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Land Use and Conservation Reserve Program Effects on the Persistence of Playa Wetlands in the High Plains

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ABSTRACT: Watershed cultivation and subsequent soil erosion remains the greatest threat to the service provisioning of playa wetlands in the High Plains. The U.S. Department of Agriculture's (USDA) Conservation Reserve Program (CRP) plants perennial vegetation cover on cultivated lands including playa watersheds, and therefore, the program influences sediment deposition and accumulation in playas. Our objective was to measure the effects of the CRP on sediment deposition by comparing sediment depth and present/historic size characteristics in 258 playas among three High-Plains subregions (northern, central, and southern) and the three dominant watershed types: cropland, CRP, and native grassland. Sediment depth and resultant volume loss for CRP playas were 40% and 57% lower than cropland playas, but 68% and 76% greater than playas in native grassland. Playas in CRP had remaining volumes exceeding those of cropland playas. Grassland playas had nearly three times more original playa volume and 122% greater wetland area than CRP playas. Overall, playas were larger in the south than other subregions. Sediment depth was also three times greater in the south than the north, which resulted in southern playas losing twice as much total volume as northern playas. However, the larger southern playas provide more remaining volume per playa than those in other subregions. The results of this study demonstrate the importance of proper watershed management in preserving playa wetland ecosystem service provisioning in the High Plains. Furthermore, we identify regional differences in playas that may influence management decisions and provide valuable insight to conservation practitioners trying to maximize wetland services with limited resources.

INTRODUCTION

Playa wetlands are principal hydrogeomorphic features in the High Plains of the United States.[1] Playas occupy approximately 2% of the Southern Great Plains landscape, yet they are crucial ecosystems in international service delivery.[2] Moreover, in a region that places high demand on groundwater for cropland irrigation, throughout much of the High Plains, playas may serve as the only significant sites of recharge to the Ogallala aquifer, one of the world's largest groundwater sources.[3] Playas also support floral communities that are typically more productive than adjacent upland plant communities; contributing to climate mitigation services by sequestering atmospheric carbon.[2] In addition, playas provide aquatic habitat for local and transient fauna[4] which ultimately increases their educational, recreational, and aesthetic value.

Natural services provided by playas are contingent upon their water storage capacity and hydroperiod. For example, playas with greater wetland volumes and longer hydroperiods are greater contributors to biodiversity provisioning and aquifer recharge.[3,5] Playa hydroperiod is determined by the rate of water loss through evapotranspiration and recharge relative to inputs from direct precipitation and watershed runoff.[6] Previous studies have demonstrated that watershed land use influences both water inputs and losses in playas.[7−9] Cropland agriculture in the High Plains has become the major threat to playa hydrology;[6] the most deleterious factor being erosion from cultivated watersheds into the wetland basin.[7,8,10] Sedimentation is a natural process in playa basins, and under natural conditions accumulated sediment is reduced through deflation during dry periods.[6] However, cultivated watersheds promote sediment accumulation that far exceeds losses due to deflation.[7] Increased sediment loads in playas force water to spread over a larger area, thus increasing water loss through evaporation, standing water over porous soils, and edge effect percolation.[7] Tsai et al.[8] found that water loss rates were greater in playas with cultivated upland watersheds compared to playas with native grassland watersheds.

Few conservation programs directly aid in playa conservation[6] though the High Plains (Figure 1) contains the greatest

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Figure 1. Northern, central, and southern subregions of the High Plains separated by the natural narrowing of the underlying Ogallala Aquifer (adapted from Smith et al. 2011).

density of U.S. Department of Agriculture (USDA) Conservation Reserve Program (CRP) property. The CRP is one of the largest conservation programs in terms of total land enrollment and distributes on average $97 million annually to participating landowners in the High Plains.[11] Since its inception in 1986, 12.9−15.8 million ha of agricultural land have been enrolled nationally in the CRP primarily to protect highly erodible soils, reduce commodity supplies, and provide other conservation benefits. Due to its widespread implementation in the High Plains, the CRP has the potential to influence playas more than any other USDA program.[2]

In the High Plains, the CRP retires highly erodible cropland which is maintained in perennial grass cover for the period of the contract (generally 10 years) in exchange for annual rental payments. Many grasses associated with CRP plantings throughout the High Plains are denser and in excess of the typical plant biomass associated with native short-grass prairie; this practice has had a negative influence on playa hydrology.[9] Grasses typical of CRP establishment dissipate much of the runoff energy from precipitation events, increasing water infiltration into the upland soil rather than filling wetland basins.[9,12] Although CRP establishment may reduce playa inundation frequency, it may be protective of other services by preventing soil erosion into playa basins, thus eliciting ecosystem service trade-offs.[13]

As part of the overall goal for the wetland component of the Conservation Effects Assessment Project, USDA conservation programs are evaluated to determine their effects on various wetland ecosystems and their services.[14] Because ecosystem services provided by playas are hydrologically driven, it is necessary to understand the effects of the CRP on factors that influence hydrology. This study was designed to compare the physical components dictating playa water storage capability among dominant watershed types throughout the entire western High Plains region, with emphasis on evaluating the efficacy of CRP to reduce sediment accumulation and protect playas. A secondary objective was to evaluate localized differences in accumulated sediment depth and water storage volume among cropland, CRP, and native grassland watershed types to provide detailed recommendations for minimizing negative impacts to playas.

METHODS

We examined sediment depth, playa area, hydric soil defined (original) playa volume, volume loss, and remaining volume of playas embedded in the dominant land uses of the High Plains (CRP, cropland, and native grassland dominated watersheds) due to the importance of these factors in influencing wetland function and service delivery. Because the High Plains ecoregion covers a large geographic area, we further compared these factors among three subregions (northern, central, and southern; Figure 1).

Study Area. The study area consisted of the High Plains, from western Nebraska and eastern Colorado, south through western Kansas and Oklahoma, to eastern New Mexico and western Texas, referred to as the western High Plains (Figure 1). This area largely coincides with much of the short-grass prairie ecoregion. In addition, the western High Plains was separated into three subregions corresponding with the hydrogeological compartments of the underlying Ogallala Aquifer.[3] A total of 258 playas was included in the study, with 86 playas in each of the three dominant watershed types: native grassland, cropland, and CRP. Playa selection was stratified based on their density within a county to ensure even coverage of the entire region. Due to the limited amount of native grassland, playas in that land use were randomly selected first from existing wetland data containing playa location along with land use information.[9] Grassland playas were then paired with nearby playas in CRP and cropland dominated watersheds producing geographically matched wetland sets.

Field Measurements. Original playa volume represents the historic volume of the playa as defined by the extent of the hydric clay layer that formed the playa under natural hydrological conditions. Original playa volume was calculated similarly to that of Luo et al.[7] assuming the shape of a truncated cone, using playa area, slope of the playa edge, location of the hydric soil edge, and difference in elevation between the visual edge and playa basin.[8] Playa area (±0.1 ha) was determined by walking the visual edge with a Trimble Series Geo XT or Geo XH GPS unit with TerraSync software. The visual edge of each playa was determined by the change in vegetation and slope from playa to surrounding upland.[7] Elevation differences (±1 cm) between the center of the playa basin and eight locations (45° angles) around the visual edge were determined using a surveyor level and stadia rod. Hydric soil edge was determined along two transects perpendicular to the visual edge on opposing sides of the playa by using a hand auger to core through the sediment until the hydric clay layer could no longer be detected. Edge of the playa floor was determined as the point at which the basin began to slope upward. Distance (±0.1 m) was measured from the playa floor edge to the hydric soil edge and from the hydric soil edge to the visual edge. Sediment depth (±1 cm) was measured at the hydric soil edge, as well as at the basin center and five points around the basin center and approximately half the distance to the basin edge. Sediment deposited on top of the hydric clay layer was distinguished by differences in soil color and texture.[10] Remaining playa volume was derived by subtracting sediment volume (determined by

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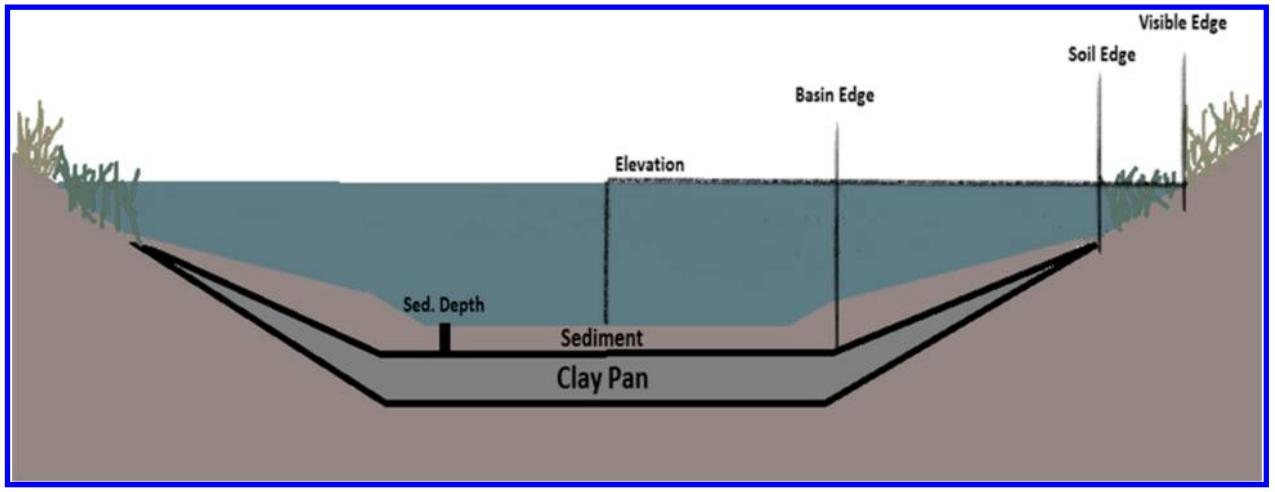

Figure 2. Cross sectional view of a playa wetland depicting the location of measured parameters used in volume calculations. Sediment depth measurements were collected in the basin center and five locations within the basin edge boundaries. Basin, soil, and visible edges were identified at two opposing sides of the playa.

sediment depth*original playa area) from original playa volume (Figure 2).

Some playas in cropland (n = 23) and CRP (n = 12) had no visible wetland vegetation and thus no discernible visual edge. For these playas, the hydric soil edge was determined and visual edge set at 1 m beyond the hydric soil edge. The perimeter of the playa was then measured by following the natural topography of the playa and calibrated via surveyor level and stadia rod at each elevation point, thus maintaining the same elevation as the initial point.

Statistical Analysis. A two-way analysis of variance (ANOVA) with interaction (Proc GLM; SAS 9.2) was used to compare playa characteristics among watershed types, subregions, and watershed*subregion interactions (α = 0.05). A protected Duncan's multiple range test was performed on independent variable means (watershed type and subregion) and watershed*subregion interactions for each response variable (sediment depth, playa area, original playa volume, volume loss, and remaining playa volume) when appropriate. Response variables were checked for model residual normalcy and homogeneity of variances prior to analyses.[15] A cropland playa in the northern subregion and a grassland and CRP playa in the central subregion had extreme volume values that heavily influenced variable means and caused standard error values to increase by an order of magnitude. These playas were considered outliers as determined by a modified Dixon's Q test[16] for sample sizes greater than 25 and thus removed from the analyses.[17]

RESULTS

Sediment Depth. There was an interaction between watershed type and subregion for sediment depth (Table 1). Therefore, sediment depth was compared within subregions. Sediment depth differed among watershed types in all three subregions. Sediment depths of native grassland playas were 58%, 40%, and 36% less than CRP playas in the north, central, and south, respectively. Cropland playas had the greatest sediment depths among all watershed types and were 23% and 120% greater than CRP playas in the central and southern subregion, respectively. In the north, CRP playas had sediment depths similar to northern cropland playas (Figure 3A). Southern playas had greater sediment depths than playas in the north across all watershed types. Average sediment depths in grassland playas were two times greater in central and southern areas than in the north. Southern CRP playas had sediment depths 44% greater than those in the north. However, sediment depth of central CRP playas did not differ from northern or southern CRP playas. Last, sediment depth in southern cropland playas was about twice that of playas in the central subregion and over four times that of cropland playas in the north (Figure 3A).

Table 1. Two-Way ANOVA Analyses Comparing the Effects of Two Factors on Playa Characteristics (Sediment Depth, Playa Area, Original Playa Volume, Volume Loss, And Remaining Volume)[a]

	source	df	F-ratio	p-value
Sediment depth (cm)	Watershed x Subregion	4	25.75	<0.001
Playa area (ha)	Watershed x Subregion	4	5.17	<0.001
Original playa volume (m^3)	Watershed x Subregion	4	2.1	0.081
	Watershed	2	12.38	<0.001
	Subregion	2	7.2	<0.001
Volume loss (%)	Watershed x Subregion	4	6.32	<0.001
Remaining volume (m^3)	Watershed x Subregion	4	2.17	0.073
	Watershed	2	13.08	<0.001
	Subregion	2	1.59	0.206
	Error	249		
	Corrected total	257		

[a]The main effects were watershed type (native grassland, cropland, and CRP) and sub-region (north, central, and south).

Playa Area. There was an interaction between watershed type and subregion for playa area; thus, metrics were examined within subregions (Table 1). Playa area differed among watershed types in the central and southern subregions, but not in the north. Central and southern grassland playas were more than two and three times larger, respectively, than CRP and cropland playas, which did not differ from each other (Figure 3B). Grassland playas were larger in the south than in the north with southern playas almost twice as large as central playas, which were almost three times larger than those in the

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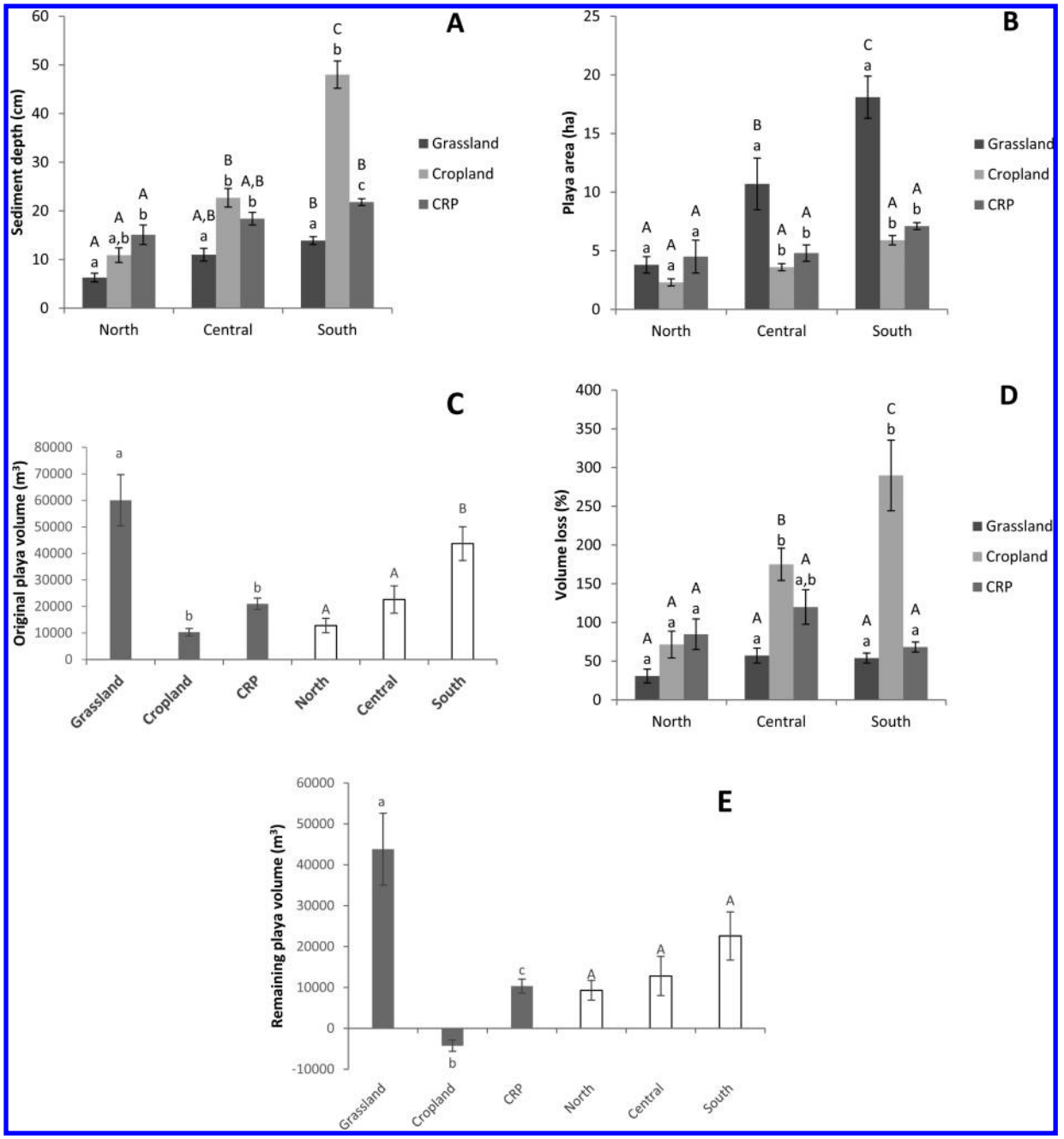

Figure 3. Mean (±SE) (A) sediment depth, (B) playa area, (C) original playa volume, (D) volume loss, and (E) remaining volume of playa wetlands sampled from 2008 to 2010 in three watershed types and three subregions of the western High Plains. Upper-case letters designate differences of the same land use across subregions and lower-case letters designate differences among land uses within subregions ($P < 0.05$).

north. Southern CRP playas were 58% larger than those in the north and central subregions, which did not differ. This pattern was the same for cropland playas; in the south they were 157% larger than central and northern cropland playas, which did not differ from each other (Figure 3B).

Original Playa Volume, Volume Loss, and Remaining Playa Volume. There was no interaction between watershed type and subregion for original playa volume or remaining playa volume (Table 1). However, interaction did exist for volume loss; thus, it was analyzed within subregions. Original playa volume differed by watershed type with volume of native grassland playas being up to six times larger than cropland playas and nearly three times larger than playas in CRP. Playa volume metrics in cropland and CRP playas did not differ from one another (Figure 3C). Original playa volume also differed among subregions; playas in the south were 93% larger than central playas and 241% larger than northern playas (Figure 3C). Though southern playas were historically larger, cropland playas in the southern subregion lost four times more volume than cropland playas in the central and northern subregions (Figure 3D). There was no difference in volume loss across subregions for native grassland or CRP playas. Indeed, cropland playas experienced the greatest loss in volume among watershed types, except in the north where volume loss was similar among watersheds. In the southern subregion, cropland playas lost about six times more volume than grassland and CRP playas. Volume loss of central cropland playas was 46%

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greater than CRP playas, which in turn lost 110% more volume than grassland playas (Figure 3D).

Cropland playas, on average, have filled beyond the hydric soil defined volume with sediment; thus, they have negative remaining volumes. The remaining volume of grassland playas was more than four times greater than that of CRP playas (Figure 3E). Remaining volume did not differ among subregions, though playas in the south did have remaining volumes that were twice as high as northern playas (Figure 3E).

DISCUSSION

Wetlands are among the most ecologically productive ecosystems in the world, providing an array of highly valued services.[18] For wetlands such as playas, the types and amounts of services provided are determined by how long a wetland holds water.[5] This study is the first to characterize water storage capabilities of playas throughout the entire western High Plains and the concomitant effects of the largest conservation program in the region on those metrics. Thus, this study provides the foundation for developing conservation approaches that preserve wetland services in a vast region.

Sediment depth is the most direct measure of the effects of erosion into wetlands, and playas embedded in active croplands have greater sediment depths and have lost more of their historic volume than playas with watersheds in any other dominant land use. A similar study, that did not evaluate CRP, also found that cropland playas have more sediment and higher volume losses than native grassland playas in the Southern High Plains (SHP), which largely corresponds to the southern subregion of our study area.[7] Indeed, sediment accumulation was greatest in cropland playas in the southern subregion, and it was in this subregion where the effectiveness of CRP to prevent soil erosion is most obvious. Sediment depths of southern CRP playas were nearly 30 cm less than in cropland playas due to CRP vegetation dampening precipitation runoff energy. These results are consistent with other findings that demonstrate CRP ability to reduce soil erosion into glaciated wetlands.[19]

Because northern cropland playas have accumulated less sediment than cropland playas in the central and southern subregions, they have lost the least amount of their historic volume. Subregional differences in sediment impact on playas are consistent with the cultivation history of the western High Plains. Large scale native prairie conversion to cropland agriculture began in the SHP in the 1930s and 1940s.[20] In contrast, parts of the central and northern regions of the High Plains such as southwest Nebraska were converted to cropland more recently with the increased use of center-pivot irrigation systems. Gutentag et al.[21] detailed the northward progression of agriculture in the western High Plains indicating that much of the central and northern subregion was not under widespread cultivation until the mid-1970s. Additionally, before widespread use of more efficient irrigation technologies, croplands in the SHP were watered using gravity-irrigation[22] which allowed a surface flow of water to run downhill and collect at the lowest point (i.e., playas) in the landscape. Therefore, irrigation also contributed to sediment deposition in playas. It is through watershed runoff that the bulk of sediments are deposited in playa basins.[10]

Johnson et al.[23] highlighted the loss of playas from the landscape due to reclassification of soils, a condition facilitated by burying playas under eroded upland soils. Playas are a primary source of surface water in the western High Plains;[24] thus, losses in water storage capabilities due to soil erosion can be detrimental to dependent biota. Cropland playas have disappeared from the landscape due to their higher rates of sedimentation[7] and lower remaining volume than playas in other land uses. Conversely, playas embedded in native grassland have the greatest remaining volumes because they are least impacted by soil erosion. Sediment deposition has been inhibited in playas embedded in existing CRP contracts, and therefore, their water storage capacity has been preserved. However, in addition to prohibiting sediment intrusion into playas, the CRP reduces watershed runoff, which may have hydrological effects similar to sedimentation. A companion study to this investigation on the same playas found that CRP playas in the western High Plains were inundated 56% less often than catchments in cropland or native grassland.[9] Similarly, in our study, 14% of playas in CRP could not be distinguished from their adjacent uplands due to a lack of hydrophytic vegetation present within the playa basin. Although playas embedded in CRP have a greater capacity to store water, less frequent inundation may reduce other services such as biodiversity provisioning and aquifer recharge. The CRP demonstrates a good example of the trade-offs in ecosystem services associated with changing land uses described by Euliss et al.[13]

Complete loss of historic wetland volume does not imply that a playa has lost all capacity to store water. Indeed, precipitation will still be funneled from the surrounding watershed and ponded on the soils overlying the historic playa basin and even sediments will store some water. However, because water inputs are displaced beyond the boundaries of the clay lens, water storage duration is shortened, thus reducing water-dependent services. Many wetland dependent species may be negatively affected, if not excluded, by increased water loss rates and shorter hydroperiods in playas with heavy sediment loads (e.g., cropland). For example, Smith and Haukos[25] found that larger playas supported more wetland plant species than smaller playas and attributed these findings to lengthened hydroperiod. Also, playas provide critical breeding and larval habitat for 13 species of amphibians, and shortened hydroperiods can exclude some species from being able to successfully reproduce.[26,27]

Although the remaining volume of playas is similar throughout the western High Plains, this measure does not coincide with water storage potential. Playa area and original playa volume increases 3-fold from the northern subregion to the south indicating that, individually, southern playas historically and currently accommodate more water than their northern counterparts. Such differences in playa size may be due to localized conditions that promote the development of larger playas. For example, playas in the northeastern part of the SHP are among the largest playas in the High Plains.[28,29] Rainfall is greater and soils are finer grained in the northeast portion of the SHP compared to other areas which increases water input and retention and forms larger playas as a result. In addition, playas that pond greater amounts of water for longer periods may be developed through wave action and subsequent deflation as well as localized dissolution processes and landscape subsidence.[28,30,31]

Conservation Suggestions. The CRP was established by Congress in 1985 as a voluntary cropland retirement program for private landowners,[32] focused on protecting erodible soils and the nation's long-term capability to produce food and fiber.[33] Although not originally designed to provide habitat or

protect sensitive ecosystems, CRP practices do provide benefits to wildlife, and it is the most significant conservation program affecting playas.[2] Provision of wetland services stems from the natural functioning of wetland systems relative to their hydrogeomorphic state.[34] For example, the functional attributes of depressional wetlands such as playas depend upon their ability to fluctuate through wet/dry phases, the impairment of which diminishes playa service potential.[5] One of the greatest threats to most depressional wetland's hydrology is unsustainable sediment accumulation, which originates from erosion of cultivated uplands.[10,24,35] The CRP prevents sediments from accumulating in playa basins, and thus, playas embedded in existing CRP contracts have a greater capacity to provide services. However, plantings typical of historic practices with the CRP reduce watershed runoff resulting in trade-offs in various ecosystem services. To restore proper hydrology to playas embedded in established CRP contracts, conservation practitioners should encourage practices that reduce vegetation in excess of native short grass prairie within the playa watershed including regular cattle grazing or mowing and planting native grass species.[9]

In 2010, the CRP enrollment cap dropped by 2.9 million ha with federal budget cuts, and with relatively high commodity prices reducing enrollment demand, expiring CRP contracts may be less likely to be renewed. To preserve the remaining volume of playas entering back into crop production, combinations of management practices should be utilized to prevent further sediment accumulation. Smith[6] and Skagen et al.[36] outlined several strategies to protect depressional wetlands embedded in agricultural landscapes including establishing vegetative buffers around the wetland, dryland farming in the wetland watershed, and conservation tillage.

Though few new CRP contracts are likely to be offered, those that are placed on playa watersheds should have consideration given to the potential environmental benefits afforded by playa restoration. Practices within CRP such as CP23-A (wetland restoration-non floodplain) and the USDA Wetland Reserve Program should be utilized and sediments removed from playa basins to restore historic volume. In addition, surrounding watersheds should be planted with native short-grass prairie species to promote proper hydrological functioning.

It is imperative that priority is given to CRP offers that have the greatest service potential. Despite increased sediment depths, playas in the south have greater volumes making them greater potential contributors to ecosystem service provisioning. A focus in conservation efforts in the SHP would afford greater environmental benefits than elsewhere in the High Plains, however, only if sediments are removed from playa basins and native short-grasses are planted in watersheds. Indeed, sediments removed from CRP and cropland playas in this study alone would result in the availability of an additional 2.2 million cubic meters of playa volume, increasing many ecosystem services. Incentives for implementing such practices do exist, such as the WRP; however, they are rarely utilized in the High Plains.[2] Programs such as the WRP should be touted in the western High Plains, most notably in the SHP, where they would benefit people by the restoration of playas and their services.

Finally, playas existing in unaltered native prairie are the remaining relics of historic functioning of wetlands in the High Plains and it is imperative that they be preserved to ensure future benefits and prevent further loss of services. If resources are limited, focus should be placed on preserving larger grassland playas like those in the south because these playas have the greatest remaining volumes and thus are more capable of providing important services such as water storage and aquifer recharge.

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Author Contributions

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Notes

The authors declare no competing financial interest.

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