GLOBAL CHANGE IN THE SUN CORRIDOR MEGAREGION: MANAGED AQUIFER RECHARGE PLANNING TOOLS IN THE CENTRAL ARIZONA DESERT, USA

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KEYWORDS

Managed aquifer recharge, Arizona, policy tools, urban development, policy package, long-term storage credit, hydrologic disconnect, climate change, economic growth

ABBREVIATIONS

USA United States of America

ADWR Arizona Department of Water Resources

AMA active management area

CAGRD Central Arizona Groundwater Replenishment District

AWS assured water supply

AWBA Arizona Water Banking Authority

MAR managed aquifer recharge

USF underground storage facilities

GSF groundwater saving facilities

LTSC long-term storage credit

CAP Central Arizona Project

CAWCD Central Arizona Water Conservation District

ABSTRACT

With a population expected to reach 10.3 million by 2040 (Gammage et al., 2008), the state of Arizona, USA is part of the transnational Sun Corridor megaregion (Las Vegas, Nevada, Phoenix and Tucson, Arizona, and Hermosillo, Mexico). Located in the Sonoran Desert, Arizona's urban development is largely based on the exploitation of groundwater, regulated since the 1980s by the Groundwater Management Act, a state law considered to be at the forefront of sustainable water management (Boyer

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& Bernat, 2020). To face climate change (Overpeck, 2013) and economic growth (Kyl Center for Water Policy et al., 2019), Arizona has since developed planning tools through managed aquifer recharge to reduce groundwater overdraft. However, recharge and recovery practices have created hydrologic imbalances between sub-basins in the most populated regions (Avery et al., 2007).

This study's objective is to 1) determine how Arizona recharge planning tools can be a model of good governance, and 2) address the flaws of the managed aquifer recharge-related policy regulatory settings. First, this intervention will describe the geopolitical and hydrologic settings of Arizona's Sun Corridor megaregion within the Colorado River Basin. Second, the presentation will explain how the recharge planning tools help store water for future use, promote the use of renewable supplies, and redistribute water supplies through the development of a policy package. Finally, this paper explains the controversies related to the aquifer level imbalance associated with the state recharge planning regime.

1 INTRODUCTION

With a population expected to reach 10.3 million by 2040 (Gammage et al., 2008), the state of Arizona, in the United States of America (USA) is part of the transnational Sun Corridor megaregion (with the cities of Las Vegas, Nevada, Phoenix and Tucson, Arizona, and Hermosillo, Mexico). With 82% of Arizona's more than seven million residents (ADWR, 2016b; U.S. Census Bureau, 2018) living in the central part of the state, this region is particularly affected by global changes and urban growth. For example, the population of Phoenix, AZ has increased by 16.2% from 2010 to 2019 (United States Census Bureau, 2020a). The cities of Buckeye and Goodyear, Arizona have been ranked second and fourteenth, as the fastest-growing large cities in the United States, with a percent change of 57% and 33%, respectively (United States Census Bureau, 2020b). Through rising temperatures and more variable rainfall (Overpeck, 2013), economic growth is exacerbated by climate change. In the Southwest of the United States, climate change reduces the quantity of water flowing down the Colorado River, the main surface water source for cities in Central Arizona, and increases the evaporation rate on bodies of water that are vital for urban regions.

Located in the Sonoran Desert, Arizona's urban development is largely based on the exploitation of groundwater, which has been regulated by the Arizona Department of Water Resources (ADWR) in regions called Active Management Areas (AMAs) since the creation of the Groundwater Management Act in 1980. This state law is considered to be at the forefront of sustainable water management (Boyer & Bernat, 2020). Therefore, Central Arizona AMAs make for a compelling case study of a water governance model to overcome climate change and economic growth. More specifically, we demonstrate Arizona has made efforts to store water for later use, promote the use of renewable supplies, and redistribute water supplies through the development of a policy package. Indeed, since 1980, the state legislature has added four provisions to the Groundwater Management Act: the Groundwater Storage and Recovery Projects Act, later revised as the Underground Water Storage, Savings and Replenishment Act, the Central Arizona Groundwater Replenishment District (CAGRD), the Assured Water Supply (AWS) rules, and last, but not least, the Arizona Water Banking Authority (AWBA). In the present article, I show these policies have been implemented by a system of five planning tools following the approach of managed aquifer recharge (MAR): underground storage facilities (USFs), groundwater saving facilities (GSFs), long-term storage credits (LTSCs), market-based transactions of LTSCs, and a replenishment program.

This study's objective is twofold. First, I want to determine how Arizona recharge planning tools can be a model of good governance. Second, I will address the flaws of their regulatory settings. As the article begins, I will describe the geopolitical and hydrologic settings of Arizona's Sun Corridor megaregion within the Colorado River Basin. Then, the paper will explain how the recharge planning tools help store water for future use, promote the use of renewable supplies, and redistribute water supplies (Bernat et al., 2020). Finally, I will explain the controversies related to the aquifer level imbalance associated with the state recharge planning regime.

2 BACKGROUND

The State of Arizona is part of the Colorado River Basin, in which the Colorado River is governed by the "Law of the River," a system of laws, Congressional actions, court cases, contracts and agreements dating back to the early twentieth century (Glennon & Culp, 2002; Kuhn & Fleck, 2019; O'Neill et al., 2016). In 1922, the Colorado River Compact divided the Colorado River Basin into the Upper Colorado River Basin—Wyoming, Colorado, Utah, New Mexico, and a small part of Arizona—and the Lower Colorado River Basin—California, Arizona, and Nevada. This Compact voluntarily over-estimated the annual estimated flow on the Colorado River and allocated half of it (more than 9 billion m^3) to each basin (Kuhn & Fleck, 2019). In 1928, the Boulder Canyon Act allocated more than 5.4 billion m^3 of the Colorado River water to California, more than 3.4 billion m^3 to Arizona, and 370 million m^3 to Nevada. Arizona's allocation of the Colorado River water is used by mainstream users, like farmers and irrigation districts in the Yuma area and four tribes (46%) (Arizona Town Hall, 2015). What remains of Arizona's share of the Colorado River water (54%) has been delivered through the Central Arizona Project (CAP), a 336-mile canal system completed in 1992 that transports water from the Colorado River on the western boundary of Arizona to Central Arizona. The Central Arizona Water Conservation District (CAWCD), a governmental subdivision of Arizona encompassing Maricopa, Pima, and Pinal counties, operates the CAP canal delivery system and sets charges for the water delivered through the canal. Generally, Colorado River water delivered via the CAP canal is referred to as CAP water.

The majority of Arizona's population lives in Central Arizona AMAs: Phoenix, Tucson, and Pinal AMAs, located within the Maricopa, Pima, and Pinal counties and created by hydrologic considerations (Figure 1). In 2018, groundwater and Colorado River water provided, respectively 41% and 34% of Central Arizona AMAs' annual water demands, while in-state rivers (17%), and reclaimed water (8%) met the remainder (ADWR, 2018). Central Arizona AMAs have four principal water sectors: municipal, industrial, agricultural, and Indian. Most of the 2018 water use (ADWR, 2018) in the Phoenix and Tucson AMAs came from the municipal and agricultural sectors. Of the Phoenix AMA's total water use of 2.7 billion m^3, 50% was municipal and 30% was agricultural, and the Tucson AMAs sectoral percentages were similar (48% and 31% respectively) out of 387 million m^3. The agricultural sector alone used 80% of m3 1.3 billion in the Pinal AMA. In the three AMAs combined, the Indian sector, a good portion of which is agricultural, accounted for 12%, and the industrial sector 7.4%, of the water demand.

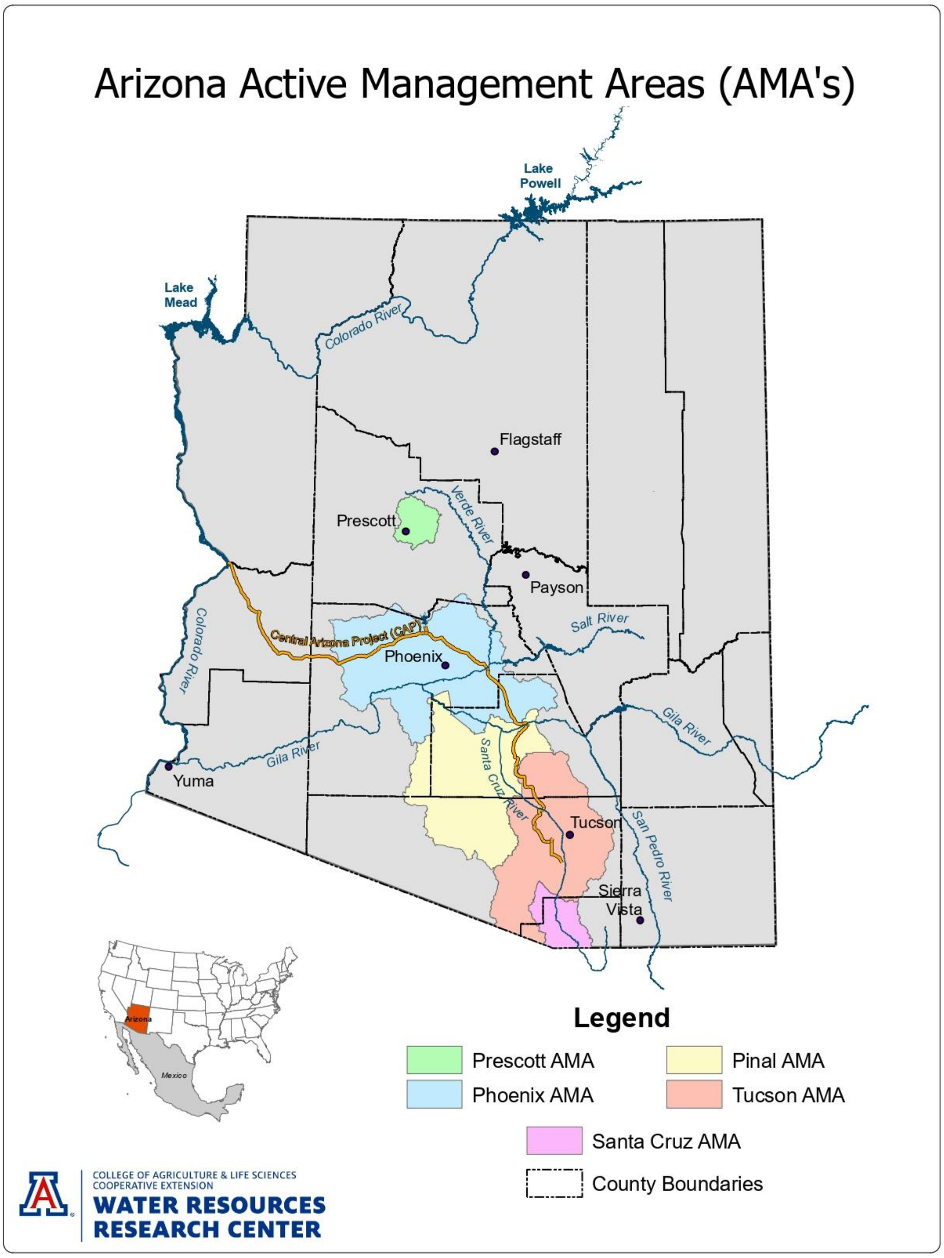


Figure 1: Map of Arizona showing the active management areas and country boundaries

Urban water demand in Central Arizona AMAs is mostly met by Colorado River (38%), other surface water (28%), groundwater (22%), and effluent (12%) (ADWR, 2018). While surface water and effluent are considered renewable, groundwater is not because only a small portion of precipitation ends up being recharged on average: 5% per rain event on average (Stewart & Howell, 2003). In a water-limited environment such as Arizona, the lack of annual precipitation prevents more natural recharge from occurring. Groundwater overdraft is caused by withdrawing more groundwater than was naturally recharged. A groundwater deficit appears in the aquifer generally in populated areas that are mostly relying on groundwater. This leads to the depletion of the city’s supply and subsidence. However, areas that use MAR in Arizona have seen their groundwater levels increased compared to areas with no recharge (Scanlon et al., 2016), which proves the efficiency of recharge. MAR refers to any kind of recharge in which water is intentionally recharged in an aquifer. Although the state of does not use the term MAR in its legal framework, Arizona’s recharge activities have been defined as being a type of MAR (Cruz-Ayala & Megdal, 2020; Lluria, 2009; Megdal et al., 2014; Megdal & Dillon, 2015; Scanlon et al., 2016). Recharge is often associated with recovery – the action of pumping back the amount of water that was previously recharged (Megdal, 2006). Many reasons can lead a country or a region to recharge water: replenishment of a depleted aquifer, development of an alternative to surface water for potable use, improvements in water quality, wastewater treatment for potable or other uses, aquifer saline intrusion prevention, inexpensive storage, as well as for agricultural, ecological or industrial purposes. In this work, I focus on three efforts that the state has made to overcome its water challenges: the storage of water for future use, the development and reuse of renewable supplies, and the redistribution of water supplies through MAR.

3 METHODS

The first objective of the study is to determine how MAR planning tools can contribute to Arizona’s governance. Historically, Arizona has had many challenges: protecting the state’s allocation of the Colorado River, preparing for shortages, limiting groundwater pumping, and allowing for economic growth (Jacobs & Holway, 2004; Megdal, 2018), as well as helping governmental agencies meet their regulatory objectives (Bernat et al., 2020; Boyer & Bernat, 2020). Those challenges lead to the following efforts: storing water for future use, promoting the use of renewable supplies, and redistributing water supplies. But, how MAR practices have played into these issues has been given little attention.

To explore these different dimensions of Arizona’s water policies I had to develop a mixed-method approach for this analysis. First, I needed to understand the extent of and importance placed upon MAR techniques and policy packages in Arizona by experts in the field. Using the method of qualitative content analysis familiar to the social and policy sciences, I coded and analyzed more than 30 archived interviews that were part of a public oral history project pertaining to Arizona Water policy. Following an inductive method, I was able to establish the most relevant interviews for this article based around the core topics I had coded: Underground Water Storage, Savings and Replenishment Act, CAGRD, AWS rules, Arizona Water Banking Authority AWBA, USFs, GSFs, and LTSCs. This process not only revealed a general history of Arizona water law and policy, but also specific elements, because the interviews are sampled from those who were the policy entrepreneurs (Kingdon, 1984)of Arizona’s water policy package. Once I had this qualitative and historical data in place, I was able to compare this information to the more recent developments in the legal and policy history of MAR in Arizona. This is work that I began with the development of my own unique quantitative database of LTSC transactions in Arizona that I built from the records of the ADWR (Bernat et al., 2020). These approaches together have allowed me to develop a robust picture of Arizona’s water management strategy and better evaluate its strengths and weaknesses.

The hypothesis I explore in this article is that the efforts Arizona took to address the challenges aforementioned are supported by MAR. Arizona's water policies are divided between Arizona's law – though the Arizona Revised Statutes – and administrative agencies that implement these statutes through rules in the Arizona Administrative Code. To that end, I have listed in Table 1 Arizona’s statutes and rules that pertain to recharge or are linked to a policy that deals with MAR operations. I noted and analyzed the planning tools involved to develop and apply these policies to Central Arizona AMAs, and analyzed those tools to check whether and how they contributed to the three policy efforts. The second objective of this study is to address the flaws of the regulatory settings, Based on a literature review, I chose to present one of the most controversial MAR-related policies in Arizona: the CAGRD. Finally, I offer an overview for a study design to find alternatives to the operations of the CAGRD.

Managed aquifer recharge-related statute or rule	Source
Underground Water Storage, Savings, and Replenishment Act	Arizona Revised Statutes, Title 45 – Waters Chapter 3: Underground Water Storage, Savings, and Replenishment
Central Arizona Groundwater Replenishment District	Arizona Revised Statutes, Title 45 – Waters Chapter 2: Groundwater Code and Chapter 3: Underground Water Storage, Savings, and Replenishment
Arizona Water Banking Authority	Arizona Revised Statutes, Title 45 – Waters Chapter 14: Arizona Water Banking Authority
Assured Water Supply Rules	Arizona Administrative Code, Title 12 – Natural Resources, Chapter 15 – Department of Water Resources Article 7: Assured and Adequate Water Supply

Table 1: Arizona's statutes and rules involving managed aquifer recharge practices

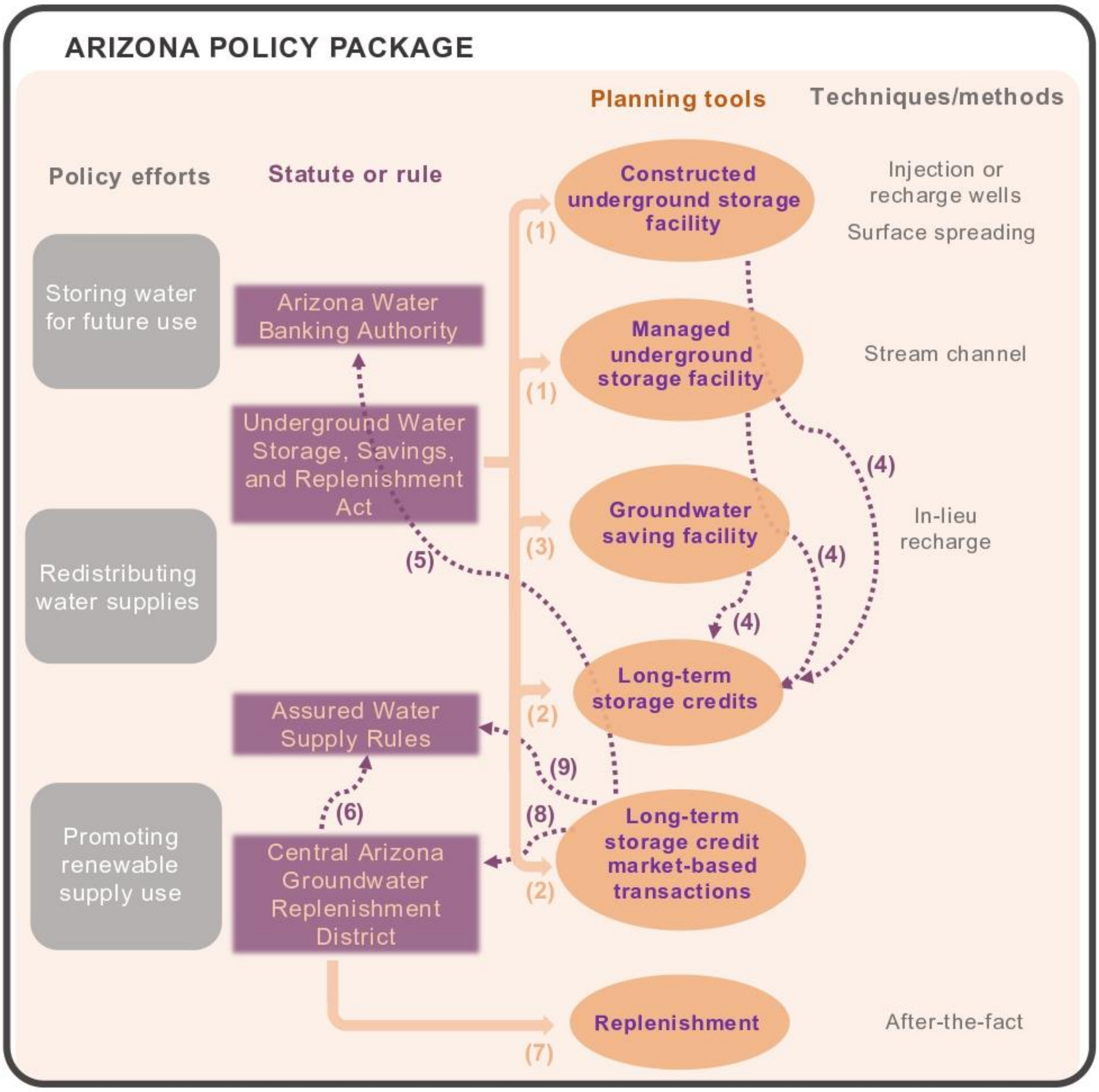
4 RESULTS

4.1 Managed aquifer recharge planning tools and techniques to store and promote the use of renewable supplies

Two of the three efforts that were identified in Arizona consist in storing water for future use and promoting the use of renewable supplies. In this section, I explain how the Underground Water Storage, Savings, and Replenishment Act, the AWBA, the AWS Rules, and the CAGRD work and rely on MAR planning tools to achieve these policy efforts.

The State of Arizona has been physically storing water in aquifers since the creation of the Groundwater Storage and Recovery Projects Act in 1986. This process is done at USFs (Figure 2, (1)). A USF is a direct recharge facility in which water enters the aquifer, either at a constructed USF through infiltration basins or injection wells, or through a natural stream channel called managed USF. The majority of USFs in Central Arizona AMAs are constructed USFs (72/79). Some of these facilities use injection wells to recharge water, which is a MAR technique defined as aquifer storage and recovery or aquifer storage using wells (Maliva, 2020b). Other constructed USFs divert water into a human-made surface spreading basin, a MAR technique called infiltration basins (Maliva, 2020b). The water then infiltrates the soil and percolates into the underlying aquifer. As for managed USF systems processes in Arizona, they are defined as an in-channel infiltration system MAR technique, in which water is diverted and poured into a river channel.

Figure 2: Arizona water policy package. Source : designed by the author



MAR in Arizona has allowed the state to diversify its renewable water with the indirect reuse of effluent. Indeed, the majority of USFs (49/79) in Central Arizona AMAs store effluent (ADWR, 2020b). The state of Arizona uses two different treatment-type MAR techniques. Through USFs with injecting wells, Arizona uses an aquifer storage transfer and recovery technique that treats water (Maliva, 2020c). The aquifer is used as an environmental buffer that filtrates, biodegrades, and dilutes contaminants. Through USFs with infiltration basins, Arizona uses a soil-aquifer treatment technique, in which water is treated vertically while seeping through the soil, and then horizontally when diluted in the groundwater. These two techniques are also beneficial to treat CAP water. In fact, soil-aquifer treatment is the method that the City of Tucson has chosen since the 1990s to treat CAP water before recovering it for drinking purposes (McGuire & Pearthree, 2018).

In 1994, the Groundwater Storage and Recovery Projects Act was updated to the Underground Water Storage, Savings, and Replenishment Act and allowed the creation of LTSCs (Figure 2, (2)) and GSFs (Figure 2, (3)). CAP water or effluent is either stored at a USF or a GSF for annual recovery (water is recovered within the calendar year it was stored), or for a longer time through long-term storage credits (LTSCs), in which case the ADWR credits LTSCs into the account of the entity that stored the water (Figure 2, (4)). One LTSC is equal to 1 acre-foot or 1233.4 cubic meters of water. Through 2016, 197 long-term storage accounts were registered in Central Arizona AMAs and 13.8 billion m^3 of water were stored and physically available through LTSCs (Arizona Department of Water Resources, 2016). GSFs are offered as a means for farmers to use renewable water instead of their entitled groundwater rights[i]. Farmers or irrigation districts who could have pumped groundwater receive surface water, or effluent and split the cost with the water provider (Seasholes, 2003). In exchange, the water provider receives LTSCs – that can be recovered later as renewable water – for the groundwater that the farmer saved. The majority of GSFs involve CAP water (ADWR, 2020a). A GSF is an indirect recharge mechanism called in-lieu recharge because renewable water is used instead of groundwater (Maliva, 2020a; Megdal & Shipman, 2008). Many municipalities, governmental agencies, industries, municipal water utilities, and Native American tribes have participated in this program. This indirect recharge program is widely regarded as a “brilliant scheme,” Grady Gammage, former President of the CAP Board of Directors (CAP Oral History - Grady Gammage Interview Transcript, 2007, p.28).

In 1996, Arizona’s legislature created the AWBA to allow the state of Arizona to fully use its allocation of the Colorado River water to ensure that Arizona’s CAP subcontractors and specified others have a stock of water if and when a shortage is declared on the river. The AWBA stores underground the surplus of Arizona's allocation of the Colorado River delivered to Central Arizona via the CAP canal. In essence, the AWBA stores CAP water to protect holders of municipal and industrial subcontracts during times of shortage and to facilitate Indian water rights settlements. To that end, the AWBA has accrued 2.9 billion cubic meters through the storage and purchase of LTSCs. The AWBA has also accrued LTSCs (Figure 2, (5)) by purchasing them from the City of Tucson and an investment firm (Bernat et al., 2020). The AWBA has been described by George Renner, Former President of the CAWCD Board of Directors, as “one of the [most] innovative tools that Arizona created to have in [its] arsenal to deal with water challenges and with growth in [the] State."(CAP Oral History - George Renner Interview Transcript, 2007, p.20).

Within an AMA, community development depends on the demonstration of a 100-year Assured Water Supply (AWS). One of the criteria for an AWS certificate or designation is consistency with the groundwater management goal of the AMA. This requirement limits the amount of groundwater that can be pumped by water providers or used by landowners in Central Arizona AMAs. The remaining supply must be met by surface water or effluent. The AWS program is the cornerstone of the Groundwater Management Act (Jacobs & Holway, 2004) as it is essential to limit groundwater overdraft in AMAs, but it also potentially limits economic growth. Not all landowners and water providers can access sufficient renewable water to meet AWS requirements. To mitigate the potential negative consequences of the AWS program for the economy, in 1993, the Arizona State legislature created the CAGRD, which provides a mechanism for landowners and water providers to demonstrate conformity with the management goal of the AMA (Figure 2, (6)). By becoming CAGRD members, land developers and municipal water providers can demonstrate an AWS, even when they may not have access to a renewable water supply. On behalf of its members, the CAGRD will replenish (Figure 2, (7)) the groundwater pumped over the members' legal entitlement. Replenishment means that the excess groundwater pumped from an area is replaced with the same quantity of renewable water in an aquifer within the same AMA wastewater region within three years of the extraction. This concept of replenishment is unique to Arizona and can be defined as an after-the-fact MAR method (Maliva, 2020b). The CAGRD may store water and generate LTSCs or the CAGRD may also purchase LTSCs, and extinguish them as part of the replenishment mechanism (Figure 2, (8)).

4.2 Long-term storage credits: market-based transactions to redistribute water supplies

The Groundwater Management Act set the stage for a series of policies that Arizona has deployed to manage its water resources. Figure 2 shows that the creation and the sales of LTSCs are at the center of this policy package. Fischhendler and Zilberman (2005a, p.1) describe policy packages as “several policies, not necessarily related, negotiated and enacted together,” but that become operationalized over time towards a common policy goal. The concept of policy package can help analyze the case of market-based transactions of LTSCs as water markets are more likely to be introduced as part of policy packages, as opposed to a singular or even national policy, because there remain institutional barriers to implementing such policy changes when done in isolation (Fischhendler & Zilberman, 2005). For 25 years, many entities in the state of Arizona have been securing water for future use through the creation or purchase of long-term storage credits (LTSCs) (Bernat et al., 2020). LTSCs allow their initiators or subsequent purchasers to recover water in times of need, subject to specific regulations. When they are bought or sold, LTSCs become part of market-based water transactions. Water markets have emerged in arid and semi-arid countries as a solution to efficiently redistribute the right to use water in times of scarcity and population growth. In Arizona, LTSC transactions allow for the voluntary redistribution of water among users. With more than 1.41 trillion m^3 of LTSCs sold from 1994 to 2016, Bernat et al. (2020) have shown that LTSCs help market participants meet their legal obligations. Indeed, LTSCs are a tool for meeting one of the requirements of the AWS Rules (Figure 2, (9)), which limits the amount of groundwater that can be supplied to the customers of several municipal water providers, and new developments. The accrual of and ability to sell LTSCs provide flexibility in the utilization of the stored water in a manner that supports economic growth. Purchasing LTSCs may help municipal water providers or developers in AMAs that do not have access to renewable water to comply with the AWS Rules. Moreover, the CAGRD and AWBA have replenishment and groundwater recharge responsibilities respectively, which they intend to meet partly through the purchase of LTSCs (Bernat et al. 2020). However, as I will now discuss, there are several important emerging consequences to Arizona’s approach.

4.3 Flaws in the system: hydrologic disconnect permitted with managed aquifer recharge

The ADWR implements and enforces three types of permits that are independent of one another and required for MAR in Arizona: the storage facility permit, the water storage permit, and the recovery well permit. The storage facility permit allows operation of a recharge facility (USF and GSF). If effluent is to be recharged, a storage facility also requires an aquifer protection permit from the Arizona Department of Environmental Quality. The water storage permit establishes the ability to store water at a facility. The recovery well permit identifies wells that may be used to recover stored water. A recovery well permit must be granted by ADWR (Arizona Revised Statute (A.R.S.) 45-834.01, n.d.) recovery must either occur within the area of impact of the stored water or be located in an area experiencing an average annual rate of decline that is less than 1.22 m per year within the AMA of the stored water (ADWR, 1999a, 1999b, 2016a).

While a hydrologic disconnect has provided flexibility to use renewable water (Megdal et al., 2014), it remains controversial: “What good is it going to do if you're not putting [water] in any of the aquifers that we're already using? And how expensive is it going to be to not only put it in, but to get it back out again and will it be there? … It was just not possible to go into a community and build a recharge project in an established urban area. The environmental issues were too great. If you were going to have something that was worthwhile, that really took enough water to be worthwhile, it had to be a new project on the periphery of the community" (CAP Oral History - Mary Beth Carlile Interview Transcript, n.d., p.25). Specifically, the only CAGRD replenishment requirement is that it must occur in the same AMA in which the groundwater was withdrawn – the minimum average annual rate of decline that is less than 1.22 m per year within the AMA does not apply to the CAGRD. The CAGRD’s replenishment rules for Phoenix AMA do distinguish between the east or west portions of the AMA, requiring that replenishment should in the same portion as the pumping, “to the extent reasonably feasible” (Arizona Revised Statute 48-3772, n.d.). This requirement shows that there is an understanding and acknowledgment of the consequences of hydrologic disconnect but that the disconnect between the location of pumping and replenishment is, unfortunately, still permissible.

This hydrologic disconnect can have adverse effects on the aquifer system in the long-term (Avery et al., 2007; Megdal et al., 2014; Vincent, 2006). According to AWS rules, groundwater can be pumped from depths down to 1000 feet below land surface in Phoenix and Tucson AMAs, and to 1100 feet below land surface in Pinal AMA (Arizona Administrative Code (A.A.C) R12-15-716, n.d.). Because groundwater is not always replenished within the area of hydrologic impact where it was pumped, some areas where water is pumped but replenished elsewhere in the AMA may experience localized overdraft. The creation of the CAGRD was essential to the passage of the AWS rules. Because CAGRD operations affects many actors, it is essential to assess the feasibility of potential alternatives to the hydrologic disconnect issue in terms of stakeholder support. Further research should assess the responses of stakeholders to adoption of a set of proposed policy alternatives and already several recommendations to change CAGRD operations have been suggested in law review articles and policy reports (Avery et al., 2007; Kyl Center for Water Policy et al., 2019). However, these recommendations often lack explanatory details about how they could be translated into implementable policies. Therefore, information should be gained from CAGRD experts to develop well thought out policy alternatives that could be used for CAGRD operations. Then, to attest to the feasibility of those policies, stakeholders that would be impacted by those policy alternatives, or by the lack of policy alternatives, should be consulted as a way to bring together academic critiques with the practical logic of water policy.

Looking into the future, the hydrologic disconnect is likely to be exacerbated because of population growth, and upcoming shortages on the Colorado River will require the recovery of LTSCs. Global changes will exacerbate the hydrologic mismatch of the activities of recharge, recovery, and replenishment.

Conclusions

Arizona has been addressing its global water challenges thanks to various policy efforts. Storing water for future use and promoting the use of renewable water supplies like CAP water and effluent were possible thanks to the Underground Water Storage, Savings, and Replenishment Act, the CAGRD, the AWS Rules, and the AWBA. The Underground Water Storage, Saving, and Replenishment Act created USFs and GSFs to recharge water. Increasing the availability of renewable supplies to cities in highly populated areas of Central Arizona has been key to reduce groundwater overdraft. Surface spreading, injection recharge wells and stream channel techniques have been key to planning tools to create storage and savings facilities. Arizona created the Assured Water Supply Rules to limit the amount of groundwater pumping in AMAs by new urban development, while creating a replenishment mechanism for entities that did not have access to enough renewable supplies. To replenish groundwater pumped by its members, CAGRD has relied on USFs and GSFs, as well as on LTSCs to develop its water supply portfolio. Replenishment as an after-the-fact method, and market-based transactions have also been key to help CAGRD fulfill its obligations. The Arizona Water Banking Authority, created to store water for future use while securing the State's allocation of Colorado River has been dependent on USFs, GSFs, and accrued many LTSCs through both storage and purchase. MAR techniques have been supporting the planning tools of Arizona to implement important provisions of the Groundwater Management Act. Supported by market-based transactions of LTSCs, Arizona's policy package has proved to be a model of good governance by redistributing renewable water for urban use.

Although Arizona was a precursor in the world of water law and management in many regards, this article also presents flaws to Arizona's regulatory settings. Several MAR activities remain controversial because they sometimes allow for a hydrologic disconnect between the area of urban development (where water is pumped from a sub basin) and the area where it is practical to recharge or replenish water (in another sub basin). To that end, a process of policy change to combine urban planning and MAR practices should be conducted, by consulting both CAGRD experts and Arizona stakeholders.

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[i] Agricultural sector users were granted groundwater rights (these are referred to as "grandfathered irrigation rights") by the Groundwater Management Act, pursuant to Arizona Revised Statutes 45-462