Managed aquifer recharge (MAR) by flooding agricultural land in the Central Valley, CA
Is this the solution?

ABSTRACT

Groundwater overdraft in the Central Valley raises concerns because 40 percent of California's water supply depends on groundwater. During the dry season when surface water is limited, groundwater has become the most reliable water source for irrigation, which has led to groundwater depletion. Managed aquifer recharge (MAR) is a widely used technique to recharge a groundwater aquifer during the wet season to store enough water for the dry season, which makes groundwater a sustainable resource. In the Central Valley, MAR by flooding agricultural land has gained enough interests from landowners to motivate multiple pilot studies. Though some raised concerns regarding groundwater quality and potential damage to crops, others proposed solutions such as planting crops that not only can endure temporary anoxic conditions in the root zone and but do not need fertilizers which could contaminate groundwater. In all, MAR by flooding farmland is promising to solve water shortage issues in the Central Valley as most studies provided positive results on the quantity of groundwater recharged.

INTRODUCTION

Fresh groundwater composes 30.1 percent of Earth's freshwater and is widespread around the globe (Gleick, n.d.). It is more reliable yet less regulated than surface water. In many places, groundwater overdraft occurs due to unrestricted groundwater extraction, especially during the dry season when surface water is not available. In the US, irrigation contributes to 70 percent of daily fresh groundwater consumption. (Dieter et al., 2018), and is the reason for groundwater overdraft in places like the Central Valley in California. Groundwater overdraft could lead to dry wells, subsidence, and other irreversible effects, such as seawater intrusion. In areas like the Central Valley in California, where groundwater accounts for about 40 percent of its water supply (Lo & Famiglietti, 2013; Massoud et al., 2018), such adverse effects caused by groundwater overdraft could be detrimental to the local economy, especially during a drought year when surface water is more limited.

Due to climate change, drought has become more frequent, prolonged and severe in California (Mann & Gleick, 2015) and across the globe (Leng et al., 2015). In California, half of its surface water storage comes from the Sierra snowpack (Joyce et al., 2011). A summary report by the California Climate Change Center (California Climate Change Center 2006) predicts that in 100 years, the volume of this snowpack may decline by 70% to 90%. Therefore, in the Central Valley, surface water will be less accessible during the dry season and groundwater demand will increase substantially.

Managed aquifer recharge (MAR) is a widely used technique to recharge a groundwater aquifer during the wet season to store enough water for the dry season and, thereby, make groundwater a sustainable resource. Among different approaches of MAR, the flooding of agricultural lands has advantages such as low design costs and the ability to catch a substantial amount of storm water during the wet season (Ghasemizade et al., 2019). It has also proved beneficial in arid areas in Iran (Hashemi et al., 2015; Pakparvar et al., 2018).

STUDY AREA

The Central Valley aquifer, as shown in Figure 1, is 40 to 60 miles wide and 450 miles long from north-northwest to south-southeast, covering 11 percent of California. The Central Valley basins, one of the most productive agricultural lands in the world, and the most productive in the US, covers more than a third of California, and accounts for one sixth of the country's irrigated land (Faunt, 2009). However, water shortage is threatening the Central Valley.

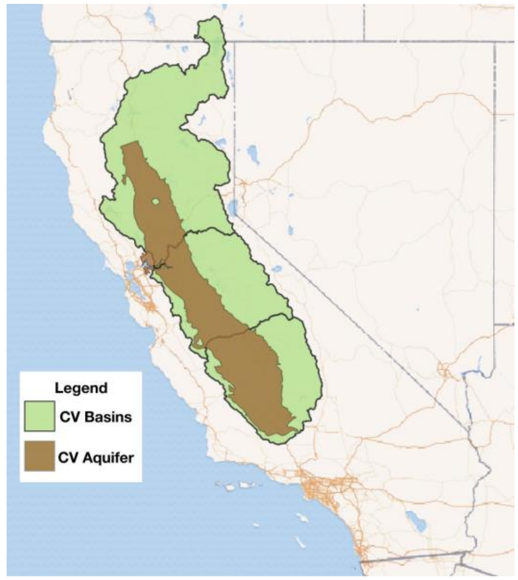

Figure 1. The Sacramento (upper), San Joaquin (middle), and Tulare (bottom) basins and respective aquifers, together forming the Central Valley in California (Massoud et al., 2018).

In the Central Valley, the average annual precipitation has been 189mm between 1921 to 2009, much less than the average annual evapotranspiration, which is 984mm, for the same period (Ghasemizade et al., 2019). There is also a temporal mismatch between water supply and demand: water is most needed for irrigation between July and September, but most of the rainfall occurs from November to March (Alam et al., 2020). Since surface water is limited during the dry season, groundwater has been seriously exploited and 2 percent of the total storage has been lost permanently (Ojha et al., 2018).

HYDROGEOLOGY

The hydrogeology within the Central Valley is heterogeneous as shown in Figure 2. The Sacramento Valley (left) aquifer is unconfined, meaning that during the wet season, groundwater can be easily recharged. The San Joaquin Valley (right) aquifer on the other hand, is semi-confined, with a confining layer of Corcoran Clay, indicating a more complicated groundwater recharge mechanism, by which even during the wet season, groundwater recharge rate may be lower than that of the Sacramento Valley.

APPROACHES

Managed Aquifer Recharge (MAR) is a widely used strategy to recharge groundwater. Scanlon et al. (2016) found that previous MAR approaches in the Central Valley increased shortterm surface water storage, facilitated water markets, and successfully enhanced drought resilience.

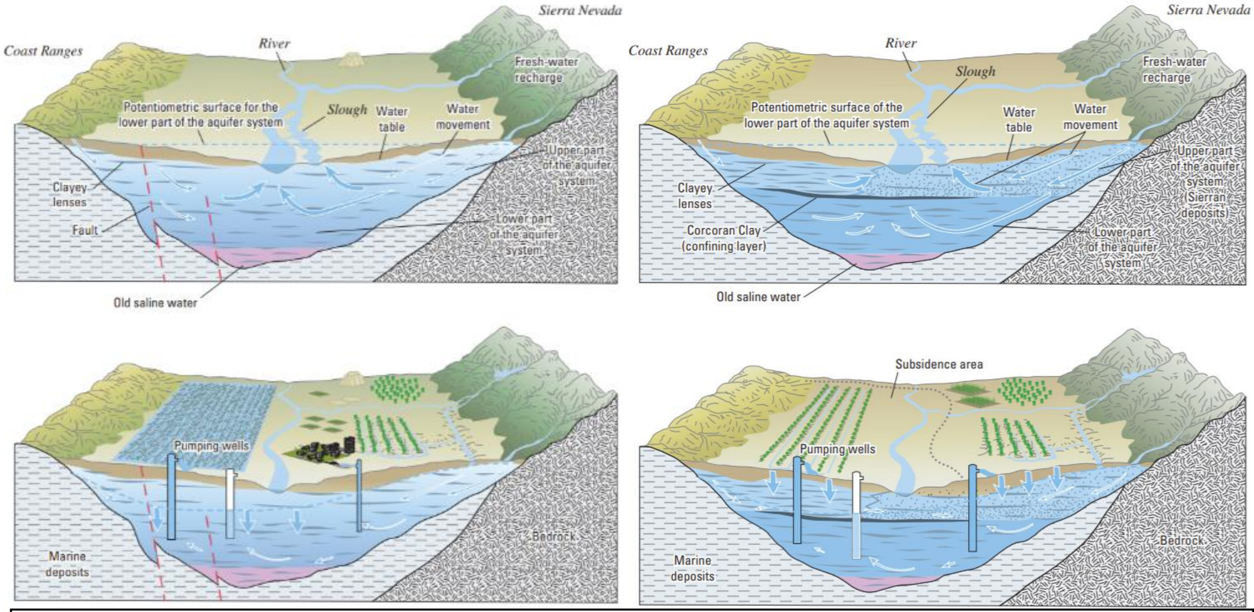

Figure 2: Pre- and post-development of the A (left), Sacramento Valley, California. B (right): Central part of the San Joaquin Valley, California (Faunt, 2009).

Managed Aquifer Recharge (MAR) by flooding farmlands is a relatively new approach to recharge groundwater by diverting nearby surface water in the wet season to a designated area of farmlands. The farmland thereby acts as a temporary aquifer to store extra surface water during the wet season while water is percolating to recharge groundwater. This approach has been proved successful elsewhere in the US (Scherberg et al., 2014) and around the globe (Hashemi et al., 2015; Pakparvar et al., 2018; Sprenger et al., 2017). There is increasing interests to adopt such approach in the Central Valley due to its cost-effectiveness.

Based on Figure 2, the approaches of MAR by flooding farmlands might be different in the Sacramento Valley and in the San Joaquin Valley. Due to the lack of a confining layer, flooding farmlands in the Sacramento Valley to recharge groundwater may be more efficient than doing so in the San Joaquin Valley. In the San Joaquin Valley (Figure 2B), since vertical water transport is limited by the confining layer, water recharged in the upper part of the aquifer system by flooding farmland might take a long time to reach the lower part. Therefore, the potentiometric surface might continue dropping at similar rates even with MAR approaches.

CASE STUDIES

Water quantity

Dahlke and Kocis (2018) identified watersheds suitable for diverting large amount of surface water to flood farmlands. They developed a rating system to rate each watershed in the

Central Valley on its availability of excess surface water, and they found that excellent watersheds based on their rating system are primarily in the Sacramento River Basin and northern San Joaquin Valley (Dahlke & Kocis, 2018).

Bachand et al. (2014) built a conceptual model to study the feasibility of flooding 1000-acre farmland in the San Joaquin Valley to recharge groundwater. They found that only 30 percent of flood flow went to direct recharge. They attributed such low recharge rates to farm infrastructures and soil properties (Bachand et al., 2014).

Effects on agriculture

While the farmland is flooded, it could still produce crops if conditions allow. Dahlke et al. (2018) studied the feasibility of flooding Alfalfa land to recharge groundwater on two sites in the Sacramento Valley. They concluded that during the two-year study in high permeable soils, not only did 90 percent of applied water go to deep percolation, but Alfalfa yield loss due to flooding was minimal. However, they also noticed that besides permeability, various natural factors such as temperature and “age, health and fall dormancy rating of the alfalfa variety” could also affect crop yield loss due to flooding farmlands. They also stated that the feasibility of flooding farmland to recharge groundwater is highly dependent on economic factors, such as “the capacity of the local water conveyance system” and the cost of the diverted surface water during the wet season (Dahlke et al., 2018).

Bachand et al. (2018) developed a flood recharge model and found that the electrical conductivity (EC) level in the root zone will drop following flood events, as salts and nitrate migrate to deeper layers. They suggested that the reduction of EC level could decrease plant stress and potentially increase crop yields.

Nitrate

Extensive nitrate has been added to California groundwater since 1945 (Rosenstock et al., 2014) and is still being added. Multiple researches found that nitrate concentration is above US Environmental Protection Agency’s (USEPA) maximum contaminant level (MCL) in multiple wells in the Central Valley (Burow et al., 2008, 2013; Bennett et al. 2010, 2011). They attributed the high nitrate concentration especially in shallow groundwater to the usage of agricultural fertilizer and dairy operations (Burow et al., 2008).

The flood recharge model developed by Bachand et al. (2014) showed a downward movement of salt and nitrate following flood events, which increased salt and nitrate concentration in groundwater. Bachand et al. (2014) stated that such increase in salt and nitrate concentration will not cease until all salts and nitrate in the root zone are flushed to groundwater.

Uranium

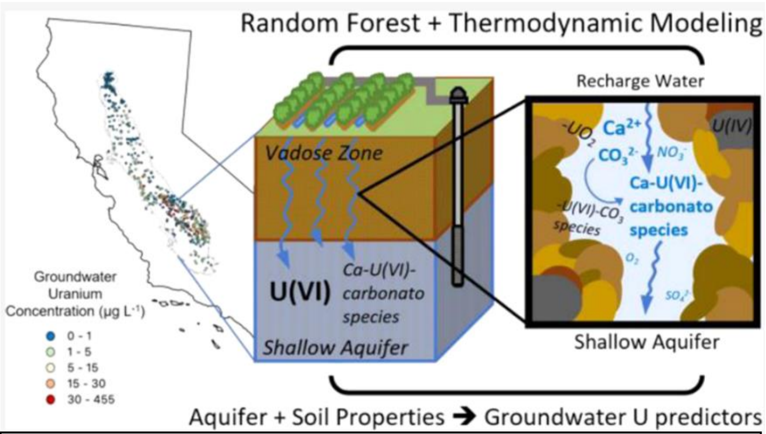

Figure 3: Uranium dissolution in the Central Valley (Lopez et al., 2021)

High Uranium concentration in the Central Valley groundwater has been attributed to downward migration of Uranium in the groundwater recharge zone (Jurgens et al., 2010; Lopez et al., 2021). In the Central Valley particularly, as shown in Figure 3, bicarbonate-rich water reacts with Uranium in sediments and forms uranyl–carbonato complexes. Such complexes have limited sorption and infiltrate through the sediments and reach the aquifer. Jurgens et al. (2010) found that 19 percent of wells in Eastern San Joaquin Valley contain Uranium concentration higher that USEPA MCL (30µg/L).

CONCLUSION

This study investigates the feasibility of MAR by flooding farmlands in the Central Valley, California. The results suggest that the success of a MAR approach depends on local hydrogeology and nearby surface water. The soil should be permeable enough to infiltrate flood flow at a reasonable rate, so that the root zone will not experience prolonged anoxic conditions. Crops such as Alfalfa could tolerate temporary but not persistent anerobic conditions. A potential farmland to be flooded should also be close to excellent watersheds such as the Sacramento River Basin and northern San Joaquin Valley, which could provide excess surface water at high enough flowrates during the wet season.

Water quality is a major issue of MAR by flooding farmland. Multiple studies (Jurgens et al., 2010; Lopez et al., 2021) mentioned high Uranium concentration in the Central Valley groundwater. Flooding farmlands will further increase Uranium concentration as bicarbonate-rich water reacts with Uranium in sediments and form a complex with limited sorption. Groundwater nitrate concentration is also high in many places in the Central Valley, exceeding the USEPA's maximum contaminant level (MCL). Flooding farmlands will transport nitrate and other salts to groundwater and will further increase groundwater nitrate concentration.

However, if the farmland flooded is Alfalfa land, where ideally no fertilizer is needed since Alfalfa is a nitrogen-fixing crop, then groundwater nitrate concentration will not increase following flooding events (Dahlke et al., 2018).

In all, MAR by flooding farmlands is a promising solution to water shortage issues in the Central Valley. However, before the solution is adopted, pilot studies need to be done to analyze soil permeability, crops' sensitivity to anoxic root conditions and high Uranium concentration, vicinity to watersheds with high flowrate during wet season and crops' productivity when little fertilizer is added.

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