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Structural impediments to sustainable groundwater management in the High Plains Aquifer of western Kansas

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Abstract Western Kansas is one of the most important agricultural regions in the world. Most agricultural production in this semi-arid region depends on the consumption of nonrenewable groundwater from the High Plains Aquifer, which will be 70 % depleted by 2070. The problem of depletion has drawn significant attention from local citizens and policymakers at the federal, state, and local levels for at least 40 years, resulting in a variety of policies and institutions to manage groundwater from the aquifer as a common pool resource. Yet depletion has persisted. We explain this conundrum as an outcome of a mismatch between the scale of resource management, which has become more intensively local, and the scale of resource exchange, which has rendered the High Plains Aquifer a global common pool resource. We then explain the deeper, structural origins of the management–exchange scale mismatch. Drawing on concepts from structural human ecology theory and empirical evidence from Southwest Kansas, we show that agriculture is predicated on local metabolic rift in the hydrological cycle that is exacerbated through ecological unequal exchange with higher-income, core areas beyond the region. We conclude by highlighting two key policies that, if implemented together, may lessen the deleterious effects of these structural dynamics and thus promote a more sustainable relationship between society and environment in this region and other water-scarce regions that are net-exporters of groundwater.

Keywords High Plains · Ogallala · Water · Agriculture · Development · Environment · Metabolic rift · Ecological unequal exchange

Abbreviations

DWR	Division of Water Resources
GMD	Groundwater management district
GMDA	Groundwater Management District Act
HPA	High Plains Aquifer
IGUCA	Intensive groundwater use control area
KWAA	Kansas Water Appropriation Act
LEMA	Local enhanced management area

> You've got to reduce your water use, but you've got to keep your economic activity flat to growing… People can't live there unless there's economic activity (Kansas Governor Sam Brownback, March 18, 2013, Pew Stateline 2013).
>
> In the West, it is said, water flows uphill toward money (Reisner 1993, p. 12).

Introduction: the problem

The High Plains Aquifer (HPA) is the largest aquifer in the US, underlying 174,000 square miles in parts of eight states—Colorado, western Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (see Fig. 1). The surface area above the aquifer was formed approximately 65 million years ago from the deposition of

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sediment eroded from the Rocky Mountains and carried by streams flowing eastward toward the Mississippi River (McGuire et al. 2003). The HPA 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 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 (McNeill 2000). As a further illustration, if all of the water in the HPA were placed on the surface, it would fill an area the size of the state of Colorado with water 45 feet deep (McGuire et al. 2003). The water, however, is not distributed evenly. 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 in parts of New Mexico and Texas to 700 feet in Nebraska (McGuire 2011). Most importantly, the HPA 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 essentially a nonrenewable resource over a human time horizon. Thus, water in the HPA is fossil water (Green 1973; Opie 2000).

Water is critical for human survival everywhere, but especially in the High Plains region (Opie 2000; Reisner 1993; Solomon 2010). The region has a semi-arid continental climate with abundant sunshine, low humidity, frequent winds, and only moderate precipitation, usually <19 in. annually in most areas. Some areas in the region receive

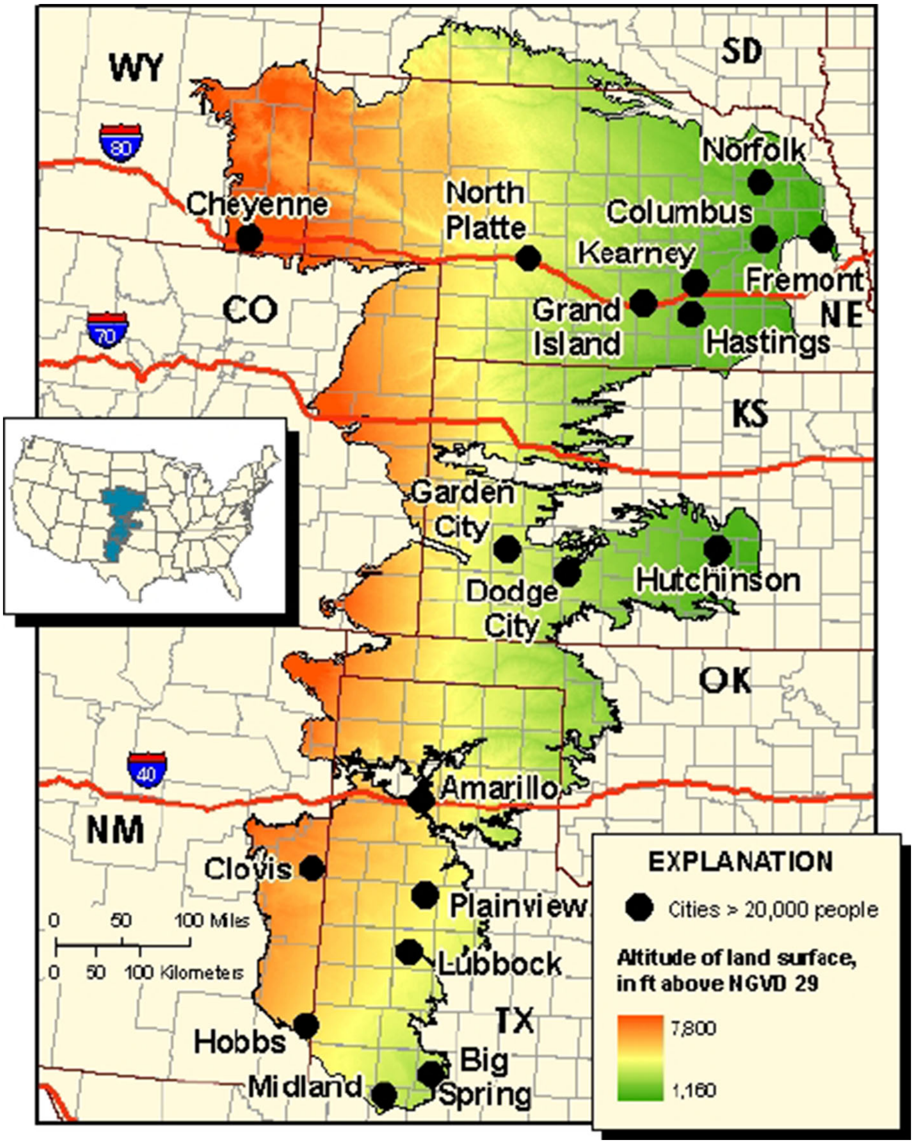

Fig. 1 The High Plains Aquifer. *Source*: U.S. Geological Survey (2013)

<10 in. of annual precipitation, and evaporation rates are relatively high. Temperatures fluctuate widely throughout the year, with differences of up to 100 °F or more between summer highs and winter lows (Gutentag et al. 1984). The region's environmental vagaries and aridity led early Euro-American explorers to describe the region in unflattering terms. In 1806, Zebulon Pike led an exploration of the Southern portion of the Louisiana Purchase through the Great Plains and into Colorado. His post-travel remarks characterized the region as unsuitable for agriculture. He believed the region would instead serve as a natural barrier to settlement, thus preventing a widely dispersed population in the new country (Pike 1811). US government surveyor Stephen Long, who led a subsequent expedition of the Louisiana Purchase in 1820, echoed such sentiments. In maps completed after his return, Long labeled the region "the Great American Desert," and 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, p. 236).

Unbeknown to Pike, Long, and all the others who ventured into the region prior to the late-nineteenth century, was the existence of the HPA, located, in some places, just a precious few feet below the surface. The discovery, and subsequent exploitation, of the HPA transformed the Great American Desert into one of the most productive agricultural regions in the world, earning it the label of "Breadbasket of the World" (Opie 2000). Today, irrigation withdrawals from the HPA support the US Congressional District with the highest market value of agricultural products in the country (U.S. Department of Agriculture 2007), and southwest Kansas is the economic center of this important region (Guerrero et al. 2013). Yet, irrigation withdrawals from the aquifer in this region are unsustainable, as annual precipitation only provides 15 % of pumping needs (Steward et al. 2013). The most recent analysis indicates that the HPA will be nearly 70 % depleted by 2070 and that a depleted aquifer would require 500–1,300 years to be replenished through annual precipitation recharge (Steward et al. 2013).

Since the 1950s, the aquifer has declined precipitously in many areas. The HPA is not only the largest aquifer in the US, 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. The aquifer is a source of drinking water for over 1.9 million people in the region, but irrigation is the principal use. Over 90 % of water withdrawals are for irrigation, and the aquifer comprises 30 % of all the water used for irrigation in the US (Rosenberg et al. 1999). The largest declines have occurred in the areas where deep-well irrigation first appeared. Irrigation demand for most crops in the region is approximately 1 foot per year, exceeding the rate of recharge, which ranges from 2 to 3 in. per year in the sand dune areas of Nebraska to <0.5 in. per year in other areas. Water-level declines have occurred in all High Plains states except South Dakota, where development is relatively sparse. Over 12,000 square miles of Colorado, Kansas, New Mexico, Oklahoma, and Texas have experienced water declines over 50 feet, and 2,500 square miles have experienced declines of more than 100 feet. In southwest Kansas and the panhandles of Oklahoma and Texas, the geographic heart of the Dust Bowl (Worster 1979; Hurt 1981; Egan 2006), more than 50 % of the aquifer was depleted by the late-1970s (Luckey et al. 1981). Some sections of the HPA are now completely exhausted (Opie 2000; White and Kromm 1992) and estimates point to complete depletion in other sections by 2025 (Sophocleous 2005).

Depletion puts at risk the long-term viability of a vital part of the Kansas economy, and indeed a region that is essential to world agriculture. Reductions in withdrawals will be necessary to extend the economic life of the aquifer, but they will come at the expense of agricultural production, which will in turn impact living standards in the region (Gasteyer 2008). Steward et al. (2013) estimate that reducing withdrawals by 20 % would return agricultural production to mid-1990s levels, which would necessitate widespread and intensive economic restructuring in the region. However, to make irrigated agriculture more sustainable in the region, that is, to bring withdrawals closer in line to the rate of natural recharge from annual precipitation, reductions on the order of 80 % would be necessary (Steward et al. 2013), which would radically reshape the economic and social context of the region.

Citizens and governments at the federal, state, and local levels are keenly aware of the importance of unsustainable groundwater consumption levels. In Kansas, 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." Over three decades later, at a meeting of irrigators in southwest 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 2011).

In the 33 years that passed between the Lieutenant Governor's remarks and the more recent comments from irrigators, citizens and governments have developed and enacted a range of policies and administrative procedures to reduce depletion. These efforts have indeed slowed the rate of depletion in many areas. Nevertheless, over these 33 years, total withdrawals have continued to exceed recharge rates over most of the region and widespread drawdown has persisted. 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 2013).

The inability to conserve the very resource on which many local livelihoods, much of an entire state, and indeed a large proportion of American agriculture, depends despite ongoing efforts to do so indicates deeper, unacknowledged tensions in the social structures that shape human interactions with the natural environment and the exchange of natural resources. Kansas Governor Brownback alludes to these tensions in the opening quotation by pointing out that sustaining human populations in the Kansas High Plains requires both economic growth and water conservation. We identify and explain these structural relations in order to more clearly illuminate the challenges of sustainably managing groundwater in this important agricultural region. We focus on the western Kansas portion of the HPA region, and on southwest Kansas in particular, an area of especially intensive rates of groundwater consumption situated in the heart of the historical Dust Bowl region (Worster 1979; Egan 2006; Hurt 1981). We begin by discussing the problem of groundwater depletion from the predominant perspective that has framed policy prescriptions: as an over-consumption problem endemic to many common pool resources; that is, as a tragedy of the commons (Hardin 1968).

The commons problem and the common solutions

The problem of unsustainable groundwater consumption in the HPA region did not emerge recently, nor has it only recently been acknowledged as a problem. There have been a series of policies and institutions designed to manage groundwater consumption more sustainably. Most, if not all, of these policies and institutions are grounded in the predominant interpretation of the problem as one endemic to common pool resources: over-consumption (Hardin 1968; Ostrom et al. 1999). A common pool resource has two characteristics: it is difficult to exclude users from access to the resource (i.e., the exclusion principle); and use of the resource by one user affects the availability of the resource for other users (i.e., the subtractability principle) (Ostrom et al. 1999). From the predominant perspective, users of common pool resources are usually presumed to be rational actors that act to maximize their self-interests. Rational, utility-maximizing actors will thus tend to consume the resource until the benefits of doing so are approximately equivalent to the costs of consumption. From any user's point of view, there is little incentive to be concerned about the costs imposed on other users. Instead, there is an incentive to reap the benefits from consumption first and fastest, lest others benefit from the same resource. Thus, common pool resources often experience Hardin's (1968) tragedy of the commons: destruction of the resource resulting from over-consumption by actors behaving in their own rational, self-interest. The tragedy of the commons is one of both time and scale: short-term, individual interests undermine long-term, collective interests in the sustainability of the resource.

Interpreting the HPA as a common pool resource has produced policies and institutions that attempt, first and foremost, to address the issue of resource access (i.e., the principle of exclusion) by more clearly defining the rights to the resource. Here, property rights have been the key policy tool. By clearly specifying access to the resource, users can more clearly identify other users, and as a result, the group can "draw on trust, reciprocity, and reputation to develop norms that limit use" (Ostrom et al. 1999, p. 279). Thus, addressing the problem of exclusion by more clearly defining property rights also addresses the problem of subtractability, as users will be less likely to draw down the resource at the expense of other users.

Kansas water law is firmly grounded in the establishment of property rights as a means of regulating access to the state's water resources, including groundwater from the HPA. The Kansas Water Appropriation Act (KWAA) of 1945 is the basis for all water law in the state. The KWAA gives to the state the authority to regulate and control water use under the "beneficial use" provision: that any use of water in the state would be "dedicated to the use of the people of the state, subject to the control and regulation of the state" (Peck 2006, p. 506). Since the KWAA, the state's Division of Water Resources (DWR) regulates access to water. DWR issues water permits, which are granted using the doctrine of prior appropriation, also referred to as "first in time, first in right" (Peck 2006; Sophocleous 2010). A permit defines the seniority of the right relative to others, if the doctrine of prior appropriation was applied, and indicates the annual withdrawal limit for a specific location.

Water rights have not been successful in stemming groundwater decline in the HPA, as evidenced by continued decline in water levels since the KWAA was enacted in 1945. The failure of property rights, in and of themselves, to stem decline was implicitly recognized in the Groundwater Management District Act (GMDA) of 1972. Following sharp declines in groundwater levels through the 1960s, the Kansas legislature enacted the GMDA, which established five groundwater management districts (GMDs) in the central and western portions of the state, including much of the area overlying the HPA. GMDs are governed by local boards of directors, which are given the power to develop management plans, standards, and policies for access and use of water, and to enforce these standards and policies on users in the districts. GMDs have overseen the development of a series of new regulations on users, including well-spacing requirements, which limit the number of wells within a particular radius of other wells, and water metering and reporting requirements (Peck 2006).

Several additional policies have strengthened the KWAA and the GMDA. In 1977, the Kansas legislature amended the KWAA to make diverting water for any non-domestic use a criminal offense without a permit (Sophocleous 2012a). The GMDA was amended in 1978 by the Kansas legislature to allow the state's Chief Water Engineer to designate Intensive Groundwater Use Control Areas (IGUCAs) in places where groundwater levels were deemed to have declined significantly or otherwise where more stringent regulation was necessary in the public interest (Sophocleous 2012b). IGUCAs are powerful policy instruments. This designation can close an area to any new water permits, reduce allowable withdrawals among existing permit holders, and require rotation of water diversions within an area (Sophocleous 2012b). There are currently eight IGUCAs in Kansas (Sophocleous 2012a).

Since the establishment of GMDs in 1972, the rate of groundwater decline has slowed, but groundwater depletion has persisted. As groundwater depletion has continued, yet another policy institution has been developed. In 2012, the Kansas legislature allowed GMDs to create local enhanced management areas (LEMAs). While a GMD spans multiple counties, a LEMA moves control even closer to local users in an attempt to more effectively manage groundwater. Currently, there is only one LEMA in Kansas: the Sheridan County 6 LEMA (located in GMD #4), which is comprised of just 99 square miles, 25,000 irrigated acres, 195 wells, and 110 landowners in Sheridan and Thomas Counties. Users within the LEMA voluntarily agree to reduce groundwater withdrawals by 20 %, equivalent to a reduction from 14 in. of water applied per year to 11 in. per year, over a five-year period for the explicit purpose of "extending the life of the aquifer" (Kansas Department of Agriculture 2014). As of this writing, the state's second LEMA (located in GMD #1) is in the early stages of implementation (Garden City Telegram 2014).

The problem with common solutions to commons problems

Whether LEMAs will be more successful than GMDs in conserving groundwater remains to be seen. The persistence of depletion in the face of nearly 70 years of reforms suggests that policies and institutions designed for managing the HPA as a common pool resource are not sufficient to ensure the long-term sustainability of water resources in the region. The ineffectiveness of groundwater management policies and institutions is not an original observation. Indeed, the National Research Council (2001, 2004) contends that extant institutions for managing water as a common pool resource are not adequate for ensuring sustainability. John Peck, a leading authority on Kansas water law in particular, states succinctly: "Our (groundwater) mining problems have arisen despite the existence of a reasonably clear water law that establishes and respects property rights and ostensibly protects the public interest" (2003, p. 502).

There are examples of effective, sustainable management of common pool resources from around the world (National Research Council 1986, 2002; Ostrom 1990). Management of the HPA in western Kansas includes several institutional arrangements that are common to cases of sustainable management (Dietz et al. 2003; Ostrom et al. 1999). For example, property rights allow for identification of users: access to groundwater, and use of groundwater, is monitored throughout the region through well spacing requirements and well metering; groundwater management institutions have been developed from the state level (i.e., DWR) to more local levels (i.e., GMDs and LEMAs); but local organizations still exist within nested layers of governance, and information is shared across the layers of governance through annual reports and meetings.

While common pool resources have been sustainably managed in several cases, there are also many examples of failed management (Dietz et al. 2003), especially where groundwater is the common pool resource. The inability of institutions and policies to enact more sustainable management of the HPA is attributable to several challenges of managing groundwater as a common pool resource. Common pool resources are more clearly defined when the resource itself is stationary (Ostrom et al. 1999). In this sense, viewing the HPA as a common pool resource requires seeing the water in the aquifer as if it is water in a bathtub. However, groundwater in the HPA is not entirely stationary; it moves, albeit slowly, making it more difficult to identify the boundaries of the resource and thus to minimize negative externalities to users by more clearly defined rights to the resource. Thus, minimizing overconsumption through policies and institutions designed for common pool resources is more challenging when the resource cannot be as clearly defined as a common pool.

Beyond limitations to management that are related to the intrinsic nature of the resource itself, unsustainable water consumption in the HPA is also attributable to the design, structure, and implementation of water management in the region. Some components of the KWAA, and the doctrine of prior appropriation which serves as the basis for the Act, might promote more sustainable water consumption if they were more strictly applied. For example, the KWAA gives the state the right to limit access to groundwater through the issuance of water permits. Yet, water has been over-allocated under the permit system. As of 2010, the Kansas DWR has issued approximately 35,000 permits (Sophocleous 2012a) and nearly 75 % of these permits were issued during a period of rapid development of agricultural production in western Kansas from 1963 to 1981 (Pfeiffer and Lin 2012). During this time, "groundwater pumping permits were granted to nearly anyone who requested them" (Pfeiffer and Lin 2012, p. 18). Indeed, prior to 1971, "DWR was essentially approving all groundwater applications without evaluating them" (Sophocleous 2012a, p. 552). Despite over-allocation of water, however, the state could have applied the doctrine of prior appropriation to stem over-consumption. However, the DWR has never enforced the doctrine of prior appropriation, the most fundamental component of Kansas water policy. For nearly 70 years, junior water permit holders have never been ordered to reduce withdrawals in favor or more senior permit holders, despite continued declines in the aquifer (Pfeiffer and Lin 2012).

Other components of the KWAA have directly inhibited water sustainability. For example, the doctrine of prior appropriation includes a stipulation requiring that a water right must be abandoned if the user does not allocate a sufficient amount of water to fulfill the permit over a 5-year period. This stipulation, commonly referred to as 'use it or lose it', was repealed only in 2012 and likely exacerbated groundwater declines throughout the twentieth century; at a minimum, the 'use it or lose it' provision did not promote water conservation. Thus, two key components of state water policy, the doctrine of prior appropriation and the permit system of water rights, have been quite limited in their practical capacity to sustainably manage groundwater.

Beyond policy, unsustainable groundwater consumption is attributable to flaws in the design and implementation of GMDs, the most significant institutions developed to manage groundwater in the region. Groundwater management district boards, where key decisions are made for entire sub-regions of western Kansas, are not representative of all stakeholders in the areas overlying the HPA (Peck 2006). Instead, GMD boards are comprised mainly of irrigators. Management of common pool resources is more effective in ensuring long-term sustainability of the resource if the interests of all stakeholders are represented in decision-making (Ostrom et al. 1999; Dietz et al. 2003). Including all stakeholders in decision-making is important because of the inherently unequal distribution of benefits and costs associated with use of common pool resource: the benefits accrue mainly to the direct consumers but the costs of consumption are spread among all stakeholders in the region (Giordano 2009). Groundwater depletion does not just affect irrigators; it affects everyone living in communities over the HPA. Yet GMD boards have not been diversified to include the voices of other stakeholders in the region. This flaw in the institutional design of GMDs has inhibited groundwater sustainability (Peck 2006).

Even though they lack broad representation, GMDs can enact policies supporting more sustainable water consumption. For example, the two central Kansas GMDs (GMD #2 and GMD #5), both of which cover the less-arid portions of the HPA, adopted 'safe-yield' management plans that place priority on attempting to match inflows to the aquifer with outflows from the aquifer (Sophocleous 2012a). Safe-yield policies have been relatively successful in reducing the number of permits for appropriation and lowering the rate of depletion in the central Kansas GMDs.

The western Kansas GMDs (GMD #1, GMD #3, and GMD #4), which overlie the more arid, but also more agriculturally productive portions of the HPA have not enacted safe-yield management plans, but instead have chosen management strategies that follow a 'planned depletion' formula (Peck 2003). Planned depletion policy allows up to 40 % depletion of the groundwater supply over a 20–25 year period (Sophocleous 2000) in an attempt to merely slow the rate of decline and prolong the resource for as long as possible (Sophocleous 2012b). Planned depletion is an explicit acknowledgment that the groundwater "is viewed as a non-renewable resource at least within a human generation" (Sophocleous 2012a, p. 553). Thus, the implementation of a planned depletion policy is especially clear evidence that water management is simply not designed to ensure the sustainability of the western Kansas portion of the HPA.

Ultimately then, if the HPA is viewed as a common pool resource, it is a case study in failure; yet another tragedy of the commons. The policies and institutions developed to manage the HPA in western Kansas as a common pool resource have failed to support a sustainable supply of groundwater for future generations, and this failure is by design; it is an outcome of the very policies and institutions developed to manage the resource.

A common pool resource perspective of the HPA is not necessarily wrong, but it is incomplete as an explanation of unsustainable groundwater consumption. A common pool resource perspective directs attention to the physical boundaries of the HPA. From this perspective, identifying the boundaries of HPA as a common pool resource is the prerequisite for addressing the problem of groundwater decline within the region. In doing so, the means of addressing the commons problem are delimited to the region overlying the HPA, and more specifically to the actors (i.e., the citizens, irrigators, and others) inhabiting the region. This perspective, however, is incomplete in that it does not account for the ways in which local actors are involved in, and shaped by, relations with social structures that extend far beyond the region demarcated by the common pool resource. Indeed, exchanges between local actors and extra-local, or external, actors that form enduring, patterned relations, or structures, are crucial for understanding environmental resource problems in particular localities. Moreover, these exchanges have only become more important as human relations have expanded and intensified across space through globalization. Dietz et al. describe how the "struggle to govern the commons" is intricately bound up with the globalization of social structures, within which local actors attempt to manage environmental challenges in particular places that are shaped by actors and exchanges at much higher levels of organization:

> The most important contemporary environmental challenges involve systems that are intrinsically global (e.g., climate change) or are tightly linked to global pressures (e.g., timber production for the world market)… These situations often feature environmental outcomes spatially displaced from their causes and hard-to-monitor, larger scale economic incentives that may not be closely aligned with the condition of local ecosystems (Dietz et al. 2003, p. 1908).

If it has been difficult to support sustainable groundwater consumption in the HPA region, it is because the scale of management does not match the scale of material exchanges that affect the common pool resource. Local actors manage the resource, but their preferences and behaviors are profoundly shaped by interactions with national and international actors in international agricultural markets. This management-exchange scale mismatch has increased over time, as markets for agricultural products from the region have globalized while responsibility for managing groundwater has become even more intensely local.

Below, we refine a common pool resource perspective of the HPA by extending the focus of the problem of depletion beyond the area of the aquifer itself to include exchanges and interactions with non-local actors. In doing so, we identify the problem of groundwater depletion in the HPA not only as common pool resource problem, but as a global common pool resource problem that is grounded in two, related structural challenges inhibiting sustainable management: a local metabolic rift between society and the natural environment in western Kansas and ecological unequal exchange in agricultural exports from the region.

Agricultural production and a local metabolic rift

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 runs off into streams and rivers, which carry the water 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 HPA 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.

However, sustaining life in a place requires that human interventions in the hydrological cycle do not disrupt the metabolic processes that replenish and renew the cycle in that particular place. A "metabolic rift" (Foster 1999) 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, p. 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 localized 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.

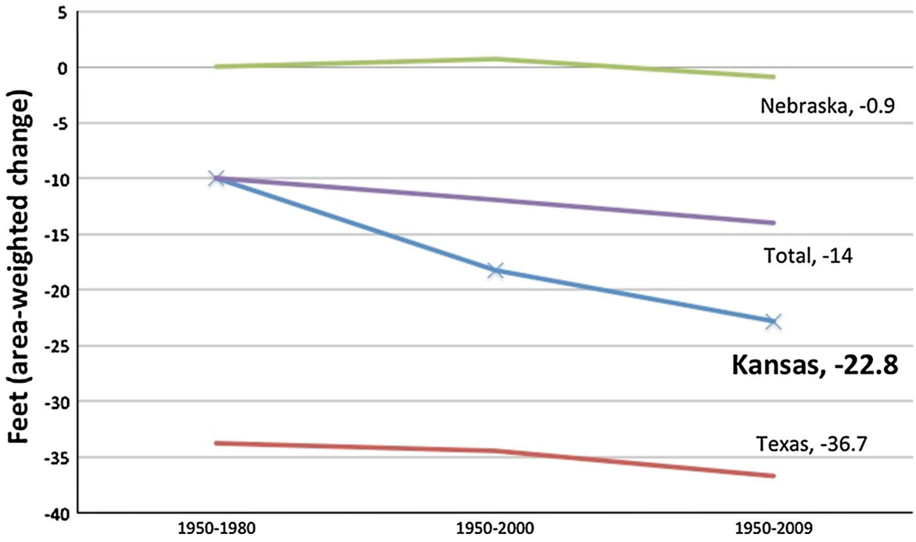

Fig. 2 Water level change in the High Plains Aquifer, 1950–2009. *Source*: U.S. Geological Survey (2011a, b)

In southwest Kansas, human intervention in the form of agricultural production has caused a localized metabolic rift in the hydrological cycle, as evidenced by groundwater depletion. Figure 2 shows trends in the HPA water levels from 1950 to 2009 (records of the aquifer levels were not kept prior to 1950). The severity of the problem varies across the HPA region. For example, the HPA has only declined an estimated one foot 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. Kansas is second only to Texas in the level of groundwater depletion. In just 60 years, an average of nearly 23 feet of water has been drained from the HPA in western Kansas. In short, the water is being mined. The 14 counties of southwest Kansas consumed nearly 1.5 billion gallons of groundwater per day in 2005 (U.S. Geological Survey 2005). Intensive and prolonged groundwater consumption has diminished surface water levels in southwest Kansas 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 HPA portion of western Kansas and begins again in south central Kansas.

As Fig. 3 shows, the vast majority (95 %) of groundwater withdrawals in southwest Kansas are for irrigation and livestock. Irrigation for crops is the single largest use, consuming 1.43 billion gallons of groundwater each day. Livestock 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 each day.

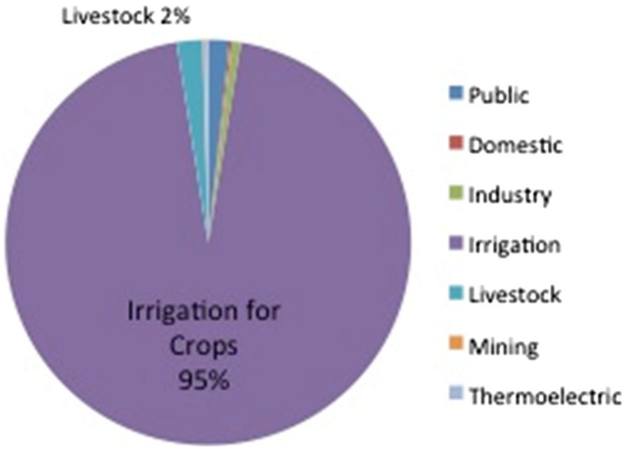

Fig. 3 Groundwater consumption, 2005. *Source*: U.S. Geological Survey (2005)

The metabolic rift in southwest Kansas supports the expansion of agricultural production in the region. Figures 4 and 5 illustrate trends in corn and livestock production, respectively, 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 <20 in. of precipitation for an entire year, including winter, which is not conducive to corn production. Yet corn requires approximately two feet 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, a 20,000 % increase over output in 1958 (497,000 bushels). And production in 2011 was actually lower than in recent years; the 1999 corn crop totaled 160 million bushels.

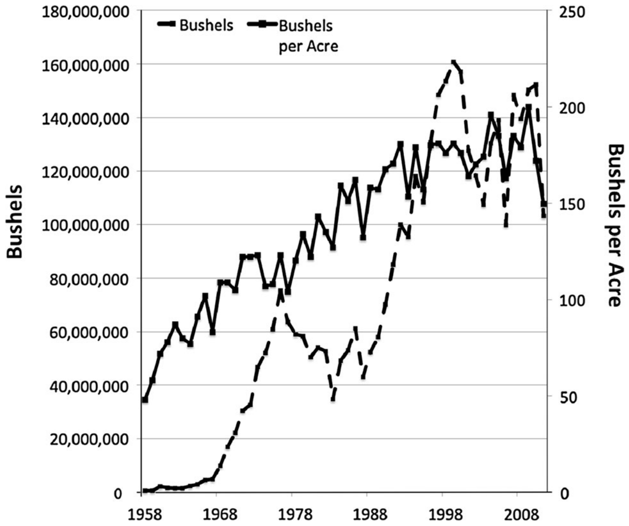

Fig. 4 Corn production, 1958–2011. *Source*: U.S. Department of Agriculture (2012)

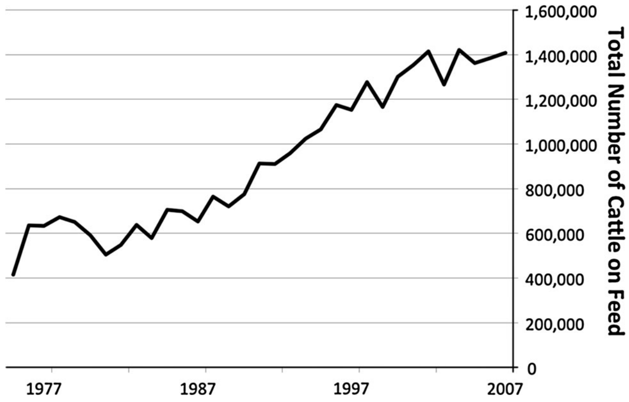

Fig. 5 Cattle on feed, 1975–2007. *Source*: U.S. Department of Agriculture (2012)

Beef production is even more water-intensive. It is estimated that approximately 4,000 gallons of water are required to produce one pound of beef (Mekonnen and Hoekstra 2012). Since 1975, the number of cattle on feed has risen 240 % to nearly 1.4 million in 2007 from 415,000 in 1975. Without groundwater from the aquifer, the production of livestock and irrigated crops such as corn would not be possible in southwest Kansas (Opie 2000). The expansion of groundwater-intensive agricultural production in this region is thus predicated on a localized metabolic rift in the hydrological cycle.

A local metabolic rift in a global common pool resource

The metabolic rift has persisted in large part, and despite widespread acknowledgment of the problem among local actors, because local actors are embedded within broader, international circuits of material-ecological exchange. In principle, a metabolic rift in a common pool resource can be addressed more effectively if exchange of the resource occurs in an area that is at least approximately delimited by the natural boundaries of the resource. In this case, for example, groundwater would be drawn down by local agricultural producers who are satisfying local consumption demand. Here, the prescriptions for managing common pool resources are more effective because the scale of resource management better matches the scale of resource exchange.

Yet the scale of groundwater management in the HPA in western Kansas does not match the scale of groundwater exchange. Local agricultural producers are not producing for local consumers; they are instead meeting demand from consumers in national and international markets. Agricultural export data are not available at the county-level in the US, but state-level data demonstrate the scale of non-local consumer demand for Kansas' agricultural products, the vast majority of which emerges from southwest Kansas. Agricultural production in Kansas far exceeds the capacity of Kansans to absorb it. Agricultural exports from Kansas totaled $4.9 billion in 2012, making Kansas the seventh-largest agricultural export-producing state in the US (U.S. Department of Agriculture 2014). Kansas is the nation's largest exporter of wheat ($1.3 billion), the third-largest exporter of beef ($639 million), the fifth-largest exporter of processed grains ($341 million), and the eighth-largest exporter of corn ($329 million).

State-level exports are conservative indicators of the scale of exchange because they only include the agricultural products produced in Kansas that are exported from the United States to other countries. Agricultural products from the region need not leave the country to have an impact on groundwater supplies and groundwater management in southwest Kansas. In this respect, the region's production figures described above more accurately capture the mismatch between the scale of exchange and the scale of management. The extent to which agricultural production in southwest Kansas is oriented to consumption in southwest Kansas can be expressed as the ratio of agricultural production to total population. Figures 6 and 7 present these ratios for corn and cattle, respectively. If local consumer demand drives local agricultural production, the ratio should equal a level that roughly approximates what a typical consumer could consume in 1 year.

Figure 6 shows that in 1960, the ratio of corn production to population in southwest Kansas was 22, which means that 22 bushels of corn, or approximately 1,232 pounds (at 56 pounds per bushel), were produced in southwest Kansas for each person in southwest Kansas. In 2010, the ratio equaled 1,101, a 49-fold increase. This means that 1,101

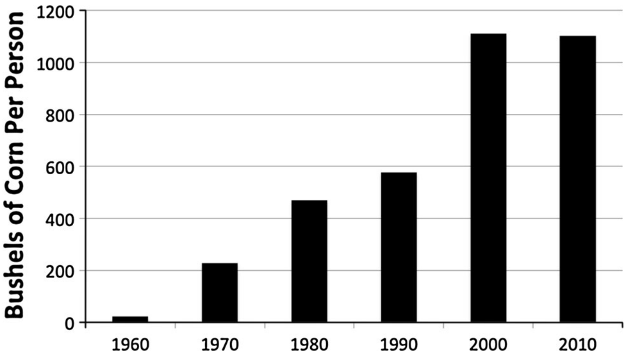

Fig. 6 Corn production per person, 1960–2010. *Source*: U.S. Department of Agriculture (2012)

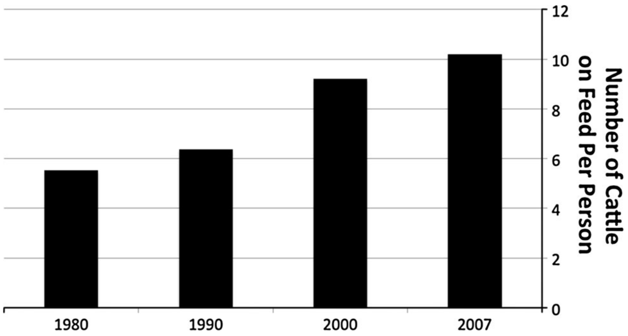

Fig. 7 Cattle production per person, 1980–2007. *Source*: U.S. Department of Agriculture (2012)

bushels of corn, or nearly 31 tons, were produced for each person in southwest Kansas. Figure 7 provides the ratios for cattle production. In 1980, there were 5.5 cattle on feed per person in southwest Kansas. At an average slaughter weight of 1,000 pounds, agricultural producers produced nearly 5,500 pounds of cattle for each person in southwest Kansas in 1980. The ratio had nearly doubled by 2010 to 10.2, indicating that there were approximately 10,200 pounds of cattle in southwest Kansas for each person in southwest Kansas. Agricultural production in southwest Kansas far exceeds consumption needs in southwest Kansas. Indeed, agricultural producers in southwest Kansas are supplying non-local consumption demands.

Focusing on the agricultural products themselves, however, conceals the fact that agricultural producers in southwest Kansas are actually exporting water from a water-scarce region. Finished agricultural products have some water content, but the total amount of water used to produce the product is usually much larger, often by an order of magnitude. The water footprint (Hoekstra and Chapagain 2008) captures the total amount of water used to produce a product. The water footprint includes three components: surface and groundwater ("blue water"), precipitation ("green water"), and pollution, or the volume of water needed to dilute polluted water so that it can meet water quality standards ("grey water") (Hoekstra and Chapagain 2008). This metric is sensitive to place: the calculation of the water footprint for an agricultural crop incorporates specific crop characteristics, climate parameters such as ambient temperatures and humidity levels, and soil water availability in the place where the crop is produced.

The water footprint can be used to estimate the amount of water embedded (Allan 1998) in the agricultural products that are transferred out of southwest Kansas to meet non-local consumption demand through agricultural trade. The water footprint for producing corn in Kansas is 910 m^3/t (Mekonnen and Hoekstra 2012) and southwest Kansas produced 4.2 million tons of corn in 2010. Thus, an estimated 3.8 billion cubic meters of water, or over 1 trillion gallons (3.1 million acre-feet), was embedded in the 2010 western Kansas corn harvest, an amount of water that would cover most of the state of Connecticut (3.56 million acres) with water one-foot deep. The water footprint for beef production is Kansas is significantly larger: 14,181 m^3/t (Mekonnen and Hoekstra 2012). Given that there were 1.4 million cattle on feed in southwest Kansas in 2007, and assuming an average slaughter weight of 1,000 pounds, southwest Kansas produced 745,000 t of beef. The associated water footprint equaled 10.5 billion cubic meters of water, or over 2.8 trillion gallons (8.6 million acre feet), an amount that would cover the states of New Jersey and Connecticut in water one-foot deep.

The groundwater footprint (Gleeson et al. 2012) provides additional evidence of the degree to which groundwater from the HPA is used to meet non-local consumption demand. The groundwater footprint is "the area required to sustain groundwater use and groundwater-dependent ecosystem services of a region of interest such as an aquifer" (Gleeson et al. 2012, p. 197). It is calculated by dividing the average extraction of groundwater for an area in a year by the difference between the long-term recharge rate and groundwater contribution to maintain stream flows. The ratio of the groundwater footprint area to the actual area of the aquifer greater is an indicator of "groundwater stress" (Gleeson et al. 2012, p. 198). Ratio values >1.0 indicate environmental stress due to over-allocation of groundwater. Ratio values significantly >1.0 indicate "unsustainable groundwater mining, often of fossil groundwater recharged under past climatic conditions" (Gleeson et al. 2012, p. 199). The ratio for the HPA is 9.1: that is, the area required to sustain groundwater use and ecosystem services that depend on groundwater in the High Plains is nine times larger than the actual area of the HPA.

The available data provide significant evidence of a metabolic rift in the hydrological cycle of the HPA, and strongly suggest that this rift has developed through non-local consumption demand, a large portion of which is situated in global markets. Thus, if the HPA is in any sense a common pool resource, it is a common pool resource embedded within global circuits of exchange between producers and consumers; it is a global common pool resource. Therefore, if the myriad local policies and institutions have not been able to sustainably manage groundwater in southwest Kansas, it is due in large part to a mismatch in the scale of resource governance and the scale of resource exchange. Agricultural producers and state and local officials in Kansas are trying to manage a local resource that is being depleted through exchanges with distanced consumers in extra-local markets.

Ecological unequal exchange in a global common pool resource

Agricultural exports drive the metabolic rift in southwest Kansas, and because of the management-exchange scale mismatch, they make sustainable management of groundwater much more difficult, but these exchanges are not sufficient as an explanation of the metabolic rift. Agricultural trade exchange, in and of itself, is not necessarily detrimental or beneficial for groundwater supplies in southwest Kansas. To more thoroughly explain the rift, it is necessary to investigate the *nature* of the exchange itself.

Through trade, agricultural producers in southwest Kansas export significant amounts of animal and crop products, but these exports also transfer large volumes of water in various forms out of the region to satisfy non-local consumer demand. These exchanges are both monetarily and ecologically unequal, placing agricultural producers in southwest Kansas on a production treadmill that exacerbates the metabolic rift in the hydrological cycle and further complicates efforts to manage groundwater in the region more sustainably.

The Earth is limited in its capacity to transform solar energy into biomass, or ecological capital (Andersson and Lindroth 2001), but human living standards develop, and are maintained, through the appropriation of ecological capital. There is tension, then, between the need to continually expand and intensify the appropriation of ecological capital to support development and the natural limits to development. Groundwater depletion, as a metabolic rift, is evidence of this tension.

If humans living in one place consume more ecological capital than the biophysical capacity of the place to support it, the place experiences an ecological deficit. Ecological deficits, or surpluses, can be assessed using the ecological footprint measure, which is defined as the "area of ecologically productive land (and water)…that would be required on a continuous basis to (a) provide all the energy/material resources consumed, and (b) absorb all the wastes discharged by the population with prevailing technology, wherever on Earth that land is located" (Wackernagel and Rees 1996, pp. 51–52). Where the ecological footprint of a place exceeds the actual area of the place, there is an ecological deficit. Gleeson et al.'s (2012) groundwater footprint described above indicates a very severe ecological deficit, or metabolic rift, in the HPA region.

Metabolic rifts can be exacerbated through ecological unequal exchange: the disproportionate and undercompensated transfer of matter and energy from lower-income, peripheral places to higher-income, core places (Bunker 1984; Hornborg 1998; Jorgenson 2003; Rice 2007a). A society with an ecological deficit can exist only until the biophysical capacity of the place is exhausted. Through trade, however, a society with an ecological deficit can maintain, and even preserve, their ecological capital by expropriating ecological capital from other places. These exchanges are "ecologically unequal" (Andersson and Lindroth 2001, p. 117) if the import and export of resources between the partners, measured as ecological footprints (Wackernagel and Rees 1996), are unbalanced. That is, if producers in one place import more ecological capital from their trading partners than they export to their trading partner, or vice versa, the exchange is ecologically unequal. Ecologically unequal exchange is unsustainable if either or both of the trading partners have an ecological deficit (Andersson and Lindroth 2001).

In this respect, agricultural exports from southwest Kansas are unsustainable because they are part of an ecologically unequal exchange relationship between producers in the region and their trade partners. Natural resource consumption is predominantly a function of aggregate income, more broadly defined as the level of development (World Resources Institute 2005). Higher income places with more extensive built infrastructures and larger consumer markets consume higher levels of natural resources, and as a result, higher-income places have larger ecological footprints that often overshoot the biophysical capacities of their territories (Jorgenson 2003, 2005; Fischer-Kowalski and Amann 2001). To support development, higher-income places therefore often import biocapacity through trade with lower-income, more peripheral places (Rice 2007b). Thus, in a stratified world economy structured by large and persistent income differentials between places, there is a 'vertical flow' (Bunker 1984) of ecological capital from less-developed, peripheral places to more-developed, core places. This vertical flow is the 'social metabolism' of the world economy (Fischer-Kowalski 1998), as the material throughput necessary to support living standards in higher-income places flows upward from lower-income places. Environmental impacts are spatially uneven because development is both spatially uneven and relational:

ecological unequal exchange promotes development in higher-income, core places by expropriating ecological capital from lower-income peripheral places, which are 'under-developed' in the process (Bunker 1984; Bunker and Ciccantell 2005).

Exports of ecological capital from less-developed places are not only disproportionate, they are also undercompensated, which further enhances inequality between places. Groundwater exports are especially undercompensated. Fresh water is exceptionally scarce. Less than 1 % of water in the hydrological cycle is available for humans as freshwater (United Nations 2003), yet fresh water is the one resource that supports all biological life. Given its scarcity and its importance, the price of water does not reflect its value (Hoekstra 2013; Allan 2011). Instead, the value of water is only recognized as it is transformed, or consumed; that is, as its productive potential decreases (Hornborg 1998).

Without water, it is not possible to produce corn, cattle, or any other agricultural product. Agricultural production consumes water, transforming it into finished products (i.e., corn and cattle) that have higher economic value or utility, but diminishing the productive potential of water in the process. The ability to consume water as an input into the agricultural production process thus gives water its value. Because water is undervalued, agricultural exports are undercompensated net transfers of matter and energy, and thus ecological and economic wealth, from the region.

To the extent that the economic wealth created through value-added agricultural production is not retained locally, there is a further transfer of wealth out of the exporting region. Through ecological unequal exchange, ecological capital is siphoned away from less-developed, net-exporting regions, to more-developed, net-importing regions, where it in effect subsidizes higher living standards through cheaper goods. Because their exports are undercompensated, agricultural producers face a production treadmill (Schnaiberg and Gould 1994): they must continually expand production in order to maintain their living standards, or avoid declining living standards. Ecological unequal exchange thus exacerbates the metabolic rift, as living standards depend directly on continually drawing down an under-valued resource.

Ecological unequal exchange thus impoverishes net resource-exporting regions both ecologically and economically, resulting in a consumption-degradation paradox (Hornborg 2009; Jorgenson 2003; Rice 2007a): higher-consuming places tend to have the lowest levels of environmental degradation within their borders, while lower-consuming places tend to the have highest levels of environmental degradation. In this respect, groundwater from the HPA is being extracted from southwest Kansas to support development in higher-income, more-developed places that consume its agricultural products through trade. If ecological unequal exchange holds any veracity for the HPA in southwest Kansas, there should be evidence of a consumption-degradation paradox. There should be very little or no relationship between groundwater depletion and incomes in southwest Kansas, but a quite strong, positive relationship between groundwater depletion and incomes in higher-income, core places such as urban areas, for example.

Figure 2 shows that there is significant groundwater decline in Kansas. Figure 3 illustrated that irrigation is responsible for 95 % of groundwater withdrawals. Figures 4, 5, 6 and 7 showed that there have been spectacular increases in agricultural production in southwest Kansas on both an aggregate and per capita basis. The question of ecological unequal exchange hinges upon whether groundwater depletion in southwest Kansas has supported increased living standards, or development, in southwest Kansas, or whether groundwater depletion is instead associated with rising living standards elsewhere.

Figure 8 plots aggregate income in southwest Kansas against aggregate incomes in urban Kansas since 1969. There is evidence that southwest Kansas is involved in ecological unequal exchange, resulting in a consumption-degradation paradox. Over time, aggregate incomes in southwest Kansas have remained stagnant, nearly flat while incomes in urban Kansas have increased. The income gap between southwest Kansas and urban Kansas has indeed widened substantially.

Southwest Kansas evinces a consumption-degradation paradox that is characteristic of ecological unequal exchange. Depletion of the HPA does not seem to have purchased higher living standards for citizens in southwest Kansas. Instead, depletion has supported rising living standards elsewhere, as higher-income urban areas in Kansas and far beyond has externalized a large share of the costs of their environmental consumption onto southwest Kansas. Southwest Kansas is depleting and exporting a scarce and precious resource from a water-scarce region

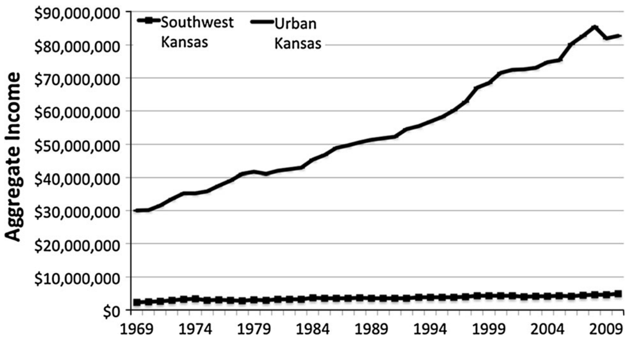

Fig. 8 Aggregate personal income (inflation-adjusted), 1969–2010. *Source*: U.S. Department of Commerce (2012)

but is not reaping most of the economic gains. As Reisner (1993, p. 12) described, "In the West…water flows uphill toward money."

Ecological unequal exchange further complicates sustainable management of the HPA as a common pool resource by both exacerbating the metabolic rift and the scale mismatch problem. The disproportionate and undercompensated export of groundwater from the region places agricultural producers on a production treadmill in which they must deepen the metabolic rift by continually expanding production to maintain their living standards. That living standards are tied to a worsening a metabolic rift is enough to make sustainable management of a common pool resource quite difficult. Yet, ecological unequal exchange introduces an additional challenge for sustainable management in that it further disempowers local actors by disembedding the locus of effective control over the resource from the local context to consumers in extra-local markets. Ironically, however, while local actors have become less able to exert effective control over the resource, the policies and institutions designed to manage the resource have become even more localized. As a result, groundwater depletion in the HPA persists despite widespread, long-term recognition of the problem.

Conclusion

The breadbasket of the world appears to be on the verge of again becoming the Great American Desert, the label given to the region in the nineteenth century, before the era of irrigation (Gutentag et al. 1984; Hurt 2011). Formed over millions of years, the HPA is being depleted in the span of one human lifetime. The loss of groundwater alters hydrological systems in the region, undermines the ecological basis of human settlement, and threatens a significant portion of US agricultural production.

The most comprehensive estimate available indicates that only 30 % of the HPA will remain in 2070 (Steward et al. 2013). The problem of groundwater depletion in western Kansas has been widely acknowledged for a long time. The past 40 years have shown that the now-conventional policies and institutions for managing groundwater will not suffice. Transitioning into a more sustainable era thus requires critical reflection on these policies and institutions and the structural relations that shape them. Why does groundwater depletion persist despite widespread acknowledgment of the problem? Why would a citizenry knowingly deplete the ecological foundation of its material well-being? Sustainable groundwater management in the HPA confronts two fundamental, related challenges that are not incorporated into water management policies and institutions.

First, the economy and the natural environment are in conflict; there is a local metabolic rift in the human-environment nexus in western Kansas. Kansas Governor Sam Brownback clearly identifies this tension: "You've got to reduce your water use, but you've got to keep your economic activity flat to growing… People can't live there unless there's economic activity." However, what is not fully appreciated is the relationship between agricultural producers' livelihoods and groundwater depletion. Producers' livelihoods are so strongly linked to groundwater depletion that any reductions in groundwater withdrawals are nearly equivalent to reductions in producers' living standards. Agricultural producers in western Kansas thus confront a production treadmill (Schnaiberg and Gould 1994), which makes sustainable management very difficult.

Second, ecological unequal exchange "puts the spin on the treadmill of production" (Bunker 2005). Because of its scarcity and its importance to life, fresh water is being labeled "blue gold" (Berfield 2008) and "the new oil" (Wachman 2007). Yet despite exporting massive amounts of this precious resource in the form of agricultural products for over 40 years, western Kansans' incomes have remained stagnant. The value of water is being recognized, or valorized, in the areas of consumption in a process of ecological unequal exchange. This structural dynamic has made sustainable management even more challenging because it exacerbates the production treadmill, and therefore the metabolic rift, necessary to sustain living standards in the region.

Identifying these two key structural challenges reveals the single most important problem of ground water management in the High Plains: the mismatch between the scale of exchange and the scale of management. Decisions about water withdrawals are made proximately by agricultural producers, which gives the appearance of local control, but these decisions are driven mainly by non-local consumers in national and international markets. Because their living standards are so closely associated with depletion, and because they are disempowered through ecological unequal exchange relations with consumers in higher-income, core places, local agricultural producers are not in a strong position to sustainably manage groundwater in the HPA. Yet, as the scale of exchange and production has increased, the scale of groundwater management has actually decreased to even more localized levels. In effect, local agricultural producers are being asked to sustainably manage a resource that is for all intents and purposes a global resource, driven by prices set in national and international markets, while their living standards depend strongly on depleting it.

Existing policies and institutions thus cannot address the fundamental structural challenges to sustainable management because they are based on a perspective of the HPA as a common pool resource delimited by the boundaries of the resource. Management policies and institutions have failed to sustainably manage the HPA in western Kansas not because they are necessarily wrong, but because they are not designed to deal with the scale of the problem. If the HPA is a common pool resource, it is a global common pool resource, with all the attendant challenges of managing one (e.g., Ostrom et al. 1999; Dietz et al. 2003). As a result, the political and institutional solutions for groundwater depletion in the HPA are situated well beyond the level of western Kansas, the state of Kansas, or even the High Plains region for that matter.

Managing a global commons is extraordinarily complex and there is not a successful example to follow (Ostrom et al. 1999; Dietz et al. 2003). Because groundwater from the HPA is being consumed globally (Mekonnen and Hoekstra 2010), management must be more closely aligned with the scale of exchange. Sustainable water management in the twenty-first century will require changes in production, consumption, trade, and regulation (Hoekstra and Mekonnen 2012), but two issues are particularly pressing at the international level: water pricing and water regulation.

Because consumption drives water extraction, prices of products must reflect the full environmental cost of water extraction (Hoekstra and Chapagain 2008). Full-cost water pricing has been recognized as important at least as far back as the Dublin Principles (International Conference on Water and Environment 1992), but there are no international forums or institutions for developing an international, binding protocol for full cost-water pricing. Unilateral implementation of a full-cost water pricing will not alleviate the problem, because it would put other countries at a competitive disadvantage; an international protocol for full-cost pricing is essential for sustainable water management (Hoekstra 2013). Moreover, the international protocol would have to include substantial reductions in agricultural subsidies, which distort price signals (Hoekstra 2013).

Pricing, however, will not be sufficient; regulation will also be necessary. The world has a finite amount of freshwater. Water allocation must reflect this environmental reality. National governments can use the water footprint measure to set limits, or caps, on the amount of water than can be extracted from any particular source within their boundaries (Hoekstra 2013). Water footprint caps should be lower than the maximum sustainable level for the source. Again, as is the case for pricing, water footprint caps must be mandated for all river basins and groundwater sources in the world through an international protocol so that no one country is disadvantaged.

Full-cost pricing and water footprint caps at the international level would greatly reduce the scale mismatch problem and lessen the problem of ecological unequal exchange. As the price of water more closely reflected its scarcity, and thus its value, agricultural exports embodying water would yield higher returns for producers. Although it is conceivable that agricultural producers would expand production to capture higher prices, worsening groundwater depletion, if a water footprint cap was in place for the HPA region, higher prices for agricultural products could slow down the treadmill of production by improving living standards for producers. Full-cost water pricing in the context of a water footprint cap would effectively weaken the association between groundwater depletion and living standards, extending the life of the HPA while allowing for more time to diversify away from groundwater as the economic foundation of the region.

These are significant, large-scale, politically complex prescriptions, but groundwater depletion means that social change will be inevitable in this region; the only question is whether human institutions in the region will adapt to the natural environment. Future research can refine and expand our understanding of the structural factors promoting water resource exploitation investigated in this paper by focusing more explicitly on the role of agro-food firms and national agricultural policies in the process of ecological unequal exchange. Agricultural producers in the HPA region, for example, are confronted by national, and international, policies that undoubtedly shape the process of ecological unequal exchange by incentivizing the production of certain crops and influencing prices for agricultural products. Similarly, firm concentration and consolidation in the increasingly global food system certainly influences exchange relations between local agricultural producers and national and international markets. Most obviously, agricultural producers are often selling into markets dominated by only a few firms. These few firms thus have very significant influence over agricultural producers but also ostensibly over national agricultural policies that also shape producers' decisions. Another potentially fruitful avenue for future research would be to build on the case of Kansas presented here through comparative research with other states in the HPA region, including Nebraska, Colorado, Oklahoma, and Texas in particular. Each of these states differs in important ways from the case of Kansas, enough so as to make such comparisons beyond the scope of this paper. Yet comparative research could shed more light on the complex and multilayered interactions promoting groundwater decline, and efforts at sustainable management, in the region.

Such research is essential. There is an emerging sense of fatalism among many residents and policymakers regarding the future of western Kansas. Groundwater levels are declining, and the cost of pumping water to the surface is increasing, as are the costs of agricultural production. At some point in the near future, it will be uneconomical to withdraw groundwater for agricultural production. Unless there are significant changes in the relationship between humans and the environment by that point, Western Kansas will have lost a way of life and the US will have lost a very large portion of its agricultural production. The region has entered a critical window of opportunity to develop a more socially and ecologically resilient economy, one that can sustain human communities over a much longer time horizon: "Water is a precious, unique resource that is important for life and a commodity for which no substitute exists… Society has an opportunity now to make changes with tremendous implications for future sustainability and livability" (Steward et al. 2013, p. 1).

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