



Examining Playa Wetland Contemporary Conditions in the Rainwater Basin, Nebraska

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Abstract Based on three critical criteria – soil, hydrology, and vegetation, this study examined contemporary playa wetland conditions to determine the extent of wetland degradation in the Rainwater Basin in south-central Nebraska. Geospatial statistics were used to evaluate the changes between historical hydric soil footprints and the most recent wetland survey datasets. The results indicate that the historical hydric soil footprints dominated by the Scott and Fillmore soil series have degraded 31.0% and 79.4% respectively. We also found approximately two-thirds of the footprints no longer pond water during spring migration. In fact, only 16.8% of the historical hydric soil footprints contain hydrophytes in recent surveys. Furthermore, the majority of these footprints (and the associated uplands) have been converted to cropland and no longer pond frequently or support hydrophytes. Additionally, the extensive grid road system supports commodity crop production, but in many instances this infrastructure has significantly altered wetland footprints and the associated watersheds to reduce the total water volume delivered to wetlands. The resulting situation is that conserved lands, including Waterfowl Production Areas (WPAs), Wildlife Management Areas (WMAs), and conservation easements only represent

11.3% of total historical footprints, but contribute to over 40.5% of the current total ponded water and hydrophytes.

Keywords Playa · Historical hydric soil footprint · Wetland loss and degradation · Conservation · Rainwater Basin · Nebraska

Introduction

Playas are depressional, shallow, ephemeral, clay-lined wetlands located throughout the U.S. Great Plains (Smith 2003). Playas are typically associated with closed basins. These depressional playas are located in the lowest areas that periodically flood and accumulate (Gilbert 1875; Russell 1885). The water depth of playas is typically less than 1.5 m and the size ranges from <1 ha to over 1000 ha (Smith 2003). Yet, playas have a negative water balance and lose water via evaporation, evapotranspiration, and groundwater recharge (Rosen 1996; Smith et al. 2011a). Within these closed watersheds, depressional wetlands do not have hydrologic inter-connectivity to other wetlands (Luo et al. 1997) and therefore rely on runoff from precipitation events or shallow groundwater flow (Rosen 1996). Playas provide critical ecological services at the regional and even global scale (Haukos and Smith 1994; LaGrange 2005; Smith et al. 2011b), including significant recharge contributions to the Ogallala Aquifer (Bolen et al. 1989). Functioning playas provide forage and water for livestock, refuge for native flora and fauna, and environmental education and recreational opportunities (USFWS 2007; LaGrange et al. 2011; Smith et al. 2011a). Perhaps the most important ecological contribution these wetlands provide is roosting and foraging habitats for millions of migratory wildlife, including

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waterfowl, shorebirds, waterbirds, and whooping cranes (National Research Council 2004).

Playa degradation has been accelerated due to anthropogenic activities that facilitate agricultural use. Some recent studies have analyzed playa degradation and loss. Anthropogenic activities that have led to altered hydrology are the primary factors responsible for playa degradation (Johnson et al. 2011). On the one hand, in agricultural-dominated landscape, altered runoff and accumulated sediment can further reduce playa water depth and alter the ponded area (Rosen 1994; Luo et al. 1997). On the other hand, playa wetlands are more vulnerable to agricultural conversion when playa wetlands exhibit less function, e.g., declined ponding frequency or reduced ponded area (LaGrange et al. 2011). Johnson et al. (2011) estimated a 65% decrease in playa numbers and 50% decrease in playa area in the Southern High Plains. In Nebraska, Tang et al. (2016a) used Google Earth Engine to analyze Landsat data and found that 81.1% of playa areas in Nebraska were not functioning during the spring migration compared to conditions that occurred 30 years ago. In the Rainwater Basin, Schildman et al. (1984) conducted early wetland surveys in 1982 and estimated that less than 10% of wetland numbers and 22% of the original wetland areas still survived. LaGrange (2015) pointed out that approximately 90% of Rainwater Basin playa wetlands have been highly altered. Yet all of these declines in playa wetland function and loss include agricultural land conversion, hydrologic modification, additions of road infrastructure, and culturally-accelerated sedimentation.

Anthropogenic influences have significantly degraded wetland hydrology and accelerated wetland loss throughout the Great Plains region of the central United States (Foley et al. 2005; Daniel et al. 2015). Playa wetlands have likely been altered since 1860. Seasonal fluctuations of wetness or dryness are important processes for playa wetlands (Haukos and Smith 1994; Rosen 1996). However, the lack of ponding during wet cycles is a good indication that wetland function has declined. This lost function can be attributed to higher infiltration rates and additional storage in the accumulated sediment layer above the clay pan that now requires saturated conditions before deeper soils can be saturated. For example, Tsai et al. (2010) found that infiltration and related water loss could be greater in playas with more sediment. Additionally, land use within the watershed can directly degrade environmental conditions that influence water yield from runoff events (Foley et al. 2005). To the point, Cariveau et al. (2011) found that playas surrounded by rangeland were more likely to pond water than playas surrounded by cropland. Yet, other aspects of runoff delivery impediments to wetlands can impact function. Li et al. (2013) used the Lighting Detection and Ranging (LiDAR) data to investigate the impacts of road systems and their culverts on water delivery to playa wetlands.

Daniel et al. (2015) found evidence that suggests all playas in the Rainwater Basin in Nebraska have been negatively impacted by watershed soil erosion. Mainly, sediment accumulation in playa wetlands is much greater in croplands at the catchment scale (Luo et al. 1997; Luo et al. 1999; O'Connell et al. 2012). Given the fact that most wetlands in the Rainwater Basin have been surrounded by cropland, this relationship is not difficult to surmise. In fact, many published articles suggest that sediment from surrounding croplands is the largest immediate threat to playa-wetland ecosystems (Belden et al. 2012; Beas et al. 2013a, b; Beas and Smith 2014; Tang et al. 2015a).

O'Connell et al. (2013) found that sediment accumulation influenced species composition and decreased habitat connectivity for wetland-dependent biota in cropland playas. Daniel et al. (2014) measured the effects of the Conservation Reserve Program (CRP) on sediment deposition in the High Plains. They found that sediment depth and resulting water volume loss for the CRP playas were significantly lower than cropland playas. Daniel et al. (2015) examined land use effects on sedimentation and water storage volume in playas of the Rainwater Basin of Nebraska. They found that cropland playas lost the greatest amount of historic wetland area. Tang et al. (2016b) estimated the mean soil erosion rate in the Rainwater Basin landscape level at 4.67 tons/ha/year. Accelerated sediment deposition facilitates aggradation and therefore reduces playa storage volume and can reduce ponding duration, resulting in changes in native plant diversity (Luo et al. 1997; LaGrange et al. 2011).

Many studies have contributed to our current ecological understanding of the mechanisms of playa wetland functions and processes (Haukos et al. 2016; O'Connell et al. 2016; Skagen et al. 2008; Tang et al. 2015b). However, little research systematically examines current playa wetland conditions and identifies the specific stressors that cause declines in playa wetland function or the complete loss of all functionality. This study assesses three critical wetland criteria – soils, hydrophytes, and hydrology – to discover changes in wetland function within the Rainwater Basin area of south-central Nebraska. This research addresses two specific concerns in the Rainwater Basin: (1) the contemporary status of soil conditions, ponding frequency, and vegetation conditions for the hydric soil footprints during the spring migration? and (2) have recent conservation delivery strategies increased playa wetland function? These research findings will help improve conservation delivery strategies that increase available spring ponded habitat to benefit many migratory species.

Study Area

This study focuses on playa-type wetlands in the Rainwater Basin area of south-central Nebraska (Figure 1). Wind is believed to be the primary factor in the formation of playa

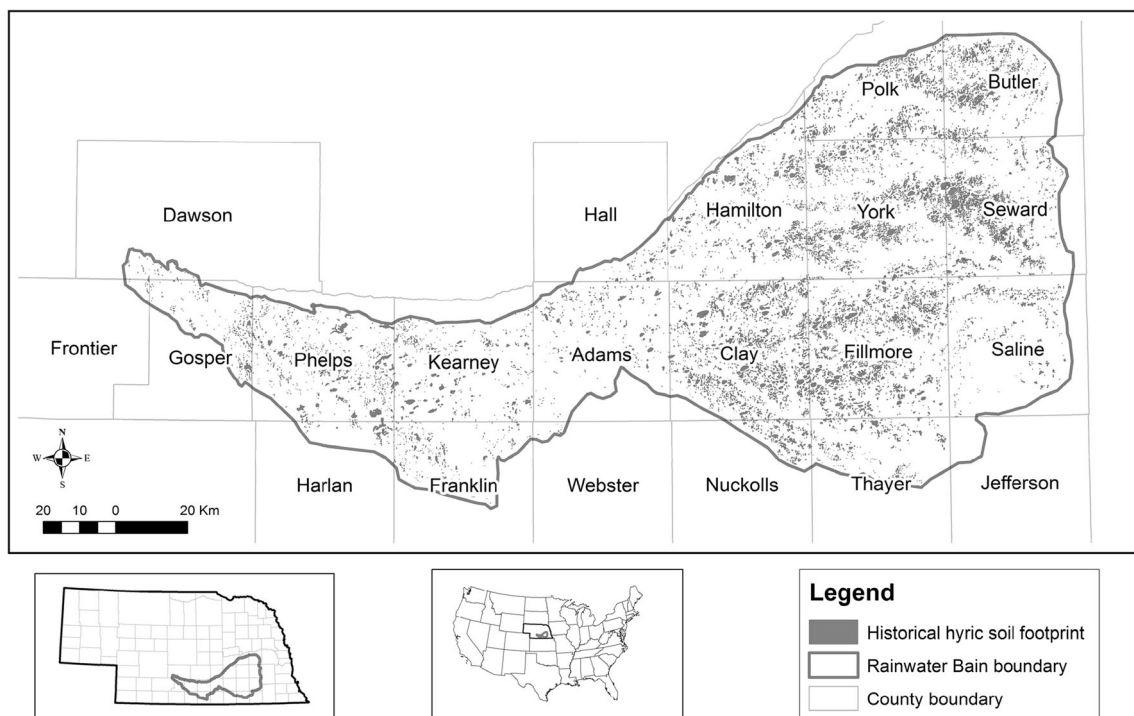


Fig. 1 Location map of playa wetlands in the Rainwater Basin in Nebraska

wetlands in the Rainwater Basin (Gilbert 1895; Frye 1950; Kuzila and Lewis 1993). Before the human settlement in this area, the predominant vegetation community was upland tall grass prairie and loess mixed-grass prairie in uplands and wheatgrass playa grasslands and cattail shallow marsh in wetlands (LaGrange et al. 2011). This landscape is currently dominated by cultivated croplands that are currently planted in a corn and soybean rotation (Bishop and Vrtiska 2008). The annual average precipitation is 46.0 cm and 71.0 cm for the western and eastern side of the Rainwater Basin, respectively (Stutheit et al. 2004), but the precipitation greatly varies seasonally and annually. These playas serve as globally significant habitats for migratory birds in the Central Flyway. These wetlands provide critical habitats for 8.6 million waterfowl and 500,000 shorebirds (Rainwater Basin Joint Venture 2013). Due to the unique ecological value, multiple federal, state, and regional wetland management plans have ranked the playa wetland complexes in the Rainwater Basin as one of the top priorities for wetland restoration (USFWS 2007; LaGrange et al. 2011; Rainwater Basin Joint Venture 2013).

Data Sources

The Rainwater Basin Joint Venture provided data on the historical hydric soil footprints layer which has a record for the location of each footprint, the annual habitat data layer which provides the ponded area, and wetland vegetation data layer which provides general plant community information. The

historical hydric soil footprint layer contains 11,707 depressional playa wetlands within the Rainwater Basin boundary. The annual habitat survey data describe the spring ponding and hydrophyte conditions of playas during peak waterfowl migration from 2004 to 2015. A wetland vegetation map records the wetland vegetation distribution and classification data in 2012. The soil data came from the Soil Survey Geographic Database (SSURGO) by the Natural Resources Conservation Service, the U.S. Department of Agriculture. SSURGO (2017) data provided the most detailed level of digital soil geographic classifications for playa wetlands. This study used SSURGO data to obtain the detailed level of soil distribution and types of soils for each historic hydric soil footprint. The stream data, the roads data, central pivot irrigation data, and Lighting Detection and Ranging data (LiDAR) layers were provided by the Nebraska Department of Natural Resources.

Methodology

ArcGIS 10.4.1 was used to conduct geospatial analysis for this study. The research framework is illustrated in Fig. 2. There are three types of analysis in this study: (1) Assessing the soil condition changes: we overlaid the historical hydric soil footprint layer and the annual habitat survey data to identify the active functioning areas with either inundation or hydrophytes. Then we calculated the condition changes for major playa wetland soil classifications including Water, Massie,

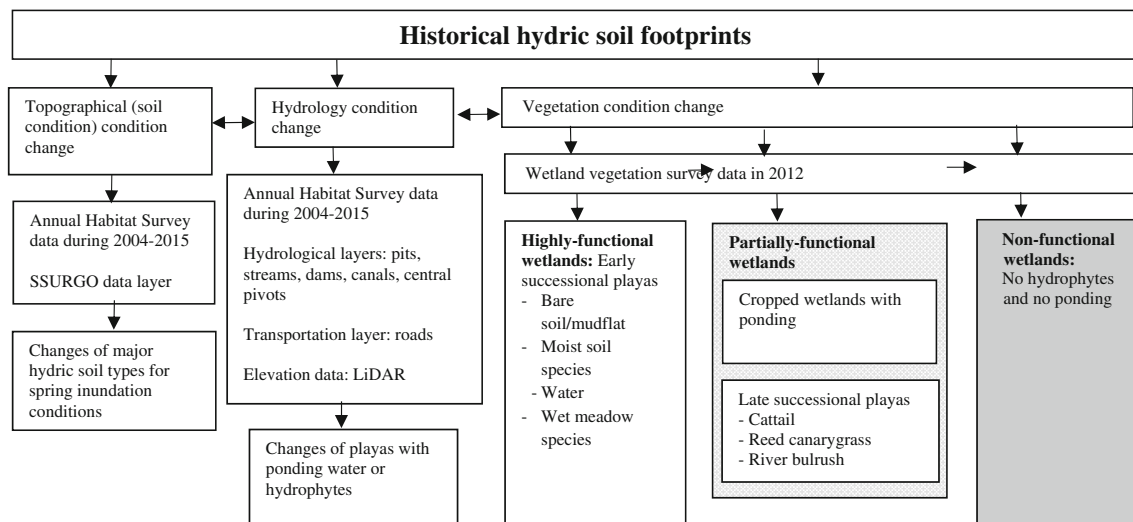


Fig. 2 Research framework to examine the contemporary conditions of playa wetland soil, hydrology, and vegetation

Scott, Fillmore, Butler, and Ruscoe. The percentages were used to measure the soil condition changes by footprint numbers and footprint areas of each soil classification, respectively. (2) Assessing the hydrological condition changes: we also overlaid the historical hydric soil footprints with the hydrological layers (e.g., pits, streams, dams, canals, central pivots) and the transportation layers (e.g., roads) to identify the impacts of hydrology on playa functionality. Then, we calculated the changes in playas with ponding water or hydrophytes under the hydrological influences. The percentages were used to calculate the ponding condition changes of footprint numbers and areas, respectively. (3) Assessing the wetland vegetation condition changes: we overlaid the historical hydric soil footprints with the wetland vegetation survey layer to identify the vegetation condition changes. The percentages were used to count the vegetation condition changes by footprint numbers and footprint areas, respectively.

Results

Playa Wetland Conditions

Soil condition: The changes in the major hydric soil types for spring inundation conditions are listed in Table 1. The soils that have the largest watersheds and thickest clay layer include “Water” and “Massie” map units in SSURGO database. The majority of these footprints still maintain wet conditions in the spring. Specifically, the Water soil series currently pond 99.9 ha (67.0%) in spring. Between 2004 and 2015, the area of ponding and hydrophytes signatures covered 115.5 ha (77.4% function). In the Massie soil series, the majority of playas still stayed wet with over 2125.2 ha of ponding (74.7%; $n = 121$). These soil types indicate a >95% functional rate based on either ponded water or hydrophyte coverage. In

the Scott soil series, there was 3136.9 ha (39.9%; $n = 602$) ponded water during peak spring migration. There were 5426.3 ha (69.0%; $n = 655$) of Scott soils that ponded water or exhibited hydrophytes. The Butler, Fillmore, and Ruscoe series indicate a far greater level of degradation. There were 33,263.3 ha of Fillmore soils, but only 2792.3 ha (8.4%, $n = 2060$) ponded water and only 5834.1 ha (17.5%, $n = 2228$) had hydrophytes. A total of 6852.3 ha (20.6%, $n = 2655$) had both ponded water and hydrophytes. An even higher level of degradation was observed in the Butler and Ruscoe soil series. The Butler and Ruscoe soils only ponded 409.4 ha (4.6%, $n = 908$) of water, 944.2 ha (10.63%, $n = 1204$) of hydrophytes, and 1122.2 ha (12.6%, $n = 1427$) of ponded water and hydrophytes.

Spring ponding conditions: From the spring Annual Habitat Survey (2004–2015), we found that over 7792 playa wetlands were not inundated in the spring over the past decade (Figure 3). This data indicates that approximately two-thirds (66.6%) of the total numbers of historical hydric soil footprints ($n = 11,707$) lost the function of holding water. Moreover, there were 3010 playas that only ponded at 25% capacity based on the hydric soil footprints, even in very wet springs. Only 549 playas (4.7%) had ponded water at 25–50% of the hydric soil capacity, and only 256 playas ponded at 50–75% of the hydric soil areas. The remaining 91 playas had ponded water on 75% of the hydric footprint areas. Similar trends were identified for the numbers of footprints with hydrophytes. We also examined the number of playas with either ponded water or hydrophytes, and slightly higher levels of percentages were observed. The playas without ponded water or hydrophytes still represented 53.2% of total footprints. Additionally, 30.4% of playas indicated 25% function of the hydric soil capacity by ponding water and having hydrophyte coverage. Only 5.9% of playas had more than 75% of areas covered by either ponded water or hydrophytes.

Table 1 Percentage of changes in major hydric soil types for spring inundation conditions

Hydric Soil type	Total area of footprints (ha)	Current ponded area of footprints (ha)	Percent of remaining footprints ponding water (%)	Current hydrophyte signature of the historic footprints (ha)	Percent of remaining footprints with hydrophytes (%)	Current ponded water or hydrophyte signature of the historic footprints (ha)	Percentage of remaining footprints with ponding and/or hydrophytes (%)
Water	149.2	99.9	67.0	100.1	67.0	115.5	77.4
Massie	2844.6	2125.2	74.7	2703.2	95.0	2760.7	97.1
Scott	7862.1	3136.9	39.9	4932.5	62.7	5426.3	69.0
Fillmore	33,263.3	2792.3	8.4	5834.1	17.5	6852.3	20.6
Butler	8883.8	409.4	4.6	944.2	10.6	1122.2	12.6
Ruscoe	1411.3	160.0	11.3	199.3	14.1	290.9	20.6

The ponded area evaluation based the findings on a total of 11,486.5 ha of wetland area according to the historic wetland mask. We found that 30.6% of the footprints or 25,169.2 ha never ponded water during the spring peak migration week (2004 and 2015) (Figure 4). We also found that those footprints that had less than 25% inundation ponded over 38,536.3 ha. When we evaluated the areas with hydrophytes as an indicator of some wetland function, we found 13,790.3 ha had hydrophytes representing a meager 16.7% of the total footprint areas.

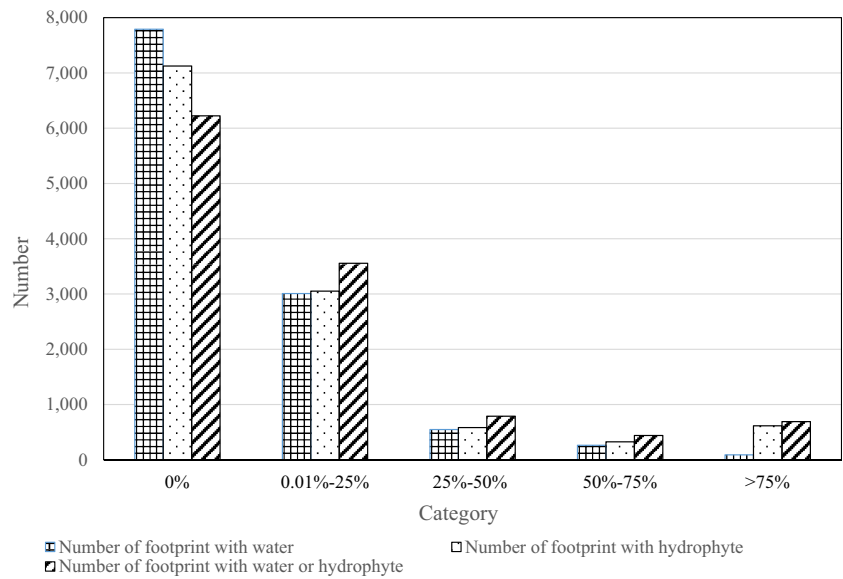
Vegetation conditions: The wetland vegetation survey in 2012 identified that the majority (82.4%) of the playa wetlands lost enough wetland function that hydrophytes were no longer supported (Figure 5). We found 65,527.5 ha without any hydrophytes or ponded water, of which agricultural lands accounted for 60,977.3 ha, grasslands accounted for 3974.2 ha in grasslands, and woody species accounted for 575.9 ha. Partially-functional wetlands only accounted for 5.7% of the total historical hydric footprint areas. Some of these wetlands occurred within croplands, representing 709.8 ha of periodically functioning wetland habitat. The remaining footprints are dominated by late successional or undesirable hydrophytes such as *Typha* spp. (488.9 ha), *Phalaris arundinacea* (2650.5 ha), and *Bolboschoenus fluviatilis* (678.5 ha). The highly-functional wetlands only accounted for 12.0% of the total footprint areas; they were covered by early successional hydrophytes, including bare soil or mudflat (686.8 ha), moist soil plant communities (7059.1 ha), water (468.5 ha), and wet meadow plant communities (1305.5 ha).

Stressors for Playa Wetland Degradation

The influence of pits, stock dams, canals, roads, and streams on playa wetland hydrology are summarized in Table 2. The results of this study indicate that all of the playa watersheds have been hydrologically modified to some degree. We found 1468 historical hydric soil footprints directly affected by pits. For these footprints, pits specifically occupy 2323.8 ha and store over 8,631,206.7 m³ of water that would otherwise reach the hydric footprints and increase the probability of ponding. At the landscape level, there are 9417 agricultural pits that directly influence (37,230.4 ha) wetland hydrology. These pits can store 31,693,074.4 m³ of water that would otherwise be delivered to or ponded in the wetland footprints.

Stock dams, canals, roads, ditches, and infrastructure that supports irrigation all affect playa hydrology. There are 54 stock dams and 57 canals, affecting 2479.5 ha and 919.5 ha of wetland footprints, respectively. More importantly, roads and related structures can directly influence playa wetland hydrology. The road density in the Rainwater Basin is 1598.1 m/km². Overall, there are 3879 playas directly affected by roads. The grid-road system includes ditches and culverts that have significantly changed the playa hydrology within

Fig. 3 Number of footprints in each category of hydrological conditions



each wetland’s watershed. For example, in Fillmore County there are 2126 culverts, or 1.4 culverts/km, that alter, restrict, or divert runoff that would otherwise reach hydric footprints. Lastly, integrated irrigation systems, including central pivot irrigation, have significantly altered groundwater and surface water levels, topography, and soil structure, which all influence how water is conveyed across the landscape. By the year 2005, over 7928 of playas covering 67.7% of historic hydric footprints in the Rainwater Basin area were overlaid by central pivot systems.

Our evaluations reveal that larger wetlands with thicker Bt horizons have higher percentages of inundation and hydrophyte coverage (Figure 6). There are only 1918 footprints larger than 5.5 ha, but they contribute to 92.2% of total inundated areas each spring migration, 91.8% of total hydrophyte

areas, and 90.7% of total area with water and hydrophytes, respectively. Playas of less than 5.5 ha only contribute <10% of total inundation and hydrophyte areas each spring.

Conservation Values

The contribution of conserved lands on playa function is summarized in Table 3. The WPAs only occupy 6.5% of the total footprint areas, but they provide over 23.3% (equivalent to 2677.2 ha) of all ponded water, over 25.6% (equivalent to 5253.2 ha) of all hydrophytes, and over 23.1% (equivalent to 5287.3 ha) of ponded water and hydrophytes during peak migration each spring. The WMAs only occupy 2.8% of total footprint areas, but they contribute 11.2% (1285.0 ha) of all ponded water, 11.1% (2281.5 ha) of all hydrophytes, and

Fig. 4 Areas of footprints in each category of hydrological conditions

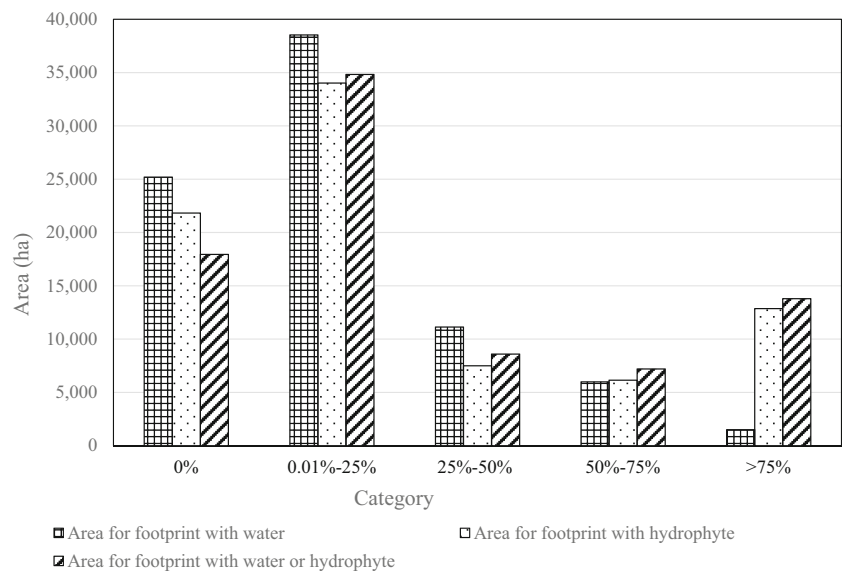
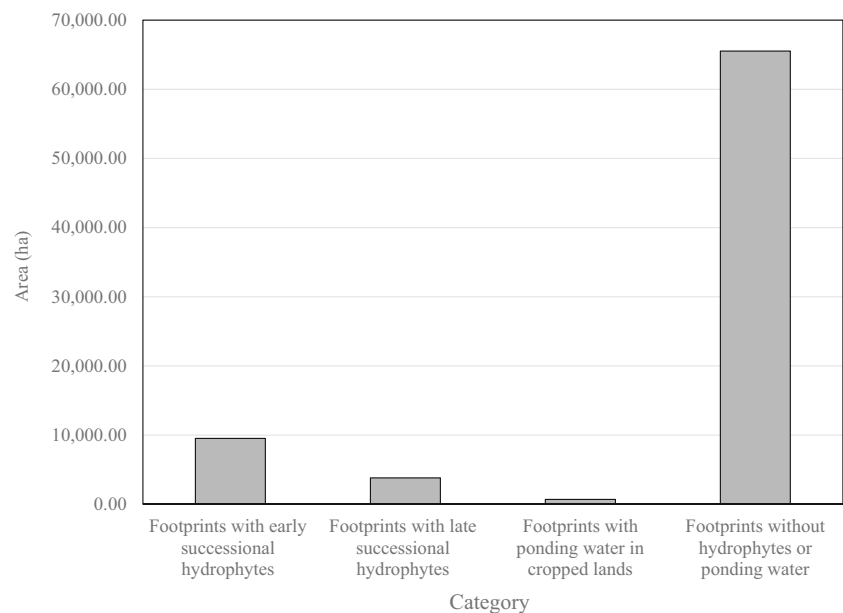


Fig. 5 Vegetation status of playa wetlands

10.0% (2294.4 ha) of ponded water and hydrophytes. Conservation easements only occupy 2.1% of total footprint areas, but contribute 8.4% (967.3 ha) of the total ponded water, 8.2% (1686.4 ha) of the hydrophytes, and 7.4% (1687.6 ha) of ponded water and hydrophytes. In summary, all conserved lands only protect 9327.0 ha and only account for 11.3% of the total footprints protected by long-term conservation programs. Yet, they contribute to 42.9% (4929.5 ha) of total ponded water, 44.9% (9221.1 ha) of the hydrophytes, and 40.5% (9269.3 ha) of ponded water and hydrophytes.

Discussion

This study directly identified the dynamic changes and the contemporary conditions for the historical hydric footprints

Table 2 Influence of pits, stock dams, canals, roads, and surface drainage on playa wetland hydrology

Factors	Numbers of footprints affected	Areas (ha)
Pits located within Rainwater Basin footprints	1468	2323.7*
Pits in Rainwater Basin wetland watersheds	9417	37,230.46**
Stock dams intersecting footprints	54	2479.5
Canals intersecting footprints	57	919.5
Roads	3879	55,890.3
Streams	875	25,354.7
Central pivot irrigation	7928	6,6201.3

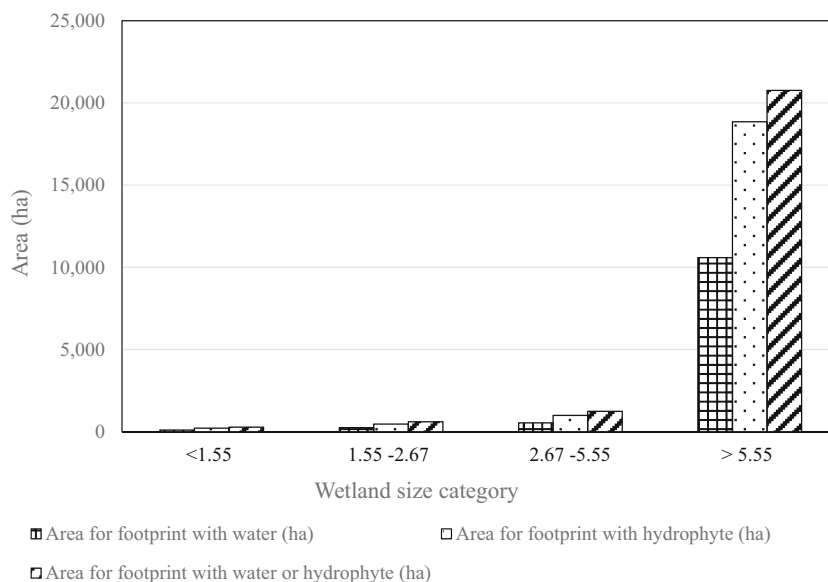
(Note: * indicates the area of pits; ** indicates the area of affected footprint areas)

for the Rainwater Basin. We found that the Massie soil footprints have maintained their ability to pond water more frequently than the other soil types. The high level of wetland function is a reflection of natural system dynamics such as the watershed-to-wetland ratio and frequent saturation that have largely been difficult to convert to cropland. These playas are typically located in relatively large watersheds and therefore have the benefit of receiving large volumes of water when runoff occurs, particularly during precipitation events that exceed 5.0 cm (approximately 2 in.) of rain. Secondly, over 60.4% of the Massie (including Intermittent soil types) have been conserved acquisition, and the managing agencies are focus on maintaining wetland function and restoring wetland function where possible.

For Scott soil footprints, we found less than 30% maintain wetland function for the Scott soils. These footprints are topographically located above the Water and Massie soil types when they occur in conjunction with these soils; thus, they have relatively fewer chances of being wet than the lower areas. Secondly, these areas are more prone to having higher amounts of sediment or deeper depths to clay (SSRGO 2017). Lastly, this soil series represents a mere 28.4% of the protected wetland acres, and the remaining unprotected areas have been altered or converted to cropland.

Finally, our results indicate that the Butler, Fillmore, and Ruscoe footprints are the most degraded soil series in the Rainwater Basin. These soil types did not exhibit ponding during spring migration or support hydrophytes. The presence of inundation or saturation is critical to maintain the function of hydric soils (Starks 1984; LaGrange et al. 2011). Perhaps the most notable finding is the fact that these soil types are the least protected under any conservation programs. They are continuously encroached upon by agricultural fields, roads,

Fig. 6 Area of footprints in each hydrological status categorized by wetland size



pits, and land-leveled areas. Thus, these playas are the most vulnerable to reductions in ponding frequency.

Our findings support unpublished and published playa inundation conditions in the Rainwater Basin, and highlight the infrequent ponding and limited available habitat during the spring migration. LaGrange et al. (2011) suggested that most of the playa wetlands in the Rainwater Basin have been drained, destroyed, and generally degraded. Yet, these results appear to be consistent with other reports for playa wetland conditions in the Great Plains. In the southern Great Plains, only 0.2% of the playas had no wetlands or watershed modifications (Johnson et al. 2012). Furthermore, Collins et al. (2014) found that the majority of playas in Texas were dry even during wet seasons between 2008 and 2011. All of these facts point to the looming issue of declining wetland connectivity.

The total inundated wetland habitat across playa wetlands in Nebraska averaged 18.9% of the footprints in either March or April from 1985 to 2015 (Tang et al. 2016a). We found evidence of two likely primary causes of wetland degradation within this region. We found that altered runoff conveyance that has disrupted natural flow and diverted water away from playa wetlands was linked to less function. We concur with previous research that has identified that when natural runoff has specifically been disrupted by agricultural activities, including concentration pits, road ditches, terraces, diversions, stream channels, and road culverts, loss of function occurs (Li et al. 2013; Tang et al. 2016a). All of these alterations can divert runoff water away from playas at the watershed scale. The second reason can be attributed to culturally-accelerated sediment deposition into playas. LaGrange et al. (2011) pointed out that wetland hydro-periods were shortened by even small amounts of sediment. With continuous sediment input, both

the depth and the inundated area can decrease. Additionally, ponding duration will be shorter and the overall hydrologic function will decline. Consequently, these conditions likely support wetland conversion to cropland and provide more frequent financial returns.

We also found that wetland conservation easements that included restoration work within the Rainwater Basin have high ponding frequency during the spring migration, particularly in newly restored areas. Our research also confirmed that smaller playas were more likely to lose wetland volume without protection from sedimentation. Playa wetlands are continually under threat by farming, land leveling or filling wetlands, excavation or cleaning out irrigation collection/drainage pits, other hydrological modifications, and of course, culturally-accelerated sedimentation.

The actual inundation and hydrophyte vegetative coverage reflects a series of mixed hydrologic processes that can be used to indicate wetland function. Ponding and hydrophyte areas are a result of the interaction of the natural hydrology and man-made hydrologic systems that can significantly alter the natural system (Beas et al. 2013a). Seasonal and annual variations in climate also cause different wetland conditions. Playa wetlands are ephemeral in nature and the inundated areas may vary in sizes across seasons. Our results support the previous findings that conservation programs influence land use and can improve overall wetland functions (Smith et al. 2011a, b; O'Connell et al. 2012). Cariveau et al. (2011) found that Nebraska playas in rangeland were more likely to become inundated than playas in cropland. Because the majority of the grasslands have been lost in south-central Nebraska, it is likely that the changes caused by agriculture are widespread, and potentially indicates that additional abiotic factors other than just sedimentation may influence overall wetland function.

Table 3 Contribution of conserved lands on playa spring ponding conditions

Type	Ponded Area (ha)	Percentage of total ponding (%)	Hydrophyte Area (ha)	Percentage of total hydrophyte (%)	Hydrophyte and ponded area if different (ha)	Percentage of total footprint area with ponding and/or hydrophytes (%)	Total area (ha)	Percentage of contribution (%)
WPA contribution	2677.2	23.3	5253.2	25.6	5287.3	23.1	5321.2	6.5
WMA contribution	1285.0	11.2	2281.5	11.1	2294.4	10.1	2302.9	2.8
Easement contribution	967.3	8.4	1686.4	8.2	1687.6	7.4	1702.9	2.1
All footprints	11,486.5	100.0	20,534.9	100.0	22,894.2	100.0	82,361.8	100.0
Total conserved land contribution	4929.5	42.9	9221.1	44.9	9269.3	40.5	9327.0	11.3

The soil types reviewed in this research have a notable clay layer near the soil surface (15–35 cm deep). When clay particles are saturated they swell and create an impermeable layer for water movement. Differences in the thickness of the clay layer within each soil series likely influence ponding duration. For example, the Massie soil series has a 109.3 cm thick clay layer (Bt), indicating that water loss through the soil profile would be very slow (SSURGO 2017). The Scott soil series likely supports a more seasonal ponding regime with a Bt thickness of 78.7 cm. However, this soils series declines in thickness in the western portion of the Rainwater Basin (SSURGO 2017). For example, in Gosper County, the thickness is only 30.0 cm. In Fillmore, Butler, and Ruscoe soils, the clay layer thickness is 63.5 cm, 53.3 cm, and 12.7 cm, respectively. Therefore, it is likely that there are gradients of water regimes within each of these soil types. The findings of this study found the ponding and vegetation conditions of major hydric soils have been obviously degraded due to intensive anthropologic activities at the watershed scale.

This study used LiDAR data to measure the topography, to locate depressional wetlands, and to determine the hydrologic status for all playas in the Rainwater Basin. Only 3423 playas maintain wetland function accounting for 29.2% of total playa footprints. By using the mean estimated sediment accumulation rates from Tang et al. (2016b), aggradation would cause a decline of each wetland's capacity at a rate of 2.0 cm/10 years. The accelerated rate of sediment deposition in these shallow wetlands would likely alter the hydrology in three ways. First, the increased sediment within the soil profile could store more water rather than expressing it as surface ponding. Second, aggradation will cause water to pond at a higher elevation and force water onto areas with more permeable soil types. Third, increased elevation and less frequent ponding will decrease hydrophyte dominance. Overall, smaller playas with large watersheds are more likely to be filled with sediment and thus lose the capacity to pond and hold water versus those with smaller watersheds.

The Wetlands Reserve Program (WRP) has the greatest potential impact on reducing sediment deposition and improving the hydrologic function of playa wetlands (Smith et al. 2011a). This study confirmed that the restored playas from the WPAs, WMAs and conservation easements provided the most reliable ponding in the Rainwater Basin during the spring migration. Additionally, conservation program implementation has had a positive impact on playa wetland function including inundation and plant composition (O'Connell et al. 2012; Beas and Smith 2014). This research further verified that a small portion of playa wetlands, particularly the conserved playas, currently contribute a large number of the total inundated area and the total available wetlands during spring migration.

Policy Implications

The findings of this study provide critical evidence that will help conservation managers understand the contemporary condition of playa wetlands and facilitate the development of appropriate conservation strategies to restore playa wetlands in the Rainwater Basin. In fact, a suite of comprehensive wetland conservation strategies are needed to support future land acquisition, removal or reconfiguration of hydrologic modification, vegetation management, sediment removal, invasive plant control, and the implementation of ecological disturbances that mimic historical disturbances in both frequency and duration (USFWS 2007).

Hydrologic restoration: The first priority should focus on full hydrologic restoration at the watershed scale. This study highlights that playa hydrologic modifications within their watersheds contribute to playa degradation and loss. Even if restoration ecologists can identify likely contributors to deficient wetland function, it is important to recognize that few studies have documented the probability of success for many of the functional objectives restoration ecologists seek. Beas and Smith (2014) found that restored playas, particularly those where sediment was removed, provided frequent and reliable ponding. Tang et al. (2012) found that most wetland restoration emphasized the recovery of the footprint area at a site level, and gave limited attention to restoring the entire watershed function when implementing restoration programs. Watershed-scale hydrologic restoration is likely the most important component for playa wetland conservation at this time (LaGrange et al. 2011; Daniel et al. 2014). We recommend restoration treatments that increase playa wetland function, which include drain closure, irrigation re-use pit closure, road removal (where possible), quick-cycle tail water recovery installation for flood irrigation systems, culvert replacement for those that have reduced function, water-control structure installation, sediment removal, promoting occasional deflation events (Gill 1996), and establishing or maintaining native perennial vegetation in waterways to protect each restored wetland from sediment-associated degradation. These findings should serve to highlight the sustainability of effective playa conservation and needed restoration activities with a focus on watershed-based conservation program delivery.

Vegetative restoration: Playa wetlands experience vegetative degradation (hemi-marsh, open water mudflat, moist soil early succession) cyclically. Yet, vegetation management can improve native wetland plant communities that can provide abundant seed resources for waterfowl during spring migrations (Drahota and Reichart 2015). However, vegetation restoration is a long-term challenge because vegetation management requires an annual budget that supports the implementation of treatment (USFWS 2007). Vegetation management can be particularly expensive when invasive plants need to be controlled or removed to promote native plant communities.

We recommend a thorough investigation of wetland degradation at the wetland scale before implementing practices that may only treat the symptoms rather than the actual problems associated with invasive or undesirable plant communities. Conservation programs that protect round-out acres adjacent to currently protected wetlands can also increase vegetation management options and facilitate hydrologic restoration. The protection of round-out lands helps build more resilient wetland systems and thus results in increased frequency and duration of functional wetland status.

Erosion control and sediment reduction: Sedimentation rates have increased with upland conversion to cropland. Luo et al. (1997) suggested that conservation delivery efforts should first prioritize erosion control on soil types that contribute to the greatest sedimentation rates. Furthermore, State and Federal programs that protect wetlands from reduced function due to sedimentation generated by cropping practices should be a high priority. The “one-size-fits-all” approach should not be implemented at the landscape scale. An effective wetland restoration program at the landscape scale should allow sequencing flexibility and address watershed-specific conditions. Sediment removal has been identified as an important approach to improve wetland ponding frequency (LaGrange et al. 2011; Beas et al. 2013a, b); however, sediment removal is expensive and ecologists should consider the accumulation of additional stressors such as nutrients, metals, pesticides, and ultimately the sustainability of each wetland’s function after restoration when prioritizing these types of restorations. Daniel et al. (2015) suggested that conservation practitioners should remove sediments down to the Bt layer and establish adjacent land treatments that prevent further erosion at the watershed scale. Therefore, we recommend developing specific objectives based on each footprint’s potential, degradation type, and extent of the cumulative degradation that has occurred. Furthermore, all of these factors influence the probability of success and future research should focus on establishing guidelines for implementing these strategies. It is important to prioritize sediment removal projects based on the current function, the probability of success, the total cost, the off-site impacts that might create third party conversions, and the overall site-specific sustainability.

Conclusion

This study analyzed the contemporary status of the historical hydric soil footprints and identified the major stressors for playa wetland degradation and loss. During spring migration, the Massie soil footprints provide frequent inundation and support hydrophytic plant communities more frequently than Scott soil depression. The highest levels of degradation were found in Fillmore, Butler, and Ruscoe soil footprints. The hydrologic condition found across the Rainwater Basin

indicated that approximately two-thirds of the footprints had lost their ability to pond surface water in the spring. The current vegetative condition also indicates dramatic changes in wetland function including early or late successional hydrophyte distribution, undesirable plant dominance, and invasive plant encroachment in most of the remaining functioning wetlands. The majority of wetland footprints occurring within agricultural fields lack frequent ponding and hydrophytes. Additionally, most wetland loss is due to the many hydrologic modifications that support agricultural production. The road system and modifications that support commodity crop marketability are contributing stressors that reduce total water volume delivered to wetlands or impede natural wetland hydrology. Conserved wetlands that have restored hydrology encompass the majority of functioning wetlands in the Rainwater Basin of Nebraska. Future conservation programs should focus on practices that restore hydrologic function and increase both ponding frequency and ponded area during spring migration.

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