From desert to breadbasket…to desert again? A metabolic rift in the High Plains Aquifer

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Abstract

The High Plains region of the U.S. is one of the most important agricultural regions in the world. Much agricultural production in this semi-arid region, however, depends on the consumption of nonrenewable groundwater from the High Plains Aquifer. Although the problem has drawn significant attention from policymakers and citizens for over forty years, depletion of the Aquifer has worsened. Why does depletion persist despite widespread and ongoing concern? We explore this conundrum by placing the region into an historical, political-economic context. We focus specifically on the case of Western Kansas, and argue that the contemporary problem is rooted in the ways in which this region was articulated into broader circuits of capital and exchange. Private capital and the state incorporated the region as a source of primary raw materials, mainly agricultural products. Water-dependent agricultural resource extraction opened up a metabolic rift in the hydrological cycle that has only been exacerbated over time through unequal ecological exchange with more politically and economically central places. These structural dynamics associated with political-economic incorporation have impeded efforts to develop more sustainable uses of groundwater consumption in the region.

Key words: groundwater management, metabolic rift, High Plains, Kansas

Résumé

La région des hautes plaines des États-Unis est l'une des régions agricoles les plus importantes du monde. Une grande partie de la production agricole dans cette région semi-aride, cependant, dépend de la consommation des eaux souterraines non renouvelables des aquifères des Hautes Plaines. Bien que le problème a attiré l'attention significative des décideurs et des citoyens pour plus de quarante ans, l'épuisement de l'aquifère a empiré. Pourquoi l'épuisement persiste, malgré la crainte généralisée et permanente? Nous explorons cette énigme en plaçant la région dans un contexte historique, politique et économique. Nous nous concentrons particulièrement sur le cas du Kansas occidental, et nous pensons que le problème contemporain est enracinée dans la façon dont cette région a été articulé dans les circuits de capitaux et des changes plus larges. Les capitaux privés et l'état incorporé la région en tant que source de matières premières, principalement des produits agricoles. L'agriculture dépendant en eau a ouvert une brèche métabolique dans le cycle hydrologique qui a été exacerbée au fil du temps grâce à l'échange écologique inégal avec des lieux qui sont au centre, politiquement et économiquement. Ces dynamiques structurelles associées à l'incorporation politique et économique ont entravé les efforts visant à développer une consommation plus durable des eaux souterraines dans la région.

Mots clés: gestion des eaux souterraines , rift métabolique, High Plains, Kansas

Resumen

La región de los Altiplanos de los EE.UU. es una de las regiones agrícolas más importantes del mundo. Gran parte de la producción agrícola en esta región semiárida, sin embargo, depende del consumo de agua subterránea no renovable del acuífero de los Altiplanos. Aunque el problema ha llamado la atención de parte de los responsables políticos y los ciudadanos durante más de cuarenta años, el agotamiento del acuífero ha empeorado. ¿Por qué el agotamiento persiste a pesar de la preocupación generalizada y permanente?

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Exploramos este dilema posicionando la región en un contexto histórico, político-económico. Nos centramos específicamente en el caso de Kansas occidental, y sostenemos que el problema actual tiene sus raíces en las formas en que esta región se articula en los circuitos más amplios de capital e intercambio. El capital privado y el Estado incorporaron la región como fuente de materias primas, principalmente de productos agrícolas. La extracción de recursos agrícolas dependientes del agua abrió una brecha metabólica en el ciclo hidrológico que sólo se ha exacerbado con el tiempo debido a un intercambio ecológico desigual con más lugares centrales política y económicamente. Estas dinámicas estructurales asociadas con la incorporación de política económica han obstaculizado los esfuerzos para desarrollar usos más sostenibles de consumo de agua subterránea en la región.

Palabras clave: gestión del agua subterránea, brecha metabólica, Altiplanos, Kansas

1. Introduction

> "You've got to reduce your water use, but you've got to keep your economic activity flat to growing," Brownback said. "People can't live there unless there's economic activity." Kansas Governor Sam Brownback, March 18, 2013.

The High Plains consists of the Western portion of the United States Great Plains region, an area delimited on the west by the Rocky Mountains and on the east by the 100th meridian (Webb, 1931; see especially Hurt 2011). Water is critical for human survival everywhere, but especially in the High Plains region (see Opie 2000; Reisner 2003; Solomon 2010). The region has a semi-arid continental climate with abundant sunshine, low humidity, frequent winds, and only moderate precipitation, usually less than 19 inches (483 mm) annually in most areas. Some areas in the region receive less than 10 inches (254 mm) of annual precipitation, and evaporation rates are relatively high. Temperatures fluctuate widely throughout the year, with differences of up to 100 degrees Fahrenheit (37.8 degrees C) or more between summer highs and winter lows (Gutentag *et al.* 1984).

Because of its semi-arid climate and broad treeless expanses, most early Anglo explorers saw little potential value in the High Plains. In 1806, Zebulon Pike led a survey of the Southern portion of the Louisiana Purchase. His post-travel remarks characterized the region as unsuitable for agriculture and therefore, for settlement. Pike believed the region would instead serve as a natural barrier to the continued western expansion of the population (Pike 1811). A few years later, U.S. government surveyor Stephen Long echoed Pike's sentiments, labeling the region "the Great American Desert", in maps completed after his return in 1820. A geographer accompanying him, Edwin James, characterized the land as, "…almost wholly unfit for cultivation, and of course, uninhabitable by a people depending upon agriculture for their subsistence" (Long and James 1823: 236).

Unbeknown to Pike, Long, and all the others who traversed the region prior to the late 19th century, was the High Plains Aquifer, a massive groundwater source that was located, in some places, just a few feet below the surface. The discovery of the Aquifer transformed the Great American Desert into one of the most productive agricultural regions – the "breadbasket of the world." The High Plains Aquifer is the largest aquifer in the U.S., underlying 174,000 square miles (450,658 km^2) in parts of eight states – Colorado, Western Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming (Figure 1). The surface area above the Aquifer was formed approximately 65 million years ago from the deposition of sediment eroded from the Rocky Mountains and carried by streams flowing eastward toward the Mississippi River (McGuire *et al.* 2003). The Aquifer is not a single, massive underground lake, but instead consists of several connected hydrologic units that store water within the pore spaces between clay, silt, sand, and gravel (McGuire *et al.* 2003). The most recent data indicate that the Aquifer holds 2,980 million acre-feet (3,675 million liters) of water (McGuire *et al.* 2003), a volume approximately equivalent to the amount of water in Lake Huron, the third largest Great Lake in the United States (see also McNeil 2000:151-156). As a further illustration, if all of the water in the Aquifer were placed on the surface, it would fill an area the size of the state of Colorado with water 45 feet deep (13.7 meters) (McGuire *et al.* 2003). The water, however, is not distributed evenly across the Aquifer. Saturated thickness, or the volume of the Aquifer in which the pore spaces are completely filled from the bedrock to the top of the water table, ranges from 9 feet (2.74 m) in parts of New Mexico and Texas to 700 feet (213 m) in Nebraska (McGuire 2011). Most importantly, the Aquifer is recharged today only by rainfall that seeps into the soil. Its original source – winter runoff carried by streams from the Rocky Mountains – no longer replenishes it, making water from the Aquifer a nonrenewable resource over a human time horizon. Thus, water in the High Plains Aquifer is considered "fossil water" (Green 1973; Opie 2000).

Figure 1: The High Plains Aquifer. Source: Colorado Geological Survey, 2013.

Since the 1950s, the Aquifer has declined precipitously in many areas. The High Plains Aquifer is not only the largest aquifer in the U.S., it is also the most intensively used source of groundwater in the country (Maupin and Barber 2005). In 2000, total withdrawals were 17.5 billion gallons *per day* (66.2 billion liters).

The Aquifer is a source of drinking and domestic water for over 1.9 million people in the region, but irrigation is the principal use. Over 90% of water withdrawals are for irrigation (calculated from USGS data), and the Aquifer comprises 30% of all the water used for irrigation in the U.S. (Rosenberg *et al.* 1999).

The "breadbasket of the world" appears to be on the verge of again becoming the Great American Desert. Formed over millions of years, the Aquifer is being depleted in the span of one human lifetime. The largest decline has occurred in the areas where deep-well irrigation first appeared. Irrigation demand for most crops in the region is approximately one foot per year (305 mm), exceeding the rate of recharge, which ranges from 2 to 3 inches (51-76 mm) per year in the sand dune areas of Nebraska to less than 0.5 inches (12.7 mm) per year in other areas. Water-level decline has occurred in all High Plains states except South Dakota, where development is relatively sparse. Over 12,000 square miles (31,080 km^2) of Colorado, Kansas, New Mexico, Oklahoma, and Texas the groundwater levels have fallen over 50 feet (15.2 meters), and 2,500 square miles (4,000 km^2) have seen drops of more than 100 feet (30.5 meters) since settlement. In Southwest Kansas and the panhandles of Oklahoma and Texas, the geographic heart of the Dust Bowl (Egan 2006; Hurt 1981; Worster 1979), more than fifty percent of the Aquifer has been depleted in less than fifty years (Luckey *et al.* 1981).

The loss of groundwater alters hydrological systems in the region, undermines the basis of human settlement, and threatens a significant portion of U.S. agricultural production. Citizens and governments, at the federal and state levels, are keenly aware of the importance of unsustainable groundwater consumption. In Kansas, for example, Lieutenant Governor Shelby Smith made manifest the magnitude of the problem in an opening letter attached to the Final Report of the Governor's Task Force on Water Resources in 1978: "Kansas, indeed, has major water problems, and a crisis is on the horizon." At a meeting of irrigators in Western Kansas in August 2011, participants publicly urged others to limit the drawdown of the Aquifer: "It's really simple…I think we need to reduce withdrawals," said Steve Irsik, an irrigator from Ingalls, Kansas. Another irrigator, Mitch Baalman from Hoxie, Kansas added: "We've all got to cut back." (Garden City Telegram, 8/30/2011).

In the thirty-three years that passed between the Lieutenant Governor's remarks and these comments from irrigators, citizens and governments have developed and enacted a slew of policies and administrative procedures to reduce depletion. These efforts have indeed slowed the rate of depletion in many areas. Nevertheless, over this period, total withdrawals have continued to exceed recharge rates over most of the region and widespread drawdown has persisted. Today, some sections of the High Plains Aquifer are completely exhausted and estimates point to complete depletion in other sections by 2025 (Opie 2000; Sophocleous 2005; White and Kromm 1992). Thus, there is now a growing fatalism among the populations of the High Plains. Kent Askren, a Kansas Farm Bureau water specialist, articulates these sentiments: "It's kind of a ticking time bomb, and we kind of know it" (Pew Stateline, 03/18/13).

Despite ongoing efforts conserve the very resource base on which livelihoods, and a large proportion of American agriculture, depends, the inability to depends to do so successfully indicates deeper, socio-structural problems in the human-environment nexus. Kansas Governor Brownback hints at these tensions in the opening quotation. His comment points to a fundamental contradiction; that sustaining human populations in the Kansas High Plains requires economic growth *and* water conservation: "People can't live there unless there is economic activity" (Pew Stateline, 03/18/13). However, economic growth has been inimical to water conservation, and is thus undermining the very resource on which these populations depend.

In this article we explore the historical-structural relations that have shaped the ways that people have used groundwater in the High Plains region. We focus on the Southwest Kansas portion of the High Plains, an area of particularly intensive rates of groundwater consumption in the heart of the historic 'Dust Bowl.' We begin by developing the historical, political-economic context in which this area was settled and then integrated into broader circuits of capital exchange and accumulation. We then trace the lineages of this context into the contemporary era, which is characterized by a metabolic rift in the hydrological cycle and ecological unequal exchange with more politically and economically central places.

2. Capital and state in the making of southwest Kansas

Southwest Kansas consists of fourteen counties in the center of the High Plains region. Owing to the arid reputation of the High Plains, Southwest Kansas was largely bypassed through the 1840s as Euro-Americans made their way to Oregon and California. The region remained sparsely settled through the mid-1800s, inhabited largely by ranchers who saw the potential for raising cattle in the open and sloping grasslands (Webb 1931). Baron von Richthofen presaged the future of the region. He was an emigrant to Colorado from what is today Germany, and a co-founder of the Denver Chamber of Commerce, and after passing through the High Plains he wrote: "…the largest and richest grass and pasture region in the world…will probably soon become the most important beef-producing country of the globe" (von Richthofen 1885: 5).

This was prescient. Southwest Kansas is today one of the largest beef producing areas in the world. Its three principal towns -- Garden City, Dodge City, and Liberal -- have been called the 'golden triangle' of beef production in the U.S. (Stull and Broadway 2003: 130). But the scale, and form, of cattle production in Southwest Kansas today would have been unimaginable even to von Richthofen because of the relative lack of surface water. Cattle ranching of the sort he envisioned was indeed predominant throughout the 1870s. However, farmers settled the region in greater numbers in the 1880s. The transition to settled farming was a watershed moment, marking the shift from a more nomadic, less intensive use of natural resources that had characterized much of human history in the High Plains region, toward a much more intensive dependency on, and exploitation of, groundwater.

Understanding the problem of groundwater use in Southwest Kansas today requires exploring the historical, political-economic context in which the area was first settled and developed (Miner 1986). In this respect, it is noteworthy that the development of a high-volume, capital and water-intensive export-agricultural economy in the Great American Desert was not endogenous; that is, it did not spontaneously develop from within the region. Instead, agents external to the region, representing the state and private capital, constructed Southwest Kansas by spearheading the extension of markets westward into the region.

Southwest Kansas is an accomplishment of a coordinated effort on the part of both federal and state governments and private capital. Two historical moments were key to its development: the Homestead Act and, more importantly, the extension of the railroad system. The U.S. federal government promoted settlement of the region through the Homestead Act of 1862. Under the Act, the U.S. government gave public domain land to private citizens (up to 160 acres each or 64.8 hectares) in an effort to encourage settlement in the land west of the Mississippi River and to promote the Jeffersonian ideal of a land populated and governed by yeoman farmers. By several measures, the Act was not as successful as intended, but it did provide significant impetus for migration and settlement in the region (Webb 1931: 410-412).

At the same time, railroad corporations were actively promoting settlement throughout the region as they expanded into new territories across the country. The railroad corporations, especially the trans-continentals, built many of the roads ahead of demand, on speculation, and were thus motivated to encourage population settlement as quickly as possible in order to recoup costs and to accumulate profits. It was to be a self-perpetuating, virtuous cycle for capital accumulation: the railroad companies would build the roads that would bring the settlers to the region; settlement would encourage development; development would attract more settlers who would ride new rails to new destinations (Miner 1986; Webb 1931).

The railroads, working in coordination with the federal and state governments, tried many strategies to encourage settlement. They tried to sell their land grants from the federal government to prospective settlers, but initial sales were disappointing. The Santa Fe railroad in Kansas was given 2.5 million acres (1.02 million ha) by the federal government in 1863, but it had only sold 700,000 acres (283,280 ha) by 1878, leaving nearly 1.8 million acres (728,434 ha) unused, despite offering the land at a relatively low cost of around US$5-6 per acre (US$12.4-$14.8 per hectare) (Emmons 1971). By the late 860s, it was becoming apparent to the railroads that the region's reputation as the Great American Desert, which reflected real ecological limits to agriculture, was a serious barrier to settlement. If Western Kansas was to be settled, public perceptions would have to change.

Land sales were thus coupled with an effort to actively change public perceptions of the Great American Desert. Here, the lines between the state and private capital were blurred. The railroads and the state began promoting pseudo-scientific studies that appeared to show that agriculture could improve the arid climate; that "the rain follows the plow"; that humans could triumph over nature. It was propaganda explicitly designed to promote settlement in an area that, ecologically, could not support capital and water-intensive agriculture. Water was the critical ecological limit to the settlement and further expansion of capitalist agricultural development. It was this limit that the railroads and the state intended to overcome, or obscure, through propaganda (Miner 1986).

The railroad corporations led the way. In September 1870, the Kansas Pacific Railroad hired an experimental farmer, Richard Smith Elliott, as an industrial agent to 'prove' that the railroad's lands were capable of supporting agriculture and that settlement would improve the climate for agriculture (Miner 1986:42-43). A few months earlier, in March 1870, Elliott had published an article on the climate of the Plains, which was replete with 'strategies' for increasing rainfall through settled agriculture (Miner 1986). Indeed, it was Smith who first promoted the idea that "the rain follows the plow" through rhetoric such as: "…were it possible, by some magic process, to break up the entire surface of Western Kansas to a depth of two feet, we should thereby begin to make a new climate" (quoted in Miner 1986: 42). Despite his hopes, and the railroad's investment, his three experimental farms in Western Kansas failed. Kansas Pacific ceased support for them in 1873.

Kansas Pacific supported other farms that failed, but one in particular would portend the future of agriculture in the region. In 1871, Dr. Louis Watson, of Illinois, developed perhaps the first for-profit, corporate farm in Kansas. Dr. Watson formed a corporation and sold US$25,000 in stock to 14 owners in what would become the Western Kansas Agricultural Association, for which he served as general manager (Miner 1986:42-47). It failed in 1872 without producing any income, but was an indicator of a trend, since it was becoming clearer to the railroads, and the state, that larger-scale agriculture would be required to be successful (i.e., profitable) in the High Plains.

The state worked alongside the railroads as a key institutional mechanism for proffering pseudo-scientific evidence to induce settlement in Western Kansas. In 1867, the state of Kansas founded the Bureau of Immigration to recruit and organize new settlers. The Bureau's Annual Report in 1868, stated: "It was our desire to fill upon the map of Kansas, the blank space heretofore allotted to 'The Great American Desert' – that myth of the old Geographers" (Emmons 1971:51). Later, the state would turn to its Board of Agriculture to propagate the "rain follows the plow" myth. In 1883, the Board's biennial report declared that Kansas had a population carrying capacity far beyond its current level: "…due to its fertility of soil…and mildness of climate (had) abundant facilities for the maintenance of tens of millions of people" (Emmons 1971: 63). A few years later, in 1886, the Secretary of the Board of Agriculture, Martin Mohler went further, arguing that any development of agriculture was a result of human settlement-induced climate change in the state: "The rapid and unparalleled progress of Kansas in agriculture is due largely to that climatic change which has been brought about by the settlement and improvement of the country" (Emmons 1971:156).

Enticed by the promise of free land from the federal government and the boosterism of the railroads and state, settlers entered Southwest Kansas in much larger numbers (see Figure 2). The 1870 Census (the first official government record of population in Southwest Kansas) reported a population of 427 people living in Ford County (home to Dodge City). Just a decade later, in 1880, all 14 counties in Southwest Kansas were settled and the region was home to 6,634 people. Between 1880 and 1890, the population of Southwest Kansas increased 350%, to nearly 30,000 inhabitants. It appeared that any ecological limits to settlement had been overcome.

Population growth, however, would become much more unstable over the next 50 years, with periods of increase and decline as settlers struggled to establish and grow their farms. The boom years of the early to mid 1880s ended when drought, an endemic climatic feature of the area that had been obscured by the state and railroads, caused widespread crop failures, prompting the first of several mass emigrations from the High Plains (Miner 1986:128-131, 212-217). By 1900, the population had declined by 30%, to 21,000 inhabitants, as settlers in increasing numbers found that the farming techniques transplanted from the more-humid Eastern portion of the country did not work as effectively in the more arid High Plains. Quite simply, the rain did not follow the plow; human settlement did not improve the natural environment. To the contrary, early agricultural practices in the High Plains region were detrimental to both the environment and the populations dependent on it (Opie 2000). The population of Southwest Kansas recovered from the 1880s drought, growing more than three-fold between 1890 and 1930 to approximately 85,000 inhabitants. Subsequent droughts in the 1920s and 1930s, however, produced the Dust Bowl, a seminal event in the history of the High Plains and perhaps the most catastrophic environmental event in the history of the U.S. Other factors were the cumulative effects of the increased price of wheat in Europe after WWI leading to the expansion of cultivation into arid areas, new agricultural technology such as the tractor and the truck, inappropriate dryland farming practices transplanted from the Eastern U.S., and the economic effects of Great Depression, (Egan 2006; Hurt 1981; Svobida 1940/1986; Sylvester and Rupley 2012; Worster 1979). Southwest Kansas was the heart of the Dust Bowl. Eroded soil from this area was picked up by winds in immense dust storms, which blackened the skies and traveled for miles across the Plains. Some of the storms reached the Eastern seaboard of the U.S., entered the interior meeting rooms of the US Congress, and deposited soil in the Atlantic Ocean (Worster 1979). Nearly 100 million acres (404,686 km^2) of farmland were degraded and 2.5 million people emigrated out of the region by 1940 (Worster 1979). Between 1930 and 1940, Southwest Kansas lost 20 percent of its population. Large portions of the High Plains region never recovered from these population losses, and the region remains sparsely populated.

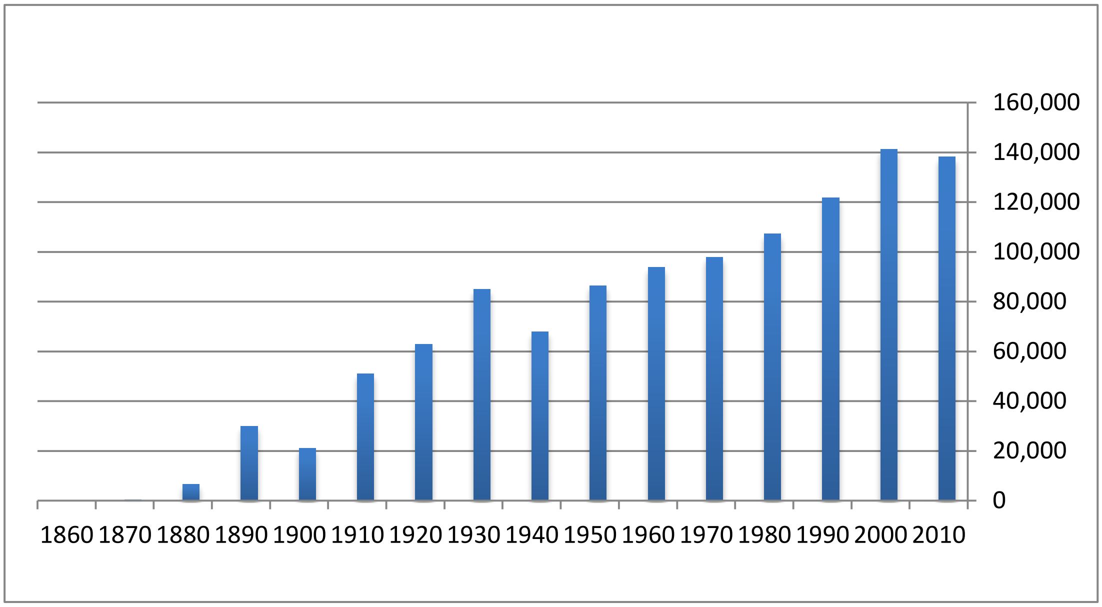

Figure 2: Total population of Southwest Kansas. Source: U.S. Census, various years.

3. Irrigation technology as a 'fix'

Those portions of Southwest Kansas that have sustained populations into the 21st century owe their existence to groundwater extraction from the High Plains Aquifer, which underlies 30,500 square miles (49,084 km^2) of the West and Central portions of Kansas (White 1994, 1998). The Ogallala formation, the largest portion of the High Plains Aquifer, is estimated to hold approximately 250 million acre-feet of water in storage (McGuire *et al.* 2003). In 2000, 4.4 million acre-feet (5,427 million m^3) were drained from the Aquifer (McGuire *et al.* 2011) at a rate of 3,000 million gallons (11,356 million liters) per day. Yet the Aquifer is recharged at a rate of less than one inch per year in most of the region. Kansas is second only to Texas in water loss in the Aquifer region. Between 1940 and 2000, Kansas lost 47 million acre-feet (5.87×10^{10} m^3) of water in storage (McGuire *et al.* 2003).

Early settlers knew about the Aquifer but were unable to fully exploit it given existing irrigation technology. Several irrigation techniques, including river diversion and water pumped to the surface by windmills, were used from the beginning of settlement (Sherow 1991; Webb 1931). These technologies were limited due to water table depth and the slope of the land surface. Indeed, nearly 100 years after Pike described the region as unfit for cultivation, the U.S. Geological Survey produced a report (Johnson 1901) concluding that High Plains could be developed for livestock production, but not for cultivated agriculture, given the low recharge rate of the Aquifer and that existing irrigation technology reduced the economic feasibility of well irrigation (see Webb 1931).

By the turn of the 20th century wind reservoir irrigation operations had been introduced with some success in areas of Southwestern Kansas and elsewhere in the High Plains, but the era of windmill technology was over by the 1930s. Windmills failed because they could not draw water from more than thirty feet (9 meters). Due to the drought of the 1930s, federal government agricultural subsidies increased and new and cheaper irrigation technologies began to emerge (Grant 2002). Rural electrification in the 1940s made electrical engines feasible for use in irrigation, and auto engines were adopted after the war to lift groundwater; irrigation spread across the High Plains. The pump and engine technologies and cheap fuel made deep-well irrigation economically feasible and promoted intensive and extensive irrigation in the High Plains region. Expansion of irrigation led to increased agricultural production and prosperity in the region (Opie 2000: Ch. 2-4).

The gravity irrigation system based on pump and engine technologies are plagued by a number of problems. They are labor intensive, and irrigated fields must be level or sloped for the water to flow evenly. If the soil is too sandy the water will seep into the ground before it reaches all areas of the field. A significant portion of water evaporates, and water is lost through seepage. Center pivot irrigation systems (initially developed by Frank Zybach of Dalhart, Texas in 1949) allowed irrigation on uneven and rolling surfaces, dramatically expanding the scale of irrigation in the High Plains Aquifer region (Splinter 1976). These systems involve an overhead irrigation machine that moves in a circular fashion over a quarter section of land (covering 133 of 160 acres; 54/64 ha) and releases water through a center pivot. From the 1950s to the 1970s, center pivot systems became the predominant method of irrigation across the region, and groundwater consumption increased dramatically as a result (Splinter 1976). Land under irrigation also increased, from 548,000 acres (221,800 ha) in 1959 to nearly 15 million acres (6 million ha) in 1980 (White 1994). By 1980, nearly 170,000 irrigation wells were yielding up to 21 million acre-feet (2.6×10^{10} m^3) of water from the High Plains Aquifer region annually (Kromm and White 1992; see also Opie 2000).

Groundwater consumption is directly responsible for an unprecedented period of sustained population growth in the latter half of the 20th century across Southwest Kansas (Opie 2000). The population of Southwest Kansas more than doubled from nearly 68,000 in 1940 to over 141,000 in 2000. More importantly, there was no annual decline the population for over 60 years, despite several droughts and dry spells. It appeared that, finally, the nineteenth century vision of the railroads and the state had been vindicated. The rain may not have followed the plow, as originally expected, but the rain that had been stored underground for centuries could be tapped indefinitely, it was believed, to allow an agricultural economy to flourish in the Great American Desert. Ecological limits appeared to be only temporary barriers that could be overcome by human ingenuity in the form of advanced irrigation technology (Opie 2000; Splinter 1976).

Southwest Kansas was settled and developed in the interests of the railroad corporations, that worked alongside the state to settle and develop water-intensive agriculture in this water-scarce region (Miner 1986). Since the beginning of Euro-American settlement in the region, the environment and capital of private economic interests have been in tension. Capital must expand unendingly through accumulation, but the scarcity of water has imposed an ecological limit on capital accumulation. The historical interaction between water and capital is imprinted on the transportation patterns and social structures of the region. Railroad corporations laid rail lines along the few major surface water flows (the Arkansas River and the Cimarron River), and today, the major roadways that transect the area follow these original routes. Along these lines, the largest population centers (Garden City and Dodge City) have grown. The transportation patterns underlie a political-economic structure, formed by capital and the state in the late-19th century, that has developed the region as a source of natural resources to be exported for development elsewhere (an idea explored more than fifty years ago by Kraenzel [1955: Ch.16]). The transportation routes established by the railroads were designed to bring in people and ship out resources in a perpetual cycle of capital accumulation. The main export of the region is water, which leaves the area in many forms, including corn, feed grains, and cattle and hogs (Opie, 2000: Ch. 4).

As the High Plains Aquifer has declined, local economies have changed. Farmers took on heavy debt in the 1970s when they adopted center pivot technology. Falling water production has increased farm foreclosures and the depopulation of smaller communities. Land ownership and agricultural production is increasingly in the hands of banks, insurance companies, and large corporate agribusiness operations, which often do little for smaller communities (see Opie 2000). As the groundwater has become increasingly scarce and its quality has declined, the optimism of the 20th century, linked to the hope of transcending ecological limits through irrigation technology, is fading. The 2010 census registered the first population decline in the region since the Dust Bowl of the 1930s and there is growing acknowledgement that groundwater consumption in the region is unsustainable. Despite the very visible nature of the problem, however, the drawdown of the High Plains Aquifer continues apace. We now explain this conundrum by applying the theories of metabolic rift and unequal ecological exchange.

4. A metabolic rift and unequal ecological exchange in southwest Kansas

The hydrological cycle describes the natural system through which water moves on Earth. The cycle begins in the ocean, as the sun transforms water into vapor through the process of evaporation. As water vapor enters the atmosphere, it cools and condenses into clouds. Winds move clouds, condensed water vapor, over the surface of the Earth. When the water particles in clouds are large enough, they fall as precipitation in the form of ice, snow, hail, or rain. Water that falls onto land can take several paths in its return to the oceans, where the cycle begins anew. Some of the water that lands on the surface and runs off into streams and rivers, which carry it back to the oceans. Some water seeps into the ground in a process of infiltration, where it is taken up by plants, and returned to the atmosphere through transpiration. Some water will seep deeper into the ground and replenish aquifers. Thus, the High Plains Aquifer region has accurately been described as the *Land of the underground rain* (Green 1973).

The hydrological cycle has its own internal metabolism that allows for its ongoing regeneration and existence through a complex interchange of materials. Water is transformed from vapor into a solid or liquid and back into a vapor as it moves across the Earth in a continual cycle. The hydrological cycle supports human existence. Without a continual supply of fresh water, human life is not possible. Thus, humans must constantly intervene in the hydrological cycle in order to sustain life (McNeill 2002).

However, sustaining life through the dialectic between the hydrologic cycle and agriculture in a place requires that human interventions in the cycle do not disrupt the metabolic processes that replenish and renew the cycle in that particular place. A "metabolic rift" (Foster 1999, 2000; Foster *et al.* 2010) develops when human intervention "…prevents the return to the soil of its constituent elements…hinder(ing) the operation of the eternal natural condition for the lasting fertility of the soil" (Marx 1976: 637). Water is the key constituent element of the soil. Without it, the soil cannot produce food to support human life.

Groundwater depletion is evidence of a metabolic rift in the hydrological cycle. Depletion occurs when human interventions remove water from storage at a faster rate than it is replenished, breaking the hydrological cycle of renewal that supports the local ecosystem. Groundwater stocks often feed surface water in the form of creeks, rivers and lakes, and supporting surface vegetation. Depletion causes surface water to dry up. Surface vegetation that relies on groundwater, especially during dry periods, cannot survive if their root systems are not adapted to reach lower water levels. The loss of surface water and surface vegetation is felt throughout the food web, disrupting or even undermining the complex linkages between food producers and consumers in an ecosystem.

In Southwest Kansas, human intervention in the form of capitalist agricultural production has caused a metabolic rift in the hydrological cycle, as evidenced by groundwater depletion (e.g., Sophocleous 2005). Figure 3 shows trends in the High Plains Aquifer water levels from 1950-2009 (records of the Aquifer levels were not kept prior to 1950). The severity of the problem varies across the Aquifer region. For example, the Aquifer has only declined an estimated one foot (30.5 cm) since 1950 in Nebraska, because precipitation rates in Nebraska are higher and the more porous soil there allows the Aquifer to recharge more quickly. The problem is more severe in the more arid portions of the region.

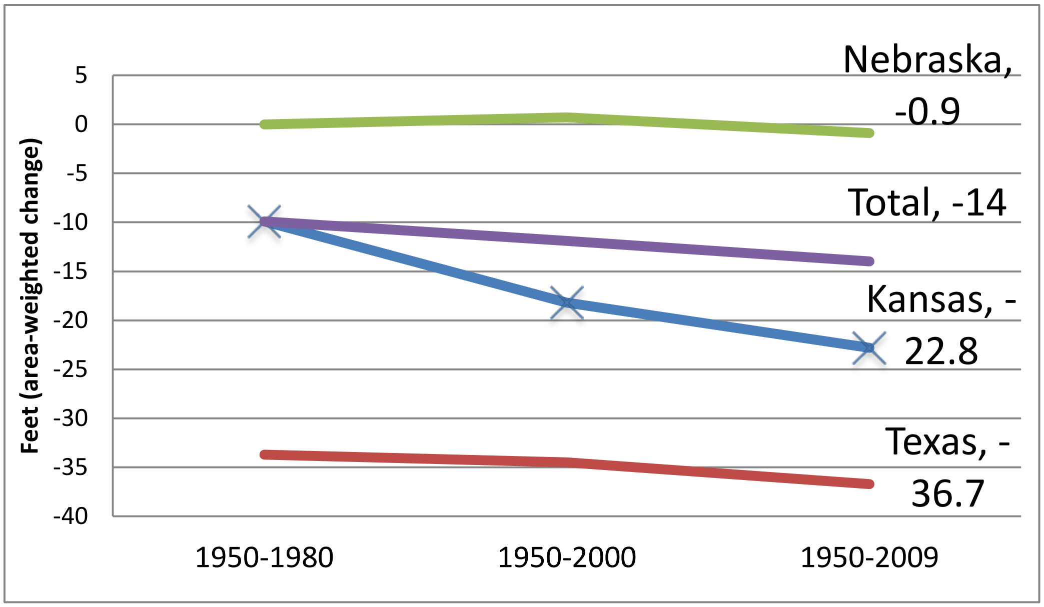

Figure 3: Water-level change in the High Plains Aquifer. Source: U.S. Geological Survey, 2011.

Kansas is second only to Texas in the level of groundwater depletion. In just sixty years, an average of nearly 23 feet of water (7 meters) has been drained from the Aquifer in Western Kansas. In short, the water is being mined. The 14 counties of Southwest Kansas consumed nearly 1.5 billion gallons (5,678 million liters) of groundwater per day in 2005 (U.S. Geological Survey 2005). To put this into perspective, in one year, the groundwater consumed in Southwest Kansas would cover the state of Delaware (2,591 square miles, 1,049 ha^2) with water to a depth of one foot (30.5 cm). Intensive and prolonged groundwater consumption has diminished surface water levels in Southwest Kansas and, with detrimental impacts for surface vegetation and the broader ecosystem (Kansas Water Office 2009). Indeed, the Arkansas River, which is the major source of surface water in the region, now only flows intermittently, rather than perennially. The river is also no longer hydraulically connected as it flows through the state of Kansas; it flows into Western Kansas from Colorado, then dries up over the High Plains Aquifer portion of Western Kansas and begins again in South Central Kansas.

As Figure 4 shows, the vast majority (95%) of groundwater withdrawals in Southwest Kansas are for irrigation and livestock, and this consumes 1.43 billion gallons (5.4 billion liters) of groundwater each day. Livestock consumption is the second major use of groundwater in the region, drawing 30 million gallons each day (2% of total daily withdrawals). In comparison, private households and public institutions together withdraw a total of 27 million gallons (102 million liters) each day.

The metabolic rift in Southwest Kansas developed due to the expansion of export-agricultural production in the region. Figures 5 and 6 illustrate trends in corn and livestock production, two economically important commodities produced in Southwest Kansas. Both are highly water-consumptive and both have increased markedly over the past 60 years. Southwest Kansas receives on average less than 20 inches (508 mm) of precipitation for an entire year, including winter, which is not conducive to corn production. Yet corn requires approximately two feet (610 mm) of water to grow to maximum yield, and production has increased dramatically in Southwest Kansas. In 2011, the region produced 103 million bushels of corn (2,616,344 metric tons, at 39.3679 bushels = 1 metric ton), a 20,000 percent increase over output in 1958 (497,000 bushels, 12,624 metric tons). And production in 2011 was actually lower than in recent years; the 1999 corn crop totaled 160 million bushels (4.06 metric tons). Beef production is even more water-intensive. It is estimated that approximately 4,000 gallons (15,142 liters) of water are required to produce one pound of beef (Mekonnen and Hoekstra 2012). Since 1975, the number of cattle on feed has risen by 240 percent from

415,000 to nearly 1.4 million by 2007. Without groundwater from the Aquifer, the production of livestock and irrigated crops, including corn, would not be possible in Southwest Kansas (Opie 2000: Chapter 4).

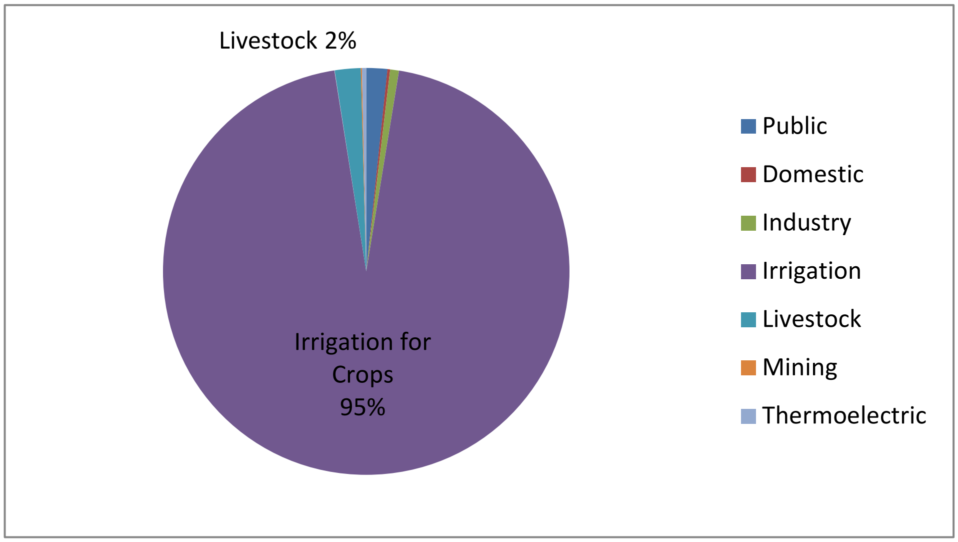

Figure 4: Groundwater use in Southwest Kansas, 2005. Source: U.S. Geological Survey, 2005.

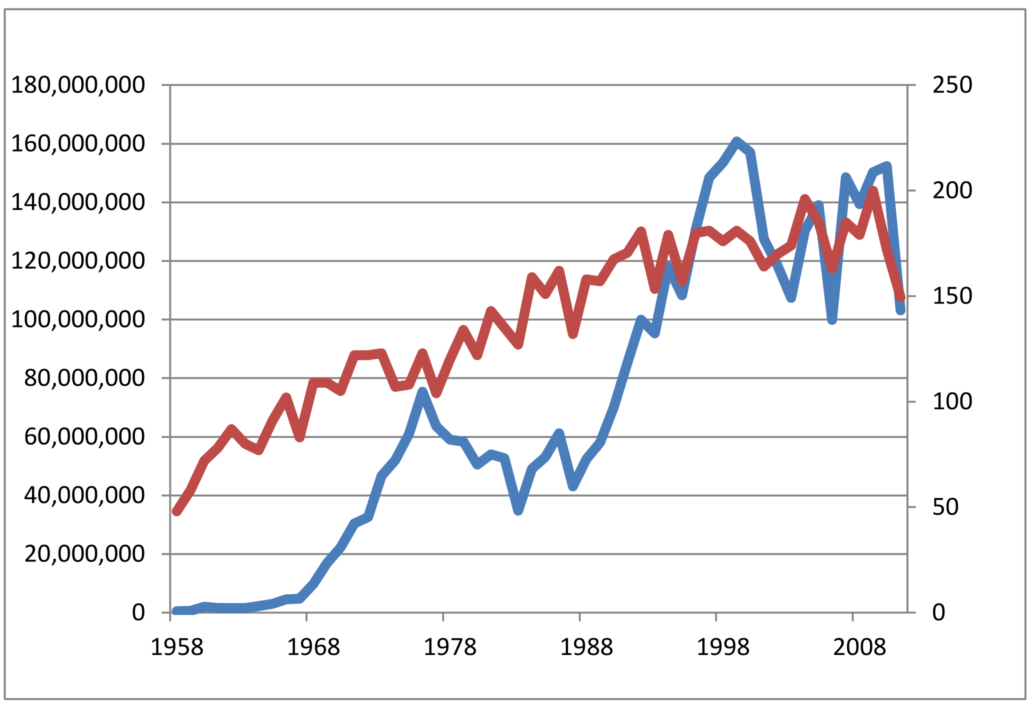

Figure 5: Corn production (bushels) in Southwest Kansas. 1 metric ton of corn = 39.4 bushels of corn. Source: U.S. Department of Agriculture, 2012**.**

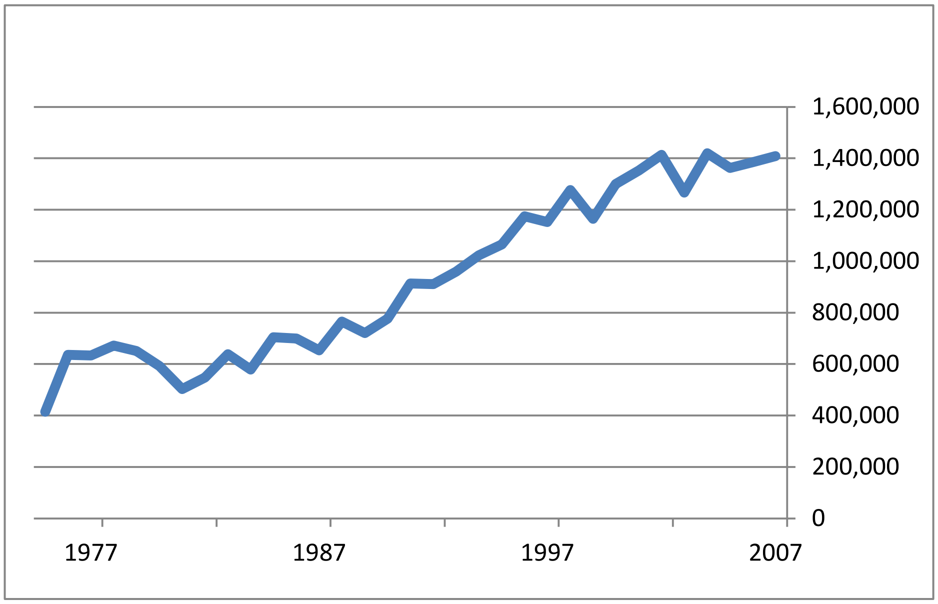

Figure 6: Head of cattle on feed in Southwest Kansas. Source: U.S. Department of Agriculture, 2012.

The expansion of water-intensive export-agricultural production in Southwest Kansas is thus predicated on a metabolic rift in the hydrological cycle, and the rift is an outcome of the tension between the desire of capital to expand through accumulation and natural environmental limits to that expansion. Agricultural production in Southwest Kansas then rests on a contradiction: depletion of the Aquifer has allowed capital accumulation based on water-intensive export-agricultural production, but depletion of the Aquifer has created a metabolic rift that ultimately limits incessant capital accumulation through water-intensive export-agricultural production. This contradiction has existed since the initial development of the region in the late-19th century, and it permeates all aspects of life in Southwest Kansas today.

On the one hand, groundwater depletion is now widely recognized as a problem, or as a limit to further capital accumulation, by key actors from the federal to local levels. In 1987, the U.S. federal government ordered the U.S. Geological Survey, in collaboration with other federal, state, and local water-resource entities, to monitor water levels in the High Plains Aquifer in response to concerns about depletion. The State of Kansas also acknowledges the problem. In 1973, the state of Kansas formed five Groundwater Management Districts, governed by local stakeholders, in the Western and Central portions of the state to oversee the administration of water rights and develop plans for future water consumption (Peck 2007). More recently, Governor Sam Brownback signed into law Kansas House Bill 2451, which eliminated the state's 'use it or lose it' water policy that gave landowners incentive to maximize their water consumption in order to maintain their right to appropriate water from the Aquifer. At the signing ceremony in Garden City, the Governor explicitly recognized the metabolic rift and its implications for the future of Southwest Kansas:

> We must save our water and conserve so we may extend the useful life of the Ogallala Aquifer. Those of you with substantial water permits, I am now asking you to step-up on behalf of your children and grandchildren. I ask you, if you have options, don't use the water. Save it for them...Without water, we have no future. (Office of the Governor, State of Kansas, 2011)

On the other hand, these acknowledgments of a problem, or of an ecological limit to capital accumulation, are juxtaposed against the empirical evidence that documents ongoing depletion. The reasons for this contradiction are manifold, but ultimately, groundwater depletion in Southwest Kansas persists because the region is enmeshed in a political-economic context of uneven development produced by ecological unequal exchange relations with urban or core areas located in the U.S. and elsewhere.

5. Exacerbating the metabolic rift through ecological unequal exchange

Southwest Kansas exports water in various forms, most notably as corn and cattle, but its exports are undercompensated because water is undervalued. Without water, it is not possible to produce corn, cattle, and other exports, but the economic value of water increases only as it is consumed, that is, as its productive potential decreases. The ability to consume water as an input into the agricultural production process gives water its value. Agricultural production transforms water into finished products (i.e., corn, cattle, hogs) with higher economic value or utility, but it diminishes the productive potential of water in the process. The export of corn, cattle, and other commodities is therefore an ecological unequal exchange. Because water is undervalued, there is an undercompensated net transfer of matter and energy, and thus wealth, from the region.

Ecological unequal exchange exacerbates the metabolic rift by impoverishing the region economically and ecologically (e.g., Hornborg 2011; Jorgenson and Rice 2012). There is a strong economic incentive to deplete the Aquifer because consuming more groundwater increases the output of higher-value, finished products. However, the undercompensated export of water drains wealth from the region. Even as agricultural production has increased dramatically, incomes in Southwest Kansas have stagnated. Total farm sales in Southwest Kansas almost tripled from less than US$2 billion in 1969 to nearly US$6 billion in 2011 (in constant 2011 dollars). Total farm income in the region, however, has remained flat, failing to keep pace with the growth in sales. In 1969, net farm income was US$480 million (constant 2011 dollars); in 2011, net farm income was US$558 million, an increase of only 15%.

Wealth is being transferred from Southwest Kansas to urban centers in the state and beyond. Figure 7 illustrates the growing gap between total personal incomes in Southwest Kansas and urban areas in Kansas. There was already a yawning gap in incomes by 1969, near the order of 13:1. In 2011, the income gap between Southwest Kansas and urban Kansas had grown to 17:1. Because living standards in the region are now closely tied to groundwater consumption, further depletion is necessary to maintain living standards. Thus, water and wealth flow out of the region in a reinforcing process. As ecological unequal exchange continues, increasing the incentives to withdraw more water, intensifying the metabolic rift in a vicious cycle that undermines the viability of the agricultural economy in Southwest Kansas.

Ecological unequal exchange undermines the natural resource base on which people's material livelihoods depend, providing incentive to deny the problem or delay addressing it, while reducing the capacity of people to act on the problem. In other words, continuous economic growth is needed to ensure the survival of the export agricultural production complex. And continuous economic growth is dependent on increased extraction of the water from the Aquifer. This treadmill of production (e.g., Schnaiberg 1980; Gould *et al.* 2008) is difficult to dismantle without severe social and economic consequences. While awareness of the problem is pervasive as noted above, those dependent on the treadmill have little choice other than to extract water at unsustainable rates.

Groundwater management policies illustrate the tension between economic growth and ecological limits to growth. In Kansas, groundwater consumption is regulated by the Kansas Department of Agriculture through its Division of Water Resources, which issues permits to appropriate water, or water rights (Peck 2007). Kansas water law is based on the doctrine of prior appropriation, or seniority: when there is insufficient water to meet all water rights, the date of water right determines the right to use it, a doctrine referred to as "First in Time, First in Right." Groundwater management district boards manage water rights using one of two concepts: 'safe yield' or 'allowable depletion.' The safe yield concept is more closely tied to the goal of sustainability, limiting total appropriations to a percentage of estimated recharge to the aquifer within a radius of a well. The concept of allowable depletion, however, explicitly permits groundwater depletion, only limiting total appropriations to a level that will deplete the Aquifer by a specified amount over a specified time horizon within a radius of a well. Allowable depletion is thus otherwise referred to as 'planned depletion.' Groundwater management District 3 in Southwest Kansas employs the concept of allowable depletion, allowing a 40% decrease in saturated thickness over 25 years (McGuire, *et al.* 2003). In effect, the metabolic rift associated with mining the Ogallala Aquifer in Southwest Kansas and the larger High Plains Aquifer area represents a serious challenge to the environment and the people living in the area and it is a sustainability challenge that cannot be easily overcome.

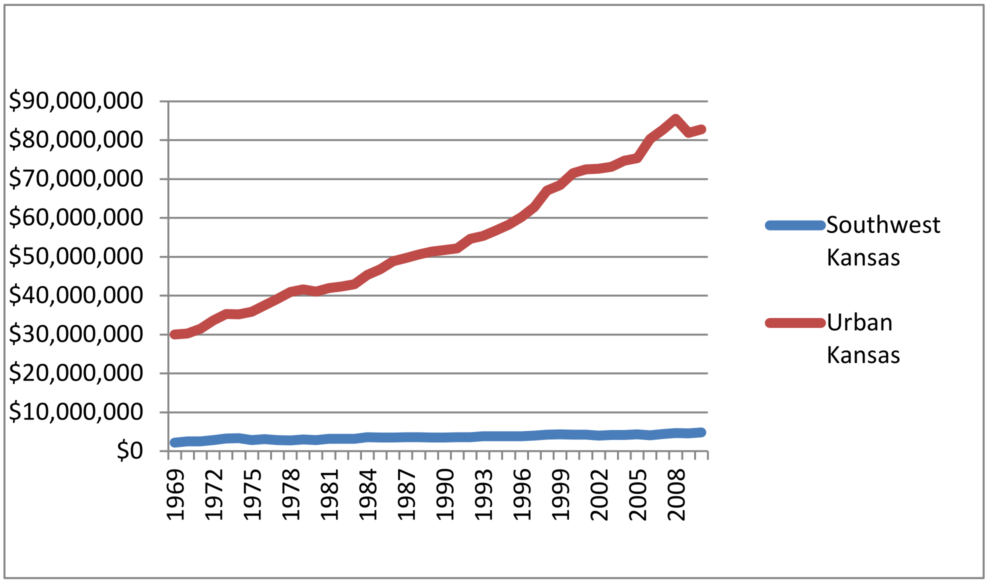

Figure 7: Aggregate (total) personal income for Southwest Kansas (14 counties) and urbanized areas of Kansas, 1969-2010. Source: U.S. Department of Commerce, 2012.

6. Conclusion

The case of the High Plains Aquifer presented here contributes to the emerging literature on the adverse environmental and related consequences associated with the metabolic rift and ecological unequal exchange relations. With few exceptions (e.g., Austin and Clark 2012), research focuses on core nations' extraction of wealth from resource extraction frontiers in peripheral countries (Bunker and Ciccantell 2005; Rodrigues *et al.* 2009) or the displacement of the core's environmental consumption patterns to the waste disposal frontiers in peripheral countries (Frey 2012). Yet our case study shows that the process of ecological unequal exchange, which is commonly studied at the *inter*-national level, across the core-periphery divide in the world-economy, also occurs at the *intra*-national level, across places *within* a country. The High Plains Aquifer in Southwest Kansas is being mined because it is embedded within unequal exchange relations with more politically and economically central areas located in the U.S. and elsewhere in the world-economy.

This export-agriculture complex based on water-intensive export crop and livestock production in Southwest Kansas is not sustainable. Continued technological innovations and organizational adaptation of High Plains agriculture to the semi-arid environment seem unlikely in the face of environmental degradation and socioeconomic uncertainties caused by a declining water supply, declining soil and water quality, and increasing economic costs of irrigation. Despite the visibility of these problems, mining the groundwater will likely continue due to the strong economic incentives built into existing ecological unequal exchange relations.

Complicating the situation, as suggested by several researchers (e.g., Narasimhan 2009; Rosenberg *et al.* 1999), is a warming climate in the region. This will likely further exacerbate the metabolic rift in the hydrological cycle, increasing drawdown of the Aquifer by the export-agricultural production complex, and hastening the decline of the area. The long-term result for Southwest Kansas and elsewhere in the High Plains may very well be the Buffalo Commons proposal envisioned by the Poppers (1987, 1993), in which private land is returned to its natural state, or the return of the Dust Bowl of the 1930s as discussed by environmental historians (Hurt 1981; Worster 1979).

The future is, of course, notoriously difficult to portend. What is clear, however, is that the region's path is untenable. And it is untenable because the political economy of the region depends upon the continued exploitation of a nonrenewable resource. Thus, it is not that "people can't live there unless there is economic activity" (Pew Stateline 03/18/13). Instead, a more accurate rendering of the historical evidence indicates that people can't live there for much longer *because there is economic activity*.

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