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

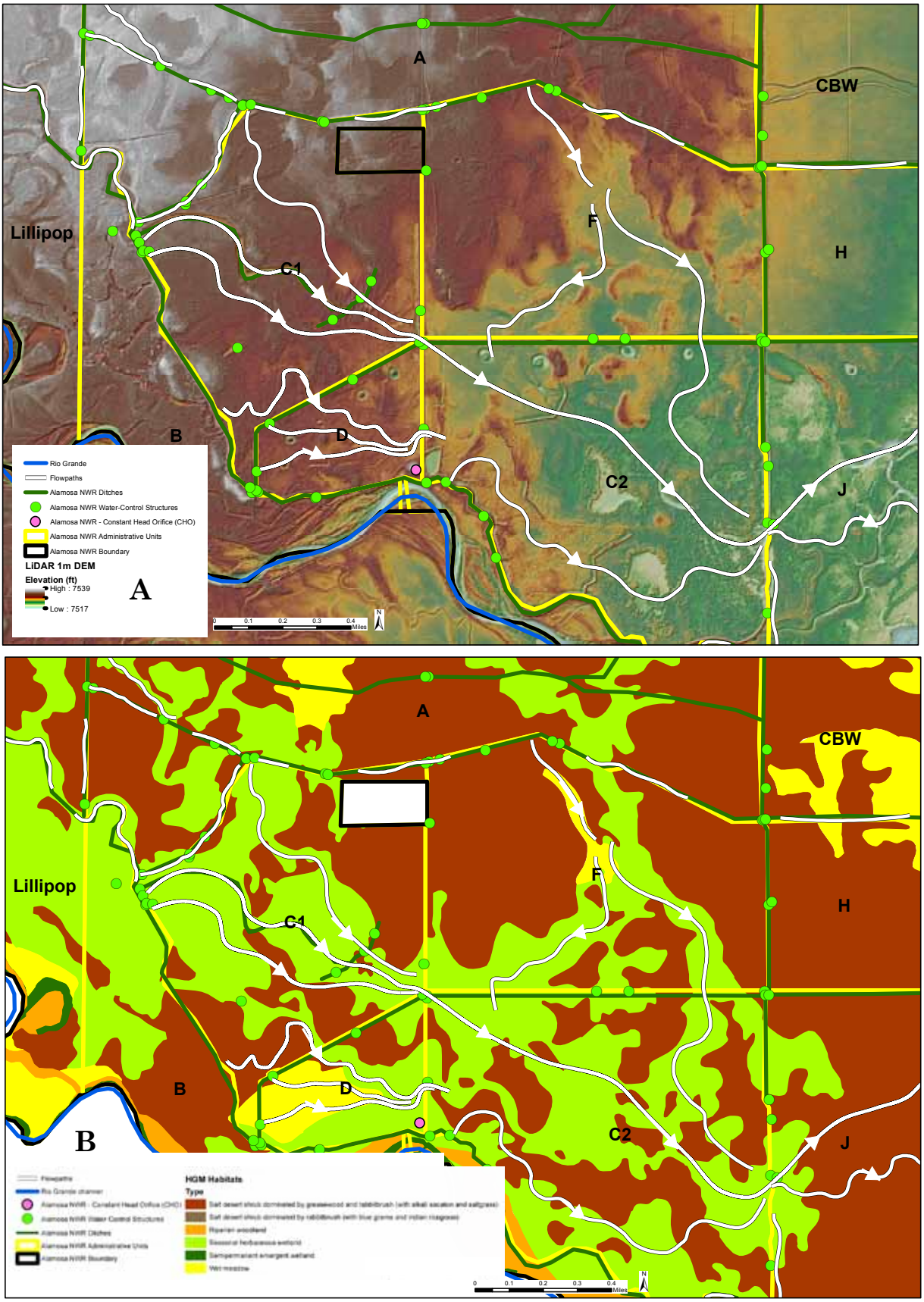

Figure 27. Natural drainage pathways on the north part of Alamosa National Wildlife Refuge overlain on: A) LiDAR 1 m DEM and B) potential historical vegetation from Fig. 16.

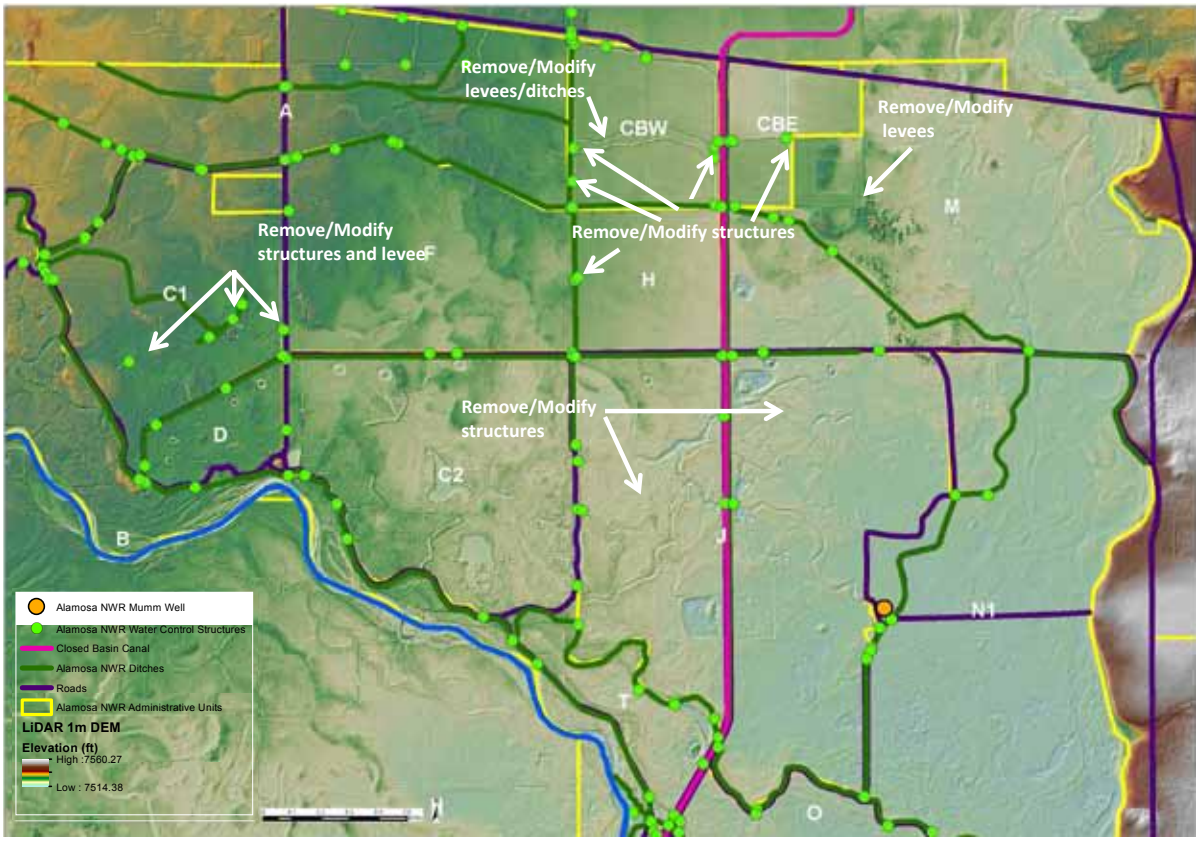

Figure 28. Location of water delivery infrastructure in the northern portion of the Alamosa National Wildlife Refuge that could be removed or modified to improve restoration potential.

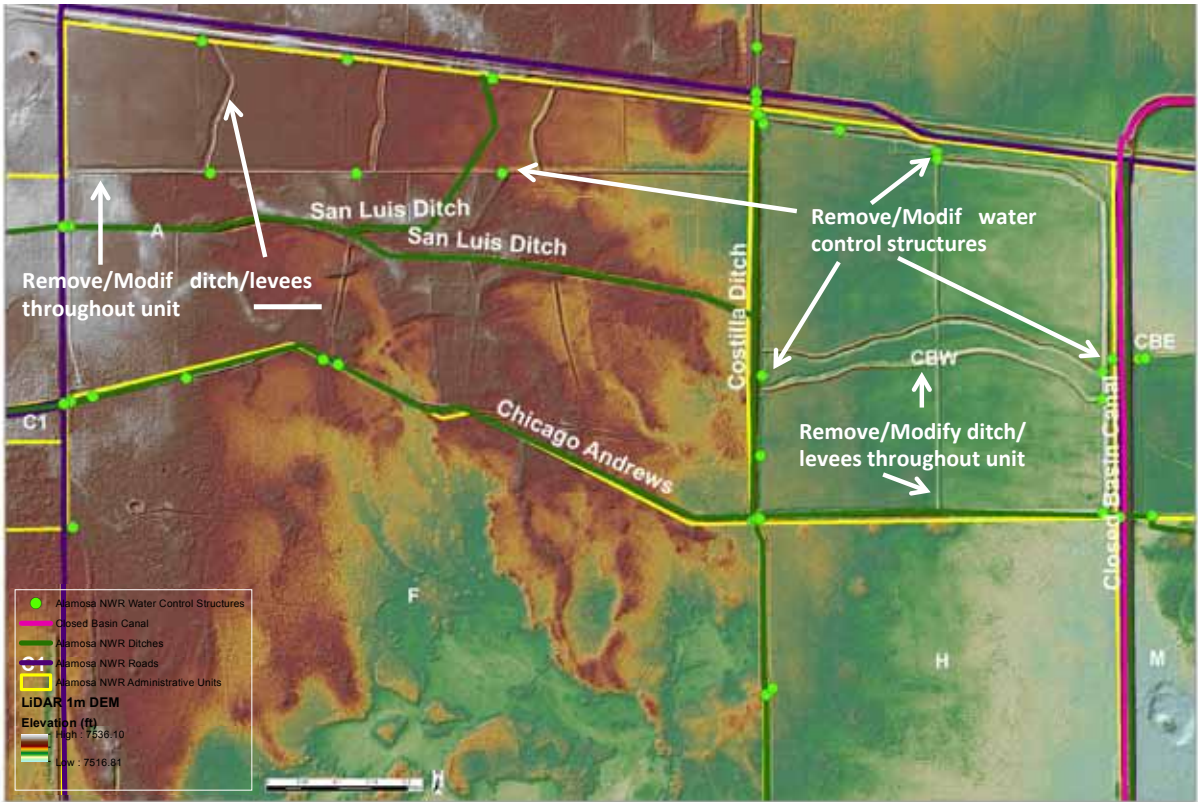

Figure 29. Location of ditches and levees in Administrative Units A and CBW outside of natural drainage pathways and in historic shrublands on Alamosa National Wildlife Refuge that could be removed or modified to improve restoration potential.

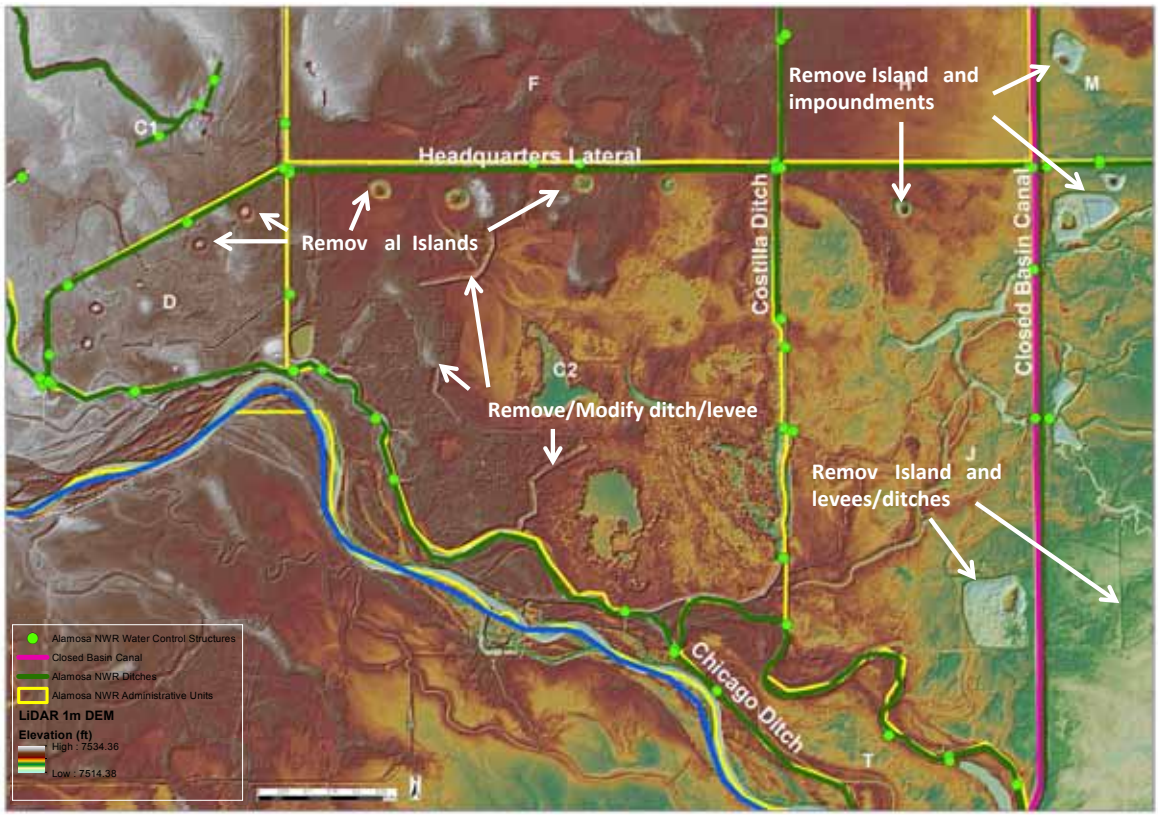

Figure 30. Location of islands and other infrastructure in Administrative Units C2 and J which could be removed to facilitate natural surface water flow across the floodplain on Alamosa National Wildlife Refuge.

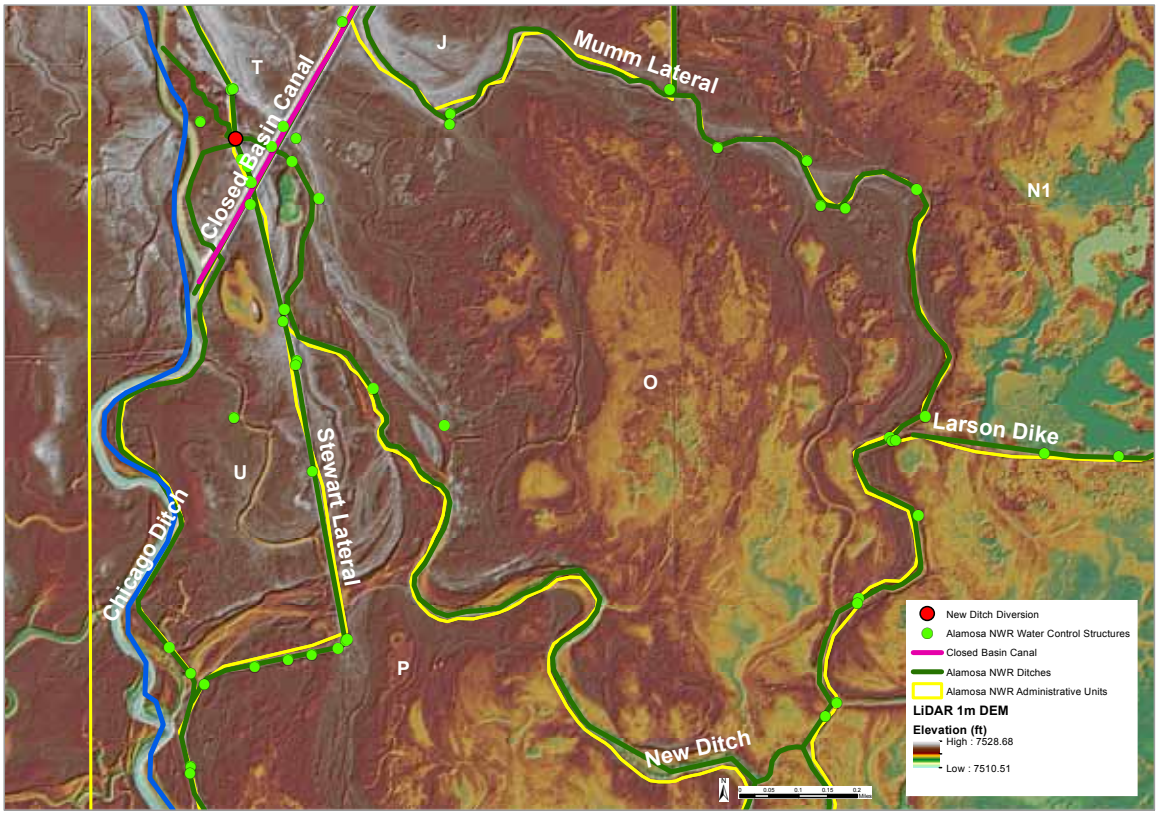

Figure 31. Location of infrastructure in Administrative Units O and U in relation to natural topography on Alamosa National Wildlife Refuge.

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.