Private Provisioning of Public Adaptation Goods: The Case of Irrigated Agriculture in Central Arizona

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Abstract-Throughout the world there are emerging challenges that must be solved through private action for the public good. In cases where the public good is adaptive capacity within a social-ecological system, the collective action problems can be especially difficult and complex. In this study we utilize the empirical case of irrigation in Central Arizona to better understand how various policy instruments: incentive, market, and technological standards, contribute to private provisioning of public adaptation goods. We focus on how these institutions create perverse incentives, as well as their potential to create collective action via private provisioning decisions. Our findings suggest that rather than using the existing institutional arrangements for private provisioning of public adaptation goods, policymakers should explicitly consider alternative forms that take into account the threat of climate change and the spatial and temporal variation of this complex urban-agricultural social-ecological system.

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Recent climate change scenarios highlight the importance of increasing provisioning of public adaptation goods for water in the arid southwest. The hydrological challenges facing Central Arizona have changed. While groundwater overdraft remains a driving concern, new evidence has emerged over the last decade that highlight the vulnerability of surface water to changing climatic conditions and demand (Overpeck and Udall 2010). Rapidly warming temperatures in the Upper Colorado Basin have contributed to poor snowpack and declining streamflows (Hoerling et al. 2007); these trends are expected to continue with global warming (Overpeck and Udall 2010).

Agriculture is the largest water user in Arizona, but it is unclear whether and how farmers and other stakeholders perceive climate change threats and experience any volatility in the water supply. Modern institutional arrangements in Central Arizona reflect the historic trends where residential development primarily occurred on former agricultural fields (York et al. 2011), so institutions focused on transfer of water rights to urban uses and preservation of groundwater supply for an urbanized future (Shrestha et al. 2012). The current booming agricultural commodity market and stagnant housing sector provides an opportunity to assess institutional arrangements that provide incentives and constraints for farmers' provisioning of adaptive public goods with regard to water in light of a growing recognition that agriculture may remain a part of Central Arizona's landscape for the long-term and not simply as a placeholder for more condos and subdivisions. Our work is part of new conversation about agriculture's role within the region and the effectiveness of Arizona's water institutions in the face of changing climatic and economic conditions.

We begin with a general discussion about policy instruments used for private provisioning of public goods. This is followed by an examination of the concept of public adaptation goods and the particular role of public adaption goods within the urban-agricultural interface. We introduce the Institutional Analysis and Development framework, our approach for this study. Then we analyze the three dominant policy instruments exploring their strengths and limitations in public adaptation goods provisioning in Central Arizona.

Policy Instruments for Private Provisioning of Public Adaptation Goods

Collective action problems can be challenging to overcome (Olson 1965), but it is more likely when all participating private actors can see clearly their stake in the collective outcome, as is often the case, for example, when such actors are mutually dependent on a scarce and salient resource base (Ostrom 2005; Dietz et al. 2003).

When there are market failures for provisioning of public goods, the government often utilizes policy instruments to reduce oversupply, e.g. pollution, or undersupply, i.e. wildlife habitat. Technology standards are one of the most common environmental policies in the USA; used since the 1970s for reduction of emissions. The creation of markets and new tradeable goods such as emissions permits is one type of policy instrument (Weimer and Vining 2005). Teitenberg (2004) has argued that permits are generally more efficient than standards because they allow firms to make choices.

Nevertheless, in the case where private actors are responsible for collectively producing a public adaptation good, institutional problems arise: the private actor may not, as an individual, perceive a direct benefit from the adaptation good -- in fact, may well experience costs or risks in participating in the good's production. Contradictory incentives, pitting private benefits against public interest, can also undermine efforts in public good provisioning.

Depending on the allocation of the resources necessary to generate public adaptation goods, a threshold of individual private contributions or participation may need to be reached before any real effect is achieved, as in the case of vaccinations providing "herd immunity," habitat conservation efforts, or the clearing of brush for firebreaks (Tompkins and Eakin 2012). Uncertainty with respect to the timing, spatial scale and thus observable impact of the adaptation good may also inhibit its production. Aakre and Rübbelke (2010) categorize public adaptation goods according to how separate contributions to the overall provision level of the public good are aggregated. Education about climate risks might be considered a simple sum, while contributions to river-basin management might be summed with greater weight given to upstream efforts. Dike construction, in contrast, requires a "weakest link" analysis to determine aggregate public goods provisioning (after Hirshleifer [1983] in Aakre and Rübbelke, 2010). Thus understanding the type of public adaptation good is imperative to assess the effectiveness of current provisioning.

Climate Change Public Adaptation Goods in the Urban-Agricultural Interface

As detailed in Tompkins and Eakin (2012) public adaptation goods are those that are designed to reduce present and/or future vulnerability to climatic changes, the benefits of which are not excludable to anyone within the geographic scope of the adaptation. Examples of public adaptation goods in climate change literature range from local to global, including protection against landslides, river-basin management measures, and climate information.

Dependence on a climate-sensitive resource base is often considered a core component of vulnerability to climatic change (Kelly and Adger 2000; Eakin and Bojorquez-Tapia 2008; Marshall 2010; and Marshall and Marshall 2007). In theory then, actors will be motivated to organize collectively to enable public adaptations when they are dependent on a resource base, and face changes that will potentially make that resource less reliable or accessible in the future.

The relationship of agriculture to public good provisioning generally, and public adaptation goods specifically, is of growing interest in public policy. A burgeoning literature on agricultural "multifunctionality" has highlighted the potential for agricultural land and land managers to participate in ecosystem service provisioning, particularly around urban areas (e.g., Boody et al. 2005; Wilson and Gibson 2000). The European Union Common Agricultural Policy, for example, explicitly recognizes the potential for farmland to provide biodiversity conservation and habitat and cultural and recreational services (Otte et al. 2007). As part of regional adaptation efforts and improved disaster prevention, in many areas rural land managers are being asked to participate in programs in which they allow their lands to be flooded in order to collectively provide an adaptation service of reducing the cost of flood events to more densely populated urban centers. Rural landowners might also participate in effort to adapt to anticipated water scarcity by improving water filtration and groundwater recharge through land surface and vegetation management (Hermosillo).

Involving irrigated producers agriculture in private provisioning of public adaptation to anticipated water scarcity caused by changes to hydro-meteorological regimes is of growing interest in the United States. Irrigated farming is one of the major consumers of water in the American West. Improved efficiencies in irrigation technology and the expansion of urban areas into formerly farming regions and put irrigated agriculture in the position of potentially collaborating with other sectors to enhance water resource availability in times of scarcity. In the Imperial Valley, California, for example, farmers have been called upon to sell sold water resources to meet urban needs in face of scarce supply; the water market institutions that have emerged to enable this exchange illustrate how agriculture water use can be considered somewhat flexible in face of inter-annual variability in water supplies. The persistence of an agricultural sector willing to engage in such water markets thus could be considered 'adaptive' for the region/system as a whole. The Imperial Valley case, however, is not without controversy (i.e. Booker and Young 1994; Maganda 2005), demonstrating the importance of understanding the incentives for private action and need to carefully design institutional arrangements in order to generate the desired public adaptation good in ways considered fair and reasonable to key stakeholders.

Methods

We utilize the Institutional Analysis and Development Framework (Ostrom 2005) to assess current institutional arrangement for private provisioning of public adaptation goods in the case of irrigated agriculture in Central Arizona. Institutional analysis is used to better understand the rules, norms, and shared strategies that are currently operating in the irrigated agricultural sector. We focus on how existing institutional arrangements affect the provisioning of public adaptation capacity for water provisioning in times of scarcity at the urban-agricultural interface.

Our analysis is based on two information sources: 1) interviews with decision-makers in the agricultural sector and primary and secondary literature on policy instruments and their effects. We focus on three major types of institutional arrangements used in Central Arizona, but also common in environmental policy, incentive, market-based, and technology.

Between June 2011 and October 2012, we interviewed 21 stakeholders in the agricultural sector including water lawyers, agricultural lobbyists, commodity and dairy producers, irrigation district managers, water policymakers and managers, and agricultural bankers. Let us begin with background about irrigated agriculture and public adaption goods in Central Arizona.

Central Arizona

The case of agriculture on the periphery of the Phoenix metropolitan area in central Arizona illustrates both notable climate adaptation successes and considerable adaptation challenges. Phoenix and other cities in the metropolitan area were founded along the Salt River where remnants of ancient Hohokam irrigation canals, some dating to 300 AD, provided the footprint for early irrigation infrastructure in the late 19th Century (Luckingham 1984). Since Phoenix's frontier days, agriculture has provided the foundation of water institutions, infrastructure, and land for urban growth and urban water use (Gober 2006).

For more than a century, as water-intensive cotton and citrus farming, copper mining, and cattle ranching became integral to the state's identity and a central driver of development (Sheridan 1995). Arizona water resources were regulated principally through common law doctrines. Surface water, as in much of the western United States, was subject to the doctrine of "prior appropriation," which stipulated that those who had initial access to water had priority rights (Blomquist et al. 2004). Groundwater was subject to the doctrine of "reasonable use," which allowed anyone who owned a well to pump any amount of groundwater for use, as long as it was not transported away from "the land from which the water was taken" (Connall, 1982). Groundwater and surface water were treated as essentially separate resources. Until the late 20th century, Arizona's water policy was considered by some to be "non-management" or unregulated water use (see, e.g. Hansen and Marsh, 1982).

Farmers in the state generally perceived use of groundwater to be an individual right associated with the parcel of land they owned and farmed.

In the late 1970s, a number of events came together to incentivize Arizona policymakers and major water users to re-assess the state's minimal groundwater regulations. Rising conflict between sector interests (mining, agriculture and urban) and clear overdraft of groundwater demonstrated not only that surface water and groundwater were interlinked not necessarily independent resources, but also that the exploitation of the resource by one actor diminished access and availability for others (Connall 1982). Existing norms were inadequate to address this common-pool resource management concern; it was necessary to define, assign and delimit water access and rights among all users (Paul 2010; Connall 1982).

At the same time, Arizona policymakers were seeking to consolidate the state's rights to access Colorado River water via the construction of the Central Arizona Project (CAP); the U.S. Bureau of Reclamation and Secretaries of the Interior had, since 1945, maintained that federal support for CAP was contingent upon effective state groundwater regulation (Hansen and Marsh, 1982). In 1980 the state began to implement legislation providing market-based instruments, subsidies, and technical assistance known as the Groundwater Management Act (GMA). The approval of the GMA allowed construction to begin on the CAP, which was declared complete in 1993.

The case of Central Arizona suggests that there are numerous public adaption goods that one should consider, but we're going to focus on two. Safe yield is defined as only pumping as much groundwater as is replenished into the aquifer either through recharge via rainfall, fields, or water banking. A second critical public adaption good for Central Arizona is maintenance of the water rights to Colorado River water through full use of Arizona's allocation. These two public adaptation goods provide water for the entire social-ecological system over the long-term (safe yield) or inter-annually (secure Colorado River flows).

The GMA was designed to serve as the primary instrument to ensure that the public good interest in terms of ground water resource availability for future generations through a goal of "safe yield": water withdrawals were not to exceed recharge rates within specified geographic regions (Active Management Areas or AMAs). Achieving this vision was, however highly contentious, particularly for the agricultural sector which perceived that it had a lot to lose with increased groundwater regulations (Ferris 2000). It was clear from the beginning of negotiations that limiting irrigation and retiring irrigated agricultural lands while allowing other sectors to grow--effectively planning the sectoral composition of the state's economy for the foreseeable future--would be a primary strategy for reaching safe yield (Hansen and Marsh, 1982). The farm sector fought hard to guarantee that under the new law farmers irrigating in the areas of most extensive groundwater overdraft, and where urban expansion was anticipated, would have irrigation grandfathered rights (IGFR) equivalent to the average water use on their farm over the period 1975-1980 (quantified as the farm's "water duty"). Under the GMA, farmers faced significant restrictions in selling water rights, and in general, agriculture's value was considered in terms of the land value for urban development, not the value of agricultural water (Connall Jr 1982).

The public interest in improving water conservation among all users was also challenged; in the end, the agricultural sector agreed to comply with gradually increasing efficiency requirements as stipulated by the state water authority created by the GMA, the Arizona Department of Water Resources. Private developers and municipalities would need to guarantee indicate 100 years of water supply and that guarantee groundwater use did not exceed recharge (safe yield). All actors eventually accepted that together they would comply with the GMA's overall objective of achieving "safe yield" by 2025, through increasing dependence on surface water, improving conservation, reusing water, and, importantly, through retiring agricultural land and converting it to urban use (Maguire 2006). Issues such as water quality, conjunctive use of surface water and groundwater, tribal water rights, and water rights attached to federal lands were not addressed in this initial round of groundwater regulation.

Policy Instruments

Over the three decades of the GMAs implementation, agriculture's contribution to the goal of "safe yield" has been incentivized through different mechanisms: efficiency standards, technology standards, market-based instruments and subsidized surface water usage.

Efficiency standards The GMA initially stipulated that the agricultural sector would need to comply with graduated minimum efficiency increases requirements, negotiated in ten-year increments corresponding to each 10-year planning period. Irrigated producers were expected to reducing their water duty over time while achieving the same yield and productivity through efficiency improvements. Due to political pressure, these graduate efficiency requirements were largely abandoned in the 1990s and today the efficiency requirement of 80% is the same as when the GMA was first put into effect. Based on the literature and our interviews, which indicate no political will for renegotiating efficiency standards, we have decided not to focus on this particular institution, as it has become a baseline condition rather of water rights for farmers rather than a gradually shifting allocation of water, as was originally envisioned.

Technology Standards- The Best Management Program (BMP) was created in the third round of management planning under the GMA, farmers lobbied and received a policy to "provide an alternative conservation program that is designed to be at least as effective in achieving water conservation as the Base Program" (Bautista and Waller 2010). The best management practices program substituted state control over absolute per acre water use for state-prescribed technologies and techniques designed to promote water efficiency. Farms that elect to enroll in the best management practices program can not use, trade, or accumulate flex credits (discussed below). BMP enrolled farms are not, however, limited in total water consumption to the water duty associated with the farm (something established through the efficiency standards base program); as long as the farm complied with the prescribed conservation technologies or practices. Thus the BMP program was particularly advantageous for farmers who typically consumed all or more of the annual water duty associated with their land, and for farmers who had already made investments in water conservation practices that made their land qualify for the BMP program, and/or were changing crops or cropping patterns (Bautista and Waller 2010, pp. 25-26).

Market

Flex credits. In 1980, the GMA allowed for farmers to use more than their allotted water duty if they could make up the difference in another year. Enacted during the first round of management planning, flex credit accounts additionally allowed farmers to bank a portion of their water duty not used in one year for use in subsequent years. Flex credit accounts primarily benefitted large, comparatively water-intensive operations that had been assigned a high water duty when the GMA went into effect. Farms that had already implemented conservation measures prior to 1980 were assigned a smaller water duty, and thus were less likely to have surplus water to "bank" into the future. As part of the GMA base conservation program, flex credits give considerable inter-annual flexibility while -- in principle -- allowing the state to control and systematically reduce the absolute average amount of water used per acre over time by reducing water duties. Analysts favored market instruments, such as direct purchase and retirement of agricultural lands or creation of capped market in water rights, early in the GMA decision making process, but these institutions were rejected by stakeholders (Connall, 1982).

Subsidies

CAP Subsidy- Arizona received 2.8 million acre-feet in the 1928 Colorado River Compact. From the time of the initial signing of the Compact, Arizona's legislators were concerned that California's and Nevada's strong and increasing water demand would lead those states to consume more than their allocation particularly if Arizona was not (yet) able to absorb its full share. Although Arizona sued California to ensure that California could not legally claim permanent rights (through the doctrine of prior appropriation) to any Colorado water that Arizona was not able to use, anxiety about losing water resources to Arizona's fast-growing neighbors permeated policy development in the 1980s and 1990s.

The inauguration of the Central Arizona Project in 1992 provided a means for water intensive agriculture to would reduce these anxieties by using Arizona's allocation. CAP water, as a surface water source, was also considered 'renewable' and thus a preferred alternative to groundwater use. The terms of the CAP repayment contract with the federal government provided an additional incentive for the state to encourage agricultural use of CAP water by exempting the portion of the project serving agriculture from loan interest, thus making agricultural CAP water consumption financially advantageous for Arizona (Megdal and Shipman 2010).

Although it was assumed that land under irrigation would gradually decline within areas governed by the GMA, in the interim agriculture was expected to make use of any excess CAP water deliveries to Arizona that was not absorbed by municipal or industrial uses (Jacobs and Hollway 2004). The combination of agricultural land retirement and shifting agricultural use to CAP supplies would then allow groundwater to underwrite future urban growth (Jacobs and Holway 2004).

However, since the mid-1960s, concerns had been raised that the cost of CAP water would be too high for most irrigators to purchase (see, e.g., Mann 1963). In theory, if CAP deliveries worked to reverse the drawdown of the aquifer, they would simultaneously reduce the escalation of groundwater pumping costs, only serving to improve the cost of groundwater relative to CAP water. The alternative assumption, that CAP water would eventually be cost-competitive with groundwater, rested on projected continued increases in the cost of pumping through a combination of falling groundwater tables, rising energy costs, increased regulation of groundwater withdrawals, and/or greater relative fixed costs as irrigation district membership contracted (Wilson and Gibson 2000). These assumptions proved weak, and CAP water was at least two times more costly than groundwater once deliveries started (Wilson and Gibson 2000).

The Central Arizona Water Conservation District, the official agency that administers CAP water allocation and operation in Arizona, organized city governments to subsidize agricultural CAP water use until 2030. According to Maguire (2006), cities were willing to subsidize agricultural CAP water use for two reasons: they saw the benefit in maximizing Arizona's claim on the Colorado River in order to avoid losing water to Nevada and California, and, in a time of rapid population growth, they saw an advantage in exchanging CAP water for agricultural groundwater, which could then be used to fuel future urban expansion. Through a program called the Groundwater Savings Program, cities, private developers and the water banking agency, the Arizona Water Banking Authority, were allowed to acquire formal entitlement to the annual groundwater water duties supplanted by agricultural CAP water use (Megdal and Shipman 2010). To participate in this program, individual farms and irrigation districts are permitted as a "groundwater savings facility," which then entitles the farm or district to "store" water on behalf of the water utility providing the CAP water to the irrigator (Megdal and Shipman 2010).

Discussion

Under the GMA and the administration of the CAP, irrigated agriculture in Central Arizona is substantially responsible for producing two public goods: groundwater safe yield and full utilization of the state's CAP allocation. The institutions designed to achieve these goals sometimes are at odds with one another. Safe yield requires water conservation and management, while the second is only possible through subsidizing water-intensive agricultural practices because of the relatively high cost of unsubsidized CAP water. Irrigated agriculture is intended to serve different and somewhat incompatible functions in relation to the public interest: on the one hand, under the GMA irrigated agriculture is subject to institutional arrangements that, on the surface at least, appear to convey the need for (ground) water conservation and improved efficiency. On the other hand, under the CAP regime, farmers are encouraged -- incentivized -- to continue their relatively water-intensive practices through subsidized surface water.

Current institutions for private provisioning of public goods

Institution	**Public good: safe yield**	**Public good: full use of**
Municipal subsidy (incentive)	Positive-Shifts groundwater extraction to surface water	Positive-Increased use
Flex credits (market-based)	Minimal effect	Minimal
BMP program (technology standard)	Negative compared to Base Program	Positive

In terms of their public interest objectives, the outcomes of the above programs have been mixed. The municipal subsidy of CAP water for agricultural use has effectively served to enhance Arizona's full utilization of its CAP allocation: farmers rapidly switched from groundwater to CAP where it was available as a result of this initiative (Megdal and Shipman 2010). The creation of the agricultural water subsidy for CAP water use appears to have had a significant positive impact of safe yield, where CAP water has replaced agricultural groundwater pumping and recharge of the aquifer has occurred, water tables have recovered by as much as 250 feet -- a benefit for those who continue to depend on wells for water supply and a hedge against further land subsidence (ADWR *Statewide Hydrologic Monitoring Report*, 2012, p. 19).

Significant progress has been made in reducing groundwater overdraft -- the explicit focus of the GMA. State officials have determined that the Phoenix groundwater basin is currently in a condition of safe yield, meaning that annual pumping from aquifers does not exceed annual recharge (ADWR *Annual Report*, 2011, pp. 16-17). They have also certified that the largest cities in the Phoenix area currently have "physically, legally, and continuously available" surface water or sustainably extracted groundwater to meet current demand over the next 100 years (pp. 10-11). Safe yield has largely been achieved through the original efficiency standards, which established the amount of water each farm could use, but the new technology standards established through voluntary participation in the BMP can lead to increased water consumption by shifting particular farms with an established base program from less to water intensive production.

Some have argued that the primary the mechanism by which agriculture has contributed to these outcomes has been largely through the retirement of agricultural land in the face of rapid urbanization, rather than changes in water management on farms. Agricultural land retirement accelerated in the 2000s: between 2002 and 2007, land in irrigated farms in Maricopa County declined 33 percent (NASS *2007 Census of Agriculture -- County Data*, p. 273). But, annual per-acre water consumption on agricultural land has been stable since 1980 (Needham and Wilson 2005).

At the scale of the private actor -- the farm enterprise -- the GMA initially provoked some concerns that, as written, it would restrict the flexibility of farmers to respond to inter-annual variability in both climatic parameters as well as market circumstances. Most farmers had sufficient water rights for irrigation in their initial allotments such that flex credits were typically accumulated rather than used or sold; in the 1990s when commodity prices were particularly low and urbanization was accelerating, many farmers found they had substantial stocks of flex credits accumulating. In this case, the flex credit program worked against any public effort to encourage water conservation in the irrigation districts; the flex credit program essentially served to reinforce the idea of agricultural water as a private good managed for individual farm benefits.

Similarly, interviews with area experts who were involved with the creation of the BMP program commented that the program was in part a political gesture to the farm community; few expected that it would serve as a motivation for a change in water practices or would serve to enhance conservation. There is also no evidence that the BMP program has been a motivation for the adoption of additional or new water conservation practices; in fact, enrollment in this program essentially exempts farms from having to comply with the limitation of the farm's water duty. Indeed, an evaluation of the BMP program suggests that the program may in fact be enabling farmers to continue to plant water-intensive crops that they would otherwise have difficulty maintaining if they complied with the water duty initially associated with their land (Bautista and Waller 2010). The BMP program has thus been most attractive for farms for which flex credits have been exhausted and the initial water duty has proven insufficient. Or, the BMP was attractive for farms that already had invested in conservation prior to the GMA, and thus were given a low water duty, or farm enterprises switching between different types of commodity production. Rather than adjust on farm practices to accommodate constraints in water, the BMP allowed the removal of the constraints within the confines of the technological standards and practices.

While not its primary intention, the GMA has contributed to strengthening of the longstanding strategy for dealing with dry conditions and climate variability in central Arizona by enhancing the diversity of water sources available to users. The development of the CAP infrastructure was made possible by the signing of the GMA. The GMA and availability of CAP water in turn, have enabled the development of a number of creative and flexible institutional mechanisms for water resource storage, transfer and exchange within the Active Management Areas with the objective of achieving safe yield over time. Thus the subsidy provided a means for municipalities to "store" groundwater on paper, although the actual physical storage through groundwater recharge is not as clear. On the farm, the subsidies allowed farmers and irrigation districts to shift their water use portfolio from pumped groundwater to surface water from the Colorado River through CAP. This program did not lead to conservation of water, but did increase provision of the two public adaptation goods: safe yield through reduced pumping and securing Arizona's share of the Colorado via beneficial use.

These institutional arrangements have been heralded as some of the more innovative in the West (2009 recognition as "Partner in Conservation" by Interior Secretary Ken Salazar). This was accomplished through institutions securing rights to groundwater and rules for the exchange of water rights. The GMA established groundwater laws and management goals in the state's most populous areas, the Phoenix area central among these. Agriculture has directly, if not intentionally, played a strong role in enabling progress towards safe yield via the retirement of agricultural land, maintenance of per-acre water usage via efficiency standards, while the substitution of CAP water for groundwater has relieved pressure on the aquifer. In contrast, the Best Management Program has allowed farmers to shift production from relatively lower to higher water intensive crops or practices, which has had a negative impact on overall agricultural water conservation and not necessarily led to increased CAP water use. Thus, we find a mixed picture of the effectiveness of these institutional arrangements in providing public adaptation goods (Ekstrom and Young 2009). Not to mention, that these two goods may not sufficiently increase adaptive capacity in the face of climate change.

Climatic change models for the Southwestern United States all project decreasing Colorado River flows and increased risk of multidecadal "megadroughts" (Overpeck and Udall 2010; Seager et al 2007), potentially drastically reducing water availability and storage across the region. Even in the absence of climatic change and megadroughts, it is now acknowledged that the Colorado River is dangerously over-allocated: instead of the 16.5 Million Acre Feet flow mandated in the Colorado River Compact of 1922, average long-term flow is now thought to be much lower, 14.7 MAF (or less) (Meko et al. 2007; Karl et al. 2009).

It is still unclear what these worrying hydro-climatic scenarios mean for Arizona and for water management. The long-term efficacy of GMA institutions is built on the assumption that water would be transferred essentially in one direction, from agricultural to municipal uses, and that climate variability would remain in the envelope of observed ranges. Groundwater is still important for meeting cultural water demands (50 percent of total supply in 2006) in the Phoenix management area (ADWR *Statewide Hydrologic Monitoring Report*, 2012, p. 13); increasing variability in surface water flows would conceivably increase stress on groundwater resources potentially reversing progress towards safe yield. Arizona has the lowest priority for Colorado River access water appropriation, and, during extreme drought conditions, would be required to cede water to other states not receive its full allocation. Within Arizona, non-Indian agricultural recipients have the most tenuous access to CAP resources; should CAP water become unavailable or unaffordable, groundwater rights would be the only recourse for these farms.

The cost of water -- regardless of any climatic influence on water availability -- is also likely to rise at some point in the near future because of increased energy costs. CAP water delivery is dependent on the coal-fueled Navajo Generating Plant, which is under scrutiny by federal regulators for its air quality emissions. Any upgrades or early retirement of the Navajo Generating Plant resulting from federal regulation enforcement would raise CAP pumping costs for all users by as much as 20-50%.

While the above scenarios do not bode well for the future reliability and affordability of CAP water for the region or for agriculture, other, more immediate factors, have breathed new vitality into irrigated farming. First, the economic crisis of the latter half of the 2000s have slowed urban expansion and reduced land prices. Second, the latter half of the 2000s has been was marked by an unprecedented -- and somewhat unexpected-- spike in global commodity prices. Cotton, the staple crop for the central Arizona region, has experienced a revival as prices have escalated. Farmers who resisted selling out during the peak of the housing boom are now expanding their production by leasing land back from developers. The surge in production has, in some irrigation districts, generated conditions of water scarcity: water rates have gone up and irrigation district managers are scrambling to resuscitate infrastructure and access the water volumes needed to cope with the unanticipated demand.

The past decade also witnessed the emergence of a new discourse associated with urbanization and agriculture that has begun to alter the ways in which both growers and urban residents view agriculture. A small but very dynamic local food movement has taken off in Phoenix, spawning several farmers' markets, CSAs and urban demonstration farms. While the vast majority of irrigated agriculture in the Phoenix region is dedicated to cotton and alfalfa, our interviews revealed that even large-scale commodity growers will mention their role in contributing to food security goals, as part of their perspective on the rationale for continued land in agriculture in the center part of the state. In short, a sector that has widely been assumed to be in a steady decline and retreat may, in fact, be more dynamic and vital that anyone has expected -- at least under current institutional arrangements that provide inexpensive surface water and means to water consumption to some extent beyond the initial GMA water allocations.

Conclusion

It is evident that agriculture is already providing a *local* public good -- or *public adaptation good*, although it is less clear that the institutional arrangements that are currently in place will serve emerging needs and risks. The more normative question of what *should* agriculture's future role be in land and water use in Central Arizona under changing climatic and socio-economic conditions is not currently in active debate, nevertheless the changing circumstances of economic development, water and climate potentially provide an opportunity to initiate such a discussion. Water use in the agricultural sector currently serves public interests because it allows the state to put its full allocation of Colorado River water to use, theoretically preventing judicial re-apportionment of the river under the doctrine of prior appropriation. This function of agricultural water use can be considered an adaptation measure because, since the inception of the GMA, agricultural water use has been viewed as a virtual bank for future municipal water demand.

Nevertheless, while the GMA was enacted to motivate all sectors to contribute towards the public interest of groundwater conservation and "safe yield", over the period of its implementation many of the rules that have been enacted for the agricultural sector have largely contributed to providing a more stable, less risky environment for agricultural decision-making. The combination of flex credits, the BMP program, the CAP subsidy and the water rights allocated to farmers have created a context that has buffered some of the volatility that farmers would normally experience from weather and markets. In some ways these concessions to agriculture have moved policy towards the domain of *public* provisioning of *private* risk management, rather than vice versa. Agricultural concessions garnered through the implementation of the GMA have largely allowed the maintenance of status quo in agriculture with ambiguous outcomes for the public interest in aggregate water conservation.

Farmers may privately take adaptive measures, and municipal interests may have identified a role for agricultural water use in the state's overall adaptation strategies, the production and provision of this public adaptation good is ultimately determined by farmers' independent decisions. As such, currently the public benefits achieved through private action are probably an example of what we have previously described as a positive externality rather than a deliberate privately-provisioned public good (Tompkins and Eakin, 2012). A consideration of agriculture explicitly in terms of public provisioning of adaptation to threats to both surface and groundwater may well open new possibilities for alternative institutional arrangements, as well as a reconsideration of possible undesirable trade-offs in agricultural land retirement. Agricultural water use has two characteristics that differentiate it from water use in another sector: first, at least in theory, agricultural demand for water has greater elasticity to respond to overall conditions of water supply and demand on an annual basis; second, agricultural water use presently supports land uses that provide secondary, or co-beneficial, public goods of local interest. The potential multiple services and functions of farmland is currently an emerging issue in regional planning and urban development (Lovell 2010). Our interviews with agricultural experts in Arizona revealed an emerging discourse related to the potential for the state's agriculture and rural communities to engage more actively with urban values and interests. While currently most land is dedicated to large-scale commodity crops, a small urban farm movement has gained momentum and the language of "food security" and "niche markets" is entering into the conversations of conventional producers.

With rising temperature, the urban heat island effect has become a significant concern for the metropolitan Phoenix area, introducing new opportunities for reconsidering peri-urban land use in terms of heat mitigation as well as in terms of nutrient recycling. While on a per-hectare basis, agriculture is assumed to use far more water than would be consumed under residential use (Megdal and Shipman 2010), once land is fully converted to urban use, water consumption is "hardened" and relatively inflexible on an inter-annual basis, whereas there is potential to temporarily halt agricultural production and farmers compensated for lost income.

The GMA and CAP subsidies have created incentives and constraints for water conservation and consumption. These institutions have helped Central Arizona achieve safe yield reducing groundwater reliance, but they have not lead to a decrease in per-acre water consumption on agriculture and have increased reliance on Colorado River water, which may be in shorter supply in climate change predictions hold. Thus, policymakers, farmers, and the entire Central Arizona region needs to reassess the water institutions for agriculture and the entire social-ecological system.

Future Directions

What might new institutions that focus on enhancing agricultural contributions to public good provisioning look like? Public interest may be served by altering current institutions to facilitate farmers' anticipatory adaptation to a more water-constrained environment, thereby extending the viability of farming not only for its market value, but also as a public goods enterprise. This may mean shifting from institutions that currently successfully protect farmers from receiving signals of environmental change -- e.g., water and energy subsidies -- to institutions that enhance flexibility and efficiency so that the industry can accommodate variable water availability. Additional institutional arrangements that incentivize the production of other public goods in agriculture may well enhance the value of the sector to urban constituencies. Compensation schemes developed in collaboration with urban and farm constituents that enable the flexible entry and exit of agriculture from water consumption regimes could be an important tool for water management in the future. Public technical assistance and research to help farmers and urban residents adjust land use and practices to enhance compatibilities and adaptation synergies may also be required. Arizona's state university system, in collaboration with water managers and farm associations, is ideally positioned to take leadership in this domain.

Prior to any discussions of the full multifunctional value of Arizona's peri-urban agriculture, the sectoralization of water policy may need to be challenged. Currently there is little incentive for the farm sector to consider altering practices, and urban constituents tend to view the decline and eventual disappearance of agriculture around Phoenix as inevitable. No one is interested in re-initiating the contentious discussions on water rights and water allocation that almost derailed the negotiations of the GMA. However positioning agricultural water interests in direct competition with urban and industrial may make less sense now than it did in the past; the pending threats to water security in Central Arizona may be the basis for re-discovering common interests and mutual gain.

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