CORRELATING CLIMATE WITH LATE-WINTER WETLAND HABITAT IN THE RAINWATER BASIN, SOUTH-CENTRAL NEBRASKA

by

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Abstract

The Rainwater Basin Wetland Complex of south-central Nebraska is a region of great climatic variability, as well as tremendous ecological importance. The Rainwater Basin Wetland Complex is located at the focal point of the Central North American migratory bird flyway, and supports in excess of twelve million birds during the spring migration period. The physical landscape has been significantly altered from its pre-settlement state by agricultural conversion via the draining of over ninety percent of the native wetlands. Due to the region's highly variable continental climate, interannual wetland water levels are also highly variable and currently unpredictable. I have used multi-year analysis, including the construction of a regional water budget assessment, to study which climatic variables play the most crucial role in the late-winter filling of wetlands. Research objectives were met by analyzing ten cold season (Oct – Feb) climatic variables and an annual measure of wetland area for five years, in order to better understand possible climatic drivers of wetland hydrologic functioning levels in March. Longer time series of winter season climatic information were also assessed to help place the recent and more detailed analysis into a longer climatic context. Research results will aid local management agencies in the future through enhanced knowledge of how climatic variation impacts wetland function. Seasonal precipitation and temperature was favored by the linear regression analysis, while the multiple regression analysis placed higher emphasis on February evapotranspiration rates, February snow depth, and February snowfall. Lastly, the hydrologic water budget that was created for the study area had several highly correlated output variables with basin-wide flooded hectares, particularly annual snow storage.

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CHAPTER 1 - Introduction

The Rainwater Basin Wetland Complex of south central Nebraska (Figure 1.1) serves as important habitat for a variety of migratory waterfowl species. The area is characterized by thousands of small, shallow depressions ranging in area (less than 1 to 50+ ha) and depth (.001-1.5 m). These low areas in the topography often fill with water in late-winter/early spring and serve as temporary habitat for migratory waterfowl. Several species of waterfowl including snow geese, mid-continent mallards, and northern pintail ducks utilize the central migratory flyway and make use of this important, but limited habitat. Seasonal filling of the Rainwater Basins, or Rainbasins as they are often called, is highly variable and it is hypothesized that certain cold season climatic events or combinations of events have significant effects upon the level of hydrologic function that occurs every spring. Exactly which combination of climatic events, including their intensity, duration, and frequency are unknown.

The conversion of once native grasslands and woodlands to agriculturally intensive farmland is a phenomenon that has been observed all over the world. Frequently, the creation of agroecosystems has been accompanied by the draining of wetland areas. Wetlands cover about six percent of the Earth’s surface. Even though wetlands tend to occur in relatively small and often geographically isolated patches, they also are responsible for approximately one quarter of the Earth’s net primary productivity and provide crucial wintering, breeding, and refuge areas for wildlife (Goudie, 2006). With these ideas in mind, it becomes even more alarming that the world has lost up to 50 percent of its wetlands since 1900 and the United States alone has lost approximately 54 percent of its native wetland habitat, mostly through the conversion to farmland.

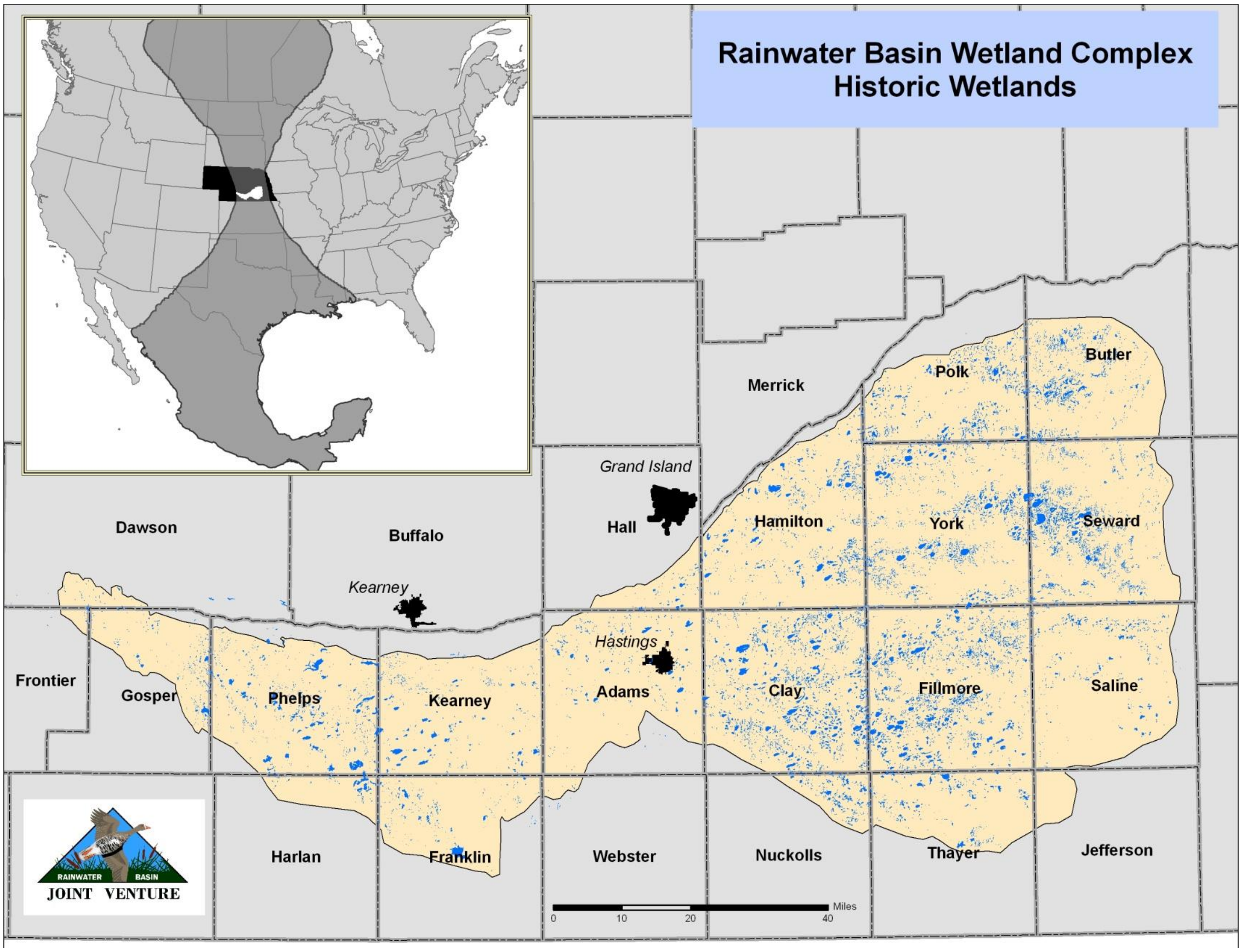


Figure 1.1 Nebraska's Rainwater Basin Wetland Complex (Source: RWBJV 2009).

According to Goldewijk (2001), in the past three hundred years, areas of cropland and pasture have increased by five to six fold. Wetlands within the Rainwater Basin region of south-central Nebraska exemplify the agricultural conversion of natural areas. This region once contained over 11,000 individual permanent/semi-permanent playas, covering approximately 80,900 to 121,400 hectares (Bishop and Vrtiska, 2008). Those numbers have been reduced over 90 percent from their original extent, with about 400 remaining functioning wetland basins (Gersib, 1992).

In 1992, the Rainwater Basin Joint Venture (RWBJV) was formed to address wetland habitat loss in the area. The RWBJV is a partnership of federal, state, local, and private entities dedicated to the enhancement and restoration of the wetlands. Partner organizations include the Nebraska Game and Parks Commission, the U.S. Fish and Wildlife Service, the U.S.D.A. Natural Resources Conservation Service, Ducks Unlimited, Pheasants Forever, the Nature Conservancy, local governments, landowners, and others (R. Reker, personal communication, 2010).

The Rainwater Basin serves as essential habitat and is recognized as the focal point of the Central Flyway during spring waterfowl migration. Annually, an estimated 12.4 million waterfowl use this region during spring/fall migrations. This includes approximately 90 percent of the continental population of greater white-fronted geese, 50 percent of mid-continent mallards, and approximately 30 percent of the breeding population of northern pintails (Bishop *et al.*, 2008). There are also an increasing number of snow geese utilizing wetlands in the region each year (NRCS, 2008). In addition to providing critical habitat, the wetlands also contribute to improving water quality, and recharge of the Ogallala Aquifer (Wood and Osterkamp, 1984; Mullican *et al.*, 1994; and Smith, 2003). The often overlooked importance of wetlands is an important driver for this research that addresses how climate variability is related to late-winter season wetland hyrdology.

This research effort provides an applied climatological study to analyze regional climate data in search of combinations of meteorological observations that correlate with late-winter water levels in the Rainwater Basin wetlands. The Rainwater Basin Joint Venture seeks an enhanced understanding of these climatic processes and relationships in order to improve local natural resource management practices that are being implemented in the area. Resource managers working for the RWBJV would like to have a predictive model, that allows them to insert recent/real-time weather/climate data, which would provide a reliable estimate of the area of wetland habitat. Due to the open ended possibilities of the results of this study, a series of more general research questions may be a more appropriate approach as opposed to a set of specific hypotheses. T.C. Chamberlin (1897) presented the idea of multiple working hypotheses as a conceptual framework to guide inductive research. Research questions that drive this study include:

- Is there a relationship between cold season climatic variability and end of winter water area in the Rainwater Basin wetlands?
- If a level of statistical significance is determined, what climatic conditions/events are more supportive or detrimental towards having higher water levels in the wetlands?

A significant amount of previous literature on the geology, biology, and ecology of the Rainwater Basin area exists, however little work has been done pertaining to the hydrology of the Rainwater Basins and their relationship with variations in local weather and climate conditions. It is hoped that this study will serve two main purposes: first, that the knowledge gained through analysis will benefit the RWBJV and improve local wetland habitat management techniques; and secondly, it is hoped that this research will aid in filling the void in scholarly knowledge pertaining to both Rainwater Basin characteristics in relation to climatic events, as well as the effects of cold-season climatological events on the late winter/early spring water budget for the area.

CHAPTER 2 - Study Area

The Rainwater Basin Wetland Complex covers approximately 15,900 km^2 adjacent to and south of the Platte River (Figure 1.1). The wetland complex extends across parts of, or all of, 21 counties in south-central Nebraska (Bishop *et al.*, 2008). The area was identified by Condra (1939) as the Loess Plains Region of Nebraska based on the prominence of loess soils. Due to the thick, highly impervious clay pan in the hydric soils of the area, the Rainwater Basin wetlands pond water, in large part isolating the pooled seasonal surface water in the wetlands from an underlying aquifer. The region is characterized by nearly level to rolling topography with generally flat upland areas between poorly developed stream drainages.

Positioned within the relatively flat upland areas, the wetland basins can be found along with downwind ridges or lunettes of coarser material (Starks, 1984). Wind deflation is hypothesized as a geomorphic mechanism for creating the Rainwater Basin wetland depressions (Evans and Wolfe, 1967) and aeolian deposition created the lunettes. It is believed that these wetland depressions fill seasonally in response to heavy precipitation events or late winter/early spring snowmelt.

Production agriculture constitutes the predominant land use throughout the Rainwater Basin. Human modification of the landscape to enable more efficient use of the land resource has had a variety of effects, including considerable wetland drainage and modification of hydrologic flow networks. The once native grassland has, in large part, been extensively transformed to the production of crops such as corn and soybeans. According to current RWBJV data, there are approximately 5,700 different farm operations in the region. Of those, 3,800 possess, or are within close proximity of an irrigation reuse pit. Past irrigation activities involved gravity flow and reuse pits were dug at the lowest elevation to capture water for possible reuse. These pits now fill with water that might otherwise move further down-slope into a nearby wetland complex. Additionally, there are approximately 11,200 land owners in the Rainwater Basin region. Of those, 4,450 own land with an irrigation reuse pit on their property (Bishop *et al.*, 2008). Irrigation reuse pits maybe located either within the historic hydric soil footprints of existing watersheds, or they maybe located in the surrounding wetland watershed. These two categories of pits have very different hydrological impacts upon the local wetland. Pits located in the upland watersheds tend to intercept water that would have flowed down to the wetland in historic conditions, whereas pits within the wetland footprint tend to remove water from shallow wetland areas and concentrate the water in the deeper pit. Moreover, the material removed to create the pits within wetlands has regularly been used to fill parts of the neighboring wetlands, further reducing a wetland's extent and functioning capability (A. Bishop, personal communication, 2009).

Bishop *et al.* (2008) noted that the large number of hydrologic modifications, including irrigation reuse pits, have had a large negative influence upon wetland functioning. A recent RWBJV inventory counted 10,217 pits within the Rainwater Basin (Bishop and Vrtiska, 2008). Additionally, Bishop and Vrtiska (2008) estimated that the pits within the Rainwater Basin capture up to 42.6 million cubic meters of water at full pool, and since they are embedded in the watershed they must completely fill before any water makes it to down-slope wetlands.

Within the Rainwater Basin itself, more than 80 percent of the area is cropland, and more than 60 percent of that cropland is irrigated. Drainage of the Rainwater Basin wetlands occurred in two primary phases. The first took place around the time of first settlement, and was marked by road construction, and the installation of ditches, drains, and drainage tunnels. In the 1970s, the second major period of drainage modification occurred, and was characterized by the large-scale loss of wetlands due to land leveling and the continued installation of irrigation reuse and drainage pits (A. Bishop, personal communication, 2009).

The climate of the Rainwater Basin is typical of middle-latitude continental locations with hot summers, cold winters, and generally light but occasionally intense rainfall. Mid-continental climates have great variation in seasonal and annual precipitation totals and average temperature (Stevens, 1959). Due to the large size and geographic location of the study area, a pronounced east-to-west precipitation gradient is present (Figure 2.1), with the eastern portion receiving approximately 760 mm (30 inches) of annual precipitation, and the western portion averaging approximately 558 mm (22 in) of precipitation (Bishop *et al.*, 2004).

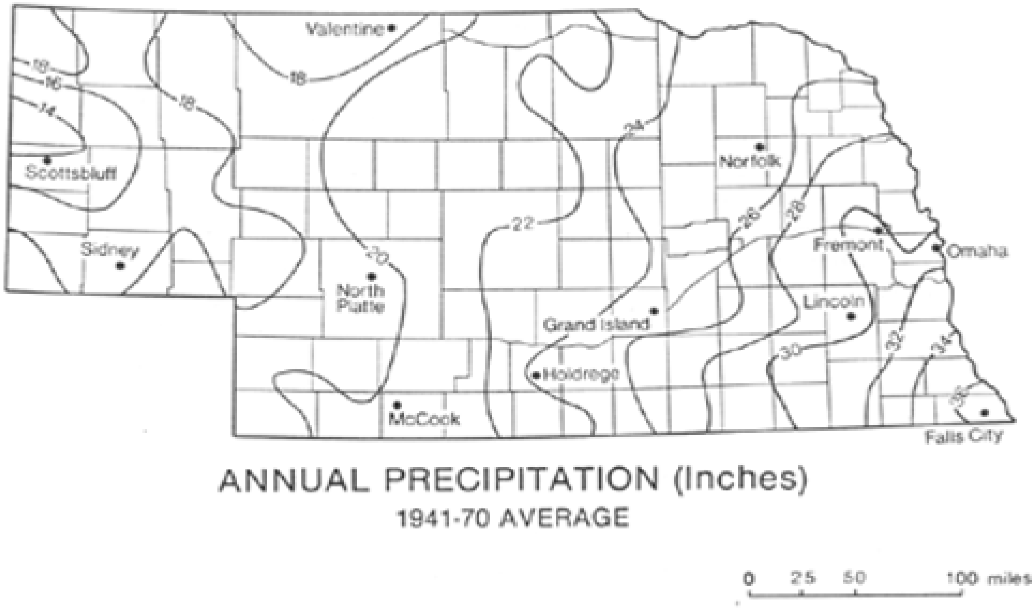


Figure 2.1 Nebraska annual precipitation gradient (source: Baltensperger, 1985).

In his Masters thesis on physical attributes of the Rainwater Basins, Starks (1984, 9) wrote:

> "Little written material aimed directly at the rainbasin area exists. The few reports that do exist, however, center on the wetland loss of the reduction of wildlife habitat."

Fortunately, Starks' work helped drastically improve the understanding of the geomorphology, the connections with soil science, the geomorphic processes related to basin formation, and other physical attributes of the rainwater basins in Clay County, Nebraska. In comparison, more extensive research has been conducted on the hydrology, ecology, and functioning of Nebraska's Sand Hills region, located in the central and northwestern portion of the state. Examples of such research will be discussed further in the hydrology section of the literature review. In comparison to the large existing body of literature pertaining to the Sand Hills, the Rainwater Basin's pool of scholarly knowledge can be viewed as relatively shallow.

It is believed that the earliest scientific mention of the Rainwater Basins came from observations made by George Condra in 1906. Condra noted that the playa wetlands were ephemeral in nature, and that they occurred primarily in York, Clay, and Phelps Counties. (Condra, 1906). A map of the basins analyzed by Starks (1984) in Clay County, Nebraska (Figure 2.2) depicts basins (both breached and intact), and their associated ridges / lunettes.

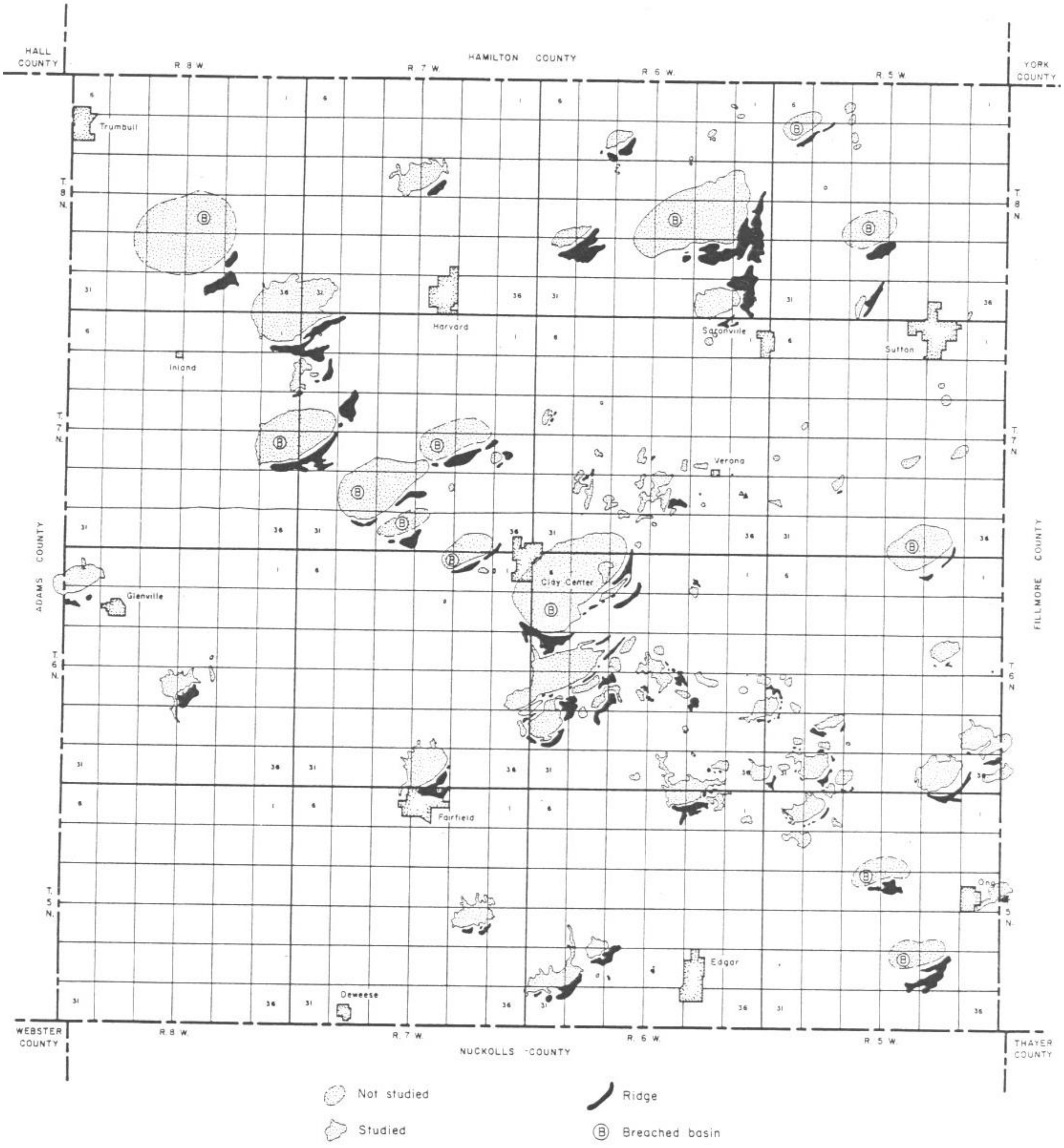


Figure 2.2 Clay County depressions (source: Starks, 1984).

Kuzila, Rundquist, and Greene (1991) noted that even though the Rainwater Basins received early attention in 1906 from Condra, it was not until the early 1970s that the Rainwater Basin wetlands began to receive somewhat more widespread scholarly attention. Classification and mapping of portions of the Rainwater Basin area were conducted in 1982 by the Nebraska Remote Sensing Center at the University of Nebraska-Lincoln (Walter and Buckwalter, 1982). Hectarages were calculated and maps constructed to estimate area increases or decreases over selected years. Starks (1984) also performed a compilation of existing soil knowledge within the wetlands. Figures from Starks' (1984), Master's thesis (reproduced here as Figure 2.3a and Figure 2.3b) provide generic topographic characteristics of seasonal and semi-permanent wetlands and the associated soil types commonly found in the subsurface of the wetlands. Soils commonly found under seasonal wetlands that tend to dry completely each year, have Scott silt loam soils in the center whereas the larger, more semi-permanent wetlands are characterized by the presence of Massie silty clay loams in the deepest areas of the wetlands (Figure 2.3b).

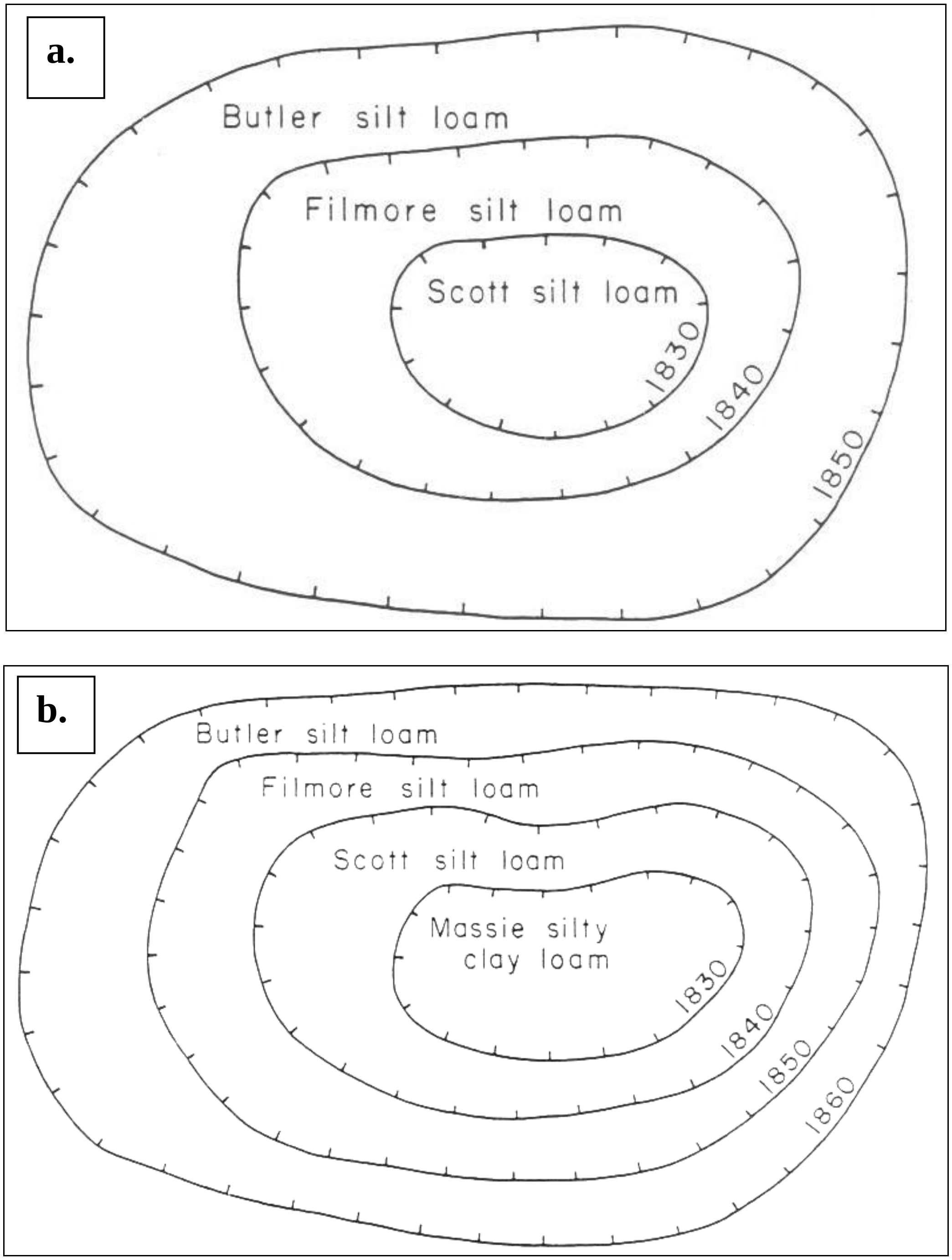


Figure 2.3 (a and b) Depression soil characteristics (Source: Starks, 1984).

CHAPTER 3 - Literature Review

The literature review section of this thesis is broken into four distinct sections to include the ecological importance of wetlands, environmental modifications within the study area, the role of applied climatology, and the role of the hydrologic cycle and related water budgets. Each of these subdivisions of scholarly knowledge play a key role in the construction of the research design and in the analysis performed within this research. This research utilizes and expands upon current academic knowledge in the aforementioned fields.

Ecological Importance of Wetlands

Wetlands in general and the Rainwater Basin area in particular serve as a vital waterfowl habitat. South-central Nebraska wetlands are recognized as a bottleneck or focal point on the Central Flyway for both the spring and fall migration for a multitude of species. Annually, an estimated 12.4 million migratory waterfowl use the Rainwater Basin during spring/fall migrations (NRCS, 2008). Of the approximately 12.4 million birds that pass through the area on an annual basis; nearly 80 percent do so in the spring migration period alone. This large population of migratory waterfowl needs a large amount of food to provide the energy for their continued northward migration. The increasing concentration of waterfowl using a reduced wetland resource is likely to cause increased competition for the birds' necessary energetic requirements (Bishop, 2008).

Bishop and Vrtiska (2008) calculated that the 12.4 million birds require approximately 24.1 billion kcals annually to fulfill their energetic needs with 22.1 billion kcals needed at the time of the spring migration. It is currently believed (Bishop and Vrtiska, 2008) that waste grain from the area's agricultural production is enough to meet the waterfowl's energetic requirements.

However, research by Loesch and Kaminski (1989) and Baldassarre and Bolen (1994) indicate that waste grain alone cannot meet the nutritional requirements of the birds and that certain inorganic elements, vitamins, and amino acids must be obtained in wetland habitats. Bishop and Vrtiska (2008) found that approximately 39 percent, or 9.5 billion kcals of the total 24.1 billion kcals needed, is available from wetland habitats within the Rainwater Basin. A total of 15,317 ha of ephemeral wetlands with early successional vegetation would be required to meet such caloric and nutritional needs. Bishop (2008) found that between the years of 2004-2007, flooded acres of wetland provided 0.004 billion to 1.9 billion kcals of available forage, which is significantly less than the estimated required 9.5 billion kcals needed from native wetland vegetation for spring migration. Bishop concluded that conservation strategies such as wetland restoration, resource acquisition, removal of off-site hydrologic modifications (irrigation reuse pits), and vegetation monitoring and management are all required to offset the current habitat deficiencies.

Migratory waterfowl have additional needs beyond just nutrition that wetlands areas provide. Requirements such as resting habitat are equally important to population sustainability. Currently, an additional 2,700 ha of semi-permanent wetlands (an approximate doubling of the current area) should be flooded in order to adequately meet resting/loafing needs (Bishop, 2008). LaGrange and Dinsmore (1988) concluded that stopover locations, such as the Rainwater Basin, that are closer to the breeding grounds were critical in ensuring that dabbling ducks acquire sufficient nutrient resources to positively influence recruitment. Waterfowl survival and recruitment are thought to be the driving factors that influence population dynamics (stable, declining, or increasing populations) (Bishop, 2008).

Environmental Modifications

In addition to providing critical migratory waterfowl habitat, the wetlands also contribute to improving water quality, as well as providing for a very gradual recharge of the Ogallala aquifer (Wood and Osterkamp, 1984; Mullican *et al.*, 1994; Smith 2003). Unfortunately, human impacts on wetlands in the Rainwater Basin are already having severe negative impacts on habitat quality and quantities (Bishop, 2008). The primary sources of environmental alteration in the Rainwater Basin are thought to be the intentional draining of the wetlands, for the creation of cropland, as well as through the construction of supplemental infrastructure such as roads, drainage ditches, irrigation reuse pits, and utilities to support local economic activities (Starks, 1984).

Smith (1998) concluded that the majority of the historical wetlands have been destroyed and those wetlands that do remain are in an agriculturally intensive area. The remaining hydrologically functioning basins are the primary focal points of wetland biodiversity in the region. Most studies and reports thus far have focused on the importance of the region to migratory birds, especially to waterfowl during spring migration (Smith, 1998). These results alone suggest a need for an enhanced understanding of both the natural and anthropogenic factors influencing the Rainwater Basin area. Ironically, although there has been a recognized need for further studies of the biology, hydrology, ecology, and geology of the Rainwater Basin, there has been very little recognition of the importance of climatic impacts on the hydrology of the region, although, Kuzila *et al*. (1991) did note that the wetlands vary considerably because of meteorological and climatic fluctuations.

Wetland habitat along the entire central United States flyway has been lost or degraded to some extent, and the habitat modifications that have been made in the Rainwater Basin are not an isolated phenomenon. All the way from the wintering grounds in the southern United States to the breeding areas in central Canada, habitat has decreased, largely due to conversion of grasslands and wetlands to agricultural production; other detrimental changes have resulted from changes in grazing, burning, mowing, sedimentation, and drainage (Kantrud *et al.*, 1989; Poiani and Johnson, 1991). Runge and Boomer (2005) have noted that since 1975, northern pintails have continued to gradually expand their migration further northward over time. In addition, Eldridge and Krapu (1998), and Dubovsky and Kaminski (1994) hypothesized that the increase in migration distance probably has a negative impact on the physical attributes of birds such as body condition, resulting in a reduced clutch size, later nest initiation, and a reduced propensity to re-nest if the initial nest is lost. It is evident that not only are waterfowl that migrate through the Rainwater Basin facing a shortage of energetic/nutritional requirements, but sufficient habitat for resting and loafing are lacking as well

The most dramatic alteration of the wetlands was the large-scale drainage of basins around the time of first settlement, thus facilitating the development of farming, and eventually large scale agricultural operations. Related infrastructure, including roads, utilities, irrigation networks, and irrigation reuse pits (tail-water recovery pits) have all had profound negative impacts on the hydrologic and biologic functioning of the wetlands, as well as the surrounding landscape and hydrologic conditions.

A recent RWBJV analysis found that over 80 percent, or almost 1.1 million hectares, of the Rainwater Basin was under cultivated agriculture, with approximately 65 percent being irrigated (22.5 percent gravity, 77.5 percent center pivot) (Bishop and Vrtiska, 2008). Before the advent of center pivot irrigation, nearly all of the land in the region was watered via gravity irrigation. The construction of irrigation reuse pits in the lowest-lying areas of each field greatly improved water-use efficiency by allowing tail-water to be pumped uphill and used again in gravity irrigation. Irrigation reuse pits caused unforeseen consequences as they interrupted watershed hydrology by intercepting natural runoff that originally drained to the nearest wetland. This interruption and localized ponding has led to a drastic reduction of water supplied to the wetlands.

Nebraska has more irrigated hectares than any other state in the U.S. (Johnson and Lukassen, 2009). It is apparent that agriculture (specifically irrigated agriculture) is the predominant land-use type throughout the Rainwater Basin of south-central Nebraska. The human-altered agricultural landscape affects migratory waterfowl populations that rely upon this threatened critical habitat. Due to conversion to center pivot irrigation, the majority of the reuse pits are no longer needed. Restoration practices, particularly earthen filling of irrigation reuse pits back to original grade, can help to restore functional watersheds and habitats. However, this restoration activity would require time, funding, and the approval of the private land owners.

Applied Climatology

When conducting climate research on the connection between the atmosphere and the hydrosphere, it is necessary to define exactly what climate is, and how climate differs from weather. Bryson (1997) differentiates the two by noting that meteorologists study the weather in terms of vertical columns measured from the ground up whereas climate is defined as “the synthesis of weather” (Bryson 1997, p.#450). Therefore, descriptive climatology maybe considered as the analysis of a collective of varying weather records, particularly those of temperatures and precipitation. Typically, climatic analysis seeks to identify the emergent properties associated with a large volume of weather data.

With the knowledge of climate's profound impact on a seasonal hydrologic system, it becomes necessary to both identify and then expand upon current relevant climatological knowledge. Climatology may be subdivided into smaller, more specialized areas for the differing demands of various kinds of research. Oliver (1981) broke climatology into four main subdivisions: Dynamic, Physical, Climatography, and Applied Climatology. These four areas can entertain research using one or more of the four methods of analysis that Oliver discussed: descriptive, statistical, mathematical, and synoptic. This study will use an applied climatology approach, and will further use statistical, as well as descriptive methods to derive and analyze climate-hydrology connections in the Rainwater Basin wetland Complex.

Research focused around temporal and spatial patterns of climate to solve issues affecting a society, economy or environment is research that falls under the category of applied climatology (Smith 1987). Landsberg and Jacobs (1951) state:

> "If we consider climate as the statistical collective of weather, we can define applied climatology as the scientific analysis of this collective in the light of a useful application for an operational purpose. …The term operational is … broadly interpreted as any useful endeavor, such as industrial, manufacturing, agricultural, or technical pursuits."

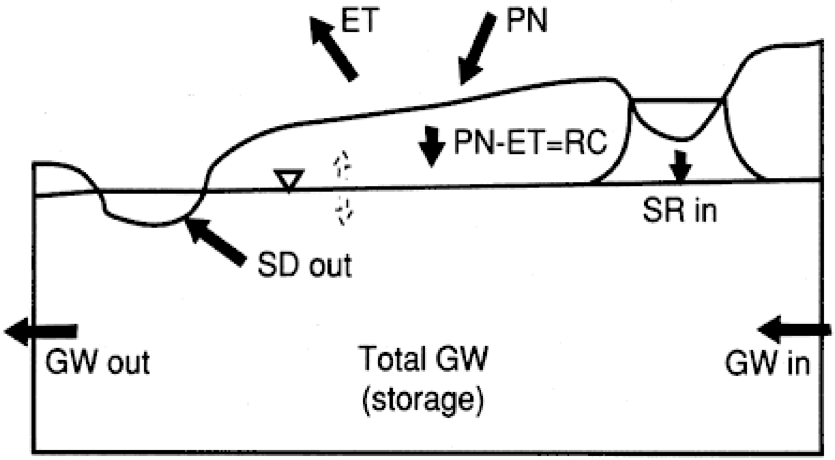
Applied climatology studies "can address a vast number of topics, but become more focused with the selection of a subject matter that the climatic patterns are impacting" (Bowles, 2004 p. 14). Additionally, climate maybe thought of as a system that has boundaries that go beyond the atmosphere to include connections with the biosphere, hydrosphere, lithosphere, and cryosphere (Ruddiman, 2007).

Water Budget and the Hydrologic Cycle

With known inputs such as precipitation, and known losses from a system such as evaporation, it becomes possible to create a water budget analysis following the principles of applied climatology (Mather and Yoshioka, 1968). Thornthwaite (1948) pioneered the idea of water budget analysis and related applications. Applied Climatology using a water budget accounting approach therefore lends itself as the ideal approach for studying the impacts of climatic events on the seasonal water availability in the Rainwater Basin area.

Land-use changes also affect near-surface hydrologic conditions. As already mentioned, some of the most rapid changes in land use/land cover can be found in the North American Great Plains (Mahmood and Hubbard, 2002). During the 19th and early 20th centuries, most native grasslands in Nebraska and in other states of this region were turned into agricultural farmlands (Williams and Murfield, 1977, Ramankutty and Foley, 1999). Therefore, an applied climatological approach serves two main purposes: first, it can identify climatic events having large influences on the filling of the Rainwater Basins, and secondly it might be used as a tool used to help gauge the impact of human alteration of the natural wetland habitat. This study will contribute to the existing body of knowledge pertaining to the physical area of water within the Rainwater Basins, the climatologically based research on cold-season climatic data, and the seasonal water budget.

A moisture index was created for this applied climatology study. The moisture index provides more descriptive information than simple precipitation amounts, and represents the net gain/loss between total precipitation and evaporation amounts (Bailey, 1958). The moisture index aids in the construction of a more holistic understanding of the water budget for the Rainwater Basin wetland complex. In 1948, C.W. Thornthwaite compared the climatic need for water with the climatic supply of water (precipitation) in a monthly climatic water balance in order to determine whether a particular climate was arid or moist (Mather and Yoshioka, 1968). Bailey (1958) noted that the entire reason for enhanced moisture indexes (as opposed to simple rain-gage data), is based upon the need to understand the water gains (precipitation), as well as the water losses (evaporation). Figure 3.1 illustrates the stocks and fluxes that are involved in a water budget analysis, where PN represents precipitation (inputs), ET represents evapotranspiration (losses), and RC represents groundwater recharge rates which can be thought of as the movement of surplus input to groundwater. The Thornthwaite (1948) equation for measuring an area's potential evaporation, in conjunction with knowledge of local soil characteristics, temperatures, and precipitation on a temporally measurable scale should lend insight into the region's water budget, and thus enhance current knowledge of the impacts of cold season climatic data upon late-winter hydrology in the wetlands.



$$\text{Input} = \text{SR} + \text{RC} + \text{GWIN}$$

$$\text{Outflow} = \text{SD OUT} + \text{GW OUT}$$

$$\text{At Equilibrium, input} = \text{output}$$

$$\text{Residence time} = \frac{\text{Total GW}}{\text{Input}}$$

Figure 3.1 Water budget components where ET= evapotranspiration, PN= precipitation, RC= recharge rates, SD and SR= surface water losses and surface water gains from a groundwater perspective. All except GW represent rates, whereas GW represents the storage volume of groundwater (source: Kansas Geological Survey, 2009).

Although the utility of water budget analysis has been widely recognized throughout the scientific community, surprisingly little research has been conducted applying cold season climatic variables, in conjunction with spring-time wetland habitat conditions. In an attempt to establish such a water budget for the Rainwater Basin wetland complex, it becomes necessary to identify the critical components of the hydrologic cycle that impact any location's water budget characteristics.

Extensive current water budget research throughout the Canadian prairie wetlands, subarctic catchments, and the northern Midwest provide insights of value for this thesis research (Fang and Pomeroy, 2008). These prior studies, looking at cold season energy budgets and impacts upon local hydrologic cycles, serve as supporting literature for this research on the Rainwater Basin, given the area's comparable physical geography, and cold-season (snowmelt) emphasis. A cold season drought is characterized by above-average air temperature, lack of precipitation, low soil-moisture content, and inadequate water supplies from the surface and subsurface. Fang & Pomeroy (2008) note that the drought of 1999-2004 was the most recent severe multi-year drought throughout the Great Plains, and that 1999-2002 marked some of the most severe levels on record for parts of the Canadian prairies. These characteristics of dry, cold drought years will aid in identifying years of low wetland functioning, and in selecting individual variables in the analysis of Rainwater Basin hydrologic conditions.

Other related literature exists for the Sandhills area of northwestern Nebraska (e.g. Lawson *et al.,* 1985). This area, like the Rainwater Basin, serves as important ecological habitat for a wide variety of avian and mammalian species. Although fundamentally different in a geological sense, the Sandhills are geographically close in a spatial and climatic sense. A simple water balance approach aimed at an enhanced understanding of groundwater fluctuations was employed by Gosselin *et al.* (2006). The study successfully created a water balance, looking primarily at potential evapotranspiration, and precipitation throughout the region. The aforementioned pronounced multi-year drought of 1999-2004 was identified as a significant event that had marked negative hydrologic effects on the region's surface and groundwater systems (Gosselin *et al.,* 2006).

Direct comparisons of climate and hydrology linkages between the Sandhills region, and the Rainwater Basin wetland complex are not possible, however, because the geology, soils, and topography are different in the two areas. Whereas the Rainwater Basin's soils are dominated by thick loess underlain by highly impervious clays resulting in a perched water table, the Sandhills are characterized by more granular sand with a shallow water table that is interconnected in many places with the surface water features (Lawson *et al.,* 1985). The presence of this sandy soil results in high percolation rates, not commonly observed in the Rainwater Basin.

The hydrologic cycle represents the endless circulatory process of transportation of water from one of Earth's storage reservoirs to the next. Reservoirs include, but are not limited to, the atmosphere, the oceans, ice caps and glaciers, groundwater, soil water, rivers, lakes, and wetlands. For this study, the research will concentrate on the interactions between the atmospheric, groundwater, and surface water reservoirs. Of the total amount of water in Earth's systems, only approximately 0.76 percent is found in deep groundwater reserves, while 0.01 percent constitutes Earth's fresh surface water (Cumming and Cockburn, 2000).

Water is transported from one reservoir to another through a series of processes. A first process is precipitation which includes all moisture reaching Earth's surface in liquid or solid forms (*e.g.*, rain, snow, sleet, or hail). Precipitation is then dispersed in one of three ways. The first of these is groundwater infiltration. Due to the Rainwater Basin's highly impervious clay soils, this value is expected to be low throughout the study area, but must be mentioned nonetheless because it interacts with precipitation to subdivide surface and subsurface flow. The next process is evapotranspiration consisting of two components: evaporation, and transpiration. This variable will be calculated by the Thornthwaite (1948) equation for PET (potential evapotranspiration). Finally, the third primary process is surface water runoff.

In order for runoff to occur, three conditions must be met. First, a slope of some measurable degree (it can be of low gradient) must be present, second, the rate of precipitation must exceed the rate of soil infiltration, and third, depression storage values must be exceeded. Due to low soil infiltration capacity, and very minor slopes throughout the study area, it is currently hypothesized that runoff amounts will be crucial in determining which climatic events/conditions effect wetland functioning. Figure 3.2 provides a simplified graphical example of the water budget (including runoff) in a rural semi-permanent prairie wetland in central North Dakota, which possesses multiple geographical similarities to the Rainwater Basin wetlands.

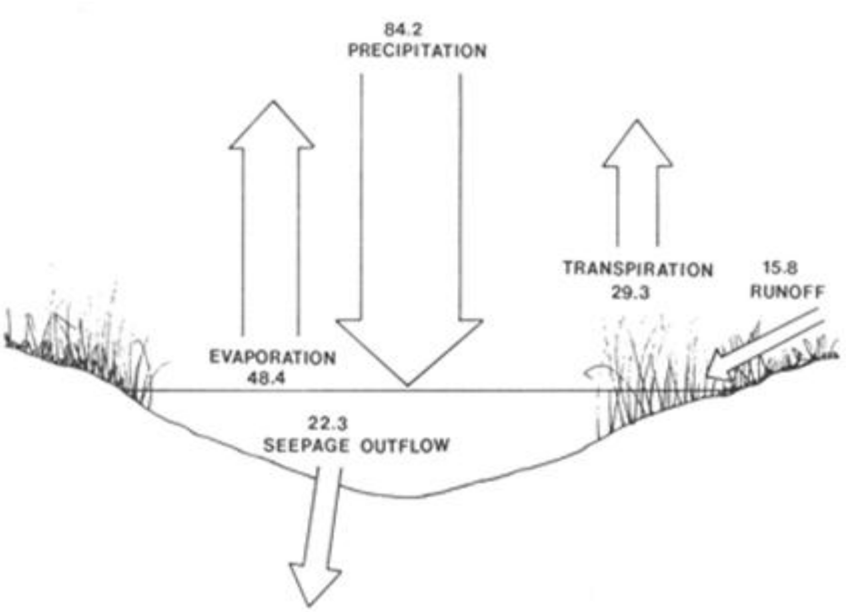


Figure 3.2 Annual water budget of a North Dakota semi-permanent prairie wetland (values in cm) (Source: Poiani and Johnson, 1999).

Once data have been obtained for related climatic variables such as precipitation and temperature, it will be possible to create a working water budget for the Rainwater Basin wetland complex. The creation of a Thornthwaite water budget for the Rainwater Basin will assist in filling the current academic void on both cold-season impacts on spring hydrologic conditions, as well as water budget data for the study area. This enhanced hydrological understanding will aid the Rainwater Basin Joint Venture and other local conservation management agencies in adopting more efficient management practices for the preservation and restoration of wetlands, as at this time, no such water budget for the study area has yet been created.

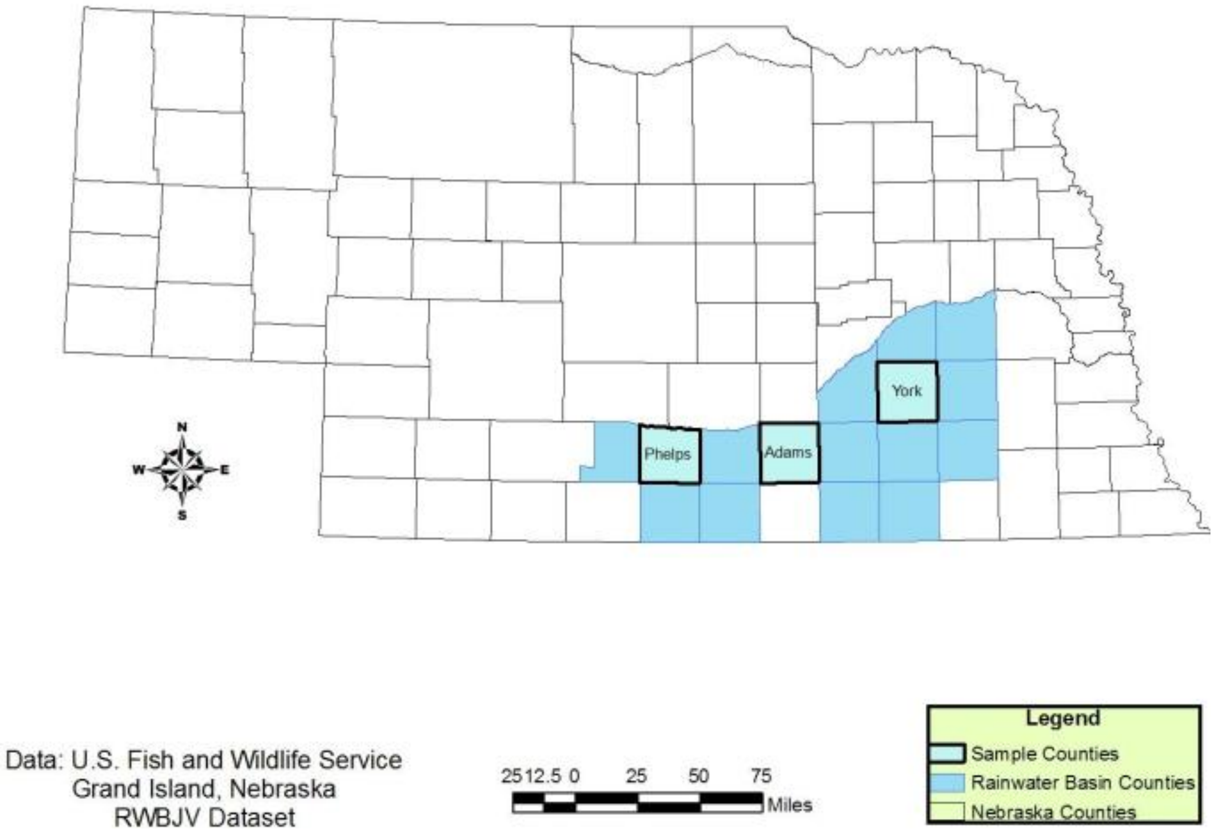
Summary

In summary, prior research has found that the Rainwater Basin wetland complex is of great importance to migratory waterfowl, supporting over 12 million birds of various species ever year. There is currently a lack of available habitat throughout the Rainwater Basin, primarily due to large scale drainage, and conversion of native grasslands and wetlands to agricultural land. The majority of historic wetlands have been destroyed or degraded, and the remaining wetlands suffer from reduced levels of hydrologic function associated with nearby infrastructure such as roads, ditches, and irrigation reuse pits (Robichaux and Harrington 2009). Applied climatology can serve a crucial role in the solving of issues facing a society, economy, or environment. Applied climate study can enhance the current understanding of how climate is related to wetlands throughout the Rainwater Basin and extensive review of available literature suggests that this is a topic wherein contributions to knowledge can be provided. Lastly, water budgets and moisture indexes will aid further research in the identification of climatic events that have predominant influence on the hydrology of wetlands, and maybe used as a tool to gauge the impacts of human alterations to the natural landscape.

CHAPTER 4 - Methods

Federal and State resource managers working on the Rainwater Basin area find data on late-winter wetland conditions to be useful due to the spring migration of waterfowl through the study area. The interannual filling of the basins is currently unpredictable and varies greatly; not knowing how much water will be available makes it difficult to manage the area for migratory waterfowl. In order to see if climatic data could be used to predict wetland area at the end of the winter, this thesis was designed to correlate a number of potential climatic predictors with data from the RWBJV Annual Habitat Survey (AHS).

Due to the large size of the Rainwater Basin, three counties were selected to serve as sample study locations to characterize the entire Rainwater Basin. The three counties that were selected for analysis are Phelps County in the western portion of the study area, Adams County near the center of the study area, and York County in the northeastern portion of the study area (Figure 4.1). These counties were selected because they contain a fairly large amount of wetland area, are spread fairly evenly throughout the Rainwater Basin, and either contain, or are within close proximity to NWS Cooperative Observer and State of Nebraska Automated Data Weather Network (ADWN) climate stations.



Data: U.S. Fish and Wildlife Service
Grand Island, Nebraska
RWBJV Dataset

Figure 4.1 Counties used for detailed statistical analysis within the Rainwater Basin.

Annual Habitat Survey (AHS)

The first step in data analysis involved using the Rainwater Basin Joint Venture’s Annual Habitat Survey (AHS). The AHS data are produced through an elaborate process that begins with the collection of aerial photography that is flown over the entire Rainwater Basin every year in early March. The aerial images are then interpreted and classified based on their spectral and geographic characteristics into various habitat classes ranging from differing wetland vegetation types to ponded water in accordance with the RWBJV’s standards. The classified dataset is then manually checked for accuracy and consistency by GIS technicians on a ¼ mile basis across the entire study area. Summary statistics are then calculated for the varying polygon classes, including total ponded area in hectares, as well as various vegetation types, for the Rainwater

Basin Wetland Complex. The GIS data layers are vector data. Tabular attribute data for each polygon includes county name, wetland name, size, and polygon type (form of vegetation, moist soil, or ponded water). This time and labor intensive process has been completed by the RWBJV for the years of 2004, 2006, 2007, 2008, and 2009. Data for 2005 are absent from the record due to a lack of aerial photography from March 2005.

The RWBJV has a longer record of habitat conditions in late-winter that are derived from visual ground-based estimates made by a trained member of the management and research staff. The visual estimates are not done for all wetlands, rather just those on public lands. Analysis of the differences between the visual estimates and the data product obtained through analysis of the aerial photography suggested that the two data sets are quite different. As such, it was decided to use the spatially-explicit data stored in a GIS environment for this research effort.

The AHS datasets lay the groundwork for future regression analysis as the GIS data possess county attributes in their corresponding tables, and therefore maybe statistically analyzed on a county-by-county basis along with corresponding climate data. Once the five years of necessary AHS data had been acquired from the RWBJV, data for the three sample counties were subset from the rest of the dataset. Total hectares of ponded water were calculated at the county level by selecting polygons representing ponded water, and then using the summary statistics function within each shapefile's attribute table on a county-by-county basis across Phelps, Adams, and York Counties. With five years for analysis and three counties, this summarization generated fifteen data points of flooded hectares. The fifteen data points were then entered into a spreadsheet for future statistical analysis. The Phelps County 2007 data point was later omitted; it was found to be a statistical outlier with a much larger hectarage of ponded water than other years for that county and compared with other counties in 2007. The presence of an outlier data point is known to significantly skew regression calculations. Omitting Phelps County data for 2007, left fourteen points for further analysis.

In attempt to avoid skewing results due to counties with varying amounts of wetland habitat area, the final fourteen habitat data values were divided by the total hydric footprint hectarage values found in the RWBJV/U.S. Fish and Wildlife dataset to obtain a percentage of maximum hydrologic function. Therefore, all habitat hectarage values used in analysis were standardized and represented percentages of maximum possible flooded hectarage. Lastly, to fill a need to compare county-level statistics with basin-wide statistics, ponded hectares were calculated for the entire Rainwater Basin for the five years of AHS data leading to an additional five data points.

Climatic Data

Climate data for this analysis were obtained from the High Plains Regional Climate Center (www.hprcc.unl.edu). These data were measured and made available in English units and were then converted into the metric system for analysis. Results will be reported in English units with metric units in parenthesis. As this is a cold season habitat study, each year was broken down into cold and warm season data periods, with analysis emphasis on the cold season data periods. The cold season was defined as October 1st of the preceding year, to February 28th / 29th of the current year, whereas the warm season was defined as March 1st of the current year to September 30th of the current year. In addition to seasonal data and in accordance with the working hypothesis that February climate has a significant impact on March wetland conditions, data for several variables were obtained for the month of February as well. Climate data obtained by local NWS Coop stations were downloaded for Adams, Phelps, and York Counties (Table 4.1). All missing values present in the data were filled with column averages.

County	NWS Station	Station ID	Latitude	Longitude
Adams	Hastings, 4N	253660	40.65	-98.38
Phelps	Holdrege	253910	40.43	-99.36
York	York	259510	40.87	-97.59

Table 4.1 Three sample counties and associated NWS Coop meteorological stations.

Data that were downloaded and summarized to provide seasonal measures for each of the five years with AHS data available include: cold season total precipitation (in inches), average cold season mean temperature (degrees Fahrenheit), February evapotranspiration rates in inches using the Nebraska wind function (ET-NE), February soil temperature (degrees Fahrenheit) at a depth of four inches, February solar radiation (in Langleys), February average wind speed (in mph), February average temperature (degrees Fahrenheit), February average snowfall (in inches), February average snowdepth (in inches), and February precipitation (in inches).

The High Plains Regional Climate Center (HPRCC) currently offers access to a variety of different climate variables through two different data management services; the Climate Information for Management and Operational Decisions (or CLIMOD) which may be found at: (http://climod.unl.edu/) and the Classic Online Services interface available at (http://hprcc1.unl.edu/cgi-hpcc/home.cgi). Both interfaces require a nominal fee for data accessibility, as well as a secure login and password created by HPRCC for the user. The seasonal averaged temperature and precipitation data were downloaded from the CLIMOD interface and organized into separate spreadsheets. The 1995 – 2009 February ET-NE, February soil temperature, February solar radiation, February average wind speed, February average temperature, February average snowfall, February snow depth, and February precipitation data were downloaded via the Classic Online interface and then saved in a large spreadsheet. These data were in the form of daily observations, and were then converted into monthly averages.

A longer time series of daily data was obtained from the automated data weather network (ADWN), as well as from the National Weather Service (NWS) COOP records to better establish a longer period of record for several climate variables including soil temperature, solar radiation, wind speed, and snow depth. These data allow a view further back in the climatic record and help to more accurately place where the five years of AHS data fall within a longer context.

Statistical Analysis

Once the appropriate habitat and climate data had been entered and converted from English to corresponding SI units, basic statistical analysis became possible. First, individual scatterplots were constructed for each county with the five year AHS data as a percentage of maximum possible area (titled "Percent of Hydrologic Function") on the Y axis, and each of the ten relevant climate variables on the X axis. Linear regression relationships were fitted to the plots, and R^2 values calculated. Once scatterplots had been created for each county for each of the five years (with the exception of Phelps County for 2007), a comprehensive 14 point dataset was created by a merger of the data for the three counties. Ten scatterplots featuring each climate variable were then created, each with fourteen data points. Linear regression relationships were fitted to each plot and R^2 values were calculated to determine the strength of the relationship between each climate variable and spring wetland habitat conditions.

In addition to the three sample counties, a series of scatterplots were also created featuring only five data points representing the five years that AHS data are available for the entire Rainwater Basin Wetland Complex in an attempt to understand how representative the three counties were of the larger region. The climate data for these scatterplots were created by averaging the data from the three counties in order to gain a basin-wide value. Following the linear regression analysis simple non-parametric tests were performed to test for significant (above .05 level) relationships between variables. Spearman's rho correlation was used for the non-parametric testing, and summary tables were produced with correlation coefficients. Finally, a multiple regression analysis was run on the data. The multiple regression analysis featured all ten climate variables and the percentage of hydrologic function as the independent or predictor variable. Summary statistical tables were produced including an ANOVA table, a variance – covariance matrix, as well as a multiple-regression R^2 value.

Thornthwaite Water Budget Analysis

Software for creating a Thornthwaite water-budget analysis for the Rainwater Basin was obtained from the USGS (McCabe and Markstrom, 2007). The software was downloaded for free from the NASA Global Change Master Directory: http://gcmd.nasa.gov/records/USGS_OFR_2007_1088.html. The software utilizes a graphical user interface (GUI). This GUI allows users to easily modify a series of selected hydrological and climatic parameters for any specified location. Analysis uses the Thornthwaite water-balance, and functions incorporated in the software to allocate water across different components of a localized hydrologic cycle (Figure 4.2). The software requires two inputs: mean monthly temperature in degrees Celsius and monthly precipitation in millimeters.

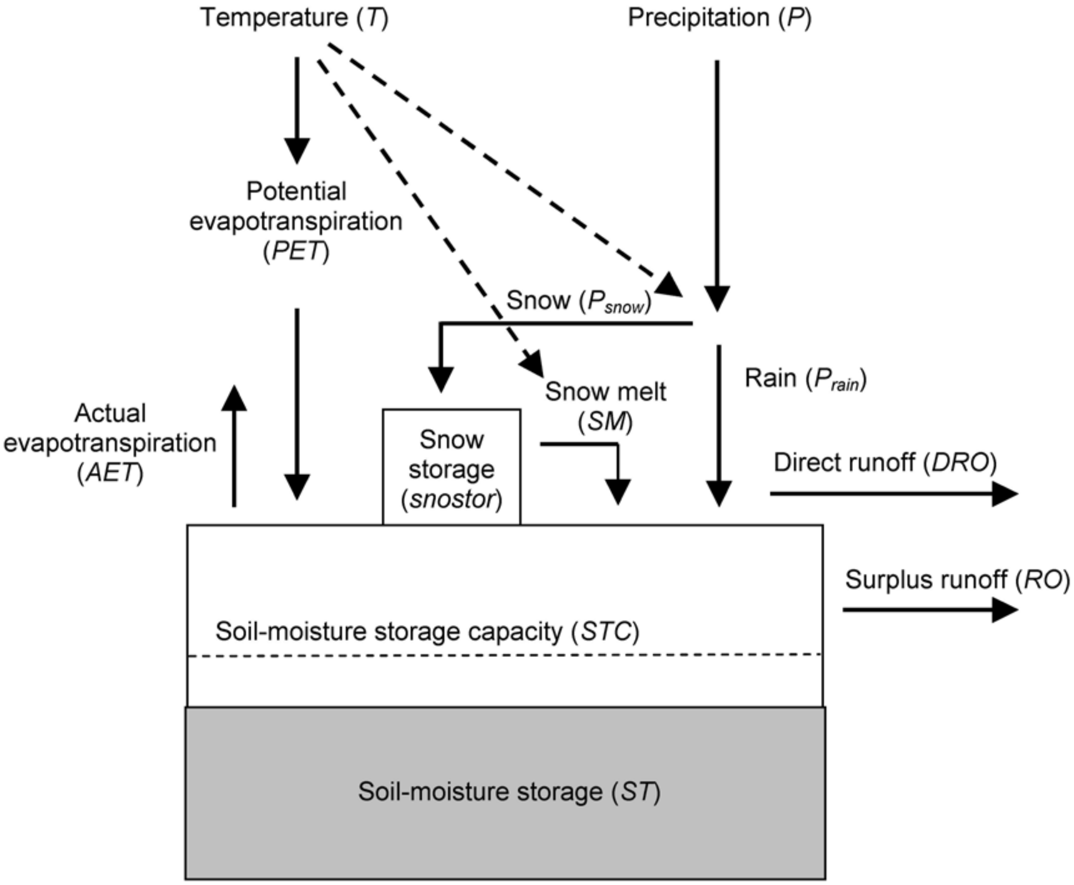
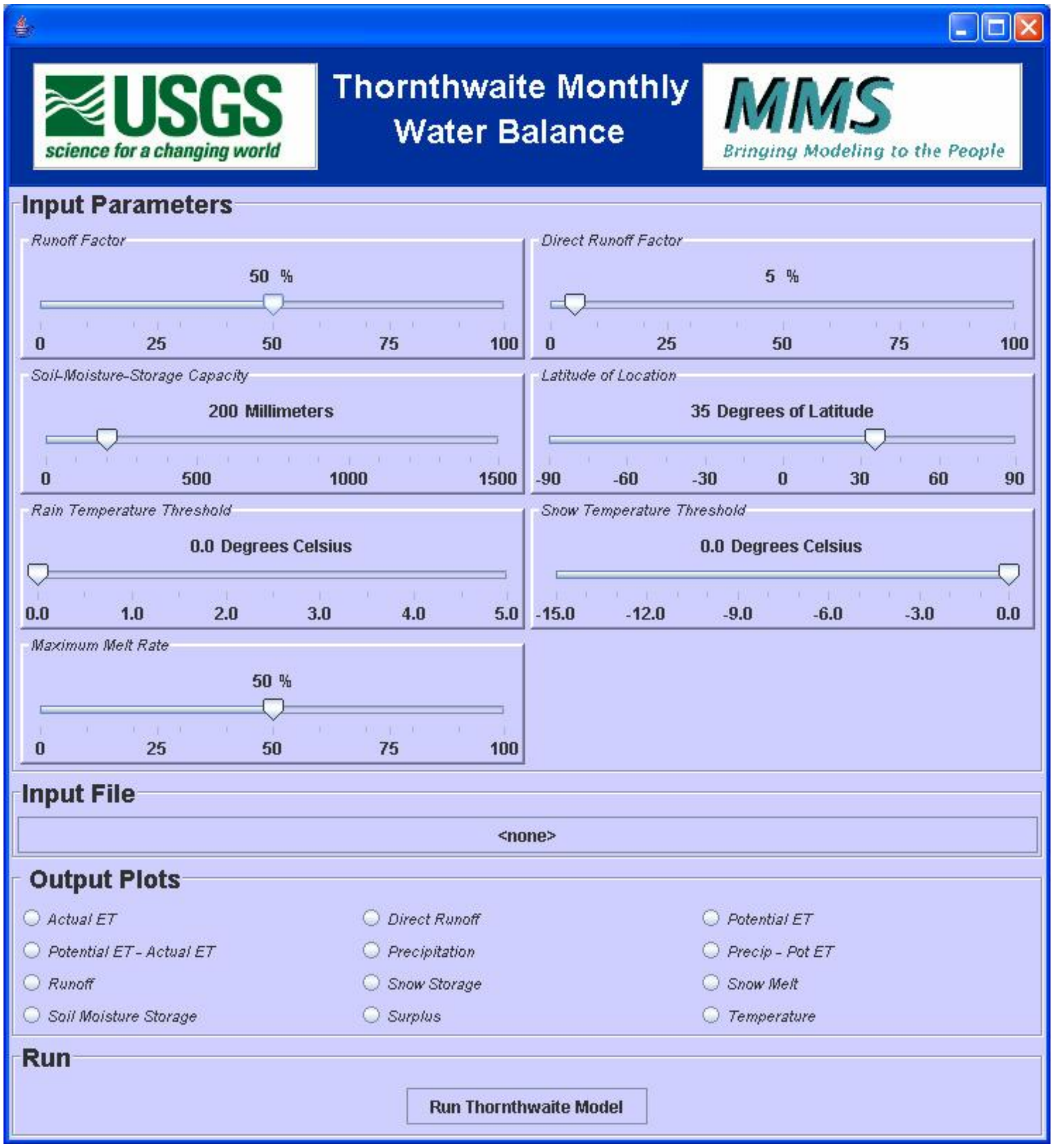


Figure 4.2 Diagram of the Thornthwaite water-balance program (source: USGS, 2010).

Monthly precipitation and temperature data from January, 1895, to December, 2009, were obtained from NOAA's National Climate Data Center (NCDC) for the south-central Nebraska climatic division. Default parameters for runoff factor, direct runoff factor, soil-moisture storage capacity, rain and snow temperature thresholds, and maximum melt rate were all used (Figure 4.3). The latitude was set at 41 degrees for the Rainwater Basin region. Following the execution of the water-budget analysis, the program provides output for each month/year, and nine hydrologic variables including: Potential ET, precipitation, precipitation –

potential ET, soil moisture, actual ET, potential ET- actual ET, snow storage, surplus water, and runoff totals.



Runoff Factor
50 %

Direct Runoff Factor
5 %

Soil-Moisture-Storage Capacity
200 Millimeters

Latitude of Location
35 Degrees of Latitude

Rain Temperature Threshold
0.0 Degrees Celsius

Snow Temperature Threshold
0.0 Degrees Celsius

Maximum Melt Rate
50 %

Input File
<none>

Figure 4.3 Water balance model GUI with adjustable parameters and output options.

A series of summary graphs were then created to visualize the water budget output for the AHS years of analysis, as well as the entire period of record from 1895 – 2009. This longer period of record was utilized in order to establish where the recent decade fell in a longer time frame and climatic context.

CHAPTER 5 - Results and Discussion

The findings from this investigation are probably not as policy-prescriptive as resource mangers might want. While the analyses and results do provide insight into the relationship between late-winter wetland condition and local climate, there is no clear single climate indicator that can be used as a surrogate for the area of open water.

Analysis results will be presented in four distinct sections. The first section will cover basic descriptive statistics for the five years of AHS data, these results will be for the entire Rainwater Basin and for each of the three selected counties. The first section will also describe the statistical variety found within the ten climate-variable dataset and will feature the county level and basin-wide individual variable regression analyses accompanied by the related scatterplot graphs associated with the results from simple linear regression. A second section will identify the results of the multiple regression analysis for climate variables and wetland area. The third section will use longer-term climate records to place the early 21st century climate data into a longer-term context. Lastly, the results of the Thornthwaite water-balance analysis and associated important variables will be discussed.

AHS and Climate Variables

The five years of AHS data provided a measurable range in interannual habitat functioning levels (Figure 5.1 and Table 5.1). On a basin-wide scale, 2007 had the highest amount of wetland functioning with approximately 4,756 ha, whereas 2006 was by far the driest year exhibiting only 865.2 ha of open water . The three sample counties selected showed similar, patterns for annual habitat functioning levels (Table 5.1). Adams County in 2004 had the lowest amount of available habitat and in 2007, Phelps County had by far the largest value. As a statistical outlier, the Phelps County 2007 value was omitted from the analyses.

Flooded Hectares by Year:

County	**2004**	**2006**	**2007**	**2008**	**2009**
Adams	9.1	86	73.2	80.1	78.1
Phelps	95.9	123.6	**1268.4**	216.9	291.7
York	508.9	61.0	358.9	430.2	361.1

Basin-Wide	**2004**	**2006**	**2007**	**2008**	**2009**
Flooded hectares	3146.8	865.2	4756.7	2991.0	2574.5

Standardized by Hydric Footprint (%)	**2004**	**2006**	**2007**	**2008**	**2009**
Adams (2,215 ha)	0.4	3.8	3.2	3.6	3.5
Phelps (5,774 ha)	1.6	2.1	**21.9**	3.7	5
York (9,591 ha)	5.3	0.6	3.7	4.5	3.7

Table 5.1 Hydrologic levels for three sample counties, and basin-wide scales. Bolded values represents Phelps 2007, which was omitted from statistical analysis (Source: RWBJV and calculations by the author).

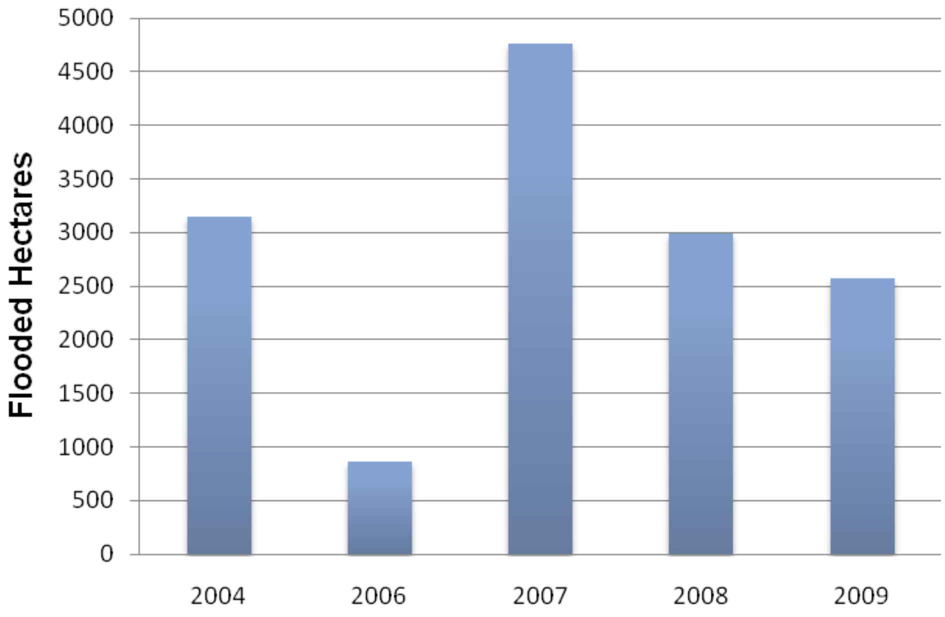


Figure 5.1 Habitat function levels for five years of AHS data basin-wide scale.

In 2007, Phelps County ponded over 1,200 ha, which is over one quarter of the entire basin-wide total. As noted from personal communication with RWBJV personnel (Bishop, 2009), this phenomenon is attributed to the multiple public wetlands found throughout Phelps County that are among the larger wetlands throughout the entire area. Variation in area or hydric function of the largest wetlands can easily skew county-level ponding values due to the ability of these big wetlands to change dramatically in areal coverage as they store changing quantities of surface water. Since the 1,268 ha (21.9% hydrologic functioning percentage) of 2007 for Phelps County severely skewed the combined county and multiple regression analyses, this data point was omitted. Total flooded hectares per county were then standardized by dividing by the total amount of flooded hectares possible per county which was derived from the RWBJV's historic wetlands mask (HWM). The total potential flooded hectares for Adams, Phelps, and York counties was 2,215 ha, 5,774 ha, and 9,591 ha respectfully (Figure 5.3).

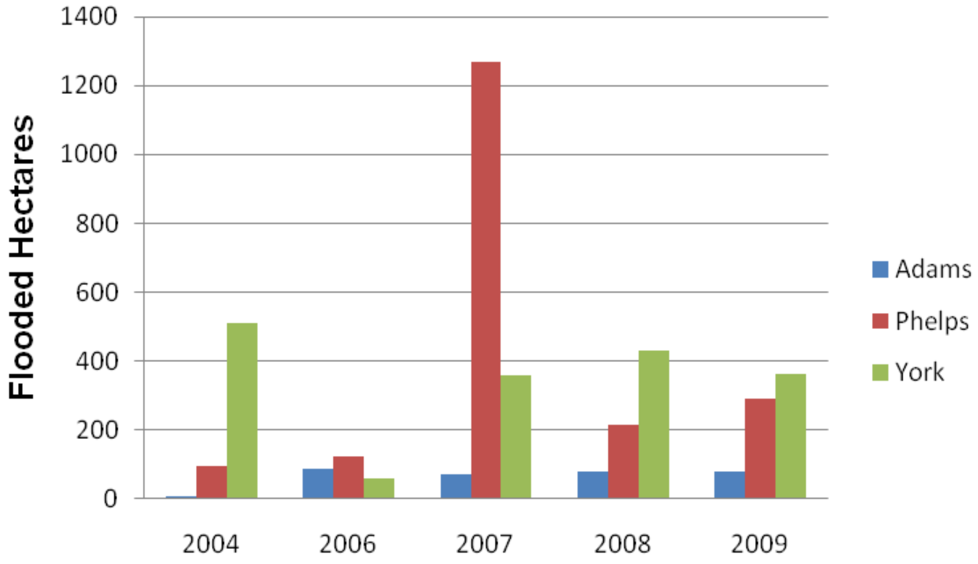


Figure 5.2 Three county total flooded hectares for Adams, Phelps, and York Counties.

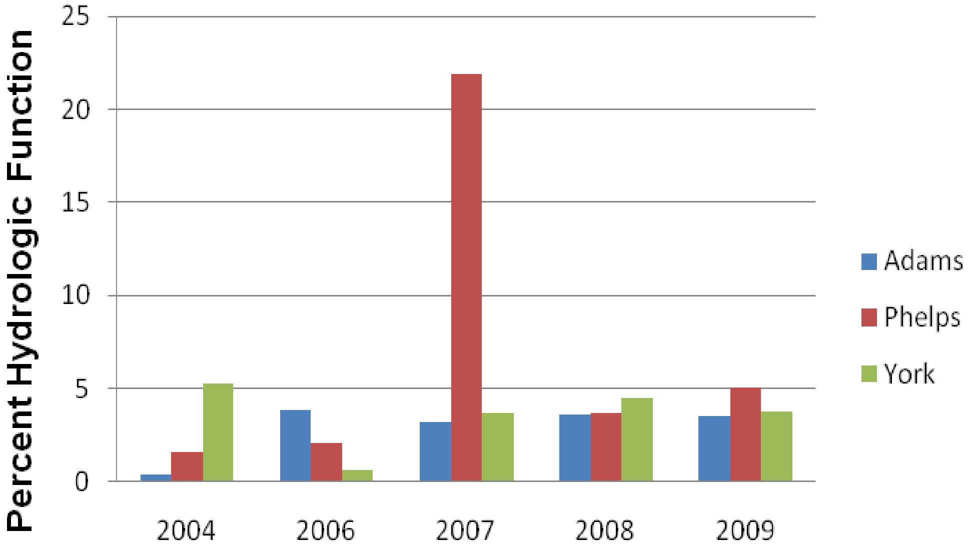


Figure 5.3 Three county percent of maximum hydrologic function- standardized by dividing by total hectares of wetlands in each county.

Climate Variables

The ten climate variables had considerable year-to-year and county-to-county variation, and there was no strong linear correlation between flooded hectarage and a single climatic element. Values for all ten climate variables used in the linear and multiple linear regression analysis (Table 5.2) exhibit considerable interannual variation. Values were downloaded in English units, and later converted to appropriate SI units. As indicated by the variable titles, eight of the ten variables are for the cold season month of February, while the remaining two are composites of the entire cold season (October 1 to end of February).

County / Year	Habitat % Function	Cold Season Precip (mm)	Avg. Cold Season Temp (C)	Feb. ET-NE (mm)	Feb. Soil Temp (C)	Solar Radiation (Langleys)	Feb. Wind Speed (m/s)	Feb. Avg. Temp (C)	Feb. Snowfall (mm)	Feb. Precip (mm)	Feb. Snowdepth (mm)
York 2004	5.3	112	1.3	1.5	0.2	261.3	3.7	-4.4	211	17	241
York 2006	0.6	104	3.6	2.5	0.1	271.9	3.6	-1.3	53	3	5
York 2007	3.7	135	2	1.3	-0.9	221.3	3.8	-4.3	74	21	10
York 2008	4.5	221	1.3	1.3	-0.3	261.1	3.7	-3.8	145	17	20
York 2009	3.8	282	1	2.0	-0.3	257.2	3.4	-0.4	198	16	15
Adams 2004	0.4	137	1.9	1.5	-0.5	271.8	4.3	-4.1	320	49	122
Adams 2006	3.8	86	3.5	3.6	1.2	313.1	4.3	0.9	28	2	3
Adams 2007	3.2	155	0.7	1.3	-1.8	232.7	4.3	-4.4	99	33	10
Adams 2008	3.6	196	0.4	1.8	-0.5	277.2	3.9	0.4	216	16	25
Adams 2009	3.5	236	1.1	2.5	1.1	308.0	3.6	1.1	163	17	13
Phelps 2004	1.6	79	1.7	1.5	0.4	256.8	4.5	-3.7	292	15	86
Phelps 2006	2.1	99	3.4	3.6	1.7	313.6	4.6	-1.4	13	3	0.3
Phelps 2008	3.7	137	0.8	1.8	-0.2	280.1	4.5	-2.9	178	17	28
Phelps 2009	5.0	272	1.5	2.5	1.2	289.6	4.2	0.3	140	23	15

Table 5.2 Ten climatic variables used in linear and multiple regression analysis.

All ten of the climate variables showed significant variation in time and space. Cold season precipitation is the total of all recorded precipitation from the first of October of the preceding year to the end of February of the year in question. Cold season precipitation had a maximum value of 11.10” (282 mm) (York 2009), a minimum value of 3.06” (78 mm) (Phelps 2004), and a range of 8.04” (204 mm). The mean for the variable was calculated at 6.26” (159 mm), with a standard deviation of 2.77” (70 mm).

Average cold season temperature is also measured from the first of October to the end of February and is the average value of the five cold season months. The maximum value is 38.5°F (3.6°C), (York 2006), the minimum value 32.8F (0.4°C) (Adams 2008), with a range of 5.7°F (3.2°C). The calculated mean for average cold season temperature is 35.1°F (1.7°C), with a standard deviation of 1.9°F (1.1° C).

February ET-NE is a calculated value in inches of the rate of evapotranspiration using the Penman equation (this calculation was performed by the HPRCC using a Nebraska specific (NE) wind function). The average value was calculated by averaging daily estimates for each of the five years for the month of February, and the daily estimates were obtained using HPRCC’s Classic data service. The variable has a maximum value of 0.14” (4 mm) (Phelps 2006), a minimum value of 0.05” (1 mm) (Adams 2007), with a range of 0.09” (2 mm). Finally, the mean value for Feb. ET-NE is 0.08” (2 mm), with a standard deviation value of 0.03” (1 mm).

February soil temperature was obtained from HPRCC’s Classic data service and the data are collected in the field at a four inch depth. The maximum value is 35.2°F (1.7°C) (Phelps 2007), the minimum 28.7°F (-1.8°C) (Adams 2007), with a range of 6.5°F (3.5°C). The mean was calculated at 32.2°F (0.1°C), with a standard deviation of 1.8°F (0.9°C).

February solar radiation (in Langleys) is a measure of total solar radiation received on a horizontal surface, and in this case, the monthly statistic was calculated by averaging the daily February observations. The maximum value is 313.6 (Phelps 2006), minimum value is 221.3 (York 2007), with a range of 92.3 Langleys. The mean was calculated at 272.5, with a standard deviation value of 27.6.

Wind speed is measured in miles per hour and is calculated by taking the average of daily wind speeds during February of each year. The maximum averaged wind speed value is 10.3 mph (4.6 m/s) (Phelps 2006), the minimum value 7.7 mph (3.4 m/s) (York 2009), with a range of 2.6 mph (1.2 m/s). The mean was calculated at 8.9 mph (4.0 m/s), with a standard deviation value of 0.1 mph (0.1 m/s).

February average temperature was derived by averaging the daily values. The maximum value is 34.1°F (1.1° C) (Adams 2009), the minimum value 24.1°F (-4.4°C) (Adams 2007), with a range of 9.9°F (5.5°C). The average of the February mean temperatures values was 28.2°F (-2.0°C), with a standard deviation of 3.7°F (2.2°C).

February snowfall is recorded in inches and is a measurement of the sum of all daily snowfall measurements throughout the month. The maximum value is 12.6” (320 mm) (Adams 2004), the minimum value 0.5” (13 mm) (Phelps 2006), resulting in a relatively large range of 12.1” (307 mm). The mean was calculated at 6.0” (152 mm) with a standard deviation value of 3.7” (94 mm).

February precipitation is the sum of all daily precipitation values (liquid equivalent) throughout the month. The maximum value is 1.92” (49 mm) (Adams 2004), the minimum value 0.08” (2 mm) (Adams 2006), with a wide range of 1.84” (47 mm). The mean was 0.69” (18 mm) and the standard deviation is 0.48” (12 mm).

February snow depth (inches) represents the average of daily snow depth measures throughout February. The maximum monthly average value is 9.5” (24 mm) (York 2004), the minimum value is 0.01” (.3 mm) (Phelps 2006), with a wide range as well at 9.49” (241 mm). The mean was calculated at 1.7” (43 mm), with a standard deviation of 2.6” (66 mm).

Linear Regression Analyses

With the habitat hectarage data standardized by hydric soil footprints and the necessary climate variables, simple linear regression analyses were performed on each of the ten variables to test for significant relationships. These analyses combine the three counties of data for the five different years and the resulting scatterplots (Figures 5.4 -5.5) feature fourteen data points (with the omission of Phelps County for 2007). Although no R^2 value above 0.22 exists, there are particular variables which stand out as being more prominent than others in predicting late-winter wetland conditions. In particular, total cold season precipitation showed a positive relationship ($R^2 = 0.22$), and averaged cold season temperature produced a negative relationship ($R^2 = 0.22$); these two variables had the highest R^2 values among the ten climate variables analyzed with the basic linear regression equation. All other variables had significantly lower values ($R^2 = < 0.09$) (Table 5.3).

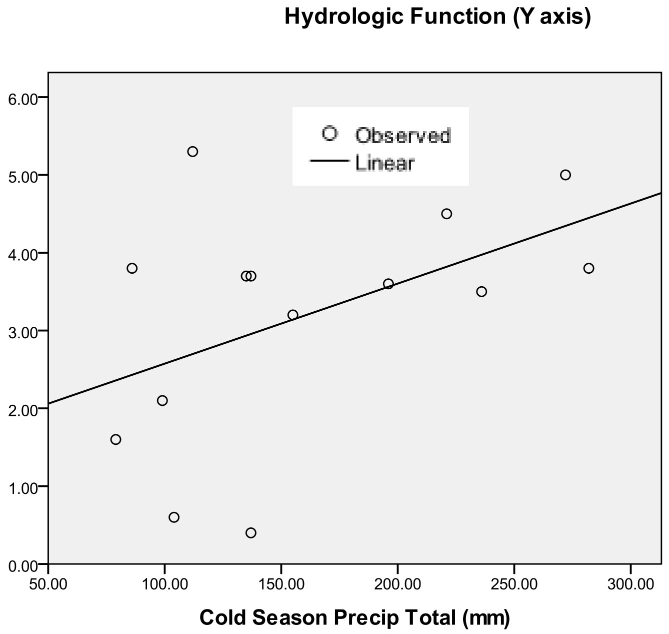


Figure 5.4 Scatterplot of wetland habitat (standardized percentage) and October – February total precipitation (mm).

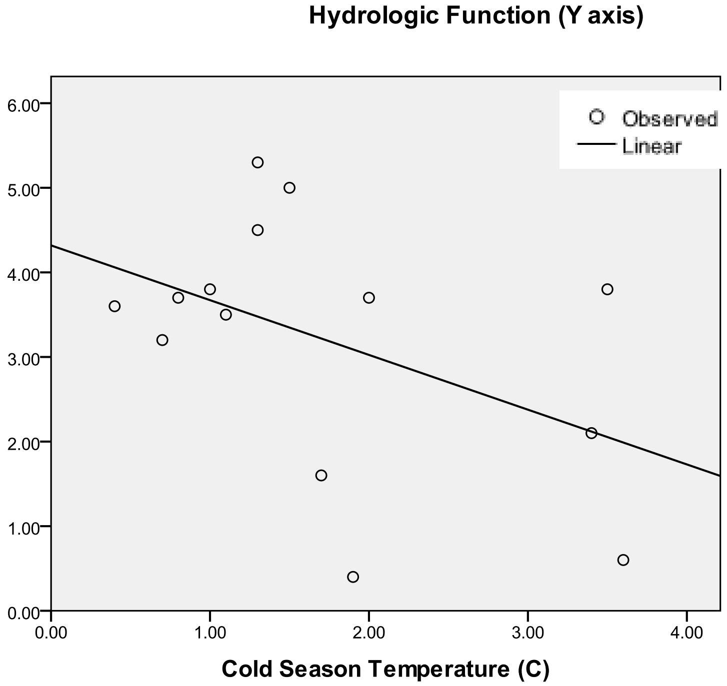


Figure 5.5 Scatterplot of wetland habitat (standardized percentage) and October – February average temperature (C).

Variable	R^2
Cold Season Precipitation	0.22
Cold Season Temperature	0.22
Feb. Wind Speed	0.09
Feb. ET-NE	0.01
Feb. Precipitation	0.02
Feb. Snowfall	0.02
Feb. Temperature	0.02
Feb. Snowdepth	0.01
Feb. Soil Temperature	0.01
Feb. Solar Radiation	0.001

Table 5.3 Ten climate variables with associated R^2 values.

Although this study lacked the recommended thirty data points needed for parametric statistical testing, these regression analyses suggest relationships between climate and habitat conditions in the Rainwater Basin. And, given the goal of developing a predictive relationship that could be used by resource managers, the use of regression analysis made some sense. In general, seasonal correlations in large part yielded higher R^2 values than monthly (February) analyses. The fact that seasonal data yielded higher R^2 values when correlated with annual habitat functioning levels indicate that cooler winter temperatures are related to improved late winter/spring wetland function. Cooler conditions are often characterized by wetter conditions due to mid-tropospheric troughs positioned with a trough axis to the west of the cool and wet location. A meridional upper-level flow pattern can produce anomalous temperature and precipitation conditions (Harman, 1991).

Spearman’s Rho Correlation

Since the fourteen points were low for parametric tests such as linear regression, non-parametric tests such as Spearman’s correlation coefficient, or Spearman’s rho, were conducted on the datasets to determine if significant relationships did exist between the ten climate variables and hydrologic function. This analysis was performed (Table 5.4) and according to the statistical output, no significant relationship exists between the climate variables and annual hydrologic function levels.

	Correlation Coefficient	Sig. (2-tailed)
Cold Season Precip. Total (mm)	.37	.19
Cold Season Temperature (C)	-.25	.39
Feb. ET-NE (mm)	-.04	.89
Feb. Soil Temperature (C)	.15	.61
Feb. Solar Radiation	.02	.95
Feb. Wind Speed (m/s)	-.31	.27
Feb. Average Temperature (C)	.05	.88
Feb. Snowfall (mm)	-.07	.82
Feb. Precipitation (mm)	.09	.77
Feb. Snowdepth (mm)	.15	..62

Table 5.4 Spearman's rho correlation coefficients for the relationship between ten climate variables and hydrologic function; in all cases, N = 14.

Basin-Wide Linear Regressions

In an attempt to see how truly representative the three sample counties had been for the entire Rainwater Basin, a set of additional scatterplots were created using only the five data points of annual wetland flooded area (ha) for the entire basin and the three county/station average of the ten climate variables. The resulting R^2 values (Figures 5.6-5.9) were significantly higher overall (0.92-0.01) denoting a couple of important findings. The first observation is, as expected, that five data points are far too few to expect a realistic and accurate coefficient of determination. More importantly however, the graphs suggest that the three sample counties were likely not highly representative of both habitat functioning, and climatic statistics over the five year study period of the analysis. Un like the 14 point regression analysis, monthly data achieved higher R^2 values than seasonal variables with the exception of February snow depth and February wind speed which were lower than the seasonal temperature and precipitation variables. The highest R^2 value was attributed to solar radiation (0.92), followed by soil temperature (0.87), followed closely by Feb. ET-NE (0.85), and Feb. snowfall (0.85). The lowest R^2 was attributed to wind speed at 0.01. Figures 5.14 - 5.17, as well as table 5.4 follow and illustrate the aforementioned trends.

Variable	R^2
Feb. Solar Radiation	0.92
Feb. Soil Temperature	0.87
Feb. ET-NE	0.85
Feb. Snowfall	0.85
Feb. Precipitation	0.80
Feb. Avg. Temperature	0.54
Cold Season Avg. Temperature	0.53
Cold Season Avg. Precipitation	0.13
Feb. Snowdepth	0.03
Feb. Windspeed	0.01

Table 5.5 Ten climate variables with associated R2 values when correlated with annual basin wide flooded hectares for the five years of analysis.

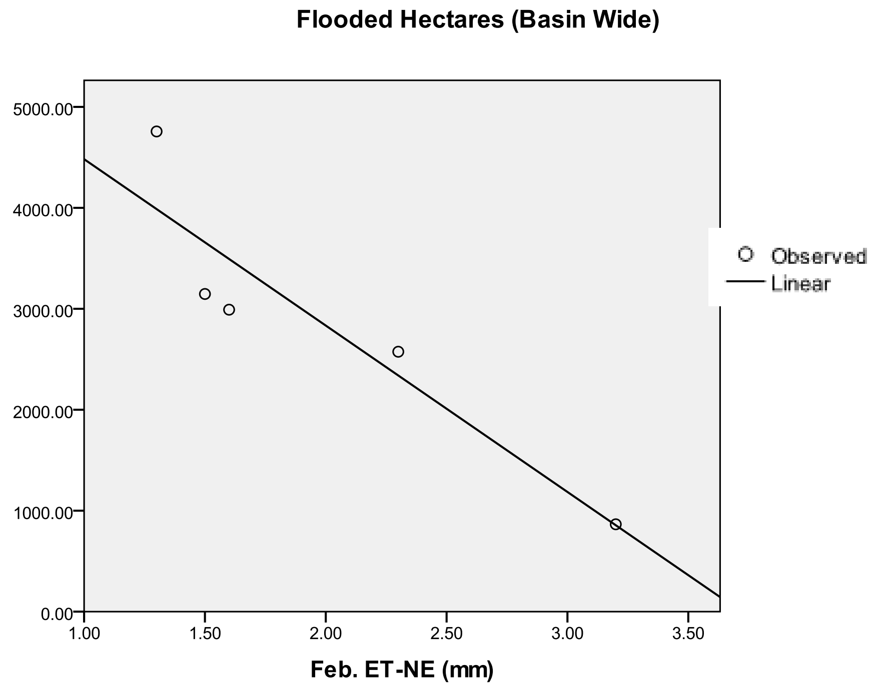


Figure 5.6 Scatterplot of Basin-wide flooded hectares and February ET rates (mm).

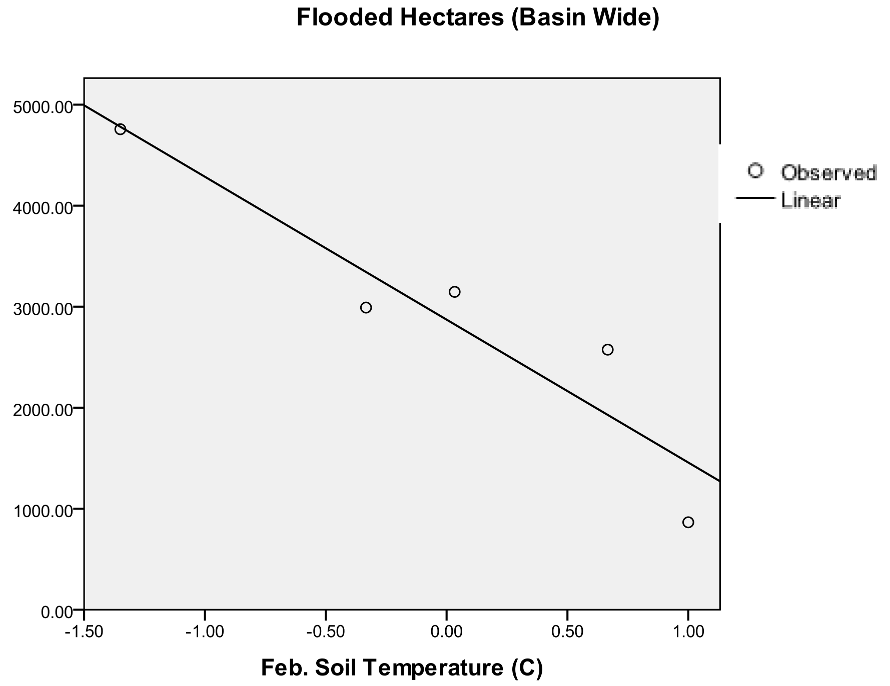


Figure 5.7 Scatterplot of Basin-wide flooded hectares and February average soil temperature (°C).

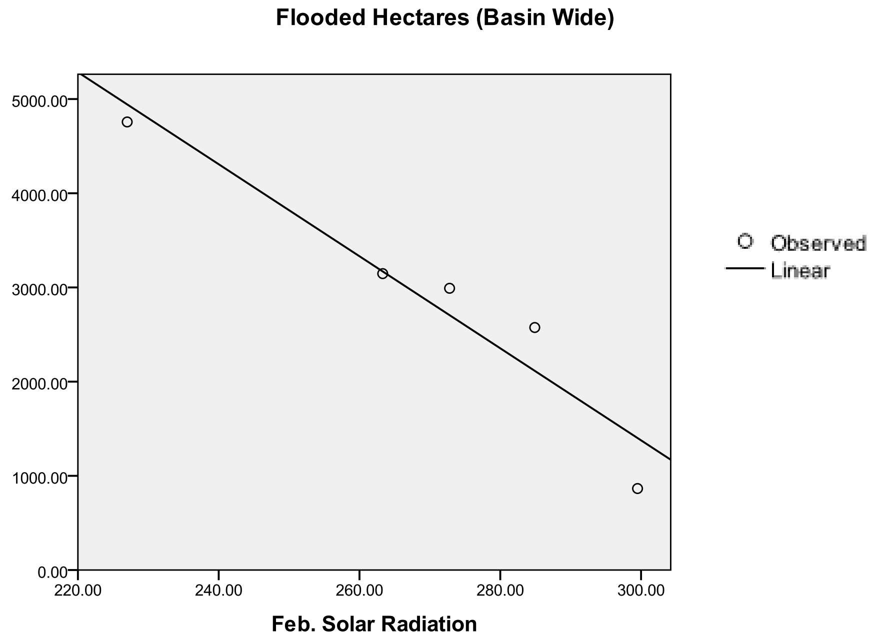


Figure 5.8 Scatterplot of Basin-wide flooded hectares and February solar radiation averages (Langleys).

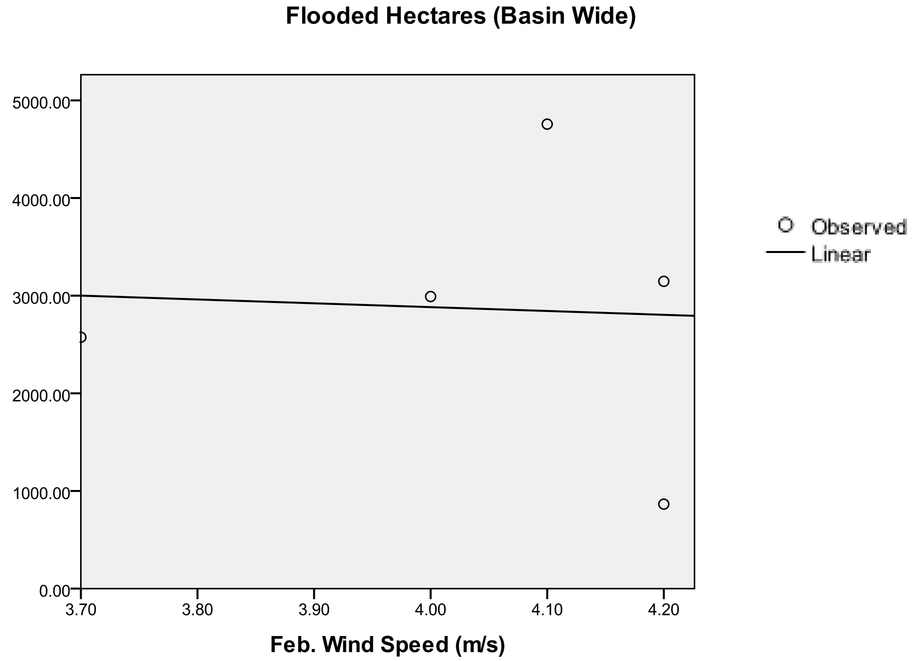


Figure 5.9 Scatterplot of Basin-wide wetland flooded hectares and February average wind speed (m/s).

Basin-Wide Spearman's Rho Correlation

Similarly to the 14 point analysis, it was necessary to perform a non-parametric correlation analysis on the basin-wide values to determine if any significant relationships exist, as well as gauge the suitability of the three sample counties to represent the basin-wide values. Unlike the fourteen point correlations, the basin wide Spearman's rho analysis found four significant relationships at or above the .05 confidence interval. The four variables with significant relationships with annual flooded hectares were February ET-NE (-1.000), February solar radiation (-1.000), February soil temperature (-.900), and February average soil temperature (-.900). No seasonal variables displayed significant relationships with annual flooded hectares on a basin-wide scale.

	Correlation Coefficient	Sig. (2-tailed)
Cold Season Precip. Total (mm)	.30	.62
Cold Season Temperature (C)	-.20	.75
Feb. ET-NE (mm)	-1.00	.00
Feb. Soil Temperature (C)	-1.00	.00
Feb. Solar Radiation	-.90	.37
Feb. Wind Speed (m/s)	.05	.94
Feb. Average Temperature (C)	-.90	.04
Feb. Snowfall (mm)	.40	.51
Feb. Precipitation (mm)	.87	.05
Feb. Snowdepth (mm)	.40	.51

Table 5.6 Spearman's rho correlation coefficients for ten climate variables and hydrologic function; in all cases, N = 5.

Multiple Regression Analysis

The final statistical test performed on the data was a multiple regression analysis of the ten climate variables aimed at identifying the predominate variable(s) in the dataset that had the largest influence on the hydrologic functioning levels of wetlands. Through multiple regression analysis, significant combinations of variables and relationships were uncovered. The multiple regression analysis was performed with the 14 climate/habitat data points, with all ten climate variables. Although this training data amount of 14 observations was low by statistical standards, the analysis still offered insight into which particular variables played the largest role in predicting late-winter wetland habitat conditions. The multiple regression analysis also calculated a multiple R^2 value of 0.84 for the dataset. Tables 5.5-5.7 display the output summary statistics from the multiple regression analysis.

ANOVA[b]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	24.533	10	2.453	1.584	.389[a]
	Residual	4.647	3	1.549		
	Total	29.180	13			

Table 5.7 Regression model ANOVA table for ten climate variables with hydrologic function as a predictor variable.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.917[a]	**.841**	.310	1.24458

Table 5.8 Multiple regression summary statistics with multiple R^2 value.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.364	15.163		.090	.934
	Cold Season Precip Total (mm)	.016	.016	.753	**1.009**	.387
	Cold Season Temperature (C)	-.495	1.146	-.350	-.432	.695
	Feb. ET-NE (mm)	**-1.922**	**2.681**	**-1.015**	-.717	.525
	Feb. Soil Temperature (C)	.328	1.193	.208	.275	.801
	Feb. Solar Radiation	-.003	.040	-.059	-.080	.941
	Feb. Wind Speed (m/s)	**2.119**	**2.358**	.564	.899	.435
	Feb. Average Temperature (C)	.425	.577	.613	.736	.515
	Feb. Snowfall (mm)	-.019	.009	-1.205	**-2.077**	.129
	Feb. Precipitation (mm)	-.048	.067	-.392	-.712	.528
	Feb. Snowdepth (mm)	.022	.013	.993	**1.690**	.190

a. Dependent Variable: Hydrologic Function (Y axis)

Table 5.9 Multiple regression analysis summary table; predominate entries are in bold.

A Climatic Context

Since the multiple regression analysis selected February ET-NE as the predominate variable in predicting late-winter habitat functioning levels, an extended period of record was selected in order to analyze how the recent detailed study period fit into the previous decade, and thus offer insight into how the Rainwater Basin wetlands have functioned over a longer period of winter climatic conditions. Surprisingly, all of the study years except for 2004 were found to be ranked as the highest ET rates of the fourteen year of available evapotranspiration data (Figure 5.18). Evapotranspiration data for 2005 were omitted due to the absence of associated habitat data for the year. The only year to have a higher ET rate than 2004 was 1999. When considering the previous multiple regression analysis denoting the importance of ET-NE rates, and habitat flooded hectarage, it is possible that the recent five years have also been among the drier years of the previous fourteen due to higher ET rates.

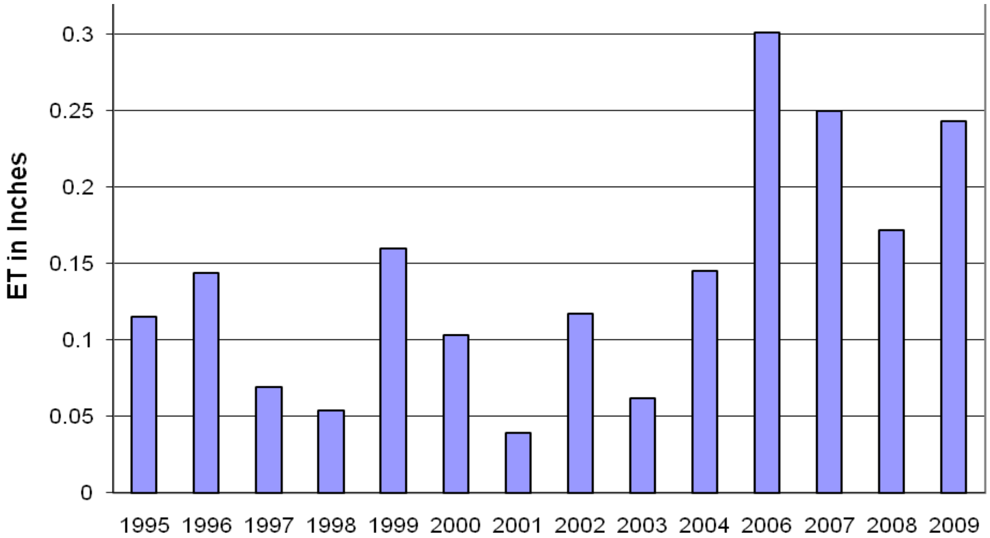


Figure 5.10 1995-2009 evapotranspiration rates (inches).

In an attempt to put the study period into an even longer perspective, cold-season temperature data (Oct-Feb) for Adams County were obtained and analyzed. Adams County was chosen because it is near the center of the study area. Recall that wetland function was negatively correlated with the seasonal temperature variable. The data record began in 1907. For the 102 year record, the average temperature is 1.59°C, with a standard deviation of 1.48°C. The data were graphed, and a smoothed five year running average established (Figure 5.11). Finally, a frequency histogram was identifying where the recent yeas of analysis fit into the last century (Figure 5.12). The running average indicates that the study period of 2004-2009 is near average for the 102 year period of record. The decade of 1912-1921, as well as the twenty years between 1972 and 1991 appear to be below average in temperature, with the 1930s – 1950s being abnormally warm.

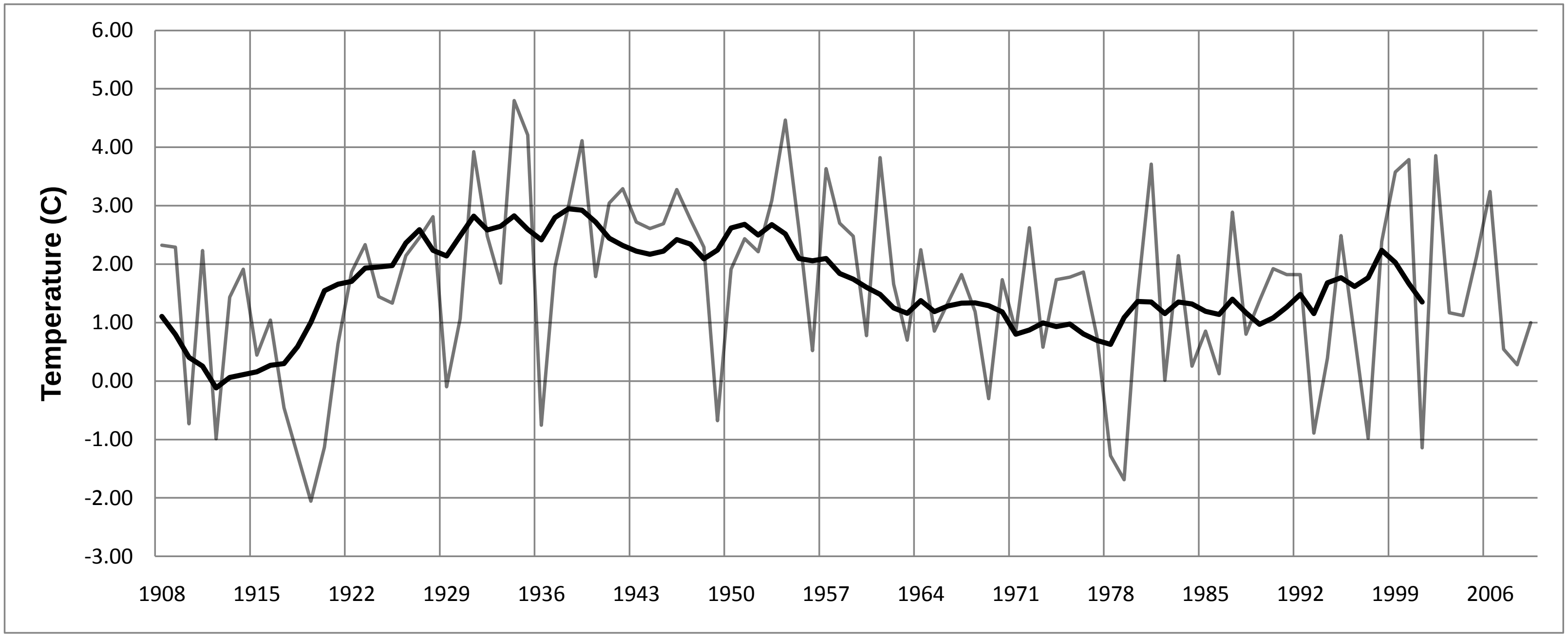


Figure 5.11 1907-2009 Winter (Oct to Feb) temperature values for Adams County, bold line = 9 year running average.

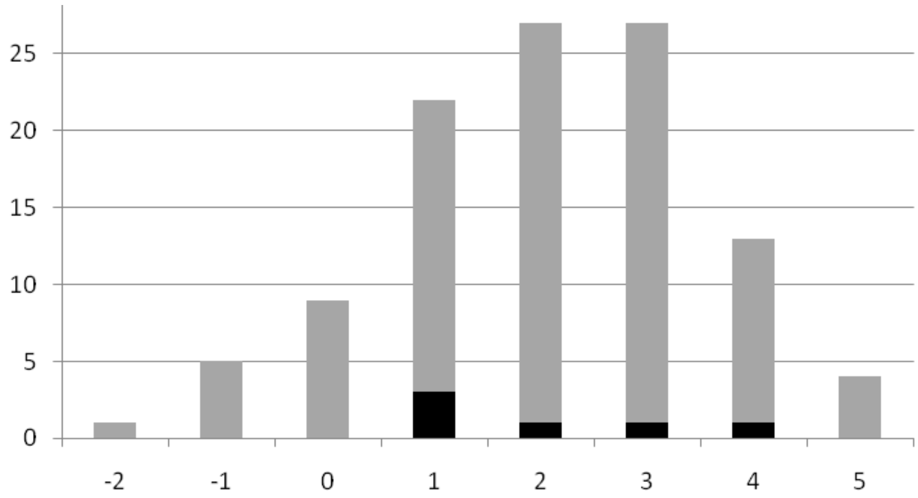


Figure 5.12 1907-2009 Winter (Oct to Feb) temperature frequency distribution. Count of years is represented on the Y axis, while temperature (°C) is on the X axis. Black indicates the five years of analysis, and grey indicates all other years in the historical data record.

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Thornthwaite Water Budget Analysis

Output from the Thornthwaite water budget assessment for the south-central Nebraska Climate Division was a month-by-month table of derived statistics. These output values were summarized on an annual basis (Appendix A - 1). Similar to the assessments of emergent properties based on raw meteorological data, period-of-record data graphics (e.g., Fig. 5.20) provide evidence of significant interannual variability. Three pronounced wet years, 1915, 1965, and 1993 are clearly evident, as are the prolonged dry periods in the 1930s and the 1950s (Fig. 5.13).

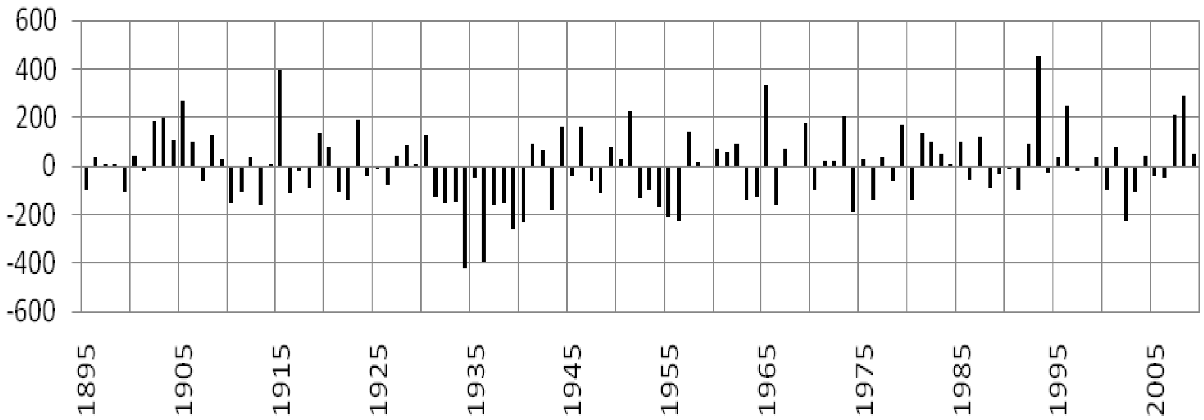

Figure 5.13 Annual deviations of P-PET (precipitation minus potential evaporation in mm) from the local mean P-PET value (- 128.7 mm).

Looking at the recent decade suggests that 2007 and 2008 were relatively wet years when analyzed on an annual basis. In an attempt to look at correlations between Thornthwaite water budget modeling results and the AHS, winter season (Oct – Feb) summary statistics were computed (Table 5.8). The winter season snow storage factor (Figure 5.21) exhibits a year to year variation that seems to match the interannual variation in the AHS with a high of 264.1 mm in 2006-07 and a low of 9.1 mm in 2005-06.

				Soil			Snow		
Date	PET	P	P-PET	Moisture	AET	PET-AET	Storage	Surplus	ROtotal
2003-04	90.9	80.5	-55.7	15.8	39.9	50.8	65.5	0.0	1.8
2004-05	94.0	125.0	16.7	69.9	80.3	13.7	27.0	0.0	5.3
2005-06	96.9	74.9	-26.7	32.4	71.3	25.4	9.1	0.0	3.3
2006-07	81.9	172.6	-16.0	51.2	51.3	30.7	264.1	0.0	3.4
2007-08	87.0	124.0	-22.1	108.4	66.1	21.1	148.8	0.0	5.6
2008-09	88.7	244.6	135.7	191.0	88.2	0.5	39.5	51.2	62.9

Table 5.10 October (prior year) through February water budget summary data.

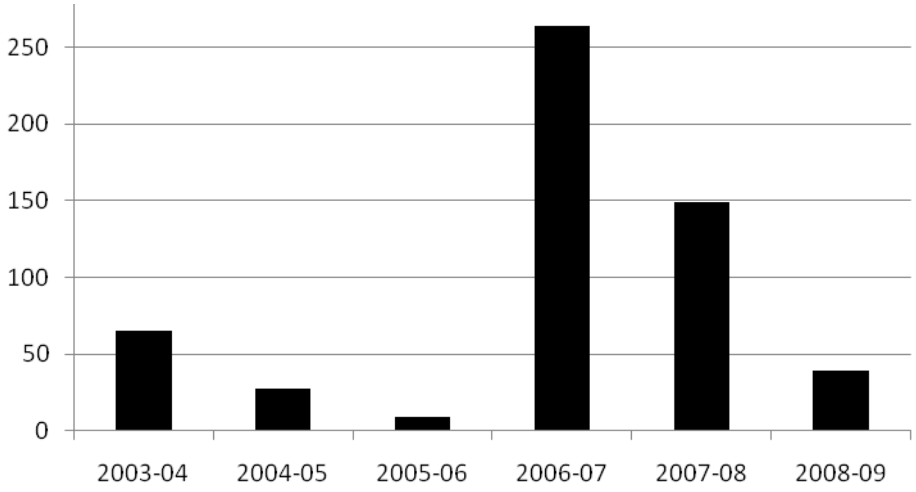

Figure 5.14 Annual winter season snow storage amounts (2003 to 2004 - 2008 to 2009.

Finally, a scatterplot with associated least squares regression analysis was performed for the five years of basin-wide AHS flooded hectares values and the Thornthwaite water budget snow storage amounts for the same years (Figure 5.15, Table 5.). Although the model suffered from a small n of only 5 data points, an R^2 value of 0.78, and an adjusted R^2 value of .71 provide evidence that a strong positive relationship does exists between the two variables. This linear regression analysis of the Thornthwaite water budget output variable and flooded habitat suggests that a water budget approach can be as effective as climate variables in predicting both past and future habitat conditions in the Rainwater Basin.

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.884	.781	.708	752.204

The independent variable is Thornthwaite Snow Storage (mm).

Table 5.11 Thornthwaite snow storage habitat regression summary.

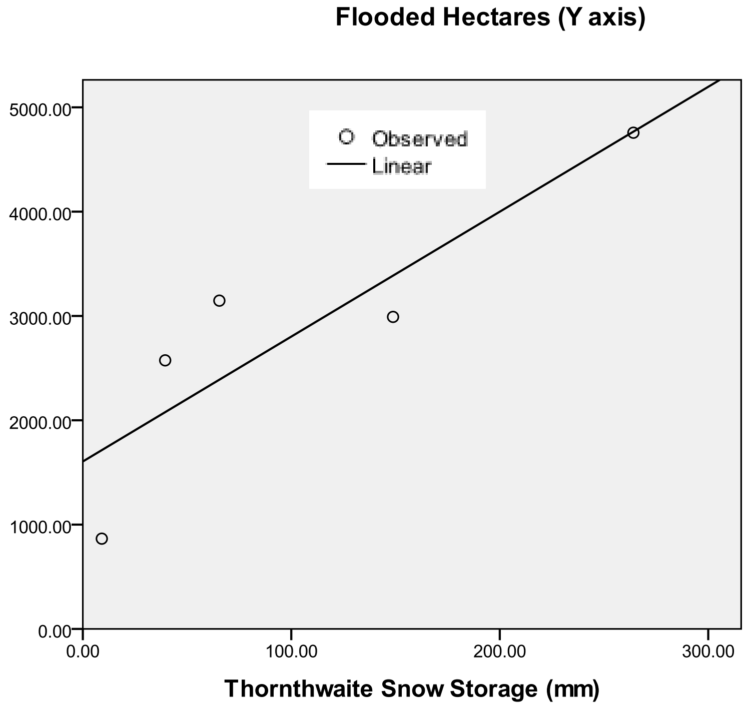

Figure 5.15 Scatterplot of Basin-wide wetland habitat (flooded hectares) and Thornthwaite water budget annual snow storage (mm).

CHAPTER 6 - Summary and Recommendations

The strength of relationships between winter season climate characteristics and late-winter wetland area in the Rainwater Basin of south-central Nebraska were investigated in this research project. A motivation for the project was to create a mathematical model that could be used to predict available habitat in March of each year for migratory waterfowl using the Central North American Flyway. Results from regression analysis indicate that some correlation between climate and wetland condition exists, but the strength of the relationship was considerably less than desired. The major research questions driving the study were:

- Is there a relationship between cold season climatic variability and late-winter water levels in the Rainwater Basin wetlands?
- If a level of statistical significance is determined, what climatic conditions / events are more supportive or detrimental towards the filling of the wetlands?

The major findings from this research effort can be summarized as follows:

- There is considerable year-to-year variability in winter climate conditions.
- There is considerable year-to-year variability in available wetland habitat in March.
- Ten simple linear regression analyses of winter climate with annual wetland habitat resulted in best fits with total precipitation (a positive relationship) for the prior five months (Oct – Feb) and average temperature (a negative relationship) for the prior five months (both with a $R^2 = 0.22$).
- Non-parametric results, based on Spearman's rho and a rank ordering of the data, confirm that a positive cold season precipitation relationship (with a correlation coefficient of 0.37) and a negative cold season temperature relationship (with a

correlation coefficient of -0.25) were the climate variables most strongly related to available wetland habitat. The Spearman's analysis also indicated a negative relationship for February wind speed and wetland habitat in March (correlation coefficient of - 0.31).

- Results from multiple regression analysis suggest that a positive relationship with wind speed in February and a negative relationship with the derived variable, evapotranspiration for February, emerge as more important climate influences on March wetland area.
- Analysis of a climate data record of over 100 years in length (for winter season temperatures) indicates that the period of available data for the annual habitat survey (the winters of 2003-04 to 2008-09) is representative of the longer term. However, it should be cautioned that a longer record is likely to produce more extreme events (both warmer and colder winters).
- Water budget analysis results also help place recent climatic conditions into a longer context. It is clear from the analysis of precipitation minus potential evapotranspiration (Fig. 5.13) that the wetlands in the Rainwater Basin benefitted from above normal available moisture in the winters of 2006-07 and 2007-08.

Nebraska has strong seasonality in the annual delivery of precipitation, with approximately two-thirds of the moisture coming in the warm season. Still, there is enough variation in the magnitude of winter season precipitation that there is an impact on wetland hydrologic conditions in March. In learning about existing conditions with the Rainwater Basin landscape, especially the human modifications to overland flow (e.g., irrigation reuse pits), it became clear that a seemingly direct connection between precipitation and available water in the wetland depressions was made considerably more complex. Given the volume of water that can be stored in these human-made irrigation pits, further research work should better quantify the trapping capacity of these human introductions to the hydrologic landscape. That work might provide strong justification for a program to fill-in the pits that are no longer in use, so that the water can continue its downhill flow into the wetland basins.

This thesis has added to available scholarship on the Rainwater Basins of south-central Nebraska, by examining the relative role of winter season climate in contributing to available waterfowl habitat in March. The Rainwater Basins are a fragile and important ecological resource and efforts by the RWBJV to document and better understand the character of the system are essential. It is clear that the ecosystem services provided by the Rainwater Basin wetlands are very important not only for migratory birds but also for services related to improving water quality and mitigating floods. It is hoped that the approach presented in this study may be an inspiration to future researchers who would have access to a longer time series of combined climate and wetland data and perhaps better models that connect climatic conditions with hydrologic functioning.

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Appendix A - 1

Date	PET	P	P-PET	Soil Moisture	AET	PET-AET	Surplus	ROtotal
1895	708.7	507.8	-229.2	92.4	585.5	123.5	0	48.6
1896	719.6	668.5	-90.3	65.5	608.5	110.9	0	31.8
1897	721.3	649.9	-124.2	83.6	560.4	161	0	29.7
1898	692.8	570.4	-125.8	98.3	611.9	81.2	0	26.2
1899	701.8	497.3	-235.4	36.7	498.6	203.1	0	22.8
1900	747.3	679.9	-87.9	71.7	624.1	123.2	0	31.9
1901	756.4	640.9	-148.7	82.4	579.5	176.7	0	29.8
1902	677.4	794.1	59.4	138.5	645.8	31.8	0	36.5
1903	639.8	708.6	70.2	155.2	620	19.6	146	178
1904	657.6	667.5	-23.2	133.1	616.9	40.5	0	33.6
1905	672.7	850.3	137.9	169.1	664.8	7.8	114.3	154
1906	664.9	670.3	-25.2	141.1	610.9	53.9	39.6	70.6
1907	675.5	532.1	-188.7	102.1	589	86.4	0	24.6
1908	689.3	698.8	-3	93.8	625.6	63.9	0	33.1
1909	698.5	671.5	-98.9	99.0	605.8	92.7	0	30.1
1910	708.4	424.9	-280.4	62.2	513.1	195.2	0	19.9
1911	744.3	549.7	-233.4	40.3	478.2	266.1	0	23.3
1912	675.7	577.3	-90.7	77.2	576.7	98.9	0	23.4
1913	744	586.1	-290.6	50.9	508.2	235.9	0	21.9
1914	747.7	550.7	-128.3	72.1	602.8	144.9	0	25.6
1915	630.7	937.9	269	148.1	595.9	34.8	161.7	198.7
1916	710	481.8	-239.9	100.6	607.6	102.7	0	24.8
1917	657	534.3	-149.1	54.0	507.7	149	0	26
1918	733.1	580.5	-216.4	40.7	489.6	243.6	0	25
1919	700.4	704.7	4.2	113.0	642.4	58	0	31.6
1920	671.6	655.4	-52.4	122.2	608.6	63.1	22.1	53
1921	755.5	525	-235.7	80.4	600.6	155.1	0	25.2
1922	731.8	484.5	-269.5	47.7	441.8	290	0	23.3
1923	685.5	804	65.9	120.7	655.8	29.8	0	39.3
1924	650.8	548.4	-166.6	106.7	568.8	81.9	0	20.5
1925	723.7	576.4	-143	73.4	588.7	134.8	0	27.4
1926	723.6	534.8	-205.1	44.6	528.3	195.4	0	25.3
1927	675.1	608.6	-84.4	93.0	584.5	90.6	0	30.2
1928	681.7	674.6	-39.4	81.9	563.8	117.9	0	31.8
1929	694.5	626.5	-125	113.9	599.5	95	0	28.4
1930	731.4	742.7	2.4	117.9	671	60.5	30.8	66.7

1931	779.3	546.2	-255.5	83.2	593.4	186	0	27.6
1932	739.2	487.6	-280.4	39.4	509.4	229.7	0	21.1
1933	781.9	522.7	-277.4	22.8	490.3	291.7	0	26.1
1934	862.7	335.4	-553.3	12.7	316.6	546	0	14.7
1935	732.4	576.8	-174.2	31.5	549.8	182.7	0	28.8
1936	825.3	337.9	-524.5	13.4	328.8	496.5	0	15
1937	769.3	478.1	-292.5	15.7	471.2	297.9	0	22.1
1938	786.5	530.8	-279.8	22.9	502.2	284.3	0	25.4
1939	791.3	422.6	-387.2	12.7	405.3	386.2	0	20.1
1940	759.4	440.9	-358.1	16.6	388.5	370.9	0	19.2
1941	734.9	712.5	-35.5	70.5	637.7	97.1	0	33.7
1942	714.9	707.4	-66.1	103.4	636	79.2	0	32.9
1943	735.3	421.3	-312.8	62.5	502.6	232.9	0	20.6
1944	697.2	769.9	37.6	107.7	616.4	80.6	30.7	63
1945	672.5	548.9	-170.4	94.5	562	110.4	0	24.7
1946	723.6	770.6	37.8	93.3	569.5	154.1	46.5	74.6
1947	705.3	564.3	-190.2	122.6	589.8	115.6	65.5	100.9
1948	720.9	497.7	-240.3	50.1	493.2	228	0	22.4
1949	699.9	669.1	-48.7	89.6	619.2	80.8	12.1	43.1
1950	657.5	580.6	-101.2	68.5	563.3	94.3	0	27
1951	637.5	779.2	98	138.0	624.3	13.2	0	38.1
1952	743.1	526	-260.2	102.5	601.5	141.7	12.1	36.8
1953	747.3	553.5	-226.1	40.8	496.4	250.9	0	26
1954	776.9	468.2	-299.9	39.6	516.7	260.3	0	23.2
1955	759.7	452.4	-341.2	18.5	407.6	352.2	0	19.9
1956	748.8	401.4	-352.6	18.0	392.8	356.1	0	18.9
1957	703.2	753.4	12.8	73.9	658.1	44.9	24.9	62.1
1958	689	603.1	-113.4	82.2	581.6	107.5	0	23.6
1959	721.1	608.9	-137.4	77.1	585.5	135.7	0	29.1
1960	686.5	663.9	-59	90.1	591.1	95.1	35.2	61.8
1961	679.1	656	-68.4	84.6	596.9	82.1	0	31.8
1962	697.9	686.1	-35.9	102.9	640.4	57.4	0	31.9
1963	778.5	524.1	-269.7	68.0	537.3	241.3	0	25.1
1964	714.6	476	-255.8	46.4	503.1	211.7	0	22.6
1965	670.6	915.3	204	130.5	634.3	36.4	76.6	112
1966	697	444.3	-291.3	94.9	554.5	142.5	0	25.3
1967	646.1	612.5	-54.5	74.4	555.7	90.5	0	29.5
1968	689.1	611.8	-129.5	61.8	562.8	126.2	0	28
1969	679.6	741.3	47.2	118.1	630.3	49.3	0	33.2
1970	719.1	503.2	-225.5	108.4	584.9	134.5	0	24.8
1971	700.8	628	-105	84.0	579.9	121	0	28.1

1972	678.6	621.4	-109.6	80.7	567.8	111.2	0	29.3
1973	699	829.3	80.2	149.3	630.7	68.3	47.3	77.6
1974	719.6	398.1	-317.3	98.9	574	145.6	0	27.1
1975	697.7	618.8	-97.5	54.2	536.1	161.6	0	29.6
1976	705.5	456.8	-266.6	66.3	476	229.3	0	22.5
1977	756.9	707.5	-92.1	79.2	652.5	104.5	0	34.5
1978	703.1	533.9	-192.9	52.4	533.3	169.8	0	24.6
1979	671.6	741.1	41.3	118.8	626	45.7	0	36
1980	737.6	492.4	-268	86.8	569.6	168	0	22.8
1981	700.8	762.7	3.7	73.0	622.6	78.3	0	36.7
1982	661.4	678.6	-31.9	116.7	607.1	54.5	35	65.6
1983	722.4	650.7	-75.9	107.1	607.7	114.8	41.9	73.4
1984	691.8	622.6	-116.9	101.3	516.7	175.2	73.7	103
1985	672.1	662	-27.8	105.5	597.2	74.8	0	31.3
1986	728.6	570.4	-184.5	85.2	590	138.7	0	27
1987	715.1	742.5	-6.2	121.7	646.5	68.7	39.6	75.9
1988	730.6	521.6	-219.4	57.8	575.1	155.7	0	24.5
1989	663.2	531.6	-165.2	27.4	508.6	154.6	0	25
1990	700.6	588.6	-142.6	60.3	535	165.7	0	28.8
1991	733.2	547.9	-226	47.6	499.5	233.6	0	24.3
1992	640.1	627.5	-35.9	97.3	560.7	79.4	0	30.3
1993	630.2	981.5	324.7	173.8	620.5	9.7	233.8	273.6
1994	702.5	596.1	-157.1	132.1	638.1	64.3	1.8	34.3
1995	676.1	593.1	-90.2	90.3	550.1	126	105.5	134
1996	652.6	813.4	122.9	109.5	626.7	25.9	0	40.1
1997	683.6	578.6	-147.6	119.8	587.3	96.2	0	26.9
1998	721.5	601.4	-136.3	115.6	631.6	89.8	0	29.5
1999	696.7	634.9	-89.6	98.2	629.6	67.1	2.6	33.6
2000	727.8	578.1	-222.9	63.9	526.6	201.3	0	26.2
2001	724.5	659.1	-48.1	83.7	630.2	94.3	0	29.9
2002	737.9	401	-355.9	50.6	401.6	336.4	0	19
2003	712.3	505.2	-230.9	56.6	528.9	183.2	0	23.8
2004	684	624.4	-88.6	43.5	538.2	145.7	0	28.9
2005	720.8	584.8	-171.6	68.8	588.8	131.9	0	27.9
2006	727.9	644.9	-173.5	39.9	536.8	191	0	28.6
2007	721.9	820.3	85.9	123.3	669.6	52.4	81.3	117.9
2008	662.9	834.9	163.4	149.6	626.9	36	116.2	150.3
2009	642.6	603.4	-78.7	152.2	604.2	38.4	0	35.5