# Groundwater Recharge for a Regional Water Bank: Kern Water Bank, Kern County, California

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**ABSTRACT** The Kern Water Bank is a semi-private groundwater bank operated by the Kern Water Bank Authority in Kern County, CA. The bank stores water from the State Water Project (SWP), Central Valley Project (CVP), and the Kern River. It is massive in scale, covering over 20,000 acres, with approximately 2.5 million acre feet diverted to the bank since 1995. The bank stores water on behalf of its member water agencies, which include both public and private water entities mainly focusing on agricultural use, along with a small number of municipal and residential customers. Water is withdrawn by the member agencies during droughts when surface water supplies from the SWP, CVP, and Kern River are insufficient to meet local demand or when member agencies elect to sell their stored water to outside third parties. In addition, the overlying land and infiltration ponds serve as habitat for some endangered and threatened species. Legal and political controversy surrounded the bank's creation, but its unique suite of physical assets, creative enabling agreements, and clear operational rules and incentives have enabled it to use managed aquifer recharge to make significant contributions to the flexibility of regional and statewide water systems over decades of operations.
**KEYWORDS** MAR, managed aquifer recharge, groundwater banking

## INTRODUCTION

The Kern Water Bank (KWB, or the bank) acts as a drought reserve for its member entities, storing excess water in wet years to supplement inconsistent deliveries of surface water in dry years [1]. The bank was formed by a group of agricultural organizations and water districts in 1995 after a 7-year drought demonstrated the unreliability of imported surface water. Water stored in the bank comes from three surface water sources and enters the aquifer via infiltration ponds. Banked water is withdrawn at the request of members for agricultural, municipal, and industrial uses. The infiltration ponds used for recharge also provide environmental benefits by creating a wetland environment for migratory birds and protected species.

This article describes the institutional context of KWB as a case of a regional groundwater bank that actively uses Managed Aquifer Recharge (MAR) as part of its operations. We define groundwater banking as a physical and institutional arrangement that involves the expectation that those recharging water into an aquifer will have the right and ability to withdraw it later, either for their own use or for use by others. As such, KWB is one of a few functioning examples of a regional groundwater bank. The purpose of this case study is to highlight its institutional structure and operating strategies. KWB has a controversial history and is subject to active litigation. This paper does not attempt to comprehensively document this controversy. Rather, our purpose is to highlight the effectiveness of

*Case Studies in the Environment*, 2021, pps. 1–12. electronic ISSN 2473-9510.  DOI: https://doi.org/10.1525/cse.2021.1223400.

KWB as an operating entity, for the benefit of those considering groundwater banking programs as a management tool.

## CASE EXAMINATION

### *Methods*

This case study forms part of the journal's special collection entitled "Institutional Dimensions of Groundwater Recharge." The collection examines empirical examples of MAR from across the United States to provide insights on the institutional structures and motivations of MAR implementation. An in-depth description of the special collection and its objectives, along with a discussion of the wider context of groundwater management concerns that MAR aims to address, is included in Miller et al. [2]. Each of the case studies in the collection examines a different physical and institutional design for MAR. Case studies were developed through an analysis of documents and expert interviews. Documents reviewed include reports from governmental agencies implementing the MAR projects, permits and reports from regulatory agencies, state laws and regulations, academic literature and technical reports, and news articles. Interviews were conducted with key individuals involved in the development of each project, including government officials, regulators, and project implementors.

### *Local Background*

The KWB is located 12 miles west of Bakersfield in Kern County, CA. The region relies on imported surface water from the State Water Project (SWP) and Central Valley Project (CVP) to meet local water demand, 87% of which is agricultural [3]. Agriculture accounts for 20% of exports from the county, totaling over US$7 billion in sales in 2017 [4, 5].

California has a natural temporal and spatial mismatch between demand and supply of water, with the most demand in the south during the summer and supply in the north during the winter. In response, California's SWP was constructed in the 1960s as a water storage and delivery system. Operated by the California Department of Water Resources (DWR), the SWP captures water in northern California and transports it throughout the state to 29 long-term contractors [6]. DWR retains the rights to SWP water, while contractors hold entitlements to an amount of SWP water called their "Table A" amount, which is the maximum amount of water they can receive in a year. Most years, SWP contractors receive an allocation based on the current water conditions, and that allocation is less than their full contract amount. Table A allocations reflect the unrealized plan for a full build-out of the SWP, as described below. Consequently, contractors and other parties involved with the SWP understand that full Table A allocations are not a predictor of available supply. Rather than a prescription for delivery of a specified amount of water, Table A allocations serve as a mechanism for determining each contractor's share of the available supply in any given year.

In 1986, DWR began exploring the possibility of adding a storage component to SWP operations by creating a groundwater bank in Kern County. Two years later, DWR purchased 20,000 acres of land in Kern County for US$31 million from Tenneco West, Inc. Tenneco West, in partnership with Wheeler Ridge-Maricopa Water Storage District, had already constructed 320 recharge ponds on the property in an attempt to establish a groundwater bank [7]. After purchasing the land from Tenneco West, DWR continued work on the bank, including completing an environmental impact report, conducting over US$28 million in studies, and starting a water quality monitoring program on the site. Including the construction of initial facilities, DWR invested an estimated US$74 million in purchasing and exploring the potential for groundwater banking at the site [8].

However, in 1993, DWR halted progress on the bank. DWR at the time cited high costs, Endangered Species Act habitat regulations, negotiations over local use of the bank, and uncertainty over the amount of water which would be available for storage in the bank as its reasons [7]. The cost of banked water was also a factor, with most estimates evaluating the cost of stored water to bank users between US$400–450/AF, which was higher than local water users indicated they would be willing to pay [7].

Local agricultural SWP contractors had long suffered from a lack of reliable water supplies. Much of the agriculture in the area was established without sustainable local surface or groundwater supplies, and the SWP never fully made up for that fact [9]. During the drought from 1987 to 1994, agricultural SWP

allocations were sharply cut and eliminated altogether in 1990 and 1991. To compensate for lack of surface water supplies, water users increased their reliance on local groundwater aquifers, which already had been heavily depleted by past pumping. In 1994, DWR and SWP contractors met behind closed doors and negotiated the Monterey Agreement, which revised several key SWP operating rules [10, 11]. The Agreement included changes to SWP policy that enabled contractors to store water locally, even outside their districts, in addition to enabling water marketing and permanent water transfers from agricultural to urban SWP contractors.[1] The Agreement also included a provision that transferred the land that would be used for the KWB to Kern County Water Authority (KCWA). Subsequently KWCA transferred the land to several Kern County agricultural entities and an Improvement District, in exchange for the permanent retirement of 45,000 AF of those entities' contracted SWP water amount.[2] KCWA then transferred the land to a joint powers authority (JPA), the Kern Water Bank Authority (KWBA), formed by the contractors who contributed SWP allocations along with a private company, the Westside Mutual Water Company [7, 12].

This case study focuses on the governance and mechanics of the KWB, which as a whole comprises an effective mechanism to enable and encourage MAR, among other functions. KWB has been the subject of controversy since its inception. Our focus in this article is on the banking mechanism that is currently in place, which has been effectively operated to serve regional management goals, and its relationship to MAR. Nevertheless, the controversy has material implications and effects on the broader perception of legitimacy for the KWB, and we discuss it briefly in the sidebar below.

Controversy and the creation of the KWB

This article focuses on the mechanics and governance of the KWB as a mechanism for enabling groundwater recharge, but such discussion needs to acknowledge public and ongoing controversy about the creation of the KWB. It is beyond the scope of this article to fully document this controversy. Nevertheless, we briefly touch on some disputed elements, leaving a comprehensive treatment to others.

Controversy over the transfer of the KWB from state to local semi-private control resulted in several lawsuits.[3] Disputes are based in part on legal grounds challenging DWR's analysis of the environmental impacts of the transfer in its Environmental Impact Report required under the California Environmental Quality Act, as well as the legality and constitutionality of the transfer of the bank from DWR to the KCWA. Many parties have also raised objections regarding the overall lack of transparency in the process. Parties also objected to the substance of the deal, arguing that it transferred a significant resource, which could be managed for broader benefits, from the state to an entity that the objecting parties view as primarily benefiting a small group of private interests.

### *SWP Contracts and Applicable Environmental Regulations*

The KWB is mainly governed by a Memorandum of Understanding (KWB MOU) and its Operation Plan. Additional regulatory requirements for the bank, including water quality, are discussed below. Both state water contracts and the Endangered Species Act (ESA) also play an important part in the regulation of the bank.

**DWR AND STATE WATER CONTRACTS.** As discussed above, the SWP is operated by DWR. Each year, DWR forecasts the amount of water that will be available in the SWP system. Allocations are then set by DWR based on each SWP contractor's request, limited by available Table A water. The total initial amount of Table A water was determined based on plans for the SWP that involved a significantly larger infrastructure project than was ultimately actualized (including dams on, and diversion tunnels from, the Eel and Klamath Rivers, both of which were foreclosed by Wild and Scenic River designations

1. California Department of Water Resources. Monterey Amendment to the State Water Project Contracts (Including Kern Water Bank Transfer) and Associated Actions as Part of a Settlement Agreement (Monterey Plus). October 2007. Available: https://calisphere.org/item/ark:/86086/n2mp52bn/.

2. State Water Contractors and the State of California, Department of Water Resources. The Monterey Agreement – Statement of Principles. 1 December 1994. Available: http://www.mwdh2o.com/PDFUWMP/1994%20Monterey%20Agreement%20and%20Amendment.pdf. Additional copy on file with authors.

3. *Planning and Conservation League v. Dep't of Water Res.,* 100 Cal. Rptr. 2d 173 (Cal. Ct. App. 2000); *Central Delta Water Agency,* et al. *v. Department of Water Resources,* et al., 3rd District Court of Appeal (Case No. C078249); *Center for Food Safety,* et al. *v. Department of Water Resources,* et al., Sacramento County Superior Court (Case No. 34-2016-800002469), but see [13].

issued by the state when Ronald Reagan was governor), but the Table A amounts were never adjusted to reflect the more limited build-out. The original SWP contracts specified that adjusting these amounts would occur to reflect actual project development, but the Monterey Amendments changed these terms to the current proportionality scheme.[4] This, combined with fluctuating annual water availability, means that contractors rarely receive their full Table A amount.

**ENDANGERED SPECIES REGULATIONS.** Due to the presence of endangered species on the property, the KWBA must comply with the federal and state ESAs. Under both laws, if actions taken by an entity have the potential to "take" a threatened or endangered species, that entity must obtain an incidental take permit from the U.S. Fish and Wildlife Service (USFWS). Incidental take permits are often contingent upon development and approval of a Habitat Conservation Plan (HCP), which indicates the steps that will be taken to reduce or mitigate harm to the species. KWBA's HCP outlines how the KWB will operate to bank water while protecting environmental uses of the property. The KWBA also voluntarily created a Natural Community Conservation Plan under California's Natural Community Conservation Plan Act with the goal of contributing to the recovery of listed species. The KWBA submits reports annually to USFWS and the California Department of Fish and Wildlife (CDFW) to demonstrate its compliance with the stated plans [1, 14]. KWBA also operates a conservation mitigation bank, as described below.

### *MAR through the Kern Water Bank*

The KWB uses infiltration ponds to recharge surface water for later recovery and use.

**WATER SOURCES FOR RECHARGE.** Recharged water for the KWB comes from three sources: the SWP, the CVP, and the Kern River. Between 1995 and 2017, KWB received approximately 2.5 million AF of water for recharge [1]. The majority (58.5%) of water banked in the KWB comes from the SWP.[5] SWP water travels to Kern County through the 444-mile-long California Aqueduct and is transported to the KWB's recharge ponds via local canals [12, 15]. The KCWA is the local SWP contractor for the area and is responsible for distributing SWP water to thirteen local water districts, including KWBA members Tejon-Castac Water District, Wheeler Ridge-Maricopa Water Storage District, Semitropic Water Storage District, and KCWA's Improvement District No. 4 (ID4) [16]. All KWBA members have contracts for SWP water, either through the KCWA or directly from DWR [1].

Approximately 27% of the water banked in the KWB comes from the Kern River [1]. The Kern River is 164 miles long and fed by snowmelt from the southern Sierra Nevada mountain range [15]. Most years, the river is dry downstream of Bakersfield due to diversions for irrigation and municipal water supply [1], and KWB has received water from the Kern River in less than half of the years that the bank has been in operation [1]. Kern River water can be diverted to the KWB through several diversion facilities, including the KWB Canal [7]. During wet years, when the U.S. Army Corps of Engineers calls for mandatory releases of flood flows on the Kern River, the Kern Watermaster offers this water to interested takers including members of the KWB. Some Kern River water rights holders have taken advantage of the KWB's ability to bank water, trading rights to inconsistent high flows from the Kern River for more reliable supplies from the SWP.[6]

Water from the CVP accounts for the remaining 14.5% of water entering the KWB [1]. The CVP is a federal water storage and delivery system operated by the U.S. Bureau of Reclamation (BOR). CVP water enters the Kern River through the Friant-Kern Canal, moving through the river channel and a local canal to reach the bank [15]. The KWB acquires CVP water through short-term arrangements with BOR [1].

**RECHARGE AND RECOVERY INFRASTRUCTURE.** The combination of natural setting and existing water conveyance infrastructure combines to make the location of the KWB ideal for recharge and storage. The KWB covers 20,480 acres, much of which is located over the highly permeable Kern River alluvial fan. The bank is also located at the intersection of several important conveyance structures that were already in existence at the time the bank was created. The Kern River flows through the

4. *Planning and Conservation League v. Dept. of Water Resources*, 100 Cal. Rptr. 173, 189–90 (Cal. Ct. App. 2000).

5. Between 1995 and 2016, 58.5% of water deposited in the Kern Water Bank came from the State Water Project [1].

6. See, for example, the Kern County Water Agency's purchase of Kern River high flows from the Nickel Family LLC and Olcese Water District [17, 18].

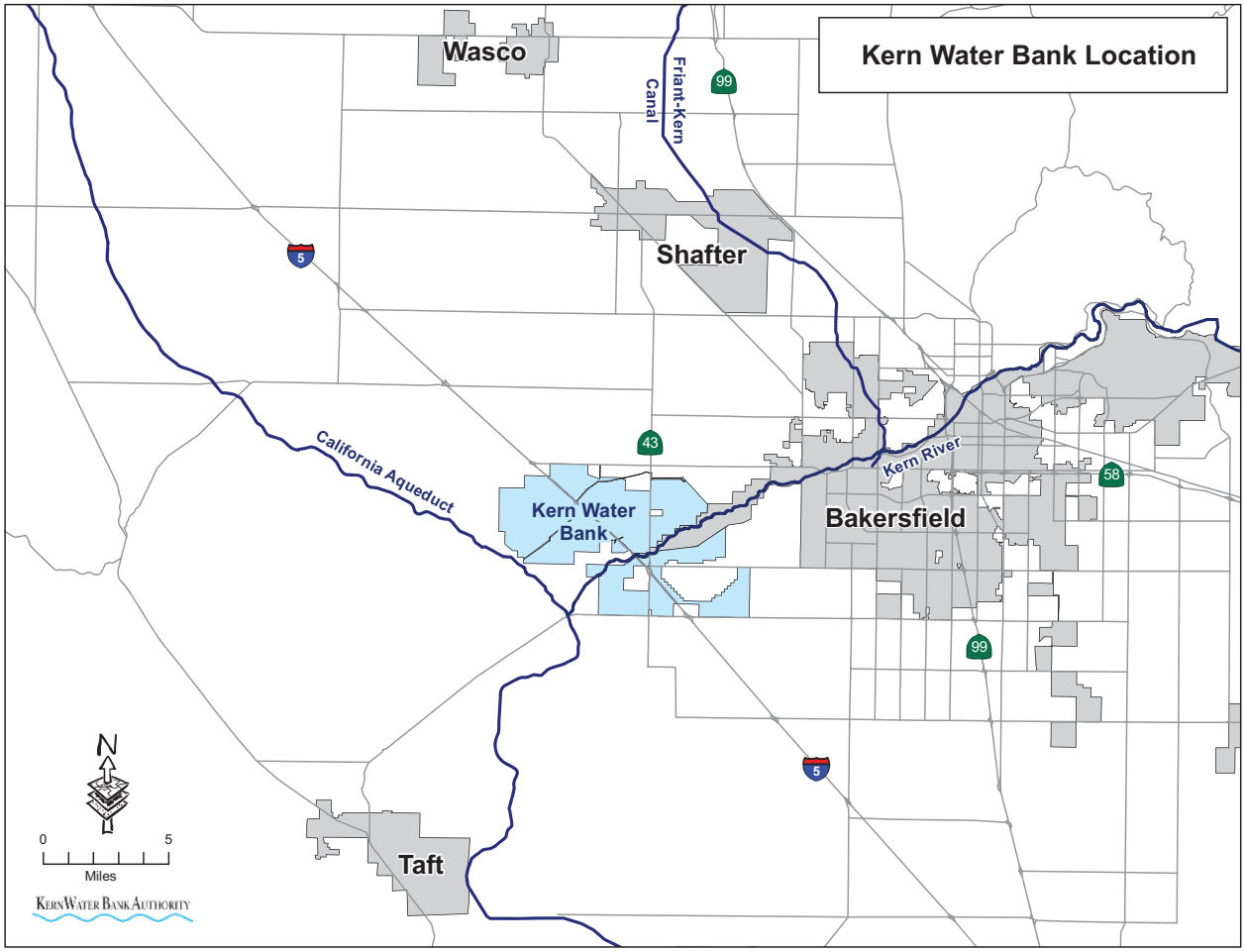


**FIGURE 1.** Kern Water Bank and vicinity. Source: Kern Water Bank Authority.

center of the bank, with the Friant-Kern Canal delivering water to the Kern River to the north and the California Aqueduct passing through the west boundary of the bank (figure 1). This geography allows the bank the flexibility to recharge water from a variety of sources, depending on where water is available.

The recharge facilities include 75 shallow recharge basins, 88 recovery wells, 36 miles of pipelines, the six-mile KWB canal to the Kern River, and three pump stations.[7] Recharge basins make up a total of 7,500 acres of the KWB property, with small canals managed by weir boxes connecting neighboring ponds [1, 19]. The basins are constructed by erecting a low earthen berm on the downslope area to create ponds on the sloping alluvial fan. Water depth in the recharge basins averages 2 ft. Due to soil permeability, recharge is relatively quick—occurring at rates of between 0.15 and 0.4 ft. per day, with slower recharge rates occurring toward the end of a long recharge cycle. Depending on the rate of recharge and water availability, the bank can recharge 40,000–60,000 AF per month.

Recovery wells are located on the northern two-thirds of the property, spaced approximately one-third of a mile apart.[8] These wells are typically 750 ft. deep and can yield up to 5,000 gallons per minute [1]. Water is pumped from the bank at the request of KWB member entities, subject to control measures set by the KWB MOU to protect water levels. These measures include the ability to limit the monthly, seasonal, or annual recovery rate or adjust pumping rates to reduce potential negative impacts caused by the operation of the bank [21].

The bank frequently operates year-round, and wells need regular rehabilitation and replacement. Maintenance scheduling and costs are an ongoing concern.

7. See, for example, Figure 3.6-10 in ICF [1].

8. For a map of the Kern Water Bank facilities, see [20].

**BANKING RULES AND ACCOUNTING.** The conceptual underpinnings of the KWB are similar to a financial bank in that multiple parties can make deposits (through physical recharge to the aquifer or by receiving credits in other ways) and are able later to withdraw physical water for their own use or transfer their credits to other entities. KWBA's rules for banking and transferring water ensure clarity in operations.

As with a financial bank, tracking and accounting for recharged water, and crediting it appropriately, is essential for ensuring the operation of the bank. DWR and KCWA each track the amount of water diverted from the SWP and regularly reconcile these numbers. The KCWA also tracks water arriving to the bank from the Friant-Kern Canal and accounts for this water for KWB participants.

Sales of water from the bank and recharge accounting are governed by several provisions in the KWB MOU and its Operations Plan.[9] First, a one-time "loss factor" of 10% is assumed for all water deposited in the KWB, consisting of two components. One portion of the loss factor stems from a joint DWR/KCWA study that showed evapotranspiration losses from the recharge ponds are approximately 2–4% [22]. Based on the assumption of a closed basin hydrology, and thus no leakage from within the aquifer, this portion is conservatively set at 6% of total water banked. The rest of the loss factor (4% of water banked) is automatically calculated for all water stored in the KWB [22, pp. 7–8 (In Appendices doc., pp. 81–82)]. This latter portion of water is kept in the bank and made available for purchase by adjoining water districts to balance groundwater overdraft in their water district, while it is thus not technically accounting for hydrologic losses, it is an important accounting element designed to make sure double counting does not occur. After the loss factor, the remaining 90% of water diverted to and stored in the bank is credited to the bank member's account and is available for later recovery and withdrawal.

Bank participants can use water themselves or sell water stored in their accounts to third parties. If water is sold to a third party outside of Kern County, an additional 5% loss factor is included in the sale. The water left in the aquifer as a result of the calculated 5% loss factor on a sale is not available for recovery by other users and remains in the aquifer [12].

Most water transferred from the bank is pumped into the California Aqueduct for transport. At this point, the KCWA and DWR track and reconcile the amount of water leaving the bank and entering the Aqueduct. Some of the water that is deposited into the Cross Valley Canal may move east for operational exchanges or at the request of Improvement District 4. KCWA tracks this water.

Water may also be recovered by exchange. Recovery by exchange can occur between either KWB members or between a KWB member and an adjacent water bank. For example, a KWB member may need to recover water at the same time that an adjacent bank needs to deposit water. Instead of a simultaneous physical withdrawal and deposit of water, the KWB member will divert the adjacent bank's incoming water and put it to use. The adjacent bank, in exchange, will receive a credit to water in the KWB from the KWB member's account.

KWB members may sell their banked water to non-participant agencies, but they must first offer the opportunity to purchase their water to other KWB members before selling to non-participants [7]. From 1995 to 2016, approximately 1.5 million AF was pumped from the bank, all during dry years [1]. As of January 2018, about 910,000 AF of water is stored in the KWB [1].[10]

**WATER QUALITY.** The KWBA's recharge and recovery operations must comply with federal and state water quality regulations. The state Porter-Cologne Water Quality Control Act requires the development of basin plans that specify beneficial uses of rivers and groundwater basins and establish water quality standards for these waters. The Central Valley Regional Water Quality Control Board implements the Tulare Lake Basin Plan, which covers the Kern County sub-basin [23]. The basin plan specifies allowable levels of pollutants in surface water and groundwater, but the Regional Board does not directly regulate the quality of water recharged in association with the Kern Water Bank. Rather, the quality of recovered water is governed by DWR's "Pump-in Policy" for the SWP [1, 24]. KWBA manages the groundwater quality effects of

9. See Appendices to Notice of Preparation of an Environmental Impact Report for the Kern Water Bank Conservation and Storage Project. Kern Water Bank Authority (2012). Appendix B contains the 1995 Memorandum of Understanding Regarding Operation and Monitoring of the Kern Water Bank Groundwater Banking Program. Appendix C contains the Long-Term Project Recovery Operations Plan Regarding Kern Water Bank Authority Project.

10. ICF. Kern Water Bank Project Facilities. Kern Water Bank Authority.

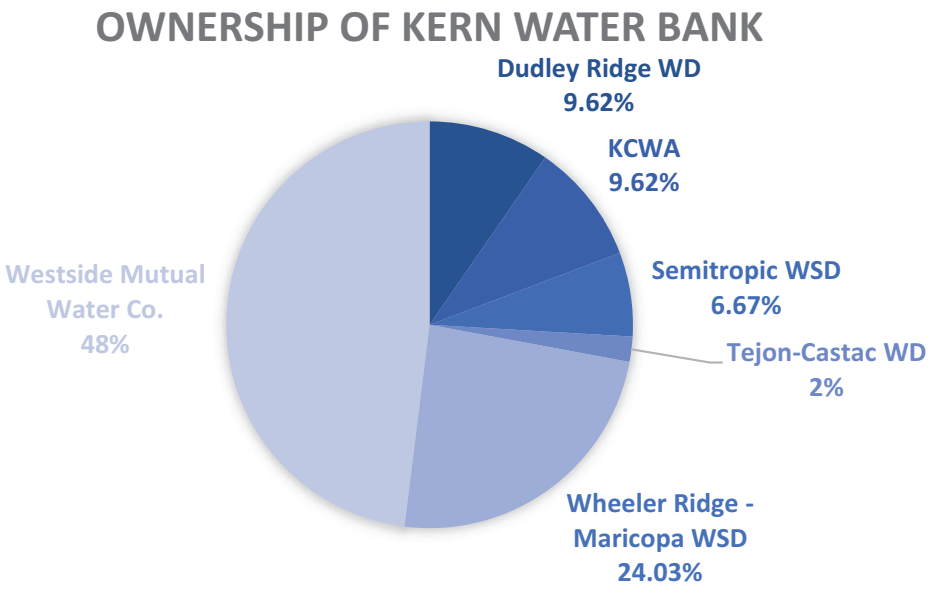


**FIGURE 2.** Ownership shares of the Kern Water Bank. Data source: DWR.

its operations under an MOU Regarding Operation and Monitoring KWBA monitors groundwater quality through testing of both dedicated monitoring wells and the recovery wells themselves [25]. The monitoring wells are sampled according to a schedule set by the Kern Fan Monitoring Committee, and results are reported to the committee. The recovery wells are monitored according to a schedule by the KWBA, which reports results to DWR.

**INSTITUTIONAL ARRANGEMENTS.** The KWB is operated for the benefit of its member agencies. It does not hold its own water rights. The bank is governed by the KWBA, a JPA consisting of six member agencies.[11] Two of the participants are California Water Districts (WDs),[12] two are California Water Storage Districts (WSDs),[13] one is a water agency,[14] and one is a private company.[15] Both WDs and WSDs are special districts, a form of local government created to deliver a specific service to a defined geographic region [26]. The four KWB member WDs and WSDs supply water for agricultural purposes. The two other members are the KCWA and the Westside Mutual Water Company. The KCWA participates on behalf of its ID4, which provides treated water for urban uses [16]. The Westside Mutual Water Company is a corporation that delivers water to its shareholders [27].[16, 17]

Under the JPA structure, each KWBA member agency has rights to the project proportional to the amount of its SWP Table A entitlement the member agency retired in the agreement that transferred the KWB from the DWR to the KWBA [12]. Figure 2 illustrates the ownership interest in the bank [12, p. E-18].

Each member of the KWBA has a seat on the Board of Directors, which governs the KWBA. The Westside Mutual Water Company currently holds two seats on the Board.[18] As with many other water districts in California, local landowners control the member agencies, which in turn collectively influence KWB operations. Voting shares are allocated on the basis of within-district landownership. Agricultural land in Westside Mutual Water Co. is wholly owned by the Wonderful Company,

11. KCWA, Semitropic Water Storage District, Tejon-Castac Water District, Wheeler Ridge-Maricopa Water Storage District, Dudley Ridge Water District, and Westside Mutual Water Company [12].

12. Dudley Ridge and Tejon-Castac are Water Districts.

13. Semitropic and Wheeler Ridge-Maricopa are Water Storage Districts.

14. Kern County Water Agency is a water agency.

15. Westside Mutual is a private water company.

16. Westside Mutual Water Company's shareholders consist only of the Wonderful Company, formerly Paramount Farms, a large agribusiness that was heavily involved in negotiating the transfer of KWB land to the KWBA [7, 28].

17. The company is owned by Linda and Stewart Resnick, who through the Westside Mutual Water Company and Paramount Farming Company's holdings in Dudley Ridge WD, own or control a total of 59% of the KWBA.

18. The Board holds meetings monthly which include space for public comment in compliance with the Brown Act [29].

a private agricultural and food processing corporation, which also owns significant portions of Dudley Ridge WD and Wheeler Ridge. Therefore, a single company controls these three agencies, and thus more than 50% of the voting shares of the KWB. These landowners, along with other water users and the residents and businesses served by ID4, ultimately are direct beneficiaries of the water deliveries made by the KWB and of the resulting profits from beneficial use of that water for agricultural purposes or from the sale of any stored water.

The KWB operates under the *Memorandum of Understanding Regarding Operation and Monitoring of the Kern Water Bank Groundwater Banking Program* (KWB MOU). The KWB MOU establishes the Kern Fan Monitoring Committee ("Monitoring Committee"), which oversees water banking in the KWB to prevent adverse changes in water levels, water quality, or land subsidence. Members of the Monitoring Committee include KCWA and all water districts adjacent to the KWB: Buena Vista WSD, Rosedale-Rio Bravo WSD, Kern Delta WSD, Henry Miller WD, and West Kern WD [1]. This Monitoring Committee can review any activities that may result in adverse impacts and may make recommendations to the KWBA based on reported data [12]. The Monitoring Committee is also responsible for suggesting resolutions to disputes regarding the operation of the KWB, before any legal action may be taken. If there is a dispute between the KWBA and the Monitoring Committee, it must be resolved through arbitration [22, p. 12 (In Appendices doc., p. 86)].

The KWBA also has two recovery operations plans that are intended to prevent pumping water from the KWB from having adverse impacts on nearby landowners. The *Long Term Project Recovery Operations Plan* (Long Term Plan) applies only to the KWB.[19] It describes KWBA's responsibility to monitor and report groundwater conditions, create a groundwater model to evaluate the impacts of project operations, and mitigate any negative impacts when necessary.[19] The *Joint Project Recovery Operations Plan Regarding Pioneer Project, Rosedale-Rio Bravo Water Storage District, and Kern Water Bank Authority Projects* is an agreement between the entities listed in the plan title.[19] It establishes a Joint Operations Committee that includes representatives from each of the entities. This Committee meets during years when recovery operations are ongoing to evaluate groundwater conditions, landowner concerns, and consider mitigation actions.[19]

**COSTS AND FINANCING.** The KWB was established after DWR had invested in land and infrastructure development, proving the physical concept for the water bank as described above but failing to establish a bank managed by a state institution. Following the Monterey Agreements, KWBA member agencies voluntarily retired contractual entitlements to 45,000 AFY of water from the SWP in return for a transfer of land from DWR to KWBA members, establishing the KWB. As noted above, these entitlements have never actually been delivered at their face amount, and climate change and other factors are likely further decreasing the reliability of this supply source [30]. Consequently, critics of the KWB argued that the state was giving up a real asset and getting "paper water" in return. In response, proponents of the deal point out that around the time the KWB was established, shares of Table A water were being purchased for significant amounts.[20] Extrapolating from this sale suggests a real and significant economic value to the exchange, with a potential valuation of the retirement of around US$45 million in 2009 [32].[21]

Following acquisition of the property, KWB made major infrastructure developments on the property. These improvements included construction of the KWB Canal. Funding was provided by US$20 million in private loans, and a US$5 million Proposition 204 loan [33]. Additional funding was acquired through a US$3.4 million Proposition 13 grant to KWB member agencies [34].

The KWBA itself does not profit from water bank operations—rather it passes net costs less any operating surplus through to its members. Member agencies pay the cost of recharge, which is US$9.50–US$16 per acre-foot, and recovery, which is US$98–US$153 per acre-foot.[22]

19. Appendices to Notice of Preparation of an Environmental Impact Report for the Kern Water Bank Conservation and Storage Project. Kern Water Bank Authority (2012).

20. Dudley Ridge WD sold 14,000 AF of Table A water to Mojave Water Agency for a face value of $5,250/AF in 2009, at the end of a significant drought period in California. See [31].

21. Note that transfers of SWP water were rare at this time, and precise and confident valuations in an illiquid market can be difficult. Further, it is important to recognize that an SWP Table A amount of 45,000 AF of water has always in reality equated to annual deliveries of significantly less than that amount. Thus, in spite of how such trades have been framed for various purposes over time, the actual wet water being traded was less always clearly less than its face amount.

22. Personal Communication, KWBA.

They also pay for operation and maintenance of the banking facilities through assessment fees levied based on their share in the project. At the end of each year, the bank reconciles its actual operating costs with what it charged members; members receive a refund on any overpaid funds. Costs of the Monitoring Committee are split between project participants and the adjacent nonmember entities on the committee [1, 7, p. 99].

Over 3,000 acres of the KWB land function as a conservation bank. Companies and organizations whose projects have been determined to impact threatened or endangered species found in the Kern County area can apply to purchase offsite mitigation credits from the KWB. USFWS and CDFW determine whether applicants are eligible for offsite mitigation based on the species present at both locations. The KWBA charges US$5,000 per transaction and US$15,000 per mitigation credit, plus another US$375 per credit that goes into an endowment fund managed by CDFW for the restoration and conservation of listed species living on lands owned by the bank [35].[23] As of 2016, 1,321 credits have been sold [14].

Previously, an additional source of income to the KWBA was the Environmental Water Account (EWA), available to the bank from 2000 to 2007. The EWA was designed to reduce conflicts between environmental needs and other uses of water in the Sacramento-San Joaquin Delta. Nominally, the primary goal of the EWA was to ensure compliance with the ESA and develop a mechanism to help protect endangered fish species in the Delta beyond the confines of ESA compliance.[24] The EWA was designed to give fishery managers flexibility to deploy environmental water to ecosystems in response to changing hydrology and fishery needs. The EWA allocated up to US$50 million per year from federal and state taxes [37, 38] to allow fishery managers to purchase water from both CVP and SWP contractors for environmental purposes [36, 38, 39]. From 2000 to 2005, the EWA bought 317,174 acre-feet of water from KWBA [12], with KWBA profiting from these sales.

**PROJECT BENEFITS.** The main benefit of the KWB is increased water supply reliability for its member agencies. The KWB provides water storage to member agencies when they have excess water and recovery when they do not, increasing the reliability of each member's water supplies. During dry years, SWP allocations have been well below 100%. For example, allocations in 2014 were set at a low of 5% [40]. During these years, when KWB members could not meet irrigation demands with SWP water alone, banked water allowed bank members to keep crops alive and maintain production and profit.

Aside from benefiting its members by providing water during shortages, the KWB also benefits the local environment by providing increased habitat for sensitive wildlife. The KWB has reestablished 12,000 acres of grassland habitat and 7,500 acres of intermittent wetland habitat, depending on how full recharge ponds are. Frequent wildlife surveys on the property monitor the diversity and abundance of plant and animal species. In 2011 and 2012, 35,000 individuals of 66 species of waterfowl were estimated to have utilized the KWB during their winter migration [1]. Endangered or threatened species found on the property include the Tipton kangaroo rat, San Joaquin kit fox, and Blunt-nosed leopard lizard. The fallowed land also provides benefits as a carbon sink. It is important to note that these benefits are in the form of compensatory mitigation, whereby credits generated from the restoration of 3,797 acres of the project are available for purchase for the mitigation of environmental damages caused by other projects, providing an additional income stream to KWBA. Such mitigation is an important mechanism that can generate significant environmental and economic benefits, but it does mean that the benefits described here are at least partially offset by environmental degradation in other areas.

## CONCLUSION

The KWB is one of very few examples of MAR that functions institutionally as a groundwater version of a financial bank. Most other examples of MAR that are dubbed "groundwater banking" operate as piggy banks, in which a single entity stores water for later use. Via the KWB, multiple parties deposit physical water through MAR, and this water is then available for later withdrawal for their own use, or for trade with other authorized parties. Employing a carefully developed set of rules, the KWB has achieved its operating goals for over two decades, providing its members a highly valued reserve of stored water for times of shortage and adding significant regional flexibility in water management to a storage- and

23. CDFW was previously known as the California Department of Fish and Game (CDFG).

24. In practice, the "EWA was successful in reducing uncertainty in water supply; however, its contribution to the recovery of listed fishes was unclear" [36].

conveyance-constrained water system. A range of factors enabled the creation and success of the KWB, including physical, geographical, and institutional ones. The bank has engendered controversy since its inception, as described above, and ongoing lawsuits challenge its legal foundations. These lawsuits emphasize the value and effectiveness of the KWB's groundwater banking structure, but their contentions that the bank therefore should have been developed and operated for public rather than private benefit continue to cast a shadow over it.

Physically, the size, quality, permeability, historic depletion, and a combination of connection to surface conveyance with relative hydrogeological isolation of the alluvial aquifer. Geographically, its proximity to the SWP means that KWB has access to a conduit for importing and exporting water that connects this storage facility to a broader system. The KWB also benefits from its location at the confluence of multiple surface water sources and the presence of conveyance infrastructure that can help transport that water. During wet periods, it can choose between purchasing excess Kern River water, CVP water, or SWP water. Existing infrastructure, including the California Aqueduct and the Friant-Kern Canal, serve to convey water to the bank.

The temporal relationship between local demands and available conveyance through the SWP is also important to the bank's success. The SWP has a conveyance bottleneck during the times of peak demand, and thus, south-of-Delta storage, such as that provided by the KWB, is highly valuable for increasing supply reliability.

The institutional and political efforts that enabled the KWB have become California water lore [32], illustrating how deeply nested such a facility is within broader water management structures and leaving unsettled the ultimate determination of the legality of the origins of this particular bank. The state's substantial investment in the development of the project laid groundwork for the physical and institutional development of the KWB. Once this physical proof of concept was made, effective (but non-transparent) negotiations by water users led to a linkage the transfer of these assets to broader changes in SWP operations. And the willingness of the state to trade the physical assets of the nascent Kern site for Table A contract water assets transferred a state-controlled MAR storage experiment to a privately controlled water bank.

The biggest potential challenge to the KWB is water supply. The bank's future operations rely on the continued availability of surplus water in wet years for recharge. In a prolonged drought, water may not be available for storage and the bank will see net outflows rather than net gains to water in storage. This is how the bank is supposed to function, but at some point, stored water could be exhausted, and with it the bank's usefulness during that drought, although this would be true of any storage project without sufficient inflows.

Ultimately, however, the KWB responds to a key central truth of water management—throughout the world, storage and conveyance are often key bottlenecks for maximizing available water supplies, and this is exemplified particularly in California south of the Sacramento-San Joaquin Delta. KWB creatively leverages an existing geological resource—the Kern Aquifer—by overlaying the incentive of a water banking structure, and deftly and efficiently manages the combination to create immense value.

The uniqueness of the KWB suggests a range of broader conclusions for the intersection between groundwater recharge and groundwater banking. Our initial exploration found few U.S. water banks that meet our admittedly strict definition stated above in the introduction, and even fewer that involve MAR and groundwater basins. The development of the KWB involved a rare alignment of geologic, hydrologic, infrastructure, funding, and institutional opportunities with a strong vision, effective multi-party negotiations, and a multiparty exercise of political will. The challenges of implementing the KWB likely reflect the complexities that would be involved in developing true groundwater banking at regional scale. But its success in harnessing MAR generate immense value for participants and for the flexibility of the broader California water system suggests that other areas could benefit from studying and potentially implementing similar schemes.

## AUTHOR CONTRIBUTIONS

KM, PG, and MK researched and wrote the original draft. AM and DO contributed to research and writing. MK and AM conceptualized, secured funding for, and managed the project.


## ACKNOWLEDGEMENTS

We are grateful to Jon Parker and Adam Keats for useful details and context. Tim Quinn, Rita Maguire, William Blomquist, and Nell Green Nylen gave helpful reviews and feedback.

## COMPETING INTERESTS

The authors have declared that no competing interests exist.


## FUNDING

Funding for this research project was provided by Nestlé Waters North America.


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