SEDIMENTATION OF NEBRASKA'S PLAYA WETLANDS

A Review of Current Knowledge and Issues

"Soil erosion is as old as agriculture. It began when the first heavy rain struck the first furrow turned by a crude implement of tillage in the hands of prehistoric man. It has been going on ever since, wherever man's culture of the earth has bared the soil to rain and wind."

-H.H. Bennett and W.C. Lowdermilk, circa 1930s

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Cover Photo: Sediment washed into the temporary zone of a wetland 3 miles east and 1 north of Harvard, Neb.
after a spring thunderstorm, April 2008. *Source: Ted LaGrange (NGPC)*

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Executive Summary

This document describes Nebraska's playa wetlands, discusses the process of sedimentation of playas, summarizes data on historic and recent wetland soil profiles, describes the impact that culturally accelerated sedimentation has on numerous wetland functions, and provides recommendations on restoration considerations. Many depressional wetlands, such as Nebraska's playas, are now embedded in agricultural landscapes where tillage of their watershed leads to increased surface runoff and sediment inputs relative to a grassland condition. Eroded sediment from culturally accelerated sources can greatly shorten the life of playa wetlands. Some key conclusions of this document are:

- Data collected in Nebraska playas confirms that over the long-term, the movement of sediment into depressional playa wetlands due to human activities has accelerated. Cumulatively, these alterations have resulted in culturally accelerated sedimentation into a majority of the playa wetlands in Nebraska.
- Culturally accelerated sedimentation has completely eliminated some wetlands.
- The literature that is summarized in this paper clearly demonstrates that culturally accelerated sedimentation, even as little as a few inches, has negative impacts on wetland hydroperiod, vegetation, bio-geochemical cycling, invertebrates, and wildlife.
- To address these negative impacts, we provide recommendations regarding ways to evaluate sediment inputs and depths and methods to address culturally accelerated sedimentation.

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Preamble

In recent years, there have been questions raised about the rate of sedimentation into Nebraska's playa wetlands, the effects of sediment on wetland functions, and how to best deal with the effects of sediment. To address these questions, this document assembles information pertaining to Nebraska's playas and sedimentation of these wetlands. We conducted a comprehensive literature review, consulted wetland and soil scientists, examined data specific to Nebraska's playa wetlands, and summarized this information. The authors' hope this document stimulates further discussion, debate, and research in regards to sediment and its effects on playas. This document is not a policy paper, but we hope that it will be used to help both conservation practitioners and administrators make better informed decisions.

Waterfowl using a Rainwater Basin wetland on the Greenwing Wildlife Management Area in Clay County after completion of the restoration project in 2000 that included sediment removal. *Source: Randy Stutheit (NGPC)*

Introduction

Because of the importance of playas, there are numerous initiatives underway to better protect, restore, and manage them. One of the greatest threats to playas is culturally accelerated sedimentation from highly altered watersheds. However, questions have been raised about the rate of sedimentation into Nebraska's playa wetlands, the effects of sediment on wetland functions, and how to best deal with the effects of sediment. There has also been misunderstandings and miscommunication due to varying definitions of terms and processes. To help address this issue, we describe Nebraska's playa wetlands, discuss the process of sedimentation of playas, summarize data on historic and recent wetland soil profiles, describe the impact that culturally accelerated sedimentation has on numerous wetland functions, and provide recommendations on restoration approaches.

Playas are a common wetland type found in Nebraska. Playa wetlands are predominately wind-formed, nearly circular depressions located throughout the state with the major complexes (regions with wetlands of a similar origin) located mostly in the southern half of the state (LaGrange 2005) (Figure 1). Precipitation declines from east to west across the playa complexes and ranges from 30 to 15 inches (Table 1). Playas have a clay layer (Bt soil horizon, also sometimes called the claypan) in the soil beneath the wetland that causes water to pond at or near the surface. Most playas are not directly connected to groundwater. Hence, water is supplied almost entirely by precipitation and runoff.

Nebraska's playas provide important habitat for numerous species of wildlife and are especially important to migrating water birds (LaGrange 2005, Cariveau and Pavlacky 2009). Indeed, the Rainwater Basin playa wetlands are of international importance for migrating waterfowl and shorebirds (Gersib et al. 1992, Jorgensen 2004). These wetlands also provide important groundwater recharge (Wilson 2010) and water quality improvement functions (Foster 2010). LaGrange (2005) and Smith et al. (2011) provide a much more detailed description of the importance of Nebraska's playas and the range of services that they provide.

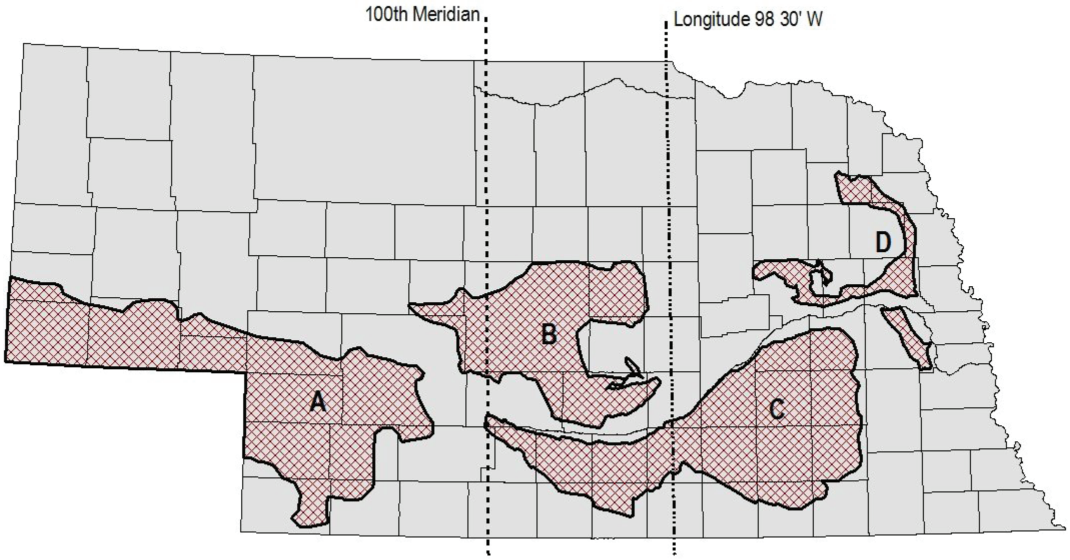


Figure 1. *Nebraska's Playa Wetland Complexes. A- Southwest Playas, B- Central Table Playas, C- Rainwater Basin, D- Todd Valley Playas. Evapo-transpiration generally exceeds precipitation west of the 100th Meridian (Powell 1878), and Weaver and Bruner (1954) documented the transition from true to mixed prairie at roughly longitude 98° 30' W.*

Most playas do not contain a natural outlet and therefore, are further classified as "geographically isolated" wetlands (Tiner 2003). Playas are classified as being in the depressional HGM subclass (Brinson 1993). Using the Cowardin classification, playas are predominately classified as palustrine, emergent, with a water regime of temporary, seasonal, and semi-permanently flooded (Cowardin et al. 1979).

Following is a brief description of each of the four complexes taken from the *Guide to Nebraska's Wetlands and Their Conservation Needs* (LaGrange 2005):

Southwest Playas: The playa wetlands (Figure 2) of southwest Nebraska occupy small depressions on nearly flat tablelands of loess soil. These freshwater wetlands receive water from runoff and most are small (<5 acres), temporarily and seasonally flooded wetlands. Most have no natural outlet for water. In most years, these wetlands dry early enough in the growing season to be farmed. Southwest Playa wetlands are similar to Rainwater Basin wetlands farther east, except that the Rainwater Basin complex receives greater rainfall, and the wetlands there tend to be larger. Southwest playas are located in Major Land Resource Area (MLRA) 72 in Land Resource Region (LRR) H (USDA 2006*)*.

Figure 2. *Southwest Playa Wetlands*
Source: NGPC

Central Table Playas: Central Table Playa (Figure 3) wetlands are situated on relatively flat, loess soil tablelands surrounded by a landscape that is highly dissected by drainages. The largest cluster of wetlands is located near Arnold, Neb., in Custer County, but similar wetlands are scattered in some of the surrounding counties. Central Table Playas receive water from runoff and most are small (<5 acres), temporarily and seasonally flooded wetlands. This complex may represent an extension of the Southwest Playas east toward the Rainwater Basin and Todd Valley complexes. The wetlands in this complex are possibly remnants of a larger complex that was naturally eroded, breached, and drained by streams. Central Table Playas are located in MLRA 71 in LRR H (USDA 2006*)*.

Figure 3. *A highly altered Central Table Playa in Custer County.*
Source: NGPC

Todd Valley Playas: This complex is split into two regions. The region south of the Platte River is located in an ancient valley of the Platte River (termed the Todd Valley) that runs northwest to southeast through part of Saunders County (Lueninghoener 1947). The valley has partially filled with sand deposits and fine, wind-blown loess soils after the river moved to its present location.

The region north of the Platte River is located on an ancient floodplain terrace between the Platte River and Shell Creek and along Logan Creek. Todd Valley wetlands occupy small, closed depressions located in loess soils. They are mostly freshwater, seasonally, and temporarily flooded wetlands that receive most of their water from runoff. Todd Valley Playas are located in MLRAs 102C and 106 in LRR M (USDA 2006*)*.

Rainwater Basin: This complex occupies a 6,100 square mile area in 21 south-central Nebraska counties. It was named for the abundant natural wetlands that formed where depressions catch and hold rain and runoff water. The landscape of this region is characterized by flat to gently rolling plains formed by deep deposits of loess. The wetlands were primarily formed by wind action and generally the long axis of the basin runs in a northeast to southwest orientation (Kuzila and Lewis 1993). There frequently is a hill (lunette) located immediately south or southeast of the wetland where the windblown loess was deposited. Surface water drainage in the region is poorly developed resulting in numerous closed watersheds (catchments) draining into these wetlands. Most of the wetlands in this region do not receive groundwater inflow. Wetlands range in size from less than one to more than 1,000 acres. The Rainwater Basin complex is located in MLRAs 73 and 75 in LRR H (USDA 2006*)*.

In the box below is a more detailed description of Rainwater Basin wetland physiography and geology taken from *A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Rainwater Basin Depressional Wetlands in Nebraska* (Stutheit et al. 2004). This same description can generally be applied to the playa wetlands of the other three complexes and provides a more complete description of the physical formation of these wetlands.

The Rainwater Basin wetland region is in the High Plains Section of the Great Plains Province (Fenneman 1931). It is in Major Land Resource Area 75, the Central Loess Plains (U.S. Department of Agriculture-Soil Conservation Service (USDA 1981). The general physiography of the area is nearly level to gently undulating loess plains with numerous closed basins. The few streams that do dissect the area are very narrow and have little terrace development, except along the Little Blue River. The Rainwater Basin wetland region is in the Central Loess Plains Section and the South-Central Great Plains Section ecoregions (Bailey et al. 1994).

The Rainwater Basin wetland region is an area with poorly developed natural surface drainage resulting in numerous closed basins in which drainage is internal. The numerous surficial depressions are underlain by clayey soils. The fine textured soils impede the infiltration of water, therefore creating numerous ponded wetlands. The origin of the depressional topography has been the subject of conjecture for many years. Early speculation was that the numerous small depressions on the Great Plains were the result of deflation (i.e., wind erosion) during drier climatic episodes, animal activity, or uneven settling of the surface (Gilbert 1895; Frye 1950), possibly because of the action of groundwater (Fenneman 1931). Starks (1984) found that the surface area and volume of the larger Rainwater Basin depressions are linked statistically to the size of the crescent-shaped ridges (lunettes) that occur on the south and east sides of many of the basins. Based upon the occurrence of the lunettes and the lack of soluble bedrock in the area, the most accepted hypothesis on the larger basin's formation is deflation by wind and enlargement by wind and end-current processes (Krueger 1986). Most likely, the depressional wetlands in the area have formed from a variety of processes. The smaller "pothole" depressions (Kuzila 1984) are irregular in shape, range from about 0.1 to 30 ha in size, and are generally less than 1 m below the surrounding land at their lowest point. These depressions do not exhibit any orientation and most likely are formed as the result of wind, animal, and/or differential compaction. The larger basins are oval or elongate in shape and range from about 30 to 1,000 ha in size. The floors of the basins are about 2 to 5 m below the surrounding landscape. Most of the larger basins have associated lunettes and likely formed in the manner described by Krueger (1986). Most of the smaller wetlands have been destroyed by agricultural activities such as filling, land leveling, drainage, and sedimentation.

Table 1. *Characteristics of Major Playa Wetland Complexes in Nebraska.*

Complex	Primary Factor in Formation	Predominant Outer Depressional Soil Series[1]	Predominant Upland Vegetation Community[2]	Predominant Wetland Vegetation Community[2]	Precip. Range[3] (1961-1990)
Southwest Playas	Wind	Lodgepole	Loess Mixed-Grass Prairie, Sandhills Dune Prairie, Sandsage Prairie, and Threadleaf Sedge Western Mixed-Grass Prairie	Wheatgrass Playa Grassland and Playa Wetland	15″ – 20″
Central Table Playas	Wind	Fillmore	Loess Mixed-Grass Prairie	Wheatgrass Playa Grassland, Playa Wetland, and Cattail Shallow Marsh	20″ – 25″
Todd Valley Playas	Wind	Fillmore	Upland Tall Grass Prairie	Wheatgrass Playa Grassland, Playa Wetland, and Cattail Shallow Marsh	25″ – 30″
Rainwater Basin	Wind	Fillmore	Upland Tall Grass Prairie and Loess Mixed-Grass Prairie	Wheatgrass Playa Grassland, Playa Wetland, and Cattail Shallow Marsh	20″ – 30″

[1] These series are classified as Mollisols in Nebraska.

[2] From Rolfsmeier and Steinauer (2010).

[3] From the High Plains Regional Climate Center (http://www.hprcc.unl.edu/maps/normals/).

Figure 4. *Wind deflation of a playa wetland in York County during a spring windstorm.*
Source: NGPC

As noted in the description of Rainwater Basin wetland physiography and geology, the depressional landscape was formed by a variety of processes. Kuzila and Lewis (1993) and Kuzila (1994) concluded that the modern basin landscape was a reflection of an older basin landscape smoothed by loess deposition on top of the older landscape.

An important factor in the formation of playa wetlands in Nebraska was wind deflation of the soil surface. The process likely begins when an area of the soil surface is exposed to the wind due to a lack of vegetative cover.

Wind begins to erode the soil surface through deflation, which is defined as the removal of loose, fine-grained soil particles by the turbulent eddy action of the wind, and by abrasion, the wearing down of the surface by the grinding action and sand blasting of windborne particles (Figure 4). As the soil surface continues to erode away, a shallow depression is formed. Another definition of deflation basins is "hollows" formed by the removal of soil particles by the wind. These basins are generally small, but some are more than a mile in diameter.

Hydric Soils in the Playa Complexes of Nebraska

This section describes the formation and characteristics of hydric soils for Nebraska's playas to help the reader better understand soil science terminology and soil formation processes as they may relate to sedimentation. Much of the following information on hydric soils and the formation of indicators are taken from the *Field Indicators of Hydric Soils, Version 7.0* (USDA 2010a).

Hydric soil is defined as a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Federal Register, 1994). Most hydric soils show characteristic morphologies that result from repeated periods of saturation or inundation that last more than a few days. Saturation or inundation, when combined with microbial activity in the soil, causes the depletion of oxygen. This results in distinctive characteristics that persist in the soil during both wet and dry periods, making them particularly useful for identifying hydric soils in the field.

These soil characteristics formed from prolonged saturation are called hydric soil indicators. In the playa regions of Nebraska, hydric soil indicators are formed predominantly by the accumulation or loss of iron and manganese in a cyclical process of soil saturation followed by soil drying. This cycle produces an alternating anaerobic and aerobic environment within the soil. Hydric soil indicators formed by the reduction of sulfur or the accumulation of organic matter are not common in the playa region but may be found in deeper depressions that are ponded or saturated with water throughout the growing season.

Iron and Manganese Reduction, Translocation, and Accumulation

In an anaerobic environment, soil microbes reduce iron from the ferric (Fe^3+) to the ferrous (Fe^2+) form and manganese from the manganic (Mn^4+) to the manganous (Mn^2+) form. Of the two, evidence of iron reduction and accumulation is more commonly observed in soils. Ferric iron is insoluble, but ferrous iron easily enters the soil solution and may be moved or translocated within the soil profile. Areas that have lost iron typically develop characteristic gray or reddish gray colors and are known as redox depletions.

Figure 5. *Redox Concentrations (reddish patches) in a prairie hydric soil.* Source: North Dakota NRCS

E horizons may have gray colors and may therefore be mistaken for a depleted matrix; however, they are excluded from the concept of depleted matrix unless the E horizon has common or many distinct or prominent redox concentrations.

If a soil reverts to an aerobic state, as is common in the playa complex soils, iron that is in solution will oxidize and form brownish to yellowish patches in soft masses and along root channels and other pores. These areas of oxidized iron are called redox concentrations (Figure 5). In Nebraska's depressional soils, redox depletions are difficult to see, due to masking by the dark color of the surface layers. Redox concentrations are easier to identify. Because water movement in these saturated or inundated soils can be multi-directional, redox depletions and concentrations can occur anywhere in the soil and have irregular shapes and sizes. Soils that are saturated and contain ferrous iron at the time of sampling may change color upon exposure to the air, as ferrous iron is rapidly converted to ferric iron in the presence of oxygen.

Organic Matter Accumulation

Soil microbes use carbon compounds that occur in organic matter as an energy source. The rate at which soil microbes use organic carbon, however, is considerably lower in a saturated and anaerobic environment than under aerobic conditions. Therefore, in saturated soils, partially decomposed organic matter may accumulate. The result in wetlands is often the development of thick organic surface horizons, such as peat or muck, or dark organic-rich mineral surface layers. Due to Nebraska's climate and the natural wetting and drying of playa wetlands, most of the state's playas do not have a thick organic surface layer.

Sulfate Reduction

Sulfur is one of the last elements to be reduced by microbes in an anaerobic environment. The microbes convert sulfate (SO_4^{2-}) to hydrogen sulfide gas (H_2S). This conversion results in a very pronounced "rotten egg" odor in some soils that are inundated or saturated for very long periods. In soils that are not saturated or inundated, sulfate is not reduced and there is no rotten egg odor. The presence of hydrogen sulfide is a strong indicator of a hydric soil, but this indicator occurs only on the wettest sites in soils that contain sulfur-bearing compounds.

Formation of Depressional Playa Wetland Soils in Nebraska

Playa wetlands occur as closed depressions on broad divides of uplands and as closed depressions on treads of stream terraces. This type of wetland depends upon rainwater and snowmelt accumulation of water from within their specific, closed watershed, and are dependent on water ponding or perching on a restrictive soil layer. This contrasts with groundwater fed and riverine wetlands as would typically be found in the Nebraska Sandhills or on flood plains. Because of this, playa wetlands rely upon a soil horizon (the Bt, sometimes also called the "claypan") that has considerable accumulation of translocated clay particles. The Bt horizon, when saturated, acts as a restricting layer to the downward movement of water.

Soils within the playa complexes are dominantly loess derived. In eastern and central Nebraska, the soils tend to have an A, E, Bt soil profile. An E horizon is lighter in color compared with the horizons above and below it. In some soils, the E horizon will be absent due to mixing by cultivation or is masked by a re-accumulation of organic material. Studies indicate that the E horizon in the soils in the Rainwater Basin complex were formed through the removal of free iron and fine clay from the surface material and the translocation of the iron and clay to an established, geologically older Bt horizon (Assmus 1993). Soil series typically associated with Rainwater Basin wetlands are from wettest to driest: Massie, Scott, and Fillmore soils (Figure 6, and see Table 2 for taxonomic definitions).

In general, the depth to the Bt horizon and the thickness of the E horizon decreases with an increase in the wetness of these soils. Filbert soils, mapped within the Todd Valley playa wetland complex, are depressional soils that have been artificially drained.

In western Nebraska and some parts of central Nebraska, soils of the playa complexes dominantly have an A, Bt, C soil profile and lack the E horizon typically found in eastern Nebraska. The primary soil in these depressions in western Nebraska is the Lodgepole Series. It is principally found in closed depressions within areas of the upland soils (Figure 7). Some phases of the Rusco series, usually a non-hydric soil, that are mapped in depressions within the central playa complex are hydric and are saturated for long durations.

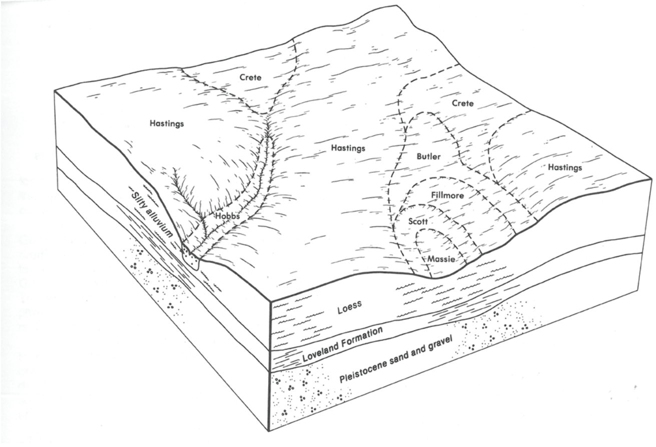


Figure 6. *A "block" diagram showing the landscape position of Rainwater Basin hydric soils in Fillmore County.*

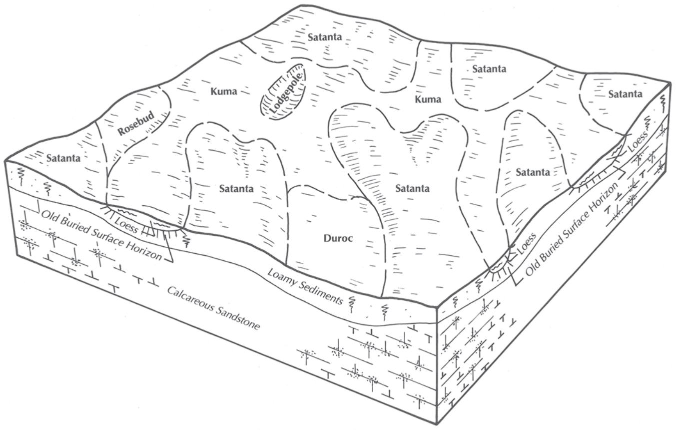


Figure 7. *A "block" diagram showing the landscape position of a Lodgepole soil series in Keith County.*

Table 2. Hydric Soils of the playa wetland complexes in Nebraska and their Taxonomic Classification.

Soil Series	Taxonomic Classification
Filbert	Fine, smectitic, mesic Vertic Argialbolls
Fillmore	Fine, smectitic, mesic Vertic Argialbolls
Lodgepole	Fine, smectitic, mesic Vertic Argiaquolls
Massie	Fine, smectitic, mesic Vertic Argialbolls
Rusco	Fine-silty, mixed, superactive, mesic Oxyaquic Argiustolls
Scott	Fine, smectitic, mesic Vertic Argialbolls

Typical Soil Profiles of Depressional Playa Wetlands

Depressional soils in eastern and central Nebraska playas are generally within the Argialbolls Taxonomic Great Group (USDA 1999). These soils characteristically have A, E, Bt, and C horizon profiles and formed in loess. The A and E horizons are typically loam or silt loam, the Bt horizon is typically clay or silty clay, and the C horizon is typically clay loam or silty clay loam. A typical example of an Argialboll in the playa region is Fillmore silt loam.

The Fillmore series (Figure 8) consists of very deep, somewhat poorly drained soils formed in loess. They are in depressions on uplands and stream terraces. Slopes are zero to 2%. Mean annual precipitation is about 23 inches and mean annual temperature is about 52° F at the type location.

TAXONOMIC CLASS: Fine, smectitic, mesic Vertic Argialbolls

TYPICAL PEDON: Fillmore silt loam on a less than 1% concave slope in native rangeland. (Colors are for dry soil unless otherwise stated.)

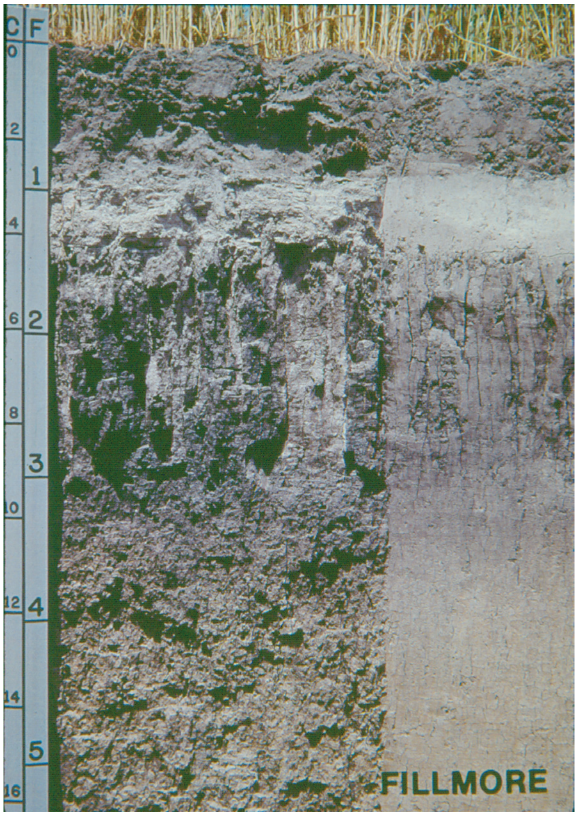


Figure 8. *Profile of Fillmore Silt Loam. Scale is in feet.*
Source: Andy Aandhal

A-- Zero to 9 inches; gray (10YR 5/1) silt loam, very dark gray (10YR 3/1) moist; weak medium subangular blocky structure parting to weak medium granular; slightly hard, friable, slightly acid; abrupt smooth boundary.

E-- 9 to 13 inches; gray (10YR 6/1) silt loam, gray (10YR 5/1) moist; weak medium platy structure parting to weak fine granular; soft, friable; slightly acid; few hard 1 to 2 mm (ferro-manganese) pellets; abrupt smooth boundary.

Bt1--13 to 24 inches; gray (10YR 5/1) silty clay, very dark gray (10YR 3/1) moist; strong coarse and medium angular blocky structure; very hard, very firm; shiny faces on most peds; many hard 1 to 2 mm (ferro-manganese) pellets; neutral; clear smooth boundary.

Bt2-- 24 to 32 inches; grayish brown (10YR 5/2) silty clay, very dark grayish brown (10YR 3/2) moist; strong coarse and medium angular blocky structure; very hard, very firm; shiny faces on most peds; slightly alkaline; clear smooth boundary.

BC-- 32 to 44 inches; grayish brown (10YR 5/2) silty clay loam, very dark grayish brown (10YR 3/2) moist; moderate coarse and medium subangular blocky structure; hard, firm; slightly alkaline; gradual smooth boundary.

C-- 44 to 60 inches; grayish brown (2.5Y 5/2) silty clay loam, dark grayish brown (2.5Y 4/2) moist; weak coarse prismatic structure parting to weak medium subangular blocky; slightly hard, friable; slight effervescence; moderately alkaline.

Soils of the Southwest Playa Complex in western Nebraska are generally within the Argiaquolls Taxonomic Great Group. These soils characteristically have A, Bt, and C horizon profiles and formed in a variety of wind-blown materials. The A horizon typically is silt loam or silty clay loam, the Bt horizon typically clay or silty clay. The C horizon ranges from very fine sandy loam to silty clay loam, depending on the nature of the parent material. A typical example of an Argiaquoll is Lodgepole silty clay loam.

The Lodgepole series consists of very deep, somewhat poorly drained soils formed in loess and loamy sediments in upland depressions and playas. Slopes range from zero to 1%. Mean annual precipitation is about 17 inches and mean annual air temperature is about 51° F at the type location.

TAXONOMIC CLASS: Fine, smectitic, mesic Vertic Argiaquolls

TYPICAL PEDON: Lodgepole silty clay loam on a concave slope of less than 1% in a cultivated field. (Colors are for dry soil unless otherwise stated.)

Ap-- Zero to 5 inches; gray (10YR 5/1) silty clay loam, very dark gray (10YR 3/1) moist; weak fine granular structure; slightly hard, friable; many very fine roots; slightly acid; abrupt smooth boundary.

Bt1-- 5 to 9 inches; dark gray (10YR 4/1) silty clay, black (10YR 2/1) moist; strong fine and medium angular blocky structure; very hard, very firm; patchy clay films on ped faces; many very fine roots; slightly acid; clear smooth boundary.

Bt2-- 9 to 24 inches; dark gray (10YR 4/1) silty clay, black (10YR 2/1) moist; few, fine distinct brown (7.5YR 4/4) moist iron masses in the soil matrix; strong coarse prismatic structure parting to strong fine subangular blocky; very hard, very firm; patchy clay films on ped faces; few very fine roots; slightly acid; diffuse wavy boundary.

Bt3-- 24 to 38 inches; dark grayish brown (10YR 4/2) silty clay, very dark brown (10YR 2/2) moist; common fine distinct brown (7.5YR 4/4) moist iron masses in the soil matrix; strong coarse prismatic structure parting to moderate medium and fine subangular blocky; very hard, very firm; patchy clay films on ped faces; neutral; clear wavy boundary.

Bt4-- 38 to 45 inches; grayish brown (10YR 5/2) silty clay loam, very dark grayish brown (10YR 3/2) moist; moderate coarse prismatic structure parting to moderate medium subangular blocky; hard, firm; dark organic stains on ped faces; neutral; gradual wavy boundary.

BC-- 45 to 54 inches; grayish brown (10YR 5/2) silty clay loam, dark grayish brown (10YR 4/2) moist; weak coarse prismatic structure parting to weak medium subangular blocky; slightly hard, friable; dark organic stains on ped faces; neutral; gradual wavy boundary.

C-- 54 to 80 inches; very pale brown (10YR 7/3) silt loam, brown (10YR 4/3) moist; massive; soft, very friable; slightly alkaline.

A "Reversed" Landscape

The sediment processes in the modern landscape are now "reversed" because most of the uplands are tilled and most of the wetlands are heavily vegetated. Before European settlement of the Great Plains, the entire region stretching from Illinois on the east, the Rocky Mountains to the west, Canada to the north and Texas in the south was a huge expanse of mostly treeless prairie. Early explorers noted the immense number of large ungulates such as bison, elk, and pronghorns living on the plains. The Great Plains, with its vast herds of grazers, was often compared to the Serengeti Plains of Africa. Embedded within this huge expanse of prairie were playa wetlands. These wetlands likely served as important watering holes for grazers during those times of the year when precipitation kept the wetlands filled. The lush vegetation growing in and near the wetlands would also have served to attract grazers. At times, grazing, trampling, drowning when water depths were significant, prairie fires, and drought would have depleted the vegetative cover in and around the wetlands (Figure 9). As wetlands dried, the trampling and hoof action of the bison, elk, and pronghorn likely kept soils loosened and aided the continuing process of wind deflation. Soil particles blown out of the wetland were deposited and trapped in upland prairie vegetation surrounding the wetlands. In addition, prairie vegetation covering surrounding uplands would have kept sediment deposited into the wetland from water and wind erosion to a minimum. These natural processes occurring over thousands of years would have kept these playa wetlands from gradually filling with soil and maintained them as important features of the Great Plains landscape.

Today, however, the natural landscape process has been altered. Nebraska's playa wetlands are located in regions of intense agricultural production. The upland watersheds of most of these wetlands are now in row crop agriculture, primarily irrigated corn and soybeans. The lack of permanent vegetative cover in the watersheds during the past 100-150 years has led to a reversal of the natural processes that created and maintained Nebraska's playa wetlands (Figure 9).

The "reversed" landscape now contains tilled uplands and mostly heavily vegetated wetlands. The wetlands are more vegetated today due to the lack of grazing, altered hydroperiods, increased nutrient loads, and the presence of invasive plants such as reed canary grass (scientific names for flora are provided in Appendix D). In this reversed landscape, wind and water erosion moves soil from the tilled uplands down into wetlands occupying the lowest point on the landscape where dense vegetation traps the soil and prevents wind deflation from removing it. Hence, the natural landscape process has been reversed.

Todd Valley wetlands in Platte County illustrating the "reversed" landscape condition. *Source: Ted LaGrange (NGPC)*

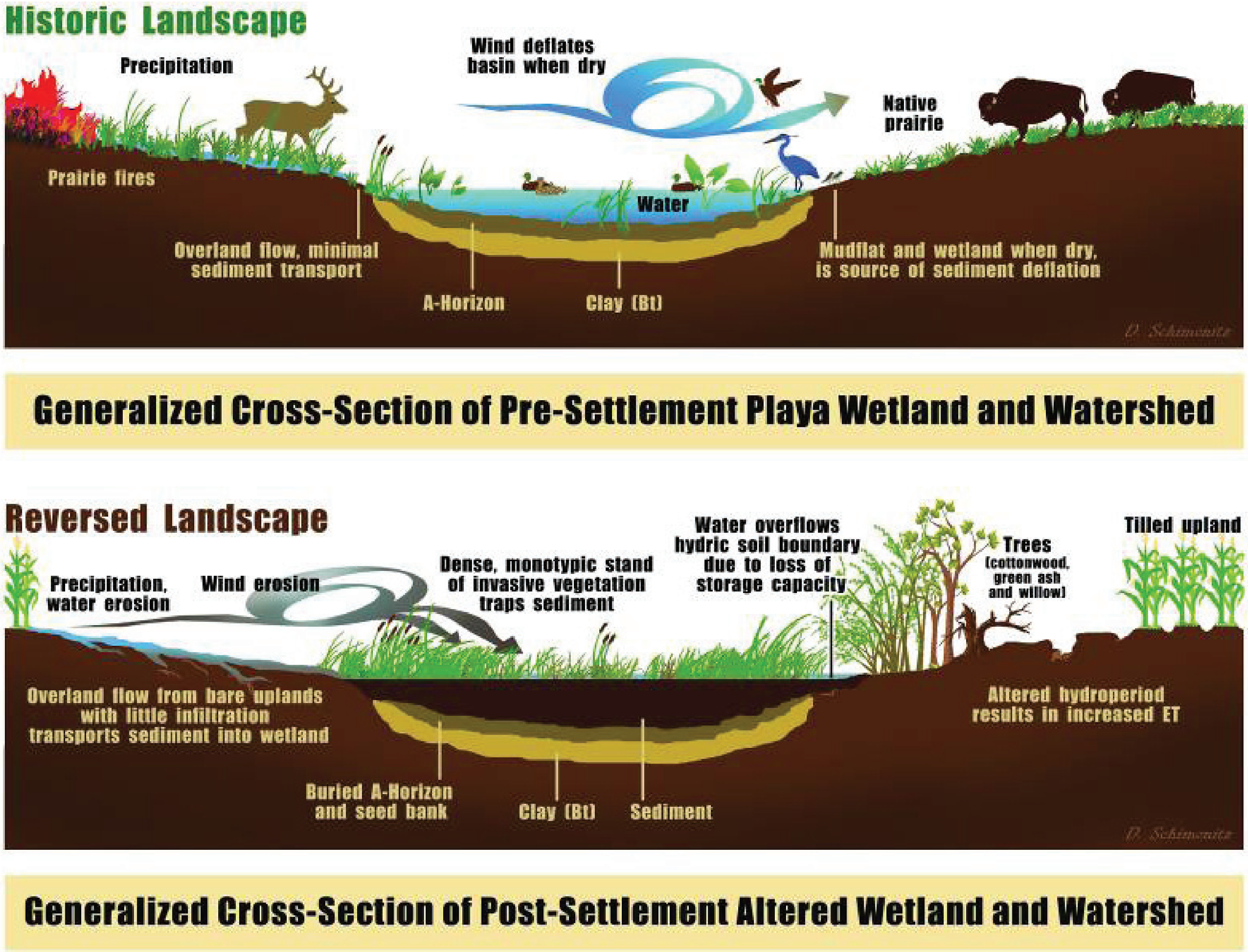


Figure 9. *A generalized cross-section of a playa wetland and its watershed in reference standard condition with natural processes at work and another playa suffering from the effects of a "reversed landscape."*

The Process of Sedimentation of Playa Wetlands

Much of the information presented in the next three sections is adapted from the publication *Sedimentation of Prairie Wetlands* by Gleason and Euliss (1998) and from the chapter by P. Michael Whited in *Wetland Restoration, Enhancement, and Management* (USDA 2003).

Definitions

Sediment is naturally occurring material that is broken down by processes of weathering and erosion and is subsequently transported by the action of wind (aeolian processes) or water (fluvial processes), and/or by the force of gravity acting on the particles to move them down slope. Alluvium-colluvium is the name for loose bodies of sediment that have been transported by water and deposited or built up at the bottom of a low-grade slope. Overland flow erodes soil particles and transports them down slope.

Erosion associated with overland flow may occur through different methods depending on meteorological and flow conditions. If the initial impact of rain droplets dislodges soil, the phenomenon is called rain splash erosion. Splash erosion is the result of the mechanical collision of raindrops with the soil surface and the movement of soil particles down slope. Dislodged soil particles can also become suspended in the surface runoff and carried down slope. If overland flow is directly responsible for sediment transport, but does not form gullies or well-defined channels, it is called sheet erosion (Figure 10).

Figure 10. *Sheet erosion and deposition of sediment (colluvium) into a Rainwater Basin (3 mi. east, 1 mi. north of Harvard, Neb.) after a thunderstorm passed through the area the previous night. Much of the sediment was trapped in the upland vegetation around the edge of the wetland and in the temporary zone. Wetlands without vegetation or not having a buffer, such as farmed wetlands, are not protected from sediment distributing throughout the entire basin via wave action and currents.*
Source: Ted LaGrange (NGPC)

Another process called ephemeral gully erosion (Figure 11) occurs when water flows in narrow channels during or immediately after heavy rains or melting snow. An ephemeral gully is normally covered up by routine tillage operations, though the gully usually reappears in the same place following another rainfall event. Rill erosion is a process in which numerous small channels, typically a few inches or less deep, form mainly on recently cultivated soils or on recent cuts and fills and is smoothed by ordinary tillage methods. Classic gullies are sufficiently deep that they would not be destroyed by tillage operations and often cannot be crossed by tractors. Classic gullies may be of considerable depth, ranging from 1 to 2 feet to as much as 75 to 100 feet. Gully erosion is significant but is not accounted for in the Revised Universal Soil Loss Equation (RUSLE). Because of the water's increased energy due to concentrated flow in a channel, gully erosion can carry a sediment load farther into a wetland.

Figure 11. *Concentrated flow of water (ephemeral gully erosion) in a cornfield. Gully erosion, due to the water's increased energy, can carry a sediment load farther into a wetland.*
Source: marvellemediablog.com

When land is tilled and soil is exposed, rainwater carries tons of topsoil into playas each year causing loss of valuable topsoil and adding sediment to surface waters.

Aeolian processes pertain to the ability of the wind to shape the surface of the earth. Wind may erode, transport, and deposit materials and is an effective agent in regions with sparse vegetation and a large supply of unconsolidated soil, such as tilled farmland. Particles are transported by wind through suspension, saltation, and creep.

Small soil particles may be suspended in the atmosphere. Upward currents of air support the weight of suspended particles and hold them indefinitely in the surrounding air. Typical winds near the earth's surface suspend particles less than 0.2 millimeters in diameter and scatter them aloft.

Saltation is the downwind movement of particles in a series of jumps or skips. Saltation normally lifts sand-size particles no more than one centimeter above the soil surface and moves them at one-half to one-third the speed of the wind. A saltating grain may hit other grains that jump up to continue the saltation process. The grains also may hit larger particles that are too heavy to hop but slowly creep forward as they are pushed by saltating grains.

Natural Sedimentation

Playa wetlands located in a landscape with no anthropogenic alterations to either the wetland or the watershed and with natural processes such as grazing, fire, flooding, and drought still at work would be under the influence of the natural sedimentation process. A mass balance would exist where the amount of sediment moving into the wetland by fluvial and aeolian processes would be countered by the amount of sediment moving out via wind deflation (Figure 12). A vegetated watershed would contribute little sediment through either wind or water erosion while deflation of the wetland would be an ongoing process occurring when the wetland soil was dry, exposed, and loosened enough to be picked up by the wind. Although likely to have been minor in its contribution, another process influencing mass balance under the historical natural landscape condition was the physical removal of soil from a wetland by large ungulates using playa wetlands as wallows. Reeves and Reeves (1996) noted that playa wetlands likely attracted herds of large mammals such as bison and elk, not only for the water and vegetation, but also to the mud for wallowing. They would then transport large amounts of soil (mud) trapped in their coats out of the depression.

Figure 12. *A Central Table Playa in reference standard condition. Sediment inputs vs. outputs are likely in balance.* Source: Ted LaGrange (NGPC)

During the times these wetlands were dry, the soil would be subject to wind erosion aided by large mammal activity such as wallowing in "dust baths," trampling of vegetation, and hoof action that all worked to loosen the soil. The natural sedimentation process in playas, where inputs and outputs were considered to be in balance, is in contrast to many other types of wetlands where sedimentation is part of the natural process. For example, the deposition and scouring of sediment is a natural and important process for many wetlands associated with streams and rivers. Similarly, many wetlands associated with beaver dams eventually become non-wetland as they fill with sediment.

Culturally Altered Sedimentation

Culturally altered sedimentation refers to changes in sediment movement, rates, and patterns affecting wetlands since European settlement (i.e., over the past 150+ years). If wetland sedimentation rates due to cultural practices exceed what had naturally occurred, this is termed culturally accelerated sedimentation. Culturally altered sedimentation began to occur after European settlement of the Great Plains. As early as the mid to late 1800s, the watersheds of these playa wetlands were plowed and planted to annual crops and were in a barren and disturbed condition for much of the year. An increase in the rate and amount of sediment moved by wind and water erosion down slope into the wetlands occurred. The "reversed landscape" condition (Figure 9) came into existence and the mass balance of soil input versus soil output switched to more sediment entering the wetland than was exported out via wind deflation. The McMurtrey survey, during the period of 1959-1965, documented eyewitness accounts of from several inches up to one to two feet of soil deposited by the wind into Rainwater Basin wetlands during the dust bowl era, as well as heavy sediment inputs due to farming in the watersheds (McMurtrey et al. 1972; see Appendix A). Other observations, such as the ongoing need to clean out irrigation reuse pits, the appearance of silt deltas around the edges of playas, and observations of continued recent sediment inputs, provide evidence that Nebraska's playa wetlands have been receiving inputs of sediment. Moreover, the basic physic's law of gravity dictates that this has occurred. Quantified data from more recent research is discussed in the *Historic Sedimentation Information and Data* section.

There are a number of studies that have described and quantified culturally altered sedimentation. Tillage has greatly altered the surface hydrologic dynamics of wetland watersheds; conventional tillage increases erosion rates and surface runoff relative to grassland landscapes (Gleason 1996; Euliss and Mushet 1996, Luo et al. 1997, Tsai et al. 2007) (Figure 13). Adomaitis et al. (1967) demonstrated that the aeolian mixture of snow and soil ("snirt") in wetlands surrounded by fields without vegetation accumulated at twice the rate as in wetlands surrounded by fields with vegetation. Similarly, Martin and Hartman (1987) found that the flux of inorganic sediment into wetlands with cultivated watersheds occurred at nearly twice the rate of wetlands with native grassland watersheds. Organic matter also occurs at significantly greater concentrations in sediment in wetlands with native grassland watersheds than in wetlands with cultivated watersheds. Dieter (1991) demonstrated that turbidity was higher in tilled (i.e., wetland and watershed areas tilled) than in untilled and partially tilled (i.e., portions of the basin tilled with a buffer strip of vegetation separating the basin and watershed area) wetlands. Similarly, Gleason (1996) and Gleason and Euliss (1998) found that sedimentation rates and the inorganic fraction of sediment entering wetlands were significantly higher in wetlands with cultivated watersheds than in wetlands with grassland watersheds. There also was more wind deposited sediment in wetlands in cultivated watersheds than in wetlands with grassland watersheds (Gleason and Euliss 1998). The use of flood irrigation in playa watersheds also can accelerate erosion.

Figure 13. *The watersheds of many playas have been highly altered, resulting in culturally accelerated sedimentation, as evidenced by the silt delta (lower left) in Smith WPA, a Rainwater Basin in Clay County.* Source: NGPC

In the playa wetlands of Texas, Luo et al. (1997) found that wetlands in cultivated watersheds had lost more than their original volume due to filling by sediment, whereas comparable sites in grassland watersheds lost only about a third of their original volume. A conclusion common to all these studies is that wetlands in agricultural landscapes have shorter hydrological lives than wetlands in grassland landscapes (see pg. IV.B1-9 by P. Michael Whited in USDA, 2003). Although studies have documented that sedimentation into playas from cropland continues to occur, it is felt that conservation measures (e.g., no-till, ridge till, conversion to sprinkler irrigation, etc.) have reduced erosion rates from what they were in the past.

As the native prairie vegetation was removed and converted to cropland, the runoff dynamics of the entire landscape changed. Surface runoff from snowmelt and storms during pre-settlement times was moderated by native vegetation dampening the effect of runoff and increasing the time available for infiltration. Conversion of native prairie grassland to cropland has likely increased the intensity of runoff events and decreased the time available for infiltration. Intensification of runoff events increases the amount of sediment the flowing water can suspend and transport. Increased surface flow can exacerbate flooding as was noted by Miller and Nudds (1996), who related intensity of floods in the Mississippi River Valley to landscape changes involving conversion of grassland to cropland in the prairies.

The Center for Advanced Land Management Information Technologies (CALMIT) at the University of Nebraska-Lincoln used the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) to estimate overall soil loss rates for publicly-owned Rainwater Basins, as well as for the entire Rainwater Basin study area (Merchant and Dappen 2010). It is generally considered that areas exceeding more than 5 tons/acre/year would require additional conservation practices, while those exceeding 8 tons/acre/year would be considered highly erodible lands. Although soil loss rates were low for a large percentage of the basin's watersheds, most did contain areas with loss rates greater than 5 tons/acre/year, and some had areas with loss rates of greater than 8 tons/acre/year.

Fill is simply defined as soil that has been mechanically removed from one area and deposited in another. Many of the playa wetlands in Nebraska contain tail-water recovery pits (also known as water concentration pits or irrigation re-use pits) dug during the 1960s, 70s, and early 80s when the primary method of watering crops in Nebraska was flood irrigation. Pits were dug at the lowest point in the landscape (frequently a playa wetland) to capture irrigation tail water so it could be re-used and to prevent impacts to neighbors from excess water. Simultaneously, the material excavated to create the pit was spread in the surrounding wetland to facilitate cropping. Fill has been placed in these wetlands for a variety of other reasons such as to build roads, create building pads, and land leveling for irrigation. An early method employed by landowners to attempt to fill wetlands was the use of a moldboard plow to "throw" soil down slope toward the wetland (Schildman, *Pers. Comm.*). After several years of this practice, a significant amount of soil could be moved down and into the wetland. This would also be considered fill, as it was material that was mechanically moved into the wetland.

The Great Plains, due to its central location in the North American landmass, is subject to climatic as well as meteorological extremes that can have a profound influence on the amount of soil eroded from the landscape and moved into playa wetlands. For instance, the dust bowl years of 1931–1940 were a result of extreme drought on the Great Plains. Due to poor soil conservation practices at the time, massive amounts of soil were moved by the wind (Figures 14 and 15). Other major droughts with conditions ranging from mild to extreme occurred in the 1890s, 1944, 1952-1957, 1963-1965, 1968-1970, 1989-1991, 2000, and 2002-2003. These periods of drought all provided the opportunity for an increase of wind-blown sediment deposits into wetlands.

Figure 14. *Large dust storm moving across the plains.* *Source: southbaytotalhealth.com*

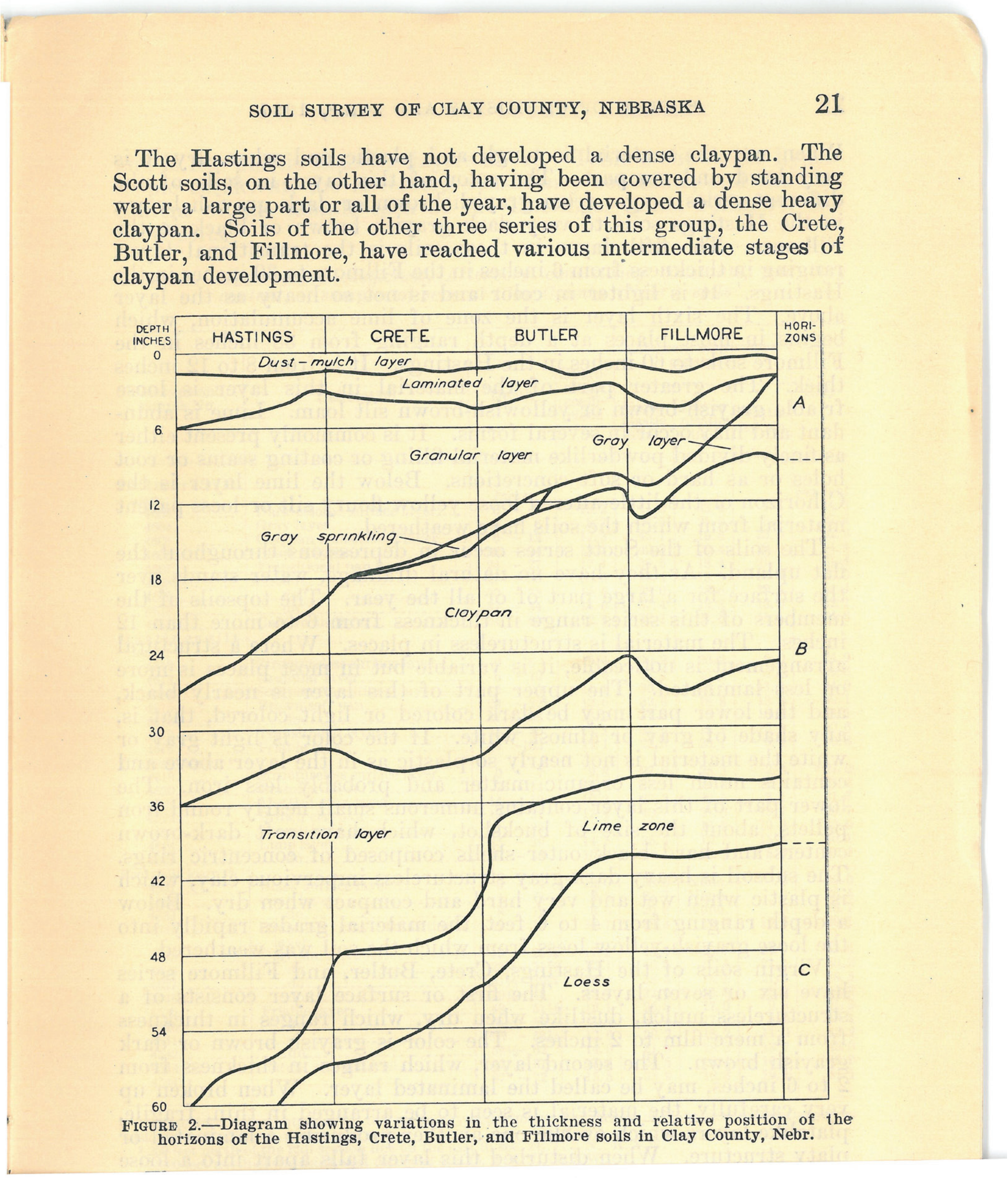
Figure 15. *Photo showing large amount of soil moved by the wind.* *Source: dailykos.com*

Extreme meteorological events common on the Great Plains, such as severe thunderstorms with intense rainfall, can also move many tons of soil down slope from tilled fields with little or no vegetative cover. Poor soil conservation practices in use until the last few decades aided both wind and water erosion. The Soil Conservation Service (now NRCS) was formed in response to the dust bowl and began educating landowners about proper soil and water conservation practices and assisted with the installation of these practices beginning in the 1930s. However, the effects of wind and water erosion as natural processes can only be slowed, not stopped.

Historic Sedimentation Information and Data

Earliest Soil Surveys of the Nebraska Playa Complex Regions, 1910-1935

The earliest soil surveys and soil descriptions within the playa complex regions of Nebraska were printed in the period between 1910 and 1935. In these pioneering soil surveys, the unique characteristics of soils formed in depressions (depressional soils) were first recorded. The Scott soil series, established in Scott County, Kansas, in 1910, was the first soil series to designate areas of depressional soils in the central plains and prairies. In the early surveys, it is most commonly described with a silt loam or silty clay loam surface soil and dense, impermeable clay subsoil. The dark colored topsoil under native grass is commonly described as having three layers: a thin, "mulch" layer consisting of plant material and dust; a "laminated layer" with a structure of thin plates that fall apart in the hand; and a granular layer below the laminated layer. The total depth of the dark colored topsoil is of varying thickness. In addition, the silt loam phase of the Scott Series is commonly described with a gray or white "ashy" layer immediately above the Bt subsoil that is termed an "E horizon" in modern soil surveys. This layer is described as being "a sprinkling" to several inches thick. The documented length of time the Scott soils pond water is extremely variable ranging from a few days to many months. Further refinement in determining the wetness limits to successful cultivation of depressional soils within the Rainwater Basin complex, resulted in the establishment of the Fillmore series (1923), the Butler series (1924), and the Massie series (1979). (For Official Series Descriptions, go to http://soils.usda.gov/technical/classification/osd/index.html). In the 1927 Soil Survey of Clay County, Nebraska, there is a diagram of the soil profiles of the arable soils of the Rainwater Basin (Figure 16).



SOIL SURVEY OF CLAY COUNTY, NEBRASKA 21

The Hastings soils have not developed a dense claypan. The Scott soils, on the other hand, having been covered by standing water a large part or all of the year, have developed a dense heavy claypan. Soils of the other three series of this group, the Crete, Butler, and Fillmore, have reached various intermediate stages of claypan development.

FIGURE 2.—Diagram showing variations in the thickness and relative position of the horizons of the Hastings, Crete, Butler, and Fillmore soils in Clay County, Nebr.

Figure 16. *Diagram from the Soil Survey of Clay County, Nebraska (USDA-Bureau of Chemistry and Soils 1927).*

Since modern soil survey descriptions are being constantly updated, to understand how a soil was originally described (i.e., reference condition), it is important to review the oldest soil survey soil descriptions available. Although no quantitative analysis can be made based on the soil descriptions in the early surveys (1913-1935), trends can be determined in the depth to Bt as described in the surveys within each of the playa complex regions. It is also important to note that even by the 1920s, the watersheds of many playa wetlands in Nebraska had been under cultivation for 40-60 years. According to the 1927 Soil Survey for Clay County, 80% of the land in the county had been "improved" (i.e., broken and tilled) by 1924, and the 1918 Soil Survey for Fillmore County stated that 90% of the land in the county had been "improved." In the narrative that follows, Butler soils are included only if an early county survey documents that water ponds on the Butler soil in that county. A summary of the early soil survey data is in Appendix B.

Rainwater Basin Complex: The county soil surveys in this region were published between 1916 and 1934. As the early soil survey era progressed, more attention was paid to the characteristics of the soils in the Rainwater Basin than in other wetland complexes of the state. In counties published before 1923 (five counties), the described depressional soils are Scott silt loam, Scott silty clay loam and Scott clay. Scott clay was described in one county, Phelps County (1919). In counties published after 1923 (14 counties), the depressional soils are Butler silt loam (when documented as ponding water), Fillmore silt loam, Fillmore silty clay loam, Scott silt loam and Scott silty clay loam. Jefferson County (1925) had no depressional soils documented.

In the soil surveys published before 1923, the depth to the Bt in the Scott silt loam soils ranged from a low of six inches to a high of 28 inches in this region. The land use was mostly hay and pasture, but in Seward (1916) and Fillmore (1918) counties, a percentage of these soils were under cultivation. In addition, Scott silt loam soils in the Seward County survey were documented as mapped on both the depression and drainage headwater landforms. The depth to Bt in Scott silty clay loam and Scott clay ranged from 1 inch to 12 inches. The land use for these two soils was predominately hay and pasture.

In soil surveys published between 1923 and 1934, the Butler soils (ponded) depth to Bt ranges from seven to 14 inches. Land use varied by county from all pasture and hayland to 75% cultivated. Fillmore soils have a range in depth to the Bt of six to 15 inches. Land use varied by county from pasture and hayland to 60% cultivated. The Scott soils had a documented depth to Bt range between 1 and 15 inches. The typical range in depth to Bt for these Scott soils was between 5 and 12 inches. Land use was pasture, hayland, or waste for Scott soils in all counties except York (1928) where almost 50% of Scott silt loam was described as cultivated.

The observations and knowledge gained in the early soil surveys of the Rainwater Basin region are presented in the "Interpreting Soils" section of the 1927 Clay County Soil Survey, the most comprehensive discussion on soil formation in the Rainwater Basin of the early soil survey era, representing the "state of the art" at that time.

Central Table Playas Complex: The county soil surveys in this region were published between 1922 and 1932. No early soil survey was published for Logan County. The depressional soils in this complex had the least amount of variation in depth to Bt of the four playa wetland complex regions. The described depressional soils were Scott silt loam and Scott silty clay loam. The documented range of depth to the Bt in these soils ranged from 6 inches to 12 inches in the soil surveys of this playa region. Land use for all of these areas was commonly described as pasture or waste.

Southwest Playa Complex: The county soil surveys in this region were published between 1916 and 1935. The described soils are Scott silty clay, Scott silt loam, Scott silty clay loam, Scott very fine sandy loam, and Butler silty clay loam. The Scott silty clay soils – mapped in Chase (1917), Deuel (1921), Perkins (1919), and Garden (1924) counties – had the Bt at the surface. Pasture and hayland were the dominant land use. The documented range of depth to the Bt in the other Scott soils ranged from 1 inch to 18 inches in the other soil surveys of this area. The typical range in depth to Bt was between 4 and 8 inches. Many of these soils were noted to be calcareous in the county soil surveys. Land use was dominantly pasture and hayland, except Hayes County (1934), where the survey documented 50% cropland on the Scott very fine sandy loam soil.

Todd Valley Complex: The county soil surveys in this region were published between 1913 and 1934. Depressional soils in this complex have a greater variation and a deeper overall depth to Bt than is documented for the surveys in the other complexes. No depressional soils are documented in the Burt (1922), Colfax (1930), and Cuming (1922) county soil surveys.

In the other counties within this playa region, the depressional soils were described as Scott silt loam. The depth to Bt ranged from a low of six inches to a high of more than 40 inches. Two counties, Madison (1920) and Platte (1923), documented a depth to Bt between 6 and 15 inches. The other counties in this playa region documented a depth to the Bt ranging from a low of 24 inches to more than 40 inches from the surface. The land use documented for the Scott soils in the county soil surveys of Dodge (1913), Thurston (1916), and Wayne (1917) was cultivated with crops often failing. In the remaining counties, land use for Scott soils was pasture, hayland, or waste.

McMurtrey Observations and Farmer Interview Results, 1959-1965

Some of the earliest information available about sediment deposition into Nebraska's playa wetlands is recorded from documented eyewitness accounts by landowners as recorded by McMurtrey et al. (1972). While conducting a "breeding waterfowl habitat" survey in the Rainwater Basin region during the period 1959-1965, he frequently interviewed landowners to gather more information about waterfowl use on a particular wetland or other pertinent information useful to the survey (see Appendix A). Many of the individuals he interviewed noted that sediment had washed and/or blown into their wetlands over time, including a large number of observations relating to the Dust Bowl era in the 1930s.

Data from Recent Soil Surveys on Playas in Nebraska

Three data sources documenting depth to Bt were compiled. These data were compared to reference data to determine if culturally accelerated sedimentation has occurred. The first data set is from Gilbert (1989). For this study, vegetation-soils correlations were evaluated in regard to wetland delineation applications, namely, the correspondence of vegetation to hydric soils. A second source of soil descriptions can be found in Stutheit et al. (2004). Soil descriptive information was collected by NRCS soil scientists to develop soil quality indicators for use in wetland functional assessment applications. The final source of information was from depth-to-clay surveys conducted by NRCS soil scientists for a number of wetlands on state-owned Wildlife Management Areas (WMA) from 1997 through 2009 (Appendix C). Depth-to-clay surveys were conducted to guide sediment removal in association with wetland restoration and enhancement activities on these areas. Some recent soils data also was examined from the Todd Valley Playas, Central Table Playas, and Southwest Playas but there were not enough data at this time to merit analysis.

The three Rainwater Basin data sets represent contemporary investigations that can be used for comparison with NRCS Official Soil Descriptions (OSD) and historic soil survey information presented earlier in this document. From OSD summaries, depth to Bt for Fillmore soil ranges from 10-29 inches. The range for Scott soil is 3-9 inches and for Massie soil is 4-25 inches. In Nebraska soil surveys published from 1923-1934, Fillmore soils had a range in depth to Bt of 6-15 inches, and Scott soils ranged from 1-15 inches, although the typical range reported was from 5-12 inches.

Raw data from these investigations are presented on the depth to Bt (claypan) for Fillmore, Scott, and Massie soil series. Data from Gilbert (1989) and Stutheit et al. (2004) have been combined in Figure 17. Data from the WMA Bt surveys are provided in Figure 18 for each site by individual soil series. Data are compared to the range in depth to Bt from both the OSD and from the historical soil surveys.

From these data, the following observations are provided as either empirical evidence of culturally accelerated sedimentation; or, to illustrate the need for refinement in soil descriptive information for wetland restoration applications.

- Contemporary observations for all soils series indicate considerable variation in the depth to Bt.
- For the Fillmore and Scott soil series, comparisons of historic to contemporary soil profile observations indicate considerable variation in the depth to Bt.
- For Scott soils, the ranges of the historic and OSD data do not vary considerably, yet substantial variation in the depth to Bt is noted in the contemporary data.
- Contemporary data sets for the Fillmore and Massie soils are generally within the range of variation reported in OSD summaries. As a contrast, actual sediment removed in association with WMA restoration would suggest a need for developing or refining field indicators for sediment.

From the data available, both from Nebraska playas and from studies done in other playas and Prairie Potholes in the Great Plains, it is evident that over the long-term, the movement of sediment into depressional wetlands due to human activities has accelerated. Cumulatively, these alterations have resulted in culturally accelerated sedimentation into a majority of the playa wetlands in Nebraska.

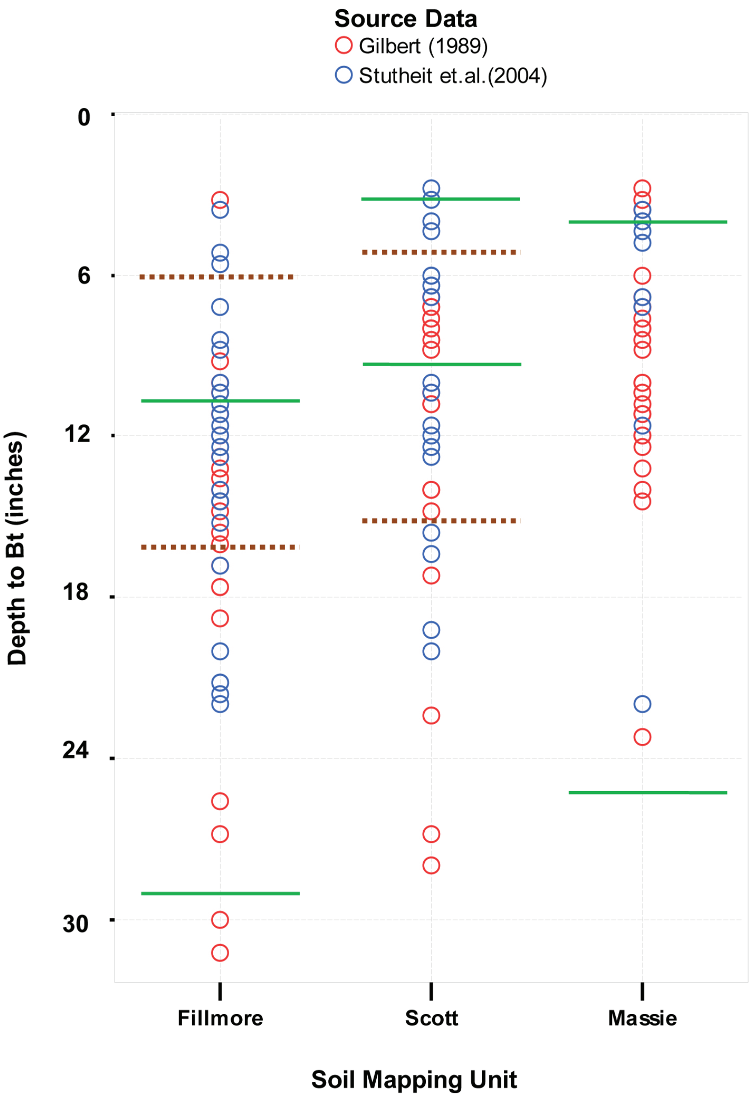


Figure 17. *Depth to clay surveys from contemporary Rainwater Basin studies involving soil pedon descriptive information. The green lines represent intervals of the depth to Bt as determined from the shallowest A horizon to the deepest Bt horizon. Source data is from NRCS Official Soil Descriptions (OSD). The brown dashed line represents the range of depth to "claypan" as reported from early soil surveys published between 1923 and 1934.*

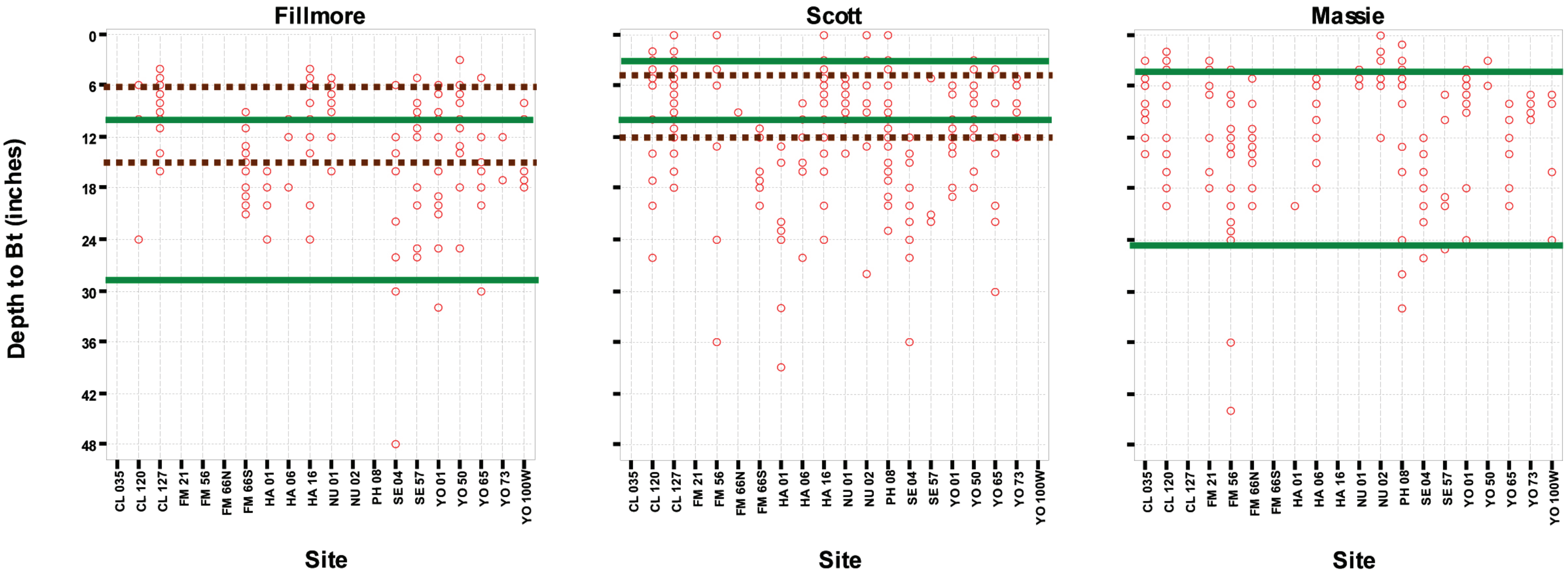


Figure 18. *Depth to clay surveys for Rainwater Basin Wildlife Management Areas restoration projects. On the X axis "Site" refers to county name abbreviations and a unique number identifying a specific wetland (i.e. CL=Clay County; the "035" is a unique basin identification number for that county). Site naming conventions are from McMurtrey et al. (1972). For more detailed site information see Appendix C .The green horizontal lines represent intervals of the depth to Bt as determined from the shallowest A horizon to the deepest Bt horizon. Source data is from the NRCS Official Soil Descriptions (OSD). The brown dashed lines represent the range of depth to "claypan" as reported from early soil surveys published between1923 and 1934.*

Effects of Culturally Accelerated Sedimentation on Playa Wetlands

Figure 19. *Recent sediment inputs into a Central Table Playa. The accumulation of sediment over the years impacts numerous wetland functions.*
Source: Ted LaGrange (NGPC)

Nebraska's playa complexes occur in a topographic, hydrologic, and land use setting that worsens both the accumulation and retention of culturally accelerated sediment in wetlands. Sediment retention is recognized as an important wetland function that provides water quality benefits, but excessive sediment inputs from erosion of agricultural soils can severely impact other functions. The effects of culturally accelerated sedimentation on wetland functions can be primary, secondary, or tertiary (Figure 23, page 35). These impacts include altered hydroperiods, increased turbidity that reduces the depth of the photic zone (the name for the depth of water which is exposed to sufficient sunlight to allow photosynthesis to take place) and covering the seed bank of primary producers and invertebrates, thus altering aquatic food webs. Excess sediment in playa wetlands also has a "smoothing" effect on basin micro-topography, therefore eliminating variable water depths and the diverse plant community supported by this variation. A recent Midwestern study of the effects of sediment on sedge meadow soils and micro-topography found that inflowing sediment reduced micro-topographic variation and surface area for native species, and that this contributed to the loss of native species in wetlands (Werner and Zedler 2002). Basic wetland functions related to water quality improvement, nutrient recycling, and biogenic processes (produced by living organisms or biological processes) that transform and sequester pollutants also are severely impacted.

High intensity rains on poorly managed tilled ground can result in high levels of runoff and considerable erosion of the soil that fills depressions with sediment (Figure 19). Runoff transports sediments down slope until they are deposited in low-relief areas, including wetlands, and fill the depressions to a degree that they no longer function as wetlands (Richardson and Vepraskas 2001). Small depressions, in particular, are functionally impacted by even small amounts of sediment. Another agricultural issue involves the transport, via runoff, of agricultural chemicals (e.g., nitrates, phosphates, pesticides, and herbicides) bound to soil particles. This result occurs to the greatest extent when chemical use is excessive or poorly timed with respect to high precipitation events. The resulting contaminated sediment and runoff represents an environmental threat to downstream ecosystems such as playa wetlands.

Naturally or lightly disturbed playa wetlands are dynamic and resilient. Historically, the interaction of flooding, drought, fire, grazing, trampling by large ungulates, and wind deflation led to systems with a wide range of hydrologic and vegetative conditions not just from one year to the next but also within any given year. Wildlife species that use playa wetlands are adapted to this wide range of conditions and depend on this variation throughout the year. However, the presence of culturally accelerated sediment, even as little as a few inches, can have severe consequences for wetlands and the many functions they perform. Excess sediment can initially alter or disrupt one or more of these functions that can then lead to a cascading of negative effects on all functions performed by a particular wetland. The natural resiliency of a wetland is overwhelmed, the dynamic cyclic processes that are important to the ecology of playa wetlands are impacted, and a condition closer to stasis is reached. A prime example of this condition can be seen in Rainwater Basin wetlands that have, over time, filled with sediment and are now dominated by a monoculture of reed canary grass.

Effects on Hydrologic Functions

Precipitation that was once lost through evapo-transpiration or infiltration to groundwater before entering wetlands in grassland watersheds may now enter wetlands via spates of surface runoff from tilled watersheds. These surface runoff spates may transport sediment, nutrients, and other pollutants into wetlands (Goldsborough and Crumpton 1998). In addition to the alteration of hydrologic inputs, the loss of basin volume from siltation reduces the water storage capacity and flood attenuation benefits of wetlands (Brun et al. 1981; Ludden et al. 1983).

The functions relating to storage of water are particularly disturbed by sediment (Richardson and Vepraskas 2001). As sediment continues to accumulate in a playa wetland, storage volume is lost not only through a reduction of wetland depth, but also by shrinking wetland size as the outer temporary zone silts in, is elevated, and eventually reverts to upland. Residency time of water in wetlands partially filled with sediment can be greatly reduced when the water is forced to overflow the outer edge of the hydric soil. Infiltration is much quicker on the "non-hydric" soils and water levels in the wetland drop much faster (Luo et al. 1997). The larger surface area reduces the function of wetland floodwater storage and results in greater evaporative losses (Tsai et al. 2007). As wetlands shrink in size and water storage becomes more temporary, they become more vulnerable to agricultural conversion (L. Smith, Oklahoma State University, pers. comm.*)*.

Culturally Accelerated Sediment Effects

- **Hydrologic Functions**
- **Vegetation**
- **Bio-Geochemical Cycling**
- **Invertebrates**
- **Vertebrates**

Sediment can act like a sponge further altering natural processes in the wetland. Due to the increased amount of interstitial pore space found in unconsolidated sediment, a greater volume of water is held in the sediment. The net result is that smaller precipitation events that formerly would be expressed as ponded water are now stored within the sediment and it takes larger events to actually pond water in the wetland. Many of the wetland wildlife species that use playas rely on ponded water being present, and they will not use the wetland if it only contains saturated soil.

Studies conducted on playa wetlands in Texas found that reduced hydroperiod lengths affect all biotic community functions altering support for biodiversity (Smith 2003). Smith et al. (2011) concluded that the hydrological function of playas is impacted more by sediment than projected climate change scenarios.

Effects on Vegetation

The major plant communities of Nebraska playa wetlands have been summarized by Rolfsmeier and Steinauer (2010; Appendix F). Similarity of dynamic processes and vegetation composition to southern high plains playa and northern prairie pothole wetland systems is noted. Given this similarity, it can be inferred that the body of knowledge from these wetland complexes is largely transferable to the ecology of Nebraska's playa complexes.

Variability in wet/dry cycles is the principal driver for playa plant community development and regeneration. Under natural conditions, plant communities in playa wetlands are dynamic and undergo cyclic changes in response to short- and long-term water-level fluctuations. Haukos and Smith (2003) stated that the vegetation present in a playa at any time is dependent on three factors:

(1) composition of viable seed within the soil capable of germinating,
(2) environmental regimes of previous years that have selected for certain species and their subsequent replenishment in the seed bank, and
(3) environmental conditions of the current growing season that regulates germination and seedling growth from the seed bank (Haukos and Smith1993).

The ability of species to persist in these environments is based on the ecology of seed banks. The seed bank includes all viable seeds present on, or in, the soil or associated litter. In general, seeds of species forming seed banks must be viable for long periods of time until conditions are favorable for germination (Murdoch and Ellis 1992). Species have distinct requirements for breaking dormancy.

Alternating flooding and drying cycles are required for many species to emerge. For example, many hydrophytes emerge immediately after flooding, whereas some plants emerge during drawdown conditions or when the water table drops below the soil surface (Cronk and Fennessy 2001).

Emergence from soil propagule banks often is the single most important colonization process affecting isolated wetlands with contrasting wet and dry phases (Leibowitz 2003, Tiner 2003). Optimal germination conditions for some species may be stressful conditions for others, and this trade-off can determine the structure of the emerged community. The emerged community represents a subset of the total individuals present in the seed bank, and its compositional or structural elements can differ seasonally because of the high variability of the disturbance regimes and life history traits. In response to this variability, species represented in the seed bank of playas have evolved mixed strategies of differential temporal emergence (Haukos and Smith 2001). The majority of plant species persisting in playas are represented by ecotypes capable of responding to this disturbance regime through rapid germination, growth, and reproduction. The interplay of hydroperiod, seed banks, and species life history traits related to germination ultimately determines natural successional cycles within playas.

The previous section discusses the influences of culturally accelerated sedimentation on playa hydrologic functions. Most prairie wetlands are embedded in agricultural landscapes and tillage of their watershed facilitates increased surface runoff and sediment inputs relative to a grassland condition. The loss of wetland volume, modification of the hydroperiod as compared to natural dynamics, decreased recharge potential on the playa floor, increased recharge at the playa edge, and increased evaporation due to shallower depths were noted. All of these alterations are largely attributable to sediment influxes from cultivated watersheds that will negatively influence characteristic hydrologic functions and subsequent vegetation dynamics.

The re-colonization of vegetation is dependent on viable seed banks; therefore, the covering of seed banks with sediment has the potential to impede the process (Jurik et al. 1994). Gleason et al. (2003) showed that excessive sediment loading associated with intensive agricultural activities altered the species richness and abundance of plants (and invertebrates) that emerged from the sediment of wetlands of the prairie pothole region. Jurik et al. (1994) and Wang et al. (1994) demonstrated that sediment depths of as little as a tenth of an inch can significantly reduce species richness, emergence, and germination of wetland macrophytes. Jurik et al. (1994) also found that the greatest decreases in germination occurred for species with the smallest seeds. Although, these studies demonstrated the relationship between sedimentation and germination, the causative agent that inhibits germination or survival is poorly understood. For example, covering of seeds with varying depths of sediment may alter light and/or redox conditions that inhibit seed germination, or the sediment may create a physical barrier to emergence.

Figure 20. *A Rainwater Basin impaired by a dense, monotypic stand of reed canary grass.* *Source: Ted LaGrange (NGPC)*

Effects of sedimentation on seed banks may be translated into large effects on the vegetation in wetlands. Anthropogenic influences modifying hydrologic functions and sediment transport dynamics toward a more "stable" environment will result in decreased species diversity as the seed banks of species requiring differing environmental conditions are unable to replenish themselves (Haukos and Smith 1994, 1997). Additionally, the loss of wetland volume from accelerated sedimentation makes wetlands shallower, allowing for monoculture stands of cattails and other invasive plants to persist. In some wetlands, a stabilized environment can result in the replacement of native species by invasive or exotic species (Brock and Casanova 1997). Smith and Haukos (2002) documented species-area relationships and the impact of watershed land use on playa flora throughout the Southern High Plains, concluding that cultivation of surrounding watersheds corresponded to an increase of annuals and exotic species in playas.

The density and abundance of both reed canary grass and river bulrush are observed to increase in response to sedimentation, likely due to changes in hydroperiod, and the presence of a moist and nutrient enriched rooting zone (Figure 20). Such stands of vegetation diminish biological diversity and overall wetland functions (Stutheit et al. 2004).

Culturally accelerated sedimentation also has the potential to suppress primary production and alter natural food chain interactions. Increased sediment in the water column generally reduces the depth of the photic zone and hence reduces the light available for primary production by aquatic macrophytes and algae (Robel 1961; Dieter 1991). As summarized by Melcher and Skagen (2005), excess nutrients entering wetlands can be a significant problem in areas subject to agricultural runoff or other non-point sources (lawn/golf course fertilizers). Nitrogen (N) and phosphorus (P) runoff occurs in dissolved (water soluble) or undissolved forms (bound to sediment or debris).

Both dissolved and undissolved forms of N are easily transported over terrestrial systems to wetlands (Magette et al. 1989). An overabundance of N and P in wetlands promotes excessive primary production, which leads to significant amounts of decomposition and associated anoxia (Sharpley et al. 2001). Algal blooms and the eventual anoxia can significantly alter chemical and community composition within a wetland (Irwin et al. 1996; Rocke and Samuel 1999).

Effects on Bio-Geochemical Cycling

When sediment enters a wetland, the elements and compounds that are attached to the sediment particles also are deposited in the wetland (Martin and Hartman 1987) (Figure 21). Recent research has documented that many emerging contaminants are also transported to aquatic systems by sediment (Kolok 2010). This in turn, affects the capacity of the wetland to sustain bio-geochemical processes over the long-term. Particulates are transported into depressional wetlands from several sources. They include dry deposition and precipitation from the atmosphere and overland flow from adjacent uplands and occasional overflows connecting wetlands during wet periods of high storage (Adomaitus et al. 1967, Grue et al. 1989, Leonard 1988, Winter and Rosenberry 1995, Waite et al. 1992).

Figure 21. *Sediment clouds the water in the cropped (left) portion of this Central Table Playa, the water is clearer in the buffered portion (right).* Source: Ted LaGrange (NGPC)

Atmospheric sources are assumed to account for a relatively small amount of the total quantity of elements, compounds, and particulates that typically impact depressional wetlands. However, in areas of intense agriculture, atmospheric inputs due to aeolian sediment deposition may be significant (Adomaitus et al. 1967, Frankforter 1995). The dominant mechanisms for the input and output of particulates in depressional wetlands are surface sources such as overland flow, surface connections between wetlands during wet periods, and human-made ditches. These sources are a function of wetland basin morphology (e.g., watershed size, slope gradient, and natural or man-made surface connections). Holding all other characteristics constant, larger watersheds have a greater source area from which inputs may come, a greater concentration of overland flows, and hence greater inputs. Similarly, overland flow on steeper slopes is more likely to run off than infiltrate, and thus, will have greater velocity and erosive power. Theoretically, holding other characteristics constant, a doubling of overland flow velocity enables the water to move particulates 64 times larger, allows it to carry 32 times more material in suspension, and increases the erosive power by a factor of four (Brady 1984).

Effects on Invertebrates

Most playa wetland invertebrates feed on microbes and algae, or they are predators that feed on other invertebrates. Because sediment has been shown to alter the bio-geochemical cycling processes in wetlands, reduce detritus, and alter the plant and algae communities, this has indirect effects on the diversity and abundance of wetland invertebrates. In addition, studies have shown a number of direct effects of sediment on wetland invertebrates, including burial of eggs and larvae, clogging filtering apparatuses, and lethality due to the presence of toxic chemicals (e.g., pesticides) in the sediment (Gleason and Euliss 1998, Gleason 2001).

Effects on Vertebrates

The effects of sediment on most vertebrates are generally in direct response to the impacts that sediment has on their habitat (due to changes in hydroperiod and vegetation structure) and to their food web (due to changes in the vegetation and invertebrate communities). Playas are of international significance as habitat for migrating waterfowl (North American Waterfowl Management Plan 2004) and shorebirds (Brown et al. 2001). These birds are responding to the abundant food resources (invertebrates, seeds, and tubers) that playas can provide (Bishop and Vrtiska 2008). As mentioned earlier in this section, sediment can greatly alter the plant and invertebrate communities in playas and this will have an impact on water bird use.

Figure 22. *Ponded water in playas provides vital habitat for numerous species of waterfowl.*
Source: NEBRASKAland magazine

Most water birds, including waterfowl and shorebirds, that use playa wetlands respond positively to ponded water (Figure 22). If water is trapped in sediment and the soil is saturated with no ponding, there is very limited use by water birds (Brennan 2006). However, when the water is ponded, even if it is only a few inches deep, there is high use by water birds (Brennan 2006, Webb et al. 2010, Joel Jorgensen, Nongame Bird Program Manager, Nebraska Game and Parks Commission, *Pers. Comm.*). Playas with shorter hydroperiods due to accumulated sediment were also found to have lower avian diversity than those with longer hydroperiods (Tsai et al. 2007).

Sediment also affects water bird use by reducing the diversity of water depths in a wetland and by contributing to the formation of dense, monotypic stands of vegetation. Water bird abundance and diversity has been shown to be higher in playas with a diversity of depths and an interspersion of water and vegetation (Webb et al. 2010).

Muskrats are often viewed as a "keystone" species in some types of prairie wetlands where their foraging creates a diverse vegetation structure and their huts and feeding areas provide bird nesting and loafing sites. Although water depths often limit muskrat presence in most playas, historically muskrats were common in the Rainwater Basin where water depths tended to be greater. A limiting factor to muskrat survival is over-wintering water depths (Errington 1961). If the depth is shallow, the water freezes to the bottom and muskrats do not survive the winter. Many people who have lived or worked in the Rainwater Basin over a long period of time have commented that muskrats used to be much more abundant. Although muskrat populations are cyclic, and memories are not always reliable, it may be that over time some of the deeper wetlands have become shallow enough due to sedimentation that they no longer are able to over-winter muskrats. A winter water depth variance of only a few inches can mean the difference between survival and death for muskrats (Errington 1961). The potential effect of sediment on muskrats is supported by observations that muskrats have quickly re-colonized wetlands where sediment has been removed, thus increasing water depth.

A Central Table Playa where both the watershed and wetland are tilled, showing the effects of recent culturally accelerated sediment.

Source: Ben Wheeler (Pheasants Forever/ Nebraska Natural Legacy Project)

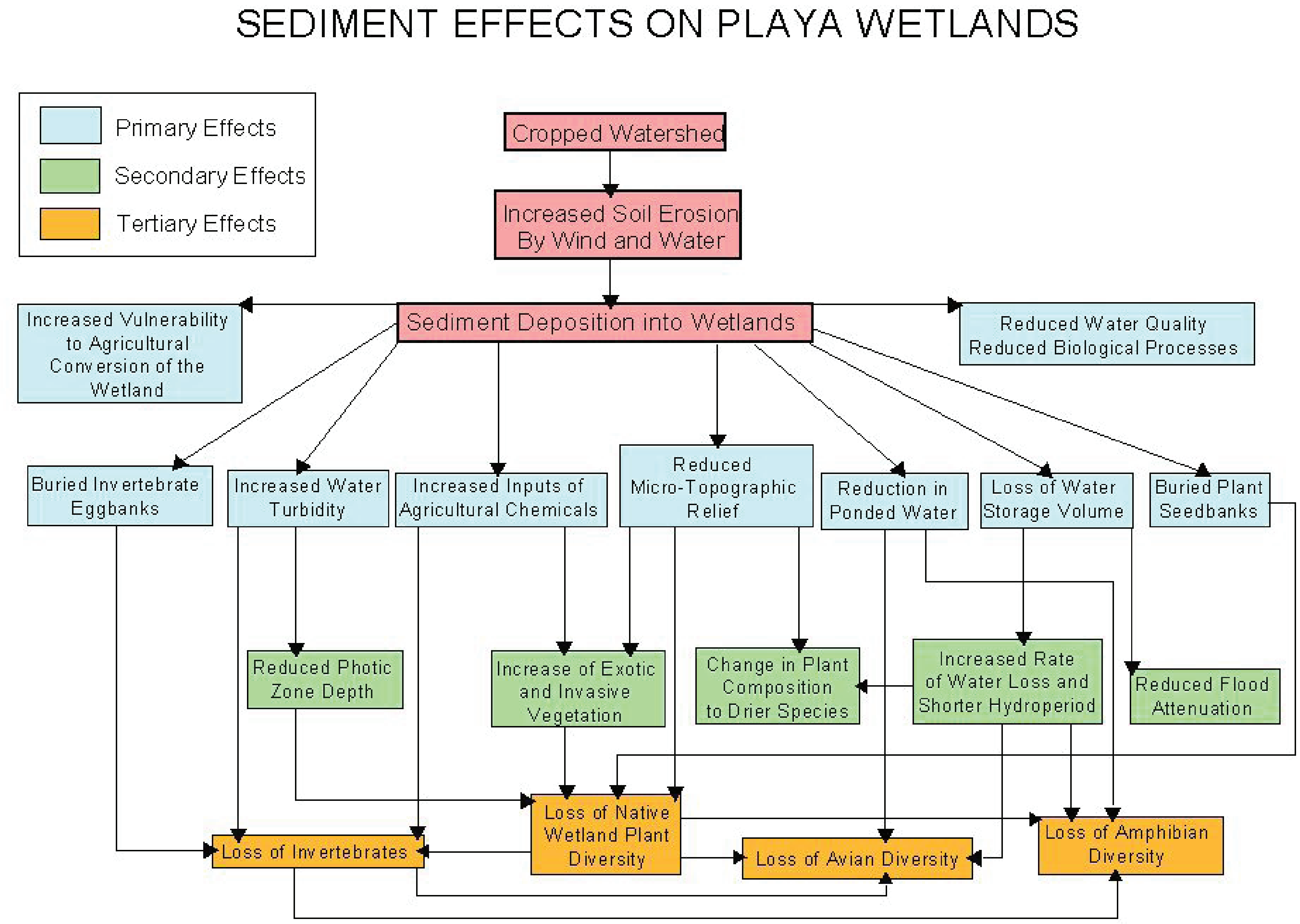


Figure 23. *Effects of culturally accelerated sediment on playa wetlands.*

Relative to biodiversity provisioning, reproduction and early development of amphibians are intimately linked to playas (Smith et al. 2011). Most of the studies conducted on the effects of sediment on amphibian populations have occurred on playas in the Southern High Plains. For example, one study documented that sedimentation in playas altered amphibian community dynamics and body size (Gray and Smith 2005). Other studies have found that the relative density of spadefoot toad metamorphs was found to be greater in cropland playas, while the density of tiger salamanders was lower in the same playas when compared to playas with native grassland watersheds (Gray et al. 2004a, Ghioca and Smith 2008, Ghioca-Robrecht and Smith 2008).

Because salamanders are a top predator in the system, their absence alters the entire trophic structure of playas (Ghioca-Robrecht et al. 2009). Body size and immune functions of amphibians in cropland playas are typically less than those of grassland playas (Gray and Smith 2005, McMurry et al. 2009).

Restoration of Playas Containing Culturally Accelerated Sediment

Excessive inputs of sediment into wetlands can have severe consequences for the entire system. Sedimentation can negatively impact nearly every function a wetland performs, decreasing its resiliency, value as wildlife habitat, and benefits to society as a whole.

Figure 24. *Sediment removal from a Rainwater Basin helps restore the full suite of wetland functions.*
Source: Randy Stutheit (NGPC)

Sediment removal (Figure 24) is one of the primary tools available to help restore the full suite of playa wetland functions because all functions are related to hydrological conditions. Sediment removal also allows for supplementing water (e.g., by pumping) into a playa when needed without impacting neighboring landowners. This is because the volume of sediment removed frees up storage volume for additional water. Tools other than sediment removal, for example vegetation management or pumping, may be used to offset some of the negative effects of sediment. However, it is beyond the scope of this document to fully evaluate the pros and cons of the decisions to apply these various tools. There are methods available to assist with evaluating the benefits of each potential decision, such as Structured Decision Making or Adaptive Resource Management (Lyons et al. 2008, Knutson et al. 2010), and these methods should be considered in helping to make restoration decisions.

Sediment removal alone is often not enough to fully restore and maintain playa wetlands. Many playas are impacted by hydrological alterations both within the wetland and the watershed. Ideally, all hydrological impairments should be addressed to fully restore a wetland. In addition, once a wetland is restored, management actions still are needed to simulate the natural disturbances and control exotic species. These management techniques could include grazing, fire, shredding, herbicide application, disking/rototilling, water level manipulation, and woody plant removal (LaGrange and Stutheit 2011).

To be most effective and efficient in the use of conservation funding, wetlands should be prioritized to determine where the functional gain through restoration will be the greatest. As an example, the Rainwater Basin Joint Venture has given a priority score to each Rainwater Basin wetland footprint based on the wetland's importance to migrating waterfowl (Bishop 2008). In addition, the Rainwater Basin Joint Venture is in the process of developing a restorable wetland index for each basin. Combining these decision support tools will be very helpful in determining when and where to do restorations, including the removal of culturally accelerated sediment.

The methods described below can be used to assess culturally accelerated sedimentation. Then, if the decision is made to remove the sediment, we believe that the following guidance will help to achieve positive, long-lasting results.

Assessment of Sedimentation

An assessment of past and present sedimentation and its impacts on wetland functions is necessary for proposed restorations. Evidence of culturally accelerated sedimentation should be addressed both within the wetland watershed and the wetland footprint. Minimally, the assessment should include estimates of the original wetland area, depth of sediment or depth to Bt, and the resultant loss of surface water storage volume.

Within the Watershed

Methods

Review the soil mapping units and the landscape that "surround" the wetland to determine:

- Are the surrounding areas cultivated, or do they have a history of cultivation? A conclusion common to many studies is that wetlands in agricultural landscapes have shorter topographical lives than wetlands in grassland landscapes because they are often dramatically altered by sedimentation.
- Are the surrounding upland soil map units designated with an erosional phase? If so, it is quite likely the wetland area has had a major influx of sediment over time.
- Are the surrounding upland units designated as highly erodible land (steeper or sandy soils susceptible to erosion) that has been farmed for many years? Sediment may be "modeled" using an erosion prediction model, such as RUSLE (Renard et al. 1997). Evaluation of historic erosion/sedimentation from water can be conducted using RUSLE2; go to http://www.ars.usda.gov/research/docs.htm?docid=6010. Caution needs to be taken when using any predictive approach because sedimentation rates are dependent upon land use over time. For example, a wetland where the watershed is in best management practices or seeded back to native vegetation may not appear to be receiving much sediment today, but historically, it may have received large quantities of sediment (Gleason 2001).
- Are the upland soils upwind (in the prevailing direction) susceptible to erosion by wind (sandy loams, loamy sands, sands, or highly calcareous soils) and have been farmed for many years? For example, sandy soils to the northwest of depressional areas can contribute significant sediment via wind deposition, especially on the windward side of the depression. Evaluation of historic erosion/sedimentation from wind can be predicted by WEPS; go to http://www.weru.ksu.edu/nrcs/wepsnrcs.html.

Within the Wetland

Evaluation of the amount of sediment in a wetland that was recently or is presently being farmed is very difficult due to the mixing of the upper layers of soil via normal tillage operations. Even natural processes of soil mixing such as hoof action by cattle, drought, freeze/thaw cycles, and burrowing by earthworms, crayfish, and other animals can make a precise evaluation of sediment difficult to achieve. Therefore, surrogate measures must frequently be used to determine the amount of sedimentation that has occurred.

Figure 25. *It is important to have a soil scientist evaluate the wetland for evidence of culturally accelerated sediment.*
Source: Ted LaGrange (NGPC)

Luo et al. (1997) and Hammer (see *A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Rainwater Basin Depressional Wetlands in Nebraska* [*Stutheit et al. 2004*]) used the depth to the Bt layer in playas as an indicator to measure sedimentation. Others have used the thickness of the A-horizon in prairie pothole wetland soils as a measure of sedimentation (Gilbert et al. 2006).

Methods

- Investigate soil profiles (Figure 25) for evidence of sedimentation (e.g., buried A horizon, thickness of A horizons/depth to Bt horizon, buried plant materials, lighter colored or different textured overburden, calcareous overwash, and elevated phosphorus levels).
- Determine the historic water regime of the wetland (using soils as indicators of water regime, water budgets, and watershed/basin ratios).
- Determine if sedimentation has changed the historic water storage capacity of the wetland (survey cross sections of present surface versus pre-sediment surface).
- Evaluate if it will it be necessary to remove sediment to restore appropriate hydroperiod and wetland plant communities.
- Determine if sediment, in conjunction with drainage and cultivation (Weinhold and van der Valk 1988), has effectively depleted the seed bank so that active re-vegetation is necessary to restore desired native plant communities.
- Evaluate if any loss of water storage and increase in nutrients due to sedimentation result in undesirable mono-dominant stands of vegetation (e.g., cattail, reed canary grass).

Using Rainwater Basin wetland soils as an example, the primary hydric soils are Fillmore (temporary zone), Scott (seasonal zone), and Massie (semi-permanent zone). For example, a typical pedon of Fillmore soil historically had 6-15 inches of silt loam in the A horizons. Therefore, a survey of a Fillmore soil that finds an A horizon exceeding this historic range could potentially indicate the presence of sediment and removal of the material would not be detrimental to the wetland. Likewise, a typical pedon of Scott soils historically had 5-12 inches of A horizon overlying the Bt. Removal of excess material that is potentially sediment would not be detrimental to these soils.

Restoration of the Historic Wetland Profile

Because sediment is the primary threat to playa hydrologic functions, two practices, sediment removal and establishment of buffers or re-vegetating watersheds with native grasses, show the most promise for restoring ecosystem function and related services (Smith et al. 2011). If culturally accelerated sediment is present in the playa, then methods to restore the wetland need to be evaluated within the context of economics and their post-restoration potential to provide targeted functions.

Once it has been determined that the existing wetland profile does not reflect historic volumes and the decision has been made to take action to rectify the situation, many functions can be re-established by removing the culturally accelerated sediment (Figure 26). Ideally, the source(s) of sediment should also be addressed.

Sediment Excavation

Advantages:

- Re-establishes the historic water storage capacity and "foot print" of the wetland.
- May expose historic seed bank and reduce need for active re-vegetation.
- Removes nutrient/contaminant laden topsoil.
- Removes some invasive plant species (e.g., reed canary grass) and their seed bank.
- Restores the entire suite of functions by re-establishing the natural condition.

Disadvantages:

- Initial costs may be more expensive than installing structural measures.
- Over-excavation can have negative consequences for wildlife and biogeochemical functions by creating steep sided, open water wetlands.

Figure 26. *Twelve inch "cut" of sediment from the wetland on the Deepwell WMA before final shaping.* Source: NGPC

Excavated sediment should be disposed of in suitable upland areas or placed in tail-water recovery pits in the wetland. Caution needs to be taken not to over-excavate material to the point where the Bt soil horizon is breeched. Generally, this becomes more of a concern the farther west you go in Nebraska due to "thinner" Bt horizons in the hydric soils. Some A horizon should be maintained so as to most closely maintain the soil profile in a reference or near reference standard condition. However, concerns have been raised about the removal of the soil and the potential to create a more sterile environment for the growth of hydrophytes. While this is a concern when removing material covering sand or bedrock, it is less of a concern when the sediment removed is over a mineral soil. To date, there has been no evidence that wetlands have been made "sterile" due to sediment removal.

A study completed by the University of Nebraska-Lincoln examined the effects on vegetative communities by sediment removal in Rainwater Basin wetlands compared to grazing (Heidi Hillhouse, University of Nebraska- Lincoln, *Pers. Comm.*). Preliminary results indicated that a desirable plant community quickly recovered after sediment removal. In 2008 and 2009, a study was conducted of 36 Rainwater Basin playas to measure the plant and animal community response to sediment removal and compared it to reference wetlands and wetlands in an agricultural setting without sediment removal (Ben Beas, Oklahoma State University, *Pers. Comm.*). Preliminary results from this study indicate that a desirable plant community becomes established in wetlands where sediment has been removed. Although completed in a different wetland system, a recent study of wetland restoration along the Platte River found that the above ground plant biomass, bulk density, microbial activity, and soil organic matter recovered within 10 years after sediment was excavated (Meyer et al. 2008).

Shorebird and waterfowl surveys have been conducted on Rainwater Basin wetlands where sediment was removed (Figure 27). Joel Jorgensen, Nongame Bird Program Manager, Nebraska Game and Parks Commission provided the following comments —

"The results I have seen indicate that aggressive sediment removal is tremendously beneficial to the overall avian community. One example is Sandpiper WMA. Prior to sediment removal this wetland did not provide even minimal habitat to birds and was rarely worth viewing, but it still was visited when conducting bird surveys. Post-sediment removal, this site has been, every spring since, a premier wetland for migratory shorebirds and other waterbirds. In the spring of 2006, when we were trapping and color banding shorebirds, our highly-experienced field assistant essentially camped out at Sandpiper late April into May because there were 2,000-3,000 shorebirds present daily and high turnover based on species composition and banded birds. Even though conditions were dry and only a handful of wetlands had water, no other site matched the density of shorebirds that Sandpiper WMA had. I am unable to explain the mechanism.

However, Sandpiper WMA is not an anomaly, but it is typical of bird response at wetlands following sediment removal. Sediment was removed from Renquist, North Lake Basin, Straightwater, Spikerush, Deep Well, and Bulrush WMAs. Many of these sites received limited bird use before sediment removal but now are among sites that consistently harbor the largest numbers and diversity of birds through the year. They also have water more often and more consistently because the hydrologic functions are no longer compromised. Again, for instance, in 2010 the breeding bird community at Spikerush WMA was remarkable (Black necked Stilt, several Pied-billed Grebes, Sora, American Coot) for the modern Rainwater Basin and there were lots of late-summer and fall migrant shorebirds using this site. This, to me, indicates a much healthier wetland than what was formerly present. Renquist is now a highly productive shorebird site when in previous years you would have had a hard time finding a Killdeer. The response of the overall bird community where sediment has been removed has been profoundly positive and overwhelming obvious."

Figure 27. *Shorebirds feeding in a Rainwater Basin (North Lake Basin WMA) after sediment was removed.* *Source: Joel Jorgensen (NGPC)*

Mark Vrtiska, Waterfowl Program Manager, Nebraska Game and Parks Commission, provided the following comments —

"Unfortunately, we've done a poor job of documenting the effects of sediment removal in Rainwater Basin wetlands and waterfowl response or use. However, we did one survey at Greenhead WMA in Clay County, where in late September – when there were waterfowl in other basins, - a few of us went out into the marsh and ran transects, just to document waterfowl and other bird use in that wetland prior to sediment removal. The wetland was choked with cattail and bulrush, and it was incredibly difficult walking through it and trying to stay on some sort of transect. All we found using the wetland were red-wing and yellow-headed blackbirds, and a few marsh wrens. After sediment removal, this site was and has been heavily used by waterfowl in both spring and fall, including a trumpeter swan during one spring. That generally has been the case for other wetlands where sediment has been removed. The change in hydrologic functions and plant communities really attracts ducks. I don't know if other management techniques would have had the same effect or for the same duration. One year, Marsh Hawk WMA near Grafton was aerially sprayed, which killed areas of cattail and bulrush and there was an increase in duck use on that marsh.

However, the next year, the areas had grown back in and waterfowl use declined. Again, there are other techniques that may work, but definitely the sites receiving sediment removal had limited bird use prior to the removal, but afterwards, they seem to consistently have lots of waterfowl using them. Also, it has increased or improved waterfowl hunter access to these marshes, which helps spread out the hunting pressure and makes for a better experience. I think sediment removal is an important component that is overlooked, particularly since the duck hunters have been the primary contributors to purchasing these areas."

Reduce Sediment Inputs

The watersheds of wetlands should be evaluated to determine the rate and source of sediment inputs. Then, practices can be implemented to reduce erosion from cropland and the sedimentation of wetlands. Ideally, depressional wetlands in agricultural settings should not be restored without addressing sediment inputs. Vegetative buffer strips are frequently used and have been shown to be effective at reducing nonpoint source pollutants, including sediment, from adjacent habitats (Castelle et al. 1992). The semi-arid Great Plains undergoes long periods of drought followed by long periods of abundant rainfall. These wet/dry cycles can persist for 10-20 years (Duvick and Blasing 1981, Karl and Riebsame 1984). During periods of severe drought, most wetlands go dry during summer and many remain dry throughout drought years. Buffer strips established to protect wetlands during a dry cycle might become submerged and ineffective in reducing sediment input in wetlands during the wet cycle (Gleason 1996). Establishing permanent vegetative cover in the watershed of a depressional wetland is the best practice for reducing sedimentation rates.

Methods

- Establish a perennially vegetated buffer of a minimum 100-foot width, the wider the better. Locally adapted, native plant species should be used as appropriate. However, the buffer needs to be designed and managed in a way that still allows overland flow to reach the wetland (e.g., reduced seeding rates).
- Consider broad, climatic shifts and maximum/minimum pool depths when establishing buffer areas in semi-arid climates.
- Establish perennial cover on adjacent uplands or implement soil conservation practices on adjacent agricultural lands. RUSLE can be used to identify areas in the watershed that contribute the most sediment and these should be targeted for conservation measures.
- Convert adjacent flood irrigated fields to sprinkler type irrigation. At a minimum, do not run irrigation rows up and down hill into basins without some sort of sediment trapping mechanism.
- Use silt-trapping fences on contours of slopes and check dams in concentrated flow areas when construction activities are occurring.

Research Needs

Although sedimentation has been studied extensively in prairie wetlands, including playas, there is a need for additional research to better protect, manage, and restore playas (Figure 28). There is uncertainty about the current rate of sediment deposition into playas compared to historical rates. It would be helpful to quantify current sediment inputs and the source of those inputs from a variety of landscapes. It would also be helpful to have a better understanding about the rates of past sedimentation and to try and correlate that to past climatic events and watershed land uses.

Groundwater recharge is an important function of playas (Gurdak and Roe 2009); however, it is unclear what effect sediment may have on this function. Current research being conducted by the University of Nebraska-Lincoln may help to address this issue (F.E. Harvey, UNL, *Pers. Comm.*), but more research likely will be needed to fully understand the effects of sediment on recharge. The effect of sediment, and the associated altered plant community, on evapo-transpiration rates in wetlands is a related area where additional research would be helpful to better understand the overall water budget for playas.

Concern has been expressed about the effects, especially to hydroperiod, that sediment removal from a portion of a playa may have on the remainder of the playa where sediment has not been removed. Quantifying this effect, including measuring how much water is displaced by sediment versus water held in the interstitial soil pore spaces, would help to better inform policy decisions such as Swampbuster "3rd party" conversion determinations.

The following list represents some of the research needs that would help answer questions regarding sediment in playa wetlands and its effects on various functions. Additional research needs will undoubtedly be identified as this issue continues to be debated and other unknowns are acknowledged:

Figure 28. *Graduate Student Ben Beas (OSU) researching the impacts of sediment on wetland vegetation in the Rainwater Basin.*
Source: Loren Smith (OSU)

- Can the age of the sediment be determined?
- What are the current rates of sedimentation compared to the historic rates?
- What are the effects of sediment on wetland evapo-transpiration?
- What is the role of sediment on recharge?
- How much water is displaced by sediment vs. water held in the interstitial soil pore spaces?
- What are the effects of sediment on invertebrates?

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Appendix A

Landowner Comments Recorded During M.S. McMurtrey Breeding Waterfowl Habitat Survey, 1959-1965 (McMurtrey et al. 1972).

County Name	County Code	Wetland Code	Legal Description	Public Area Name	Silt/Sediment Comments
Adams	1	5	SW1/4 23-6-11		Basin has silted in where it floods into crops.
Adams	1	9	S1/2 33-11-9	Ayr Lake WMA	Depth has been reduced by 1/2 from silting.
Butler	12	9	NW1/4 29-14-1		Drainage ditch has been silted full for many years and Mr. Nikl says would be trouble with some landowners if an attempt was made to open ditch.
Butler	12	17	SW1/4 34-15-1		Silting has reduced original waterfowl value. Erosion from the cultivated watershed has not only reduced the depth, but also the original size.
Clay	18	11	SW1/4 16-6-6	Harms WPA	If slopes around basin were grass, would help stop silting and make area more attractive to waterfowl. Over the past 50 years, due to silting, has lost 25% of water holding capacity.
Clay	18	21	SE1/4 19-6-6		The potential of this basin is being rapidly reduced by silting.
Clay	18	22	S1/2 30-5-6	Bluewing WMA	A good large basin. If took over would be necessary to get enough land to protect from silt coming in due to farming on north side down to shoreline.
Clay	18	24	30-6-6		Marsh has 2 blinds on it and is supposed to furnish good hunting. My inspection does not support this. Farming has caused a lot of silting which makes the water quite muddy. Basin sits down in a bowl. Due to farming to shoreline and on the slopes the silt has deposited pretty well over the entire basin.
Clay	18	25*	N1/2 30-6-6		Farming operations to shoreline cause too much silting.
Clay	18	117	SE1/4 24-6-7		Water cloudy, heavy load of silt.
Fillmore	30	68*	W1/2 31-8-3		50 acres in SW1/4 drained and silted in - farmed.
Fillmore	30	106	NE1/4 7-6-2		A small basin that was once an excellent production area. Due to farming, silting in has been the most damaging.
Fillmore	30	107	NW1/4 8-6-2		Due to farming operation the depth of basin has been reduced from silt washing into basin.
Franklin	31	4	5-3-15	Ritterbush WPA	Mrs. Ritterbush said they had boated across section to the south line and all the youngsters in the neighborhood came to swim and skate. The water is not as deep due to silting from farming.
Gosper	37	5*	NE1/4 36-7-21		Mr. Maaske says he remembers when the water was much deeper. He believes silting from farming has reduced depth.
Gosper	37	7*	SW1/4 20-7-21		Mrs. Hock says they drained it because their milk cows would get mud on their teats and bags. Since then they have quit milking. She said when she was a girl they boated on basin.
Gosper	37	10	12-7-21	Victor Lakes WPA	160-acre marsh that has silted considerably. Sixty years back generally held water year round.
Gosper	37	13*	SW1/4 5-7-22		Farming to shoreline has caused a lot of silting in low area.
Gosper	37	14	NE1/4 17-7-22		Has silted in some from the farmland.
Gosper	37	19	15-8-22		Farming on the slopes has caused heavy rains to bring heavy loads of silt into basin.
Hall	40	11	NW1/4 36-10-9		Over the past 100 years this basin has lost much of the original depth from silting. Mark said his father told of using a sailboat on the basin.

Hamilton	41	12*	SW1/4 32-10-8		I was told in the early days this little basin held water year round. There is about two feet of silt in the basin at this time.
Hamilton	41	15*	E1/2 12-10-8		Mr. Stahlnecker says 50 years ago the basin held water year round. He says the depth has dropped to around one foot due to heavy silting from cultivated fields.
Hamilton	41	17	N1/2 3-11-5		Area in SE 1/4 of Sec 34 has about 1 foot of silt deposited over bottom.
Hamilton	41	20	NE1/4 21-10-8		Has a small drainage that could be plugged with a little work with a power shovel. Plugged with silt at present time.
Kearney	50	12	N1/2 30-5-15	Clark WPA	Says during the dust storm days about a foot of silt was deposited in the basin.
Kearney	50	14	SE1/4 16-5-13	Youngson WPA	Mr. Hansen said the basin in 1903 was 6 feet deep and early years they used motorboats. Silting caused by farming has been a big factor in cutting down the depth. Also, six inches to 1 foot of soil was moved in by wind in 1930's.
Kearney	50	18*	32-5-16		Early days an excellent basin. Farming and silting has partially destroyed this basin.
Nuckolls	65	2	NE1/4 8-4-6	Smartweed Marsh WMA	Would be hard to drain but received a silt load from farming the watershed.
Phelps	69	3	SW1/4 34-5-19		Is fairly shallow due to silting from farming operation.
Phelps	69	4	NW1/4 34-5-19		Due to so much silting, would take considerable development. I would doubt advisability of trying to do anything with this basin at this late date.
Phelps	69	6	21-5-19	Atlanta WPA	A large basin that was 10 feet deep 50 years ago. Has silted in more than 1/2. Most of silt coming from 6 miles of drainage starting near Loomis.
Polk	72	20*	E1/2 26-13-2		Mr. Strem said in the early days before so much farming causing silting, in the wet years there was some production in the deep portion that was leveled.
Saline	76	5*	N1/2 13-8-1		This is a flat basin that has silted in.
York	93	1	25-10-4	Kirkpatrick Basin So. WMA	Tile drainage attempted several years ago. System plugged with silt. Drainage improbable for present only.
York	93	8	S1/2 11-10-3		Area disappearing due to attempts at leveling and silting.
York	93	13*	SE1/4 31-10-4		Mr. P.C. Friesen saw area in early 1890's. He told me the entire Sec 31 was a basin and under water. When he was a boy they used a boat on the area.
York	93	34	SE1/4 28-9-2		The shallow part has heavy stand of smartweed- surrounded by cultivated fields it will gradually fill with silt and become just a wet area.

* These wetlands may no longer exist.

Appendix B

Depth to claypan and land use of depressional soils in early soil surveys in Nebraska.

County	Year printed	Playa Complex Region	Soil Name	Depth to Claypan	Land Use	Notes
Adams	1923	Rainwater Basin	Fillmore silt loam	6 to 15 inches	better drained areas are included in cultivated fields. Greater part of the soil used for hayland or pasture.	"gray layer" (E horizon) described
Adams	1923	Rainwater Basin	Scott silt loam	1 to 12 inches	pasture and waste	"gray layer" (E horizon) described
Banner	1921	Southwest Playas	Scott Silt Loam	6 to 8 inches	pasture and hayland	no "gray layer" described; effervesces in HCl
Buffalo	1924	Central Table Playas	Scott Silt Loam	10 to 12 inches	pasture, waste	"gray layer" (E horizon) described
Burt	1922	Todd Valley	No depression soils described			
Butler	1929	Rainwater Basin	Butler silt loam	4 to 14 inches	pasture and hayland	"gray layer" in more poorly drained areas
Butler	1929	Rainwater Basin	Scott Silt Loam	5 to 11 inches	pasture, hayland and waste	A: 3 to 6 inches thick; E: 2 to 5 inches thick
Chase	1917	Southwest Playas	Scott silty clay	0 inches	pasture and hayland	Profile is clay throughout and "compact" in surface soil. No E horizon stated.
Cheyenne	1918	Southwest Playas	Scott silt loam	6 to 8 inches	pasture and hayland	no "gray layer" described; effervesces in HCl
Clay	1927	Rainwater Basin	Fillmore silt loam	6 to 14 inches	40% cultivated	"gray layer" (E horizon) described
Clay	1927	Rainwater Basin	Scott Silt Loam	8 to 12 inches	pasture and hayland-some waste	"gray layer" (E horizon) described
Colfax	1930	Todd Valley	No depression soils described			
Cuming	1922	Todd Valley	No depression soils described			
Custer	1926	Central Table Playas	Scott silty clay loam	8 inches	pasture, waste	variable depth of topsoil stated, but no range given
Dawson	1922	Central Table Playas	Scott silty clay loam	8 to 12 inches	waste, pasture	"gray layer" (E horizon) described
Deuel	1921	Southwest Playas	Scott silty clay	0 inches	pasture and hayland	Profile is clay throughout and "compact" in surface soil. No E horizon stated. Surface is silty clay loam in loess areas
Dodge	1916	Todd Valley	Scott silt loam	less than 36 inches	nearly all cultivated	Includes non-claypan soils; typical profile is 30 inches to claypan

Dundy	1931	Southwest Playas	Scott silt loam	8 to 9 inches	pasture, hayland, waste	“gray layer “ (E horizon) described
Fillmore	1918	Rainwater Basin	Scott silty clay loam	1 to 4 inches	35% drained and cultivated; the rest is pasture and hayland	No “gray layer” (E horizon) described
Fillmore	1918	Rainwater Basin	Scott Silt Loam	7 to 25 inches	20% under cultivation	“gray layer “ (E horizon) described
Franklin	1926	Rainwater Basin	Fillmore silty clay loam	6 to 14 inches	pasture and hayland-some waste	“gray layer “ (E horizon) described
Frontier	1935	Southwest Playas	Butler silty clay loam	12 inches	35% drained and cultivated; rest waste	E horizon described. variable depth of topsoil stated, but no range given
Garden	1924	Southwest Playas	Scott silty clay	0 inches	pasture and hayland	Profile is clay throughout and “compact” in surface soil. No E horizon stated.
Gosper	1934	Rainwater Basin	Butler silt loam	11 to 14 inches	45% cultivated	“gray layer “ (E horizon) described
Gosper	1934	Rainwater Basin	Scott Silt Loam	4 to 10 inches	waste, pasture	“gray layer “ (E horizon) described
Hall	1916	Rainwater Basin	Scott silt loam	6 to 12 inches	hay and pasture	“gray layer “ (E horizon) described
Hamilton	1927	Rainwater Basin	Fillmore silt loam	6 to 14 inches	about half is cultivated	“gray layer “ (E horizon) described
Hamilton	1927	Rainwater Basin	Scott silty clay loam	6 to 14 inches	pasture and hayland	“topsoil closely resembles Fillmore”
Harlan	1930	Rainwater Basin	Butler silt loam	7 to 10 inches	75% under cultivation	“gray layer “ (E horizon) described
Harlan	1930	Rainwater Basin	Scott silty clay loam	5 to 6 inches	pasture, waste	“gray layer “ (E horizon) described
Hayes	1934	Southwest Playas	Scott silt loam	1 to 8 inches	pastures, waste	“gray layer “ (E horizon) described
Hayes	1934	Southwest Playas	Scott very fine sandy loam	8 to 12 inches	50%pasture;50% crop	“gray layer” (E horizon) described
Hitchcock	1930	Southwest Playas	Scott silty clay loam	5 or 6 inches	pasture, waste	“gray layer” (E horizon) described
Jefferson	1925	Rainwater Basin	No depression soils described			
Kearney	1927	Rainwater Basin	Scott silt loam	10 to 12 inches	Pasture; smaller depressions may be cropped with surrounding soils.	some clay surfaces in western part of county; where this occurs the gray layer is very thin and the hardpan is at 10 inches.
Keith	1926	Southwest Playas	Scott silt loam	18 inches	pasture, hayland, waste	No “gray layer” described; variable depth of topsoil stated, but no range given; depth to claypan not clear in description.

Kimball	1916	Southwest Playas	Scott silt loam, calcareous phase	4 to 8 inches	native grass	no “gray layer” described; effervesces in HCl
Lincoln	1926	Southwest Playas	Scott silt loam	8 inches	cultivated with surrounding soils	variable depth of topsoil stated, but no range given
Logan		Central Table Playas				No early soil survey published.
Madison	1920	Todd Valley	Scott silt loam	6 to 12 inches	pasture	“gray layer ” (E horizon) described
Nuckolls	1925	Rainwater Basin	Fillmore silt loam	6 to 14 inches	pasture and hayland	“gray layer ” (E horizon) described
Nuckolls	1925	Rainwater Basin	Scott silt loam	1 to 15 inches	pasture, waste	“gray layer ” (E horizon) described
Perkins	1921	Southwest Playas	Scott silty clay	0 inches	pasture and hayland	Profile is clay throughout and “compact” in surface soil. No “gray layer” described, includes loam, silt loam, silty clay loam surfaces
Phelps	1919	Rainwater Basin	Scott Clay	Below 12 inches.	Pasture and waste	“hardpan” described as below 12 inches. Profile is described as clay throughout. No “E horizon” described.
Phelps	1919	Rainwater Basin	Wabash silt loam, basin phase	18 to 24 inches	all cultivated	No “gray layer” described; subsoil not described as claypan
Platte	1923	Todd Valley	Scott Silt Loam	6 to 15 inches	Pasture and waste	“gray layer ” (E horizon) described
Polk	1917	Rainwater Basin	Scott silt loam	12 to 22 inches	pasture	A: 8 to 10 inches thick; E: 4 to 12 inches thick
Saline	1928	Rainwater Basin	Fillmore silt loam	less than 12 inches	pasture	“gray layer ” (E horizon) described
Saline	1928	Rainwater Basin	Scott Silt Loam	6 to 8 inches	wasteland	“gray layer ” (E horizon) described
Saunders	1913	Todd Valley	Scott silt loam	24 to 30 inches	pasture and hayland	“gray layer ” (E horizon) described
Seward	1916	Rainwater Basin	Scott silty clay loam	1 to 6 inches	pasture	No “gray layer” described
Seward	1916	Rainwater Basin	Scott silt loam	7 to 28 inches	about half is cultivated	A: 3 to 14 inches thick; E: 4 to 14 inches thick; not confined to depression landscape
Sherman	1931	Central Table Playas	Scott Silt Loam	6 to 8 inches	pasture, waste	“gray layer ” (E horizon) described
Thayer	1927	Rainwater Basin	Scott Silt Loam	6 to 10 inches	pasture, waste	Fillmore soil included in Scott but not correlated

Thurston	1916	Todd Valley	Scott Silt Loam	24 to 30 inches	cultivated	one area - 4 miles NW of Pender. Not on map,
Valley	1932	Central Table Playas	Scott silt loam	6 to 8 inches	pasture, waste	"gray layer" (E horizon) described
Wayne	1917	Todd Valley	Scott Silt Loam	25 to over 40 inches	cultivated	"gray layer" (E horizon) described
Webster	1929	Rainwater Basin	Fillmore silt loam	6 to 14 inches	pasture and hayland-some waste	"gray layer" (E horizon) described
York	1928	Rainwater Basin	Fillmore silt loam	8 to 13 inches	60% cultivated	"gray layer" (E horizon) described
York	1928	Rainwater Basin	Scott Silt Loam	6 to 10 inches	almost 50% cultivated	"gray layer" (E horizon) described

Appendix C

Depth to Bt surveys for Rainwater Basin Wildlife Management Area wetland restoration projects.
All surveys were done by NRCS personnel.

1) Straightwater WMA – Seward County, McMurtrey Wetland Code **(80-4)**
Depth to clay survey - Richard Zink, NRCS, September 1997.
Fillmore Soil – Max: **48** inches, Min: **6** inches, **Average: 17½ inches**
Scott Soil – Max: **36** inches, Min: **12** inches, **Average: 21 inches**
Massie Soil – Max: **26** inches, Min: **12** inches, **Average: 16 inches**
Restoration plan called for removal of 12-24 inches of sediment and fill along with reed canary grass from the wetland west of the County road and 4 inches of sediment and reed canary grass east of the road. A lot of the material in the center of the basin was fill deposited during pit construction. Entire wetland had been planted to reed canary grass under a previous CRP contract. Restoration project completed 11/2002.

2) Sandpiper WMA – Fillmore County, McMurtrey Wetland Code **(30-21)**
Sediment survey - Richard Zink, NRCS, date unknown.
The following numbers were expressed as **Depth of Sediment**.
Massie Soil – Max: **18** inches, Min: **3** inches, **Average: 8 inches**
Restoration plan called for removal of 6-8 inches of sediment from the Massie soil.
Entire soil unit was a dense stand of cattail. Restoration project completed 1/2001.

3) Kirkpatrick Basin South WMA – York County, McMurtrey Wetland Code **(93-1)**
Depth to hydric soils survey (*probably depth to clay*) - Not sure who did this survey, but was probably Richard Zink, NRCS, date unknown.
Fillmore Soil – Max: **32** inches, Min: **6** inches, **Average: 13¾ inches**
Scott Soil – Max: **19** inches, Min: **6** inches, **Average: 12 inches**
Massie Soil – Max: **24** inches, Min: **4** inches, **Average: 9 inches**
Restoration plan called for removal of material (probably fill) to a maximum depth of 12" in the immediate vicinity of the two pits on the west side of the County road and a small area of re-contouring east of the road to fill another small pit. Maximum depth of removal was 6". Restoration project completed 2/2001.

4) Kirkpatrick Basin South WMA (2nd Project) – York County, McMurtrey Wetland Code **(93-1)**
Depth to clay survey - Jim Husbands, NRCS, April 18, 2007
Scott Soil – Max: **18** inches, Min: **6** inches, **Average: 9 inches**
The restoration plan (WRP 10-Year Cost Share Only) was designed to finish restoring the wetland on the west side of the County road. Additional sediment and fill removal (only on the Scott soil), re-contouring, and control of reed canary grass were the main elements of this project. Areas where sediment and fill removal occurred were dominated by reed canary grass. Restoration was completed 7/2009.

5) West Sacramento-Wilcox WMA – Phelps County, McMurtrey Wetland Code **(69-8)**
Sediment survey - Not sure who did this survey, but was likely either Casey Latta or Tyler Labenz, NRCS, date unknown. The following numbers were expressed as **Depth of Sediment**.
Butler Soil – Max: **8** inches, Min: **0** inches, **Average: 4½ inches**
Scott Soil – Max **23** inches, Min: **0** inches, **Average: 11 inches**
Massie Soil – Max **32** inches, Min: **1** inch, **Average: 10 inches**
Restoration plan called for excavation of a maximum of 8" of material from selected areas in order to construct low-level berms and waterways within the wetland and to place fill on top of an area that was "leaking" water. All "sediment removal" was done strictly to generate fill material. Restoration project completed 12/2001.

6) Renquist WMA – York County, McMurtrey Wetland Code **(93-65)**
Sediment survey - Richard Zink, NRCS, date unknown.
The following numbers were expressed as **Depth of Sediment**.
Fillmore Soil – Max: **30** inches, Min: **5** inches, **Average: 18 inches**
Scott Soil – Max: **30** inches, Min: **4** inches, **Average: 16 inches**
Massie Soil – Max: **20** inches, Min: **8** inches, **Average: 15 inches**
Restoration plan called for removal of sediment to a depth of 12" on the Massie soil unit and 6" on the Scott soil. Both soil units were dominated by a dense stand of reed canary grass. Restoration project completed 10/2002.

7) Spikerush WMA – York County, McMurtrey Wetland Code **(93-50)**
Depth to clay survey – NRCS, date unknown.
Butler Soil – 1 sample, **8 inches**
Fillmore Soil – Max: **25** inches, Min: **3** inches, **Average: 10 inches**
Scott Soil – Max: **18** inches, Min: **3** inches, **Average: 9 inches**
Massie Soil – Max: **6** inches, Min: **3** inches, **Average: 4½ inches**
Restoration plan called for removal of sediment to a maximum depth of 6 inches from selected areas on Spikerush WMA that were dominated by reed canary grass. Fill was removed to an elevation that left 3" of A-Horizon on the Massie soil and 8" of A-Horizon on the Scott soil. Restoration project completed 1/2002.

8) Bulrush WMA – Clay County, McMurtrey Wetland Code **(18-120)**
Depth to clay survey – NRCS, date unknown.
Fillmore Soil – Max: **24** inches, Min: **6** inches, **Average: 11½ inches**
Scott Soil – Max: **26** inches, Min: **2** inches, **Average: 9½ inches**
Massie Soil – Max: **20** inches, Min: **2** inches, **Average: 7 inches**
Restoration plan called for removal of sediment and reed canary grass along northeast edge of wetland where obvious sedimentation deposition had occurred. Along this edge of the wetland average depth to clay on the Fillmore soil was 13 inches, on the Scott soil 13 inches, and on the Massie soil 15 inches. Restoration project completed 11/2002.

9) Bluebill WMA – Fillmore County, McMurtrey Wetland Code **(30-66)**
Depth to clay survey – NRCS, date unknown.
<u>North Wetland:</u>
Scott Soil – Only one sample taken in the Scott soil unit. Depth to clay was **9** inches.
Massie Soil – Max: **20** inches, Min: **5** inches, **Average 13 inches**
<u>South Wetland:</u>
Fillmore Soil – Max: **21** inches, Min: **11** inches, **Average 16 inches**
Scott Soil – Max: **20** inches, Min: **11** inches, **Average 15½ inches**
Restoration plan called for excavation of 12 inches of sediment and reed canary grass in the center of the north wetland ringed by an area of 6-inch excavation, all on the Massie soil unit. On the south wetland, 12 inches of sediment were removed from the Scott soil unit ringed by an area of 6-inch removal on the Fillmore soil. Restoration project completed 1/2003.

10) Whitefront WMA – Clay County, McMurtrey Wetland Code **(18-127)**
Depth to clay survey - Mark Willoughby, NRCS, March 2002
Fillmore-drained Soil – Max: **16** inches, Min: **4** inches, **Average: 9½ inches**
Scott Soil – Max: **18** inches, Min: **0** inches, **Average: 8 inches**
Restoration plan called for excavation of sediment (maximum of 6") in selected areas where the survey found the most deposition. The material was used to fill pits and construct berms. Restoration project completed 5/2003.

11) Marsh Hawk WMA – Fillmore County, McMurtrey Wetland Code **(30-56)**
Depth to clay survey – NRCS, date unknown.
Scott Soil – Max: **36** inches, Min: **0** inches, **Average: 10 inches**
Massie Soil – Max: **44** inches, Min: **4** inches, **Average 14 inches**
Restoration plan called for excavation of sediment and reed canary grass from south portion of the wetland where the average depth to clay on the Scott soil was 13 inches and depth to clay on the Massie soil was 22 inches. Six inches of soil was excavated from the Scott soil in this area while the sediment found on the Massie was excavated 10 inches in depth. Restoration project completed 7/2003.

12) Deep Well WMA – Hamilton County, McMurtrey Wetland Code **(41-6)**
Depth to clay survey – NRCS, date unknown.
Fillmore Soil – Max: **18** inches, Min: **10** inches, **Average: 13 inches**
Scott Soil – Max: **26** inches, Min: **8** inches, **Average: 13 inches**
Massie Soil – Max: **15** inches, Min: **5** inches, **Average: 11 inches**
Restoration plan called for excavation of 6-12 inches of sediment along with river bulrush and reed canary grass from the Massie soil north of the County road and from the Scott soil south of the road. Restoration project completed 1/2004.

13) North Lake Basin WMA – Seward County, McMurtrey Wetland Code **(80-57)**
Depth to clay survey – NRCS, date unknown.
Fillmore Soil – Max: **26** inches, Min: **5** inches, **Average: 15 inches**
Scott Soil – Max: **22** inches, Min: **5** inches, **Average: 16 inches** (only 3 samples in Scott soil)
Massie Soil – Max: **25** inches, Min: **7** inches, **Average: 16 inches** (only 5 samples in Massie soil)
This wetland restoration project was part of the USDA's groundwater remediation project for Utica, NE. The restoration plan called for excavation of 6 inches of sediment and reed canary grass from the Fillmore, Scott, and Massie soil area along the west side of the wetland unit south of the County road. Sediment and river bulrush was excavated to a depth of 6 inches from the Fillmore soil unit north of the County road. Restoration project completed 8/2004.

14) Gadwall WMA – Hamilton County, McMurtrey Wetland Code **(41-16)**
Depth to clay survey – NRCS, date unknown.
Fillmore Soil – Max: **24** inches, Min: **4** inches, **Average: 10 inches**
Scott Soil – Max: **24** inches, Min: **0** inches, **Average: 9 inches**
Restoration plan called for excavation of 6-9 inches of sediment and reed canary grass from 3 distinct areas within the wetland where sediment deposition was heaviest. Restoration project completed 12/2004.

15) Greenhead WMA – Clay County, McMurtrey Wetland Code **(18-35)**
Depth to clay survey - Mark Willoughby, NRCS, March 2002.
Entire wetland unit on the WMA is a Massie soil.
Massie Soil – Max: **14** inches, Min: **3** inches, **Average: 10 inches**
Restoration plan called for the excavation of 6 inches of sediment along with river bulrush and cattail from the entire Massie soil footprint. Restoration project completed 6/2006.

16) Pintail WMA – Hamilton County, McMurtrey Wetland Code **(41-1)**
Depth to clay survey - Jim Husbands, NRCS, April 16, 2007
Fillmore Soil – Max: **24** inches, Min: **16** inches, **Average: 19 inches**
Scott Soil – Max: **39** inches, Min: **13** inches, **Average: 24 inches**
Massie Soil – 1 sample, **20 inches**
Restoration plan called for the excavation of 6 inches of sediment along with reed canary grass from a portion of the Fillmore soil unit. Ten inches of sediment and reed canary grass were removed from the "west" portion of Scott soil while only 6 inches were removed from the "east" portion. Restoration completed 9/2009.

17) Hidden Marsh WMA – York County, McMurtrey Wetland Code **(93-100?)**
Depth to clay survey - Neil Dominy, NRCS, October 2006
Second depth to clay survey - Jim Husbands, NRCS, May 31, 2007
Fillmore Soil – Max: **18** inches, Min: **8** inches, **Average: 14 inches**
Massie Soil – Max: **24** inches, Min: **7** inches, **Average: 12 inches**
The restoration plan (WRP 10-Year Cost Share Only) called for the excavation of 6 inches of sediment and the heavy organic layer from the entire Massie soil unit. The plant community was mostly composed of river bulrush, perennial smartweed, and reed canary grass. Restoration completed 7/2009.

18) Smartweed Marsh WMA – Nuckolls County, McMurtrey Wetland Code **(65-2)**
Depth to clay survey – Mark Willoughby, NRCS, September 21, 2007
Scott Soil – Max: **28** inches, Min: **0** inches, **Average: 5½ inches**
Massie Soil – Max: **12** inches, Min: **0** inches, **Average: 4½ inches**
This restoration plan (WRP 10-Year Cost Share Only) involved several activities including tree removal, road culvert replacement, re-building the County road and shoulders, low-level berm and island removal, and sediment excavation. The primary vegetative community on areas where sediment removal occurred was reed canary grass. Project construction completed in 2/2010.

19) Smartweed Marsh West WMA – Nuckolls County, McMurtrey Wetland Code **(65-1)**
Depth to clay survey – Mark Willoughby, NRCS, March 23, 2009
Butler Soil – 1 sample, **5 inches**
Fillmore Soil – Max: **16** inches, Min: **5** inches, **Average: 8½ inches**
Scott Soil – Max: **14** inches, Min: **5** inches, **Average: 8½ inches**
Massie Soil – Max: **6** inches, Min: **4** inches, **Average: 4½ inches**
This restoration plan (WRP 10-Year Cost Share Only) involved several activities including, tree and brush removal, berm removal, and sediment excavation. This project was completed 12/2009.

20) Marsh Duck WMA – York County, McMurtrey Wetland Code **(93-73)**
Depth to clay survey - Jim Husbands, NRCS, March 20, 2007
Fillmore Soil – Max: **17** inches, Min: **12** inches, **Average: 13½ inches**
Scott Soil – Max: **12** inches, Min: **6** inches, **Average: 7 inches**
Massie Soil – Max: **10** inches, Min: **7** inches, **Average: 8½ inches**

This restoration plan (WRP 10-Year Cost Share Only) involves several activities including pit fills, tree removal, re-building the County road and shoulders, and sediment excavation. This project was completed 12/2010.

Appendix D

Play Wetland Vegetation Communities in Nebraska*			
Community	**Cowardin Type**	**Most Abundant Vegetation Species**	**Diagnostic Species**
Cattail Shallow Marsh	**PEMC & PEMF**	Lesser Duckweed (Lemna aequinoctialis), Turion Duckweed (Lemna turionifera), River Bulrush (Bolboschoenus fluviatilis), Largespike Spikerush (Eleocharis macrostachya), Rice Cutgrass (Leersia oryzoides), Short-beak Arrowhead (Sagittaria brevirostra), Duck-potato Arrowhead (Sagittaria cuneata), Swamp Smartweed (Persicaria coccinea), Large-fruit Burreed (Sparganium eurycarpum), Narrowleaf Cattail (Typha angustifolia), Broadleaf Cattail (Typha latifolia)	River Bulrush, Broadleaf Cattail, Slender Bulrush (Schoenoplectus heterochaetus)
Eastern Bulrush Deep Marsh	**PEMF**	Coontail (Ceratophyllum demersum), Leafy Pondweed (Potamogeton foliosus), Dwarf Pondweed (Potamogeton pusillus), Horned Pondweed (Zannichellia palustris), Turion Duckweed (Lemna turionifera), Greater Duckweed (Spirodela polyrhiza), Common Watermeal (Wolffia columbiana), Northern Water-plantain (Alisma triviale), Bald Spikerush (Eleocharis erythropoda), Rice Cutgrass (Leersia oryzoides), Common Reed (Phragmites australis ssp. americanus), Swamp Smartweed (Polygonum coccineum), Common Arrowhead (Sagittaria latifolia), Hardstem Bulrush (Schoenoplectus acutus), Threesquare Bulrush (Schoenoplectus pungens), Softstem Bulrush (Schoenoplectus tabernaemontani), Large-fruit Burreed (Sparganium eurycarpum), Broadleaf Cattail (Typha latifolia)	Common Arrowhead, Hardstem Bulrush, Softstem Bulrush, Large-fruit Bur-reed, Broadleaf Cattail
Playa Wetland	**PEMA & PEMC**	Water-hyssop (Bacopa rotundifolia), Plains Coreopsis (Coreopsis tinctoria), Short-point Flatsedge (Cyperus acuminatus), Blunt Spikerush (Eleocharis obtusa), Barnyard Grass (Echinochloa spp.), Common Waterwort (Elatine rubella), Mud-plantains (Heteranthera limosa and Heteranthera rotundifolia), False Pimpernel (Linderia dubia), Carpetweed (Mollugo verticillata), Pink Smartweed (Persicaria bicornis), Nodding Smartweed (Polygonum lapathifolia), Narrowleaf Dock (Rumex stenophyllus), Hooded Arrowhead (Sagittaria calycina)	Plains Coreopsis, Barnyard Grass, Water Mudwort (Limosella aquatica), Scoular's Popcorn Flower (Plagiobothrys scouleri)
Spikerush Vernal Pool	**PEMA & PEMC**	Needle Spikerush (Eleocharis acicularis), Water Clover (Marsilea vestita), Water-thread Pondweed (Potamogeton diversifolius), Largespike Spikerush (Eleocharis macrostachya), Water Starwort (Callitriche palustris)	Water Starwort, Needle Spikerush, Largespike Spikerush, Water-thread Pondweed
Wheatgrass Playa Grassland	**PEMA & PEMC**	Ticklegrass (Agrostis hyemalis), Common Ragweed (Ambrosia artemisiifolia), Bur Ragweed (Ambrosia grayi), Buffalograss (Buchloe dactyloides). Shortbeak Sedge (Carex brevior), Largespike Spikerush (Eleocharis macrostachya), Foxtail Barley, (Hordeum jubatum), Inland Rush (Juncus interior), Western Wheatgrass (Pascopyrum smithii), Wedgeleaf Fog-fruit (Phyla cuneifolia), Kentucky Bluegrass (Poa pratensis), Prairie Ironweed (Vernonia fasciculata)	Buffalograss, Western Wheatgrass, Wedgeleaf Fog-Fruit, Prairie Ironweed, Spotted Evening Primrose (Oenothera canescens)
***From Rolfsmeier and Steinauer (2010)**			