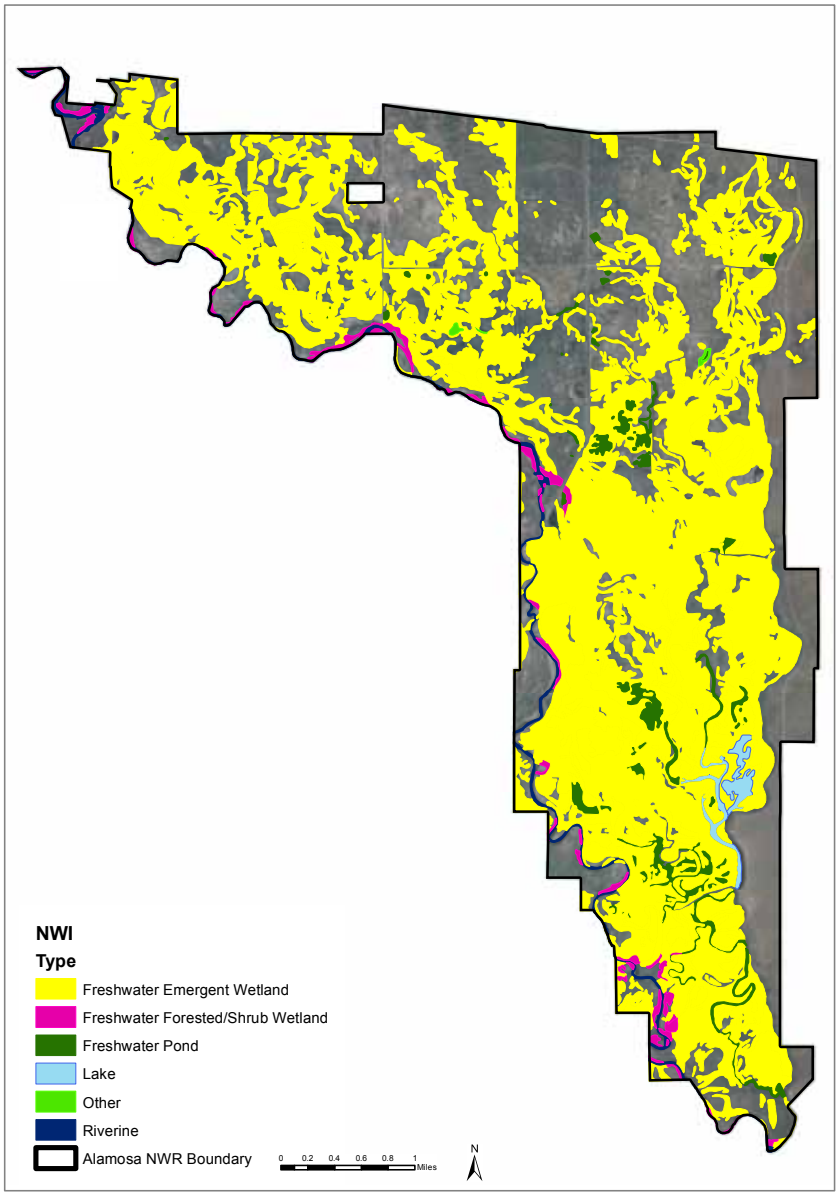

Figure 22. National Wetland Inventory categories on Alamosa National Wildlife Refuge (data 9/1984, from www.fws.gov/wetlands/data).

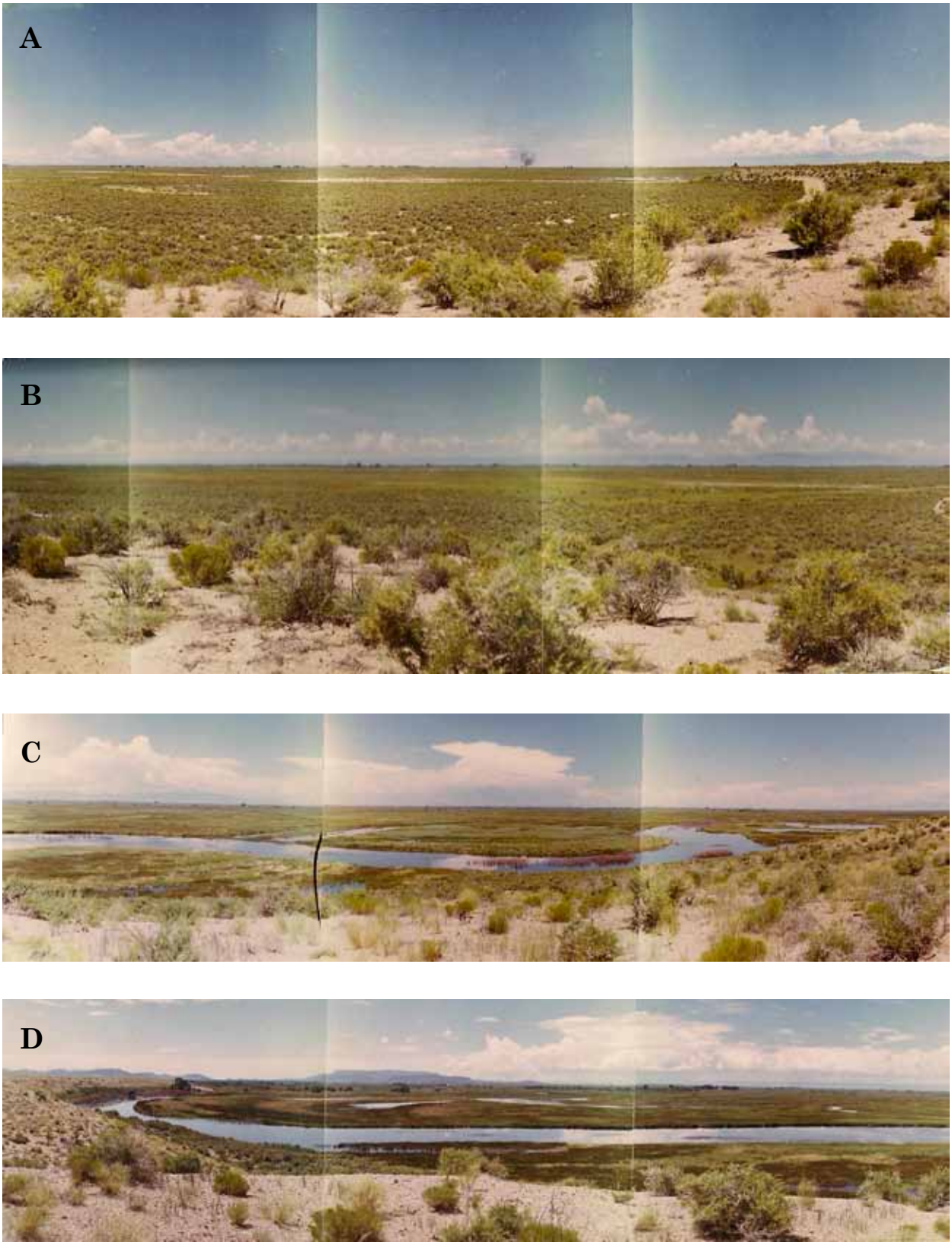

Figure 23. Panoramic photos of Alamosa National Wildlife Refuge in 1967: A) Point A on Bluff Road near units M and N1 looking north in 1967; B) Point A on Bluff Road near units M and N1 looking southwest in 1967; C) Point B on Bluff Road near overlook looking north in 1967; and D) Point B on Bluff Road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

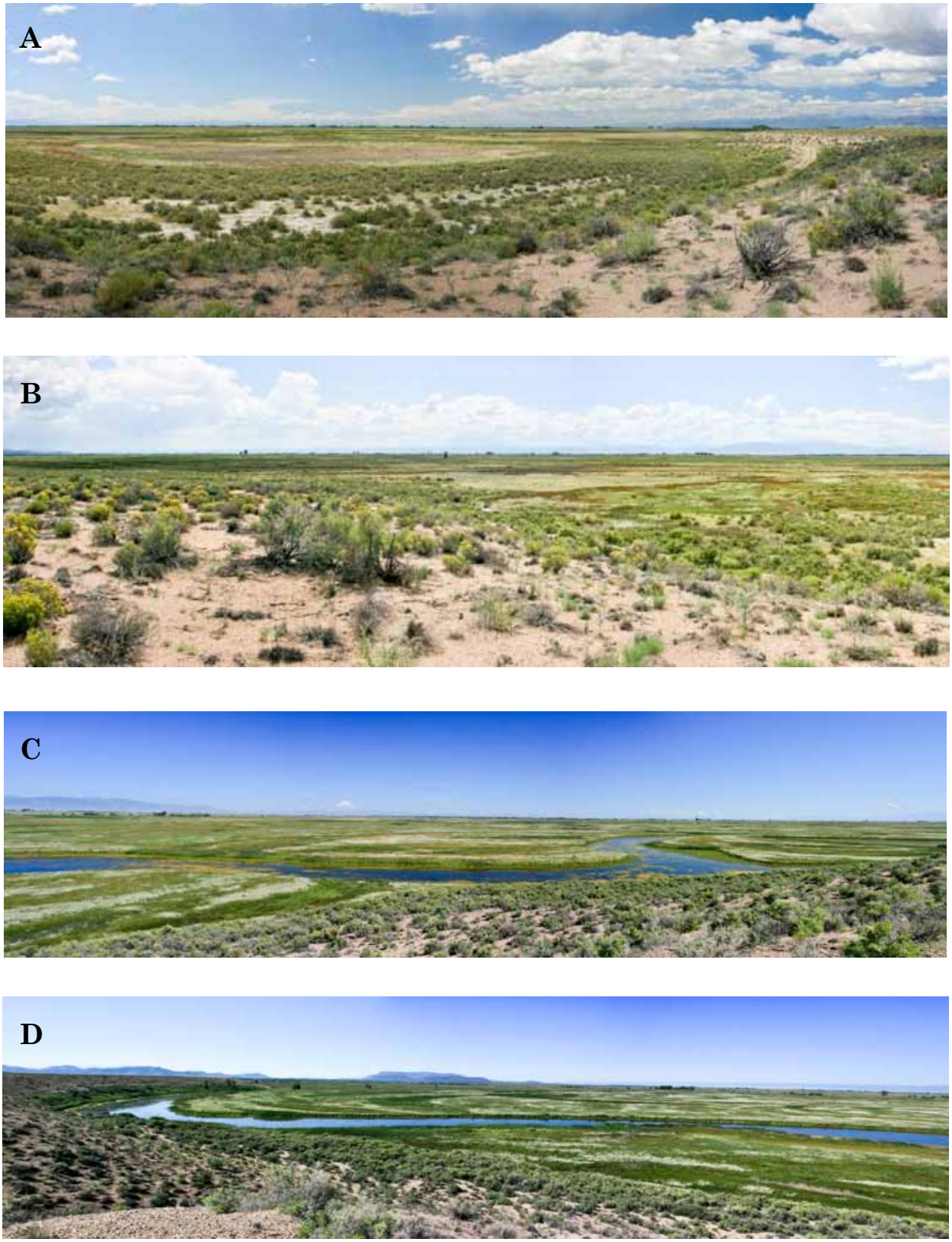

Figure 24. Panoramic photos of Alamosa National Wildlife Refuge in 2012: A) Point A on Bluff Road near units M and N1 looking north in 2012; B) Point A on Bluff Road near units M and N1 looking southwest in 2012; C) Point B on Bluff Road near overlook looking north in 2012; and D) Point B on Bluff Road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

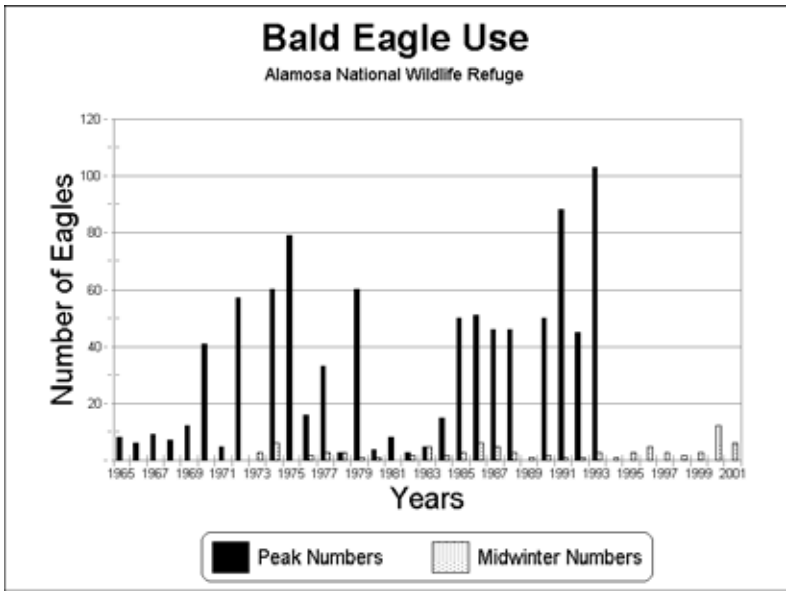

Figure 25. Population trends for bald eagles on Alamosa National Wildlife Refuge (USFWS 2003).

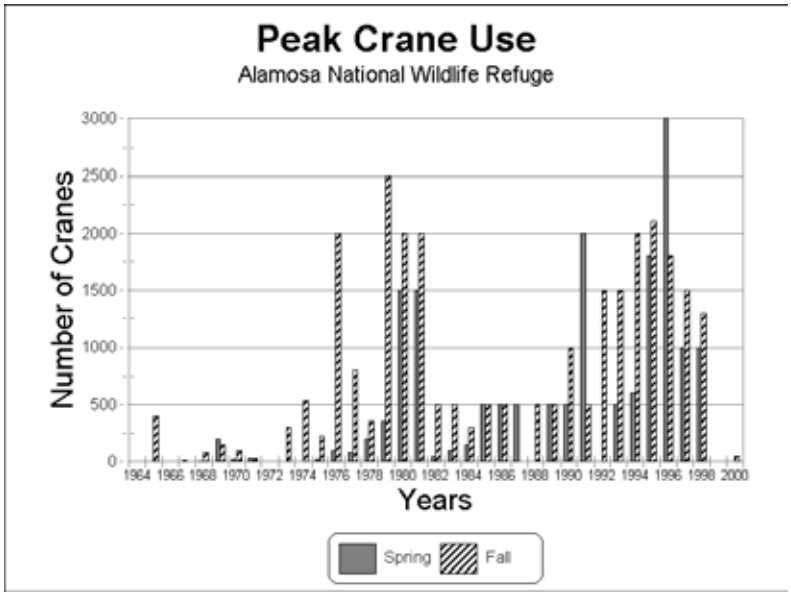

Figure 26. Population trends for sandhill cranes on Alamosa National Wildlife Refuge (USFWS 2003).

Cary Aloia