Blue Gold of the Ogallala Aquifer

by

Claire Dutkewych

Thesis submitted in partial fulfillment of the

requirements for the Degree of

Bachelor of Arts with

Honours in History

Acadia University

April, 2015

This thesis by Claire Dutkewych

is accepted in its present form by the

Department of History and Classics

as satisfying the thesis requirements for the degree of

Bachelor of Arts with Honours

Approved by the Thesis Supervisor

Dr. David Duke	Date

Approved by the Head of Department

Dr. Paul Doerr	Date

Approved by the Honours Committee

Dr. Anthony Thomson	Date

I, Claire Dutkewych, grant permission to the University Librarian at Acadia University to reproduce, loan or distribute copies of my thesis in microform, paper or electronic formats on a non-profit basis. I, however, retain the copyright in my thesis.

____

Signature of Author

____

Date

Acknowledgments

I would like to thank Dr. David Duke, for his constant encouragement, guidance, and sarcastic sense of humour over the last four years. Dr. Duke is an exceptional thesis advisor, without whom I might be a very different student today. I would also like to thank Dr. Michael Dennis for his invaluable advice for my thesis, and the support that the Department of History and Classics, and the Department of Earth and Environmental Science have provided as a whole. I am grateful to Acadia University for the wonderful experience I have gained, it has changed my life and has set me on my current path. Finally, I want to thank my husband, without whose overwhelming support I would never have attended Acadia University, and our children, for putting up with my constant studies.

Table of Contents

Abstract

The history of expansion and settlement in the American West is one of conquering the harsh, yet fertile environment and terrain. As European settlers expanded westwards, they encountered geological and climatic diversity in land that Native American cultures had utilised from as early as 10,000 B.C. To survive in this environment settlers needed a reliable and accessible water resource.

The Ogallala aquifer was formed between two and six million years ago, from the slow accumulation of fossil water, across geological timescales, from the ancestral Rocky Mountains. It underlies 174,000 square miles of eight High Plains states. Since the 1950s, irrigation technology has enabled industrial-scale extraction from the aquifer. The High Plains region became the wealthiest agricultural region in the country, because the water was, and continues to be, mined as if it were an infinite, essentially cost-free, resource. Groundwater-rights legislation is vital for governing water usage in a sustainable manner. However, the eight states that rely on Ogallala water for irrigation, municipal, and industrial needs, and for human consumption, all have differing legislation that produces conflicts that are resolved through the court system, which is based on precedence rather than rational allocation strategies. Attempts to generate policies governing the more sustainable use of the aquifer are being undertaken. However, for the effective, long-term sustainable future of the aquifer, it is essential that a fundamental change in utilisation and pricing of groundwater must occur within American society. This will necessitate similar large-scale alterations of agricultural subsidy policies and physical practices also. Failure to do so will be catastrophic for the High Plains, and for the people and economy of the United States more generally.

Chapter 1

The history of expansion and settlement in the American West is one of conquering the often harsh yet beautiful environment and terrain. The frontier was seen as a fertile land ripe for the picking, and pioneers gradually expanded westwards with regard neither for Native people already inhabiting the land, nor any geographic barriers. In 1893, American historian Frederick Jackson Turner described the existential character of the westward expansion in a theory that became known as the Frontier Thesis, which was also based on his personal experience. In it Turner asserted that the very nature of the American national character derived from the frontier experience. Turner also argued that the frontier was a place of opportunity and escape, and that as long as free land existed, the American people would develop it because this was, to use the overarching phrase of American politics in the nineteenth century, their Manifest Destiny. Manifest Destiny expressed the belief that it was the Anglo-Saxon American's mission, destiny, or God-given right to expand their civilization over the entire continent. Ultimately though, the rich and diverse agricultural and urban economy created in the High Plains zone east of the Rocky Mountains is an unsustainable one, with current resource-use strategies based on a perspective that can be described as little more than a fool's paradise. Unless those strategies change, both radically and soon, then it is overwhelmingly likely that one of the richest and agriculturally advanced regions in the United States will face environmental collapse through resource depletion and the effects of climate change.

The very elements that in Turner's view led to the settlement of the High Plains – the rugged individualism, suspicion of external government intervention, and sense of destiny-driven action – may well, if not tempered with environmental sensibility and a recognition of the natural limits of human agency, lead to the end of a quintessentially American way of life.

As the ambitious, overwhelmingly white European-descended farmers journeyed west they encountered a variety of different climate and terrains. The 100th meridian runs through North Dakota, Nebraska, Kansas, Oklahoma and Texas and broadly delineates the boundary of different climates. East of the meridian moist air moves north from the Gulf of Mexico bringing abundant precipitation while to the west of the line the climate is semi-arid with little rainfall. Up to roughly 105 degrees west, the terrain is relatively flat with an elevation above sea level ranging from 350 meters at its eastern end to more than 2,400 meters in the west zones. The High Plains are extensive; they span "nearly twelve degrees of latitude [and] more than eight degrees of longitude", (or approximately a quarter of a million square miles)[1] and due to the low moisture and high elevation the High Plains experiences a large range in temperature between day and night, and often extreme weather conditions. The western region of the High Plains has a semi-arid climate because it is situated in the rain shadow of the Rocky Mountains, the mountain range that stretches from Alaska in the north, through Canada and the United States, ending in New Mexico in the south. In the rain shadow of the mountains the climate is warm and dry due to the eastern movement of Pacific air masses; as the air mass rises over the mountains it expands and cools, releasing its moisture on the western side of the mountains. As the air mass crosses the peak of the mountains and moves down the other side the moisture depleted air warms and the cloud dissipates resulting in lower rainfall amounts. Despite the extreme variations of the climate and terrain, and the variability of

1. William Ashworth. *Ogallala Blue, Water and Life on the High Plains* (New York: W. W. Norton & Company, 2006), 18.

the High Plains zone, wave after wave of settlers continued in large numbers to gradually move westwards claiming their plot of land in the late 19th and early 20th century.

The first white settlers of the High Plains in the late 18th century were originally ranchers, then farmers, however Native Americans inhabited the land for centuries prior to their arrival. The vast open prairie grass plains were remote and inaccessible, apart from the millions of buffalo that feasted upon the prairie grass, which in turn were preyed on by wolves, vultures and Indians. The Indians of the Sioux, Comanche, and Cheyenne tribes used the open plains mainly for hunting, as there was little surface water or woodlands to sustain sedentary populations. Archaeological evidence indicates that earlier cultures temporarily inhabited the area, especially in the southern plains, from as early as 10,000 B.C.[2] Just like the Native Indian cultures that roamed the plains for centuries, white settlers of the 18th century could only survive if they had access to water for themselves, their cattle and their crops.

The early white settlers soon observed that the soil was unusually fertile, with no trees or roots to entangle ploughs, or rocks to damage their blades. However, the richness of the fertile soil could only be released through constant irrigation. The image of fertile agricultural land was further enhanced by the fact the land was flat, resulting in "nowhere [being] too steep for the wagon of the plow [sic]".[3] No matter how fertile the soil may be, no settlement, let alone a farm, would survive without a constant supply of water. The High Plains has numerous rivers and springs that enabled settlers within a close proximity to tap both surface and groundwater supplies for their own use. However,

---

2. Marc Reisner, *Cadillac Desert, The American West and its Disappearing Water* (London: Penguin Books, 1987), 435.
3. John Opie, *Ogallala, Water for a Dry Land* (London: University of Nebraska Press, 1993), 57.

beyond these local sources it was well known that there was a major source of underground water, if only they had the technology to access it.

The Ogallala Aquifer is a unconfined, vast, fresh water underground ocean, that underlies “112 million acres of the central United States”,[4] extending from South Dakota in the north, to Texas in the south and Wyoming and the eastern edge of Nebraska in the west and east respectively, (see image 1). The Ogallala aquifer was formed between two and six million years ago by slow drop-by-drop accumulation of “fossil water”[5] from prehistoric ice sheets. The water carried fluvial debris from the ancestral Rocky Mountains creating a huge “geological trash heap”,[6] that was dumped on the plains. Gradually, as the rivers reached level ground, they become blocked by debris and bifurcated,[7] cutting new channels, a process that was repeated again and again, with sediment being carried along with the flow until the water was just a gentle trickle and no longer had the energy to carry it. This incredibly slow process, called anastomosis, is how the High Plains and the Ogallala Aquifer was formed. The water within the aquifer, originally estimated to be “probably about three billion acre-feet in confinement”,[8] is not a gushing torrent of crystal blue water flowing amongst wide cavernous tunnels and caves; rather, it is dirty water, mixed in with sediment and soil that does not flow but seeps very slowly in a south easterly direction. The hidden treasure of the Ogallala

---

4. V. L. McGuire et al., *USGS, Conceptual and Numerical Model of Groundwater Flow in the Ogallala Aquifer in Gregory and Tripp counties, South Dakota, Water Years 1985-2009* (Reston: Library of Congress Cataloging-in-Publications Data, 2000), 2.
5. Steven Solomon, *Water, The Epic Struggle for Wealth, Power, and Civilization* (New York: Harper Perennial, 2010), 345.
6. Ashworth, *Ogallala Blue*, 17.
7. Please see Glossary at the back for explanation of terms
8. Reisner, *Cadillac Desert*, 436. 1 acre-foot equals the amount of water needed to cover 1 acre of area to a depth of 1 foot and is therefore equivalent to 325,851 gallons, or 1,233 m^3.

aquifer is covered by another geological gift of fertile soil. The gravel, rocks and silt that tumbled down from the Rocky Mountains combined with aeolian deposits, forming an expansive range of flat, fertile soil. However, this phenomenal natural gift of immense proportion is not inexhaustible. Since the end of the last ice age some 15,000 years ago the Ogallala aquifer has been cut off from its original source of water; there is no perpetual recharge, and the only persisting recharge that it does receive is from precipitation that, as we have seen, is very low.

From the time the first white settlers built homesteads and farmed their land, the belief was that the Ogallala aquifer was inexhaustible, which resulted in water being withdrawn from the aquifer at an unprecedented rate. At first, farmers used windmills to run pumps to draw water from the ground, at flow rates of a few gallons per minute.[9] These wooden windmills with their fabric-covered sails became iconic images of prairie settlement, and it was not until after World War II that the industrial-scale extraction of the aquifer occurred with the invention of the center-pivot irrigation system in 1949. The system of a row of sprinklers mounted on a wheeled frame threw "water over a field like light rain falling from the sky",[10] which irrevocably transformed the parched, brown earth, one of the poorest farming regions in the United States, to the wealthiest agricultural region in the country. By the 1980s, it produced "40 percent of the fresh beef cattle in America",[11] and a staggering "$20 billion [dollars] worth of food and fiber",[12]

9. Jane Braxton, "Saving the Ogallala Aquifer," *Scientific American Special Edition*, (Mar., 2009) Vol. 19, Issue 1. Accessed: 15 October 2014, http://www.scientificamerican.com/article/the-ogallala-aquifer/ 2.
10. Donald Worster, *Rivers of Empire, Water, Aridity, and the Growth of the American West*, (New York: Oxford University Press, 1985), 313.
11. Reisner, *Cadillac Desert*, 437.
12. Braxton, "Saving the Ogallala Aquifer," 6.

which is distributed to markets around the globe. As the ability to extract water in larger quantities increased, additional land, usually deemed unsuitable for agriculture, was bought under the plough. To facilitate the use of the center-pivot irrigation system, fences of trees and shrubs that had originally been planted to mitigate wind erosion of topsoil were removed. The result is a lush, green checkerboard of crops as far as the eye can see, which was all due to, and inextricably reliant on, the Ogallala aquifer.

The natural gift that geology provided in the form of the Ogallala aquifer has provided an abundant source for literature on, but not limited to, its geological, historical, and environmental science dimensions. John Opie's *Ogallala, Water for a Dry Land*, is a groundbreaking 1993 book on the environmental history of the Ogallala aquifer and plains farming. Opie describes the history of how the Ogallala formed. He is careful to explain the geology in a way that is understandable to readers that have little, or no prior knowledge. When describing how sediment was deposited on what is now the High Plains, Opie discusses how America has been inundated by epeiric seas a number of times, the last one being sixty million years ago, which is a timeframe that is nearly incomprehensible to humans, but a blink of an eye in the geologic time scale. Opie describes how the erosion from the Rocky Mountains formed the Ogallala from the flow of a river that carried "melting snow and ice",[13] depositing the fossil water in storage, which was then cut off by a change in climate. Opie visually describes the aquifer as a beach where "the tide has recently gone out [and] no new water comes in",[14] a rather sobering description considering how much the aquifer is relied upon. William Ashworth has also written a detailed account of the history and settlement of the Ogallala aquifer

13. Opie, *Ogallala, Water for Dry Land*, 32.
14. Opie, *Ogallala, Water for Dry Land*, 2.

and the High Plains. Ashworth describes in *Ogallala Blue, Water and Life on the High Plains*, how the aquifer formed in more detail than Opie, noting that the Ogallala "resembles an uprooted mushroom [and that] the plains and the aquifer are tied intimately together".[15] Unlike Opie, Ashworth describes the climate and vegetation and how they change with the different topography. Once Opie has described how the Ogallala formed, he devotes the rest of his book to the evolution of white settlement on the High Plains. Opie describes the ecology of water use with vivid descriptions of the Dust Bowl era in the 1930's, and how since after World War II, advanced irrigation technology has impacted the land and the aquifer. He concludes his study with a discussion of what is needed to move towards sustainable agriculture. Ashworth also discusses the ecology of water use and how irrigation technology has changed agriculture from a family-farm base to one that is industrialized and dominated by economies of scale, but writes in more detail about different local solutions to sustainability and additional aspects of water consumption and how other people are affected.

Opie carefully details how white Americans gradually moved westwards despite the Plains historically being described as a "dangerous and useless place"[16] by Spanish explorer Francisco Vazquez de Coronado in the 16th century. This was confirmed by James Munroe in the 18th century when he informed Thomas Jefferson, an American Founding Father, that the plains were "too remote and inaccessible, devoid of the major rivers"[17] that successful settlement required. However Opie describes how, by the mid 19th century, adventurous settlers, discovering how fertile the soil was, pushed further

15. Ashworth, *Ogallala Blue*, 16.
16. Opie, *Ogallala, Water for Dry Land*, 55.
17. Ibid, 55.

westward, believing that not to do so was an affront to Manifest Destiny. He points out the way in which the 1862 Homestead Act was an additional inducement for people to settle and make a living on the soil. Early settlers chose homesteads near rivers and streams, the best locations for their homesteads. Later arrivals reluctantly had to settle on land often without a source of water near-by, resulting in the opportunity of successfully establishing a farm as very unlikely. Opie, similar to Ashworth but without as much detail, describes irrigation development from water wells that were initially hand dug, to town communities organizing and excavating ditches, channeling water for irrigation and personal use, to the invention of irrigation systems that were powered by the internal combustion engine, enabling much more water to be extracted to irrigate the expanding agricultural land. Opie develops his discussion by examining the centrifugal pump with modernized irrigation systems using engines fueled by petrol and moving on to the center-pivot irrigation sprinklers that produce the huge circular patterns that are characteristic of plains agriculture today.

Throughout Opie's description of irrigation techniques, he continues to introduce individuals that raised concerns about the inadvisability of settling on the semi-arid land. One of these critics was the renowned scientist and explorer John Wesley Powell, who claimed in 1878 that the "climate was so arid that agriculture is not successful",[18] and who was discredited by the plains boosters who encouraged settlement on the plains. When discussing the future of industrialized irrigation Opie mainly focuses on Kansas and Oklahoma, and includes interviews with farmers and water district workers to augment his explanations. Ashworth focuses on Texas and Kansas, but both Opie and

18. Ibid, 64.

Ashworth use case studies to examine the specific issues those farmers experienced. Ashworth quite bluntly describes the depletion, or "groundwater mining"[19] of the aquifer as a crisis that has been ignored too long. However, he concludes on a hopeful note by describing some of the water management experiments that are producing good results, and how changing from agriculture back to freely wandering bison[20] would be beneficial for the high plains and the Ogallala aquifer alike. Opie, like Ashworth, discusses in detail the future of industrialized irrigation agriculture by explaining the current water saving practices, and the employment of alternative crops that are more resistant to drought. Unlike Ashworth, Opie does not discuss or mention the possibility of returning the plains back to what they once were, with roaming bison herds. Opie describes how global warming will exacerbate the already tenuous situation that farmers face, and explains how there is a need to change to an agricultural system that is based on sustainable development and not market exploitation.

There are other authors that have devoted scholarly attention to the Ogallala aquifer and the High Plains. Donald Worster is considered to be one of the founders and leading figures in the field of environmental history, and Marc Reisner, an environmentalist, wrote about the history of water management in the American West in his *Cadillac Desert, The American West and its Disappearing Water*. Worster briefly describes in *Rivers of Empire, Water, Aridity, and the Growth of the American West*, the Ogallala as being the "largest fresh-water aquifer in the world",[21] but due to the center-

---

19. Ashworth, *Ogallala Blue*, 11.
20. Prior to the arrival of white people on the plains, vast herds of Bison roamed the grasslands which, unlike cattle as they are intensive grazers, helped produce surface water like springs and seeps.
21. Worster, *Rivers of Empire*, 313.

pivot irrigation system that opened additional fragile lands to cropping, the Ogallala is being rapidly depleted, with the withdrawal being "over the rate of replenishment equivalent to the entire Colorado River flow".[22] Worster, like Opie and Reisner, discusses some of the schemes that have been proposed to bring in additional water to the plains.[23] Reisner describes the plains and how the Ogallala aquifer formed in a manner similar to Opie and Ashworth, and he also, like Ashworth describes the farming industry as behaving more like a mining industry, as the aquifer is a finite resource. Reisner explains how the decision to treat the aquifer as a coal mine, because farmers are "milking every cent out of the land while the water lasts",[24] will result in another catastrophic Dust Bowl.

Brian Fagan is another author who discusses the importance of the Ogallala aquifer in his book *Elixir, A History of Water and Humankind*. Fagan devotes only a few pages to the Ogallala in his study, but like Reisner, Opie and Ashworth, he briefly describes how the Ogallala formed and how vital the resource is to the United States as it "supplies about a third of the nation's groundwater used for irrigation".[25] Fagan clearly describes how important the Ogallala is to the United States' cereal production and ranching, but how this was not possible until "sophisticated centrifugal pumps brought up

22. Ibid, 314.
23. These include towing Arctic icebergs, or collapsible bladders filled with Columbia water down to the California coast, or Project Skywater, that proposed cloud seeding to make more snow fall on the Rocky Mountains which would produce more spring runoff.
24. Reisner, *Cadillac Desert*, 439.
25. Brian Fagan, *Elixir, A History of Water and Humankind* (New York: Bloomsbury Press, 2011), 340.

thousands of gallons of water a minute", in the 1950's, which resulted in 7 million hectares of land irrigated by the Ogallala, by 1980.[26]

There are many common conclusions generated in the work of the authors discussed above. Although the geological description of how the Ogallala formed may differ slightly because one or another author has gone into more detail, they are discussing geological facts, which do not allow for differing interpretations. This also applies to the size of the aquifer, and both the drawdown rate and recharge rate. These figures do vary from state to state and often from county to county, but again this is measurable data, which the authors would have obtained from geological surveys, or state-produced statistics. The most obvious difference between the works described is the methodology employed by the authors to present their work. Opie and Ashworth use case studies to describe how the Ogallala has affected, and continues to affect, individual farmers. Others, such as Worster, Braxton and Reisner, tend to present their work as a more holistic interpretation and do not focus on any individuals. Opie and Ashworth discuss in detail the geological facts, but also spend some time describing early settlement patterns and how agriculture evolved from the mid 19th century to the current day. Each of the authors are careful to explain how vital the Ogallala aquifer is to the continued success of agriculture in the High Plains, and how the region's agricultural economy is totally dependent on Ogallala water. The message that all the authors stress in their work, with varying degrees of directness, is that the Ogallala is a finite resource, and that it has been and continues to be mined as if it were an infinite resource. This, perhaps the most important and sobering fact, leads the authors to discuss a number of important

26. Ibid, 340.

policy-related issues. The first of these relates to the sustainability programs that have already been put in place, and the extent to which they have had the desired effect. Following naturally from this is the question of what programs should be put in place in the future and how they can be enforced, to extend the life of the Ogallala aquifer.

As one of the largest aquifers in the world, the Ogallala underpins a major portion of the United States' agricultural productivity, a productivity that supplies both domestic and international markets. Because the success of the agricultural sector immediately east of the Rockies is almost totally reliant on the continuing use of the water drawn from the aquifer, a significant amount of scientific and environmental effort has been devoted to quantifying, categorizing, and characterizing its history, volume, and geomorphology. The basic information describing the actual location and size of the aquifer is well-accepted and uncontroversial. As noted above, William Ashworth describes the shape of the aquifer as an "uprooted mushroom"[27] that underlies eight states from Nebraska in the north to the Texas panhandle in the south, and describes the net loss of the aquifer since the 1950's from widespread irrigation to be as much as "120 trillion gallons – 11 percent of its original volume,"[28] with an annual withdrawal amounting to "five trillion gallons of water".[29] Opie also describes the Ogallala as "enormous, trapped below 174,000 square miles of fertile but dry plains farmland",[30] with about a "half-billion acre-feet of Ogallala water being consumed…between 1960 and 1990",[31] which, like Ashworth, he attributes to industrialized agriculture on the High Plains. Reisner, writing in 1987, describes the

27. Ashworth, *Ogallala Blue*, 16.
28. Ibid, 11.
29. Ibid, 10.
30. Opie, *Ogallala, Water for Dry Land*, 2.
31. Ibid, 3.

water withdrawal in Texas alone as being "eleven billion gallons of groundwater – per *day"*,[32] with the remaining seven states that overlie the aquifer using a variation between of five to 1.4 billion gallons per day for each state. More recent studies that include 2008 by the US Geological Survey, reveal startling drawdown figures. In *Groundwater Depletion in the United States (1900 – 2008),* Leonard F. Konikow describes the annual pumpage from between 1949 to 1995 as increasing "from 5 to 23 km^3/yr".[33] However, depletion during the years 2001 and 2008 "is about 32 percent of the cumulative depletion during the entire 20th century [which] averages about 10.2 km^3/yr",[34] which displays the quantitatively increasing nature of water consumption.

The United States Geological Survey has produced a wealth of literature on many aspects of the Ogallala aquifer. V. L. McGuire et al. describes in *Water in Storage and Approaches to Ground-Water Management, High Plains Aquifer, 2000,* the Ogallala underlying "111 million-acre area (173,000 square miles) in parts of eight states".[35] Water consumption, or annual pumpage from the aquifer for irrigation use, rose during the years of 1949 to 1997, from "4 to 19 million acre-feet",[36] however, as the USGS is responsible for the production of scientific data to inform policy but not for the formulation of the policy itself, McGuire et al. exhibit water consumption graphically for each state. An additional method of describing the sheer extent of the aquifer is by the amount of land the aquifer irrigates. This varies a little between studies but this is

32. Reisner, *Cadillac Desert*, 437.
33. Leonard F. Konikow, "Groundwater Depletion in the United States (1900 – 2008), Scientific Investigations Report 2013 – 5079, USGS, 2013, accessed: 15 November 2014, http://pubs.usgs.gov/sir/2013/5079/
34. Konikow, "Groundwater Depletion in the United States." 22.
35. McGuire et al., *USGS, Water in Storage and Approaches to Ground-Water Management*, 1.
36. Ibid, 5

understandable considering the literature has been researched and written over different years, or even decades. Ashworth, Opie and McGuire et al. give a similar figure of about fourteen million acres of agricultural fields on the High Plains that rely completely on the Ogallala. In *The Ogallala Story – What Have We Learned?,* Morton W. Bittinger states the irrigated land is "12+ million acres".[37] Jane Braxton Little, a Sciencist and Conservationist, intriguingly describes the aquifer as a "Rorschach inkblot",[38] with the annual consumption being equivalent to the water carried by "18 Colorado Rivers".[39]

Other important factors regarding the Ogallala aquifer, or any aquifer, that need to be understood include the recharge rate, the depth of the water table and the thickness of the water-saturated layers beneath the ground. Recharge of the Ogallala aquifer only occurs through natural processes, such as precipitation or snowmelt. Opie describes the recharge rate as "less than an inch a year under irrigated land and 0.15 inches a year under dry land",[40] with the depth of the zone of saturated thickness varying from between 50 to 300 feet below the surface and the zone itself being anywhere from "150 to 300 feet thick".[41] Ashworth explains that the saturated thickness could be as much as one thousand feet and in other locations "less than ten",[42] the problem being that average figures do not represent an accurate picture of the health of the aquifer. Ashworth describes the connection between the saturated thickness and the yield of wells upon

37. Morton W. Bittinger. "The Ogallala Story – What Have We Learned?" *Ground Water, Vol. 19, No. 6,* November-December 1981. Accessed: 3 October 2014, 586
38. Braxton, "Saving the Ogallala Aquifer," 2.
39. Ibid, 3.
40. Opie, *Ogallala, Water for Dry Land*, 3.
41. Ibid, 3.
42. Ashworth, *Ogallala Blue*, 22.

which irrigated agriculture is entirely dependent. If the aquifer's saturated thickness decreases below thirty feet, the yield at wellhead is no longer adequate for irrigation.

Opie and Solomon also connect the level of the water table and overuse of the aquifer. Opie explains how due to the declining water table, land in some areas is turning barren, while Solomon argues that the water table is "falling precipitously, causing land subsidence and salt contamination of drinking water and farmland".[43] McGuire et al. note that the upper boundary of the High Plains aquifer, the water table, ranges "from about 6,000 to 1,200 feet above NGVD 29",[44] with the water moving in a southeasterly direction. McGuire et al also displays through the use of figures, the location of areas where there is little or no saturated thickness due to overconsumption of the resource. The majority of these locations are on the western edge of the high plains, south of the middle of Kansas and Colorado.

All information gathered about aquifers is important in measuring the extent and stability of the resource, however, the recharge rate is the main factor which determines the health of an aquifer. If the Ogallala's recharge rate was similar to its withdrawal rate, the aquifer would be deemed healthy and stable, and so long as water consumption was not excessive in comparison to its recharge, the aquifer might be classed for practical

---

43. Solomon, *Water, The Epic Struggle*, 348.
44. McGuire et al, 12. NGVD 29 is specialist terminology for the National Geodetic Vertical Datum of 1929. The National Geodetic Survey, which is the oldest scientific agency in the United States, is responsible for mapping the nation's landforms and coastlines, needed a common, consistent national datum to serve as a baseline for the elevation mapping of the whole country. In the 1920's the NGS established a network of 26 tidal gauges in the United States and Canada and maps were prepared on "mean Sea Level Datum of 1929." This allowed the standardized elevation of a building, or water table, above (or below) sea level. In the 1970s the name of this reference gauge was changed to National Geodetic Vertical Datum (NGVD) of 1929.

purposes as an infinitely renewable resource, although this would not take into account unpredictable impacts of future climate change.[45]

Unfortunately this is not the case with the Ogallala. All the authors mentioned quite clearly state that the source of the aquifer was cut off many thousands of years ago when the runoff from several ice ages ceased to flow, and as we have seen, the recharge rate is miniscule in comparison to the withdrawal rate. There is in fact considerable scholarly agreement on the aquifer's recent recharge rate. Opie and Solomon describe it as a "paltry inch-a-year trickle",[46] whereas Ashworth goes in to a bit more detail. He breaks the aquifer into sections, explaining that in the south the principal mechanism of aquifer recharge is in the region's Playa Lakes which are low spots in the otherwise flat high plains. These lake are inundated through precipitation on and off throughout the year. As the lakes are transitory, filled by temporary rainfall events, there are few plants to uptake the water biologically. This allows the water to gradually infiltrate the soil, thus "accounting for 95 percent of all aquifer recharge for the southern High Plains".[47] Where playas do not exist, most of the recharge to the Ogallala takes place through percolation through sand dunes. Ashworth explains that since there is no runoff nearly all the precipitation that falls on sand dunes "sinks straight down and plunges toward the water table",[48] leaving very little on the surface. Other authors, like Braxton Little, explain how northern parts of the aquifer receive a slow recharge from precipitation and river systems,

---

45. The effect of climate change on the Ogallala aquifer will be discussed later chapter 3 of this study.
46. Opie, *Water for Dry Land*, 32.
47. Ashworth, *Ogallala Blue*, 246.
48. Ibid, 246.

but other locations cannot keep up with human demand resulting in wells and agricultural land being abandoned.

McGuire et al. do not specifically detail the recharge rate of the Ogallala. Rather they display the water level changes and the saturated thickness changes in graphical form. All their figures and diagrams clearly display that from predevelopment to 2000, from central Colorado and Kansas southwards, the water level has declined, in some cases by more than 150 feet which is more than a 50 percent decrease, and in some locations, mostly in Texas, the most southern state that overlies the aquifer the saturated thickness is as little 0 to 50 feet. Another figure displays well locations and depth; with the majority of the deepest wells at more than 300 feet being located in the southern half of the Ogallala aquifer. Additional USGS literature does give specific details of recharge rates, and all information specific to the Ogallala aquifer. One such analysis looks at Gregory and Tripp Counties in South Dakota, the most northern state overlying the aquifer's range, between the years 1985 to 2009. Over this time period, the estimated annual recharge rates for these two counties ranged from "0.51 to 5.95 in., with a mean of 3.14 in."[49]

When looking at the wealth of literature and scientific data of the Ogallala aquifer, a picture is built up detailing quite clearly where the aquifer is being used to such an extent that it can be called a dying resource. The implications of this – economic, social, political, and environmental – are exceptionally serious. The High Plains are the

---

49. Kyle W. Davies and Larry D. Putman. *Scientific Investigations Report 2013-5069. Conceptual and Numerical Models of Groundwater Flow in the Ogallala Aquifer in Gregory and Tripp Counties, south Dakota, Water Years 1985-2009.* Prepared in cooperation with the Rosebud Sioux Tribe. (Reston, Virginia: U.S Geological Survey, 2013), 21.

"…breadbasket of America – the region that supplies at least one fifth of the total annual U.S. agricultural harvest."[50] Its productivity is similar to that of the other well-known "breadbasket" region, like the Ukraine, but Ukraine does not rely on groundwater for its productivity as it enjoys abundant precipitation and fertile black soil. The estimated 174,000 square miles of land that overlies the Ogallala aquifer is split between being used as rangeland and agricultural land. As of 1997, collectively 56 percent[51] of the United States crop production of wheat, cotton, corn and sorghum was produced on the High Plains. It also encompassed a population of 2.3 million people in 2000, [52] all of whom completely rely on the Ogallala aquifer for their economic wealth, daily needs, and material and prosperity.

The sheer extent of human dependency on the Ogallala aquifer cannot therefore be overstated. Throughout the history of white settlement and development of the High Plains, numerous warnings have been expressed concerning the inadvisability of intensely farming the semi-arid landscape. However, once the richness of the Ogallala aquifer was successfully and economically tapped roughly 60 to 70 years ago, thereby allowing farmers to abundantly irrigate their land, the High Plains changed from a region of brown arid land to a circular patchwork of richly-productive irrigated green fields as far as the eye can see. The High Plains farmers, and their economy, and in fact the nation's agricultural economy, are utterly dependent on the water of the Ogallala aquifer.

---

50. Braxton, "Saving the Ogallala Aquifer," 1.
51. "USGS Science for a Changing World," High Plains Water-Level Monitoring Study (Groundwater Resource program) accessed: 2 November 2014. http://ne.water.usgs.gov/ogw/hpwlms/physsett.html
52. High Plains Water-Level Monitoring Study, "USGS science for a Changing World,"

What, then, is being done to delay, mitigate, or plan for the inevitable catastrophe that will occur once the Ogallala is finally depleted?

Mapping of aquifers is a vital undertaking to determine the extent of the natural resource, but this information needs to be used to generate sustainable consumption policy. The USGS has produced a Ground Water Atlas of the United States, which, in reference to the Ogallala aquifer, details important and necessary information, such as the hydrogeological units, groundwater hydrology, and groundwater quality. However, when the original settlers and farmers established their farms on the High Plains in the late 19th century, there was no regulation of water usage. In fact, there was little regulation up until the mid 20th century. Legal structures that regulate water are called water-rights laws, and have been around a long time. The code of Hammurabi, the king of Babylon, "included a couple of [water laws] as early as 1790 B.C.",[53] but the states that overlie the Ogallala aquifer did not enact meaningful groundwater- rights legislation until "panic over declining water tables began in the 1970's".[54] This was nearly forty years after the disastrous Dust Bowl of the 1930's that greatly damaged the agriculture of the High Plains.

The legal philosophy underpinning groundwater rights in America originated in England. The basic premise was that groundwater was separate from surface water and that the overlying landowners had the right to reasonable use on the overlying land. However, this presented challenges that are still evident today, as the original doctrines were based on site-specific doctrines, and failed to take account of the complex nature of groundwater. Early laws were rather vague and were not defined on scientific data.

---

53. Ashworth, Ogallala Blue, 64.
54. Ibid, 64.

Today however, there are various groundwater rights in different states, and this legal landscape, and its implications for the development of rational water-use policies on the High Plains, will be discussed in chapter 2.

Legislation concerning water usage of the Ogallala aquifer is rather piecemeal and frequently contradictory. The eight states of South Dakota, Wyoming, Nebraska, Kansas, Colorado, Oklahoma, New Mexico and Texas all have different legislation regarding access to and consumption of Ogallala water. The result of this is often confusion leading to legal battles and conflict between the different states. In this project I intend to analyze some of these important issues. I will examine the current perspective of what the local and state governments deem as important by establishing what groundwater-rights laws each state has enacted, and by examining the evolutionary history of those legal frameworks. I will then determine how these individual and often conflicting laws affect the farmers, agriculture, and often the general population in neighbouring states, and what has been done to remedy the situation. Once I have established the legislative history, I will take a more holistic approach and discuss what practices and policies have been put in place to promote a more sustainable use of the Ogallala aquifer. What options are there to prolong the use of the aquifer? What has been tried, and what has failed and why? I will also look at new methods pertaining to agriculture that new technologies have introduced, such as drip irrigation and robotic agriculture, and try to determine from current literature if these new practices could delay the impending catastrophe of the Ogallala running out of water. Throughout this work I will also assess both the predictable and unpredictable effects that climate change may have on the continued use of the Ogallala aquifer.

Chapter 2

The United States has an abundant supply of groundwater. The estimated quantity as of 1980 was "fifty times the total amount of water that flows annually through rivers, streams, and lakes".[55] Groundwater sources supply nearly one-quarter of all freshwater in the United States, and they have a number of built-in economic advantages in comparison to surface water. For example, aquifer groundwater is already held within a natural storage facility, expensive dams are not needed to contain it and the loss of water through evaporation is nonexistent until it reaches the surface. The quality of groundwater sources tends to be much higher than that of surface water also, and can often be consumed domestically or agriculturally with little or no treatment. The storage of surface water presents added risk factors, such as dam failures, which have occurred on a number of occasions, sometimes with catastrophic results. However, despite the apparent abundance of fresh water in the United States it cannot be classed as a sustainable resource if the laws and regulations in place are not enforced to protect it and promote its sustainable use and availability for future generations.

Groundwater-rights legislation is vital for governing water usage in a sustainable manner; however, water legislation varies from state to state. This is apparent in the conflicts among the eight states that overlie the Ogallala aquifer. Wyoming overlies the north-western region of the Ogallala aquifer, which lies under about 10% of the state's area. Wyoming covers the highest part of the High Plains, averaging an altitude of approximately one mile above sea-level,[56] with severe winters that restricted the growth

---

55. John H. Davidson, "South Dakota Groundwater Protection Law," *The National Agricultural Law Center*, Vol. 40 (1995): 3.
56. Ashworth, *Ogallala Blue*, 26.

of agriculture as a commercial activity. Until the 1980s this harsh environment also restricted the use of the Ogallala water for irrigation purposes. Due to the late development of commercial agriculture, the state is not in any difficulty regarding water shortage, despite the water table declining "an average of three and a half feet" since widespread irrigation first began.[57] The state enacted its first groundwater legislation in 1947, which required any owners of groundwater wells that were drilled prior to 1947 to register their existing wells. New wells drilled after 1947 had to be registered with the State Engineer. This resulted in the prior appropriation system to groundwater use in Wyoming, meaning that a registered well owner would "receive a priority as of the date their new filing was made with the State Engineer".[58] This naturally encouraged exploitation, as only exploited water could have access rights attached to it. A more comprehensive groundwater code was established in 1957, which determined that wells used for domestic and stock uses would have preferred rights over other groundwater uses and were "exempt from filling requirements".[59] This legislation is easy to understand considering that the beef cattle business has long been established, since the late 19th century, as Wyoming's main economic activity.

South Dakota overlies the most northerly region of the Ogallala aquifer. South Dakota's public water supply relies about "ninety-five percent on groundwater",[60] but accesses only a little over "2 percent of [the aquifer's] water".[61] Only a small amount of the aquifer in South Dakota, has therefore been exploited by the state's population. The

57. Ashworth, *Ogallala Blue*, 26.
58. "Wyoming State Engineer's Office," About The Ground Water Division, accessed: 10 November 2014, http://seo.wyo.gov/ground-water
59. " Wyoming State Engineer's Office," http://seo.wyo.gov/ground-water
60. Davidson, "South Dakota Groundwater Protection Law," 4.
61. Ashworth, *Ogallala Blue*, 26.

saturated thickness ranges from between 100 feet to 400 feet in many places, which encourages the deceiving belief that the South Dakota portion of the aquifer is healthy, but it is not. The water contains a high proportion of minerals, which in some cases makes it unpotable, which has only been exacerbated by human pollution. South Dakota has a long history of water rights legislation, dating from the late 19th century. Originally, the law governing water rights treated surface water and groundwater separately, which caused problems as groundwater and surface water are connected hydrologically. John H. Davidson discusses the confusion that occurs from the separation of groundwater and surface water in his 1995 article, "South Dakota Groundwater Protection Law." Before the end of the 19th century, numerous laws had been passed, including the Riparian Law, followed by the Adoption of Appropriation Law.[62] In 1907, the State Legislature declared that these two acts "existed simultaneously [which] created much confusion".[63] An amendment was duly incorporated into the legislation, which defined all state waters as public property, regardless of their source. Six years later, the South Dakota Supreme Court declared the 1907 law unconstitutional, but it remained in place as a *de facto* statute until 1955. The 1955 law that replaced it recognized that groundwater and riparian rights were based on actual use practices of the water prior to the enactment of the new law. Or to put it another way: prior access and ownership rights were enshrined by the 1955 law, despite the fact that those rights had been secured by the application of a legal framework that had been determined to be unconstitutional. The current process in

---

62. Prior appropriation rights, a legal concept that established the right to use scarce water, can be summed up as 'first in time is first in line'. Prior appropriation laws are distinguished from Riparian laws, under which those who own land next to water have rights to use the water.
63. John H Davidson, "South Dakota Groundwater Protection Law," 7.

South Dakota, which is still based on the 1955 law, is simpler. A permit must be obtained before a new well can be installed and water extracted, and this requirement applies to groundwater and surface water. Unlike Wyoming, South Dakota is a 'true preference' state, meaning that domestic water use takes precedence over all other rights. Thus, even if the date of a well established for watering cattle for example, pre-dated the drilling of a well for domestic use, the domestic-use well would receive precedence in case of access conflicts. Wells used for the irrigation of crops are subject to unique treatment in South Dakota. The same regulations apply to domestic wells. However, the most important addition is that if the applicant for irrigation water intends to engage in chemigation[64] there are "specific regulatory requirements"[65] in place related to pollution.

Nebraska is in a unique position compared to the other seven states that overlie the Ogallala aquifer. An estimated 80% of Nebraskan territory overlies the aquifer, and the state has nearly "two-thirds of the water [and] the water table beneath Nebraska has been creeping upward by an average of 1.6 inches per year".[66] These figures are deceiving however. While the saturated thickness is as great as "twelve hundred feet",[67] on the surface the dominant terrain is un-irrigable sand hills. In "Nebraska Ground Water Law and Administration," J. David Aiken discusses the development of groundwater law and policy. Nebraska has a large agricultural sector, with corn, soybeans and sorghum being the most prevalent crops. Historically, cattle were the primary business in the state, until new irrigation technologies enabled a more efficient means of pumping

64. Chemigation is the injection of chemicals such as nitrogen, phosphorus or a pesticide into irrigation water and applied to the land using the irrigation system. It is recognized as a Best Management practice for irrigated agriculture.
65. John H. Davidson, "South Dakota Groundwater Protection Law," 18.
66. Ashworth, *Ogallala Blue*, 25.
67. Ashworth, *Ogallala Blue*, 26.

groundwater. By 1975, irrigation used "87% of the ground water [and] ground water supplied 99% of total municipal water use".[68] Despite the high demand for groundwater, Nebraska did not develop many water right laws because there was such an abundance of water, which minimized user conflicts,[69] as legislation is usually introduced in response to an issue, such as a drought, rather than as a pre-emptive measure.

Groundwater resolution is based on common law principles in Nebraska. Correlative Water Rights govern Nebraska's groundwater, which allows landowners to drill wells and extract water from an underlying aquifer "for beneficial purposes subject to management by the public".[70] Registration of irrigation wells did not become a legal requirement until 1957, from which point landowners were mandated to obtain a permit to drill a well. The Nebraska Unicameral[71] has enacted numerous legislative acts regarding the use of groundwater. In 1972, the Nebraska Natural Resources Districts were assigned the legal authority to regulate the usage, management plans, water quality and the sale of water. Additionally, in 1985, groundwater management plans were developed that govern water quantity, and since 2004 annual assessments of water sources and water uses are compiled in order to monitor the ongoing status of the aquifer.

Kansas overlies about 10% of the eastern side of the Ogallala aquifer. Eastern parts of Kansas are blessed with ample precipitation, and this is where the state's grain belt is located, in turn the major area of grain production in the United States. The high

68. J David Aiken, "Nebraska Ground Water Law and Administration," University of Nebraska, Vol. 59:917, (1980), 918. http://digitalcommons.unl.edu/ageconfacpub/30/
69. Water conflicts, in many different forms, have occurred since the relationship between humans and water began. An excellent source on Water Conflict is *Elixier, A History of Water and Humankind*, by Brain Fagan, New York: Bloomsbury Press, 2011.
70. University of Nebraska-Lincoln, "Nebraska Correlative Water Rights for Groundwater," accessed: 11 November 2014. http://water.unl.edu/cropswater/regulations
71. A Unicameral government or legislature consists of only one chamber or house.

production of wheat, sorghum, cotton, corn and beef cattle has resulted in "nearly sixty million acre-feet of water [being] removed… almost half of that since 1980 – a net loss [to the aquifer] of nineteen quadrillion gallons".[72] This has resulted in the decrease of the water table by 100 to 150 feet in some locations. Similar to Nebraska, Kansas' water laws are based on common law, and distinguish between surface water and groundwater. The common law principle regarding groundwater is that the resource belongs to the owner of the land overlying the groundwater deposit. This is called the Doctrine of Absolute Ownership, meaning that the landowner can use as much groundwater as they wish with no regard to the needs of their neighbours, nor with any fear of legal consequences. This common law was established in 1868, however, as the population increased, it became inadequate as the demands for water increased. Kansas moved towards appropriation concepts in water law in 1917, and in 1927, the Division of Water Resources replaced the old legislation. Water rights legislation continued to evolve, resulting in the Kansas Water Appropriation Act (KWAA), of 1945, which adopted the prior appropriation doctrine as its legal foundation. The basic concept of the appropriation doctrine is that "the individual who establishes a beneficial use first, has the priority right [to the water resource]".[73] The individual citizens of the state own water in Kansas, like in other states, so long as those individual owners put the water to beneficial use. In the 1960's, the decline of the Ogallala aquifer became evident, especially in the southwest of the state. The thickness of the saturated zone had decreased to below "the thirty-foot minimum

72. Ashworth, *Ogallala Blue*, 25.
73. Danny H. Rogers, G. Morgan Powell and Kerri Ebert, "Water Law," *K-Sate Research and Extension*, (January 2013): 1.

necessary to sustain a standard irrigation well".[74] Groundwater Management Districts (GMDs) were established to monitor the water usage and investigate the overdevelopment of some areas. The formation of the GMDs allowed "local water users more input into determining the policies for water use in their areas",[75] which is unusual as normally legislation is determined by officials, and usually in the absence of input from the people who may be affected by the legal frameworks put in place.

To the west of Kansas, Colorado overlies about 15% of the Ogallala aquifer. Because the High Plains slope to the east, the aquifer underlying Colorado has been draining ever since the aquifer was cut off from its original water source roughly three million years ago.[76] Irrigation has accelerated the decline of the aquifer, resulting in drops averaging nine feet in water saturation in some locations. Along the eastern side of the state border "the decline is closer to fifty feet".[77] Groundwater in Colorado is a public resource, which is subject to the usage rights established by constitutional and statutory provisions. The Colorado Division of Water Resources has administered water rights in the state for over 125 years, based on the Appropriation Doctrine. Similar to Nebraska, in 1957, Colorado "established the permitting requirement of ground water wells",[78] and by 1969 both groundwater and surface water were managed as a unified resource rather than as separate entities. Despite this, groundwater in Colorado is administered under four categories: Tributary Ground Water, Designated Ground Water, Denver Basin Ground

74. Ashworth, *Ogallala Blue*, 25.
75. Rogers, Powell and Ebert, "Water Law," 2.
76. Ashworth. Ogallala Blue, 25.
77. Ashworth, Ogallala Blue, 25.
78. "Colorado, Division of Water Resources Department of Natural Resources," Water Rights, accessed: 12 November 2014. http://water.state.co.us/surfacewater/swrights/Pages/default.aspx

Water, and Non-Tributary Ground Water. Only the latter category applies to the Ogallala aquifer. Much like other states, this means that a landowner overlying the aquifer can pump as much groundwater as they like "so long as it will not affect surface water levels". [79] However, there is an interesting contradiction regarding non-tributary groundwater. If the non-tributary groundwater is outside of designated basins and the Denver Basin Groundwater, the water "may be mined regardless of any consideration of recharge",[80] meaning there is no legally imposed limitation on the amount of water the landowner may withdraw from the aquifer.

South of Colorado, New Mexico overlies about 5% of the aquifer's total area, and similar to Colorado, the aquifer has been draining from the highest point in the west, slowly eastwards, resulting in nearly "30 percent of the state's portion of the aquifer [having] no significant saturated thickness at all".[81] This has limited agriculture mainly to the eastern regions of the state. Water rights laws in New Mexico have been in place since the late 19th century and were initially governed by the prior appropriation rule, which basically means "first in time, first in right",[82]. However, this policy applied to surface water as farmers and other water users appropriated the available surface water first as it was more accessible. At the beginning of the 20th century, groundwater laws stagnated in New Mexico but were revamped after World War I due to new technologies and population growth in the 1920's. Regulation of groundwater was established in the

---

79. "Douglas County Colorado," Colorado State Water Law, accessed: 12 November 2014. http://www.douglas.co.us/water/colorado-state-water-law/
80. Reagan Waskom, "Are We Thinking Big Enough," *Newsletter of the Water Center of Colorado State University, Colorado Water*, Vol. 24. Issue 5, (Oct/Nov 2007): 3.
81. Ashworth, *Ogallala Blue*, 24.
82. James C. Brockmann, Overview of New Mexico's Groundwater Code, *27th Biennial Groundwater Conference and 18th Annual Meeting of the groundwater Resources Association of California*, (October 6-7, 2009): 1.

1930's when uncontrolled exploitation through agricultural irrigation imperiled the groundwater supply.[83] Similar to other states, permits are required from the Office of the State Engineer (OSE) for new wells. In 1953, legislation was passed that required applicants for wells supplying water for livestock and for "irrigation of up to one acre of non-commercial"[84] crops. This occurred in response to studies which determined that there was a hydrologic connection between groundwater flow and the flow of the Pecos River, which flows through the western portion of the state and Texas, into the Rio Grande.

South of Kansas lies Oklahoma, and the High Plains occupy the panhandle that juts out westwards from the body of the state north of Texas. In terms of the health of the Ogallala, this region is one of the bright spots as "more than 90 percent of the 118 million acre-feet"[85] of Ogallala groundwater that could be accessed still remains intact beneath the state, and it is marked by a healthy saturated thickness of between 200 and 400 feet.[86] However, Oklahoma also has the dubious distinction of being the area worst hit by the devastating Dustbowl of the 1930's, due to aggressive exploitation of the land for agricultural purposes that resulted in an ecological disaster for the region. As early as 1890, Oklahoma statutes stated that the "owner of the land owns [the] water standing thereon, or flowing under or over its surface".[87] The use of water, rather than the

83. Peggy Barroll, Ph. D, "Regulation of Water Versus Hydrologic Reality in New Mexico," New Mexico Office of the State Engineer, southwest Hydrology, (July/August 2003) Accessed: 13 November 2014, 20.
84. James C. Brockmann, "Overview of New Mexico's Groundwater Code," 6.
85. Ashworth, *Ogallala Blue*, 24.
86. Ashworth, *Ogallala Blue*, 24.
87. Water Law and Management in Oklahoma, 1.
https://www.owrb.ok.gov/supply/ocwp/pdf_ocwp/WaterPlanUpdate/joint_committee/WATER%20LAW_MANAGEMENT%20IN%20OKLAHOMA.pdf

ownership of water, is governed by common law and like other states is divided in riparian, appropriation, correlative rights and allocation. The current groundwater legislation was established in 1973, and classifies groundwater as a private property that belongs to the overlaying surface owner (the same as in the 1890's), but is subject to reasonable use regulations. As is the case in other states, as a method to regulate wells, they can only be sunk by permit, whether the well is being established on private land or public property.

Texas is the most southerly state that overlies the Ogallala aquifer and has access to "20 percent of the aquifer's land area, but only 12 percent of the water".[88] Texas' portion of the High Plains is separated by the Canadian River, via a gorge that cuts to between "500 to 800 feet below the plateau".[89] Pumping of groundwater began to the south of the gorge in 1910, and the water table has decreased by between one to two hundred feet, with the saturated thickness layer being reduced by half. Texas has the distinctive groundwater law of Rule of Capture, or as William Ashworth calls it in *Ogallala Blue*, the Law of the Biggest Pump, which stems from a court case in 1904, and which has been upheld in the face of challenges ever since. The choice of upholding the Rule of Capture doctrine is significant, as unlike other doctrines, such as Reasonable Use Doctrine, Rule of Capture generally interferes less with agriculture and industry, and therefore the economic development of the state. Rule of Capture controversially provides that as the landowner "owns the water beneath his property, the landowner has

88. Ashworth, *Ogallala Blue*, 23.
89. Texas State Historical Association, "Canadian River," accessed: 17 November 2014. https://www.tshaonline.org/handbook/online/articles/rnc02

the right to pump as much water as he wishes even at the expense of his neighbour",[90] which also interestingly applies to other sub-surface resources such as oil and gas. This does not mean, however, that there are no limitations on the Rule of Capture.

Rule of Capture limitations fall in to two categories, Common Law exceptions and Legislative exceptions, each of which clearly establish conditions of exemption. In 1917, the state legislature passed a constitutional amendment that established Groundwater Conservation Districts intended to conserve the state's natural resources, including (as the name implied) groundwater. Texas' groundwater legislation has been refined over the years since the early 20th century; however, the Rule of Capture is about liability rather than good management, as it prohibits an individual from "suing [their] neighbor for draining water from beneath [the aggrieved individual's] land".[91] Rule of Capture is a disturbing and classic example of Garrett Hardin's, *Tragedy of the Commons*. In his classic paper Hardin describes how every person that uses a natural resource, such as the Ogallala aquifer, either has the choice to appropriate it for their own use or to risk having a neighbour or other member of the community access it for their purposes instead. In the environment established by the Rule of Capture elements in Texan groundwater legislation, the logical behaviour is to consume the water resources as extensively as possible, lest another user beat you to the punch. Ashworth describes this as the human tendency to "overuse and abuse common property out of fear that someone else will get your share before you can",[92] the result of which is the growing dilemma

90. Texas A&M Agrilife Extension, "Texas Water: Basics of Groundwater Law", accessed: 17 November 2014. http://agrilife.org/texasaglaw/2013/10/22/texas-water-basics-of-groundwater-law/
91. Ashworth, *Ogallala Blue*, 76.
92. Ashworth, *Ogallala Blue*, 71.

that individuals, counties, and states will have to face. As I have discussed, each state has differing groundwater legislation that is deemed the most beneficial for their own economic prosperity and growth, but what if Hardin's analogy is extended to encompass whole states, rather than just individuals or counties? This does not seem an unreasonable hypothesis considering what the eight states of the High Plains are facing, as their appetite for water outstrips the supply.

Geology has produced the marvel of abundant waters of the Ogallala aquifer in the High Plains of the United Stares, but not a climate that will induce adequate replenishment. Ironically, across the entire region, the landforms, demography, land use and water resources are relatively consistent, but the legislation that governs groundwater varies a great deal across the eight states of the High Plains. The federal government has claimed authority over navigable waterways in the United States since 1789, and in 1820, federal authority was further established and extended to "navigable rivers and lakes as well as to the ocean",[93] however, all other issues pertaining to water have historically been left within the purview of individual states. The fact that water issues are left to each individual state raises complications, as many rivers, streams and aquifers, are neither neatly nor conveniently contained within states' boundaries. Each of the eight states that overlie the Ogallala have enacted groundwater legislation that is deemed best suited for their particular economic needs, rather than what is best for the aquifer's health, or even what is most logical for its exploitation. This has resulted in states within the High Plains region having conflicting groundwater management policies, that affect individuals, agricultural and industrial businesses, the general population, and often, neighbouring

93. Ashworth, *Ogallala Blue*, 194.

states. However, it is important to acknowledge that having groundwater legislation in place does not necessarily insure conservation of the resource, sustainable use, or prevention of groundwater mining. Indeed, it must be recognized that, in many instances, the legislation actually encourages or rewards irrational and demonstrably damaging misuse of the Ogallala waters.

The philosophy of first use in groundwater historically underlies the formation of a lot of groundwater legislation in the High Plains states. Of the four basic doctrines that form the basis for groundwater legislation, reasonable use, correlative rights, and absolute ownership are similar as they share the premise that the right to use groundwater is based "on owning land overlying the aquifer",[94] whereas prior appropriation rights to use groundwater, are based on the actual act of withdrawing groundwater, not on the actual ownership of the land under which the resource lies. The "first use' doctrine is easier to understand when you take into account that in American law, water is deemed personal property, which includes things that are moveable so not real estate. The Uniform Commercial Code was established in 1952, to deal with the growing problems within American business, such as the legal requirements of doing business, interstate commerce, and the difference in state laws, and "would therefore cover water purchase contracts".[95] Problems arise when states sell or transfer a portion of their water to other states, but conflicts also occur at a more local level, between neighbours, and counties.

---

94. Marios Sophocleous, "Groundwater legal framework and management practices in the High Plains aquifer, USA," *Kansas Geological Survey, The University of Kansas,* (2012): 18.
95. John C. Peck, "Groundwater Management in the High Plains Aquifer in the USA: Legal Problems and Innovations," *The Agricultural Groundwater Revolution" Opportunities and Threats to Development.* (2007): 298

The following examples of these demonstrate how the first use concept predominates High Plains legislation, and the many issues that arise from it.

A number of states in America have enacted legislation to protect water – which is treated in law as both a natural resource and a moveable good – from being exported to another state. As mentioned earlier, Correlative Rights govern the use of Nebraska's groundwater. In 1967, new legislation was established that regulated the movement of groundwater out of the state, but such transfers could only occur on the basis of a permit and if the withdrawal is deemed to be "reasonable".[96] In 1978, Nebraska revised the order prohibiting withdrawals for use in another state unless "the destination state granted a 'reciprocal right to withdraw and transport groundwater from that state' to Nebraska". [97] This clause in the transfer of groundwater legislation, and differing legislation between neighbouring states has resulted in legal cases, such as the case of *Sporhase v. Nebraska*, in 1982.

The case of *Sporhase v. Nebraska* is a classic example of the difficulties that arise from differing groundwater legislation among different states. Joy Sporhase and his son in law, Delbert Moss, purchased land by auction that spanned the state line separating Nebraska and Colorado. At the time, Colorado's policy was to prevent the establishment of high-capacity wells, but Nebraska still allowed the practice. The portion of land purchased by Sporhase and Moss in Nebraska was too small for effective irrigation, and in the remaining portion of land in Colorado, wells were prohibited. In resolving this issue, Sporhase and Moss irrigated the whole plot of land from the Ogallala aquifer, from

96. John C. Peck, "Groundwater Management in the High Plains Aquifer in the USA," 307.
97. John C. Peck, "Groundwater Management in the High Plains Aquifer in the USA," 307.

the Nebraskan side, which conflicted with Nebraskan's reciprocity clause every time the system's center pivot rotated the irrigation head onto the Colorado side, irrigating the crops. The problem being was that the sprinkler's location was "precisely fifty-five feet from the Colorado state line",[98] and because Colorado did not allow the farmers to install a well in Colorado, the reciprocity clause was violated. Ironically, the farmers were transferring water for irrigation out of Nebraska "precisely because it *couldn't* be transferred back in".[99] The state of Nebraska successfully sought an injunction on the basis that as Colorado's groundwater legislation did not allow for the transfer of water to another state, they could not "reciprocate as required by the Nebraska statute".[100] Upon appeal the Nebraskan Supreme Court upheld the lower court's decision. Sporhase then appealed this ruling and the case went to the United States Supreme Court.

The United States Supreme Court's decision to overturn the decision made by the Nebraska court centered on an amendment in the reciprocity clause on Nebraskan groundwater legislation. Firstly, the US Supreme Court noted that the Commerce Clause in the American Constitution governs regulation of interstate commerce, and water is classed as an "article of commerce",[101] so the movement, or restriction of the resource across state lines cannot be restricted unless the welfare of the people where the resource comes from is endangered. This was not the case in Nebraska, and the reciprocity clause was deemed an "explicit barrier to commerce"[102] and violated the commerce clause in the

---

98. Ashworth, *Ogallala Blue*, 197.
99. Ashworth, Ogallala Blue, 198.
100. John C. Peck, "Groundwater Management in the High Plains Aquifer in the USA. 307.
101. John C. Peck. Groundwater Management in the High Plains Aquifer in the USA, 307.
102. Ashworth, *Ogallala Blue*, 198.

Constitution. The reciprocity clause is still effective, but only if it can be proven that the state "as a whole suffers a water shortage [and that] waters from areas of abundance to areas of shortage is feasible regardless of distance".[103] This change acknowledges that political boundaries, such as state boundaries, cannot restrain the movement of water.

The doctrine of prior appropriation originated in English Common Law, and is the most common legal framework for dealing with water access across the High Plain states that overlie the Ogallala aquifer, and in other western states more generally. However, the concept of prior appropriation is applied in various ways in the different states. Of the eight High Plains states, South Dakota, Kansas, Colorado, New Mexico and Wyoming employ prior appropriation exclusively in groundwater legislation, and in some cases use it as the foundation of surface water legislation as well. The remaining three states, Nebraska, Oklahoma and Texas, use a mix of prior appropriation and the riparian doctrine, or as it is also known, the Rule of Capture. The principal feature of prior appropriation is that it gives "exclusive right to the first appropriator; and…the rights of later appropriations are conditional upon the prior rights of those who have preceded".[104] It is important to remember that most of the western states, including the eight that overlie the Ogallala aquifer, are classed as arid or semi-arid in nature, as this means that the overall availability of water in these estates is inadequate to cultivate crops, or in other words, there "is more land than water in the West".[105] This echoes historical concerns regarding the suitability of the land for agricultural purposes that Francisco

103. John C. Peck, Groundwater Management in the High Plains Aquifer in the USA, 307.

104. Chennat Gopalakrishnan, "The Doctrine of Prior Appropriation and Its Impact on Water Development: A Critical Survey," *American Journal of Economics and Sociology*, Vol. 32, No. 1 (Jan., 1973): 63 http://www.jstor.org/stable/3485791

105. Gopalakrishnan, "The Doctrine of Prior Appropriation," 62.

Vazquez de Coronado raised as early as the 16th century, and James Munro and John Wesley Powell remarked upon in the 18th and 19th centuries respectively. In the rush to settle and agriculturally develop the west those concerns were not heeded, however. The prior appropriation doctrine goes hand in hand with that settlement impulse, and so a consideration of its history is important to understanding the development of groundwater resources legislation across the High Plains.

In, Prior Appropriation: Rule, Principle, or Rhetoric, A. Dan Tarlock introduces an argument that the idea of priority, or, first in time, first in right, is attributed to human nature that has been established through social construction, or social biology,[106] as humans desire to "acquire, is a universal rule grounded in human nature".[107] The impulse to acquire resources, or their rights, is therefore, by this theory, very deep-seated indeed. Legislative frameworks place social and legal structure and in some cases limitations on this biological impulse. Prior appropriation was implemented to provide order in the expanding West and the frontier economy, and to "support local individual[s] and cooperative irrigated agriculture",[108] as a method of managing the allocation of water. However, as the conditions of the plains changed, with an increasing number of settlers all needing a constant supply of water for expanding and increasingly commercialized agriculture, support for irrigation drew the attention of politics at a national level. However, since the invention of center-pivot irrigation in the 1950's, industrial agriculture has come to dominate the High Plains region and the continued suitability of

---

106. Social Construction is something that a person may not be aware of, and that only has meaning because society gives it meaning. Social Biology is the biology of social behavior.
107. A. Dan Tarlock, "Prior Appropriation: Rule, Principle, or Rhetoric?" North Dakota Law Review, Vol. 76:881, (2000): 885.
108. A. Dan Tarlock, Prior Appropriation, 892.

prior appropriation is being questioned. Tarlock argues that prior appropriation is an "extreme default rule of decreasing marginal importance".[109] On the other hand, Chennat Gopalakrishnan argues in, "The Doctrine of Prior Appropriation and Its Impact on Water Development: A Cultural Survey," the doctrine continues to grow in importance due to the "distinctive advantages[110] of [the] system".[111] In either interpretation, there is no doubt that prior appropriation continues to be the prevalent groundwater legislation across the High Plains and, indeed, throughout much of the American west. It has been amended over the decades. In some states the common-law rule has been replaced by the rule of reasonable use, which still allows the landowner to capture and use the water, but "limits him to such quantity of water necessary for some useful purpose in connection with the land from which the water was extracted".[112] Prior appropriation has always been controversial, however: individual rights of prior appropriation have been challenged throughout their existence; one such recent case that demonstrates the fractures and conflicts produced by prior appropriation is Bounds v. State of New Mexico, in 2013.

---

109. A. Dan Tarlock. Prior Appropriation, 894.

110. Gopalakrishnan refers to 5 advantages in his article. The first is the principle of full utilization of the water resources. Second, the appropriation system permits the use of water where needed without tying use to riparian ownership. Third, it restricts an appropriator to beneficial use. Fourth, the amount, purpose and place of use of appropriated water are definitely indicated, and this adds an element of certainty, which is unknown under the riparian system. Fifth, management of water resources by the courts through individual case rulings gives way under appropriation to management by a full-time administrative agency staffed by experts.

111. Gopalakrishnan, The Doctrine of Prior Appropriation, 71.

112. Gopalakrishnan, The doctrine of Prior Appropriation, 68.

The case originated when Horace Bounds, a farmer in the Mimbres Basin in south western New Mexico, brought a facial[113] challenge to New Mexico's domestic well statute, arguing that the requirement of a State Engineer issuing a permit to an applicant for the sinking of a well that would have a solely domestic purpose, violates the prior appropriation clause within the New Mexico Constitution. The district court ruled in Bounds' favour, however, the New Mexico Court of Appeal reversed the district court's decision. The main issue in this case was exempt wells, which refers to water wells that are "subject to relaxed or different requirements with respect to obtaining permits for the use of water",[114] which is often used in states that use prior appropriation legislation for groundwater. This means that in certain circumstances, the expensive and often time consuming process of gaining a well permit is bypassed. The reason for exempting wells is to reduce the paperwork for wells that draw a smaller amount of water, so more time is available for the review and administration of "much larger appropriations".[115] The term 'exempt' does not just apply to the permit process being bypassed, it is also based on either the pumping rate or quantity of the water used, the purposes to which the water will be put, or sometimes both. Another issue that Bounds argued was that, as the Mimbres Basin was already fully appropriated, meaning that all the water in the basin

113. Facial, or *prima facie*, challenges argue that the law itself, without looking at a particular situation, violates the state of United States Constitution. The opposite is applied challenges, which is what most cases are. In applied challenges the complaining party acknowledges that the law is generally valid, but asserts that as applied to their particular situation, the law violates either the states or U.S. Constitution.

114. Jesse J. Richardson, Jr, and Tiffany Dowell, "The Implications of Bounds v. State of New Mexico," *Journal of Contemporary Water Research & Educa*tion, Issue 148. (August 2012): 17. Accessed: 17 November 2014. http://onlinelibrary.wiley.com/doi/10.1111/j.1936-704X.2012.03109.x/citedby

115. Jesse J. Richardson, Jr. and Tiffany Dowell, "The Implications of Bounds v. State of New Mexico," 18.

was already allocated to existing users, any new permits granted by the State Engineer "harms his [Bounds] rights as a senior water user by taking his water",[116] basically, Bounds argued that since all the water in the basin has already been appropriated, no one else even has the right to petition to have access to it. Additionally Bounds also argued that the requirement to obtain a well permit from a State Engineer violates the constitutional rights of a senior water appropriator and the prior appropriation doctrine that is clearly established in the New Mexico Constitution. In other words, because he was *already* a user of the Basin's water resources, the state had no standing to prevent him from accessing the resources in any future way that he saw fit.

The term "senior appropriator" is an interesting one. As previously mentioned, prior appropriation literally means 'first in time, first in right', or, as Richardson and Dowell describe it, "In times of water shortage, the first appropriator gets his full amount, then the second appropriator, and so forth until the water is exhausted. The more junior appropriators receive no water in times of scarcity",[117] which does not display the equality that many of the American people have been demanding since before prior appropriation was established. The case ultimately progressed to the Supreme Court of New Mexico, as a result of Bounds' appeal of the Court of Appeals decision, which had ruled in the State's favour. The Supreme Court of New Mexico issued its judgement of the Bounds case in July 2013. The court found in the State's favour, finding that the

116. "Universities Council on Water Resources," Summary of Bounds v. New Mexico, New Mexico Supreme court, Jesse J Richardson, Jr., and Tiffany Dowell, accessed: 26 November 2014. http://ucowr.org/call-for-papers/summary-of-bounds-v-new-mexico-new-mexico-supreme-court

117. Jesse J Richardson, Jr. and Tiffany Dowell, The Implications of Bounds v. State of New Mexico, 17

domestic well statute did not violate the doctrine of prior appropriation, and reaffirming that domestic wells are not exempt from priority, only administered in a different way.[118]

The Bounds v New Mexico case was interesting and was not only followed within New Mexico, but also elsewhere in America. If Bounds had been successful, his challenge to State authority to modify first appropriation to ensure the more effective administration of groundwater resources would have generated litigation in other states faced with similar problems, as the precedent had been set. Even though Bounds was ultimately unsuccessful in his challenge, the case has nevertheless generated legislative attention. It demonstrated that it is difficult, if not impossible, to prove "impairment by a single domestic well pumping a small amount of water",[119] which is what Bounds argued. The New Mexico State Legislature amended the legislation as a result of the case, reducing the amount of water allowed to be drawn from exempt domestic wells, and granted the State Engineer "extensive authority to further regulate exempt wells".[120] In effect, the Bounds case weakened the doctrine of first appropriation and strengthened the power of the state to control and administer the distribution of its groundwater resources for non-commercial purposes.

The *Bounds v. New Mexico* case involved a limited number of people within two states, however, interstate litigation that involves and negatively affects the people of

---

118. "JUSTIA US Law," Horace Bounds v. State of New Mexico, ex rel. John R. D'Antonio, Jr., New Mexico State Engineer. Filing date: July 25, 2013, Docket No. 32,713. Regulation of Domestic Wells to Protect Senior Water Rights, (32), accessed: 27 December 2014, http://law.justia.com/cases/new-mexico/supreme-court/2013/32-713.html
119. "Universities Council on Water Resources," Summary of Bounds v. New Mexico, New Mexico Supreme Court.
120. "University Council on Water Resources," Summary of Bounds v. New Mexico, New Mexico Supreme Court.

whole counties or states is not uncommon. A clear example of this is the Pecos River Conflict between New Mexico and Texas.

The Pecos River is one of the major tributaries of the Rio Grande. It begins in North central New Mexico, flowing in a south-easterly direction in to Texas where it joins the Rio Grande, flowing eventually to the Gulf of Mexico. The Pecos River is a boundary between Texas and the country of Mexico, and from the north heading south the topography changes from one of mountain pastures to grasslands, semi-arid land desert and deep canyons, with the watershed extending approximately 44,000 square miles across New Mexico and Texas.[121] Water development in the Pecos River basin began in the mid- 19th century, and since the introduction of more advanced irrigation techniques in the mid 20th century irrigation has become extensive and economically vital for the two states. Similar to watersheds, which flow from a small scale to form a larger water course, water conflicts also have the potential to become large-scale problems, and the often overlapping and conflicting legislation within different jurisdictions complicate such matters. Before we examine the Pecos River Conflict, it is important to explain the connectivity between groundwater and surface water and the legislation governing each.

The Pecos River Basin in Western Texas is composed of extensive alluvial deposits that form an aquifer, which is part of the High Plains, Ogallala Aquifer. Groundwater is inextricably connected to surface flows, and therefore interstate streams, the laws of hydrology dictate this. Due to the interconnectedness between surface water and groundwater, both play an important role is supplying water for irrigation in a location where precipitation is limited. Initially, surface water rights legislation was

121. "Texas State Historical Society," Pecos River, accessed: 30 November 2014. http://www.tshaonline.org/handbook/online/articles/rnp02

based on property rights, but groundwater presented a more difficult process to legislate. In the 19th century, the task was deemed impossible because the

> Secret, changeable, and uncontrollable character of underground water in its operations, is so diverse and uncertain that we cannot well subject it to the regulations of law, nor build upon it a system of rules, as is done in the case of surface streams, [resulting in it being] better to leave them to be enjoyed absolutely by the owner of the land.[122]

In the United States, groundwater and surface water were treated as two different property rights, which often bought different users into conflict. Additionally, scientific knowledge regarding the nature of groundwater, and how surface water and groundwater were connected hydrologically was in its infancy in the 19th century. When issues arose, the simplest method of resolving the conflict was by applying the same rules to define groundwater rights that were used for surface water.

The Pecos River conflict clearly displays the trans-boundary conflicts that can arise from individual states employing different water rights legislation. As previously discussed, New Mexico practices the Prior Appropriation doctrine and regulates groundwater consumption by the requirement of well permits from the State Engineer. Meanwhile, Texas' groundwater is governed by Rule of Capture, which means the overlying landowner has the right to use as much water has he chooses. The difference between the two states is clear, New Mexico attempts to maximise its water by "efficient

---

122. Olen Paul Matthews, "Ground Water Rights, Spatial Variation, and Transboundary Conflicts," *Ground Water*, Vol. 43, No. 5, (Sept., Oct., 2005), 692. http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.2005.00067.x/abstract

groundwater management",[123] whereas Texas has no limitation on groundwater consumption. This has produced conflict between the two states.

Texas, being the downstream water user, has actively sought to increase its share of water "since the early days of development … in the last half of the 19th century".[124] The first legislative attempt occurred in 1925, when Texas sought an agreement with New Mexico that would assure them a certain amount of water each year. Texas wanted to construct a reservoir near the state line; however, New Mexico also wanted to build a reservoir because it had experienced water shortage due to "leakage and siltation … of the McMillan Reservoir".[125] The Compact of 1925 was unequal, as it authorised the construction of a reservoir in Texas but did nothing to rectify the sedimentation of the McMillan reservoir in New Mexico. The situation was stalemate: Texas wanted to build a dam to hold water for use within Texas, but New Mexico objected claiming that the water that was to flow into the reservoir was water "already appropriated for use in New Mexico".[126] Negotiations at the local level failed, and political leaders escalated the problem to the national level in 1926. Again, there was no resolution that was acceptable to both states, until the Secretary of the Interior, Hubert Work, "threatened to drop both projects if the states could not resolve their differences",[127] which resulted in the

123. Marilyn C. O'Leary. "Texas v. New Mexico: The Pecos River Compact Litigation," *Natural Resources Journal*, Vol. 20, (April, 1980) 399, accessed: 16 November 2014. http://lawschool.unm.edu/nrj/volumes/20/v20_no2.php

124. Marilyn C. O'Leary, "Texas v. New Mexico: The Pecos River Compact Litigation," 399.

125. Marilyn C. O'Leary, "Texas v. New Mexico: The Pecos River Compact Litigation," 399.

126 . Marilyn C. O'Leary, "Texas v. New Mexico: The Pecos River Compact Litigation," 400.

127. Marilyn C. O'Leary, "Texas v. New Mexico: The Pecos River Compact Litigation," 400.

compromise Alamogordo Agreement. The agreement enabled each state to build its dam, and New Mexico agreed that it would continue to allow the same amount of water, calculated on the amounts from the 20 years prior to the agreement, to flow downstream to Texas. Initially, the agreement was successful; both states got what they wanted, however, in the 1930's, unusually high precipitation resulted in extensive flooding which caused millions of dollars of damage in New Mexico. This in turn produced litigation concerning salinity contamination, initiated by farmers near Roswell, New Mexico, alleging the United States Potash Company was contributing to the salinity of the river. The case was not successful for the farmers as it was settled in favour of the company on the basis of U.S. Geological Survey reports "absolving the potash company of adding to the salinity of the river As a result, New Mexico became careful about entering in to any future agreement until "more was known about the hydrology of the [Pecos] river".[128] Despite the initial acceptance and success of the Alamogordo Agreement discontent continued, and in 1941 Texas repealed its participation in the Alamogordo Agreement as a precursor to launching legal action against New Mexico concerning access to the river's water. The litigation was averted due to the establishment of the National Resources Planning Board that opened an office in Roswell, New Mexico, and completed fieldwork on the Pecos River. The result of this work was a substantial amount of data that covered the "issues of water supply, irrigation development, salinity, water uses and requirements, floods, … and the use of water under given conditions".[129] The study of the river, and factual data, resulted in the signing of The Pecos River Compact of 1948, between New

128. Marilyn C. O'Leary, "Texas v. New Mexico: The Pecos River Compact Litigation," 401.
129. Marilyn C. O'Leary, "Texas v. New Mexico: The Pecos River Compact Litigation," 401.

Mexico and Texas. However, the long process of disagreements and conflict that eventually led to the Pecos River Compact is representative of the tortuous path that is often taken by water rights legislation.

The Pecos River Compact was ratified by the two states and signed by President Truman in June 1949. The compact had four purposes, the most important and perhaps the most controversial of which was contained in the apportionment article. As stated in Article III (a), of the Compact, "New Mexico shall not deplete by man's activities the flow of the Pecos River at the New Mexico – Texas state line below an amount which will give to Texas a quantity of water equivalent to that available to Texas under the 1947 condition".[130] The conflict continues based on the definition of the "1947 condition" in New Mexico. As with any river, the flow volume can vary from day to day, month to month, and year to year, depending on many variables. However, there was an assumption that the different variables would smooth out in to an overall average that would establish a baseline that would ensure fairness for the states involved. But what was not considered was the possibility that the baseline could shift over time and not represent an unchanging long-term average. This fact undermines the assumption on which the legislation rests.

At the time the compact was established, the Pecos River Commission was also formed, which consisted of a Commissioner for each state plus a nonvoting representative of the federal government that had the power to administer the compact. The Commissioners for the two states could not agree, however, on the definition of the

130. "Water Code, Chapter 42," Title 3. River Compacts, Pecos River Compact. Article III, (a), Accessed: 1 December 2014. http://www.statutes.legis.state.tx.us/Docs/WA/htm/WA.42.htm

"1947 condition". In 1973, Texas filed an action against New Mexico claiming that the state "had breached its obligations under Article III (a) [and was] seeking a decree commanding New Mexico to deliver water in accordance with the Compact".[131] The term "1947 condition" is questionable. This was the year prior to the compact being signed, but the study that was used in formulating the compact covered the years of 1905 to 1946, so there are no actual figures on the condition of the Pecos River for 1947. This is the stance that New Mexico argued; the state's defense rested on the contention that as the term "1947 condition" does not include changes that occurred during this year that state would "lose that substantial part of its groundwater usage that was developed in that year".[132] Texas argued that the language laid out in the Compact at the time of its signing in 1948, that "1947 condition" meant the condition of the Pecos River at the beginning *of that year*. It is evident that each states construed the term "1947 condition" in a manner that most benefitted their own state. Because of the continued intransigent attitude evident in New Mexico and Texas, similar to many other states, conflict between the two states continues to this day, even in light of solemnly concluded agreements between the two parties.

The Pecos River Compact, and conflict that followed is interestingly connected to the previous case discussed, *Sporhase v. Nebraska*. When the Supreme Court handed down their verdict on the *Sporhase* case in 1982, the long-standing assumption regarding the exportation of water interstate was shattered. Originally, a ruling in 1905 in the

---

131. "Cornell University Law School," State of TEXAS, Plaintiff v. State of NEW MEXICIO. Accessed: 1 December 2014.
http://www.law.cornell.edu/supremecourt/text/462/554
132. Marilyn C. O'Leary, "Texas v. New Mexico: The Pecos River Compact Litigation," 408.

Hudson County Water Co. v. McCarter, stated that an embargo statute did not "violate any provision on the United States Constitution".[133] This decision resulted in states, especially western semi-arid states, enacting statutes the either prohibited or restricted the exportation of water across state lines. The *Sporhase* case ruled that the interstate transfer of water was unconstitutional if it negatively affected interstate commerce, in other words, in the interest of the nation overall. Individual states are prohibited from "enacting laws that interfere too much with the free flow of interstate commerce".[134] As Douglas L. Grant discusses in his "Commerce Clause Limits on State Regulation of Interstate Water Export", this latter aspect of the clause is known as the negative, or dormant, commerce clause, since it "negates power states would otherwise have to regulate interstate commerce".[135] The question that arises from this is how do you justify the national interests, against the interest of the individual state, and, how much federal interference is acceptable in state legislation? These issues that arose from the *Sporhase* case have been challenged in numerous other cases, one of which was the *El Paso* Case.

The City of El Paso, Texas, is located below the southern border of New Mexico. El Paso filed applications with the New Mexico State Engineer to appropriate almost "300,000 acre-feet of groundwater annually for export to the city".[136] The increase was required, stated the application, because the city was considering present use and future use requirements. The New Mexico State Engineer refused the request based on the pre-existing understanding of the prohibition of interstate water transfers. El Paso challenged

---

133. Douglas L. Grant. Commerce Clause Limits in State Regulation of Interstate Water Export. *Journal of Contemporary Water Research and Education*, Vol. 105 (1996) 10, accessed: 26 November 2014. http://opensiuc.lib.siu.edu/jcwre/vol105/iss1/3/
134. Douglas L. Grant, "Commerce Clause Limits," 10.
135. Douglas L. Grant, "Commerce Clause Limits," 10.
136. Douglas L. Grant, "Commerce Clause Limits," 13.

the decision under the negative commerce clause, and the Federal District Court ruled that New Mexico's argument, that they had a water embargo because they were practicing conservation and water preservation as otherwise they would "suffer a state-wide water shortage"[137] in the future, to be unconstitutional. This was, not surprisingly, a controversial decision, and there are differing opinions about how such cases should be resolved.

Albert E. Utton discusses this issue in "The *El Paso* Case: Reconciling *Sporhase* and *Vermejo*." Utton argues that not only was the *El Paso* case brought to the wrong court, but also the wrong theory was argued. Disputes over interstate streams are decided by the Supreme Court of the United States, as stated in the U.S. Constitution, the El Paso case was held in a Federal District Court, which under federal common law are "governed by equitable apportionment, not by the commerce clause".[138] Equitable apportionment is a doctrine that American courts have established that attempts to maintain the balance between the different states, by assuring each state receives a "fair share, and prevents any state, simply because it is bigger, more economically advanced, or more aggressive, from taking more than its share of the river".[139] The decision that the Federal District Court laid down presented similar unfortunate outcomes that have

137. Douglas L. Grant, "Commerce Clause Limits," 13.

138. Albert. E. Utton. The *El Paso* Case: Reconciling *Sporhase* and *Vermejo*, *Natural Resources Journal*, Vol. 23, No. 1, (Jan., 1983), 2. The Commerce Clause and Equitable Apportionment are tools that were developed for protecting and maintaining the balance of federalism between the nation as a whole and the individual states. The commerce clause protects the national union from being economically fragmented and thus weakened by individual states imposing measures such as tariffs or taxes that would impede commerce. Equitable apportionment recognizes the equal rights of the states, while at the same time attempts to establish justice between them. So, if there is a dispute between two states over interdependent groundwater and interstate rivers, this is settled by allocating each state a fair share, an equitable apportionment.

139. Albert E. Utton, "The *El Paso* Case," 3.

previously been discussed. New Mexico was penalized although they have a progressive water law system, whereas Texas has no legislation to control or limit groundwater consumption. In essence, New Mexico was being legally instructed to surrender water resources to their more profligate neighbour on the basis of the principle of "use it or lose it" – not one that is especially conducive to the effective management of resources.

There have been further changes, subsequent to the *Sporhase* legislation. The case revolutionized legislation regarding the transportation of water interstate by making it subject to the negative commerce clause. Furthermore, a number of western states have re-examined their current legislation regarding the transportation of water interstate. New Mexico now no longer pursues the reciprocity clause, but interestingly has undertaken to use the market-participation exemption, which allows the state "to favour residents over nonresidents",[140] another attempt to protect the gains of a progressive water-management policy framework.

The Pecos River Compact was the result of development in Texas and New Mexico, which led to water conflicts because there was not enough water. As with many other water conflicts on the High Plains and elsewhere, the different forms of legislation from state to state and even county to county cannot co-exists harmoniously because there are no established rules or provisions to monitor water-related activities (or even non-water related activities that could impinge upon the integrity of the groundwater resource), and there are few if any enforcement mechanisms to deal with individuals, businesses, or governmental authorities, who do not comply with the incomplete and even contradictory legislation as it currently stands. Because of the disharmony, the only

140. Douglas L. Grant. Commerce Clause Limits," 15.

recourse for resolving conflicts is through the court system, which, unfortunately, is bound by precedent, which often is quite simply out-dated and entirely incompatible with both the current exploitation conditions and those of the larger environment.

Chapter 3

The cases described in the previous chapter are just a small example of the water conflicts that occur between neighbours, counties and states, which are resolved by costly, time consuming legislation based on precedent. Based on common law, precedent is a legal system that utilizes previous rulings when deciding subsequent cases with similar issues or facts, and those precedents can sometimes be over a century old. Despite the obvious stagnation in the legal system, changes regarding water usage have occurred that may potentially have an effect on prolonging the life of the Ogallala aquifer, though not, unfortunately, on the resolution of conflict through the litigation process. The challenge is to identify and cultivate those practices which seek to exploit the groundwater resources sustainably and equitably, and to attenuate those which do not. Of potentially greater difficulty is the challenge of tackling the *mindset* that underpins unsustainable use of the aquifer's water: the twin attitudes of first-use rights and "use it or lose it" are, without doubt tremendously important factors contributing to the current patterns of overexploitation.

As previously discussed, the introduction of the center-pivot irrigation system in the early 1950's revolutionized crop irrigation, but to the detriment of the aquifer, as it is being mined as if it were an infinite resource. Opie has described in some detail the effects that center-pivot irrigation had on water usage. Initially, when center-pivot irrigation was first installed in the late 1950's, farmers found that they "pumped 20 percent less water"[141] than when they used furrow irrigation, but because the center-pivot irrigation system sprayed water in a fine mist into the air, as much as "50 percent of the

141. Opie, *Ogallala, Water for Dry Land*, 234.

water"[142] was lost due to dry, hot, and windy weather through evaporation before it even reached the crops. The unsuitability of the High Plains for agriculture, even habitation, has been expressed since the 16th century, and the unsustainable use of the Ogallala aquifer has been evident since the 1950's, however, in the last few decades there has been a change in attitudes, but not by all, towards improvements in irrigation technology that wastes less water between the well and the plants. This change did not occur without some major encouragement however.

In 1984, a mid-term report of a ten-year study of the Ogallala aquifer was presented at a meeting at Texas Tech University aimed at conserving the Ogallala aquifer. Ed Guttentag and John Weeks, the geologists who prepared the report, compiled a Regional Aquifer-System Analysis (RASA) by gathering data on "more than twenty thousand wells".[143] The study ignored political and watershed boundaries and looked at the aquifer in its physical entirety. Guttentag and Weeks created three interconnected computer models, which produced an alarming picture. The report predicted a devastating declining water table that would dramatically "drop in the acreage irrigated by each well".[144] The authors predicted that the area irrigable by the diminished supply of water would consequently fall by 50 percent in less than thirty years. Despite the emerging abundance of evidence and scientific data confirming, and warning, of the unprecedented withdrawal of water for the Ogallala aquifer, and the effect that droughts will have on the water table, federal policy makers still treat the idea of drought as "an

142. Opie, *Ogallala, Water for Dry Land*, 234.
143. Ashworth, *Ogallala Blue*, 154. The data consisted of historical accounts, previous geological studies, driller's logs and water-level data from stream gauges and spring-flow measurements, weather and climate records and LANDSAT images
144. Ashworth, *Ogallala Blue*, 155.

anomaly",[145] despite the Dust Bowl in the 1930's, of the 1988, and the current drought that has continued since 2011.

However, the findings in the Guttentag and Weeks report were widely accepted, mainly because it was no longer possible to deny the unsustainability of then-current practices. Irrigation sprinklers that used to spray water into the air above the plants have, in many cases, been replaced with sprinkler nozzles at the end of tubes that place water at the base of the crop, reducing evapotranspiration. This new practice did not just come about because individuals wanted to do what was best for the aquifer however. As the aquifer's water level declined well yields also declined, producing overall reductions in water pressure in sprinkler systems. A high capacity sprinkler system requires "fifty to one hundred pounds per square inch [whereas] drop tubes can get by on ten to fifteen".[146] Subsurface drip irrigation (SDI) is another more sustainable irrigation system. This system "supplies water directly to the crop root-zone via buried polyethylene drip lines",[147] and if it is installed correctly, the system has the potential to be the "most efficient irrigation system available today".[148] While these systems may be more water efficient, they are often management intensive and costly. However, if the cost of producing sustainable produce was passed on to the consumers in the form of higher prices, then this would help alleviate the initial expenditure to install sustainable practices.

145. Opie, *Ogallala, Water for Dry Land*, 228.
146. Ashworth, *Ogallala Blue*, 163.
147. Suat Irmak, A Brief Research Update on Subsurface Drip Irrigation, University of Nebraska-Lincoln, 1. accessed: 2 January 2015. http://water.unl.edu/
148. Suat Irmak, "A brief Research Update on Subsurface Drip Irrigation," 2.

Microclimate technology is the installation of windbreaks, such as hedgerows, that helps to produce a microclimate near plants and protects them from damaging wind and cold conditions. They are also physical barriers that help minimize soil erosion. This system is interesting as it is a reversal back to how farming used to be done. Prior to the introduction of center-pivot irrigation windbreakers were often used to protect fields, however, center-pivot irrigation systems need vast, obstacle free land for the irrigation arm to move freely, which required the removal of the natural windbreakers.

Dry land farming is another option that some farmers have taken. Dry land farming is a complex enterprise that includes hard work and often-experienced intuition by the farmer. Dry land farmers "revert back from dependable irrigation to luck with the weather: the right rain at the right time",[149] but this does mean that it is unpredictable. If the prospect of a good crop are not favorable due to the unpredictability of the weather, then a crop will not be planted, or the farmer uses a less water-sensitive crop, such as wheat, canola, sunflowers, or sorghums. Conservation tillage also reduces the amount of water used for irrigation. No-till, or low-till farming uses crop residue to protect the soil, this is achieved through leaving plant litter on the surface, between harvest and the next year's planting, which holds "water in place, reduces evaporation, controls wind and water erosion, and increases organic matter in the soil".[150] No-till farming has many benefits, but there are also a number of arguments against no-till farming, such as unpredictable yields, and the hard work that is involved in seeding crops in heavy stubble. Ironically there is even a psychological reason why no-till farming is not as popular as it could be, American "family farms… [are] still admired as the bearers of

149. Opie, Ogallala, Water for Dry Land, 255.
150. Opie, Ogallala, Water for Dry Land, 256.

basic American values",[151] but the abundance of stubble, weeds and insects on the fields – elements key to the success of no-till farming – gave them an unkempt appearance which seems to be aesthetically offensive to farmers and perhaps the broader community also.

Finally, robotic irrigation is being developed that improves efficiency. Agricultural robotics, once established and after the initial financial outlay, have lower labour costs and can be programed to do re-seeding, weeding, preparing the seedbed, and irrigation. A robotic irrigator can be programmed to apply the optimal amount of water in the right place at the right time, but also has the ability to "irrigate into field corners,[152] unlike the more traditional irrigation systems. However, it is important to remember that none of the more sustainable irrigation practices are legally required. It is a choice individuals make, either by reducing water consumption by the methods already mentioned or changing to crops that require less water. Additionally, there are governmental economic incentives for the conservation of grassland, or even returning agricultural land to grassland, which reduces erosion, however, governmental incentives for the production of corn for example, which needs a lot of water to grow, are far higher than those for grassland, resulting in a simple choice for farmers. This interestingly, displays the economic drivers, such as the monetary donations by lobbyists from agribusinesses, that influence the American governments policies, which do not seem to work in conjunction with the long term well-being of the Ogallala aquifer.

151. Opie, Ogallala, Water for Dry Land, 257.
152. Simon Blackmore, Bill Stout, Maohua Wang, Boris Runov. "Robotic Agriculture – The Future of Agricultural Mechanisation?," 5th European Conference on Precision Agriculture, Uppsala, Sweden, (June 2005): 8.

So far I have discussed the effect of water shortage on crop production and how some farmers are attempting to move to more sustainable practices with the intention of extending the life of the Ogallala aquifer, and, how different levels of water conflict are resolved through the legal system. However, there is another challenge that is already being felt, and will increase in the future, and that is climate change.

It is impossible to regard the High Plains as an isolated entity. Like the rest of the world, the changes in climate that affect the High Plains are inextricably connected to the jet stream, which drives our weather systems by transporting air masses. There is an abundance of literature about global warming and the corresponding change in weather patterns. Mike Blackburn and Tim Woollings discuss different climate models that study the outcome of variations on the movement of the jet stream.[153] While there was some variance between the models, the authors agree that the "poleward shift to the jet stream [is] in response to anthropogenic forces",[154] which may increase the probability of extreme weather events.

Water supply issues are already evident on the High Plains, and will only become more so when "competition between urban development and agriculture increases".[155] A global weather change will have increased negative affects on water resources that may

---

153. Mike Blackburn and Tim Wollings, "The North Atlantic Jet Stream under Climate Change and its Relation to the NOA an EA Patterns," *Journal of Climate*, Vol. 25, (July, 2011): 886.
154. Mike Blackburn and Tim Wollings, "The North Atlantic Jet Stream under Climate Change and its Relation to the NAO and EA Patterns," *Journal of Climate,* Vol. 25, (July, 2011): 886.
155. Dennis Ojima, Luis Garcia, E. Elgaali, Kathleen Miller, Timothy G .F. Kittel, and Jill Lackett, "Potential Climate Change Impacts on Water Resources in the Great Plain," *Journal of the American Water Resources Association*, Vol. 35, No. 6, (Dec., 1999), accessed: 12 January 2015, 1444. Note: The High Plains, the region the Ogallala aquifer occupies, is part of the Great Plains Physiographic province, which, in America, ranges from the northern border with Canada to the southern Texas, at the Mexican border.

result in increased extreme events such as droughts and floods. Increased regional temperatures are already apparent. The warming "trend for the last 30-year period is roughly three time that for the past 100 years as a whole",[156]and in the northern region of the High Plains the "average winter temperatures rises to 7 [degrees celsius] above historical averages",[157]and models predict that this figure will increase. Precipitation will also affect the distribution of precipitation, which in turn will affect the recharge rate of the Ogallala aquifer.

The value of groundwater, in terms of both economic and human welfare is incalculable, but the effect that climate change will have on the Ogallala aquifer will "profoundly affect the accessibility and reliability of water supplies",[158] which produces "$20 billion [dollars] worth of food and fiber"[159] per year. Rosenberg et. al. discuss the estimated water yield and recharge rate under three different general circulation model (GCM) experiments. All three GCM's indicate that the High Plains will experience significantly warmer temperatures, with varying precipitation patterns. Rosenberg et.al concludes that "climate change forced by global warming will make mining of the

---

156. Kevin Hiscock and Yu Tanaka, "Potential Impacts of Climate Change on groundwater resources: From the High Plains of the U.S. to the Flatlands of the U.K., Paper presented at the National Hydrology Seminar, (2006): 19.
157. United states Environment Protection Agency, Great Plains, last updated: 9/9/2013, accessed: 11 January 2015. http://www.epa.gov/climatechange/impacts-adaptation/greatplains.html
158. Norman J. Rosenberg, Daniel J. Epstein, David Wang, Lance Vail, Raghavan Srinivasan and Jeffery G. Arnold. "Possible Impact of Global Warming on the Hydrology of the Ogallala Aquifer Region", *Climate Change*, Issue: 4, Volume: 42, (August 1999), accessed: 11 January 2015. http://link.springer.com/article/10.1023%2FA%3A1005424003553
159. Braxton, "Saving the Ogallala Aquifer," 6.

Ogallala aquifer's water even less sustainable than it is now".[160] Ojima et. al. have also produced an interesting study of the effect of climate change on the High Plains.

Like Hiscock and Yanaka, Ojima et.al. discuss the rise in temperature over the last 100 years as being "1.8 to 3.6F (1-2 degrees)"[161] up to 1997. They also predict that annual average temperatures will continue to increase with global warming along with annual precipitation, but the increase is not uniform. In Colorado and Wyoming, Ojima et. al predict a rise of " 7.2 F (4 degree) increase … for the winter period at the end of [this] century",[162] along with the possible change of precipitation during the winter. As previously discussed, the High Plains region is one of the largest and most productive agricultural regions in America, but the allocation and control of the available water is dependent on social, political and economic means. Climate change is going to exacerbate the already tense and often confusing and conflicting water management practices among the eight states that overlie the Ogallala aquifer. Water quality is another important issue. The Ogallala aquifer provides drinking water for "more than 80% of the population"[163] of the region, and salinity management will need to be implemented. Also, the increase and affect in the "numbers and types of pests"[164] are additional issues that will need to be addressed with climate change.

---

160. Rosenberg et. al. "Possible Impacts of Global Warming on the Hydrology of the Ogallala Aquifer Region", 690.
161. Dennis Ojima et. al. "Potential Climate Change impacts on Water Resources in the Greta Plains," 1447.
162. Ojima et. al. "Potential Climate Change Impacts on Water Resources in the Great Plains", 1447.
163. Great Plains, http://www.epa.gov/climatechange/impacts-adaptation/greatplains.html
164. Ojima et. al. "Potential Climate Change Impacts on Water Resources in the Great Plains", 1452.

Climate change models very strongly predict the general changes that are expected as a result of changes in the earth's atmospheric chemistry. At a more regional level, however, the particularities of climate change impacts are less certain. Due to this lack of clarity it is impossible to tell the character and severity of particular effects. For example, Nebraska overlies about "just over one-third of the Ogallala's total land area, but it has nearly two-thirds of the water",[165] and the state has the deepest saturated thickness. Whereas Texas, in the southern region of the aquifer, has around "12 percent of [the aquifer's] water",[166] and due to aggressive groundwater pumping has a water table that decrease "one to two feet each year".[167] The effects of climate change will be different in each state. Texas already faces water shortage, but this problem will be exacerbated with climate change and they will feel the negative effects before Nebraska, which is situated over the northern portion of the aquifer that has more water in storage.

The possible consequences of future drier conditions can also, interestingly, affect the total annual precipitation in a region. Ojima et. al. discuss the possible changes in wintertime precipitation and how this would "greatly modify the amount and timing of snow-melt from the Rocky Mountains".[168] The fluctuation in temperature change between night and day may increase evaporation and precipitation, so "the hydrological cycle may also be affected, resulting in more intensive convective storm activity",[169] which can affect water quality and the supply of water. The dire consequences of the

165. Ashworth, *Ogallala Blue*, 25.
166. Ashworth, *Ogallala Blue*, 23.
167. Ashworth, *Ogallala Blue*, 23.
168. Ojima et.al. "Potential Climate Change on Water Resources in the Great Plains," 1447.
169. Ojima et. al. "Potential Climate Change in Water Resources in the Great Plains," 1447.

effects of climate change have been discussed and analyzed, producing a wealth of extensive literature that predicts the general outlines of climate change impacts on the High Plains, and does so with a high degree of confidence. In the face of these predictions, what should be done, and what can be done, within current political, legal, social, cultural, and economic constraints, to generate a more sustainable future for the communities that call the High Plains home? Or are those constraints exacerbators of the problem; only when they are broken can meaningful change toward sustainability be made?

One problem in resolving groundwater depletion is farm, or agricultural subsidies. Since the Great Depression of the 1930's, American farmers have benefited from a "medley of subsidies and support programs",[170] introduced with the intention of keeping the farmers farming, stabilizing crop prices and providing the country with a reliable domestic supply of food. However, the program has tended to concentrate support on farmers of only a few particular crops; wheat, soybeans, rice, cotton and corn, which certainly are important crops, but which are consequently overproduced often to the detriment of the production of other crops, such as fruit and vegetables. Farming is risky, not only because of droughts and water shortage, but also due to disease and insects. Farm subsidies take some of the risk out of farming, but by having subsidies, farmers are protected from losses and price drops meaning that certain crops are much lower-risk propositions. Corn subsidies in particular are a huge business in the United States, and

170. Scott Fields, US National Library of Medicine, National Institutes of Health. "The Fat of the Land: Do Agricultural Subsidies Foster Poor Health?", (Oct. 2004), accessed: 17 January 2015. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1247588/

have totalled "$84.4 billion from 1995 – 2012",[171] with a greater number of recipients than any other subsidy program.

There is abundant literature regarding the use of high fructose corn syrup, a product of corn that was introduced in the early 1980's in to a huge variety of food and drink produced in the United States, and the effect consumption of the product has on the American people. Additionally, corn ethanol that is used as a biofuel and mainly used in gasoline, is a big business. The value since 2011 is "$392 million in revenue from corn oil",[172] which demonstrates the importance placed on corn production. However, there are additional problems that arise from corn subsidies, chief among which is the overabundance of cheap corn which is used as cattle feed, with consequent negative environmental effects.

Since the 1950's, America's beef cattle have been fed on corn rather than grass. Cattle raised on corn reach maturity earlier and therefore are ready for slaughter in "fourteen to sixteen months",[173] compared to grass fed cattle that take two to three years to reach maturity. The cattle industry is designed to take advantage of the overabundance of corn that is generated by subsidized agriculture. While the benefit of cheap beef is obvious for the American people, there are many environmental costs of its production and consumption as well. For example, it takes about "108 gallons of water to produce

171. EWG Farm Subsidies, "Corn Subsidies", accessed: 17 January 2015, http://farm.ewg.org/progdetail.php?fips=00000&progcode=corn
172. Ethanol Producer Magazine, "Corn Oil Make the Grade," accessed: 18 January 2015. http://www.ethanolproducer.com/articles/9755/corn-oil-makes-the-grade
173. Michael Pollan. The Omnivore's Dilema, A Natural History of Four Meals. New York: The Penguin Press, 2006. 71

one pound of corn",[174] but when you factor in the amount of water, for cleaning, processing and consumption, to produce one pound of beef, around "1,800 gallons of water"[175] is required per *pound*. In addition to the huge amount of water required to produce beef cattle, very high levels of phosphorous, nitrogen and chemicals are generated in industrialized feedlots that pollute groundwater through infiltration, and the build-up of methane, of which a single cow can "produce between 250 and 500 liters"[176] each day, and which is a greenhouse gas roughly eight times as potent as carbon dioxide. The current cattle industry, and the harmful environmental effects that stem from it, could not have been developed in the absence of cheap corn, the overabundance of which was, in turn, the result of corn subsidies.

Ideally, the cultivation of thirsty crops that require abundant irrigation would be decreased, to be replaced by crops that can be produced with less water and in a more sustainable way. As noted previously, there is an abundance of evidence and analysis that clearly indicates the Ogallala aquifer is being mined as though it was a renewable resource, and the only way High Plains agriculture can continue to be productive into the future is if sustainable methods of irrigation are used that reduce water consumption. However, based on the tremendous amount of revenue that is raised in the United States just from the production of corn and its products, the reduction of subsidies on certain crops that would allow for the promotion of different crops that require less water for

---

174. Grace Communications Foundation. The Water Footprint of Food. Accessed: 20 February 2015. http://www.gracelinks.org/1361/the-water-footprint-of-food
175. Grace Communications Foundation. The Water Footprint of Food. Accessed: 20 February 2015. http://www.gracelinks.org/1361/the-water-footprint-of-food
176. International Business Times. Cow Farts have 'Larger Greenhouse Gas Impact' than previously thought" Methane pushes Climate Change. Philip Ross. 26 November 2013. Accessed: 20 February 2015. http://www.ibtimes.com/cow-farts-have-larger-greenhouse-gas-impact-previously-thought-methane-pushes-climate-change-1487502

irrigation seems very unlikely to occur. The few particular products that are now being produced unsustainably, and with serious negative consequences to the environment and the health of American population, appear to have more importance to policy makers than safe guarding a natural fresh water supply for future agricultural production for future generations. Basically, decisions are being made today are what is deemed to be what is best for the present, rather than what is best for the future.

High Plains agriculture relies extensively on groundwater irrigation for its fertility, which means that Ogallala water underpins the entire economy of the region. The industrialization of agriculture that is the result of the introduction of center-pivot irrigation in the early 1950's, means that the American farming system measures success in "maximum yields and immediate profits",[177] which makes the transition to sustainable irrigation very unlikely indeed. The environmental benefits of sustainable irrigation have already been discussed at length, and there is documented evidence that confirms sustainable agriculture and irrigation can be productive and "not be less profitable than conventional agriculture".[178] Additional research into irrigation technology and biotechnology has also produced promising results.

Similar to subsurface drip irrigation (SDI), Low energy precision application (LEPA) irrigation systems can significantly increase water use efficiency and therefore "decrease the amount of water needed to produce a crop",[179] but combined with

177. Opie, *Ogallala Blue*, 10.
178. Opie, *Ogallala Blue*, 11.
179. Talah S. Arabiyat, Eduardo Segarra, and David B. Willis. "Sophisticated Irrigation Technology and Biotechnology Adoption: Impact on Ground Water Conservation," *AgBioForum*, Vol. 2, No. 2, (1999): 132.

biotechnology[180] the efficiency is increased still further. A case study by Arabiyat et. al. in Texas has shown that the joint adoption of LEPA and biotechnology reduces groundwater use by 31.37 percent while increasing the net present value of return by 65.59 percent per acre.[181] The adoption of both these technologies would, according to the study, "eliminate the overdraft of the aquifer"[182] in that specific location.

However, despite the evidence that sustainable irrigation can produce crops in quantity similar to older, more extensive methods of irrigation, farmers only change irrigation practices by choice. An interesting example is in Texas, where particular water districts are now restricting groundwater withdrawals from the aquifer. But this raises a legal conundrum; how will this affect a landowner's right based on the rule of capture, as the landowner owns the water beneath his property and "has the right to pump as much water as he wishes"?[183] In a similar way to farming subsidies, unless a farmer is socially conscious and is concerned enough to want to decrease water consumption, there are no legal means to compel them to behave otherwise.

It is important to remember however, that although sustainable irrigation is a good route to take for conserving water and needs to be more widespread, good management

---

180. Biotechnology: is technology based on biology. Biotechnology is a collection of scientific techniques used to improve plants, animals and microorganisms. Based on the understanding of DNA, scientists develop solutions to increase agricultural productivity. Farmers have been improving wild plants and animals through the selection and breeding of desirable characteristics for about 10,000 years.

181. Arabiyat et. al. "Sophisticated Irrigation Technology and Biotechnological Adoption," 135.

182. Arabiyat et. al. "Sophisticated Irrigation Technology and Biotechnological Adoption," 135.

183. Texas A&M Agrilife Extension, "Texas Water: Basics of Groundwater Law", http://agrilife.org/texasaglaw/2013/10/22/texas-water-basics-of-groundwater-law/

practices in conjunction with an independent body that regulates and resolves issues is also needed to effectively manage water consumption and groundwater depletion.

The International Joint Commission is a good model that could be transferred to the protection and management of groundwater. The International Joint Commission (IJP) is an independent organization created and maintained jointly by the United States and Canada. It was formed in 1909 to help prevent and resolve issues of quality and use of water shared by the two countries,[184] and has been successful in mediating transboundry disputes to a successful conclusion. As previously discussed, in the United States, groundwater laws are governed by legislation at the state level, not by the federal government, and the only method for resolving water rights issues between individuals or states is through the court system.

An inter-state authoritative entity is needed that has no connection to the government, that can resolve the numerous issues that arise from any aspect of water rights within the eight states that overlie the Ogallala aquifer. The entity would focus on the aquifer as a single natural resource, that would agree on the current status of the aquifer, such as capacity and draw down rate, and would work towards sustainable use based on the current figures. Such an entity would need to bridge the gap between the often confusing and conflicting legislative frameworks, while at the same time enable different parties that are involved in water conflicts to work together in a participatory way to resolve issues. There would also need to be enforcement mechanisms in place for those that do not comply. Another tool for dealing with water conflicts are compacts, such as the previously discussed Pecos River Compact, but they usually come about after

---

184. Specifically the Great Lakes, Superior, Michigan, Huron and Ontario, which form the largest group of freshwater lakes on earth

a conflict has arisen. However, if compacts between states or countries were already in place, the agreed water allocation would already be established. While compacts do not insure against any additional conflicts, the ability to negotiate, discuss and resolve any issue by compact is favourable compared to costly and time consuming legal battles in court.

An inter-state entity that uses a holistic approach to managing the many different aspects of groundwater does seem to be a sensible alternative and a reasonable policy direction to go in. It could also work for other locations that experience similar situations, such as in California and Florida. However, the biggest and maybe the most important and difficult task would be to overhaul and implement water rights legislation that reaches across political boundaries such as state lines, that everyone, from the small scale farmers to the large industrialized agricultural and livestock farmers, acknowledge. This certainly seems a daunting and perhaps impossible task considering the existing situation, and how the current mentality favours exploitation of resources for financial gain today, rather than planning and extending resources for generations in the future. Obviously, there would be objections to an inter-state authoritative entity, for example, from farmers who practice the 'first in use' water policy. But there would also be an ethical question. Current legislations and policies allow irrigation water users to make beneficial use of the Ogallala aquifer. Is it possible to have policies that require farmers and landowners to restrict their groundwater usage now, to protect the water supply for future generations, without any form of compensation? But if compensation is required, then surely the taxpayers will be 'losing out'.

Despite the often-demonstrable reluctance among farmers to switch to more sustainable irrigation practices, there are numerous examples that have been successful; these stories provide hope for the future of the Ogallala aquifer. The motivation for change in irrigation methods varies. The most common reason is necessity, which is expressed very clearly when groundwater management professionals state, "if we lose the Ogallala aquifer, the decimation of farms will be tremendous".[185]As the Ogallala aquifer decreases due to over pumping the water table lowers, which can result in the decline of the "rate of water the well can yield",[186] which in turn produces higher operating costs as the water needs to be pumped higher to reach the land surface.

Another reason is economic: despite the current decrease in oil prices, fuel costs for irrigation systems generally increase and will probably continue to do so in the future. As the cost of pumping specific amounts of groundwater increases farmers will look to alterative, more cost effective irrigation systems to protect and maintain their livelihood. In some instances counties have implemented withdrawal restrictions, such as in Texas, which does force farmers to change irrigation practices, but there tends to be financing available to mitigate the impact of the transition. Finally, the most ethical reason is because changing to sustainable irrigation is the right thing to do, but this is not usually the dominant reason farmers change their groundwater consumption. Many of these decisions are local, and usually made by individual farmers. Although small in scale they

185. Kansas group advocates fro aqueduct from Missouri River. "Midwest Producer", 21 January 2015. Accessed: 14 February 2015. http://www.midwestproducer.com/news/regional/kansas-group-advocates-for-aqueduct-from-missouri-river/articlecce

186. USGA, Science for a Changing World. "The USGS Water Science School," last modified: 17 March 2014, accessed: 27 January 2015. http://water.usgs.gov/edu/gwdepletion.html

do suggest ways forward to an environment of high-efficiency, low-impact water usage, and they are therefore worth a brief review.

In Nebraska, a corn and soybean farmer outside Lexington changed his irrigation system to subsurface drip irrigation (SDI), despite the initial higher installation costs in comparison to center pivot irrigation, and has improved his "watering efficiency by 35%".[187] At the same time he practices no-till farming which helps to retain moisture received via precipitation. A farmer near Lubbock, Texas, switched to drip irrigation in 1984, for his 317-acre farm despite the initial expensive outlay. The method is like "spoon-feed[ing] a crop",[188] which considerably reduces the amount of water wasted, and the well levels on the farmer's property "have remained nearly constant for several years".[189]

Farmers in the Texas Panhandle have started to plant corn later in the season thereby intending to "tap the summer rain".[190] The change coincides with a policy change instituted by groundwater authorities, restricting access to a certain limit. This in turn has motivated farmers to explore new technologies, such as soil sensors, along with new farming techniques such as the later planting dates. The intent is to determine which practices are most likely to succeed with "less water while still remaining profitable".[191]

---

187. Corn+Soybean Digest. "Switch to Drip Irrigation," (Feb., 1, 2013), accessed: 24 January 2015, http://cornandsoybeandigest.com/equipment/switch-drip-irrigation
188. Opie, *Ogallala Blue*, 235.
189. Opie, *Ogallala Blue*, 235.
190. Environmental Leader, Environmental & Energy Management News. "Drought-Hit Farmers Explore New Irrigation Methods," (July 3, 2013), accessed: 26 January 2015. http://www.environmentalleader.com/2013/07/03/drought-hit-farmers-explore-new-irrigation-methods/
191. Environmental Leader, Environmental & Energy Management News. "Drought-Hit Farmers Explore New Irrigation Methods," (July 3, 2013), accessed: 26 January 2015.

Policy changes are also being implemented with the intention of delaying aquifer depletion. The town of Hays in Kansas has implemented a 50-year water vision, to sustain its dwindling supply of groundwater by "balancing short-term economic interests with long-term sustainability",[192] there is enthusiasm for the plan but also indifference, with some farmers thinking "it's too little, too late"[193] to try to conserve the aquifer. These policy changes and changes in irrigation practices are vital for the survival of the Ogallala aquifer and the future of agricultural business on the High Plains, but they are even more crucial because of the increasing drought conditions affecting an already naturally arid landscape.

Drought does not uniformly and continuously spread across a region. As an example, the continued drought conditions on the High Plains in Spring 2014 initially contracted due to "above-normal rainfall during the summer",[194] but abnormal dryness during the rest of the year caused the drought to progress from an extreme drought to an exceptional drought.[195] According to the United States Drought Monitor, in January 2015 the southern regions of the High Plains, specifically Texas and Oklahoma, were suffering from long term droughts between the D3 and D4 range, which is the highest intensity on

---

http://www.environmentalleader.com/2013/07/03/drought-hit-farmers-explore-new-irrigation-methods/

192. Kansas Plan to Conserve Water looks to combine Carrots and Sticks. "Kansas City Public Media", 13 January 2015. Accessed: 13 February 2015. http://kcur.org/post/kansas-plan-conserve-water-looks-combine-carrots-and-sticks

193. Water plan tackles critical issue of supply, demand. The Hays Daily News, Andy Marso, 18 January 2015. Accessed: 13 February 2015. http://hdnews.net/news/waterkhi011815

194. NOAA, National Climatic Data Center, "State of the climate: Drought for Annual 2014," accessed: 28 January 2015. http://www.ncdc.noaa.gov/sotc/drought/

195. Droughts are measured on a scale, similar to the Fujita scale for Tornado intensity. The Drought Monitor Scale ranges from D0: abnormally dry, to the highest level D4 – Drought: exceptional dry

the U.S. drought Monitoring Scale, with temperatures "up to 20 degrees Fahrenheit above normal level over the High Plains".[196] People are not ignorant of the drought, as made evident by numerous eye-catching headings in newspapers, such as the Naturel News headline in July 2014, "The vital Ogallala Aquifer is drying up, putting billions of people at risk", and The Washington Post headline in September 2013, "How long before the Great Plains run out of water"?. One study describes the situation as a "megadrought, [because the] drought severity [is] outside the bounds of what's thought to have occurred over the past 1,000 years",[197] which can have severe consequences for agriculture and settlement patterns within the affected region. The effect of droughts on groundwater resources represents an additional strain on the already high, and growing, demand for water in the High Plains, a demand driven not only by agriculture but to urban migration, population increase and economic growth. The unpredictability of climate change will only serve to exacerbate these effects.

---

196. United States Drought Monitor. "U.S. Drought Monitor, January 27, 2015," accessed: 29 January 2015. http://droughtmonitor.unl.edu/

197. The United States of Megadrought, If you think that California is dry now, wait till the 2050's, "Future Tense, Slate", Eric Holthaus, 12 February 2015, accessed: 14 February 2015. http://www.slate.com/articles/technology/future_tense/2015/02/study_climate_change_may_bring_about_megadroughts_this_century.html

Conclusion

It is no mere truism to state that water is life. Millions of years ago, geological activity in what would become the High Plains of the United States, created the natural marvel of the fertile plains and Ogallala aquifer. The aquifer underlies 174,000 square miles of the territory of eight states, and has provided the fresh water required to sustain life, and agricultural and economic stability for the country.

As ambitious white European settlers expanded westwards they encountered different climate and often inhospitable terrain, but also unusually fertile soil, which encouraged settlers to establish farms on land they saw as theirs by right. Historically, farmers were constrained by water scarcity, with the early farmers settling near the life-giving rivers and springs, however, the apparent abundance of groundwater was well known among the settlers, if they could only access this resource. Agricultural irrigation on the High Plains was on a small scale until the advent of center-pivot irrigation in the early 1950's. The incredible increase in water extraction from the aquifer transformed the landscape from one of parched brown earth, the poorest farming region in the United States, to one of the wealthiest agricultural regions in the country, with green irrigation circles spreading out to the horizon.

The importance of the Ogallala aquifer cannot be understated. The water extracted from the aquifer underpins a major portion of the United States' agricultural and beef industry productivity, a productivity that supplies both domestic and international markets. Furthermore, the aquifer provides the majority of the High Plains residents with fresh drinking water, municipal water, and water for industrial use. The increased use of groundwater that provides the backbone to life on the High Plains has resulted in conflict between neighbours, counties and states, which has increased in inverse proportion to the groundwater available from the aquifer. Water conflicts that arise often intensify due to the interminable, and often-conflicting water rights legislation between different states.

Why then, have there been such intense and diverse disputes over water? In short, it is because water conflict occurs because the basic doctrines that form the basis for groundwater legislation are not compatible. The most common is the law of appropriation, which is used in South Dakota, Kansas, Colorado, New Mexico and Wyoming. This allows for the landowners to receive priority based on the date their well was drilled and registered. This process may seem fair at first, however problems arose when latecomers either receive little or no groundwater during a water shortage period, such as droughts, and landowners that drilled their wells earlier are able to continue extracting water unchecked. Correlative Rights and Reasonable Use doctrines are similar and are used in Nebraska and Oklahoma. They allow landowners to drill wells and extract groundwater for beneficial purposes and as long as the result does not damage other wells of the aquifer system. Finally, Rule of Capture, used in Texas, is the most controversial doctrine. This allows the landowners to pump as much water as they want with very little restrictions, even at the expense of their neighbours. These four water rights doctrines were established in the eight different states from the early 20th century to within the last forty years. Conflict arises within states, but also between states, and currently the only method of resolving conflict is through the courts, which can be a lengthy and costly process.

A large amount of literature has been produced concerning the Ogallala aquifer and the causes and consequences of groundwater mining. Faced with the abundance of disturbing evidence, and also a change in people's mindset, more sustainable agricultural and irrigation processes have begun to be adopted over the last thirty years. Center-pivot irrigation systems are still in use, but the acreage that they cover has decreased as sustainable systems are put into practice. Subsurface drip irrigation, low energy precision application, robotic irrigation, dry land farming, and no-till farming are examples of new farming and irrigation methods. Unfortunately, installation of new irrigation systems is often costly and time consuming, and there is the added psychological obstacle that apparently unkempt, weedy farmland seems to be offensive to American farmers' sensibilities. Despite these changes in local attitudes and activities in relation to the aquifer, there are broader, more systemic factors that exacerbate the problem of groundwater depletion on the High Plains.

American farmers have benefited from farming subsidies since the Dust Bowl in the 1930's, with the intent of keeping farmers farming and guaranteeing protections on certain crops. However, corn subsidies receive the highest monetary amount and are received by the highest numbers of recipients. But growing corn requires a large amount of water compared to other crops. Ideally, subsidies should be distributed to farmers who produce crops that require less water, and that form part of a healthy diet, such as fruit and vegetables, and not to crops that are processed into foodstuffs that contribute to health crises such as obesity or diabetes. Nor should farming that has an obviously negative impact on the environment, such as huge-scale cattle-ranching operations on the High Plains, be heavily subsidised as a matter of general policy. Changing the way subsidies are distributed to prioritize more sustainable crops seems very unlikely, however, at least in the current economic and political climate in the United States. The revenue that is derived from corn products is huge. In 2014, the revenue from corn farming was $63 billion dollars[198], up $2 billion from the previous year. With this amount of revenue, agribusinesses would fight against any legislation that would affect their profits negatively.

An inter-state authority that focuses on the Ogallala aquifer as a single natural resource would be a sensible method to govern groundwater usage and conflicts. It would provide the tools to resolve conflicts in a participatory manner and have enforcement mechanisms in place. The biggest challenge would be to overhaul and implement water rights legislation that reaches across political boundaries such as state lines, that everyone, from the small scale farmers to the large industrialized agricultural and livestock farmers, acknowledge. However, given the current conditions of the aquifer, the existing agricultural practices and the unpredictable changes due to climate change, an inter-state entity could work, if people are willing to make it work.

Aquifers are crucial in providing freshwater all over the world. Yet because we cannot see them, they are invisible to us, we do not see the depletion of aquifers as a threat, like we would when rivers run dry. The Ogallala aquifer is a critical natural groundwater resource to the High Plains of the United States and its importance, and mounting crisis cannot be overstated. The resource has played an important role in shaping America's agricultural production and therefore America's economy.

However, people are mining the aquifer as though it is a sustainable resource, despite the knowledge and scientific evidence that there is no or very little recharge

198. Revenue of Corn Farming (NIACS 11115) in the United States from 2009 to 2014 (in billion U.S. dollars). The Statistics Portal. Accessed: 7 February 2015. http://www.statista.com/statistics/296374/revenue-corn-farming-in-the-us/

capability, once the fossil water is gone, it is gone for centuries. The aquifer's health is variable as the water is distributed unevenly, depending on the location. In some areas the aquifer has already decreased below the minimum depth for large-scale irrigation, and crop yields are decreasing, in other areas, irrigation is no longer possible. But farming is not going to go away. It is the backbone of American culture and the tendency is to overproduce agricultural supplies, because technology has physically enabled us to do so. These practices must change for many reasons, but also because ethically it is the right thing to do. Implementing sustainable agricultural practices uniformly across the High Plains will extend the longevity of the aquifer, and allow future generations inhabiting the High Plains the ability to have access to the fresh, fossil water, of the Ogallala aquifer.

The wide-open expanse of the High Plains was not only inviting to the first wave of white settlers, but also deemed as their destiny, as their God-given right to expand their civilization westwards. Despite the semi-arid climate, and the native inhabitants that had existed on the High Plains for millennia, white settlers were determined to take advantage of the unusually fertile soil; they established ranches, then family farms, and eventually industrial-scale agriculture that covers the landscape today. However, only the most basic of agriculture, carried out by widely scattered communities, would have been possible without the presence of the Ogallala aquifer.

As we have seen, the Ogallala aquifer is a geological marvel which lies underneath eight of the High Plains states, encompassing an area of roughly174,000 square miles. An unconfined aquifer that was formed between two and six million years ago, the Ogallala brings life to the High Plains region through its slowly accumulated reserve of non-renewable fossil water. The gift of that water is being used profligately and in an entirely unsustainable manner, and current legislative frameworks are simply incapable of resolving the many different forms of conflict that arise over the water's use. As the resource dwindles, those conflicts are likely to increase in number and severity, and the legal incapability will only deepen.

In several of the High Plains states water rights legislation was implemented over a century ago. Water rights legislation in America originated from English common law. Initially, water rights legislation was limited to the access and navigation of surface waters, as there was only limited knowledge at the time of subsurface hydrogeology, including water movement and recharge rates. As questions and conflicts arose pertaining to groundwater, individual states began to address the issue by establishing groundwater legislation, which is vital in governing groundwater sustainably. At the time, these laws were thought to be efficient and made sense, although the different types of legislation concerning water usage of the Ogallala aquifer tended to be rather piecemeal and frequently contradictory between states. Subsequently the contradictions and even incoherence of water rights legislation across the High Plains has served as a block to the development of broadly sustainable policies governing the use of the Ogallala water. But this problem is exacerbated by other economic policies that in fact drive water use even further in unsustainable directions.

Agricultural subsidies were introduced in the 1930's as a method of keeping farmers farming, stabilizing crop prices and providing the country with a reliable domestic supply of food. Although the initial intention was to provide help for farmers, the current beneficiaries from agricultural subsidies, especially corn subsidies, are the large international food processing and commodities trading corporations, such as Archer

Daniels Midland and Cargill, whose joint lobbying efforts to influence the government regarding agricultural products, was nearly $3 million in 2014.[199]

Subsidies, unfortunately, produce a wide range of detrimental effects to people and the environment. Due to overproduction of corn, by-products such as high fructose corn syrup have become incorporated into nearly all processed foods, which increase the rate of obesity and diabetes.[200] Another by-product, ethanol, cannot really be classed as an alternative to oil-based fuels, nor does it do anything towards reducing climate change. If America dedicated their entire corn crop to ethanol production, this still would not alleviate the high demand for gasoline. Additionally, to produce more ethanol, cultivation of corn would require more fossil fuels, and water for irrigation. Subsidies do not really benefit the farmer; rather they are welfare programs for agribusiness.

The current practices that govern groundwater from the Ogallala are unsustainable. There is abundant scientific data that confirms the recharge rate and every other factor required to determine the health of the aquifer. The reason the current practices are not working is because the groundwater legislation is out-dated, and the policies that affect every aspect of groundwater use have been put in place for economic, political, or agricultural reasons.

For the health of the aquifer, and for a long-term sustainable future, it is essential that the current groundwater policies be changed, including agricultural policies that affect groundwater usage. This will not be easy, as it requires a fundamental change in

---

199. OpenSecrets, Center for Responsive Politics. "Archer Daniels Midland", "Cargill Inc". Accessed: 28 February 2015. https://www.opensecrets.org/lobby/clientsum.php?id=D000000511, https://www.opensecrets.org/lobby/clientsum.php?id=D000000132

200. *Fed Up* Documentary, 2014. Director: Stephanie Soechtig, Production Company: Atlas Films

long-standing, entrenched policies, and a change in people's mindset. However, a change in mind-set and established practices is not impossible, as can be seen by the decommissioning and intentional destruction of dams in America.

America has built federally funded dams both small and large since the 1820's, for the purpose of hydropower and water storage. However, over the last 30 years there has been a change in the national attitude towards dams as people became aware of the many negative effects they produce,[201] and there has been a number of dam removals, such as on the Elwha River in Washington State, and on the Penobscot River in Maine.[202] If, as a society, a change in mental outlook can result in the destruction of dams after decades in which they were seen as the very hallmarks of progress, then the same can occur with regard to mining of fresh groundwater on the High Plains.

There is a third, crucial reason why change must occur, indeed *will* occur, whether it is a consequence of political change or not: the effects of climate change are beginning to be felt across the United States and, despite the denial of much of the political establishment (and a significant majority of the US population), the evidence of a changing climate is both plain and increasingly real in people's lives. The current severe drought affecting the High Plains and across the Rockies into California is not an unusual occurrence in and of itself, but there is strong scientific evidence that its effects are being exacerbated by climate change and that its severity is deepening rather than relaxing.

---

201. Negative effects of dams include biological, chemical and physical properties, such as reduced river levels, an alteration in water temperature, an alteration in the flow of the river, the decrease in oxygen levels in reservoir waters, holding back silt, nutrients and debris which eliminates their use downstream, blocking often centuries old fish migration routes, and aesthetic effects

202. For a very good documentary of Dam removal, see *Damnation*, 2014, Director: Ben Knight and Travis Rummel. Produced by Felt Soul Media and Stoecker Ecological, Distributed by United People.

That *is* a rarity, and it is stretching the capacity of governments and communities to deal with it. Scientific projections suggest strongly that if climate change is not stalled, by the reduction of anthropogenic greenhouse gas emissions, we can expect "megadroughts,… [which are] probably going to last at least 30 to 35 years".[203] Droughts of this extent have not occurred in North America for over 800 years. The joint effects of climate change and current human activity will have a catastrophic impact on every aspect of life on the High Plains.

The over dependence on the Ogallala aquifer water for irrigation, businesses and the population, is unsustainable. With very little recharge, the aquifer will continue to decrease and in some locations will no longer yield water; in some locations in the South this has already occurred. This will decrease dramatically the historically rich agricultural region's productivity, which will in turn result in the loss of revenue for the country but also a sharp reduction in domestic food supply capacity. Towns, communities, and everyday life for nearly 10 million people[204] will also be affected. People will abandon the region as it returns to semi-aridity, which characterized it prior to the arrival of white settlement, that is if people have the financial means and the opportunity to relocate. As out-migration occurs, services and businesses will become limited, which could have serious impacts for those left behind.

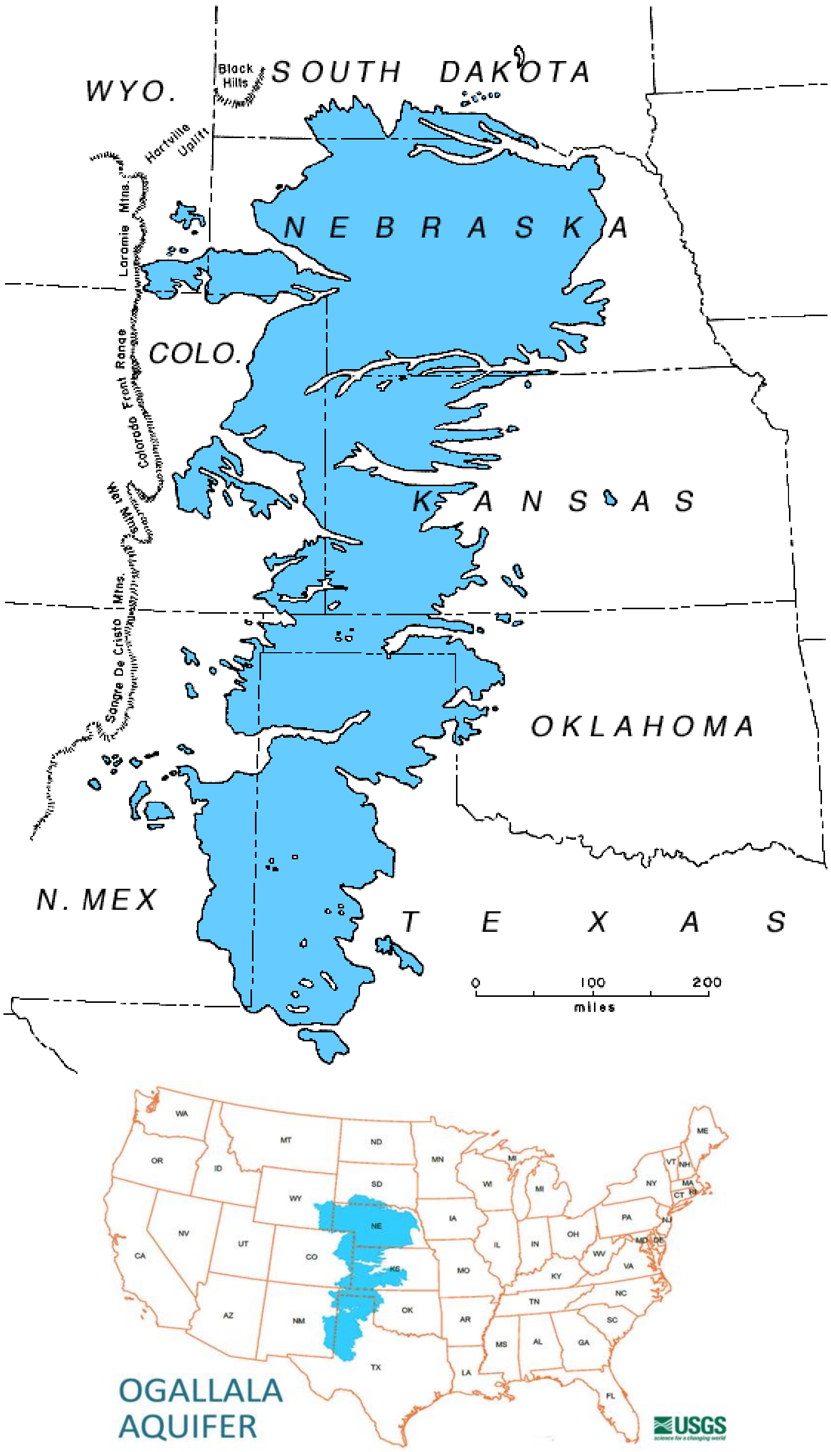
---

203. NASA. "NASA Study Finds Carbon Emissions Could Dramatically Increase Risk of U. S. Megadroughts". 12 February 2015. Accessed: 20 February 2015. http://www.nasa.gov/press/2015/february/nasa-study-finds-carbon-emissions-could-dramatically-increase-risk-of-us/

204. United States Environmental Protection Agency. "Great Plains". Last updated: 9/9/2013. Accessed: 21 February 2015. http://www.epa.gov/climatechange/impacts-adaptation/greatplains.html

We know what needs to be done to protect the incredible natural resource that underlies the High Plains, which ensures the expected American way of life for millions of people. We know that people are capable of changing their mindset and taking action. To have uniform sustainability across on the High Plains, and elsewhere in America, a fundamental change must occur within American society, that will facilitate a revolution in agricultural practices to sustainable methods, and which will require massive changes in American policies, legislation, and even the eating habits of the population. Failing to do so will be nothing short of catastrophic for the High Plains, for the populations that make their lives there, and for the larger population of the United States as a whole.

Image 1: The Ogallala Aquifer



http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/?cid=stelprdb1075336
http://en.wikipedia.org/wiki/File:Ogallala_Aquifer_map.png

Glossary

Acre-foot: the volume of water required to cover 1 acre of land (43,560 square feet) to the depth of 1 foot. Equal to 325,851 gallons or 1,223 cubic meters.

Anastomosis: The connection of two streams that previously branched out.

Anthropogenic: something that is caused or produced by humans.

Drawdown: the lowering of groundwater surface caused by pumping.

Impermeable: a layer of soil material, such as rock or clay, which does not allow water to pass through.

Epeiric sea: an inland, shallow sea that covers central areas of continents during periods of high sea level that results in marine transgressions. In the current geologic timescale, continents are high and the sea levels are low, but one example is the Caspian Sea, located between Europe and Asia.

GMD: Groundwater Management Districts are local units of government in Kansas that provide water-use administration, information and planning.

LEPA: Low Energy Precision Application, an irrigation method that involves applying water below 12 to 18 inches above the ground surface. It reduces energy due to reduced water pressure and increases application effectiveness.

NGVD: National Geodetic Vertical Datum of 1929. A vertical control datum established for vertical control surveying in the United States. It is used to measure elevation (altitude) and depression (depth) below mean sea level.

Non-tributary groundwater: Underground water in an aquifer which is situated so that it neither draws from, or contributes to a natural surface stream in any measurable degree.

Overdraft: Pumping water from a groundwater basin or aquifer in excess of the supply flow into the basin; results in a depletion or "mining' of the groundwater in the basin.

Precipitation: rain, snow, hail, and sleet.

RASA: Regional Aquifer System Analysis, a program of the U.S. Geological Survey that started in 1978 and was completed in 1995. It was designed to define regional geohydrology and establish background information on geology, hydrology, and geochemistry of America's aquifer system, with the purpose of gaining a better understanding of the major groundwater flow systems and to support better management practices of groundwater resources.

Recharge: water added to the aquifer, for example, rainfall that seeps into the ground
Saturated thickness: the saturated depth of an aquifer. For the Ogallala aquifer, an unconfined aquifer, the saturated thickness at any point is the distance from the top of the water table to the bottom of the aquifer. The saturated thickness changes with recharge and discharge (as in pumping water).

SDI: Subsurface Drip Irrigation, an irrigation system for crops through buried plastic tubes containing embedded emitters located at regular intervals. It is efficient and often results in saving water.

Unconfined: an unconfined aquifer receives recharge from ground surface directly above the aquifer. A confined aquifer has soil or bedrock below the land surface, above the aquifer that is impermeable that prevents water from seeping into the aquifer from the ground surface directly above. Instead, water seep into confined aquifers from further away where the impermeable layer doesn't exist.

USGS: United States Geological Survey, a science organisation that provides impartial information on the health of ecosystems and the environment, including natural resources, natural hazards, and impacts of climate and land-use change.

Yield: mass per unit time per unit area.

Bibliography

Primary sources:

"Corn Oil Makes the Grade", Ethanol Producer Magazine, April 16, 2013 accessed: 18 January 2015. http://www.ethanolproducer.com/articles/9755/corn-oil-makes-the-grade

Drought-Hit Farmers Explore New irrigation Methods. "Environmental Leader, Environmental & Energy Management News." 3 July 2013. Accessed: 26 January 2015. http://www.environmentalleader.com/2013/07/03/drought-hit-farmers-explore-new-irrigation-methods/

Justia US Law, Bounds v. State ex rel. D'Antonio, Filing date: July 25, 2013, Docket No. 32,713, accessed: 27 December 2014, http://law.justia.com/cases/new-mexico/supreme-court/2013/32-713.html

Kansas Plan to Conserve Water Looks To Combine Carrots And Sticks. " Kansas City Public Media." 13 January 2015. Accessed: 13 February 2015. http://kcur.org/post/kansas-plan-conserve-water-looks-combine-carrots-and-sticks

Kansas group advocates for aqueduct from Missouri River. "Midwest Producer." 21 January 2015. Accessed: 14 February 2015. http://www.midwestproducer.com/news/regional/kansas-group-advocates-for-aqueduct-from-missouri-river/article_cce5ad16-a1a2-11e4-bdc2-076502c46591.html

Revenue of corn farming (NAICS 11115) in the United States from 2009 to 2014 (in billion U. S. dollars). "The Statistic Portal." Accessed: 7 February 2015. http://www.statista.com/statistics/296374/revenue-corn-farming-in-the-us/

River Compact, Pecos River Compact. "Water Code," Article 111, (a) Accessed: 1 December 2014. http://www.statutes.legis.state.tx.us/Docs/WA/htm/WA.42.htm

Switch to Drip Irrigation. "Corn and Soybean Digest." 1 February 2013. Accessed: 24 January 2015. http://cornandsoybeandigest.com/equipment/switch-drip-irrigation

The United States of Megadrought, If you think that California is dry now, wait till the 2050's. "Slate, Future Tense." 12 February 2015. Accessed: 14 February 2015. http://www.slate.com/articles/technology/future_tense/2015/02/study_climate_change_may_bring_about_megadroughts_this_century.html

Water plan tackles critical issue of supply, demand. " The Hays Daily News." Andy Marso. 18 January 2015. Accessed: 13 February 2015. http://hdnews.net/news/waterkhi011815

Secondary sources:

About The Ground Water Division. "Wyoming State Engineer's Office." Accessed: 10 November 2014. http://seo.wyo.gov/ground-water

Aiken, J. David. "Nebraska Ground Water Law and Administration." University of Nebraska, Vol. 59: 917, (1980): 917 – 1000, Accessed: 12 November 2014. http://digitalcommons.unl.edu/ageconfacpub/30/

Aiken, J. David. "Development of the Appropriation Doctrine: Adapting Water Allocation Policies to Semiarid Environs*." Great Plains Quarterly*, (1988): 38 – 43.

Archer Daniels Midland and Cargill Inc. "OpenSecrets, Center for Responsive Politics." Accessed: 28 February 2015. https://www.opensecrets.org/lobby/clientsum.php?id=D000000511, https://www.opensecrets.org/lobby/clientsum.php?id=D000000132

Ashworth, William. *Ogallala Blue, Water and Life on the High Plains*. New York: W. W. Norton & Company, 2006.

Barrol, Peggy. "Regulation of Water versus Hydrologic Reality in New Mexico." New Mexico Office of the State Engineer, *Southwest Hydrology*, (July/August 2003). www.swhydro.arizona.edu/swhydro/archive/V2_N4/feature5.pdf

Blackburn Mike and Tim Wollings. "The North Atlantic Jet Stream under Climate Change and Its Relation to the NAO and EA Pattern," *Journal of Climate*, Vol. 25 (July 2011): 886 – 902.

Blackmore, Simon, Bill Stout, Maohua Wang, and Boris Runov. "Robotic Agriculture – The Future of Agircultural Mechanisation?," 5th European Conference in Precision Agriculture, Uppsala, Sweden, (June 2005): 1-9.

Brockman, James, C. "Overview of New Mexico's Groundwater Code." *27th Biennial Groundwater Conference and 18th Annual Meeting of the Groundwater Resources Association of California,* (October 6-7, 2009), Accessed: 12 November 2014.

Bittinger, Morton, W. "The Ogallala Story – What Have We Learned?", *Ground Water,* Vol. 19, No. 6, (November-December 1981): 586 – 587.

Braxton, Jane. "Saving the Ogallala Aquifer." Scientific American Special Edition. Vol. 19, Issue 1 (Mar., 2009): 32 – 39. Accessed: 15 October 2014. http://www.scientificamerican.com/article/the-ogallala-aquifer/

Canadian River. "Texas State Historical Association." Accessed: 17 November 2014. https://www.tshaonline.org/handbook/online/articles/rnc02

Colorado State Water Law. "Douglas County Colorado." Accessed: 12 November 2014. http://www.douglas.co.us/water/colorado-state-water-law/

"Corn Subsidies", EWG Farm Subsidies, accessed: 17 January 2015. http://farm.ewg.org/progdetail.php?fips=00000&progcode=corn

Cow Farts Have 'Larger Greenhouse Gas Impact' Than Previously Thought; Methane Pushes Climate Change. "International Business Times." 26 November 2013. Accessed: 20 February 2015. http://www.ibtimes.com/cow-farts-have-larger-greenhouse-gas-impact-previously-thought-methane-pushes-climate-change-1487502

Davidson, John H. "South Dakota Groundwater Protection Law". *The National Agricultural Law Center,* Vol. 40 (1995).

Davies, Kyle W., and Larry D. Putnam. *Conceptual and Numerical Models of Groundwater Flow in the Ogallala Aquifer in Gregory and Tripp Counties, South Dakota, Water Years 1985 – 2009.* U. S. Geological Survey Scientific Investigations Report 2013 – 5069. Reston: U. S. Geological Survey, 2013.

Drought – January 2015. "National Climatic Data Center." 11 February 2015. Accessed: 28 January 2015. http://www.ncdc.noaa.gov/sotc/drought/

Fed Up, Documentary. Director: Stephanie Soechtig, Production Company: Atlas Films

Fagan, Brian. *Elixir, A History of Water and Humankind*. New York: Bloomsbury Press, 2011

Gopalakrishnan, Chennat. "The Doctrine of Prior Appropriation and its Impact on Water Development, A Critical Survey." *The American Journal of Economics and Sociology*, Vol. 32, No. 1 (Jan., 1973), 61 – 72. http://www.jstor.org/discover/10.2307/3485791

Grant, Douglas, L. "Commerce Clause Limits on State Regulations of Interstate Water Export." *Journal of Contemporary Water Research and Education*, Vol. 105 (1996):10 – 16. http://opensiuc.lib.siu.edu/jcwre/vol105/iss1/3/

Great Plains. “United States Environmental Protection Agency. Last update: 9/9/2013. Accessed: 11 January 2015. http://www.epa.gov/climatechange/impacts-adaptation/greatplains.html

Groundwater Depletion. “USGS Science for a Changing World.” Last modified: 17 March 2014. Accessed: 27 January 2015. http://water.usgs.gov/edu/gwdepletion.html

Hiscock, Kevin and Yu Tanaka, “Potential Impacts of climate change on Groundwater Resources: from the High Plains of the U.S. to the Flatlands of the U.K.”, Presented at the National Hydrology Seminar, (2006): 19 – 26.

Irmak, Suat. “A Brief Research Update on Subsurface Drip Irrigation”. University of Nebraska-Lincoln. Accessed: 2 January 2015. water.unl.edu/c/document_library/get_file?folderId=350019...pd

Konikow, Leonard F. *Groundwater Depletion in the United States (1900 – 2008),* U. S. Geological Survey, Reston Virginia: 2013, Scientific Investigations Report 2013 – 5079. Accessed: 15 November 2014. http://pubs.usgs.gov/sir/2013/5079/

Matthews, Olen Paul. “Ground Water Rights, Spatial Variation, and Transboundary Conflicts.” *Ground Water,* Vol. 43, No. 5 (Sept., - Oct., 2005) 691 – 699. http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.2005.00067

McGuire, V. L., M. R. Johnson, R. L. Scheiffer, J. S. Stanton, S. K. Sebree, and I. M. Verstraeten. *Water in Storage and Approaches to Ground-Water Management, High Plains Aquifer, 2000.* U.S. Department of the Interior, U. S. Geological Survey. Reston: Library of Congress Cataloguing-in-publications Data, 2003.(this one has the good map)

NASA Study Finds Carbon Emissions Could Dramatically Increase Risk of U.S. Megadroughts. “NASA.” 12 February 2015. Accessed: 20 February 2015. http://www.nasa.gov/press/2015/february/nasa-study-finds-carbon-emissions-could-dramatically-increase-risk-of-us/

Nebraska Correlative Water Rights for Groundwater. “University of Nebraska-Lincoln.” Accessed: 11 November 2014. http://water.unl.edu/cropswater/regulations

Ojima, Dennis, Luis Garcia, E. Elgaali, Kathleen Miller, Timothy G. F. Kittel, and Jill Lackett. “Potential Climate Change Impacts on Water Resources in the Great Plains,” *Journal of the American Water Resources Association*, Vol. 35, No. 6, (Dec., 1999): 1443 – 1454, accessed: 12 January 2015.

O’Leary, Marilyn, C. “Texas v. New Mexico: The Pecos River Compact Litigation.” Natural Resources Journal, Vol. 20, (April, 1980), 395 – 410. http://lawschool.unm.edu/nrj/volumes/20/v20_no2.php

Opie, John. *Ogallala, Water for Dry Land*. Lincoln: University of Nebraska Press, 1993.

Peck, John C. "Groundwater Management in the High Plains Aquifer in the USA: Legal Problems and Innovations," *The Agricultural Groundwater Revolution, Opportunities and Threats to Development,* (2007): 296-314.

"Pecos River". Texas State Historical Society. Accessed: 30 November 2014. http://www.tshaonline.org/handbook/online/articles/rnp02

Pollan, Michael. *The Omnivores Dilemma, A Natural History of Four Meals*. New York: The Penguin Press, 2006.

Rainwater, Ken, Jeff Stovall, Scott Frailey, and Lloyd Urban. "Transboundary Impacts on Regional Ground Water Modeling in Texas." Ground Water, Vol. 43, No. 5, (Sept., - Oct., 2005): 706 – 716. http://www.ncbi.nlm.nih.gov/pubmed/16149966

Reisner, Marc. *Cadillac Desert, The American West and its Disappearing Water*. New York: Penguin Books, 1993.

Richardson, Jesse, J. Jr, and Tiffany Dowell. "The Implications of Bounds v. State of New Mexico." *Journal of Contemporary Water Research & Education*, Issue: 148 (August 2012): 17 – 23. http://onlinelibrary.wiley.com/doi/10.1111/j.1936-704X.2012.03109.x/citedby

Richardson, Jesse, J. Jr. and Tiffany Dowell. "Summary of Bounds v. New Mexico, New Mexico Supreme Court, Decided July 25, 2013. Accessed: 17 November 2014. *aquadoc.typepad.com/files/jjr_td_bounds_v_nm_supct25july-2013.pdf*

River Compact, Pecos River Compact. "Water Code," accessed: 1 December 2014. http://www.statutes.legis.state.tx.us/Docs/WA/htm/WA.42.htm

Rogers, Danny, H., G. Morgan Powell and Kerri Ebert. "Water Law." *K-State Research and Extension,* (January 2013), 1 – 8. www.ksre.ksu.edu/bookstore/pubs/MF3024.pdf

Rosenberg, Norman, J., Daniel J. Epstein, David Wang, Lance Vail, Raghaven Srinivasan, and Jeffrey G Arnold. "Possible Impacts of Global Warming on the Hydrology of the Ogallala Aquifer Region," Climate Change, Issue: 4, Vol., 42, (August 1999): 677 – 692, accessed: 11 January 2015. http://link.springer.com/article/10.1023%2FA%3A1005424003553

Solomon, Steven. *Water, The Epic Struggle for Wealth, Power, and Civilization*. New York: Harper Perennial, 2010.

Sophocleous, Marios, Groundwater Legal Framework and Management Practices in the High Plains Aquifer, USA. *Kansas Geological Survey, The University of Kansas*, (2012): 1-55

State of Texas, Plaintiff v. State of New Mexico, Cornell University of Law School. Accessed: 1 December 2014. http://www.law.cornell.edu/supremecourt/text/462/554

"State of the Climate", NOAA, National Climatic Data Center, Drought – Annual 2014. Accessed: 28 January 2015. http://www.ncdc.noaa.gov/sotc/drought/

Talah S. Arabiyat, Eduardo Segarra, and David B. Willis. "Sophisticated Irrigation Technology and Biotechnology Adoption: Impacts on Ground Water Conservation," *ABioForum*, Vol. 2, No. 2, (1999): 132 – 136.

Tarlock, A. Dan, "Prior Appropriation: Rule, Principle, or Rhetoric? *North Dakota Law Review*, Vol. 76:881, (2000): 881- 910. www.kysq.org/docs/Tarlock.pdf

Texas Water: Basics of Groundwater Law. "Texas A&M Agrilife Extension." Accessed: 17 November 2014. http://agrilife.org/texasaglaw/2013/10/22/texas-water-basics-of-groundwater-law/

The Fat of the Land: Do Agricultural Subsidies Foster Poor Health?" US National Library of Medicine, National Institute of Health. (Oct. 2004), Accessed: 17 January 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1247588/

Turner, Frederick Jackson. *The Frontier in American History*. New York: Dover Publications, 1996.

The Water Footprint of Food. "Grace Communications Foundation." Accessed: 20 February 2015. http://www.gracelinks.org/1361/the-water-footprint-of-food

High Plains Water-Level Monitoring Study (Groundwater Resource Program). "USGS Science for a Changing World." Last Modified: 4 February 2014. Accessed: 2 November 2014. http://ne.water.usgs.gov/ogw/hpwlms/physsett.html

U.S. Drought Monitor, January 27, 2015. "United States Drought Monitor," accessed: 29 January 2015. http://droughtmonitor.unl.edu/

Utton, Albert. "The *El Paso* Case: Reconciling *Sporhase* and *Vermejo*." Natural Resources Journal, Vol. 23, No. 1 (Jan., 1983):1 – 7. *lawschool.unm.edu/nrj/volumes/23/1/01_utton_comment.pdf*

Waskom, Reagan. "Are We Thinking Big Enough." Newsletter of the Water Center of Colorado State University, Colorado Water, Vol. 24. Issue 5, (Oct/Nov 2007), Accessed: 12 November 2014. www.cwi.colostate.edu/newsletters/2007/ColoradoWater_24_5

Water Law and Management in Oklahoma. Accessed: 14 November 2014. https://www.owrb.ok.gov/supply/ocwp/pdf_ocwp/WaterPlanUpdate/joint_committee/WATER%20LAW_MANAGEMENT%20IN%20OKLAHOMA.pdf

Water Rights. "Colorado Division of Water Resources." Accessed: 12 November 2014. http://water.state.co.us/surfacewater/swrights/Pages/default.aspx

Worster, Donald. *Rivers of Empire, Water, Aridity, and the Growth of the American West.* New York: Oxford University Press, 1985.