CLASSIFICATION OF DEPRESSIONAL WETLANDS IN THE GREAT PLAINS AND DEVELOPMENT OF A SAMPLING MANUAL TO PREDICT PLAYA ECOSYSTEM SERVICES

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Abstract: Most depressional wetlands in the Great Plains, an area where wetland losses are estimated to be over 50%, exist in highly cultivated landscapes. The depressional wetlands of the Great Plains include prairie-potholes in the Prairie Pothole Region and playas in the High Plains Region. Both prairie-pothole and playa wetlands provide a host of ecosystem services to society, but service provisioning is greatly influenced by land-use practices that occur both in the wetland and in the surrounding watershed. The most common wetland classification system used to group Great Plains wetlands by type often combines wetlands with of functionally different types into a single grouping, thereby hampering efforts to evaluate ecosystem service provisioning. Thus, my objectives were to 1) develop methodologies, and associated keys, that use aerial and/or satellite imagery and other readily available data sources to place pothole and playa wetlands into hydrogeomorphic function focused groupings to facilitate ecosystem-service assessments, 2) develop a process to remotely determine metrics needed to apply preexisting predictive ecosystem-service models in the playa region and rank the models according to ease of use, and 3) develop a sampling manual for playa wetlands that incorporates the playa-specific key and associated models. Using remotely sensed data, I observed the geomorphic setting of 200 randomly selected palustrine wetlands in each of the two regions and developed a hydrogeomorphic classification key specific to each region. The key included 5 Prairie Pothole Region classes with 12 subclasses and 4 High Plains Region classes with 9 subclasses. The predictive playa ecosystem-service models I evaluated included quantified contaminant filtration, contaminant concentration, pesticide residue, sediment depth, floodwater storage, greenhouse-gas flux, soil organic carbon, plant species richness, amphibian species richness, waterfowl abundance, and avian species richness. I ranked each of these ecosystem-service models by ease of use. The ranking of models resulted in the abiotic-service models being identified as the simplest models to apply and biotic service models as the most complex. I then incorporated the playa-specific hydrogeomorphic key, model rankings and application processes into a sampling manual. The sampling manual included the High Plains Region key and instructions for remotely estimating 10 different playa ecosystem services. This manual will facilitate the identification of wetland function and the estimation of ecosystem services derived from playa wetlands. Use of this manual by natural resource managers would provide information regarding changes in playa wetland service provisioning and inform conservation decisions.

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CHAPTER I

INTRODUCTION

Wetlands are one of the most threatened ecosystem types in the United States with an estimated 53% of an original 89 million ha lost between 1780 and 1980 (Dahl 1990). The rate of loss for wetlands slowed from approximately 185,000 ha per year in the mid 1900s, to about 5,500 ha per year in the early 2000s (Dahl 2011). Although the implementation of conservation policies and practices have decreased the rate of wetland loss, other factors have also had influence. For example, smaller and shallower wetlands were historically more plentiful and were easily drained at a faster rate than more permanently ponded wetlands resulting in their selective loss (Galatowitsch 2012). Many remaining wetlands are therefore those that are more difficult to drain. Moreover, recent inventories of wetland area have included constructed ponds causing inflated totals (Smith 2003). In addition to wetland losses, prairie ecosystems have also experienced significant losses due to land conversion, primarily to agriculture, with tallgrass-prairie losses estimated at between 82 and 99% and shortgrass-prairie losses over 70% between the 1830s and the 1990s (Samson and Knopf 1994). Losses of wetlands embedded in prairies of the northern Great Plains are estimated to be between 60 and 65% from 1850 to the 1980s (Dahl 2014).

National inventories identify wetlands and are used to determine the total area of differing wetland types, resulting in data concerning wetland-area gains and losses (U.S. Fish and Wildlife

Service 2011; U.S. Department of Agriculture 2018). Unfortunately, the condition and function of remaining wetlands are not currently documented in these inventories. Disturbance in the watershed of a wetland can move sediments into the basin through overland water flow, and many depressional wetlands in cultivated watersheds have become completely filled with sediments. Even lesser degrees of sediment infilling can greatly affect ecosystem functions (Luo et al. 1997, 1999). However, these highly disturbed wetlands still occur in inventories but no longer carry out important functions that support the delivery of ecosystem services (U.S. Fish and Wildlife Service 2011). Thus, knowledge of wetland condition is valuable for determining the conservation needs of prairie wetlands and for understanding the ecosystem services they provide to local and global communities (Brinson 1993).

Ecosystem services are defined as functions or processes of an ecosystem that provide environmental benefit to humans (Costanza et al. 1997). Some of the ecosystem services of wetlands include carbon and nutrient cycling, water filtration, floodwater storage and biotic-diversity provisioning (Zedler and Kercher 2005). Service types have been grouped into four categories, i.e., provisioning, regulating, cultural, and supporting, (Millennium Ecosystem Assessment 2005). Provisioning services include such things as the provisioning of food, fresh water, wood, fiber and fuel. Regulating services include climate regulation, floodwater retention, disease regulation, and water purification. Cultural services are more intrinsic and include aesthetic and spiritual services, in addition to educational and recreational services. Supporting services, as the name implies, are those functions that support the provisioning of provisioning, regulating or cultural services. Some example supporting services include nutrient cycling, soil formation and primary production. (Millennium Ecosystem Assessment 2005).

Services carried out by well functioning ecosystems are closely tied to human well-being (Carpenter et al. 2009). Monetary value can be placed on some services either directly if they are provision services or, in the case of regulating and cultural services, based on the cost of an artificial imitation or society's "willingness-to-pay" for the same service to be carried out manually (Costanza et al. 1997). Through these monetization methods, worldwide services have been estimated to have an annual worth over $33 trillion with grassland services valued at $906 billion and services from "swamp-type" wetlands valued at approximately $3 trillion per year (Costanza et al. 1997). Wetland services include water storage, nutrient cycling, climate regulation, and biodiversity (Finlayson et al. 2005). The extent to which these services are provided depends on the level of function occurring in a wetland, and modified wetlands often lose the ability to provide certain services when compared to more natural wetland ecosystems (Brinson 1993). However, since the nationwide condition of wetlands is not monitored, the state of prairie wetland ecosystem services across the nation is largely unknown.

Depressional wetlands exist within shallow depressions within closed watersheds and can range markedly in size (Smith et al. 1995). Water sources for depressional wetlands are mostly limited to precipitation and overland flow, although discharge from groundwater can occur (van der Kamp and Hayashi 2009). The period of time a wetland contains ponded water (i.e., a wetland's hydroperiod) can vary greatly with flooding and drying often occurring within a single year (Euliss et al. 2013). In addition to prairie-pothole and playa wetlands in the Great Plains, other depressional wetland types include cypress domes in Florida, Carolina bays in the Atlantic Coastal Plain, and vernal pools in the west coast steppes and terraces (Tiner 2003). In the Great Plains, prairie-pothole wetlands dominate in the north (i.e., the Northern Glaciated Plains) and playa wetlands dominate in the High Plains to the south (Bolen et al. 1989; Kantrud et al. 1989). Although both prairie-potholes and playas are depressional wetlands and somewhat similar in appearance, these wetlands carry out differing functions mainly due to their different formation processes and hydrology (Smith 2003). However, both wetland types exist as hotspots for flora and fauna within their respective regions due to the aquatic habitats they provide in an otherwise semi-arid environment (Haukos and Smith 1994).

Prairie-pothole Wetlands

Prairie-pothole wetlands exist throughout the northern Great Plains covering parts of Iowa, Minnesota, the Dakotas and Montana, in addition to parts of three Canadian provinces (Gleason et al. 2005). This area has been labeled the Prairie Pothole Region (PPR) (Galatowitsch 2012). Annual evapotranspiration in the PPR exceeds precipitation and the region is therefore considered to be semiarid (Winter 1989). Historic land cover consisted mainly of tallgrass prairie to the east, with short-grass prairie in the western portions and mixed-grass prairie in between, all maintained by intermittent fire and ungulate grazing (Doherty et al. 2013). Land conversion, largely to facilitate crop production, has resulted in prairie losses totaling over 99% in Iowa, Minnesota and North Dakota, and losses up to 85% in South Dakota (Samson and Knopf 1994). Prairie potholes formed through glacial activity with the movement of glacial till allowing hummocky terrain and depressions to develop (Galatowitsch 2012). Potholes are scattered throughout the PPR with Minnesota exhibiting the lowest densities (8.1 km^{-2}) and greatest mean basin size (2.7 ha) and South Dakota exhibiting the highest densities (38.8 km^{-2}) with the lowest mean basin size (1.1 ha) (Cowardin et al. 1995, van der Kamp and Hayashi 2009).

Pothole hydrology can be complex relative to groundwater interactions with basins that can both recharge groundwater as well as receive groundwater discharge (Hayashi et al. 2016). These groundwater relationships exist along a continuum that are locally influenced by wetland elevation (Euliss et al. 2004). The direction of water movement can change throughout time, and some wetlands exhibit flow-through patterns receiving and discharging groundwater simultaneously. These complex flow patterns alter water chemistry of the wetland pond, which in turn influences composition of the wetland-plant community (Stewart and Kantrud 1972). Pothole basins which are hydrologically connected via surface or groundwater connections are often referred to as a wetland complex. Topography of a wetland complex can allow the ponds of higher elevation wetlands to spill over the land surface into nearby basins when water storage capacities are exceeded (Shaw et al. 2012). This phenomenon is known as the spill-and-fill process and increases the dynamic nature of wetlands within a complex (van der Kamp and Hayashi 2009).

Prairie-pothole wetlands support a large portion of the northern Great Plains plant and animal biodiversity (Knutsen and Euliss 2001). This PPR has been estimated to provide breeding habitat for 50% of the North American duck population (Batt et al. 1989). These wetlands also contribute to atmospheric services and it has been shown that while only covering 17% of the land surface, they are capable of storing twice the amount of carbon compared to local no till croplands across the entire region over a ten-year period (Euliss et al. 2006). Other services provided by prairie-pothole wetlands include water storage and sediment retention (Gleason et al. 2007, 2008).

Playa Wetlands

Playas are present in the High Plains Region (HPR), which covers the western portions of Texas, Oklahoma, Kansas and Nebraska as well as the eastern portions of New Mexico, Colorado and the southeastern corner of Wyoming (Brinson and Eckles 2011). This area consists of the Llano Estacado plateau to the south and the plains east of the Rocky Mountains to the north (Bolen et al. 1989; Smith 2003). The area was historically short-grass prairie with mixed-grass and tall-grass species occurring in the eastern subregion known as the Rainwater Basin of Nebraska (Küchler 1975). Mean annual precipitation ranges from 38 cm in Midland, Texas to 63 cm in Grand Island, Nebraska, but yearly totals fluctuate markedly around these averages (Smith 2003). In the Southern High Plains, playa wetlands cover approximately 2% of the region and mean sizes range from less than 1 ha to greater than 16 ha with 87% of playas being less than 12 ha (Guthery and Bryant 1982; Haukos and Smith 1994). The landscape is very flat which results in large watersheds that range from 25.3 ha up to 2,608 ha (Tasi et al. 2007). Formation processes for playas in Southern High Plains include dissolution, along with wind and wave activity

(Osterkamp and Wood 1987; Sabin and Holliday 1995). Dissolution occurs when organic matter accumulates in a ponded location and oxidation forms carbonic acid that interacts with the calcium carbonate soils. The carbonic acid dissolves the soil and forms the circular playa basin (Wood and Osterkamp 1987). In more northern portions of the HPR including the Rainwater Basin of Nebraska, playas are similar in size or slightly larger but exhibit more irregular shapes. Formation processes of wetlands in the Rainwater Basin are understood to be mainly wind and wave driven (Smith 2003).

Playas receive water only through precipitation and overland flow from their watershed. Water can leave a playa wetland through evapotranspiration and groundwater recharge (Bolen et al. 1989). Groundwater recharge occurs through the basin floor, and playas are understood to be the main source of water recharge for the Ogallala Aquifer (Gurdak and Roe 2009). This aquifer is one of the largest in the conterminous U.S. and supports a significant portion of U.S. agricultural production through pumping of its water for irrigation (Gutentag et al. 1984).

Playa wetlands naturally fluctuate between ponded and dry conditions throughout the year (Haukos and Smith 1992). Ponded playas support different species than dry playas and biodiversity generally decreases with shortened periods of ponding, often referred to as a wetland's hydroperiod (Tsai et al. 2007). Playas exist as biodiversity hotspots in which species richness can be 300% greater than a similar grassland area with no playa present (Smith 2003). Playas are situated within the southern portion of the Central Flyway and are important as stopover and wintering habitat for migratory birds (Bolen et al. 1989). Playas are estimated to support millions of waterfowl each year throughout both winter and during migration (LaGrange 2005). Many other avian species use playa habitats, including grassland birds, shorebirds, and sandhill cranes (*Grus canadensis*) (Iverson et al. 1985; Conway et al. 2005; Tsai et al. 2012). Besides providing wildlife habitat in support of biodiversity, playas also provide many other services including floodwater storage, carbon sequestration, nutrient processing, and pesticide filtration (Smith et al. 2011).

Wetland Classification

In the United States, the Classification of Wetlands and Deepwater Habitats developed by Cowardin et al. (1979), hereafter referred to simply as the “Cowardin classification,” is commonly applied to group wetland types across the nation. This classification system was established to standardize the terminology and definitions associated with describing a wetland or deepwater habitat (Federal Geographic Data Committee 2013). The Cowardin classification is applicable in any region for any wetland type and provides a succinct labeling system to aid communication (Cowardin and Golet 1995). The Cowardin classification is hierarchical, consisting of five systems most of which contain sub-systems. Sub-systems are further divided into classes and sub-classes. The system also provides optional modifiers that can be used to increase information provided (Cowardin et al. 1979). Groupings in the Cowardin classification are based on abiotic features such as water chemistry and wetland size, as well as biotic features including vegetation structure and type. The classification often describes the habitat features of a waterbody and is used in largescale inventories such that performed by the U.S. Department of Agriculture’s National Wetlands Inventory (NWI) to identify a variety of wetland types (Dahl et al. 2015). Unfortunately, the Cowardin classification does little to communicate the function occurring within a given wetland type and inferring ecosystem services is therefore problematic using this classification system (Tiner 1997).

In contrast to the Cowardin classification, the Hydrogeomorphic (HGM) Classification for wetlands was developed as a function-focused approach to classifying wetlands (Brinson 1993). The HGM classification recognizes three, broad categories that describe geomorphic setting, water source and hydrodynamics. Geomorphic setting identifies the position of a wetland within the surrounding landscape and therefore can be related to wetland function, formation, and to some extent hydrology (Brinson 1993). Water source identifies how water enters a wetland with primary as well as secondary sources often determined. Hydrodynamics describes the direction of water movement within a wetland, which can be bi-directional with vertical movement through groundwater recharge and evapotranspiration, along with horizontal movement through overland flow or stream bank flooding (Smith et al. 1995). In specific situations, the HGM classification is used in the application of functional assessments (Natural Resource Conservation Service 2008). Region specific manuals have been developed for areas such as the Mid-Atlantic Region, the Prairie Pothole Region and the Nebraska Rainwater Basin to facilitate the further identification of wetland function through field sampling and functional indices (Stutheit et al. 2004; Gilbert et al. 2006; Brooks et al. 2011). Basic application of the HGM classification can be carried out through the use of remotely sensed imagery, such as satellite imagery, and open source databases that include topographic maps and flow-lines of streams and rivers (Brinson 1993). The HGM classification allows for function to be understood and ecosystem services of wetlands inferred, thereby providing a greater understanding of natural resource condition (Smith et al. 1995).

The National Resources Inventory (NRI)

The Natural Resources Inventory (NRI) is a nation-wide inventory of natural resources on non-federal, rural lands. The NRI is conducted by the Natural Resource Conservation Service (NRCS) across the conterminous U.S. to determine the change in status and condition of these natural resources over time (Natural Resource Conservation Service 2016a). The NRI uses remotely sensed imagery and local databases to quantify resource condition on randomly selected, but intermittently repeated, sampling points, by observing the presence of grassland, cropland, erosion and wetland resources (U.S. Department of Agriculture 2018). When a wetland is encountered at a sampling point, the total area of the wetland is measured and the wetland type determined using the Cowardin classification (Natural Resource Conservation Service 2016a).

Once all wetlands and waterbodies encountered at sampling points are identified, the total area of wetlands by Cowardin classification type is calculated and results are presented as gains and losses by system type (Schnepf 2008). The NRI gathers information across a large geographic region, thereby providing insight to the change in land cover and natural resources. However, NRI wetland data are limited in terms of usefulness for determining wetland function and evaluating ecosystem services provided by the differing wetland types.

Conservation Effects Assessment Project (CEAP)

Natural resources are affected by land-use practices. The NRCS implements conservation programs that financially assist with conservation-focused land management on private lands across the U.S. (Natural Resource Conservation Service 2014, Farm Service Agency 2016). The effects of these assistance programs are assessed through the Conservation Effects Assessment Project (CEAP) carried out by NRCS (Duriancik et al. 2008). The CEAP–Wetlands component is focused specifically on wetlands within regions where conservation programs are widely applied and wetland losses due to agricultural activities are high (Brinson and Eckles 2011). Eleven CEAP–Wetlands regions were established, including the PPR and the HPR (Eckles 2008). In both of these regions, the Conservation Reserve Program (CRP) and the Wetland Reserve Program (WRP), which is now carried out under the Agricultural Conservation Easement Program (ACEP), are commonly applied and have significant impacts on depressional wetlands (Gleason et al. 2011; Smith et al. 2011). Under CEAP–Wetlands, data were gathered on wetland ecosystem services and relationships among those services, watershed land use and relevant field measurements were analyzed (Smith et al. 2012a). Numerous regression equations and predictive models were developed and provided to the NRCS in report form. These relationships indicate how services change in wetlands when surrounded by native grass, crop, and conservation-program (CRP, WRP) lands. Some services documented for the PPR included plant-community species richness, carbon sequestration, sediment retention and nutrient reduction (Conservation

Effects Assessment Project 2008a). Some of the HPR services include plant-community species richness, amphibian species richness, floodwater storage and contaminant reduction (Conservation Effects Assessment Project 2008b). CEAP–Wetlands is included in the Integrative Landscape Modeling (ILM) partnership which seeks to quantify ecosystem services provided by wetlands and conservation practices (Mushet and Scherff 2016). Prediction of ecosystem services was carried out using regression equations as well as modeling platforms. Predictive equations have been incorporated into the ILM through CEAP–Wetlands work in the PPR as well as the HPR and further integration would provide increased options for ecosystem-service estimation.

Thesis Organization

This research was requested by the NRCS to integrate the completed CEAP–Wetlands work for the prairie-pothole and playa regions into current sampling methods for the NRI and ILM. Following this introductory chapter, the next chapter focuses on developing an HGM classification key for PPR and HPR wetlands. The third chapter details my selection and ranking of pre-existing predictive models for estimating the ecosystem services of potholes and playas and discusses sampling manual development. Lastly, the attached appendix consists of an instructional sampling manual for Great Plains wetlands that incorporates the findings discussed in chapters two and three. Objectives were altered during my work to focus the sampling manual on the HPR only. This change was made since predictive models for the PPR and HPR differ significantly in structure and in application. In the HPR, most developed models consisted of regression equations and could be easily applied to most playa basins due to the uniformity of function across all playa wetlands. In the PPR, models were built using the Agricultural Policy/Environmental Extender (APEX) model and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) modeling platform which are not readily integrated into rapid service estimation (Mushet and Scherff 2016).

CHAPTER II

DEVELOPMENT OF A HYDROGEOMORPHIC CLASSIFICATION KEY FOR GREAT PLAINS WETLANDS

Abstract

Depressional wetlands in the Great Plains of the United States have experienced significant losses due to anthropogenic activities. Prairie-pothole wetland losses have exceeded 50% in most states and playa-wetland losses are estimated at over 60%. Wetland inventories are carried out to determine wetland gains and losses by type. The commonly applied Cowardin classification system uses biotic and abiotic features to determine wetland type resulting in potholes and playas being grouped with functionally different wetlands types. This grouping means that changes in the presence or function of these depressional wetlands can go undetected. The objective of this research was to build a hydrogeomorphic classification key capable of grouping wetlands within the Prairie Pothole Region and the High Plains Region of the United States so that known functions can be used to estimate ecosystem service provisioning. In each region, 200 palustrine wetlands were randomly selected from the National Wetlands Inventory database. Each wetland was then assessed using remotely sensed imagery and data. This resulted in the appropriate hydrogeomorphic classification being assigned. Once all potential wetland types were examined, a dichotomous key was built to include the encountered hydrogeomorphic classes as well as subclasses based on likely formation processes observable in the spatial data. In both regions the

two most common functional classes were depressional and riverine. The resulting regional keys are designed to facilitate determination of likely functions for any NWI identified palustrine wetland in a designated region. The keys can be used to indicate the function of a palustrine wetland within these regions which is related to the provisioning of ecosystem services.

Introduction

Prairie-pothole and playa wetlands are two different types of depressional wetlands that exist within the Great Plains of the U.S. (Sloan 1972; Bolen et al. 1989). Prairie-pothole wetlands dominate the glaciated portions of Minnesota, Iowa, South Dakota, North Dakota, Montana, and three Canadian provinces, i.e., the Prairie Pothole Region (PPR) (van der Kamp and Hayashi 2009) (Figure 2.1). Playa wetlands exist across the High Plains Region (HPR) of New Mexico, Texas, Oklahoma, Kansas, Nebraska, Colorado and southeast Wyoming (Smith 2003) (Figure 2.1). Both wetland types typically exist within closed watersheds, and their functions provide ecosystem services to local and global communities (Gleason et al. 2011; Smith et al. 2011). Functions refer to the natural processes occurring within a wetland while ecosystem services are benefits that humans receive from those functions (Costanza et al. 1997). Ecosystem services provided by prairie-pothole and playa wetlands include habitat provisioning, floodwater storage, carbon sequestration and groundwater recharge (Gleason et al. 2011; Smith et al. 2011). Native grassland losses in the Great Plains have totaled 70% with most of this change being attributed to agricultural production, which can have marked negative impacts on the function and presence of wetlands (Samson et al. 2004; Johnson et al. 2012). Drainage of wetlands for agricultural purposes has contributed greatly to wetland losses across the Great Plains with prairie-pothole wetland losses estimated at greater than 50% in most states that include these wetland types (Tiner 1984; Dahl 1990). Additionally, cultivation of depressional-wetland watersheds causes increased amounts of soil to flow into the wetland basin. These sediment inputs diminish functions and services, eventually filling in the basin and potentially eliminating the wetland entirely (Luo et al 1997; Detenbeck et al. 2002; Tsai et al. 2007). Playa losses are estimated to be approximately 60% due to drainage and sedimentation with only about 0.2% of playas in the southern portion of the HPR being without some wetland or watershed modification (Johnson et al. 2012). In the Rainwater Basin of Nebraska, up to 90% of wetlands have been lost, mainly due to drainage (Gersib et al. 1992).

The National Resources Inventory (NRI) is carried out by the Natural Resource Conservation Service (NRCS) to monitor the condition of natural resources over time on non-federal, rural lands (US Department of Agriculture 2015). Included in the NRI is documentation of wetland gains and losses across the United States. Of the 26-million ha of wetlands and waterbodies sampled in 2012, 66% were identified as palustrine under the Cowardin et al. (1979) wetland classification (U.S. Department of Agriculture 2015). This palustrine system includes many smaller inland waterbody types and can include small reservoirs, ponds, riparian wetlands and also depressional wetland types including playas and prairie potholes. Although certain features are shared among all palustrine wetlands, features that are not incorporated into the Cowardin et al. (1979) classification, can cause functions to vary widely. Wetland function depends on geomorphic setting and hydrodynamics with some examples being formation of soil, primary production and nutrient cycling (Brinson 1993; Euliss et al. 2013). Under the NRI and other wetland inventories, the level of function is not documented or considered since geomorphology is not consistently identified (U.S. Department of Agriculture 2015; U.S. Fish and Wildlife Service 2018).

Two Classifications

The Classification of Wetlands and Deepwater Habitats (Cowardin et al. 1979) uses a hierarchical format to indicate biotic and abiotic features of wetlands and waterbodies. The first level of the hierarchy is titled the ‘system’ and contains five types. The palustrine system, which includes freshwater wetlands with emergent vegetation dominating the surface, is one of these five. Wetlands without emergent vegetation are included in the palustrine system only if the wetland size is less than 8 ha, no wave formed shorelines are present and water depths are less than 2 m at low water (Cowardin et al. 1979). The range of functional wetland and waterbody types within this system is broad and in addition to prairie-pothole and playa wetlands can include flooded forest, bogs, fens, ponds, and man-made catchments including lagoons, drainage ditches and irrigation pits (Federal Geographic Data Committee 2013). Classes, subclasses and modifiers are used within the palustrine system but have limited ability to distinguish between functionally different waterbodies. The classes, subclasses and modifiers of the Cowardin classification identify features such as vegetation type and structure, general water regime, water chemistry and alterations including diked, farmed or excavated (Cowardin et al. 1979).

In contrast to the approach of Cowardin et al. (1979), the Hydrogeomorphic (HGM) classification was established to identify wetland function through three abiotic characteristics which include geomorphic setting, hydrodynamics and water source (Brinson 1993). Wetland classes in the HGM classification are based on geomorphic setting and include riverine, depressional, slope, mineral soil flats, organic soil flats, estuarine fringe and lacustrine fringe (Smith et al. 1995). Numerous ecosystem functions can be inferred when HGM class is known since the geomorphic setting is closely related to wetland function (Brooks et al. 2013). The HGM classification also can be applied remotely since topographic maps, stream lines and satellite imagery can be used to determine all necessary features needed to place a wetland into an HGM class (Brinson 1993). To understand the function of a palustrine wetland, it is also necessary to identify hydrodynamics and water source. Because these features are also not identified in the Cowardin et al. (1979) classification, translating a type to HGM is not always possible (Tiner 2014). Not only do features used in identification differ significantly between these two classifications, there is also overlap in the terminology used between the two (Smith et al. 1995).

Reclassification Key

In order to overcome limitations associated with the Cowardin classification as currently used in NRI, I developed a key that can be applied to obtain the HGM class of any Cowardin et al. (1979) classified palustrine wetland in the HPR or PPR. The extents of these regions have been designated by the Conservation Effects Assessment Project Wetlands Component (CEAP–Wetlands) (Duriancik et al. 2008) (Figure 2.1). The objective of this research was to build a key to identify the correct HGM class for wetlands in these regions that can be applied using remotely sensed imagery and other data available to most users. This key, used along with topographic maps, satellite imagery, and the National Hydrography Dataset (NHD), can be used to identify the HGM class as well as likely hydrodynamics and water source of a Cowardin et al. (1979) identified palustrine wetland. I also developed region specific subclasses that are capable of identifying depressional wetlands down to playa and pothole types. Once the Cowardin et al. (1979) classified wetlands are reclassified in HGM, predictive models can then be used to estimate services based on wetland characteristics and surrounding land use (Euliss et al. 2011).

Methods

Data Selection

To develop a regionally specific HGM classification key, a random sample of Cowardin et al. (1979) classified wetlands was selected from the HPR and the PPR. Two hundred National Wetlands Inventory (NWI) wetland polygons were randomly selected from each region. This was done by downloading all wetland polygons from the NWI database for the states within the regions of interest (U.S. Fish and Wildlife Service 2017). Wetlands classified as palustrine were selected and saved in state specific shapefiles. Wetland regions, determined by the Conservation Effects Assessment Project Wetlands component (CEAP–Wetlands) (Eckles 2008), were designated using polygons sourced from the Natural Resource Conservation Service (NRCS) and were used to clip all palustrine wetlands within the HPR and PPR regions. Once clipped to the regions, palustrine shapefiles were merged to produce one HPR dataset, consisting of 284,206 palustrine polygons and one PPR dataset, consisting of 3,575,916 palustrine polygons. From these large sets, the Sampling Design Tool was used to randomly select a subset of 200 palustrine wetlands from each region (Buja 2016). Two hundred within each region were selected since our methods required individual examination of each wetland basin and 400 was determined to be a manageable number within our research objectives. Data were processed using Esri ArcMap 10.4 (Esri 2011).

Classifying Wetlands

Each of the 200 palustrine polygons were visually examined and the necessary HGM features (Brinson 1993) were identified. Wetland polygons were examined along with Esri's U.S. Geological Survey (USGS) based topographic maps, Esri's satellite imagery basemap and the National Hydrography Dataset (NHD) stream lines developed by USGS (Esri 2017a, 2017b; U.S. Geological Survey 2017a). Geomorphic setting was determined through topographic maps and through use of satellite imagery (Esri 2017b) to identify any obvious features that could indicate formation. Identification of geomorphic setting was based on the relationship of the wetland to the surrounding upland and determined using HGM class definitions developed by Smith et al. (1995). Hydrodynamics were identified through potential inflow and outflow locations based on observable topographic relief. Water source was assumed to come only from precipitation and overland flow, unless streamflow or spill from another water source was determined. Although this assumption is true for playas, it may not always be accurate for pothole wetlands since these can receive groundwater discharge. Groundwater contributions in a prairie-pothole wetland can increase salinity and are difficult to detect. Therefore, within my classification, identification of prairie-pothole water source is restricted to precipitation and overland flow (Hayashi et al. 2016). If a wetland intersected a streamline, or was adjacent to a channel containing a streamline, streamflow was understood to contribute water. The nature of the Cowardin et al. (1979)

classification allows for numerous labels to be given to one wetland when different subclasses or modifiers are present. When numerous polygons were encountered within one wetland, the entire observable wetland was considered and examination was not limited to the single palustrine polygon selected.

After identifying broad HGM classes, subclasses based on hydrology and likely formation processes were developed (Smith et al. 1995). I developed unique subclass labels that provide descriptions of waterbody features that were detectable within the datasets examined. These definitions were not from the HGM or any other established classification system. A wetland was considered artificially formed if it appeared that diking or excavating created the wetland and that it would not be present but for the dike or excavation. All other wetland types were considered naturally formed, and if dikes or excavations were present, they were considered modifications to the original wetland. During my examination of imagery, I found that nine selected “wetlands” in the HPR and three in the PPR had been either misclassified or lost since the NWI polygons were delineated. This number was not extremely high considering the shortcomings of NWI wetland data. The NWI database consists of polygons derived from aerial imagery which has been interpreted by a variety of government and non-government agencies and universities across many different project areas (U.S. Fish and Wildlife Service 2018). Some of the project areas within our sample regions used images that dated back to 1982 making it probable that some wetlands in these areas to have since been filled with sediments or drained. To make up for these lost wetlands, replacement polygons were selected from the region-specific palustrine datasets that were originally assembled.

Results

Of the 200 palustrine wetlands in the HPR, 118 wetlands (59%) were HGM depressional with 101 of these 118 being playas and the other 17 being other depressional-wetland types (Table

2.1). The second largest HGM category in the HPR was riverine with 81 total wetlands (40.5%) and evidence of three different natural formation subclasses and two mechanical formation subclasses. Only a single wetland of the HGM lacustrine-fringe class was present in our sample of playa wetlands. Of the 200 PPR palustrine wetlands, 165 (82.5%) were depressional with 144 being prairie-pothole wetlands and 22 being wetlands in other depressional subclasses (Table 2.1). The HGM riverine class in this region consisted of 31 wetlands (15.5%), with three natural formation and two mechanical formation subclasses. Wetlands in the PPR sample also contained three lacustrine-fringe wetlands and a single slope wetland type.

Hydrogeomorphic Classification Key

The key was built to identify the HGM class of a wetland while also identifying a regionally specific subclass based on likely formation processes. Two sections were included, one for the HPR and one for the PPR (Figures 2.2 and 2.3). Within the PPR, modifiers were added to the prairie-pothole wetland subclass to label modifications observed within a wetland.

High Plains Region Wetlands

For the HPR, the key was built with four classes labeled riverine, depressional, lacustrine fringe and a lost/misclassified (Figure 2.2). The riverine class included five subclasses two of which were based on indicators of mechanical formation and three on natural formation. Mechanical formation subclasses were “excavated” and “diked” which both were associated with an NHD stream but retained water due to the presence of an excavation or dike, respectively. Natural formation subclasses were made up of “floodplain” wetlands, which formed adjacent to a stream through overbank flow, “streambed” in which standing water was held in within the banks of a stream during low flow, and “oxbow” formed through change in stream location. The depressional class included four subclasses based on visual indicators. Two subclasses were based on the appearance of mechanical formation and two on the appearance of natural formation. The mechanical formation subclasses were “excavated,” which held water due to excavation, and “diked,” which retained water due to the presence of a constructed dike or dam. The natural formation subclasses were the “draw” identified as an upland location where water is intermittently held when moving downhill and “playa,” identified as a natural depression not within a drainage. The final HPR classes were designated as lacustrine fringe, where wetland presence was associated with the edge of a lake or reservoir, and lost/misclassified, where a wetland not detectable. Neither of these classes included a subclass since no varying types were encountered through the sample of 200, Cowardin classified, palustrine wetlands.

Prairie Pothole Region Wetlands

The PPR classification key contained classes for riverine, depressional, slope, lacustrine fringe and lost/misclassified wetlands (Figure 2.3). The riverine class contained five subclasses which were identical to those in the HPR. The depressional classes also included subclasses identical to the HPR except with two options for the non-drainage depressional type identified as a pothole. A depressional pothole could be labeled simply as “pothole wetland” or as “altered pothole” which contained a list of possible modifiers, including diked, drained or excavated. These modifiers identified a naturally formed pothole wetland with mechanical alterations present. The slope class was identified as a wet area existing on a slope with the “slope wetland” attributed to natural formation while “excavated” and “diked” subclasses were attributed to mechanical formation. Lastly, lacustrine fringe included wetlands adjacent to lakes or reservoirs.

Discussion

HGM Classification

As expected, the largest HGM class within both regions was the depressional class. Both regions are dominated by wetlands that exist within closed watersheds. Although depressional types were most common, these are not the only wetlands identified as palustrine under the Cowardin classification. The HGM classes that I encountered showed numerous Cowardin classified palustrine wetlands that were associated with streams and draws or were artificially constructed. In the Cowardin classification, no distinctions between these functionally different wetlands types are made. Approximately 80% of all HGM depressional wetlands identified in each region shared the exact Cowardin label with one or more HGM riverine wetlands and therefore services would vary. The differences in the geomorphology of these waterbody types became obvious when remotely sensed imagery was viewed. The HGM rules allowed for rapid grouping by HGM class. It should be noted that known wetland type called a saline lake exists within the HPR but was not encountered in our sampling. Although uncommon, these wetlands do exist and the key we developed would identify these as depressional and potentially as playas. These wetlands appear geomorphically similar to large playas but historically received groundwater from the Ogallala aquifer in the form of springs (Smith 2003). Due to the rarity of these wetlands and the difficulties in distinguishing them from playas based on geomorphology, they were not included in this key.

A Comparison of Two Wetlands

The differences in the HGM and Cowardin et al. (1979) system can be illustrated by comparing two sample wetlands encountered in the HPR (Figure 2.4). Under the Cowardin et al. (1979) classification, both palustrine wetlands in the figure were classified as PEM1C, indicating the palustrine system (P), emergent class (EM), persistent subclass (1) and a seasonally flooded modifier (C). In contrast, the HGM classification identified the first wetland as depressional while identifying the second as riverine, i.e., two very different functional classes. In the key I developed, the depressional wetland was further identified as a playa based on its geomorphic setting and the region within which it exists. The riverine wetland was geomorphically associated with a stream and the primary water source was identified as streamflow. Because hydrology differed between these two wetlands, different functions were occurring causing a dissimilarity in ecosystem service provisioning (Brinson 1993). Playas offer services such as floodwater storage, groundwater recharge, and carbon sequestration along with amphibian and waterfowl habitat (Smith et al. 2011). While this riverine wetland provides floodwater storage and wildlife habitat, the functions and services have more of an effect on stream flow and downstream water quality through filtration and trapping of sediments due to differing hydrology from differing formation and geomorphic setting (Brinson 1993).

The Regional Key

The need for adding function-based details to the Cowardin et al. (1979) wetland classification was addressed by the Keys to Landscape Position and Landform Descriptors built by the U.S. Fish and Wildlife Service in 1997 (Tiner 2014). Descriptors were formed to describe landscape position, landform, water flow path and waterbody type with the process being referred to as the LLWW. The process uses remotely sensed data and was designed to address all wetland types potentially encountered in the NWI through the addition of hydrogeomorphic type descriptors to the Cowardin labels. Overall, these descriptors communicate similar features to Brinson's (1993) HGM classification and can provide information that indicates likely wetland function. For the HPR and the PPR, we chose to use Brinson's (1993) HGM classification modified by Smith et al. (1995) because it is more widely used and because the terms are more intuitive in communicating wetland appearance, location, and function. In the LLWW, a playa landscape position and landform would be considered terrene non-riparian and basin respectively. The same features in HGM are communicated simply as a geomorphic depression. Playas and potholes are commonly referred to as depressional wetlands when described apart from any specific classification system. This makes the HGM terminology more intuitive for the dominant wetlands within our regions of interest. The LLWW also uses numerous established dichotomous keys that include all possible wetland types across the nation (Tiner 2014). In order to simplify the identification of functional waterbody types in the PPR and HPR, we choose to develop HGM classification keys that are region specific and include only waterbody types that are likely to occur.

Application for the Future

The resulting classification keys were designed to be most helpful in identifying a Great Plains palustrine waterbody as playa wetland or prairie pothole (Figures 2.2 and 2.3). Use should be limited to the PPR or the HPR based on the CEAP–Wetlands region designations (Eckles 2008). Since hydrology is the main driver of wetland function, ecosystem services can be inferred due to current knowledge about the hydrology of these specific wetland types and of the services they provide within their respective regions (Euliss et al. 2008; Smith et al. 2008). Regression equations and predictive models have also been built for these wetland types (See Chapter 3). When a playa or pothole is positively identified, numerous ecosystem services can be predicted using these models with features of the wetland and the associated upland.

The key developed here may also be applicable to Cowardin lacustrine wetlands in the HPR and PPR that appear to be misclassified. When examining NWI wetlands identified as playas by the Playa Lakes Joint Venture (PLJV), it was observed that a large number were placed in the lacustrine system. This is likely a misclassification since playas generally do not meet the depth requirements of being greater than 2 m to truly be lacustrine (Smith 2003). Because the NWI was carried out using aerial imagery, it is likely that the size of these playas was considered without knowledge of wetland depth. For this HGM classification key to be used in identifying the extent of playas and potholes, it may need to be applied on lacustrine wetlands so that large playas and potholes are not excluded. Further examination of lacustrine waterbodies in these regions would determine the extent of these NWI misclassifications.

Conclusion

The key I developed can be applied by researchers and natural resource managers alike to identify the presence of playas and potholes within their respective regions. Inventories such as the National Resources Inventory, could use this information to track changes in not just playa and prairie-pothole wetland numbers, but also services (Chapter 3). Knowledge of these changes could also be used to communicate the value or need for additional conservation programs focused on conserving these wetlands and the ecosystem services they provide.

Tables and Figures

Table 2.1. Hydrogeomorphic classification results for 400 palustrine wetlands sampled in the High Plains Region and the Prairie Pothole Region.

	High Plains Region (HPR)		**Prairie Pothole Region (PPR)**	
Class and Subclass	Palustrine (N=200)	Percent	Palustrine (N=200)	Percent
Depressional	**118**	**59.00%**	**165**	**82.50%**
naturally formed				
Pothole/Playa	101		144	
Draw	1		4	
mechanically formed				
Diked	10		2	
Excavated	6		16	
Riverine	**81**	**40.50%**	**31**	**15.50%**
naturally formed				
Floodplain	21		14	
Oxbow	2		3	
Streambed	24		9	
mechanically formed				
Diked	30		2	
Excavated	4		3	
Lacustrine Fringe	**1**	**0.01%**	**3**	**0.02%**
Slope	**0**	**0.00%**	**1**	**0.01%**

Figure 2.1. Conservation Effects Assessment Project (CEAP) – Wetlands regions in the Great Plains of the United States.

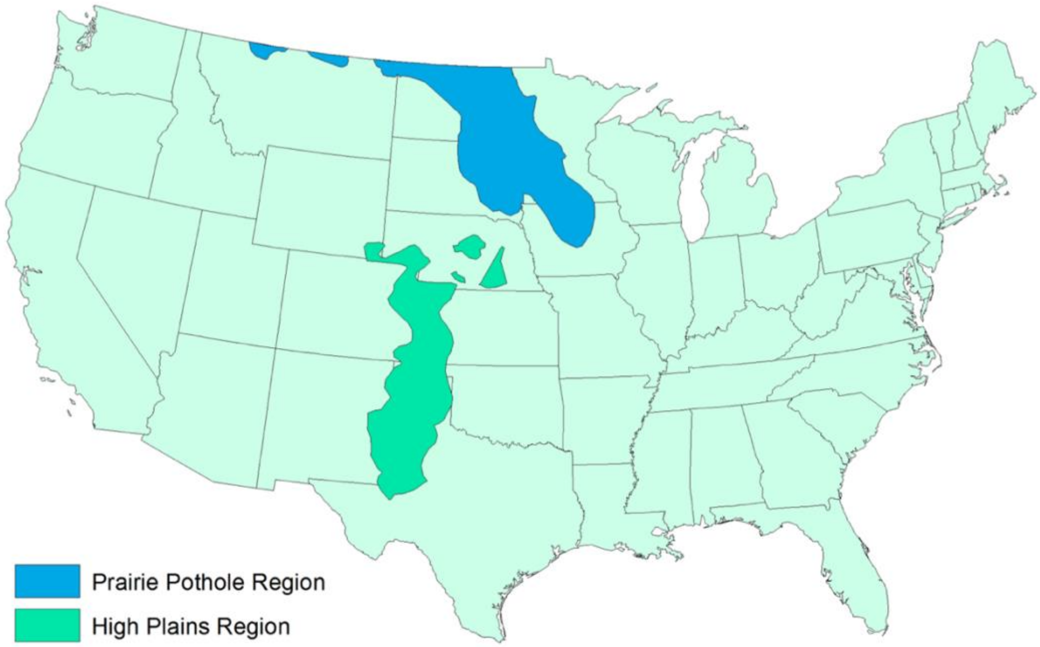


Figure 2.2. A hydrogeomorphic classification key for Cowardin et al. (1979) classified palustrine wetlands in the High Plains Region (HPR).

High Plains Region (HPR) Hydrogeomorphic Key

1 Wetland is classified as Cowardin Palustrine 2
1 Wetland is not classified as Palustrine .... Stop here (this key is not applicable)
2 Wetland is detectable via remotely sensed data 3
2 Wetland is not detectable via remotely sensed data .... ***Lost/Misclassified***
3 Wetland is associated with a natural, continuous NHD stream or surrounding floodplain .... ***Riverine* (5)**
3 Wetland is not associated with a natural, continuous NHD stream 4
4 Wetland exists within a closed watershed .... ***Depressional* (9)**
4 Wetland exists along the edge of a lake or reservoir .... ***Lacustrine Fringe***

5 Wetland retains water due to landscape alteration (anthropogenic or beaver activity) 6
5 Wetland does not retain water due to landscape alteration 7
6 Wetland is excavated .... Riverine Excavated
6 Wetland is diked .... Riverine Diked
7 Wetland is situated within current or historic streambed 8
7 Wetland is outside of streambed but within the floodplain .... Riverine Floodplain
8 Wetland exists within streambed during low flow .... Riverine Streambed
8 Wetland is disconnected and was formed by streamflow at bend .... Riverine Oxbow

9 Wetland retains water due to landscape alteration 10
9 Wetland does not retain water due to landscape alteration 11
10 Wetland is excavated .... Depressional Excavated
10 Wetland is diked .... Depressional Diked
11 Wetland is situated within a drainage .... Depressional Draw
11 Wetland is not situated within a drainage .... Playa Wetland

Figure 2.3. A hydrogeomorphic classification key for Cowardin et al. (1979) classified palustrine wetlands in the Prairie Pothole Region (PPR).

Prairie Pothole Region (PPR) Hydrogeomorphic Key

1 Wetland is classified as Cowardin Palustrine..2
1 Wetland is not classified as Palustrine.................................. Stop here (this key is not applicable)
2 Wetland is detectable via remotely sensed data 3
2 Wetland is not detectable via remotely sensed data .... ***Lost/Misclassified***
3 Wetland is associated with a natural, continuous NHD stream or surrounding floodplain
.... ***Riverine*** **(6)**
3 Wetland is not associated with a natural, continuous NHD stream..4
4 Wetland exists within a closed watershed .... ***Depressional*** **(10)**
4 Wetland does not exist within a closed watershed 5
5 Wetland exists across a topographic slope .... ***Slope*** **(14)**
5 Wetland exists along the edge of a lake or reservoir .... ***Lacustrine Fringe***

6 Wetland retains water due to landscape alteration (anthropogenic or beaver activity) 7
6 Wetland does not retain water due to landscape alteration...8
7 Wetland is excavated .... Riverine Excavated
7 Wetland is diked .... Riverine Diked
8 Wetland is situated within current or historic streambed 9
8 Wetland is outside of streambed but within the floodplain .... Riverine Floodplain
9 Wetland exists within a streambed during low flow .... Riverine Streambed
9 Wetland is disconnected and was formed by streamflow at bend .... Riverine Oxbow

10 Wetland retains water due to landscape alteration 11
10 Wetland does not retain water due to landscape alteration...12
11 Wetland is excavated .... Depressional Excavated
11 Wetland is diked .... Depressional Diked
12 Wetland is situated within a drainage .... Depressional Draw
12 Wetland is not situated within a drainage...13
13 Wetland is not diked, drained or excavated.. Pothole Wetland
13 Wetland is diked, drained or excavated........................... Altered Pothole (see modifiers below)

14 Wetland retains water due to landscape alteration 15
14 Wetland does not retain water due to landscape alteration.................................. Slope Wetland
15 Wetland is excavated .... Slope Excavated
15 Wetland is diked .... Slope Diked

Modifiers for Altered Pothole
a. Diked: a dike has been constructed to increase water permanence in part of the basin
b. Drained: a trench has been built to decrease water permanence in the basin
c. Excavated: a portion of the basin has been excavated to concentrate water accumulation

Figure 2.4. Two National Wetlands Inventory wetlands in the High Plains Region labeled as palustrine, emergent, seasonally flooded (PEM1C) according to the Cowardin et al. (1979) classification. Using the hydrogeomorphic classification key, the first wetland was identified as the depressional class with the playa subclass and the second is identified as the riverine class and the floodplain subclass.

CHAPTER III

SELECTION AND RANKING OF PREDICTIVE ECOSYSTEM SERVICE MODELS FOR PLAYA WETLANDS AND DEVELOPMENT OF A SAMPLING MANUAL FOR THE HIGH PLAINS REGION OF THE U.S.

Abstract

Playa wetlands provide numerous ecosystem services to society. These depressional recharge wetlands exist within closed watersheds and are often negatively impacted by disturbances occurring in the adjacent upland. The land use surrounding a playa influences function and the provisioning of ecosystem services. The U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) established the Conservation Effects Assessment Project Wetlands Component (CEAP – Wetlands) to determine the effects that USDA conservation programs have on ecosystem services provided by wetlands in numerous regions of the United States. In the High Plains Region, previous work has examined playa-wetland ecosystem services relative to surrounding land use as influenced by various conservation programs. Predictive models capable of quantifying various ecosystem services resulted from these efforts. The objectives of my work were to compile these preexisting predictive models for playa ecosystem services and develop a sampling manual with application instructions detailing use of these predictive models. I also used various open source spatial databases, e.g., CropScape land cover

data, Landsat 8 imagery, Soil Survey Geodatabase (SSURGO), to populate and rank the predictive models based on ease of use. In this ease-of-use evaluation, models of abiotic services were ranked as the simplest to use. Because biotic services rely heavily on hydroperiod and water presence, these models were ranked as the most difficult to use since determining hydroperiod remotely is not straightforward.

Once models were ranked, I incorporated them into a sampling manual for High Plains depressional wetlands. The sampling manual included instructions of the model application processes and a previously developed hydrogeomorphic key for classifying National Wetlands Inventory classified palustrine wetlands in the High Plains Region into functional groupings. Together, the models, instructions and keys provided in the manual can be used to classify a playa wetland and to estimate ecosystem services. These estimates can be based on current conditions, past conditions if historical data are accessible, or future conditions by simulating possible future scenarios. Knowledge of wetland-ecosystem service provisioning can be used by natural resource managers and policy makers to inform decisions for conservation practices and policies regarding playa wetlands the services they provide to society.

Introduction

Playa wetlands are shallow, depressional, recharge wetlands that exist within closed watersheds. Playa wetlands are the dominant hydrologic feature within the High Plains Region (HPR) of the United States (Bolen et al. 1989). The HPR covers the plains of western Texas, Oklahoma, Kansas, western and central Nebraska along with eastern Colorado, New Mexico and southeastern Wyoming (Figure 3.1). Because playas exist mostly in a semi-arid region, the length of time a playa contains ponded water (i.e., its hydroperiod) is naturally variable and drives the functions and processes occurring within these wetlands (Smith et al. 2008). Numerous subregions are recognized in the HPR, one being the Western High Plains (WHP), which covers the large, western portion of the region, and another being the Rainwater Basin (RWB) in central Nebraska (Figure 3.1) (Smith 2003). In central Nebraska, there is also another area where playa wetlands occur known as the Central Table Playas. However, knowledge of Central Table Playas is limited (LaGrange 2005) and none of the work in my research is specific to this portion of the HPR (Figure 3.1). The WHP was historically short-grass and mixed-grass prairie while the RWB contained mixed-grass and tall-grass species (Küchler 1975; Stutheit et al. 2004). The WHP has little topographic relief, while the RWB contains gently rolling plains and stream networks that have facilitated the mechanical drainage of wetlands (Smith 2003; LaGrange et al. 2011). Losses of playa area have been estimated to be 60% in the southern WHP and over 90% in the RWB (Gersib 1991; Johnson et al. 2012).

Remaining playa wetlands provide numerous ecosystem services to the region and are considered biodiversity hotspots in a largely semiarid environment (Smith et al. 2011). However, ecosystem service provisioning can be degraded when basin modifications or filling with sediments occur (Luo et al. 1997). Increased sediment inputs resulting from upland cultivation is one of the largest threats to remaining playa wetlands and the functioning of over 95% of playas are estimated to be affected by sedimentation from modified watersheds (Johnson et al. 2012). When sedimentation occurs, infilling of the playa basin decreases water volume and alters the hydrology limiting ecosystem service provisioning (Smith et al. 2011). The ability to estimate how land use and conservation programs affect the provisioning of ecosystem services could be used to prioritize the implementation of conservation programs and practices for conserving playa-wetland functions. Conserving playa-wetland functions has the potential to improve ecosystem service provisioning to local and global communities.

Conservation Effects Assessment Project (CEAP)

The U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) established the Conservation Effects Assessment Project (CEAP) to evaluate the effects of conservation assistance programs on private lands across the United States (Tomer et al. 2014). The current goal of CEAP is to understand and measure ecosystem service provisioning on the landscape and how conservation programs affect those services (Duriancik et al. 2008). The CEAP wetlands component (CEAP–Wetlands) has focused on the effects that conservation programs have on wetland ecosystem services in regions where wetlands were historically abundant, losses have been high due to agricultural activity, and a large percentage of lands are enrolled in conservation programs (Eckles 2008). In the HPR, CEAP–Wetlands studies have collected field data and quantified ecosystem services of playas surrounded by native grass, agricultural lands, and federally assisted conservation program lands (Smith et al. 2012a). The Conservation Reserve Program (CRP) and the Wetlands Reserve Program (WRP) now carried out as the Wetland Reserve Easement (WRE) under the Agricultural Conservation Easement Project (ACEP), are the two most common conservation programs in the HPR (Natural Resource Conservation Service 2014; Smith et al. 2015). In the WHP, the CRP is more common and in the RWB, WRP/WRE is more common (Smith et al. 2015). The CRP is administered by the Farm Service Agency (FSA) with NRCS technical assistance and focuses on establishing perennial cover on previously farmed and highly erodible lands (Stubbs 2014; Farm Service Agency 2016).

The focus of CRP is not on wetland condition but on management practices within the watershed that can have indirect effects on playa wetlands (Tsai et al. 2007). The WRP/WRE is administered by NRCS and focuses on protecting, restoring and enhancing wetlands (Natural Resource Conservation Service 2014).

Ecosystem Service Predictions

Another goal of CEAP–Wetlands was to develop, using data from the field studies, predictive models that could be used to estimate ecosystem service provisioning (Duriancik et al. 2008). Some models developed for playa wetlands in the HPR included contaminant filtration and concentration, floodwater storage, greenhouse-gas flux, soil organic carbon and plant species richness (O'Connell et al. 2012a; Haukos et al. 2016; Zhuoqing et al. 2016a, 2016b; McMurry and Smith 2018). Characteristics of the playa basin and upland such as dominant surrounding land use, wetland area, and watershed size were used as explanatory variables (Kensinger et al. 2013, 2014). Since estimations through field surveys and sampling require significant expenditures of time and financial resources, services could be more easily and economically estimated using the models developed under CEAP—Wetlands populated with remotely sensed data.

Objectives

My first objective was to assemble all pre-existing, playa, ecosystem-service models developed through CEAP–Wetlands and rank them by ease of use. Models that could be applied using entirely data from remotely sensed sources were considered ideal since the time requirements associated with remote measurements are less than those associated with taking field measurements. My second objective was to develop a sampling manual using the ranked ecosystem service models along with the hydrogeomorphic (HGM) classification key developed for my previous research objective (See Chapter 2). A manual capable of identifying playas using the HGM key and estimating ecosystem services remotely could be used to inform decisions regarding conservation practice and program implementation.

CEAP–Wetlands High Plains Region

Numerous research projects had previously been carried out in the HPR measuring playa ecosystem services along with playa and upland characteristics. Data from these projects were used to develop ecosystem-service models for CEAP–Wetlands (Duriancik et al. 2008). The research projects and resulting models are summarized below and are organized by subregion sampled.

Projects were carried out in both the WHP and the RWB, but some were specific to only one subregion or portions within a subregion. The WHP is often divided into three portions, the Northern, Central and Southern High Plains (Figure 3.1). In the portion of the WHP known as the Southern High Plains (SHP), researchers sampled sediment depth, floodwater storage, and avian and amphibian presence in 2003 and 2004 (Tasi et al. 2007, 2010, 2012; Venne et al. 2012), as well as contaminants in 2008 and 2009 (Haukos et al. 2016). In the entire WHP, plant communities were sampled in 2008 and 2009 and soil carbon was sampled in 2009 (O'Connell et al. 2012b, 2016) (Figure 3.1). Playas in the entire WHP and in the RWB were sampled for pesticide residues in 2008 and 2009 (Belden et al. 2012) (Figure 3.1). Lastly, greenhouse-gas fluxes in playas were sampled in the WHP portion known as the Northern High Plains (NHP) along with the RWB in 2012 and 2013 (Daniel et al. 2019) (Figure 3.1). The ecosystem-service models developed from these data are most effective in the subregions where the data were collected. Application of these models outside of the area of development should be done with caution.

Western High Plains Research

In 2003 and 2004, 80 SHP playas were sampled measuring sediment depth, playa volume, avian and waterfowl presence, and amphibian species richness (Tasi et al. 2007, 2010, 2012; Venne et al. 2012) (Figure 3.1). Field measurements included identification of the playa edge, water depth, and hydroperiod length, while remote measurements included watershed size and land use within the watershed. These data were used to calculate additional features including playa area, original playa volume based on the truncated cone calculation method in Tsai (2007) and sediment volume based on sediment depth and playa area (Tsai et al. 2010). The proportion of playa volume loss was calculated as the current volume with sediment infilling divided by the original volume, and a tilled index was developed based on surrounding land use; calculations followed those provided in Tsai et al. (2007). The resulting data were later used to build regression equations capable of estimating SHP playa sediment depth, floodwater storage, avian abundance and waterfowl species richness, and amphibian species richness (Kensinger et al. 2013, 2015; McMurry and Smith 2018).

In 2008 and 2009, 36 SHP playas were sampled measuring contaminant concentration and contaminant filtration (Haukos et al. 2016) (Figure 3.1). Field data included runoff-water samples collected at the cultivated edge of a vegetative buffer and repeated at 10-m increments moving inward towards the playa edge. Vegetative-buffer type was identified as CRP, fallow crop, or native grass. Mean concentrations for 19 common contaminants were quantified at each buffer distance and maximum percent contaminant removal for 18 contaminants was also calculated by buffer type. Predictions for contaminants can be carried out for SHP playas by selecting mean values based on buffer width and type (Haukos et al. 2016).

In growing seasons of 2008 and 2009, plant-community composition in 261 playas was measured and in 2009 soil organic carbon was measured in 162 playas across the WHP (O'Connell et al. 2012b, 2016) (Figure 3.1). Playas were selected from an established set of 300 and measurements included both wetland and upland characteristics. In the field, playa edge was delineated by the visual change in elevation and confirmed with identification of the hydric-soil boundary (O'Connell et al. 2012b). Dominant land use within the watershed was identified remotely as either cropland, CRP or native grass and verified in the field by visually confirming and sampling vegetation 100 m into the upland. Variables quantified included plant cover by species as determined using step-point surveys across the playa basin (O'Connell et al. 2012b). To measure soil organic carbon in the playa and surrounding upland, soil samples were collected from the playa basin (n = 1) and from outside the basin (n = 3) at 10-m, 40-m and 100-m distances from the playa edge (O'Connell et al. 2016). Presence or absence of water was also recorded during sampling. These data were later used in developing predictive models for both plant species richness and soil organic carbon for WHP playas surrounded by the three land-use types (O'Connell et al. 2012a; Zhuoqing et al. 2016b). The plant species richness model variables included water presence, playa area, area of all surrounding grassland playas within a given distance, sediment depth and UTM location (O'Connell et al. 2012a). The soil carbon model was built to estimate values within the playa basin using the Soil Adjusted Vegetation Index (SAVI) and Soil Survey Geographic Database (SSURGO) values as explanatory variables to estimate wetland SOC using basin as well as upland measurements (Zhuoqing et al. 2016b).

Western High Plains and Rainwater Basin Research

In 2008 and 2009, pesticide residues were measured in sediments from 264 playas in both the WHP and the RWB subregions (Belden et al. 2012) (Figure 3.1). The WHP was divided in half at the northern border of Oklahoma due to differing pesticide application practices in these distinct areas (Belden et al. 2012). The NHP and the northern half of the Central High Plains (CHP) were labeled as the 'northern playas', while the SHP and southern half of the CHP were labeled as the 'southern playas' (Figures 3.1 and 3.2). Soil samples were taken from each wetland basin, and surrounding land use was identified by establishing a 500-m buffer in a GIS and determining the dominant land-use type within the buffered area. In the WHP, land-cover type was classified as cropland, CRP, or native grassland. In the RWB, land-cover type was classified as cropland playa, WRP/WRE playa, or reference playa with reference playas being sampled from those playas designated as least disturbed by Nebraska Game and Parks Commission (NGPC) (Belden et al. 2012). The resulting pesticide data were used to develop tables for selecting mean pesticide concentrations according to land uses within the northern and southern playa groups in the WHP as well as the RWB (Kensinger et al. 2014).

In 2012 and 2013 greenhouse gas (GHG) flux was measured in 42 playas located in the NHP of Nebraska and the RWB (Daniel et al. 2019) (Figure 3.1). GHG flux was standardized as carbon dioxide equivalents over 100 years using the Global Warming Potential (GWP) metric and was calculated as the sum of the changes in carbon dioxide, methane and nitrous oxide (Daniel et al. 2019). Biweekly gas measurements were taken at three different points in the playa. Land use in the WHP was identified as cropland, CRP, or native grass while land use in the RWB was identified as cropland playa, WRP/WRE playa, or reference playa. Models were developed using these data along with spectral reflectance data accessed through NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) (Zhuoqing et al. 2016a). Values used from MODIS were related to vegetative cover and included Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR).

Methods

Ecosystem Service Model Application

I developed methods for measuring the metrics required for each of the ecosystem service models and then applied and ranked the models according to ease-of-use. I did this using randomly selected playas from the subset of National Wetlands Inventory (NWI) identified palustrine wetlands that were identified as playas in chapter 2, along with the Playa Lakes Joint Venture Probable Playa dataset (Playa Lakes Joint Venture 2010; U.S. Fish and Wildlife Service 2017).

Playa polygons were selected by randomly scrolling through the attribute table and clicking the playa information row in ArcMap 10.4 (Esri 2011). Measurements required for model application were carried out on playas that were not significantly altered by an excavated pit or an established dike and that were no less than 0.2 ha in size. This was done to avoid NWI polygons which represented lost wetlands or only partial playas due to the application of the Cowardin et al. (1979) classification which can identify different areas of vegetation structure as different polygons. Different playas were measured for different ecosystem service models to incorporate the variability of playa characteristics. In order to develop methods for some specific metrics I selected a playa with the necessary features present. For example, to develop methods for the contaminant concentration model, I selected a playa with a measurable vegetative buffer present to determine the potential difficulty of application when measuring a buffer. Throughout the application process, I identified datasets that would be suitable for providing the data needed to populate the model being evaluated. These datasets included NWI wetland shapefiles, Esri's U.S. Geological Survey derived topographic basemap, Esri's satellite imagery basemap, the National Agricultural Statistics Service (NASS) CropScape land-use dataset, Landsat 8 satellite imagery and reflectance products, Moderate Resolution Imaging Spectroradiometer (MODIS) values for vegetative reflectance data, and the Web Soil Survey's Soil Survey Geodatabase (SSURGO) (Weiguo et al. 2012; Myneni et al. 2015; Vermote et al. 2016; Esri 2017a, 2017b; U.S. Fish and Wildlife Service 2017; Soil Survey Staff 2017).

When models included equations built for separate subregions or land-use types, the techniques for measuring metrics remained the same and therefore did not influence the ranking of the models. For example, when applying the greenhouse-gas flux model either in the WHP or the RWB, the MODIS metric would be measured using the same technique. Similarly, identifying land-use type as cropland or CRP would require the same technique and effort no matter the data layer being used. Because of this, it was suitable to determine ease-of-use by applying all of the models on randomly selected playas regardless of subregion or land-use type.

When models are being applied for service valuation, subregion and land-use type must be identified for an individual playa so the corresponding equation can be selected and used appropriately. The WHP subregion can be identified according to CEAP—Wetlands with the Northern, Central and Southern High Plains identified as designated by Smith et al. (2012b) (Figure 3.1). The RWB subregion within the CEAP—Wetlands HPR can be defined according to the Rainwater Basin Joint Venture (2017) (Figure 3.1). Lastly, the northern and southern playa groups designated by Belden et al. (2012) for pesticide residue in the WHP can be determined using the northern border of Oklahoma to separate the two (Figure 3.2). Land use can be identified as grassland, fallow crop and active cropland using U.S. Department of Agriculture's CropScape data. When the models were developed, grassland consisted only of native grassland cover that had not been previously tilled. CropScape data only identifies grasses as a broad type that may include restored or non-native grass types but was the most applicable and broadly available dataset for my application purposes. For future application, users must be aware of the limitations of identifying native grassland using CropScape and may consider more specific data sources. Identification of federal conservation program lands was not carried out for ranking models by ease-of-use since, as stated previously, it would make no change in the methods for land-use determination and would therefore not alter the model ranking. To identify conservation program lands, a user would need to access federal conservation program spatial data and apply the same methods used with CropScape to identify land-use type. However, these data are tightly controlled to maintain the privacy of program participants. For determining if an RWB playa is considered reference condition, the NGPC should be contacted. The processes I carried out to measure metrics for application of each model are detailed below.

Sediment Depth: The sediment depth model was applied using the provided regression equation along with percent cropland within the surrounding watershed (Table 3.1) (McMurry and Smith 2018). Watershed was delineated using the USGS topographic base map available in Esri's ArcMap 10.4 and edge was determined according to high points in the surrounding landscape based on the New Hampshire Method (Natural Resource Conservation Service n.d.; Esri 2017a). A new polygon was built in ArcMap and the Sketch Editor tool was used to build the watershed edge by drawing lines between the highest points surrounding the basin to form a polygon. Percent cropland was determined using the CropScape land-use raster which is managed by the U.S. Department of Agriculture and identifies numerous crop types as well as grassland and fallow cropland (Weiguo et al. 2012). The number of 30-m pixels within the watershed by land-use type was calculated using the ArcMap Zonal Statistics tool and the total number of cropland pixels divided by the total number of pixels within the watershed was used to calculate percent crop.

Floodwater Storage: The floodwater storage-volume model was applied using two regression equations along with playa area and sediment depth (McMurry and Smith 2018). Four equations were used to determine the current storage volume (Table 3.1) The first was used to calculate original volume (OVol) based on playa area measured in hectares. Playa area was determined using the selected wetland polygon. Next, percent volume lost (%Lost) was calculated using the model equation with sediment depth in centimeters which was determined using the sediment depth model. Total volume lost (LVol) was then determined by multiplying the percent volume lost with the original volume and finally, current floodwater storage (FwSt) was calculated as the difference between original volume and volume lost.

Amphibian Species Richness: Three metrics were used to apply the amphibian species richness model (Kensinger et al. 2013). Metrics included the ratio of watershed area to playa area and hydroperiod length in days (Table 3.2). Playa area was measured from the wetland polygon.

Watershed area was measured after delineating the watershed using a topographic map as mentioned above. Hydroperiod was not measurable using the sources available but an average playa value of 98 days measured by Tsai et al. (2007) was used for my application purposes. Methods for measuring actual hydroperiod can include field sampling or estimation using Agricultural Policy Environmental EXtender (APEX) simulation platform, but I was not able to access the APEX code for my methods (contact USDA Temple, TX; Willis 2008).

Avian Species Richness and Waterfowl Abundance: Eight equations were available to estimate avian-fauna metrics. The avian species-richness models as well as waterfowl abundance models were built for each season throughout the year (Table 3.3) (Kensinger et al. 2015). Each equation was applied and required three to five metrics. Playa area was determined using the selected playa polygon and watershed area was determined through wetland delineation using a topographic map as stated previously. Water presence in the basin was measured as present or absent using Landsat 8 satellite imagery nearest to the sampling date which was sourced from the U.S. Geological Survey Earth Explorer (U.S. Geological Survey 2017b). Water depth was not measurable using available data sources, but field sampling or APEX modeling could be used (contact USDA Temple, TX). For my application purposes, I applied an average water depth value of 37 cm as provided in Tsai et al. (2012). Lastly, tilled index was calculated by dividing the difference between tilled and untilled landscape by the sum of tilled and untilled landscape in the watershed. This was done using the Zonal Statistics tool in ArcMap 10.4 to measure pixels within the watershed using a CropScape data raster and by summing the tilled and untilled pixel types. Tilled land in the model was considered cropland and CRP while untilled was grassland (Tsai et al. 2007). To identify CRP land use, the same land-use summation would be carried out as above using conservation program spatial data.

Percent Contaminant Filtration: The model for average percent removal of 18 different contaminants was applied using a set of given values based on vegetative-buffer type (Haukos et al. 2016) (Table 3.4). Buffer type was identified using CropScape land-cover classes to visually observe the non-crop land-use type directly adjacent to greater than 50% of the playa edge. Land cover in this dataset was identified as fallow crop or grassland. To identify a CRP buffer, the same method would be applied along with CRP spatial data. To apply the model, the appropriate contaminant removal value was then selected from the given table.

Contaminant Concentration: Mean contaminant concentrations could be estimated for runoff flowing into a playa based on the width of a non-crop vegetative buffer. The model was applied by selecting concentration values for 19 common contaminants from the provided table based on the value for mean buffer width rounded to the nearest 10 (Table 3.5) (Haukos et al. 2016). Mean vegetative buffer width was determined by measuring the buffer up to a distance of 60 m. Measurements were taken in ArcMap by first calculating the playa centroid location in decimal degrees and displaying the centroid as a point. Next, the Create Features tool was used to create 4 new points on the playa edge each at a 0-, 90-, 180- and 270-degree angle from the centroid to correspond with the four cardinal directions. Once edge points were established, the non-crop buffer width was identified within the CropScape land use layer and measured at approximately 90-degree angles from the playa edge using the Measure tool. The four buffer widths were averaged to produce a mean width value.

Plant Species Richness: The plant species-richness model was applied using equations for native wetland plant species and native upland plant species within the playa basin (O'Connell et al. 2012a). Dominant land use was again identified as grassland or cropland using CropScape data through visual examination or by summing the pixels of each land-use type within a 500-m radius area surrounding the playa. Once again, CRP lands are identifiable using this same method along with CRP spatial data. All other potential metrics were then measured including playa area, total area of nearby playas, UTM location, water presence and distance to nearest grassland playa (Table 3.6). Playa area was determined using the playa polygon representing the playa of interest.

The total area of all playas within 1 km or 5 km was determined by building a buffer of the required width around the playa polygon and selecting all Probable Playa dataset polygons within the buffer using the ArcMap Select by Location tool (Playa Lakes Joint Venture 2010). These selected playas were displayed as a separate data layer and Summary Statistics was used to calculate total area summed. The nearest grassland playa was also identified using the Probable Playa polygons along with CropScape land-use database by identifying grassland as dominant land use within a 500 m radius of each near playa. The Measure tool was used to measure the distance from the edge of the playa of interest to the edge of the nearest grassland playa. Northing and easting UTM values were determined by converting the decimal degree coordinates of the playa centroid. Lastly, water presence or absence was obtained using the most recent available satellite image for the playa location observed with Landsat 8 imagery downloaded from USGS Earth Explorer (U.S. Geological Survey 2016, 2017a).

Soil Organic Carbon (SOC): The carbon storage model can estimate soil carbon in a playa basin at a 0 to 50 cm depth (Zhuoqing et al. 2016b). Equations were each associated with a dominant land-use type in the surrounding watershed (Table 3.7). Each equation was applied. Dominant land use was identified as grassland or cropland by examining CropScape data visually when obvious, or by establishing a 500-m buffer around the playa and summing the pixels of each land-use type to determine the most common. For identification of CRP lands, this same method could be applied with CRP spatial data displayed. Metrics were determined at the playa location using the Soil Survey Geodatabase (SSURGO) accessed through the USDA Web Soil Survey (Soil Survey Staff 2017). Most soil characteristic values were measured at the playa center but the ASUR modification required the average of measurements at 10 m and 40 m directly southwest of the playa edge. To determine the location of these points the playa centroid was displayed in ArcMap and the Create Features tool was used to place a point at the end of a line drawn at a 225-degree angle. One point was built on the playa edge, one point was 10 m from the playa edge and another point was 40 m from the edge. The coordinates for all points were identified in decimal degrees. These coordinates were then used in the SSURGO web platform to determine an Area of Interest (AOI) and identify values at each necessary location using the available soil data look up categories (Soil Survey Staff 2017). This model also required the Soil Adjusted Vegetative Index (SAVI) value which indicates vegetative reflectance with a correction for soil reflection (Zhuoqing et al. 2016b). This was downloaded from Landsat 8 Level-2 product data through the U.S. Geological Survey and scaled by a value of 0.0001 as required according to the product guide (U.S. Geological Survey 2017c).

Greenhouse-gas Flux: The greenhouse-gas flux (GHG) model was applied across two sets of equations, one set for playas in the RWB and one for playas in the NHP portion of the WHP (Table 3.8) (Zhuoqing et al. 2016a). Dominant land use was identified as grassland or cropland using CropScape as previously stated. Both CRP and WRP/WRE lands are identifiable using the same methods but access to conservation program spatial data would be required. In the RWB, reference wetlands are identifiable through contact with the NGPC. Metrics required for model equations were Fraction of Photosynthetically Active Radiation (FPAR) and Leaf Area Index (LAI). These data were accessed through NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) products on the Earth Observation System website (Vannan et al. 2009). Raster values for the MODIS data were scaled by the appropriate factors and applied in the equations (Zhuoqing et al. 2016a).

Pesticide Residue: The mean pesticide residue model was applied by selecting values in a table according to subregion and land use type (Table 3.9) (Kensinger et al. 2014). Dominant land use again was identified as grassland or cropland using CropScape and CRP or WRP/WRE lands are identifiable from conservation program spatial data. Again, reference wetlands can be identified through contact with NGPC. Land use was identified and a mean value was selected from the pesticide-residue table.

Ecosystem Service Model Ranking

Once all necessary metrics had been explored for model application, all models were placed in rank order based on ease of use according to three accumulating factors. The first factor was number of metrics required, the second was method of application, and the third was location of required metrics. Fewer metrics required by a model resulted in a simpler ease-of-use ranking with more metrics increasing the difficulty rank. Method of application included either the selection of mean values from a provided table or application of one or more regression equations. Selection of mean values was considered simplest and complexity increased with the requirement of numerous equations. Lastly, location of a data source was considered in the rank order. Models using data that could be broadly displayed in a GIS such as land-use data and topographic maps were considered simplest in application, while models using data considered to be external, either location/time specific or accessed through a web platform such as the Web Soil Survey, were considered to require greater effort and were ranked higher. External data additionally included modeling within APEX (contact USDA, Temple, TX) or field sampling which were considered to require the greatest effort.

Sampling Manual Development

After models were applied and ranking was carried out, an instructional manual was developed using the selected models and the metrics required (Appendix A). The manual was built similarly to the Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems developed by the USDA – Agricultural Research Service Jornada Experimental Range (Herrick et al. 2005). The hydrogeomorphic classification key developed as a separate research objective (See Chapter 2) was included in the manual along with all 10 ecosystem service models and their application instructions. Models were provided in rank order and the instructions were developed based on the model application process.

Results

Ecosystem Service Model Ranking

Ranking results placed services on a scale from 1 to 10 (Table 3.10). The first three models in the ranking were contaminant filtration, contaminant concentration and pesticide residue with each requiring one metric and mean values selected from the provided tables (Tables 3.4, 3.5, 3.9, 3.10). Model application was considered simplest among these models since only one metric was required of each and service values were selected from provided tables. The fourth and fifth ranked models were for sediment depth and floodwater storage (Table 3.10). Each of these also required only one metric but one or more equations were used for service estimations (Table 3.1). Models ranked as sixth, seventh and eighth were greenhouse-gas flux, soil organic carbon and plant species richness (Table 3.10). These required multiple metrics and equations but also included external data from MODIS, SSURGO and recent Landsat 8 imagery (Tables 3.6, 3.7 and 3.8). The last two ranked models were amphibian species richness and avian species richness with waterfowl abundance (Table 3.10). These both required multiple metrics and at least one equation, but each included one feature requiring either field measurements or APEX modeling (USDA, Temple, TX) to completely populate the model parameters (Tables 3.2 and 3.3).

Playa Sampling Manual

The sampling manual was titled Ecosystem Services Estimation for Depressional Wetlands in the High Plains Region: Sampling Manual for the Integrated Landscape Modeling Partnership and is provided as Appendix A. The manual was intended for application on wetlands across the HPR. Three chapters were included as Chapter 1: Introduction, Chapter 2: HGM Classification Key and Chapter 3: Models for Predicting Ecosystem Services.

The first chapter of the sampling manual included an introduction and gave a brief background on playa wetlands, ecosystem services, wetland classification and predictive models. Potential manual users were identified and included conservation managers and policy makers within the USDA and Department of the Interior as well as others such as state biologists and wetland managers who could make use of the manual. Determining land use for some conservation program lands requires access to confidential USDA spatial data. Users may inquire with the NRCS about potential access to these data. The High Plains Region (HPR) was defined according to the CEAP–Wetlands designation and the existing subregions explained.

The second chapter of the manual provided instructions on applying the hydrogeomorphic key (See Thesis Chapter 2). The manual chapter detailed important definitions as well as instructions. Recommendations were made for the datasets and map projections that could be used for key application. The terms used in the key were listed and defined since a clear understanding of key-specific terms was deemed necessary for application. The last portion of the chapter contained the HGM classification key.

The third and final chapter in the sampling manual presented all 10 ecosystem service models in rank order from simplest to most complex in application. The majority of the chapter contained instructions on model application and remote measuring of necessary metrics. Within each set of model instructions, metrics were detailed, recommended methods were provided and recommended datasets were included. Due to the regions in which model data were sampled, six of these models were recommended for use only in the SHP portion of the WHP (sediment depth, floodwater storage, amphibian species richness, avian species richness with waterfowl abundance, contaminant concentration and contaminant filtration), two were recommended for use across the full WHP (soil organic carbon and plant species richness), one for playas across both the entire WHP and the RWB (pesticide residue) and one restricted to the NHP portion of the WHP along with the full RWB (greenhouse gas) (Figure 3.1). This was done since differences between the subregions are significant and predictive models built from data within one subregion or portion may not be informative for another. If a user applies a model to a subregion or portion apart from the origin of data used in development, they must do so with caution. To assist with model application, datasheets specific to each ecosystem service model were included in the sampling manual appendix.

Discussion

Ecosystem Service Model Ranking

The ranking of models showed that those predicting abiotic ecosystem services were the least complex to apply as they were ranked as 1–7 (Table 3.10). Models predicting biotic ecosystem service were considered most complex to apply and were ranked as numbers 8–10. All abiotic ecosystem-service metrics could be measured using open-source remotely sensed data. Abiotic functions within a playa are closely tied to the activities taking place within in the watershed and soil disturbances in the watershed are capable of increasing sediments, decreasing volume and shortening hydroperiod (Luo et al. 1997). Remotely sensed data can be used to observe watershed characteristics with simple methods in a GIS.

The complexity of predicting biotic ecosystem services is related to the importance of hydroperiod and water presence. In wetlands, biotic services such as amphibian and avian richness and waterfowl abundance, are reliant on inundation and hydroperiod (Ghioca and Smith 2008; Tsai et al. 2012). The natural hydroperiod in playas relies on precipitation which is seasonal and intermittent (Smith 2003). This makes measuring hydroperiod using remotely sensed data more difficult. Collection of remotely sensed data are often limited in sampling frequency and repetition which causes rapidly changing features, such as playa hydroperiod, to go undetected. The lack of hydrologic data resulted in the biotic models being ranked as most complex since external modeling or gathering of field data were necessary for model application to occur. External modeling for hydroperiod and water depth can be done using the APEX platform to simulate watershed scale features on a landscape. This platform is open source and a playa watershed can be simulated using code from the ARS office in Temple Texas although we were not able to get access to this code for our application and ranking purposes.

Playa Sampling Manual

The Ecosystem Services Estimation for Depressional Wetlands in the High Plains Region, Integrated Landscape Manual offers a set of cost-efficient methods that can be used for estimating ecosystem services provided by playa wetlands. Application of this manual can be used to monitor wetland service changes across time, and between changing land-use types and conservation programs. The hydrogeomorphic key included is useful for distinguishing a playa wetland from other wetland types common to the region by determining geomorphology and water source (Brinson 1993). Knowledge of wetland hydrogeomorphology can indicate basic wetland function of many different wetland types (Smith et al. 1995). Once a playa is identified, ecosystem-service provisioning can be estimated using the ecosystem-service models included. Users could include any federal natural-resource manager as well as state and non-government organization managers. Because most of the metrics can be measured through remote sensing, application of the models is cost efficient and requires a minimal time input when compared to field sampling.

The predictive models within the sampling manual can be used by land managers or researchers seeking to identify how playa ecosystem services might be altered with changing land use. This could be used to target conservation efforts within a specific HPR county or subregion by identifying practices that would maximize ecosystem service provisioning through conservation programs and practices. For example, if a playa or set of playas are currently surrounded by cropland and a change to CRP is proposed, the effect on ecosystem services could be simulated by applying the predictive models for both land-use types and comparing the ecosystem-service estimates. These estimations could be used to inform conservation decisions by quantifying the future service provisioning likely to occur and therefore indicating the effects of conservation practices. When models are applied in this way, a user must be sure that all metrics represent the future conditions when estimating future services. For example, when estimating greenhouse-gas flux, vegetative reflectance data are required. These data values should represent cropland reflectance when applying a cropland model and CRP playa reflectance when applying the CRP model. This can be achieved by identifying the spectral reflectance of a nearby CRP playa or by using an average value from local CRP playas.

Important playa water-quality services are related to contaminant and pesticide concentrations and sediment deposition (Tsai et al. 2007; Belden et al. 2012; Haukos et al. 2016). Sediment depth is of particular importance since playas presence and function are being diminished due to the effect of widespread watershed alteration (Johnson et al. 2012). Models for atmospheric services included greenhouse-gas flux and carbon storage as soil organic carbon (O'Connell et al. 2012a, 2016; Zhuoqing et al. 2016a, 2016b; Daniel et al. 2019). Estimation of these services provides an understanding of how changes in land management are likely to impact global climate change and what practices could improve greenhouse gas flux (Natural Resource Conservation Service 2016b).

Service models related to biotic provisioning included plant, amphibian and waterfowl species richness as well as avian abundance (O'Connell et al. 2012a, 2012b; Tsai 2012; Venne 2012; Kensinger et al. 2013, 2015). The presence of wetland plant species relies on hydrology and impacts many other services including water quality and atmospheric interactions (Daniel et al. 2017). Plants are a food source for migrating waterfowl and shelter for amphibian reproduction (Tsai et al. 2012). Playas support waterfowl migration occurring through the Central Flyway and the ability of playas to provide waterfowl habitat impacts populations across North and Central America (Bolen et al. 1989). Because playa function is so closely tied to activities within the watershed, estimation of the provisioning of these ecosystem services would give natural resource managers an understanding of playa quality as well as upland quality (Smith and Haukos 2002).

Future work with the sampling manual could involve the addition of models specifically built for the RWB subregion resulting in more service estimation possibilities across both subregions of the HPR. Models for services such as soil organic carbon, floodwater storage and plant species richness would be informative for wetlands in the RWB. Pollinator presence has recently been modeled in the RWB and SHP and could be implemented into our model ranking. Field testing and application of currently available models would contribute to the accuracy and improve model details.

Playa ecosystem services can be estimated based on current as well as future land use conditions. Models could also estimate historical services if data were available for the required metrics. The ability of this sampling manual to estimate past, present and future services makes it ideal for use in wetland inventory and the support of conservation decision making. Knowledge of playa service changes over time would be useful to inform management and conservation concerns to policy makers which could drive future conservation programs and practices. The comparison of service provisioning from current to proposed land use practices could indicate where and how future conservation programs should be implemented for the greatest improvements. These estimates could support decision making within target regions to protect current playa wetlands and maintain or improve the ecosystem services provided to society. Although these may not be entirely accurate for individual metrics, relative differences among land uses and conservation programs should be robust.

Tables and Figures

Table 3.1. Equations and metrics required for estimating sediment depth and potential floodwater storage of a playa basin. Metrics are percent crop in watershed, playa area (ha) and sediment depth (cm) (McMurry and Smith 2018).

Model Name	***Equation***
Sediment Depth (cm)	sed.depth = 0.44987 + 0.4457*percent.crop.watershed
Original Volume (m^3)	OVol = 13868.5182 + 740.5821 * area + 135.0543 * $area^2$
Percent Lost (%)	%Lost = 20.9841 + 2.4595 * sediment.depth
Total Volume Lost (m^3)	LVol = (OVol * (%Lost / 100)
Floodwater Storage (m^3)	FwSt = OVol – Lvol

Table 3.2. Equation and metrics for estimating amphibian species richness. Metrics are hydroperiod (days) and the ratio of watershed area to playa area (Kensinger et al. 2013).

Model Name	***Equation***
Amphibian Species Richness	amph.rich = EXP(1.0669053 + 0.0016115*hydroperiod – 0.0020619 *ratio.watershed.to.playa)

Table 3.3. Equations and metrics for estimating avian species richness and total waterfowl abundance. Metrics are as follows WD – water depth (cm), WET – playa wetness (binary), PA – playa area (ha), TI – tilled index, WA – watershed area (ha). Modified from Kensinger et al. (2015).

Model Name	***Avian Species Richness***
Fall	$F\_Richness = EXP(- 0.10 - 0.0011*WD + 1.09*WET + 0.031*PA + 0.31*TI)$
Winter	$W\_Richness = EXP(- 0.37 + 0.69*WET - 0.0005*WA + 0.043*PA + 0.22*TI)$
Spring	$Sp\_Richness = EXP(0.66 + 0.0011*WD + 1.03*WET - 0.00012*WA + 0.02*PA + 0.13*TI)$
Summer	$Su\_Richness = EXP(0.87 - 0.0048*WD + 0.85*WET + 0.00014*WA + 0.025*PA + 0.27*TI)$
Model Name	***Total Waterfowl Abundance***
Fall	$F\_WF\_Abundance= EXP(- 4.86 - 0.0077*WD + 7.11*WET + 0.00015*WA + 0.104*PA + 0.43*TI)$
Winter	$W\_WF\_Abundance = EXP(- 3.57 + 0.0201*WD + 0.27*WET - 0.0023*WA + 0.229*PA)$
Spring	$Sp\_WF\_Abundance = EXP(- 3.53 + 0.0639*WD + 4.09*WET + 0.066*PA)$
Summer	$Su\_WF\_Abundance = EXP(- 4.59 - 0.0198*WD + 5.47*WET + 0.00085*WA + 0.076*PA)$

Table 3.4. Mean (±SE) values for percent contaminant filtration estimated by vegetative buffer type. From Haukos et al. (2016).

Contaminant Filtration	***Vegetative Buffer Type***					
	CRP	(SE)	Fallow	(SE)	Native Grassland	(SE)
Total Suspended Solids (TSS) (%)	85.43	(6.16)	79.76	(4.91)	83.44	(3.84)
Total Dissolved Solids (TDS) (%)	57.53	(8.29)	57.62	(6.61)	58.85	(5.17)
Aluminum (Al) (%)	69.71	(8.14)	74.11	(6.65)	77.59	(5.54)
Arsenic (As) (%)	81.31	(8.81)	84.24	(7.20)	74.5	(5.99)
Barium (Ba) (%)	63.73	(8.47)	69.93	(6.92)	79.79	(5.75)
Calcium (Ca) (%)	58.55	(9.86)	62.7	(8.05)	67.17	(6.70)
Chromium (Cr) (%)	98.93	(11.21)	71.54	(9.15)	92.94	(7.62)
Copper (Cu) (%)	68.65	(8.51)	64.35	(6.95)	82.67	(5.78)
Iron (Fe) (%)	71.61	(7.62)	74.93	(6.22)	81.83	(5.18)
Potassium (K) (%)	64.25	(7.81)	60.92	(6.38)	66.89	(5.31)
Magnesium (Mg) (%)	72.97	(8.00)	68.56	(6.53)	69.93	(5.44)
Manganese (Mn) (%)	72.54	(7.54)	74.81	(6.12)	83.64	(5.12)
Nitrogen (N) (%)	85.65	(10.45)	77.96	(8.34)	76.46	(6.52)
Sodium (Na) (%)	58.63	(9.51)	57.38	(7.77)	54.66	(6.46)
Phosphorus (P) (%)	72.04	(8.69)	59.43	(7.09)	76.13	(5.90)
Strontium (Sr) (%)	50.01	(9.97)	65.78	(8.41)	67.21	(6.77)
Vanadium (V) (%)	89.95	(10.11)	77.81	(8.25)	82.3	(6.87)
Zinc (Zn) (%)	60.6	(7.67)	65.64	(6.26)	76.69	(5.21)

Table 3.5. Mean (±SE) contaminant concentrations within runoff water collected at varying buffer widths. From Haukos et al. (2016).

Contaminant	***Buffer (m)***	***Mean (ppm)***	***SE***	***Contaminant***	***Buffer (m)***	***Mean (ppm)***	***SE***
Aluminum	0	168.5	23.9	*Arsenic (As)*	0	0.218	0.0275
(Al)	10	105.82	17.176		10	0.1359	0.0215
	20	69.857	14.039		20	0.0912	0.0188
	30	54.374	11.966		30	0.0723	0.0156
	40	46.923	11.629		40	0.0643	0.0162
	50	44.595	13.133		50	0.0555	0.016
	60	45.899	20.774		60	0.0575	0.0246
Barium (Ba)	0	0.6636	0.0768	*Calcium*	0	66.791	18.747
	10	0.4589	0.0593	*(Ca)*	10	22.676	3.2419
	20	0.3138	0.0484		20	16.793	2.4937
	30	0.2491	0.0439		30	15.127	2.5467
	40	0.2157	0.0483		40	11.179	1.5925
	50	0.2118	0.0542		50	8.4427	1.6784
	60	0.205	0.0645		60	13.014	5.2814
Cadmium	0	0.0048	0.001306	*Chromium*	0	0.1452	0.0418
(Cd)	10	0.003704	0.0009471	*(Cr)*	10	0.0674	0.0122
	20	0.005385	0.001384		20	0.0442	0.0104
	30	0.002273	0.0009145		30	0.0309	8.35E-03
	40	0.003077	0.001332		40	0.0307	8.86E-03
	50	0.004545	0.001574		50	0.0273	0.0102
	60	0.00875	0.002266		60	0.0275	0.0128
Copper (Cu)	0	0.1936	0.1281	*Iron (Fe)*	0	101.99	15.005
	10	0.0493	0.007356		10	64.23	10.582
	20	0.0327	0.005161		20	40.975	7.9188
	30	0.025	0.003989		30	31.506	6.6278
	40	0.0221	0.004591		40	28.186	6.9828
	50	0.02	0.004671		50	26.699	8.034
	60	0.0175	0.006748		60	27.207	12.058
Potassium	0	42.36	5.4731	*Magnesium*	0	32.521	9.0387
(K)	10	29.008	2.9826	*(Mg)*	10	16.388	2.1295
	20	19.606	2.3005		20	10.67	1.555
	30	17.454	2.2876		30	8.5486	1.5101
	40	15.169	2.6746		40	7.9557	1.7998
	50	12.425	2.7249		50	6.75	1.8378
	60	14.52	4.2032		60	7.9787	2.8199

Table 3.5. continued

Contaminant	Buffer (m)	Mean (ppm)	SE	Contaminant	Buffer (m)	Mean (ppm)	SE
Manganese (Mn)	0	1.4572	0.2053	*Sodium (Na)*	0	39.209	35.808
	10	0.9444	0.1621		10	2.2037	0.3591
	20	0.6385	0.1138		20	1.6469	0.2664
	30	0.4682	0.1057		30	1.3859	0.2701
	40	0.4307	0.1114		40	1.3493	0.3214
	50	0.3318	0.0697		50	1.1082	0.336
	60	0.4013	0.1568		60	1.0475	0.3601
Nitrogen (Ni)	0	0.272	0.1716	*Nitrate_p*	0	4.1667	1.2052
	10	0.0737	0.009625		10	3.2844	0.8423
	20	0.0608	0.007584		20	2.3781	0.7942
	30	0.0491	0.005342		30	1.3133	0.3859
	40	0.04	0.006202		40	0.955	0.3957
	50	0.0327	0.007273		50	0.4	0.1187
	60	0.0363	0.0116		60	0.4818	0.1667
Phosphorous (P)	0	2.0396	0.2101	*Total Dissolved Solids (TDS)*	0	0.2659	0.1036
	10	1.4426	0.1596		10	0.1111	0.0145
	20	1.08	0.1509		20	0.0737	8.19E-03
	30	0.9241	0.1417		30	0.0703	0.0119
	40	0.8629	0.1556		40	0.0666	0.0164
	50	0.7273	0.1697		50	0.0438	7.43E-03
	60	0.6837	0.1824		60	0.0457	9.18E-03
Total Suspended Solids (TSS)	0	2.7231	0.5349	*Vanadium (V)*	0	0.1584	0.0296
	10	1.7194	0.3595		10	0.1148	0.0205
	20	1.0846	0.2339		20	0.1208	0.0267
	30	0.7682	0.2107		30	0.0636	0.0134
	40	0.6345	0.2448		40	0.0669	0.0223
	50	0.6218	0.2588		50	0.0909	0.0283
	60	0.8159	0.3379		60	0.1288	0.0423
Zinc (Zn)	0	0.8736	0.4365				
	10	0.3544	0.0371				
	20	0.2869	0.035				
	30	0.2082	0.0214				
	40	0.19	0.0242				
	50	0.2	0.0425				
	60	0.1763	0.0304				

Table 3.6. Equations and metrics for predicting plant species richness in a WHP playa basin. Equation is selected based on species type (wetland or upland) and dominant land use. Metrics include p_area – playa area (ha), 5km_p – area of all playas within 5 km (ha), east – easting UTM, wet – water presence in basin (binary), gr_dist – distance to nearest grassland playa (km), 1 km – area of all playas within 1 km (ha), north – northing UTM. Modified from O'Connell et al. (2012b).

Land Use	***Native Wetland Species Richness***
Native Grassland	Gr_W_Richness = EXP(9.91E-01 + 1.21E-02**p_area*+ 1.14E-03**5km_p* + 1.91E-06**east*+ 3.25E-01**wet*)
CRP	CRP_W_Richness = EXP(4.55E+00 – 2.71E-02**gr_dist* + 7.36E-03 **1km_p* + 2.23E-06**east* – 8.49E-07**north* + 4.98E-01**wet*)
Cropland	Cr_W_Richness = EXP(9.18E-01 + 5.27E-02**p_area* + 2.87E-02**gr_dist* + 1.62E-02**1km_p* + 2.01E-03**5km_p* – 2.86E-06 *east**+ 7.45E-01**wet)*
Land Use	***Native Upland Species Richness***
Native Grassland	Gr_U_Richness = EXP(8.31E-01 – 5.16E-03**1km_p* + 7.10E-04 **5km_p* – 5.15E-07**north* – 1.85E-01**wet*)
CRP	CRP_U_Richness = EXP(2.41E+00 + 2.45E-04**5km_p)*
Cropland	Cr_U_Richness = EXP(2.42E+00 + 3.61E-02**p_area* + 1.46E-02**gr_dist* + 8.94E-03**1km_p* + 1.42E-03**5km_p* – 2.29E-06**east* + 4.95E-01**wet*)

Table 3.7. Equations and metrics for predicting soil organic carbon (kg/m^2) in a WHP playa basin at 0-50 cm depth. Equation is based on surrounding land use. Various metrics are required including one vegetation index and numerous SSURGO values. Metrics are SAVI – Soil Adjusted Vegetation Index, DB – soil bulk density, RangPro – range productivity, WC – water content, pH – acidity, OrgMat – soil organic matter, Sand – percent sand, Ksat – saturated hydraulic conductivity, Slope – representative slope, EC – electrical conductivity, AWS – available water supply, ASUR – modifier to include upland values. Modified from Zhuoqing et al. (2016b).

Land Use	***Soil Organic Carbon (kg/m^2)***
Agriculture Playa	Ag_SOC = POWER (5.46 – 1.955*ASUR_SAVI – 2.438*ASUR_DB + 0.00048*ASUR_RangPro + 0.027*WC – 0.778*pH + 3.921*DB, 2)
CRP Playa	CRP_SOC = POWER (1.162 + 0.53*ASUR_OrgMat + 0.037*Sand – 0.124*Ksat + 0.396*Slope, 2)
Native Grassland Playa	NG_SOC = EXP (1.473 + 0.605*ASUR_EC + 0.028*ASUR_Ksat + 1.932*ASUR_SAVI – 0.356*EC - 0.192*Slope – 0.095 * ASUR_AWS)

Table 3.8. Models and metrics for greenhouse gas flux (g C/ha/day) within a playa basin. Equation is selected based on subregion (RWB or NHP) and surrounding land use. Metrics include the MODIS values FPAR – Fraction of Photosynthetically Active Radiation and LAI – Leaf Area Index. Modified from Zhuoqing et al. (2016a).

Rainwater Basin Land Use	***Rainwater Basin GHG Flux (g C/ha/day/)***
Agriculture	Ag_RWB_GHG = 196485.656 * Power(FPAR,1.357)
Reference	Ref_RWB_GHG = 171901.578 * Power(FPAR,1.222)
WRP(ACEP)	WRP_RWB_GHG = 82717.861 – 13595.894 / FPAR
Northern High Plains Land Use	***Northern High Plains GHG Flux (g C/ha/day)***
Agriculture	Ag_WHP_GHG = EXP(11.568 – 0.538/FPAR)
Native Grass	NG_WHP_GHG = EXP(11.118 – 0 .27/LAI)
CRP	CRP_WHP_GHG = EXP(11.447 – 0.603/FPAR)

Table 3.9. Mean (±SE) pesticide residue concentrations (μg/kg) for 5 different pesticides within playa basins. Values are selected based on playa area or subregion and surrounding land use. Modified from Kensinger et al. (2014).

Northern Playas	***Acetochlor***	***(SE)***	***Atrazine***	***(SE)***	***S-metolachlor***	***(SE)***	***Trifluralin***	***(SE)***
Cropland	0.11	0.11	23.78	13.84	10.36	7.36	0.10	0.07
Native prairie	0.23	0.05	0.42	0.09	0.42	0.09	0.18	0.04
CRP	0.00	0.00	0.67	0.15	0.00	0.00	0.05	0.01
Southern Playas	***Acetochlor***	***(SE)***	***Pendimethalin***	***(SE)***	***S-metolachlor***	***(SE)***	***Trifluralin***	***(SE)***
Cropland	1.64	0.72	15.12	14.28	2.35	2.13	4.87	1.91
Native prairie	1.13	0.61	0.00	0.00	0.23	0.23	0.25	0.12
CRP	0.18	0.03	0.29	0.04	0.00	0.00	0.71	0.10
RWB Playas	***Acetochlor***	***(SE)***	***Atrazine***	***(SE)***	***S-metolachlor***	***(SE)***	***Trifluralin***	***(SE)***
Cropland	1.26	1.26	86.08	80.33	3.61	1.68	0.19	0.10
Reference	0.00	0.00	4.47	3.30	0.68	0.26	0.42	0.15
WRP/WRE	3.61	3.03	1.48	0.64	0.42	0.17	0.13	0.09

Table 3.10. Ecosystem service models for playa wetlands in order of rank based on ease of use from simplest to most complex.

Rank	***Service***	***Metric(s)***	***Model Application***
1	*Contaminant Filtration (%)*	vegetative buffer type	- measure one metric - select value(s)
2	*Contaminant Concentration (ppm)*	vegetative buffer width	- measure one metric - select value(s)
3	*Pesticide Residue ($\mu g/kg$)*	dominant land use	- measure one metric - select value(s)
4	*Sediment Depth (cm)*	percent crop in buffer	- measure one metric - apply equation
5	*Floodwater Storage (m^2)*	playa area	- measure one metric - apply four equations
6	*Greenhouse Gas Flux (g c $ha^{-1}day^{-1}$)*	dominant land use MODIS – FPAR MODIS – LAI	- measure one metric - gather two external data features - apply one equation
7	*Soil Organic Carbon (kg m^{-2})*	dominant land use SSURGO values (up to 10) SAVI	- measure one metric - gather up to 11 external data features - apply equation
8	*Plant Species Richness – Native Wetland and Native Upland*	dominant land use playa area area of all near playas UTM coordinates water presence distance to near grass playa	- measure five metrics - gather one external data feature - apply equation
9	*Amphibian Species Richness*	playa area watershed area hydroperiod (APEX)	- measure two metrics - calculate ratio of metrics - apply APEX - apply equation
10	*Avian Species Richness and Waterfowl Abundance*	playa area water presence water depth (APEX) tilled index watershed area	- measure three metrics - gather one external data feature - apply APEX - apply equation

Figure 3.1. High Plains Region (HPR) as determined by the Conservation Effects Assessment Project Wetlands portion (CEAP–Wetlands). Subregions as designated by LaGrange et al. (2005) and Smith et al. (2012b).

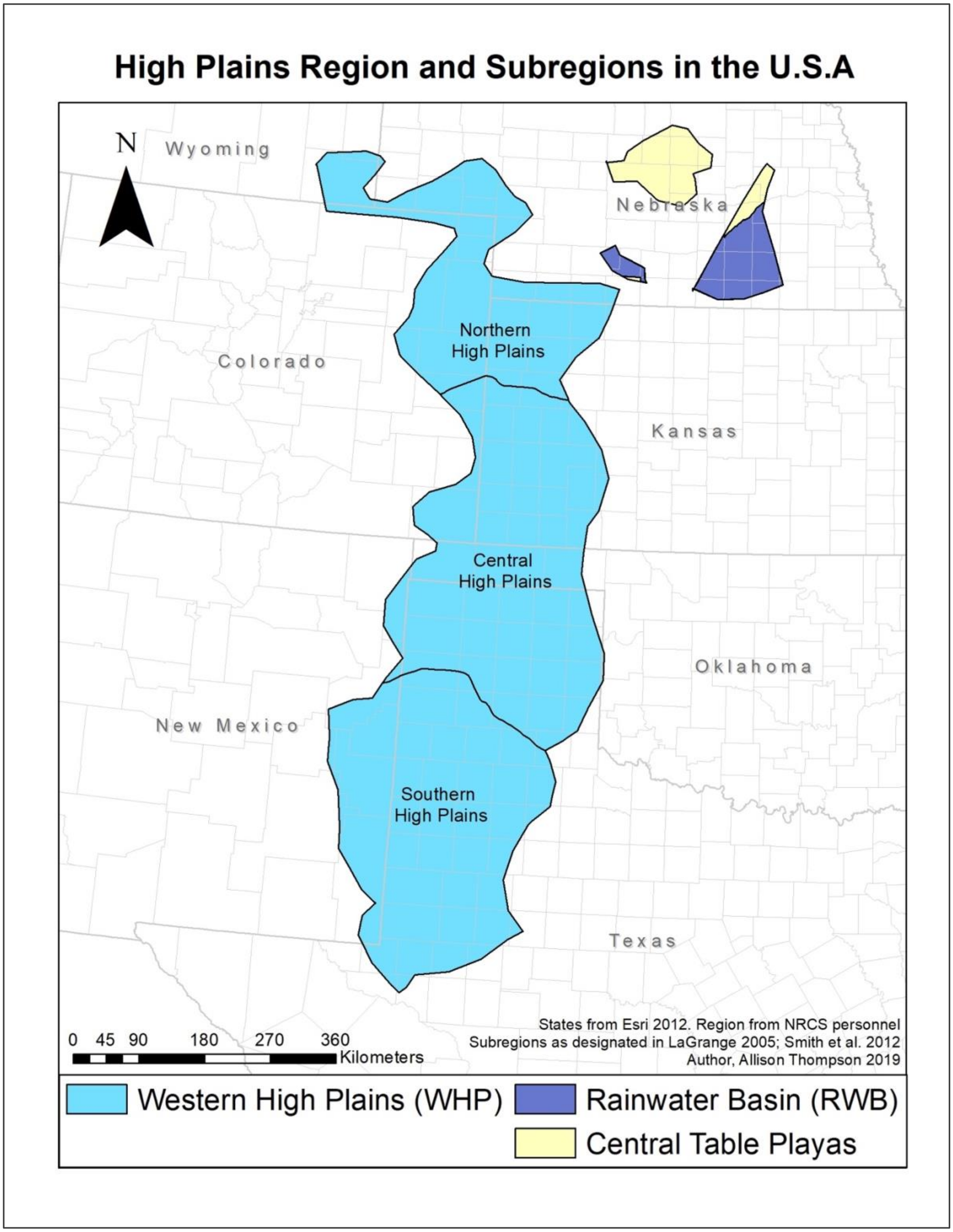
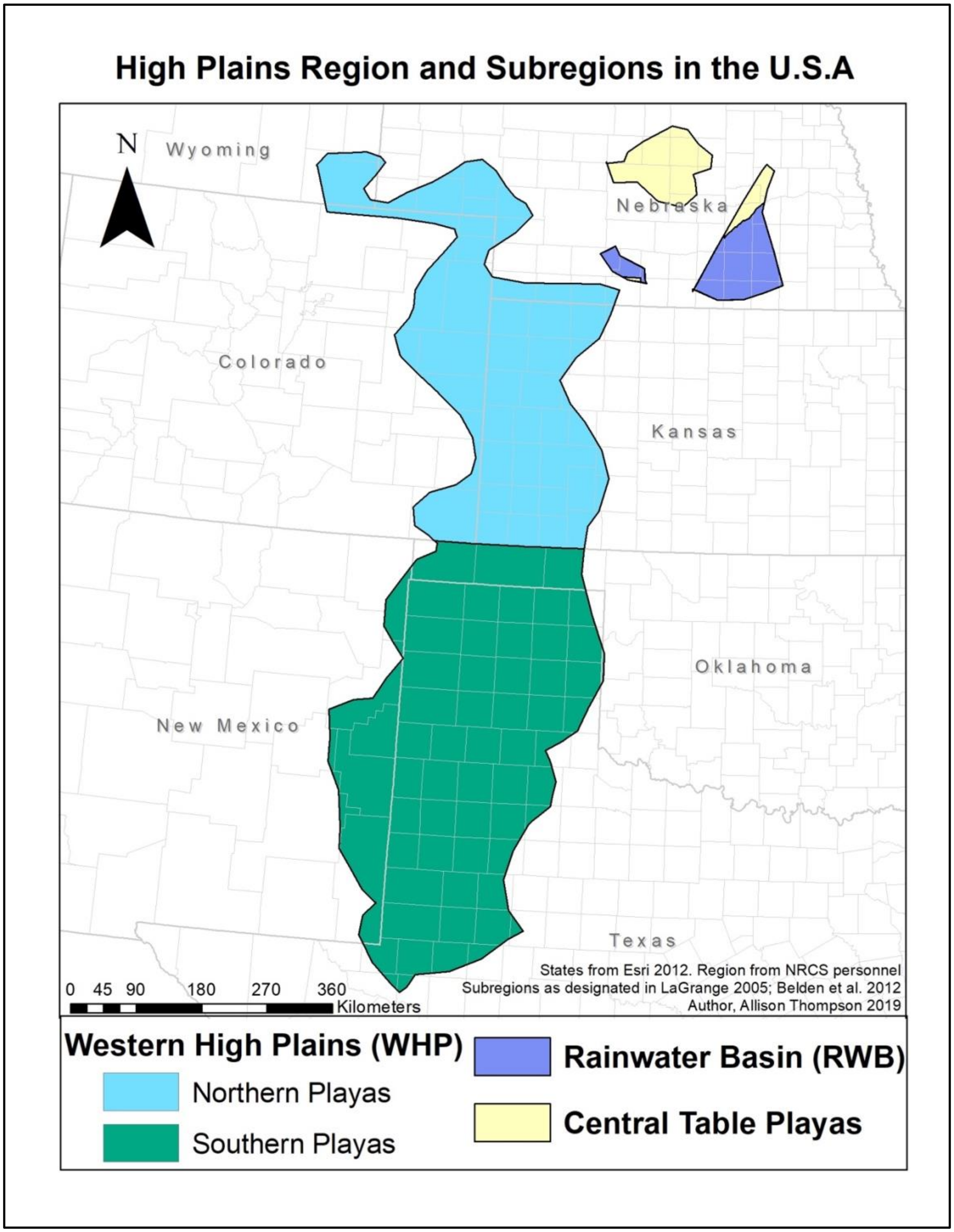


Figure 3.2. High Plains Region (HPR) as determined by the Conservation Effects Assessment Project Wetlands portion (CEAP–Wetlands). Subregions are shown along with WHP playa groups as designated for estimating pesticide residues by Belden et al. (2012).



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APPENDICES

APPENDIX A: Ecosystem Services Estimation for Depressional Wetlands in the High Plains Region: Manual for the Integrated Landscape Modeling Partnership

ECOSYSTEM SERVICES ESTIMATION FOR DEPRESSIONAL WETLANDS IN THE HIGH PLAINS REGION: MANUAL FOR THE INTEGRATED LANDSCAPE MODELING PARTNERSHIP

Allison J. Thompson
Loren M. Smith
Scott T. McMurry

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Chapter 1: Introduction

Wetlands across the United States are valuable as natural and unique ecosystems. Their social and economic importance can be described through the ecosystem services they provide to individuals and societies (Millennium Ecosystem Assessment 2005). Services include but are not limited to wildlife habitat, water filtration, floodwater storage and carbon sequestration (Millennium Ecosystem Assessment 2005). Over 230,000 ha of vegetated, freshwater wetlands in the conterminous United States were converted to other land-use types from 1974 to 2009, and conservation of remaining wetlands has become a nationwide priority (Dahl 2011).

This manual was developed for use by the Integrated Landscape Modeling (ILM) partnership in the High Plains Region (HPR) where playa wetlands are dominant. This region was designated by the U.S Department of Agriculture (USDA) Conservation Effects Assessment Project (CEAP) wetlands component (CEAP—Wetlands), which evaluates the effects of landowner assistance conservation programs on wetland resources (Durianick et al. 2008) (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/na/?cid=nrcs143_014155). This manual includes instructions on identifying the Hydrogeomorphic (HGM) classification of wetlands and waterbodies in the HPR as well as models for estimating ecosystem services of playa wetlands and their vegetative buffers. Numerous models are included and many are predictive regression equations based on field data. The techniques and models in this manual provide information regarding the function of playa wetlands in the HPR and can be applied through use of remotely sensed data. Estimation of ecosystem services can be carried out for historic as well as current and future conditions to determine how services have changed and will potentially change under different land use types.

Users

INTEGRATIVE LANDSCAPE MODELING (ILM)

The ILM Partnership was established in 2004 with the goal of identifying, evaluating and developing models for the purpose of quantifying wetland ecosystem services. The focus of the partnership was originally on wetland systems and their response to USDA conservation programs and practices (Mushet and Scherff 2016). Initial ILM work centered on northern prairie wetlands in the CEAP Prairie Pothole Region (PPR). The Integrated Valuation of Ecosystem Service Tradeoffs (InVEST) modeling platform was used in the PPR for landscape scale ecosystem service valuations (Mushet and Scherff 2016).

The CEAP—Wetlands ILM effort in the HPR developed predictive regression models that have been successful in estimating ecosystem services of playa wetlands and their vegetative buffers.

This manual can be applied by ILM partners and others to predict ecosystem services provided by playa wetlands, and determine the effects conservation programs and practices have on these services. Historic, current and future condition estimates provide critical information to policy makers for the management of these important and unique wetlands.

CONSERVATION USERS

Any land manager or researcher in the HPR can use this manual to determine the function of a wetland or other waterbody, or to predict the ecosystem services of a playa or its vegetative buffer. Much of the required data are available online through land-use datasets, topographic maps and hydrography maps. The HGM key and predictive models can be applied using a Geographic Information System (GIS) and can be re-applied to a site for an understanding of changes throughout time. Users should be aware that the spatial data identifying federal conservation program lands is confidential and not accessible to the public through open source land-use databases. Access to this data must be permitted by the Farm Service Agency (FSA). If land use cannot be distinguished between native grassland or Conservation Reserve Program (CRP) using other resources, the user must contact the local or regional NRCS office for determining if a parcel is in CRP.

THE NATIONAL RESOURCES INVENTORY

The National Resources Inventory (NRI) is a largescale inventory focused on land use, soil erosion and water resources on private lands nationwide (U.S. Department of Agriculture 2018). It is carried out by the USDA Natural Resource Conservation Service (NRCS) and tracks changes in natural resources over time (Nusser et al. 1989). Wetlands and deepwater habitats encountered at sample locations are identified according to their Cowardin et al. (1989) classification and reported in net gains and losses by system type. The inventory is a robust dataset that has the potential to provide detailed information about depressional wetlands and the ecosystem services they provide.

This manual introduces a range of new techniques which could be used by the NRI or by others allowed to view NRI imagery as a simple method of estimating wetland function in the HPR using the HGM key. Further, ecosystem service estimations could be carried out for playa wetlands using the included models and remotely sensed data. Integrating the methodologies and models presented in this manual would increase the amount of information gained by NRI assessments and provide more detailed data on the state of the Nation's wetland resources.

APEX

The Agricultural Policy/Environmental eXtender (APEX) is a modeling platform developed to simulate impacts of land management and land use at a small-medium watershed scale (Gassman et al. 2005). A few features which can be quantified include carbon flux, erosion, pesticide runoff and water flow. APEX has been used in CEAP to determine the effectiveness of practices and programs in conserving natural resources (Plotkin et al. 2011). The models in this manual estimate services provided by playa wetlands, and the CEAP modeling team has indicated the models could be incorporated into APEX for the purpose of simulating landscape conditions where playas are present. Erosion, floodwater storage, pesticide filtration and carbon storage are a few of the services which playas provide to the local region, all of which can be quantified using the models in this manual. Playa models incorporated into APEX could then reveal the ecologic and economic value these wetlands provide to the landscape and provide APEX users much more utility from an ecosystem perspective.

Depressional Wetlands

HIGH PLAINS REGION (HPR)

Eleven assessment regions (Figure 1-1) were identified by CEAP—Wetlands based on the dominant, naturally formed, wetland type in the area (Eckles 2008). In the HPR (Region 7 in Figure 1-1), the dominant wetland type is a depressional wetland known as a "playa wetland", "playa lake" or simply "playa". Playas exist throughout portions of Texas, New Mexico, Oklahoma, Colorado, Kansas and Nebraska (Figure 1-1) (Haukos and Smith 1994). The majority of the HPR exhibits variable rainfall amounts with evapotranspiration exceeding precipitation and much of the region is therefore considered semiarid (Bolen et al. 1989). Annual precipitation averages can range from 30 to 63 cm with annual evaporation between 165 and 284 cm (Smith 2003). Topography is fairly flat and natural upland vegetation type consists primarily of prairie grasses, but large portions of the region have been converted for agricultural production (Bolen et al. 1989).

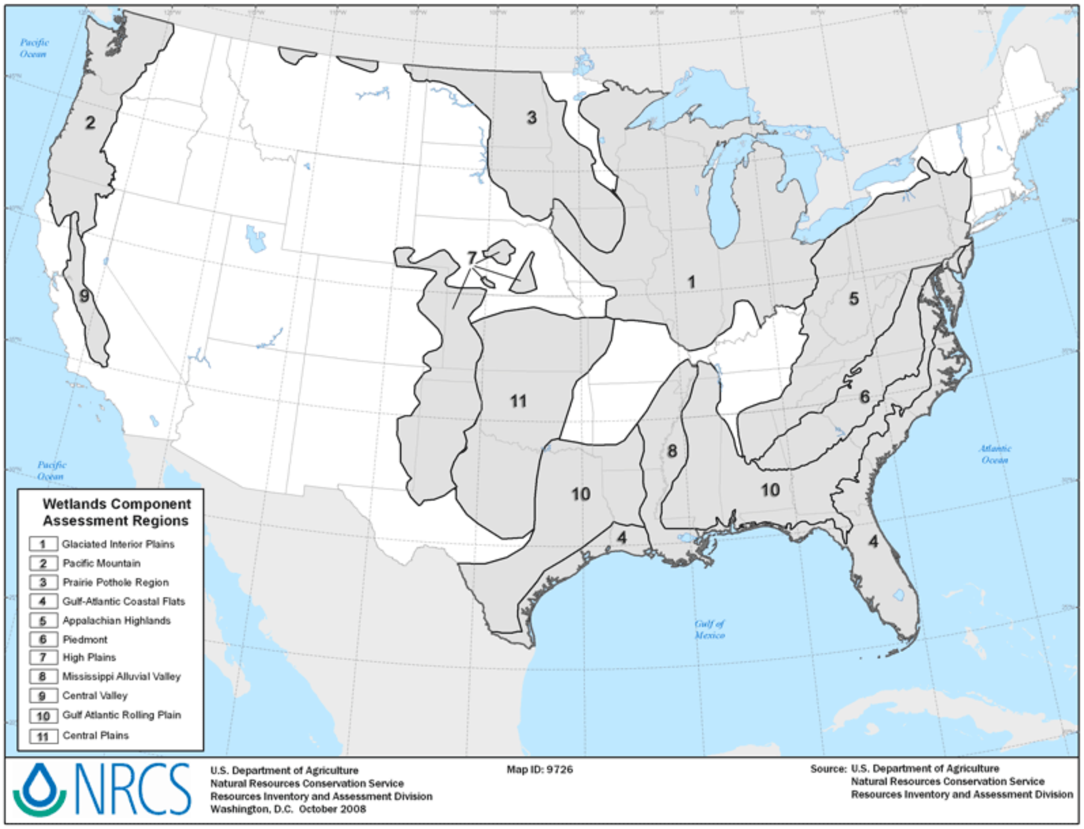

FIGURE 1-1. THE ELEVEN CONSERVATION EFFECTS ASSESSMENT PROJECT (CEAP)—WETLANDS REGIONS IN THE UNITED STATES. THE HIGH PLAINS REGION (HPR) IS LABELED AS REGION 7. IMAGE FROM ECKLES (2008).

HPR SUBREGIONS

The region where playas exist has been divided into subregions due to differing climate, topography and land management practices. The HPR is mostly comprised of the Western High Plains (WHP) subregion, the Rainwater Basin (RWB) subregion south of the Platte River in Nebraska as well as the Central Table Playas in Nebraska which have not been widely researched. (Figures 1-2 and 1-3). The WHP is topographically flat and is often split into three portions known as the Northern, Central and Southern High Plains (Figure 1-2). The RWB is a landscape of rolling plains and this topography has historically allowed playas in the RWB to be more easily drained for agriculture, resulting in a greater amount of loss (LaGrange 2005, Smith 2003). Federal conservation programs differ between the regions with the Conservation Reserve Program (CRP) being commonly applied in the WHP while the Wetlands Reserve Program (WRP), now carried out as the Wetlands Reserve Easement (WRE) under the Agricultural Conservation Easement Program (ACEP), is applied to playa wetlands in the RWB (Ferris and Siikamäki 2009). The goals and practices of these programs have differing consequences for wetlands in their respective regions. Conservation program effects have not been explored in the Central Table Playas and the application of techniques in this manual are not recommended for use here.

Numerous predictive ecosystem service models were built based on playa data from the HPR but some datasets were restricted to the WHP subregion, the Northern High Plains (NHP), Southern High Plains (SHP) and the RWB. Because the data used to develop these models were restricted to certain subregions and portions, a user must take caution if seeking to apply these models to playas within a different area.

The size of the RWB subregion shown in figure 1-2 is limited within the CEAP—Wetlands HPR. The commonly accepted RWB physiographic area is continuous along the southern edge of the Platte River and playas are present throughout (Figure 1-3).

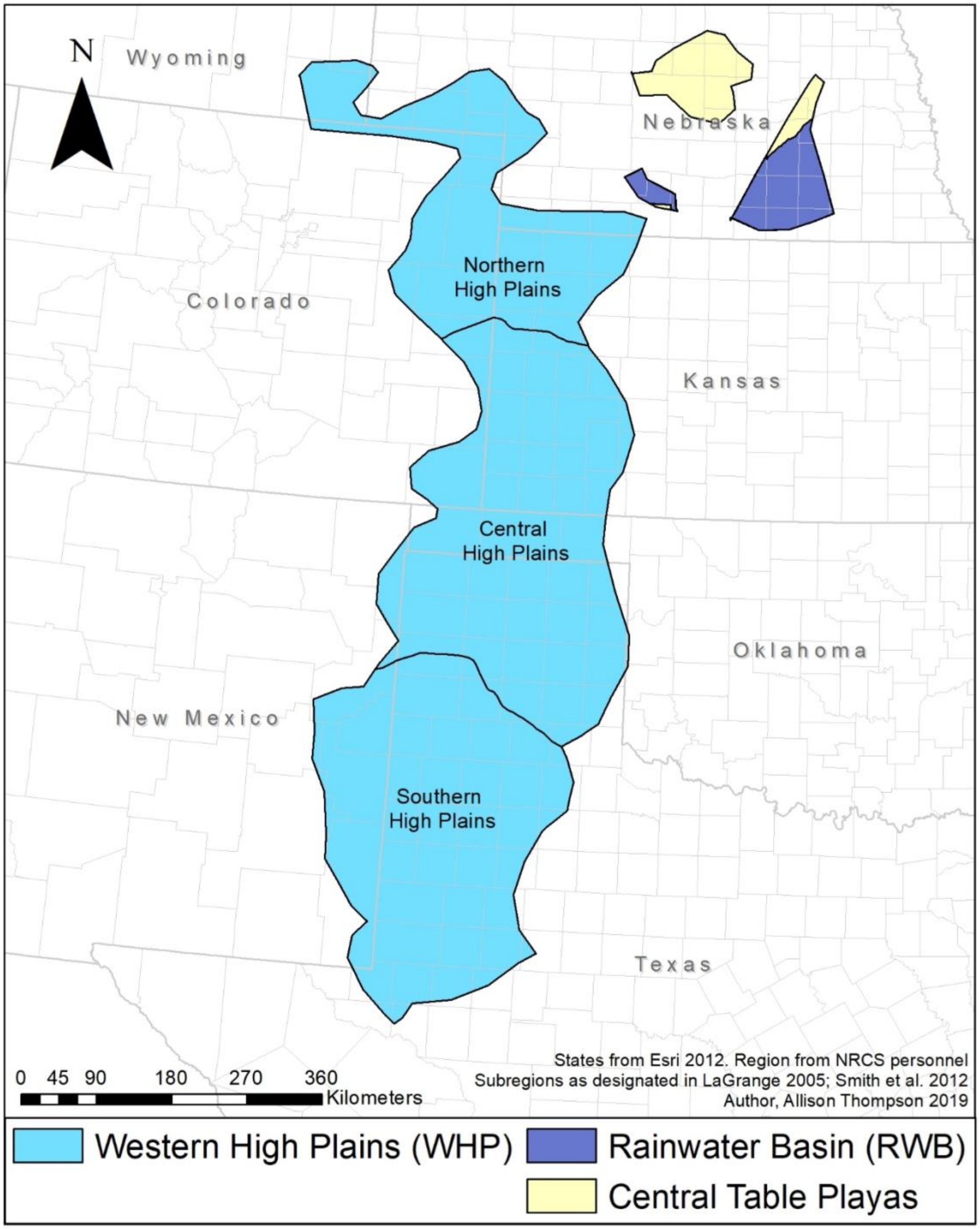

FIGURE 1-2. SUBREGIONS AND PORTIONS OF THE CONSERVATION EFFECTS ASSESSMENT PROJECT (CEAP) – WETLANDS HIGH PLAINS REGION (HPR) AS DESIGNATED BY MODELS SELECTED FOR THIS MANUAL. SUBREGIONS AND PORTIONS AS DESIGNATED BY LAGRANGE (2005) AND SMITH ET AL. (2012). DATA FROM ESRI (2017), RAINWATER BASIN JOINT VENTURE (2018) AND PERSONAL COMMUNICATION WITH WILLIAM EFFLAND (2017).

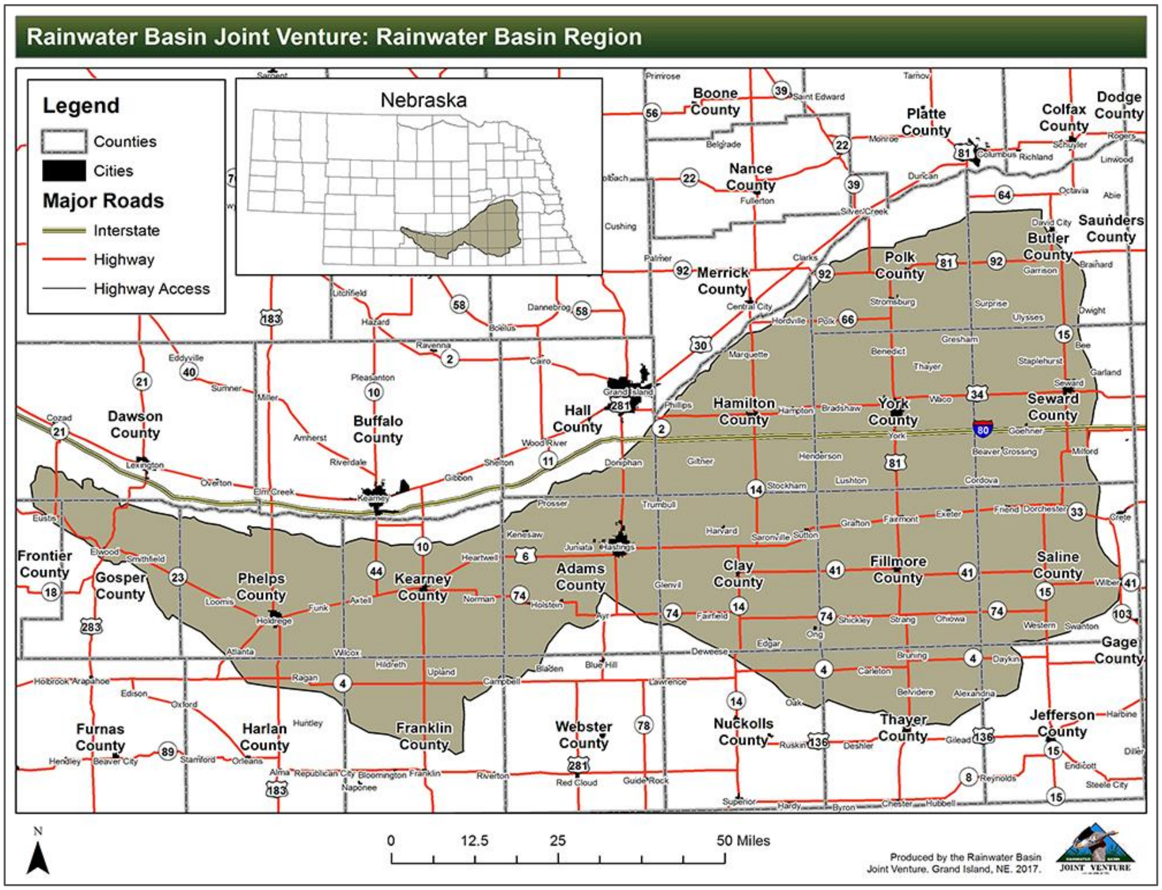

FIGURE 1-3. RAINWATER BASIN (RWB) PHYSIOGRAPHIC REGION. FROM RAINWATER BASIN JOINT VENTURE (2018).

PLAYAS

Playas are shallow, depressional, recharge wetlands characterized by having a closed watershed and receiving water through precipitation and overland flow (Smith 2003, Tiner 2003). Hydroperiod, i.e., the length of time a playa contains standing surface water, is variable and highly dependent upon precipitation events. Playas in the WHP tend to have a circular shape and be less than 2 m deep. Sizes range from less than 1 ha up to 400 ha, but the majority are less than 12 ha in size (Smith 2003). Playa formation is attributed to wind and wave as well as dissolution processes (Haukos and Smith 1994; Reeves and Reeves 1996). Dissolution occurs when decomposition of organic matter results in the production of carbonic acid in a low point on the landscape where water has accumulated. This carbonic acid causes calcium carbonate in the soil to dissolve forming a shallow basin with a flat bottom (Osterkamp and Wood 1987). Playas within the RWB exhibit a more oblong shape when compared to WHP playas since formation occurred through wind and wave processes (LaGrange 2005). Although slightly different in shape, RWB playas are similar in size and carry out the same wetland functions (Smith 2003).

Ecosystem Services

DEFINITION

Ecosystem services are defined as the natural processes or functions of a system that provide environmental benefit to humans (Millennium Ecosystem Assessment 2005). Costanza et al. (1997) estimated that the global monetary value of ecosystem services could total more than $33 trillion per year. Services are provided by a variety of systems including, but not limited to, forests, grasslands, stream systems and wetlands. Ecosystem services are often grouped into four categories; supporting, provisioning, regulating and cultural (Millennium Ecosystem Assessment 2005). Supporting services affect all others through primary production, nutrient cycling and soil formation. Provisioning services include food, water and fiber production while regulating services include flood regulation, climate regulation and water purification. Services related to culture include those which are educational, recreational, aesthetic and spiritual. Wetlands provide numerous services within each of these four categories, but have been estimated to have a greater annual value per hectare regarding disturbance regulation, waste treatment and habitat provisioning (Costanza et al. 1997).

WETLANDS

Monetary valuation of wetland ecosystem services has been estimated at $4 trillion globally per year (Costanza et al. 1997). Depressional wetlands specifically have been shown to provide services such as floodwater storage, groundwater recharge, biodiversity support, carbon sequestration, sediment reduction and nutrient reduction (Smith et al. 2011). In playas, it has been observed that surrounding land use is a primary driver of wetland function and therefore services. For example, carbon storage in the soil of playa wetlands was decreased by approximately 20% when surrounding land was in cultivated crops (O'Connell et al. 2016). Sediments carried by overland water flow can fill the basin of a depressional wetland, decreasing both water volume and hydroperiod. Because the function of a wetland provides many services to humans, degradation in the quality and function of depressional wetlands by sediment infilling can have a negative impact on the services provided (Tsai et al. 2007). Thus, knowledge of wetland functions over time provides valuable information needed for the future conservation and management of the Nation's wetland resources.

Wetland Classification

COWARDIN ET AL.

Wetlands are commonly classified according to the Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979), hereafter referred to as the Cowardin classification. The Cowardin classification was developed to bring uniformity to the terminology used in identifying wetlands in order to avoid inconsistent labeling. The classification is organized as a hierarchy comprised of systems, subsystems, classes, subclasses and modifiers. Classification of a wetland is based on both abiotic and biotic features including size, depth, water movement, substrate structure and type, and vegetation structure and type. Classifications of wetlands under the Cowardin classification can be used to track net gains and losses of wetlands by system type but provides little information on function and therefore service provisioning citation.

The Cowardin classification is used in the National Wetlands Inventory (NWI). The NWI provides a database developed by the U.S. Fish and Wildlife Service (FWS) with the goal of mapping and classifying all wetlands nationwide (Dahl et al. 2015). Data in the NWI was compiled from aerial imagery, and wetlands are denoted by digital polygons and classified according to the Cowardin classification. This database can be accessed in The Wetlands Mapper on the FWS website (https://www.fws.gov/ wetlands/data/mapper.html). National Wetland Inventory data are used by many researchers and inventory projects to identify the location and classification for wetlands of interest.

Palustrine wetlands are the most widely encountered wetland system in the Cowardin classification. The NRI, uses the NWI to identify wetlands and other waterbodies encountered on non-federal, rural lands (Nusser and Goebel 1997) but since this classification does not include function, few inferences can be made about the services palustrine wetlands provides beyond simple presence/absence. Palustrine waterbodies were shown to make up 66% of 64.7 million ha of wetlands observed in the NRI (U.S. Department of Agriculture 2018). Palustrine wetlands are described as shallow, inland, freshwater systems and are defined as being mainly non-tidal with emergent vegetation dominating the wetland area. Palustrine wetlands have no maximum size limit, but if vegetation is lacking, they must be less than 2 m deep at low water (Cowardin et al. 1979). Most playas are classified as palustrine wetlands. Other waterbody types in the HPR identified as palustrine include drainage ditches, waste treatment lagoons and excavated ponds. Although the Cowardin classification identifies characteristics that are shared between these waterbodies and naturally formed wetlands, differences in the function of differing types of palustrine wetlands can be great.

HYDROGEOMORPHIC (HGM)

Another broadly used wetland classification system is the Hydrogeomorphic (HGM) classification. The HGM classification was developed by Brinson (1993) for the purpose of classifying wetlands according to function. Because this classification system helps provide function information its utility for providing service information is better than Cowardin. However, there is not a national GIS database delineating wetlands by HGM as there is for the Cowardin system. The HGM classification is independent of biogeographic distribution and is based on abiotic factors only resulting in wetland groups that share similar function. Rather than following a hierarchy, this classification identifies three features that drive wetland function, these are geomorphic setting, water source and hydrodynamics (Brinson 1993). Geomorphic setting is defined as the wetland’s position within the surrounding landscape. Water source identifies primary water inflows to a wetland while hydrodynamics identifies potential outflows and other water movements. Seven geomorphology types have been established and include depressional, riverine, tidal fringe and lacustrine fringe (Smith et al. 1995).

A waterbody with depressional geomorphology sits within a closed watershed. The primary water source is often overland flow with evapotranspiration and groundwater recharge as common hydrodynamics (Natural Resource Conservation Service 2008). A waterbody with riverine geomorphology is situated within or adjacent to a streambed with water sources being overland flow and streambank flooding. Hydrodynamics in riverine wetlands can include bidirectional flow in and out of the stream during changing stream levels (Natural Resource Conservation Service 2008). With knowledge of abiotic factors, the function of a waterbody can often be inferred. For example, when the primary water source is overland flow, and hydrodynamics include spilling into a stream or other waterbody, it is understood that some portion of water is being held in the wetland and therefore floodwater is being stored.

Identifying Depressional Wetlands

PALUSTRINE VARIABILITY

When identifying wetlands in the Great Plains using the Cowardin classification, there can be a wide variety of functional types that become grouped. Palustrine waterbodies can include naturally formed depressions, pools associated with intermittent streams, wetlands adjacent to streams, man-made ponds, drainage culverts and even wastewater lagoons. Modifiers are available to describe flooding regimes and mechanical alterations/formation but playas can also show alterations and accurate inclusion of these is not consistent. When waterbodies are labeled using the Cowardin classification it becomes difficult to distinguish natural, closed depressions from other waterbody types.

PALUSTRINE EXAMPLES

In the HPR, two palustrine wetlands with the same Cowardin classification label were observed using satellite imagery (Figure 1-4). These both were labeled as PEM1C in the NWI, which translates as palustrine system, emergent class, persistent subclass and seasonally flooded. Based on geomorphic setting it can be observed one is a depression and the other sits on the edge a streambed and is considered riverine. The first can be identified as a playa in a closed depression while the second appears to be an area which holds intermittent overbank flow. Ecologically, these two waterbodies carry out drastically different functions and grouping them as the same waterbody type is not effective in determining the quality or status of wetland and waterbody resources within a region.

Figure 1-4. Two National Wetlands Inventory (NWI) wetlands in the High Plains Region (HPR). Both are classified as palustrine, emergent, persistent and seasonally flooded (PEM1C) according to the Cowardin et al. (1979) classification system. The wetland on the left is classified as an HGM depressional and is a playa. The wetland on the right is classified as an HGM riverine and is within the river floodplain. Data from ESRI (2018) and U.S. Fish and Wildlife Service (2017).

This Manual

Purpose

This sampling manual was built for use by ILM partners and by others in the conservation community to determine general function or specific ecosystem services for depressional wetlands within the High Plains Region of CEAP—Wetlands. The most common wetland type in this region is the playa wetland. Understanding wetland function is necessary when establishing the status or changes of wetland resources over time. Knowledge of change is important for policy makers faced with decisions on future conservation laws and practices influencing wetland resources.

Hydrogeomorphic Key (Chapter 2)

A key for applying the HGM classification to waterbodies in the HPR has been developed for understanding function using the NWI GIS database to identify wetland presence. Abiotic features identified in the HGM classification allow function to be inferred. The combination of biotic and abiotic features required in the Cowardin classification result in the placement into a single group wetlands and waterbodies that are functionally very different. The HGM system is more capable of identifying the variety of functional types found within the Cowardin classification's palustrine system. The HGM key included in this manual can be applied on any palustrine or lacustrine waterbody within the HPR and can be carried out entirely through remote sensing. This key identifies broad HGM classes as well as more detailed wetland features that are likely to be encountered within the region; this includes identifying playa wetlands specifically. Determining HGM classification would allow the ILM to infer wetland function for most waterbodies found within the HPR.

Ecosystem Service Estimates (Chapter 3)

Predictive regression models were included to determine the ecosystem services provided by playa wetlands and their vegetative buffers under specific land-use conditions. If a waterbody in the HPR is identified as a playa using the HGM key provided, further information can be determined using the predictive models included in the final chapter of this manual. Predicted values are based on relationships between wetland features that have been identified from field data. Many services are related to surrounding land use, waterbody size and adjacent vegetation type. All features required to predict services can be determined remotely and detailed instructions for gathering these data are included. A list of the metrics that must be collected is included (Appendix A). Datasheets are also included for simplified organization of data (Appendix B). Using these models, the ILM partners would be able to estimate current playa ecosystem services and track changes over time.

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Chapter 2: HGM Classification Key

The HGM Key

THE HYDROGEOMORPHIC CLASSIFICATION

The Hydrogeomorphic (HGM) wetland classification system was established by Brinson (1993) as a function focused approach to classifying wetlands. The HGM classification is capable of determining ecosystem services that might be provided by a wetland based on functions identified through geomorphic setting, water source, and hydrodynamics. The key included in this chapter has been developed to determine the HGM class for wetlands and other waterbodies in the Conservation Effects Assessment Project (CEAP)—Wetlands High Plains Region (HPR).

GENERAL PURPOSE USES

- Only applicable for wetlands and waterbodies in the HPR as designated by CEAP—Wetlands.
- Only applicable for wetlands and waterbodies identified as palustrine class in the Cowardin et al. (1979) classification.
- Uses remote sensing through topographic maps, satellite imagery and other spatial datasets. A GIS is required to determine wetland classification.
- Depressional wetlands identified as playas can further be assessed using models in Chapter 3 of this manual to estimate ecosystem services.

GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

Data sources

Selected data sources should be of equal or greater reliability compared to the recommended sources. Topography for example, may be available at higher resolutions or from more direct measurement methods such as LiDAR derived Digital Elevation Models (DEM). It must be noted, if ecosystem services are to be compared across time, or between wetlands, the same data sources must be utilized for accurate comparison. For this reason, we have selected data that are present across the entire region and are accessible to most users.

National Wetland Inventory (NWI): this dataset was established by the U.S. Fish and Wildlife Service (FWS) and identifies all wetlands and waterbodies across the United States via aerial imagery. Polygons represent wetland and other waterbodies by their location and attribute data includes Cowardin classification. Data can be downloaded by state from the USFWS website (https:// www.fws.gov/wetlands/data/State-Downloads.html).

National Hydrography Dataset (NHD): was developed by the U.S. Geological Survey (USGS) and consists of digitized flowlines representing streams and rivers across the United States. Stream location can determine the water source of a wetland. Data can be accessed as shapefiles within a file geodatabase through The National Map (TNM) (https://viewer.nationalmap.gov/basic/).

USGS Topographic Maps: were developed by the U.S. Geological Survey (USGS) and can be downloaded directly from The National Map (TNM) in geo.pdf format (https://viewer.national map.gov/basic/). A digital continuous version of the USGS developed map is also available through ESRI as a basemap in the ArcGIS program (http://www.arcgis.com/home/item.html?id=99cd5fbd9 8934028802b4f797c4b1732).

Satellite Imagery: recent imagery can be accessed through Earth Explorer where Landsat 8 scenes can be downloaded for the location of interest (https://earthexplorer.usgs.gov/). Smaller features such as constructed dikes, pits and drainage canals can be detected using this imagery. Historical Landsat imagery is also available.

Coordinate Systems

For observing maps and other spatial data, the authors recommend 'NAD_1983_Albers' as the coordinate system. This system is used by the NWI and limits area distortions across the extent of the United States (for more information see https://www.fws.gov/ wetlands/data/Projection.html). When using a GIS to observe numerous datasets, which may include vector and raster type data, the data frame and all data layers should have matching geographic and projected coordinate systems. This prevents measurement and location errors between data layers. Transformations between coordinate systems may be required.

- Coordinate System: North American Datum 1983 Albers (NAD 1983 Albers)
    - Datum: North American 1983 (NAD 1983)
    - Geographic Coordinate System: GCS North American 1983
    - Projected Coordinate System: Albers Conical Equal Area

Application of the HGM Key

INSTRUCTIONS

When a waterbody is located in the HPR *and* it is identified as palustrine through the NWI, the following HGM key can be applied.

Region Identification

Across the U.S., wetland regions have been identified for CEAP—Wetlands work. This manual can be applied for all depressional wetlands in the HPR regardless of subregion type (Figure 2-1). CEAP—Wetland region details are available on the NRCS website (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/na/?cid=nrcs143_014155).

Wetland Cowardin Class and Shapefile(s)

The National Wetlands Inventory (NWI) has produced shapefiles and Cowardin et al. (1997) titles for all wetlands and waterbodies in the United States. Due to the nature of the Cowardin classification, some wetland basins may have numerous wetland types present. All shapes that sit within a topographic wetland basin should be included when measuring wetland size.

This key may also be applicable on lacustrine waterbodies that appear to be misclassified playas. The authors observed numerous mis-classified depressional wetlands that were placed in the lacustrine class. We consider this a mis-classification since playas being generally less than 2 m deep, do not exhibit the features necessary to be placed in the lacustrine class.

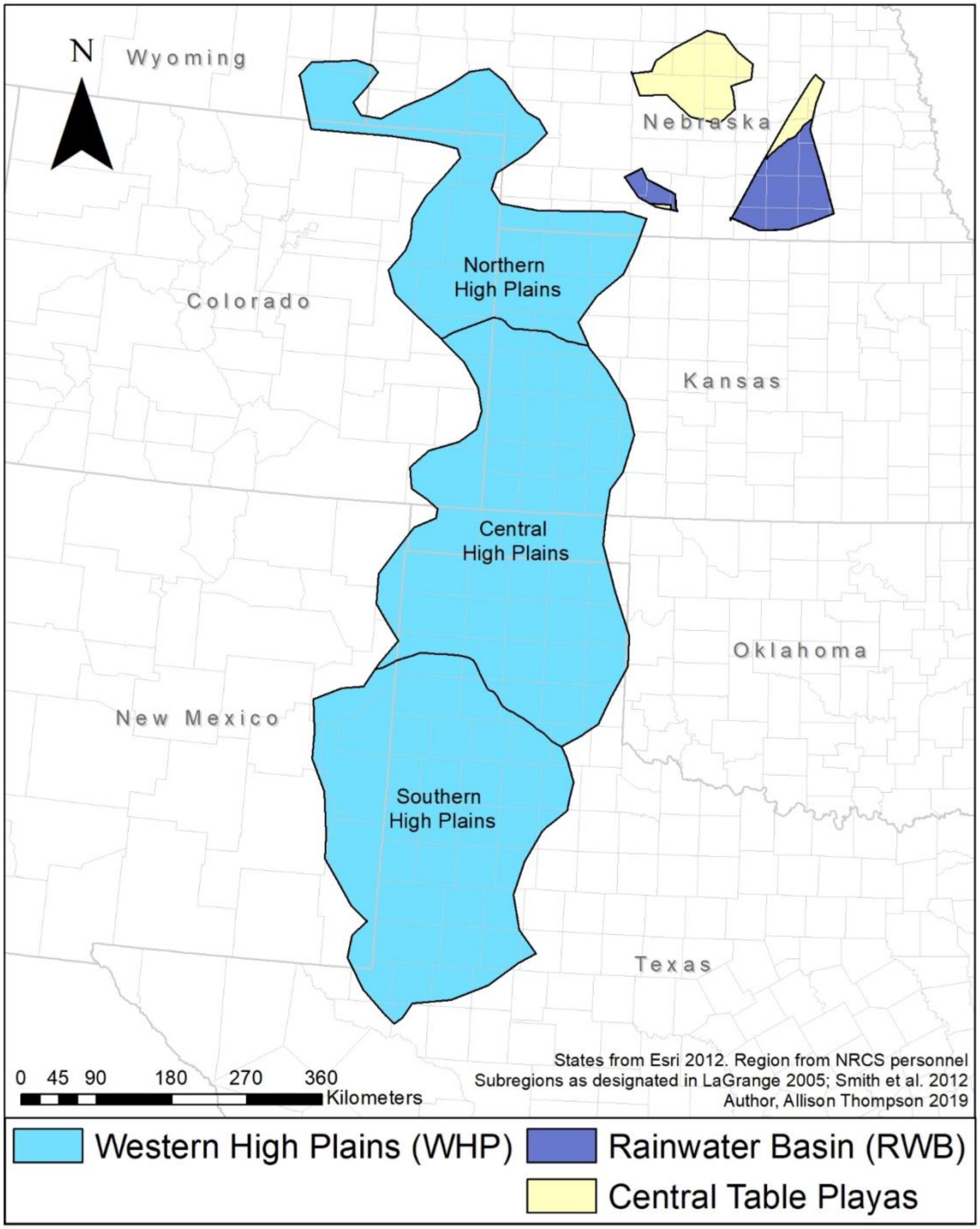

Figure 2-1. Subregions and portions of the Conservation Effects Assessment Project (CEAP) – Wetlands High Plains Region (HPR) as designated by models selected for this manual. Subregions and portions as designated by LaGrange (2005) and Smith et al. (2012). Data from ESRI (2017), Rainwater Basin Joint Venture (2018) and personal communication with William Effland (2017).

DEFINITIONS

Associated: intersects with the stream line or its topographically connected basin

Bend (Stream): a change in direction of the stream

Closed Watershed: due to topography, water cannot exit the watershed via overland flow

Diked: a structure has been human-built to retain water or slow the movement of water

Drainage: an intermittently wet location where water moves from higher elevation to lower elevation

Excavated: mechanical alteration is evident through straight edges or hard corners of a waterbody

Floodplain (Stream): an area which a stream can topographically supply water to during flood events

Lake/Reservoir Edge: a permeant waterbody which can supply water to an adjacent waterbody

Natural and Continuous Stream: all streams that are not human-made and that have a topographic connection to a stream network. It excludes any longstanding canals and ditches or topographically eroded drainages

Slope: a topographic gradient on which intermittent water can be observed

Streambed: the area adjacent to an NHD stream line that is the topographic low

HGM Classification Key for Depressional Wetlands in the HPR

High Plains Region

1 Wetland is classified as Cowardin Palustrine.. 2
1 Wetland is not classified as Palustrine....................Stop here (this key is not applicable)
2 Wetland is detectable via remotely sensed data 3
2 Wetland is not detectable via remotely sensed data ....Lost/Misclassified
3 Wetland is associated with a natural, continuous NHD stream or surrounding
floodplain ....Riverine (5)
3 Wetland is not associated with a natural, continuous NHD stream 4
4 Wetland exists within a closed watershed .... Depressional (9)
4 Wetland exists along the edge of a lake or reservoir ....Lacustrine Fringe

5 Wetland retains water due to landscape alteration (anthropogenic or beaver activity) 6
5 Wetland does not retain water due to landscape alteration 7
6 Wetland is excavated ....Riverine Excavated
6 Wetland is diked ....Riverine Diked
7 Wetland is situated within current or historic streambed 8
7 Wetland is outside of streambed but within the floodplain .... Riverine Floodplain
8 Wetland exists within streambed during low flow .... Riverine Streambed
8 Wetland is disconnected and was formed by streamflow at bend ....Riverine Oxbow

9 Wetland retains water due to landscape alteration.. 10
9 Wetland does not retain water due to landscape alteration 11
10 Wetland is excavated .... Depressional Excavated
10 Wetland is diked .... Depressional Diked
11 Wetland is situated within a drainage ....Depressional Draw
11 Wetland is not situated within a drainage... Playa Wetland

Literature Cited

Belden JB, Hanson, BR, McMurry, ST, Smith LM, Haukos DA (2012) Assessment of the effects of farming and conservation programs on pesticide deposition in High Plains wetlands. Environmental Science & Technology 46:3424-3432

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Chapter 3: Models for Predicting Ecosystem Services

Ecosystem Service Models

SELECTED MODELS

The models included in this sampling manual have been developed through various projects in which wetland data were gathered to observe and predict ecosystem services. These models estimate services provided by playas and their associated vegetative buffers. All are based on field-collected data and indicate the condition of the wetland as a natural resource. A list of metrics required for applying models is included in Appendix A, while datasheets for all models are in Appendix B. At the time of writing this manual, the included models were deemed the most suitable in terms of applicability and ecosystem service estimations. These models will likely improve over time with increased application and ground truthing.

Application of these methods within NRI and other inventory protocols would expand the understanding of wetland condition by incorporating estimates of wetland function. Models could also be used to estimate service provisioning of playas within a current land use and to make a comparison to expected service provisioning under a potential future land use. This type of comparison could be used to estimate the effects of future conservation practices on ecosystem services provided by wetlands in the High Plains Region (HPR).

GENERAL PURPOSE USES

- Applicable for playa wetlands in the HPR.
- Developed through CEAP—Wetlands and other playa wetland research.
- Utilizes remote sensing through maps, imagery and databases. A GIS is necessary for most of the metrics required to run these models.

RESTRICTIONS AND LIMITATIONS

Estimates: Users should note that these ecosystem service models are able to give general estimates based on a set of features specific to a playa and its surrounding landscape. Variables that are not considered could greatly affect the actual value compared to the model predicted value.

Subregions: The two HPR subregions of interest for this sampling manual are the Western High Plains (WHP) and the Rainwater Basin (RWB) (Figure 3-1). Models were built using data from playas in a specific subregions or areas of the HPR. For the most accurate estimates, each model should be applied within the appropriate subregion and area. Models are ideal for the subregions as listed below in Table 3-1.

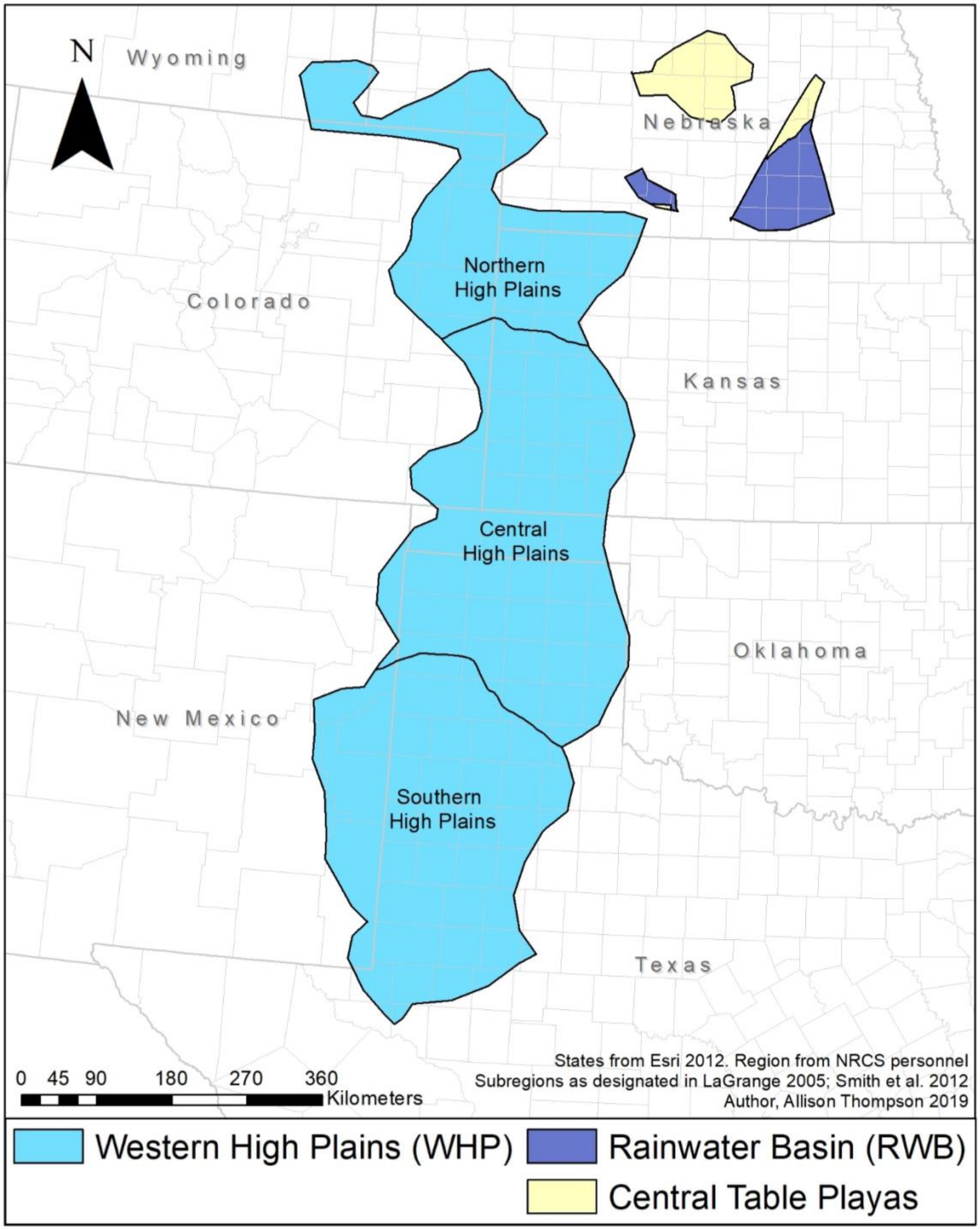

Figure 3-1 Conservation Effects Assessment Project (CEAP) - Wetlands High Plains Region (HPR) with subregions and portion shown as designated by LaGrange (2005) and Smith et al. (2012). Data from ESRI (2017), Rainwater Basin Joint Venture (2018) and personal communication with William Effland (2017).

Table 3-1 Subregions and portions within the HPR recommendations for models for most accurate predictions.

Subregion/Portion	*Model (number of rank)*
Western High Plains (WHP)	*Pesticide Residue (3)* *Soil Organic Carbon (7)* *Plant Species Richness (8)*
Northern High Plains (NHP) Only	*Greenhouse Gas Flux (6)*
Southern High Plains (SHP) Only	*Contaminant Filtration (1)* *Contaminant Concentration (2)* *Sediment Depth (4)* *Floodwater Storage (5)* *Amphibian Species Richness (9)* *Avian Species Richness and Waterfowl Abundance (10)*
Rainwater Basin (RWB)	*Pesticide Residue (3)* *Greenhouse Gas Flux (6)*

Data Limitations: Some models were built from data within a given portion of the year or season. The model for Amphibian Species Richness was built using data when hydroperiod was between 18 and 453 days. Each model includes a description section which contains any limitations based on timing or range of values considered appropriate. It is recommended that for the most accurate estimate, a user does not apply the model outside of these recommended limitations.

Land Use Change: Care should be taken when seeking to estimate potential ecosystem services under future land-use conditions on a playa or a set of playas. Some of these models use a separate equation for predicting conditions under each available land use type. If future conditions are to be estimated using a different land use equation, all metrics should represent what would be present under those future conditions. If a vegetative reflectance value is required such as the Fraction of Photosynthetically Active Radiation or the Leaf Area Index, a value representing future conditions and not current conditions, should be used. For example, if a user was interested in comparing the change in Greenhouse Gas Flux of a playa converted from cropland to CRP, two equations would need to be applied. First the cropland equation would be used with the current cropland vegetative reflectance values. Secondly, the CRP equation would need to be applied using a representative CRP vegetative reflectance value to simulate what would be present if land use were converted. This representative value could be measured within a nearby CRP playa or could simply be an average CRP reflectance value within the local region.

GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

Data sources

Selected data sources should be of equal or greater reliability compared to the suggested sources. Topography for example, may be available at higher resolutions or from more reliable documentation methods such as LiDAR derived Digital Elevation Models (DEM). The user however must keep in mind that if ecosystem services are to be compared across time or between potential land use changes the same data sources should be used for accurate comparisons. For this reason, most of the data sources we have suggested are present across the entire HPR and are accessible to any user. The only exception to availability is that of USDA conservation program land data which is confidential and requires FSA permission to access.

National Wetland Inventory (NWI): this dataset was established by the U.S. Fish and Wildlife Service (USFWS) and has identified all wetlands and waterbodies across the United States via aerial imagery. Polygons represent wetlands and other waterbodies by their Cowardin et al. (1979) classification. Data can be downloaded by state on the USFWS website https://www.fws.gov/wetlands/data/State-Downloads.html (U.S. Fish and Wildlife Service 2017).

USGS Topographic Maps: were developed by the U.S. Geological Survey (USGS) and can be downloaded directly from The National Map in geo.pdf format (https://viewer.nationalmap.gov/advanced-viewer/). A digital continuous version of the USGS developed map is also available through ESRI for use in the ArcGIS program (http://www.arcgis.com/home/item.html?id=99cd5fbd98934028802b4f797c4b1732).

CropScape: was created by the USDA National Agricultural Statistics Service (NASS) and provides estimates on land use regarding crops and crop types during each growing season nationwide. CropScape includes 132 categories for land cover, each with a designated numeric code. Data is organized in a 30 x 30 m raster grid and is downloadable from the NASS website (https://nassgeodata. gmu.edu/CropScape/). This land-use dataset covers some of the categories necessary for applying the models in this manual. These include croplands, fallow crop and grassland.

CRP, WRP/WRE and Reference: CropScape does not include a land cover class for Conservation Reserve Program (CRP) or Wetland Reserve Program (WRP), now Wetland Reserve Easement (WRE) under the Agricultural Conservation Easement Program (ACEP) (Natural Resource Conservation Service 2018). The spatial data on enrollment lands are not available to the public. If the user does not have special access to CRP and WRP/WRE land-use layers, they may inquire with NRCS regarding land use identification and confidentiality. Similarly, reference wetland locations in the RWB are not available in an open source dataset. These reference wetlands have been designated as such by the Nebraska Game and Parks Commission (NGPC) and a user must make contact to verify this land use type.

Land use types for predictive models should be accessed according to table 3-2:

Table 3-2. Data sources for land use identification.

Model Land Use	*Source*
CRP and WRP/WRE Conservation Reserve Program/Wetland Reserve Program (now Wetland Reserve Easement)	*Conservation Program Spatial Data: Permission to access data is required*
Cropland/Agriculture Currently cultivated	*CropScape: Any Crop Land Cover, includes all but non-crop (i.e. fallow, forest, developed, water, barren)*
Fallow Crop Previously cultivated but unmanaged	*CropScape: Fallow/Idle 61 – Fallow/Idle Cropland*
Native Grassland Non-cultivated	*CropScape: Grass or Pasture 176 – Grassland/Pasture*
Reference Wetland	*Contact Nebraska Game and Parks Commission*

Satellite Imagery: recent imagery can be accessed through Earth Explorer where Landsat 8 scenes can be downloaded for the location of interest (https://earthexplorer.usgs.gov/). Smaller features such as constructed dikes, pits and drainage canals can be detected using this imagery. Historical Landsat imagery is also available.

Other Datasets

SSURGO: is the Soil Survey Geographic Database which contains information from the National Cooperative Soil Survey. This survey has collected field data and mapped soil types in the United States for almost a century. Data can be accessed through the Web Soil Survey and many different soil characteristic data are available (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx).

MODIS: is the Moderate Resolution Imaging Spectroradiometer. This is a sensor that is onboard the Terra and Aqua Satellites run and monitored by the National Aeronautics and Space Administration (NASA). This sensor is able to gather images from many different spectral bands and is capable of determining vegetative condition through Fraction of Photosynthetically Active Radiation (FPAR) and Leaf Area Index (LAI). Data can be accessed from NASA's Earth Data web page (https://search. earthdata.nasa.gov/search).

Coordinate Systems

For observing maps and other spatial data, the authors recommend 'NAD_1983_Albers' as the coordinate system. This system is used by the National Wetlands Inventory (NWI) and limits area distortions across the extent of the United States (for more information see https://www.fws.gov/ wetlands/data/Projection.html). When using a GIS to observe numerous datasets which may include vectors and rasters, the data frame and all data layers should have matching geographic and projected coordinate systems. This prevents measurement and location errors between data layers. Transformations between coordinate systems may be required.

- Coordinate System: North American Datum 1983 Albers (NAD 1983 Albers)
    - Datum: North American 1983 (NAD 1983)
    - Geographic Coordinate System: GCS North American 1983
    - Projected Coordinate System: Albers Conical Equal Area

ArcMap Instructions

Geographic Information System (GIS) instructions are included throughout this manual for ESRI ArcMap 10.4. The authors sought to provide a straightforward method with detailed instructions for this commonly used system. While instructions provided here are specific to ArcMap, other geographic information systems can be used. As stated above, datasets and remote sensing tools and programs with equal or greater reliability are encouraged for use with this manual.

Ecosystem Service Models

1. Percent Contaminant Filtration (%)

PERCENT REMOVAL BY VEGETATIVE BUFFER TYPE

Playas accumulate contaminants from the surrounding upland through runoff. For a playa in a cultivated watershed, a buffer of vegetation along the wetland edge is capable of filtration by trapping a certain percentage of runoff contaminants and withholding those from the wetland basin. The filtration occurring in a vegetative buffer depends on the type of vegetation present. The percent of an upland contaminant removed by a buffer can be estimated when the vegetative type is identified. Vegetative buffer type includes Conservation Reserve Program (CRP), fallow crop, and native grassland. If no buffer is present between cultivated crops and playa edge, filtration is considered to be 0%. Once the vegetative buffer is identified, a maximum filtration percent can be selected based on the contaminant of interest utilizing Table 3-3 below (Haukos et al. 2016).

Sub-Region(s): Southern High Plains (SHP). Not recommended for use in other portions of the Western High Plains (WHP) or the Nebraska Rainwater Basin (RWB) playas (Figure 3-1).

Note: Estimation for Percent Contaminant Filtration (Model 1) was included here along with wetland Contaminant Concentration (Model 2). Although these estimations both predict contaminants, they answer slightly different questions. Percent filtration can be used to determine the effectiveness of a vegetative buffer based on its land-use type. Contaminant concentration determines the amount of contaminants estimated to be present within the water moving into the wetland.

COMPONENTS

- Metric A: Vegetative Buffer Type
- Land-use data along with conservation program spatial data
- Table 3-3: Contaminant Filtration by Buffer Type

METHODS

1. Determine Vegetative Buffer Type (Metric A)

Instructions

1.1. Identify the vegetative buffer by observing a land-use dataset and conservation program spatial data. Buffer is determined by the land use surrounding >50% the wetland edge that is not classified as cropland.

1.2. Can be any of the following non-crop vegetation type. CropScape land cover in parenthesis (Table 3-2).

- **CRP**: Conservation Reserve Program (not in CropScape)
- **Fallow:** unmanaged, previously cultivated (61 – Fallow/Idle)
- **Native Grassland**: rangeland/grazing land (176 – Grassland/Pasture)

- **None** = no vegetative buffer, no filtration

2. Select average percent contaminant filtration Table 3-3

Instructions

2.1 Use table 3-3 and select contaminant of interest.

TABLE 3-3. PERCENT (±SE) CONTAMINANT REMOVAL carried out by a playa vegetative buffer WITHIN A CROPLAND WATERSHED. REMOVAL VALUES BASED ON VEGETATION TYPE. FROM HAUKOS ET AL. (2016).

Contaminant	Vegetative Buffer Type					
	CRP	(SE)	Fallow	(SE)	Native Grassland	(SE)
Total Suspended Solids (TSS) (%)	85.43	(6.16)	79.76	(4.91)	83.44	(3.84)
Total Dissolved Solids (TDS) (%)	57.53	(8.29)	57.62	(6.61)	58.85	(5.17)
Aluminum (Al) (%)	69.71	(8.14)	74.11	(6.65)	77.59	(5.54)
Arsenic (As) (%)	81.31	(8.81)	84.24	(7.20)	74.5	(5.99)
Barium (Ba) (%)	63.73	(8.47)	69.93	(6.92)	79.79	(5.75)
Calcium (Ca) (%)	58.55	(9.86)	62.7	(8.05)	67.17	(6.70)
Chromium (Cr) (%)	98.93	(11.21)	71.54	(9.15)	92.94	(7.62)
Copper (Cu) (%)	68.65	(8.51)	64.35	(6.95)	82.67	(5.78)
Iron (Fe) (%)	71.61	(7.62)	74.93	(6.22)	81.83	(5.18)
Potassium (K) (%)	64.25	(7.81)	60.92	(6.38)	66.89	(5.31)
Magnesium (Mg) (%)	72.97	(8.00)	68.56	(6.53)	69.93	(5.44)
Manganese (Mn) (%)	72.45	(7.54)	74.81	(6.12)	83.64	(5.12)
Nitrogen (N) (%)	85.65	(10.45)	77.96	(8.34)	76.46	(6.52)
Sodium (Na) (%)	58.63	(9.51)	57.38	(7.77)	54.66	(6.46)
Phosphorus (P) (%)	72.04	(8.69)	59.43	(7.09)	76.13	(5.90)
Strontium (Sr) (%)	50.01	(9.97)	65.78	(8.41)	67.21	(6.77)
Vanadium (V) (%)	89.95	(10.11)	77.81	(8.25)	82.3	(6.87)
Zinc (Zn) (%)	60.6	(7.67)	65.64	(6.26)	76.69	(5.21)

2. Contaminant Concentration (ppm)

CONCENTRATION IN RUNOFF BY AVERAGE VEGETATIVE BUFFER WIDTH

Contaminants from the upland are carried into the wetland basin by runoff. Although an established vegetative buffer is capable of filtering a percentage of runoff contaminants, most contaminant types still occur at some level in wetlands with cultivated watersheds. The concentration of contaminants found in the runoff flowing into a playa is related to the width of the vegetative buffer surrounding the playa edge. An increased distance between the cultivated edge and the playa basin causes a decrease in contaminant concentration. The mean width of a non-crop vegetative buffer up to 60 m can be used to estimate the mean concentrations of widespread contaminants within the runoff moving into a wetland. Vegetative buffers exceeding 60 m have not been tested for this model but are understood to provide negligible improvements in contaminant removal (Haukos et al. 2016).

Subregion(s): developed for the SHP and not recommended for use in other portions of the WHP or the RWB (Figure 3-1).

COMPONENTS

- Metric B: Mean Vegetative Buffer Width (m)
- Land-use dataset along with conservation program spatial data
- Table 3-4: Contaminant Concentrations

METHODS

1. Calculate Mean Vegetative Buffer Width (Metric B)

Instructions

1.1. Determine playa centroid.

ARCMAP INSTRUCTIONS

Make data fields

- *Open the wetland shapefile Attribute Table. Select Table Options > Add Field. Make a field labeled 'Latitude' with the field type set as double*
- *Repeat above steps for a field labeled 'Longitude'*

Calculate Latitude and Longitude values

- *Begin an editing session for the playa shapefile*
- *Right click the 'Latitude' field and select 'Calculate Geometry'. In this dialog box, select 'X Coordinate of Centroid' from the property drop down. Units should be selected as 'Decimal Degrees' from the drop down.*
- *Repeat above for 'Longitude' field using the 'Y Coordinate of Centroid'*

Export coordinates to a table

- *In the Attribute Table, select Table Options > Export*
- *Select the save location and when prompted, add the table to the current map*

Display coordinates

- *Right click added table and choose "display xy coordinates"*
- *Set XField as 'Longitude' and YField as 'Latitude'*

- *Right click points layer and export as shapefile to location of choice*

1.2. Select points on playa edge corresponding with the four cardinal directions from centroid.

ARCMAP INSTRUCTIONS

- *Add 4 edge points to shapefile*
  - *Add the coordinate points shapefile to the current map document*
  - *Begin an editing session for the point shapefile*
  - *Use the 'Create Features" window and select the shapefile. Use 'Construction Tools' to add points to the shapefile. Use 'Point at end of line' tool to make points on playa edge. Direction from centroid point should be 0°, 90°, 180°, and 270° corresponding with the 4 cardinal directions.*
  - *Attribute table can be edited to label each point for each associated cardinal direction.*

1.3. From each edge point, measure and record the vegetative buffer width up to 60 m. Measurement should be taken at an approximately 90 ° angle from playa edge to measure width.

1.4. Identify land use as any of the following non-crop vegetation type from a land-use dataset and conservation program spatial data. CropScape land cover in parenthesis (Table 3-2).

- **CRP**: Conservation Reserve Program (not in CropScape)
- **Fallow:** unmanaged, previously cultivated (61 – Fallow/Idle)
- **Native Grassland**: rangeland/grazing land (176 – Grassland/Pasture)

1.5. Calculate the mean vegetative buffer width using the measurements from all four directions.

2. Select average contaminant concentration (ppm)

2.1. Use table 3-4 to select contaminant of interest.

2.2. Round the mean buffer width to the nearest 10 and select concentration for contaminant of interest.

TABLE 3-4. Mean (±SE) concentrations (ppm) of 19 contaminants found in runoff flowing into playas at increasing vegetative buffer widths. From haukos et al. (2016*).*

Contaminant	*Buffer (m)*	*Mean (ppm)*	*SE*	*Contaminant*	*Buffer (m)*	*Mean (ppm)*	*SE*
Aluminum (Al)	*0*	*168.5*	*23.9*	*Arsenic (As)*	*0*	*0.218*	*0.0275*
	10	*105.82*	*17.176*		*10*	*0.1359*	*0.0215*
	20	*69.857*	*14.039*		*20*	*0.0912*	*0.0188*
	30	*54.374*	*11.966*		*30*	*0.0723*	*0.0156*
	40	*46.923*	*11.629*		*40*	*0.0643*	*0.0162*
	50	*44.595*	*13.133*		*50*	*0.0555*	*0.016*
	60	*45.899*	*20.774*		*60*	*0.0575*	*0.0246*
Barium (Ba)	*0*	*0.6636*	*0.0768*	*Calcium (Ca)*	*0*	*66.791*	*18.747*
	10	*0.4589*	*0.0593*		*10*	*22.676*	*3.2419*
	20	*0.3138*	*0.0484*		*20*	*16.793*	*2.4937*
	30	*0.2491*	*0.0439*		*30*	*15.127*	*2.5467*
	40	*0.2157*	*0.0483*		*40*	*11.179*	*1.5925*
	50	*0.2118*	*0.0542*		*50*	*8.4427*	*1.6784*
	60	*0.205*	*0.0645*		*60*	*13.014*	*5.2814*
Cadmium (Cd)	*0*	*0.0048*	*0.001306*	*Chromium (Cr)*	*0*	*0.1452*	*0.0418*
	10	*0.003704*	*0.0009471*		*10*	*0.0674*	*0.0122*
	20	*0.005385*	*0.001384*		*20*	*0.0442*	*0.0104*
	30	*0.002273*	*0.0009145*		*30*	*0.0309*	*8.35E-03*
	40	*0.003077*	*0.001332*		*40*	*0.0307*	*8.86E-03*
	50	*0.004545*	*0.001574*		*50*	*0.0273*	*0.0102*
	60	*0.00875*	*0.002266*		*60*	*0.0275*	*0.0128*
Copper (Cu)	*0*	*0.1936*	*0.1281*	*Iron (Fe)*	*0*	*101.99*	*15.005*
	10	*0.0493*	*0.007356*		*10*	*64.23*	*10.582*
	20	*0.0327*	*0.005161*		*20*	*40.975*	*7.9188*
	30	*0.025*	*0.003989*		*30*	*31.506*	*6.6278*
	40	*0.0221*	*0.004591*		*40*	*28.186*	*6.9828*
	50	*0.02*	*0.004671*		*50*	*26.699*	*8.034*
	60	*0.0175*	*0.006748*		*60*	*27.207*	*12.058*
Potassium (K)	*0*	*42.36*	*5.4731*	*Magnesium (Mg)*	*0*	*32.521*	*9.0387*
	10	*29.008*	*2.9826*		*10*	*16.388*	*2.1295*
	20	*19.606*	*2.3005*		*20*	*10.67*	*1.555*
	30	*17.454*	*2.2876*		*30*	*8.5486*	*1.5101*
	40	*15.169*	*2.6746*		*40*	*7.9557*	*1.7998*
	50	*12.425*	*2.7249*		*50*	*6.75*	*1.8378*
	60	*14.52*	*4.2032*		*60*	*7.9787*	*2.8199*

Table 3-4. Continued.

Contaminant	Buffer (m)	Mean (ppm)	SE	Contaminant	Buffer (m)	Mean (ppm)	SE
Manganese (Mn)	0	1.4572	0.2053	Sodium (Na)	0	39.209	35.808
	10	0.9444	0.1621		10	2.2037	0.3591
	20	0.6385	0.1138		20	1.6469	0.2664
	30	0.4682	0.1057		30	1.3859	0.2701
	40	0.4307	0.1114		40	1.3493	0.3214
	50	0.3318	0.0697		50	1.1082	0.336
	60	0.4013	0.1568		60	1.0475	0.3601
Nitrogen (Ni)	0	0.272	0.1716	Nitrate_p	0	4.1667	1.2052
	10	0.0737	0.009625		10	3.2844	0.8423
	20	0.0608	0.007584		20	2.3781	0.7942
	30	0.0491	0.005342		30	1.3133	0.3859
	40	0.04	0.006202		40	0.955	0.3957
	50	0.0327	0.007273		50	0.4	0.1187
	60	0.0363	0.0116		60	0.4818	0.1667
Phosphorous (P)	0	2.0396	0.2101	Total Dissolved Solids (TDS)	0	0.2659	0.1036
	10	1.4426	0.1596		10	0.1111	0.0145
	20	1.08	0.1509		20	0.0737	8.19E-03
	30	0.9241	0.1417		30	0.0703	0.0119
	40	0.8629	0.1556		40	0.0666	0.0164
	50	0.7273	0.1697		50	0.0438	7.43E-03
	60	0.6837	0.1824		60	0.0457	9.18E-03
Total Suspended Solids (TSS)	0	2.7231	0.5349	Vanadium (V)	0	0.1584	0.0296
	10	1.7194	0.3595		10	0.1148	0.0205
	20	1.0846	0.2339		20	0.1208	0.0267
	30	0.7682	0.2107		30	0.0636	0.0134
	40	0.6345	0.2448		40	0.0669	0.0223
	50	0.6218	0.2588		50	0.0909	0.0283
	60	0.8159	0.3379		60	0.1288	0.0423
Zinc (Zn)	0	0.8736	0.4365				
	10	0.3544	0.0371				
	20	0.2869	0.035				
	30	0.2082	0.0214				
	40	0.19	0.0242				
	50	0.2	0.0425				
	60	0.1763	0.0304				

3. Pesticide Residue (µg/kg)

CONCENTRATION IN PLAYA SEDIMENTS BY LOCATION AND LAND USE

The concentrations of pesticide residue in playa sediments vary depending on surrounding land use and subregion. In the High Plains, there are three areas that exhibit slight differences, the southern playas, northern playas and those in the RWB in Nebraska (Figures 3-2 and 3-3). Discrete values can be estimated for a playa of interest based on subregion and surrounding land use (Kensinger et al. 2014).

Subregion(s): developed for both WHP and RWB subregions (Figures 3-2 and 3-3). Conservation programs differ between subregions.

COMPONENTS

- Metric C: Dominant Surrounding Land Use (500 m)
- Land-use dataset along with conservation program spatial data
- Table 3-5: Pesticide Concentrations

METHODS

1. Determine playa subregion

Instructions

1.1. Identify the state/area that the playa of interest exists within (Figure 3-2).
- **Northern Playas**: Kansas, Colorado, Western Nebraska
- **Southern Playas**: Oklahoma, New Mexico, Texas
- **Rainwater Basin**: South Central Nebraska

2. Determine Dominant Land Use (Metric C)

Instructions

1.1. Establish a 500 m radius buffer around playa shape.
1.2. Within the land-use buffer, measure or visually inspect the categories displayed in the land-use dataset and conservation program spatial data.
1.3. Calculate (or estimate if obvious) land-use type covering >50% of the area within the buffer. CropScape land cover in parenthesis (Table 3-2).
- **Cropland**: in production (any crop type)
- **Native Prairie:** rangeland/grazing land (176 – Grassland/Pasture)
- **Reference (RWB)**: contact NPWC
- **CRP or WRP/WRE**: Conservation Reserve Program or Wetland Reserve Program/Wetland Reserve Easement (none)

3. Select average contaminant concentration (ug/kg)

Instructions

3.1. In Table 3-5, select the appropriate heading based on subregion.
3.2. Select the column which corresponds with the contaminant of interest.
3.3. Select the row based on dominant land use and identify the corresponding concentration value.

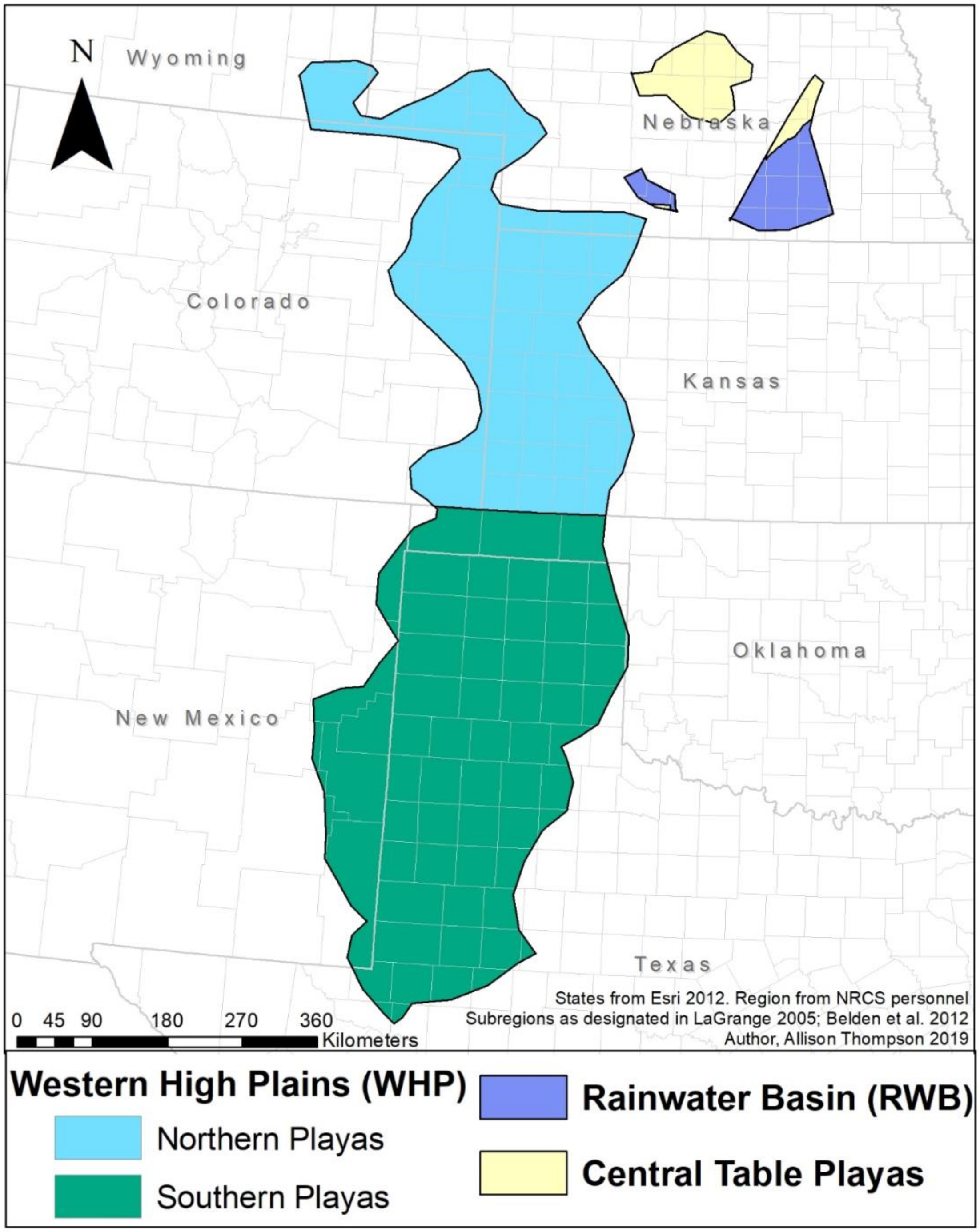

Figure 3-2 Conservation Effects Assessment Project (CEAP) - Wetlands High Plains Region (HPR) with Subregions and playa groups shown as designated by LaGrange (2005) and Belden et al. (2012). Data from ESRI (2017), Rainwater Basin Joint Venture (2018) and personal communication with William Effland (2017).

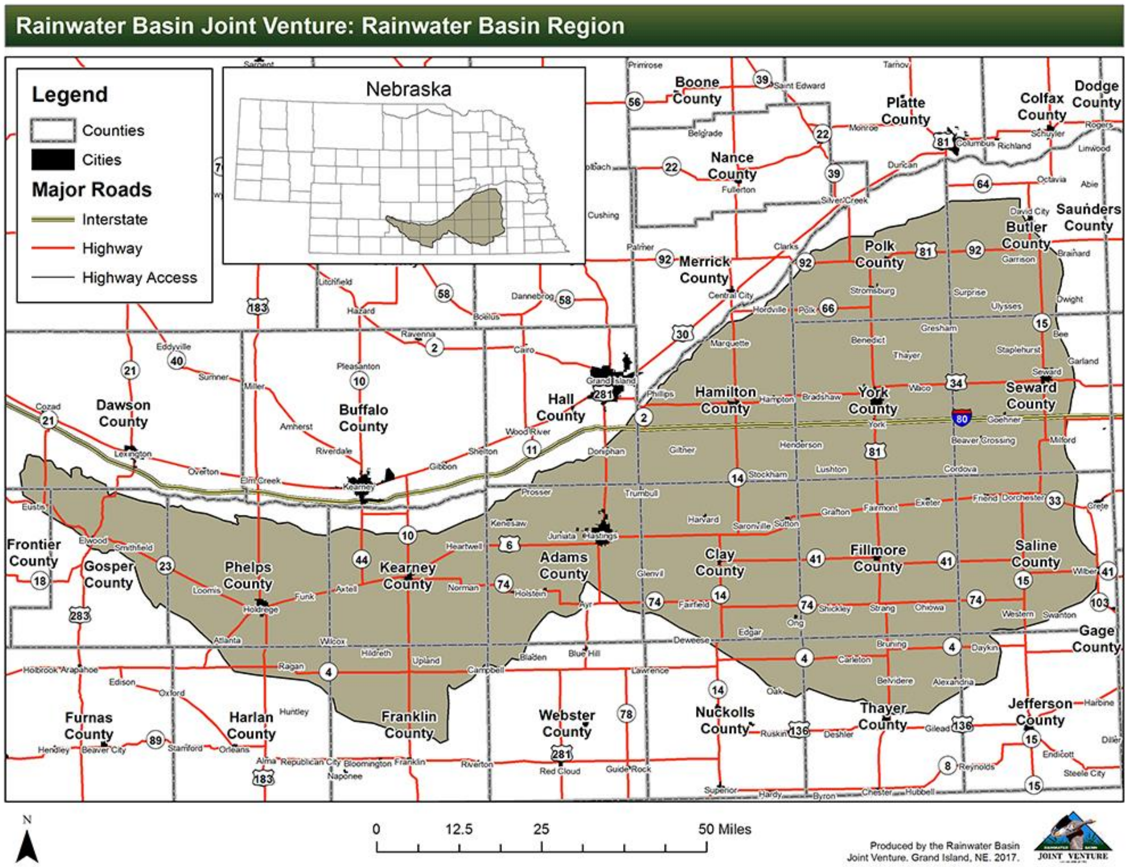

FIGURE 3-3. RAINWATER BASIN (RWB) SUBREGION OF NEBRASKA. FROM RAINWATER BASIN JOINT VENTURE (2018).

Table 3-5. Mean (±SE) pesticide residue concentrations (µg/kg) for common pesticides found in playa sediments across three different portions of the HPR. Table modified from Kensinger et al. (2014).

Northern Playas	***Acetochlor***	***(SE)***	***Atrazine***	***(SE)***	***S-metolachlor***	***(SE)***	***Trifluralin***	***(SE)***
Cropland	0.11	0.11	23.78	13.84	10.36	7.36	0.10	0.07
Native prairie	0.23	0.05	0.42	0.09	0.42	0.09	0.18	0.04
CRP	0.00	0.00	0.67	0.15	0.00	0.00	0.05	0.01
Southern Playas	***Acetochlor***	***(SE)***	***Pendimethalin***	***(SE)***	***S-metolachlor***	***(SE)***	***Trifluralin***	***(SE)***
Cropland	1.64	0.72	15.12	14.28	2.35	2.13	4.87	1.91
Native prairie	1.13	0.61	0.00	0.00	0.23	0.23	0.25	0.12
CRP	0.18	0.03	0.29	0.04	0.00	0.00	0.71	0.10
Rainwater Basin Playas	***Acetochlor***	***(SE)***	***Atrazine***	***(SE)***	***S-metolachlor***	***(SE)***	***Trifluralin***	***(SE)***
Cropland	1.26	1.26	86.08	80.33	3.61	1.68	0.19	0.10
Reference	0.00	0.00	4.47	3.30	0.68	0.26	0.42	0.15
WRP/WRE	3.61	3.03	1.48	0.64	0.42	0.17	0.13	0.09

4. Sediment Depth (cm)

PLAYA BASIN BY PERCENT CROP IN WATERSHED

There is a strong relationship between playa sediment accumulation and land use within the watershed. Sediments depths increase within a playa basin when soil disturbance occurs in the watershed and increased agricultural production causes greater sediment accumulation. Sediment depths can be estimated based on the percent cropland within the watershed using equation 3-2 (McMurry and Smith 2018).

Subregion(s): this predictive model was developed for the SHP and not recommended for use in other portions of the WHP or the RWB (Figure 3-1).

COMPONENTS

- Metric D: Percent Crop in Watershed
- Land-use dataset
- Equations 3-1 and 3-2

METHODS

1. **Determine percent crop within the watershed (Metric D)**

Instructions

4.1. Delineate the playa watershed using a topographic map in a GIS

ArcMap Instructions

- Open a spatially referenced topographic map as a basemap with the playa of interest. Projections for data frame, playa polygon and topo map should be the same.
- Create a new feature class and begin an editing session. In the Create Features window use the Construction Tool to make a polygon by placing points on all high terrain locations surrounding the playa. For more detailed instructions on watershed delineation see https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_014819.pdf
- Save the polygon and label the watershed to correspond with the playa label.

4.2. Calculate the total area within the watershed

4.3. Calculate the area within the watershed that is identified as crop or agriculture using the land-use dataset of choice. CropScape land cover in parenthesis (Table 3-2).

- **Cropland**: in production (any crop type)

4.4. Determine the percent of the total area that is identified as crop or agriculture. This can be done by using equation 3-1.

Equation 3-1

$$percent.crop = \frac{crop.area}{total.area} * 100$$

2. Solve for sediment depth (cm) using percent crop

Instructions

2.1. Use percent crop value from the method listed above and apply to equation 3-2 to determine sediment depth (cm).

Equation 3-2

$$sediment.depth = (0.44987 + 0.4457 * percent.crop)$$

5. Floodwater Storage (m^3)

EQUATIONS USING ORIGINAL VOLUME AND VOLUME LOSS

Precipitation from a playa's watershed can flow into the basin and be stored as floodwater. Sediments also flow into the basin and are deposited there, decreasing the basin depth and causing reduction in floodwater storage volume. Increase in sediment depth is related to land disturbance in the watershed and causes a predictable change in the volume of floodwater that can be stored. The relationship between playa area and original playa volume before sedimentation, is quantified in the *Original Volume* equation (Table 3-6). The relationship between percent volume loss and sediment depth is quantified in the *Percent Lost* equation (Table 3-6). These values are both used to estimate volume of current potential floodwater storage for a playa of interest (McMurry and Smith 2018).

Subregion(s): this predictive model was developed for the SHP and not recommended for use in other portions of the WHP or the RWB (Figure 3-1).

COMPONENTS

- Metric E: Playa Area (ha)
- Playa Model 4: Sediment Depth
- Table 3-6: Volume equations

METHODS

1. Determine Playa Area (Metric E)

Instructions

1.1 Calculate playa area (ha) within the shapefile using a GIS

2. Calculate Floodwater Storage based on original volume (OVol) and volume loss (LVol)

Instructions

2.1. Determine Original Volume (m^3) using playa area (ha) and the equation (Table 3-6).
2.2. Determine Percent Lost using sediment depth (cm) from Model 4 and the given equation (Table 3-6).
2.3. Calculate Total Volume Lost (m^3) using original volume (m^3) and percent volume lost along with the given equation (Table 3-6).
2.4. Calculate current floodwater storage (m^3) using original volume (m^3) and volume lost (m^3) along with the given equation (Table 3-6).

TABLE 3-6. EQUATIONS TO DETERMINE PLAYA ORIGINAL VOLUME (M^3), PERCENT VOLUME LOST (%), TOTAL VOLUME LOST (M^3) AND CURRENT FLOODWATER STORAGE (M^3). MODIFIED FROM MCMURRY AND SMITH (2018).

Model Name	***Equation***	***Predictors***
Original Volume (m^3)	OVol = 13868.5182 + 740.5821*area + 135.0543*area^2	area (ha)
Percent Lost (%)	%Lost = 20.9841 + 2.4595*sed.depth	sed.depth (cm)
Total Volume Lost (m^3)	LVol = OVol*(%Lost / 100)	OVol (m^3) %Lost (%)
Floodwater Storage (m^3)	FwSt = OVol – LVol	OVol (m^3) LVol ($m^{3)}$)

6. Greenhouse Gas Flux (g C/ha/day)

REGRESSION USING MODIS VALUES

Greenhouse gases include carbon dioxide, methane, and nitrogen dioxide. A playa can be both a source and sink for greenhouse gasses depending on the wetland condition and water level at a given time. Net greenhouse gas (GHG) flux is defined here as the carbon dioxide equivalent for the sum of all emissions and absorptions of the three most common greenhouse gasses (CO_2+CH_4+N_2O). This metric indicates the overall exchange of these gasses occurring in wetland. GHG flux differs across playas in varying land-use types and is related to remotely sensed vegetation metrics. Fraction of Photosynthetically Active Radiation (FPAR) represents the amount of radiation absorbed by green vegetation and Leaf Area Index (LAI) represents green leaf area per unit ground area. These values relate to GHG flux differently within different regions of the High Plains. Remotely sensed measurements for both are provided by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) (Zhuoqing et al. 2016a).

Subregion(s): developed for the Northern High Plains (NHP) portion of the WHP as well as the RWB. Not recommended for use in other portions of the WHP (Figures 3-1 and 3-3).

Limitations: Data used to build this model were sampled from the months of April to October. Estimates are considered most accurate for predicting GHG values during this time. To predict service provisioning based on future land use conditions, reflectance values representing that type should be used.

COMPONENTS

- Metric C: Dominant Land Use (500 m)
- Land-use dataset along with conservation program spatial data
- Metric F: Moderate Resolution Imaging Spectroradiometer (MODIS) Values
- Table 3-7: GHG Flux Equations

METHODS

1. Determine High Plains Subregion

Instructions

1.1. Identify the subregion for the playa of interest (Figures 3-1 and 3-3).
- **Northern High Plains (NHP)**: Northern portion of the WHP
- **Rainwater Basin (RWB)**: South Central Nebraska

1.2. Use sub region to select necessary section of Table 3-7.

2. Determine Dominant Land Use (Metric C)

Instructions

2.1. Establish a 500 m radius buffer around playa shape.

2.2. Within the land-use buffer, measure or visually inspect the categories displayed in the land-use dataset and conservation program spatial data.

2.3. Calculate (or estimate if obvious) land-use type covering >50% of the area within the buffer. CropScape land cover in parenthesis (Table 3-2).

- **Cropland**: in production (any crop type)
- **Native Prairie:** rangeland/grazing land (176 – Grassland/Pasture)
- **Reference (RWB)**: contact NPWC
- **CRP or WRP/WRE**: Conservation Reserve Program or Wetland Reserve Program/Wetland Reserve Easement (none)

2.4 From dominant land use, select necessary GHG equation from Table 3-7.

3. Determine appropriate MODIS values (Metric F)

Instructions

3.1. Go to https://search.earthdata.nasa.gov/search and download <MODIS/Terra Leaf Area Index/FPAR 8-day L4 Global 500m SIN Grid> granule for location of interest.

3.2. View the raster in a GIS and read values of the pixel at the playa center.

ArcMap Instructions

- MODIS User Guide for reference
- https://lpdaac.usgs.gov/documents/2/mod15_user_guide.pdf
- Upload rasters into ArcMap along with a playa shapefile
- Re-project LAI and FPAR rasters from sinusoidal to projection of choice (new projection should match data frame and playa shapefile)
- Determine the raster cell value within the playa basin
  - LAI (Leaf Area Index)
    - Range: 0-100
    - Scale factor: multiply cell value by: 0.1
  - FPAR (Fraction of Photosynthetically Active Radiation)
    - Range: 0-100
    - Scale factor: multiply cell value by 0.01

TABLE 3-7. GREENHOUSE GAS FLUX (G C/HA/DAY) ESTIMATES FOR PLAYAS BASED ON SUBREGION, DOMINANT LAND USE AND REMOTELY SENSED VEGETATION FEATURES. MODIFIED FROM ZHUOQING ET AL. (2016A).

Rainwater Basin Land Use	***Rainwater Basin GHG Flux (g C/ha/day)***	***Predictors***
Agriculture	Ag_RWB_GHG = 196485.656 * POWER(FPAR,1.357)	FPAR
Reference	Ref_RWB_GHG = 171901.578 * POWER(FPAR,1.222)	FPAR
WRP/WRE	WRP_RWB_GHG = 82717.861 – 13595.894/FPAR	FPAR
Northern High Plains Land Use	***Northern High Plains GHG Flux (g C/ha/day)***	***Predictors***
Agriculture	Ag_WHP_GHG = EXP(11.568 – 0.538/FPAR)	FPAR
Native Grass	NG_WHP_GHG = EXP(11.118 – 0.27/LAI)	LAI
CRP	CRP_WHP_GHG = EXP(11.447 – 0.603/FPAR)	FPAR

7. Soil Organic Carbon (kg/m^2)

REGRESSION USING SSURGO METRICS

The ability of a wetland to sequester carbon is related to a host of variables including geographic features, vegetative communities and water presence. Soil organic carbon (SOC) values at a 0–50 cm depth within a playa basin can be estimated for three separate land uses across the WHP. This estimation uses equations developed with SSURGO values. Estimated SOC is closely related to dominant land use. Once an equation is selected, numerous predictors must be determined from the SSURGO database and remotely sensed imagery to be used in the given equations (Zhuoqing et al. 2016b).

Subregion(s): this predictive model was developed for the WHP and not recommended for use in RWB playas (Figure 3-1).

COMPONENTS

- Metric C: Dominant Surrounding Land Use (500m)
- Land-use dataset along with conservation program spatial data
- Metric G: Soil Survey Geographic Database (SSURGO) Predictors
    - websoilsurvey.gov
- Metric H: Soil Adjusted Vegetative Index (SAVI)
    - NIR Satellite Imagery Band and RED Satellite Imagery Band
    - Or Landsat 8 Spectral Reflectance
- Table 3-8 through 3-10: SSURGO metrics for estimating soil organic carbon

METHODS

1. Determine Dominant Land Use (Metric C)

Instructions

1.1. Establish a 500 m radius buffer around playa shape.

1.2. Within the land-use buffer, measure or visually inspect the categories displayed in the land-use dataset and conservation program spatial data.

1.3. Calculate (or estimate if obvious) land-use type covering >50% of the area within the buffer. CropScape land cover in parenthesis (Table 3-2).

- **Agriculture**: in production (any crop type)
- **Native Grass:** rangeland/grazing land (176 – Grassland/Pasture)
- **CRP:** Conservation Reserve Program (not in CropScape)

1.4. Use dominant land use to select necessary SOC equation from Table 3-8

2. SSURGO feature values for playa points of interest (Metric G)

Instructions

2.1. Determine playa centroid coordinates.

ARCMAP INSTRUCTIONS

Make data fields

- Open the wetland shapefile Attribute Table. Select Table Options > Add Field. Make a field labeled 'Latitude' with the field type set as double
- Repeat above steps for a field labeled 'Longitude'

Calculate Latitude and Longitude values

- Begin an editing session for the playa shapefile
- Right click the 'Latitude' field and select 'Calculate Geometry'. In this dialog box, select 'X Coordinate of Centroid' from the property drop down. Units should be selected as 'Decimal Degrees' from the drop down.
- Repeat above for 'Longitude' field using the 'Y Coordinate of Centroid'

Export coordinates to a table

- In the Attribute Table, select Table Options > Export
- Select the save location and when prompted, add the table to the current map

Display coordinates

- Right click added table and choose "display xy coordinates"
- Set XField as 'Longitude' and YField as 'Latitude'
- Right click points layer and export as shapefile to location of choice

2.2. From Table 3-8, observe which predictors are needed to apply the equation. Data source location and variable descriptions are provided in tables 3-9 and 3-10 respectively.

2.3. Use Web Soil Survey (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx) and search a location by the playa centroid using the GPS coordinates. An Area of Interest (AOI) polygon should be drawn that encompasses the playa and its general area (≈500 m circumference).

2.4. Use the "Soil Data Explorer" tab to locate necessary feature values and record results for required points.

2.5. Refer to Table 3-9 for details on locations and how to find metrics. (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053375).

3. ASUR modification

Instructions

When the ASUR modification is present in an equation, two additional location points besides the playa centroid are required. These two points are located outside of the wetland basin at 10 m and 40 m from the wetland edge. These two are averaged to determine the necessary value according to the ASUR modification.

3.1. Build necessary data points.

- From playa centroid, measure in the southwest direction (225 degrees) to playa edge
- From edge location, measure at the same angle and build two points, one 10 m and one 40 m from the SW edge

3.2. Use the Web Soil Survey and under the "Soil Data Explorer" tab, locate necessary predictors.

3.3. Determine necessary feature value for 10 m point.

3.4. Determine necessary feature value for 40 m point.

3.5. Calculate and document ASUR value by averaging the two values.

4. Soil Adjusted Vegetation Index (SAVI) (Metric H)

Instructions

4.1. Calculate Index (Choose one of the two methods below).

Basic Remote Sensing Instructions

- Use Landsat 8 spectral reflectance bands to determine index
- Red: Landsat band 4 (0.636–0.673 µm)
- NIR: Landsat band 5 (0.851–0.879 µm)
- Apply equation $SAVI = \frac{(1+L)(NIR-Red)}{(NIR+Red+L)}$

  Where L value is 0.5 (adjustment to minimize soil brightness)

Landsat 8 Image Download Instructions

- Use https://earthexplorer.usgs.gov/ to determine the name of the most recent required Landsat 8 OLI/TRS C1 Level-2 scene.
- Create a .txt file with the scene name pasted within.
- Go to USGS bulk ordering page https://espa.cr.usgs.gov/ordering/new/
- Under “Scene List” choose .txt file with scene name.
- Under “Level-2 Products” check ‘Spectral Indices’ and in the dropdown, select ‘SAVI’
- Submit order under USGS log-in username
- Once order has been processed and sent in email, download the zipped file with type being tar.gz
- Unzip tar.gz file and save in desired folder
- Open folder in arcmap and upload SAVI scene as .tif
- Read pixel value for point of interest and scale by given factor
  - SAVI scale factor = 0.0001 (see product guide for more information) (https://landsat.usgs.gov/sites/default/files/documents/si_product_guide.pdf)

TABLE 3-8. EQUATIONS FOR ESTIMATING SOIL ORGANIC CARBON (KG/M^2) IN PLAYAS WITH ESTIMATES BASED ON SURROUNDING LAND USE AND SSURGO VARIABLES. MODIFIED FROM ZHUOQING ET AL. (2016B).

Land-Use	Soil Organic Carbon (kg/m^2)	Predictors
Agriculture Playa Basin	Ag_SOC = POWER(5.46 – 1.955*ASUR_SAVI – 2.438*ASUR_DB + 0.00048*ASUR_RangPro + 0.027*WC – 0.778*pH + 3.921*DB,2)	ASUR_ SAVI DB RangPro WC pH
CRP Playa Basin	CRP_SOC = POWER(1.162 + 0.53*ASUR_OrgMat + 0.037*Sand – 0.124*Ksat + 0.396*Slope,2)	ASUR_ OrgMat Sand Ksat Slope
Native Grassland Playa Basin	NG_SOC = EXP (1.473 + 0.605*ASUR_EC + 0.028*ASUR_Ksat + 1.932*ASUR_SAVI – 0.356*EC – 0.192*Slope – 0.095 * ASUR_AWS)	ASUR_ EC Ksat SAVI Slope AWS

TABLE 3-9. VARIABLE NAMES AND DATA SOURCES FOR ALL PREDICTORS REQUIRED FOR SOIL ORGANIC CARBON MODELS. TABLE MODIFIED FROM ZHUOQING ET AL. (2016B).

Data Source	***Name***	***Code***	***Soil Data Explorer Tab***	***Category***	***Depth***	***Aggregation Method***	***Rating Unit***
SSURGO DATA	Range productivity (normal year)	RangPro	Suitabilities and Limitations	Vegetative Productivity	N/A	Weighted Average	lbs/ac/yr
	Representative Slope	Slope	Soil Properties and Qualities	Soil Qualities and Features	N/A	Dominant Component	percent
	Electrical Conductivity (EC)	EC	Soil Properties and Qualities	Soil Chemical Properties	0-50 cm	Dominate component	dS/m at 25 C
	pH (1 to 1 Water)	pH	Soil Properties and Qualities	Soil Chemical Properties	0-50 cm	Dominate component	pH scale
	Available Water Supply, 0 to 50 cm	AWS	Soil Properties and Qualities	Soil Physical Properties	0-50 cm	N/A	cm
	Bulk Density, One-Third Bar	DB	Soil Properties and Qualities	Soil Physical Properties	0-50 cm	Dominate component	g/cm^3
	Organic Matter	OrgMat	Soil Properties and Qualities	Soil Physical Properties	0-50 cm	Dominate component	percent by weight
	Percent Sand	Sand	Soil Properties and Qualities	Soil Physical Properties	0-50 cm	Dominate component	percent by weight
	Saturated Hydraulic Conductivity (Ksat)	Ksat	Soil Properties and Qualities	Soil Physical Properties	0-50 cm	Dominate component	µm/s
	Water Content, One-Third Bar	WC	Soil Properties and Qualities	Soil Physical Properties	0-50 cm	Dominate component	volumetric percentage
MODIFICATIONS	10m and 40m point values required	ASUR_		Method	N/A	N/A	
SATELLITE DATA	Soil Adjusted Vegetation Index	SAVI		Vegetation	N/A	Nearest	

TABLE 3-10. VARIABLE DETAILS FOR SSURGO PREDICTORS REQUIRED FOR SOIL ORGANIC CARBON MODELS. TABLE MODIFIED FROM ZHUOQING ET AL.

Code	Notes
RANGPRO	Total range production is the amount of vegetation that can be expected to grow annually in a well-managed area that is supporting the potential natural plant community. It includes all vegetation, whether or not it is palatable to grazing animals. It includes the current year's growth of leaves, twigs, and fruits of woody plants. It does not include the increase in stem diameter of trees and shrubs. It is expressed in lbs/ac of air-dry vegetation. In a normal year, growing conditions are about average. Yields are adjusted to a common percent of air-dry moisture content.
SLOPE	Slope gradient is the difference in elevation between two points, expressed as a percentage of the distance between those points.
EC	Electrical conductivity (EC) is the electrolytic conductivity of an extract from saturated soil paste, expressed as dS/m at 25 ° C.
PH	Soil reaction is a measure of acidity or alkalinity.
AWS	Available water supply (AWS) is the total volume of water (in cm) that should be available to plants when the soil, inclusive of rock fragments, is at field capacity. It is commonly estimated as the amount of water held between field capacity and the wilting point, with corrections for salinity, rock fragments, and rooting depth. AWS is reported as a single value (in cm) of water for the specified depth of the soil. AWS is calculated as the available water capacity times the thickness of each soil horizon to a specified depth.
DB	Bulk density, 15 bar, is the ovendry weight of the soil material less than 2 mm in size per unit volume of soil at water tension of 1/3 bars, expressed in g/cm^3.
ORGMAT	Organic matter is the plant and animal residue in the soil at various stages of decomposition. The estimated content of organic matter is expressed as a percentage, by weight, of the soil material that is less than 2 mm in diameter.
SAND	Sand as a soil separate consists of mineral soil particles that are 0.05 mm to 2 mm in diameter. The estimated sand content of 0-50 cm soil layer is given as a percentage, by weight, of the soil material that is less than 2 mm in diameter.
KSAT	Saturated hydraulic conductivity (Ksat) refers to the ease with which pores in a saturated soil transmit water. The estimates are expressed in terms of µm/s. They are based on soil characteristics observed in the field, particularly structure, porosity, and texture. Saturated hydraulic conductivity is considered in the design of soil drainage systems and septic tank absorption fields.
WC	Water content, one-third bar, is the amount of soil water retained at a tension of 1/3 bar, expressed as a volumetric percentage of the whole soil. Water retained at 1/3 bar is significant in the determination of soil water-retention difference, which is used as the initial estimation of available water capacity for some soils.
ASUR_	Metrics from points in the watershed are incorporated in this method. The modified parameter value is calculated by taking the mean of the 10 m and 40 m measurements.
SAVI	SAVI is calculated as a ratio between the R and NIR values with a soil brightness correction factor (L) defined as 0.5 to accommodate most land cover types. It represents the extent of land with vegetation covered.

8. Native Plant Species Richness

REGRESSION EQUATIONS USING BASIN AND UPLAND FEATURES

Species richness of native plants within a playa basin is related to various features within and surrounding the playa. These include surrounding land use, water presence, playa size and features of nearby playas. These relationships change between changing dominant land-use types. Native wetland species richness and native grassland species richness within the playa basin can be estimated using numerous variables and equations included below (O'Connell et al. 2012).

Subregion(s): this predictive model was developed for the WHP and not recommended for use in RWB playas (Figure 3-1).

Limitations: Data used to build this model were sampled from the months of May to August. Estimates are considered most accurate for predicting Plant Species Richness values during this time.

COMPONENTS

- Metric C: Dominant Land Use (500 m)
- Land-use dataset along with conservation program spatial data
- Metric E: Playa Area
- Metric I: Area Total of Near Playas (within 1 km or 5 km)
- Metric J: UTM Location easterly or northerly
- Metric K: Water Presence
- Metric L: Distance to Nearest Grassland Playa
- Hydrogeomorphic Classification Key (Chapter 2)
- Table 3-11: Plant Species Richness Models

METHODS

1. Determine Dominant Land Use (Metric C)

Instructions

1.1 Establish a 500 m radius buffer around playa shape.

1.2 Within the land-use buffer, measure or visually inspect the categories displayed in the land-use dataset and conservation program spatial data.

1.3 Calculate (or estimate if obvious) land-use type covering > 50 % of the area within the buffer. CropScape land cover in parenthesis (Table 3-2).

- **Cropland**: in production (any crop type)
- **Native Grass:** rangeland/grazing land (176 – Grassland/Pasture)
- **CRP:** Conservation Reserve Program (not in CropScape)

1.4 Use Dominant Land Use to select necessary plant species richness equation from Table 3-11.

2. Use Table 3-11 to select appropriate model

Instructions

2.1. Determine plant richness type of interest.
2.2. Use Dominant Land Use to select model.

3. Determine Playa Area (Metric E)

Instructions

3.1. Calculate playa area (ha) within the playa shapefile using a GIS.

4. Determine Area Total for Nearby Playas (1 km or 5 km) (Metric I)

Instructions

4.1. Build area buffer with radius distance of 1 km or 5 km depending on metric required.
4.2. Use NWI dataset and observe all palustrine and lacustrine waterbodies within the given buffer.
4.3. Apply the Hydrogeomorphic HPR Identification Key and select all playas (See Chapter 2).
4.4. Determine area of each playa and sum the values for total area of surrounding playas (ha).

5. Determine UTM Location for playa centroid (Metric J)

Instructions

5.1. Determine the coordinates of the playa centroid.

ARCMAP INSTRUCTIONS

Make data fields

- Open the wetland shapefile Attribute Table. Select Table Options > Add Field. Make a field labeled ‘Latitude’ with the field type set as double
- Repeat above steps for a field labeled ‘Longitude’

Calculate Latitude and Longitude values

- Begin an editing session for the playa shapefile
- Right click the ‘Latitude’ field and select ‘Calculate Geometry’. In this dialog box, select ‘X Coordinate of Centroid’ from the property drop down. Units should be selected as ‘Decimal Degrees’ from the drop down.
- Repeat above for ‘Longitude’ field using the ‘Y Coordinate of Centroid’

Export coordinates to a table

- In the Attribute Table, select Table Options > Export
- Select the save location and when prompted, add the table to the current map

Display coordinates

- Right click added table and choose “display xy coordinates”
- Set XField as ‘Longitude’ and YField as ‘Latitude’
- Right click points layer and export as shapefile to location of choice

5.2. Convert lat long to UTM

Easterly: 6 digit east-west position.
Northerly: 7 digit north-south position.

6. Determine Water Presence (Metric K)

Instructions

6.1. Use playa location to download most recent Landsat scene.

Download Landsat imagery at https://earthexplorer.usgs.gov/ .

6.2. Visually inspect the wetland location and look for water presence.
6.3. Record as 1-yes or 0-no.

7. Distance to Nearest Grassland Playa (Metric L)

Instructions

7.1. Use NWI dataset and observe all palustrine wetlands surrounding the playa of interest.
7.2. Use land-use dataset and conservation program spatial data to identify near grassland waterbodies.
7.3. Apply the Hydrogeomorphic Classification Key for High Plains Wetlands and select all grassland playas.
7.4. Use GIS measuring tool to measure the distance (km) to the nearest grassland playa.

TABLE 3-11. MODELS ESTIMATING RICHNESS FOR NATIVE WETLAND PLANT SPECIES AND NATIVE UPLAND PLANT SPECIES WITHIN A PLAYA BASIN. ESTIMATES ARE BASED ON LAND-USE TYPE ALONG WITH PLAYA AND NEAR PLAYA CHARACTERISTICS. MODIFIED FROM O'CONNELL ET AL. (2012).

Land Use	***Native Wetland Species Richness***	***Code***	***Predictor***	***Units***
Grassland	Gr_W_Richness = EXP(9.91E-01 + 1.21E-02**p_area* + 1.14E-03**5km_p* + 1.91E-06**east* + 3.25E-01* *wet*)	*p_area*	Playa Area	ha
		5km_p	Playa Areas w/in 5km	ha
		east	Easting UTM	6 digits
		wet	Wet Basin	binary
CRP	P_W_Richness = EXP(4.55E+00 – 2.71E-02* *gr_dist* + 7.36E-03**1km_p* + 2.23E-06* *east* – 8.49E-07**north* + 4.98E-01**wet*)	*gr_dist*	Grass Playa Distance	km
		1km_p	Playa Areas w/in 1km	ha
		east	Easting UTM	6 digits
		north	Northing UTM	7 digits
		wet	Wet Basin	binary
Cropland	Cr_W_Richness = EXP(9.18E-01 + 5.27E-02**p_area* + 2.87E-02**gr_dist* + 1.62E-02**1km_p* + 2.01E-03**5km_p* – 2.86E-06**east* + 7.45E-01* *wet)*	*p_area*	Playa Area	ha
		gr_dist	Grass Playa Distance	km
		1km_p	Playa Areas w/in 1km	ha
		5km_p	Playa Areas w/in 5km	ha
		east	Easting UTM	6 digits
		wet	Wet Basin	binary
Land Use	***Native Upland Species Richness***	***Code***	***Predictor***	***Units***
Grassland	Gr_U_Richness = EXP(8.31E-01 – 5.16E-03**1km_p* + 7.10E-04**5km_p* – 5.15E-07**north* – 1.85E-01**wet*)	*gr_dist*	Grass Playa Distance	km
		1km_p	Playa Areas w/in 1km	ha
		5km_p	Playa Areas w/in 5km	ha
		east	Easting UTM	6 dgits
		north	Northing UTM	7 digits
		wet	Wet Basin	binary
CRP	P_U_Richness = EXP(2.41E+00 + 2.45E-04**5km_p*)	*5km_p*	Playa Areas w/in 5km	ha
Cropland	Cr_U_Richness = EXP(2.42E+00 + 3.61E-02**p_area* + 1.46E-02**gr_dist* + 8.94E-03**1km_p* + 1.42E-03**5km_p* – 2.29E-06**east* + 4.95E-01**wet*)	*p_area*	Playa Area	ha
		gr_dist	Grass Playa Distance	km
		1km_p	Playa Areas w/in 1km	ha
		5km_p	Playa Areas w/in 5km	ha
		east	Easting UTM	6 digits
		wet	Wet Basin	binary

9. Amphibian Total Species Richness

ESTIMATED BY PLAYA AND WATERSHED AREA ALONG WITH HYDROPERIOD

Amphibian presence is largely determined by hydroperiod but there are other determining habitat features. Total amphibian species richness is shown to be related to the ratio between watershed area and playa area. Richness can be estimated at a given time using these metrics (Kensinger et al. 2013).

Subregion(s): this predictive model was developed for the SHP and not recommended for use in other portions of the WHP or the RWB (Figure 3-1).

Limitations: Data used to build this model were sampled from spring inundation until playa basins were dry (October). Data was also restricted to playas with hydroperiod lengths ranging from 18 to 453 days. Estimates are considered most accurate for predicting Amphibian Species Richness during this time and under these conditions.

Note: to determine Metric P: Playa Hydroperiod, code has been developed for the APEX modeling platform by USDA's Agricultural Research Service office. To access this code, contact Kate Behrman ARS-Temple.

COMPONENTS

- Metric E: Playa Area
- Metric M: Watershed Area
- Ratio of Watershed Area to Playa Area
- Metric N: Playa Hydroperiod (modeling code, contact Kate Behrman ARS Temple TX)
- Equation 3-3: Amphibian Species Richness

METHODS

1. Calculate Playa Area (Metric E)

Instructions

1.1. Calculate area within shapefile (ha).

2. Determine watershed area (Metric M)

Instructions

2.1. Delineate the playa watershed using a topographic map in a GIS (if Metric D: Percent Crop in Watershed was previously calculated, use watershed from step 1.1).

ArcMap Instructions

- Open a spatially referenced topographic map as a basemap with the playa of interest. Projections for data frame, playa polygon and topo map should be the same.
- Create a new feature class and begin an editing session. In the Create Features window use the Construction Tool to make a polygon by placing points on all high terrain locations surrounding the playa. For more detailed instructions on watershed delineation see https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_014819.pdf

- Save the polygon and label the watershed to correspond with the playa label.

2.2. Calculate the area within the watershed (ha).

3. Calculate Ratio between watershed and playa

Instructions

3.1. Calculate the ratio by dividing watershed area (ha) by playa area (ha).

4. Determine Hydroperiod (Metric N)

Instructions

4.1. Use APEX for the playa basin to determine hydroperiod.
(Code for APEX application in playas, contact Kate Behrman ARS Temple, TX)

4.2. Value for hydroperiod must be 18 – 453 days to work in the model

5. Estimate Amphibian Species Richness

Instructions

5.1. Use hydroperiod and the ratio of watershed to playa area in the equation 3-3 below.

5.2. Calculate and record predicted species richness.

Equation 3-3

$$Amph\_Richness = EXP(1.0669053 + 0.0016115 * hydroperiod - 0.0020619 * ratio\ of\ watershed\ area\ to\ playa\ area)$$

10. Avian Total Species Richness and Waterfowl Abundance

ESTIMATED BY PLAYA AND UPLAND CHARACTERISTICS

Suitable playa habitat for avian species requires water presence. Avian total species richness and waterfowl abundance, specified as duck and goose abundance combined, can be estimated for a playa in each season. These estimates are built on habitat and hydrology features for the playa of interest as well as the surrounding upland. Once the season of interest is selected the necessary metrics can be obtained for the given equations (Kensinger et al. 2015).

Subregion(s): this predictive model was developed for the SHP and not recommended for use in other portions of the WHP or the RWB (Figure 3-1).

Note: to determine Metric M: Playa Water Depth, code has been developed for the APEX modeling platform by USDA's Agricultural Research Service office. To access this code, contact ARS-Temple, TX.

COMPONENTS

- Metric E: Playa area (ha)
- Metric K: Water Presence
- Metric M: Watershed Area (ha)
- Metric O: Water Depth (cm) (modeling code, contact Kate Behrman ARS Temple, TX)
- Metric P: Tilled Index
- Land-use dataset along with conservation program spatial data
- Table 3-12: Models for Avian Total Species Richness and Waterfowl Abundance

METHODS

1. Select appropriate model from Table 3-12.

Instructions

1.1. Select between avian total species richness or waterfowl abundance for estimate.

1.2. Identify season of interest for estimates and determine necessary metrics.

2. Determine Playa Area (Metric E)

Instructions

2.1. Calculate playa area (ha) within the shapefile using a GIS.

3. Determine Water Presence (Metric K)

Instructions

3.1. Use playa location to download the Landsat scene nearest to date of interest with adequate visibility (low cloud cover).
Download Landsat imagery at https://earthexplorer.usgs.gov/.

3.2. Visually inspect the wetland location and look for water presence.

3.3. Record as 1-yes or 0-no.

4. Determine Watershed Area (Metric M)

Instructions

4.1. Delineate the playa watershed using a topographic map in a GIS (if Metric D: Percent Crop in Watershed was previously calculated, use watershed from step 1.1).

ArcMap Instructions

- Open a spatially referenced topographic map as a basemap with the playa of interest. Projections for data frame, playa polygon and topo map should be the same.
- Create a new feature class and begin an editing session. In the Create Features window use the Construction Tool to make a polygon by placing points on all high terrain locations surrounding the playa. For more detailed instructions on watershed delineation see https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_014819.pdf
- Save the polygon and label the watershed to correspond with the playa label.

4.2. Calculate the area (ha) within the watershed

5. Estimate Water Depth (Metric O)

Instructions

5.1. Use APEX to estimate water depth.
(Code for APEX application in playas, contact Kate Behrman ARS in Temple, TX)

6. Determine Tilled Index (Metric P) (Tsai et al. 2007)

Instructions (Tsai et al. 2007)

6.1. Delineate the playa watershed using a topographic map in a GIS. (if Metric D: Percent Crop in Watershed was previously calculated, use watershed).

ArcMap Instructions

- Open a spatially referenced topographic map as a basemap with the playa of interest. Projections for data frame, playa polygon and topo map should be the same.
- Create a new feature class and begin an editing session. In the Create Features window use the Construction Tool to make a polygon by placing points on all high terrain locations surrounding the playa. For more detailed instructions on watershed delineation see https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_014819.pdf
- Save the polygon and label the watershed to correspond with the playa label.

6.2. Using a land-use dataset and conservation program spatial data, identify all land uses within the watershed.

6.3. Measure the area of tilled land and the area of untilled land. CropScape land cover in parenthesis (Table 3-2).

- **Tilled lands**: cropland (in production, any crop type) and CRP (not in CropScape)
- **Untilled land**: native grass (176 – Grassland/Pasture)

6.4. Apply equation 3-3 to determine the Tilled Index (TI).
Values range from -1(untilled watershed) to +1(tilled watershed)

Equation 3-4

$$Tilled\ Index(TI) = \frac{Tilled\ landscape - Untilled\ landscape}{Tilled\ landscape + Untilled\ landscape}$$

7. Apply the appropriate model and record predicted avian values

7.1. Select model based on season and service of interest from table 3-12 and solve the given equation using the necessary metrics.

TABLE 3-12. MODELS ESTIMATING AVIAN SPECIES RICHNESS AND WATERFOWL ABUNDANCE IN A PLAYA. ESTIMATES ARE BASED ON SEASON ALONG WITH PLAYA AND NEAR PLAYA CHARACTERISTICS. TABLE MODIFIED FROM KENSINGER ET AL. (2015).

Season	***Total Avian Species Richness***	***Code***	***Predictor***	***Units***
Fall	F_Richness = EXP($-0.10 - 0.0011*WD + 1.09*WET + 0.031*PA + 0.31*TI$)	*WD*	Water Depth	cm
		WET	Water	binary
		PA	Playa area	ha
		TI	Tilled index	none
Winter	W_Richness = EXP($-0.37 + 0.69*WET - 0.0005*WA + 0.043*PA + 0.22*TI$)	*WET*	Playa wetness	binary
		WA	Watershed area	ha
		PA	Playa area	ha
		TI	Tilled index	none
Spring	Sp_Richness = EXP($0.66 + 0.0011*WD + 1.03*WET - 0.00012*WA + 0.02*PA + 0.13*TI$)	*WD*	Water depth	cm
		WET	Water	binary
		WA	Watershed area	ha
		PA	Playa area	ha
		TI	Tilled index	none
Summer	Su_Richness = EXP($0.87 - 0.0048*WD + 0.85*WET + 0.00014*WA + 0.025*PA + 0.27*TI$)	*WD*	Water Depth	cm
		WET	Water	binary
		WA	Watershed area	ha
		PA	Playa area	ha
		TI	Tilled index	none
Season	***Total Waterfowl Abundance***	***Code***	***Predictor***	***Units***
Fall	F_WF_Abundance= EXP($-4.86 - 0.0077*WD + 7.11*WET + 0.00015*WA + 0.104*PA + 0.43*TI$)	*WD*	Water Depth	cm
		WET	Water	binary
		WA	Watershed area	ha
		PA	Playa area	ha
		TI	Tilled index	none
Winter	W_WF_Abundance = EXP($-3.57 + 0.0201*WD + 0.27*WET - 0.0023*WA + 0.229*PA$)	*WD*	Water Depth	cm
		WET	Water	binary
		WA	Watershed area	ha
		PA	Playa area	ha
Spring	Sp_WF_Abundance = EXP($-3.53 + 0.0639*WD + 4.09*WET + 0.066*PA$)	*WD*	Water Depth	cm
		WET	Water	binary
		PA	Playa area	ha
Summer	Su_WF_Abundance = EXP($-4.59 - 0.0198*WD + 5.47*WET + 0.00085*WA + 0.076*PA$)	*WD*	Water Depth	cm
		WET	Water	binary
		WA	Watershed area	ha
		PA	Playa area	ha

Example Application on a WHP Playa

Values estimated for an example playa are included below. The playa of interest was selected from the Playa Lakes Joint Venture Probable Playas dataset (Playa Lakes Joint Venture 2011) and was in Baca county Colorado and within the boundaries of the Comanche National Grassland (Figure 3-4). The dominant surrounding land use of the playa was identified as native grassland in CropScape and the playa area was 10.43 ha. All models were applied to this playa as an illustration of how services might be estimated. Location of playa was not considered when applying models but should be considered when seeking to most accurately estimate service provisioning. Ecosystem service estimates for the current playa conditions are included in Table 3-13.

Services can be compared and modeled under potential future conditions. If land use was converted from grassland to cropland without an established vegetative buffer, mean pesticide residues of runoff are estimated to change from 0.0363 ppm up to 0.272 ppm nitrogen and from 0.6837 ppm up to 1.443 ppm phosphorous. Similarly, greenhouse gas flux in the grassland is estimated to be 17,465 g C/ha/day and when modeled under cropland conditions would increase to 27,3211 g C/ha/day. Under grassland conditions, this playa is estimated to support 16 different upland plant species and 16 wetland plant species. If land use was converted to cropland, those numbers would be reduced to 5 upland species and 1 wetland species.

FIGURE 3-4. SATELLITE IMAGERY OF A COLORADO PLAYA IDENTIFIED BY THE PLAYA LAKES JOINT VENTURE PROBABLE PLAYA DATASET (PLAYA LAKES JOINT VENTURE 2011). DATA FROM ESRI (2018).

TABLE 3-13. ECOSYSTEM SERVICE PREDICTIONS FOR A GRASSLAND PLAYA IN COLORADO

Ecosystem Services	***Estimate***
1. Contaminant Filtration A. Vegetative Buffer Type – Native Grassland	Nitrogen: 76.46 % Phosphorous: 76.13 %
2. Contaminant Concentration B. Vegetative Buffer Width – 60 m	Nitrogen: 0.0363 ppm Phosphorous: 0.6837 ppm
3. Pesticide Residue C. Dominant Surrounding Land Use (500 m) – Native Grassland	Atrazine: 0.42 µg/kg
4. Sediment Depth D. Percent Crop in Watershed – 8.09 %	4.06 cm
5. Floodwater Storage E. Playa Area – 10.43 ha	25,047.53 m^3
6. Greenhouse Gas Flux F. MODIS – LAI – 0.2	17,4565.8 g/C/ha/day
7. Soil Organic Carbon G. SSURGO ASUR_EC – 0.1 dS/m ASUR_Ksat – 1.601 um/s EC – 0.1 dS/m Slope – 1 % ASUR_AWS – 7.67 cm H. SAVI – 0.1011	Grassland: 2.27 kg/m^2
8. Plant Species Richness E. Playa Area – 10.43 ha I. Area of all Near Playas 1 km – 0 ha 5 km – 23.34 ha J. UTM East – 690228.85 North – 4116040.18 K. Water Presence – 1	Wetland Species: 16.24 Upland Species: 16.16
9. Waterfowl Abundance E. Playa Area – 10.43 ha K. Water Presence – 1 M. Water Depth – 37 cm N. Tilled Index – 0.43 O. Watershed Area – 630.66 ha	Fall Abundance: 16 Summer Abundance: 4
10. Amphibian Total Species Richness E. Playa Area – 10.43 ha O. Watershed Area – 630.66 ha P. Hydroperiod – 98 days	Species Richness: 3

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Appendix A: List of Metrics for Models

Appendix B: Data Sheets for Models

Datasheets are provided for ease of use and metrics can be handwritten in the available cells. Many models do not require all metrics in datasheet, see instructions to determine which metrics to select. See example of plant species richness below.

Playa ID: Example27 Date: 1/20/19

8. Native Plant Species Richness

Predictors from Table 3-11

Metric C: Dominant Land Use	Grassland		
Metric E: Playa Area		10.43	ha
Metric I: Area Near Playas	1 km	0	ha
	5 km	23.34	ha
Metric J: UTM	East:	690228.85	
	North:	4116040.18	
Metric K: Water Presence	Yes - 1		
Metric L: Distance to Nearest Grassland Playa		2	km

Apply Table 3-11

Wetland Species Richness	16.23
Upland Species Richness	16.15

Playa ID: Date:

1. Percent Contaminant Filtration (%)

Metric A: Vegetative Buffer Type	

Apply Table 3-3

Contaminant	**Filtration %**	SE

Playa ID: Date:

2. Contaminant Concentration (ppm)

Metric B: Mean Buffer Width	m

Apply Table 3-4

Contaminant	**Concentration (ppm)**	SE

Playa ID: Date:

3. Pesticide Residue (ug/kg)

Subregion:	
Metric C: Dominant Land Use	

Apply Table 3-5 Pesticide Residue

Pesticide	**Concentration (ug/kg)**	SE

Playa ID: Date:

4. Sediment Depth (cm)

Apply Equation 3-1

Cropped Area		ha
Total Area		ha
Metric D: Percent Crop in Watershed		%

Apply Equation 3-2

Sediment Depth (cm):		cm

Playa ID: Date:

5. Floodwater Storage (m^3)

Metric E: Playa Area	ha

Apply Table 3-6 (Ovol)

Original Volume (OVol)	m^3

Apply Table 3-6 (% Lost)

Percent Lost (%Lost)	%

Apply Table 3-6 (Lvol)

Total Volume Lost (Lvol)	m^3

Apply Table 3-6 (FwSt)

Floodwater Storage (FwSt)	m^3

Playa ID: Date:

6. Greenhouse Gas Flux (g C/ha/day)

Metric C: Dominant Land Use	

Table 3-7 Choose LAI or FPAR

Metric F: MODIS		
	LAI:	ha
	FPAR:	%

Apply Table 3-7

Greenhouse Gas Flux	g C/ha/day

Playa ID: Date:

7. Soil Organic Carbon (kg/m^2)

Metric C: Dominant Land Use	

Predictors from Table 3-8

Metric G: SSURGO

RangPro	lbs/ac/yr
ASUR_RangPro	lbs/ac/yr
10m value	
40m value	
Slope	%
EC	dS/m
ASUR_EC	dS/m
10m value	
40m value	
pH	
AWS	cm
ASUR_AWS	cm
10m value	
40m value	
BD	g/cm3
ASUR_BD	g/cm3
10m value	
40m value	

OrgMat	% by wt
Sand	% by wt
Ksat	um/s
ASUR_Ksat	um/s
10m value	
40m value	
WC	vol %

Metric H: SAVI	
ASUR_SAVI	
10m value	
40m value	

Apply Table 3-8

Soil Organic Carbon	kg/m^2

Playa ID: Date:

8. Native Plant Species Richness

Predictors from Table 3-11

Metric C: Dominant Land Use	
Metric E: Playa Area	ha
Metric I: Area Near Playas	1 km ha
	5 km ha
Metric J: UTM	Easting:
	Northing:
Metric K: Water Presence	
Metric L: Distance to Nearest Grassland Playa	km

Apply Table 3-11

Wetland Species Richness	
Upland Species Richness	

Playa ID: Date:

9. Amphibian Total Species Richness

Determine Ratio

Metric E: Playa Area		ha
Metric M: Watershed Area		ha
Ratio		

Metric N: Playa Hydroperiod		days

Apply Equation 3-3

Amphibian Species Richness	

Playa ID: Date:

10. Avian Species Richness and Waterfowl Abundance

Metric E: Playa Area (PA)		ha
Metric K: Water Presence (WET)		binary
Metric M: Watershed Area (WA)		ha
Metric O: Water Depth (WD)		cm
Tilled Watershed Area		ha
Total Watershed Area		ha
Metric P: Tilled Index (TI)		

Apply Table 3-12

Total Avian Species Richness	Fall:
	Winter:
	Spring:
	Summer:
Total Waterfowl Abundance	Fall:
	Winter:
	Spring:
	Summer:

VITA

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