Supporting Information for

Enhancing Drought Resilience with Conjunctive Use and Managed Aquifer Recharge in California and Arizona

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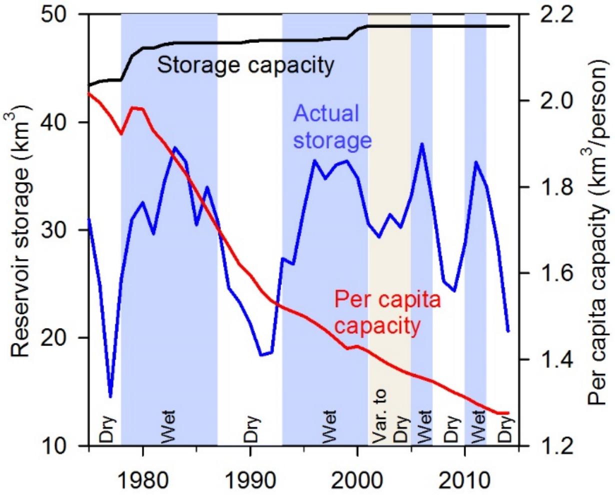


Figure S1. Temporal variations in surface reservoir capacity, reservoir storage, and per capita reservoir capacity in California. Total reservoir capacity changed little between 1975 (43.4 km^3) and 2014 (48.9 km^3) in 160 reservoirs while the population increased by 72% from 21.5 million to 38.3 million, resulting in a per capita storage capacity decrease of 35% from 2.0 ML/person to 1.3 ML/person. Prevailing climatic conditions are indicated by shaded areas. Data on reservoir storage from California Data Exchange Center (CDEC: http://cdec.water.ca.gov/reservoir.html). Population data were obtained from http://www.census.gov/popest/data/state/totals/2013/index.html.

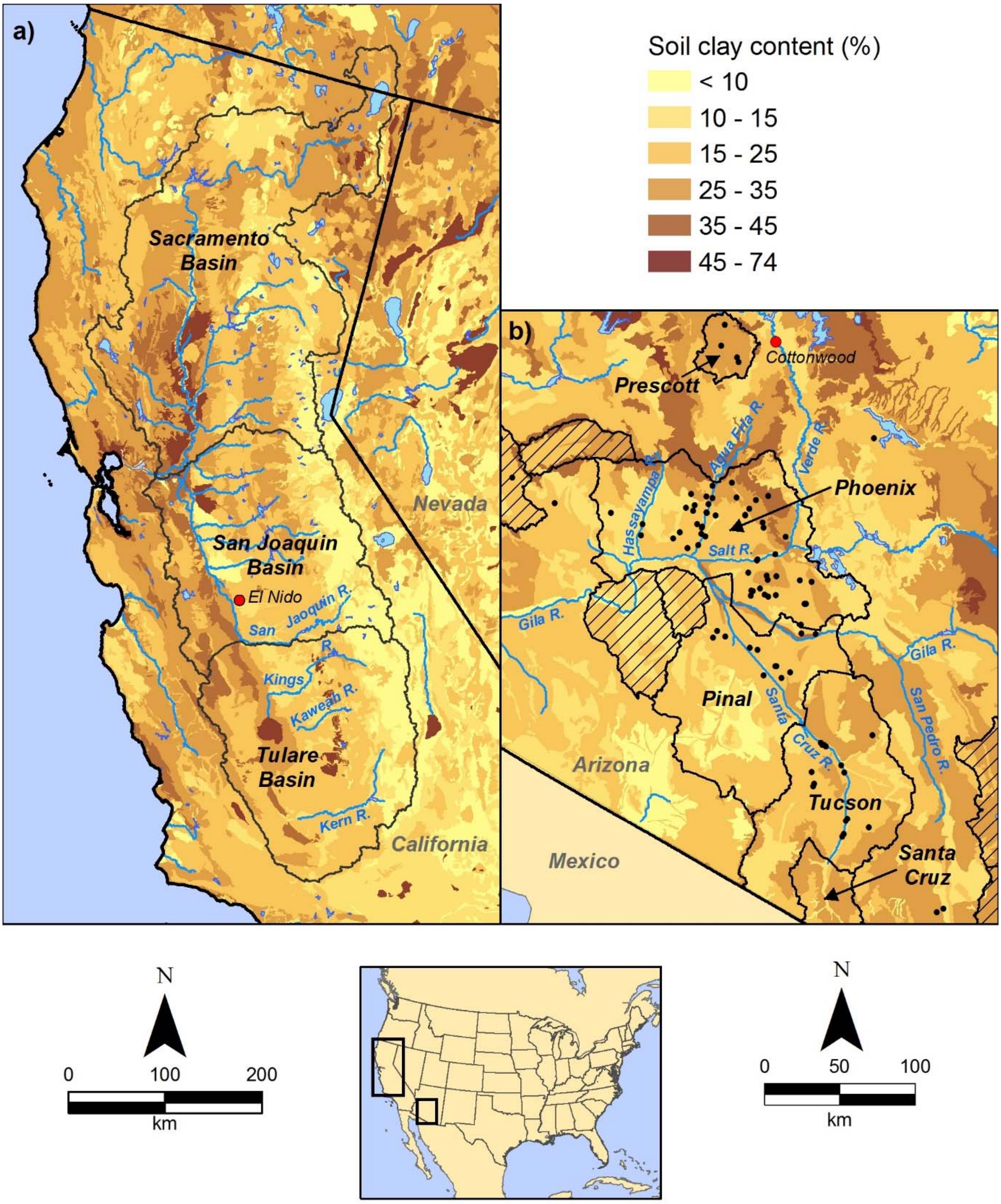


Figure S2. Soil texture based on percent clay content from STATSGO[1] in a) the California Central Valley and b) south central Arizona where managed aquifer recharge systems are located. In the Tulare Basin soils are coarser grained to the east along the margins of the Sierra Nevada Mountains and become finer grained toward the center and western regions. Soils in Arizona are generally finer grained. Point symbols in Arizona represent the location of managed aquifer recharge facilities, primarily spreading basins. Boundaries for Aquifer Management Areas (Prescott, Phoenix, Pinal, Tucson, Santa Cruz) in Arizona are shown for reference. Hatched areas in Arizona represent non-AMA regions in Arizona with substantial agricultural water use that do not have access to surface water from CAP.

Section 1. Legal and Regulatory Aspects of Conjunctive Use and Managed Aquifer Recharge

Arizona has a long history of regulations to support CU and MAR with the passing of the Groundwater Management Code (GMC) in 1980[2]. While CU and MAR have been practiced in California since the 1960s, the Sustainable Groundwater Management Act (SGMA) was only passed in 2014 (SI, Section 3b). Both provisions identify areas with excessive groundwater depletion, designated as Active Management Areas in Arizona (Fig. 2) and high and medium priority groundwater basins in California. The goals of the GMC vary among regions in Arizona. According to the GMC all new development in AZ should have an Assured Water Supply for 100 yr with rules adopted in 1995. The goal of some of the AMAs (Phoenix, Prescott, and Tucson) is safe yield by 2025, defined as groundwater withdrawal ≤ groundwater replenishment. The Pinal AMA management goal is to preserve the primarily agricultural economy for as long as feasible, while considering the need to preserve groundwater for future non-irrigation uses. Two Irrigation Non-Expansion Areas (INAs) were also established- Joseph City INA and Douglas INA. These plans give an idea of the range of goals for each region. The California SGMA requires sustainable groundwater management in each basin, allowing 20 years (2040) to achieve this goal (i.e. within 20 yr of plan implementation). The history of regulations and institutional frameworks developed in Arizona gives an indication of what was required to establish and incentivize CU and MAR in the state [2]. Because storage in aquifers is not visible and more difficult for the public to understand, the Arizona legislature established six demonstration projects in 1990. In 1993 the Legislature indicated that developments that could not meet the Assured Water Supplies could purchase credits from the Central Arizona Groundwater Replenishment District (CAGRD). The Arizona Water Banking Authority (AWBA) was established in 1996 to ensure that all CAP water is used and stores it in facilities owned and managed by other entities, such as Tucson Water. There is excellent reporting of water deliveries, storage, and use in the AMAs, indicating the fraction in CU and MAR. In addition, regional groundwater modeling studies provide valuable information on groundwater storage changes over time. In contrast, reporting of water management and detailed modeling of CU and MAR systems in California are limited. The differences in reporting may reflect state oversight in AZ versus local control in CA. The legislative acts and the related institutions established to oversee CU and MAR emphasize the long timescales required for planning and implementation of these programs.

Legislation Related to Conjunctive Use and Managed Aquifer Recharge

1a. The Groundwater Management Code in Arizona

The State owns the groundwater in Arizona and it is governed by the doctrine of reasonable use. This is important because it impacts the security of water stored underground. The Arizona Groundwater Management Act, also termed code, was passed in 1980 and resulted in creation of the Arizona Dept. of Water Resources to oversee the administration of the Code provisions. Details of the Code can be found in http://www.azwater.gov/AzDWR/WaterManagement/documents/Groundwater_Code.pdf

The following is excerpted from the website.

The goals of the Code are to:

1. Control severe overdraft
2. Provide a means to allocate groundwater resources
3. Augment groundwater through supply development

Three levels of water management were set up to accommodate different conditions in the state: 1. Lowest level with conditions applying throughout the state, next level applying to Irrigation Non-

Expansion Areas (INAs) and the highest management level applying to Active Management Areas where historical groundwater overexploitation was most severe. The AMAs are shown in Fig. 2 and include Prescott, Phoenix, Pinal, Tucson and Santa Cruz. The INAs include Douglas, Joseph City, and Harquahala.

The goal of the Phoenix, Prescott, and Tucson AMAs is to reach "safe-yield" by 2025, defined as a long-term balance annual groundwater withdrawal and natural and artificial recharge. The goal of the Pinal AMA is to extend the agricultural economy lifespan for as long as possible, and preserve water supplies for future activities not related to agriculture.

Six provisions were established:

1. A program of groundwater rights and permits.
2. Prohibition of irrigation of new agricultural lands within AMAs.
3. Five water management plans for each AMA for conservation targets and other criteria.
4. Demonstration of a 100-year assured water supply for new development by developers.
5. Metering water pumped from large wells.
6. Annual reporting of water withdrawal and use reporting.

Groundwater rights in AMAs include 1. Grandfathered rights, 2. Service area rights, and 3. Withdrawal permits.

The Grandfathered rights include irrigation rights that apply to land irrigated between 1975 and 1980, type 1 non-irrigation grandfathered right to land permanently retired from irrigation, and type 2 non-irrigation grandfathered right for non-irrigation purposes. Irrigation grandfathered rights are tied to the associated land. Type 1 rights can only be transferred with the land also whereas Type 2 rights are may be sold separately from the land or well.

Service area rights refer to rights of cities, private water companies, and irrigation districts to withdraw groundwater for their customers. Withdrawal permits allow new groundwater withdrawals for non-irrigation uses in AMAs. No new irrigation is allowed in AMAs.

Management plans for AMAs include conservation plans related to agricultural, municipal and industrial water users for 10 yr intervals from 1980s – 2020 and the 5th plan is for 2020 – 2025.

Land (subdivided or unsubdivided) cannot be sold in AMAs without assurance of sufficient water quantity and quality for 100 years.

1b. The Sustainable Groundwater Management Act in California

Issues of groundwater ownership and rights are important because they affect the security of water stored underground through CU or MAR. In California, the landowner owns the groundwater and non-landowners can obtain groundwater from landowners through the appropriation process and are junior to those of the landowner. Groundwater pumping is controlled at the local level in California, mostly by counties, outside of adjudicated basins. Groundwater rights are classified as (1) overlying, (2) appropriative, and (3) prescriptive. According to overlying rights, a landowner can pump a limitless amount of water outside adjudicated basins. Appropriative rights rely on availability of surplus water. During times of water scarcity, the water rights are correlative among owners and the term "First in time, first in right" applies among appropriators.

Most agricultural regions in the Central Valley are under the jurisdiction of water districts which contract with water suppliers and the government to provide water and electricity for irrigation and municipal use.

History

- 1913—Legislature adopts Water Commission Act that requires permits for non-riparian diversion of surface water but excludes groundwater, goes into effect in 1914

- During the intervening 100 years groundwater is treated as a common resource allowing anyone to pump groundwater as long as it is put to a beneficial use
- 2014—Legislature amends Water Code to require ‘sustainable’ management of groundwater, using a local approach with state oversight

The act allows 20 years to achieve sustainability. The legislation – collectively referred to as the “Sustainable Groundwater Management Act” includes AB 1739, SB 1168, SB 1319, with all three bills signed into law by Governor Jerry Brown on 9/16/2014 (go into effect 1/1/2015) http://opr.ca.gov/docs/2014_Sustainable_Groundwater_Management_Legislation_092914.pdf

The Sustainable Groundwater Management Act

applies to:

- Groundwater basins (defined in California Department of Water Resources (DWR) Bulletin 118)

does not apply to:

- Adjudicated basins
- Low and very low priority basins as designated by DWR

DWR identifies 127 groundwater basins and sub-basins that are high or medium priority for monitoring. This is only a quarter of all California groundwater basins, but they account for almost 96 percent of California’s groundwater pumping.

<u>Timeline</u>

There are three categories of dates and deadlines: (1) DWR lays ground rules and provides information; (2) local agencies define and implement groundwater sustainability plan; and (3) State Water Resources Control Board (SWRCB) could potentially intervene to address local management deficiencies.

By January 31, 2015

- High and medium priority basins identified by DWR are subject to sustainable groundwater management mandates.

By December 31, 2016/January 1, 2017

- DWR releases its best estimate of how much water is available for groundwater replenishment
- DWR releases its best management practices for sustainable groundwater management

By June 30, 2017

- Local agencies affirm they will be a GSA for each high- or medium- priority basin (if an alternative has not been or pending approval)
    - The entire basin must be covered, i.e., no unmanaged areas

By January 31, 2020

- Basins designated by DWR as critical overdraft must be covered by a groundwater sustainability plan

By January 31, 2022

- High and medium priority basins as designated by DWR (through CASGEM) must be covered by a groundwater sustainability plan

Periodic reporting

- Annually the GSA must report to DWR
    - Groundwater level
    - “aggregate” extraction
    - use and availability of surface water for recharge or in-lieu use
    - total water use
    - change in groundwater storage

By January 1, 2040/2042 (within 20 years of plan implemented) each GSA must achieve sustainability (operating within the basin's sustainable yield). For good cause, DWR may allow up to 10 years more

GSA powers and authorities

- Adopt a plan, regulations, ordinances and resolutions, fees
- Monitor compliance
- Register wells
- Measure groundwater extraction
- Acquire, import, conserve and store surface water and groundwater
- Determine the validity of the GSA plan

Contents of a GSA plan

Required

- Implementation horizon of at least 50 years
- Measurable objectives to achieve sustainability within 20 years
- How objectives will achieve sustainability
- Monitoring components—groundwater levels and quality, subsidence, related changes in surface flow
- Mitigation of overdraft

Sustainable Yield

- The maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result

Undesirable result is significant and unreasonable (may include some or all):

- Depletion of groundwater in storage
- Seawater intrusion
- Degraded groundwater quality
- Land subsidence
- Surface water depletion causing adverse effects

Note:

- data should be collected over the long term on annual amount of recharge, extraction and change in groundwater storage

Summary

May require restricting pumping as a tool to bring overdraft into balance

Based on the timelines, we would not expect to achieve sustainable groundwater management (basins operating at sustainable yield) for at least a 25 years

Links and Timeline

Article with associated timeline:

http://legal-planet.org/2014/10/08/californias-new-groundwater-law-an-interactive-timeline/

Article:

http://hanfordsentinel.com/features/community/meet-doug-verboon-reluctant-groundwater-activist/article_eb295ea7-b73f-5762-9dc9-4affc5fbfe19.html

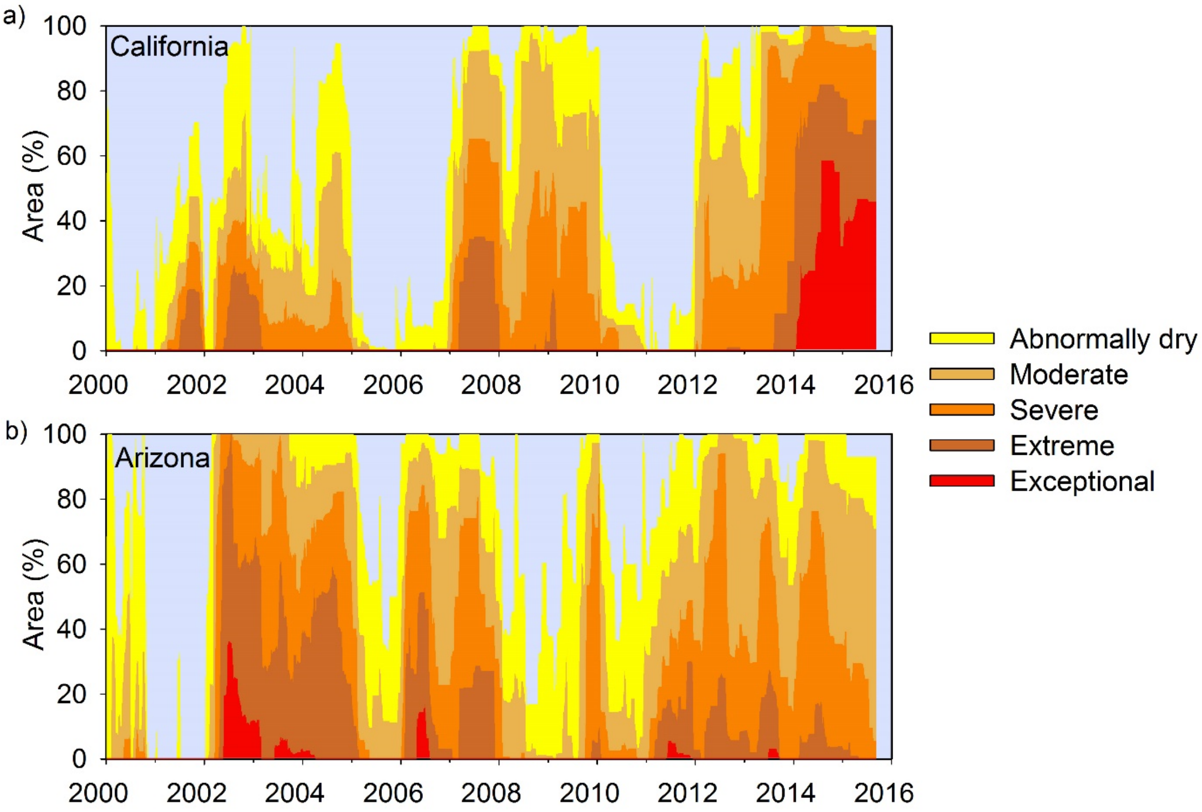


Figure S3. Time series of drought intensities by area in a) California and b) Arizona through Sept. 8, 2015. Data for California show the recent drought beginning in 2012, preceded by the 2007 – 2009 drought (DWR drought report). Data for Arizona show the recent drought (2011 – present), preceded by drought in 2006 – 2008 and 2002 – 2005. Data source: http://droughtmonitor.unl.edu/, accessed October, 2015.

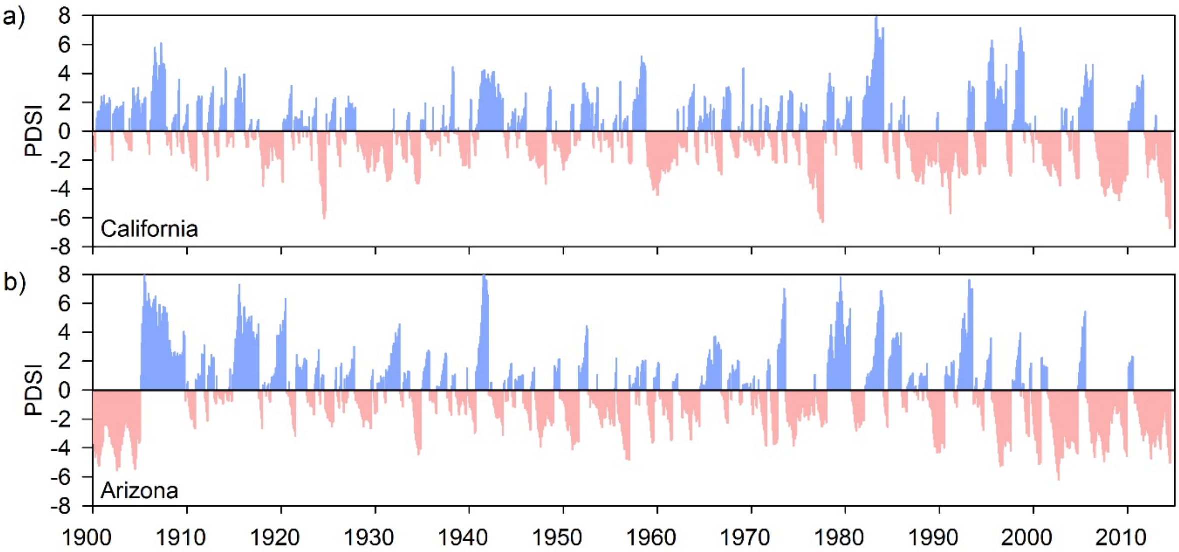


Figure S4. Temporal variations in Palmer Drought Severity Index (PDSI) in a) California and b) Arizona. Positive values indicate wet periods and negative values indicate droughts. Source of data: US NOAA National Climate Data Center (NCDC, http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php).

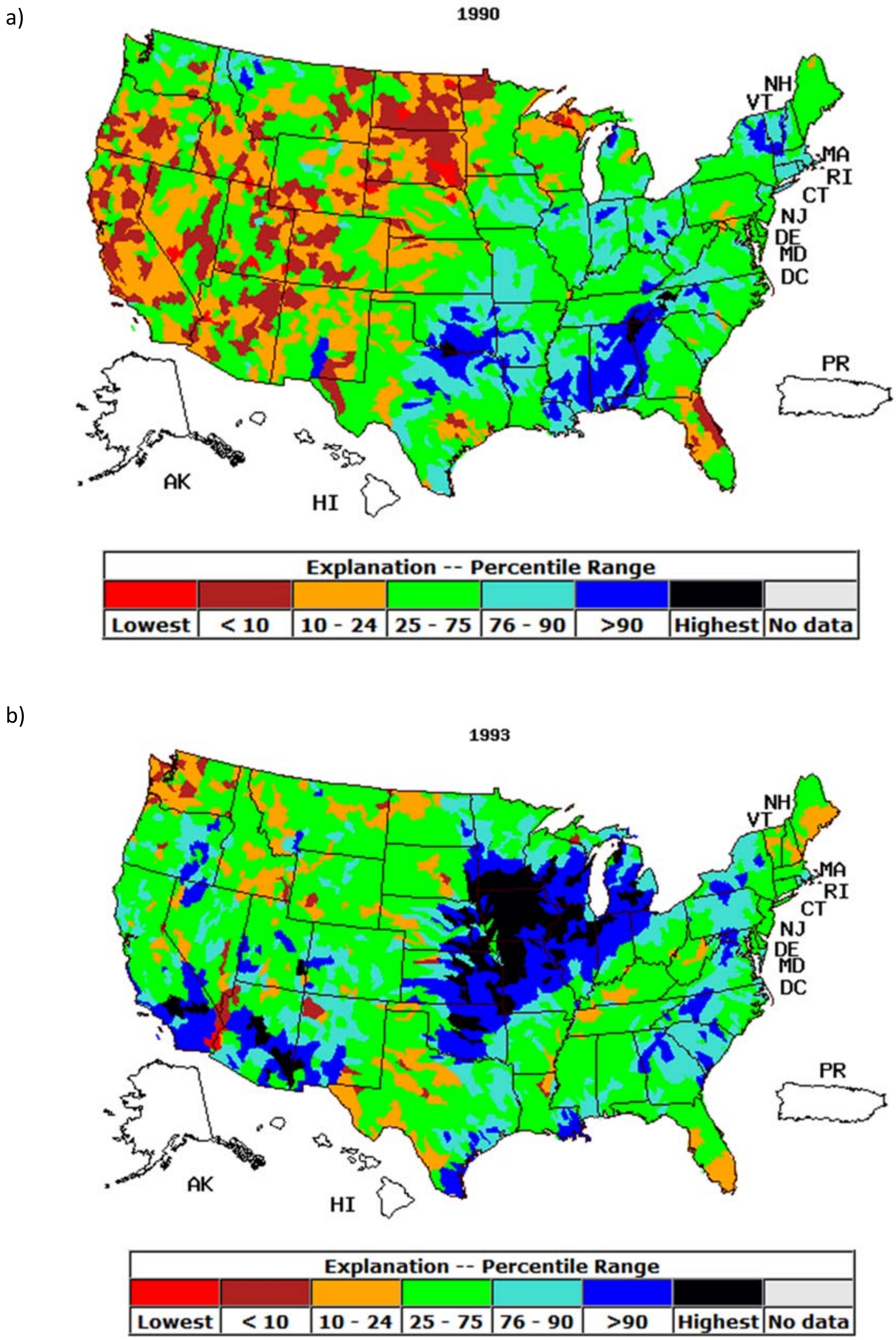


Figure S5. Comparison of runoff in a) 1990 (drought in SW U.S.) relative to b) 1993, a wet period in the SW. Extreme precipitation in 1993 is attributed to southerly movement of the jet stream and moisture input from the Pacific (Smith et al., 1993). Data source: USGS WaterWatch (http://waterwatch.usgs.gov/).

Section 2. Colorado River Allocations

The Colorado River Basin is managed according to the “Law of the River” (http://www.usbr.gov/lc/region/g1000/lawofrvr.html) which includes various compacts, laws, and regulatory guidelines. The Colorado River Compact of 1922 apportioned Colorado River water equally between the Upper Colorado River Basin and Lower Colorado River Basin (7.5 maf/yr each, 9.2 km^3/yr). The Boulder Canyon Project Act of 1928 apportioned the 7.5 maf (9.2 km^3) among the Lower Basin states (Arizona, 2.8 maf [3.5 km^3], California, 4.4 maf [5.4 km^3], and Nevada, 0.3 maf [0.4 km^3]). The Mexican Water Treaty of 1944 committed 1.5 maf/yr (1.8 km^3/yr) to Mexico. The Upper Colorado River Basin Compact of 1948 apportioned the 7.5 maf (9.2 km^3) among Colorado (3.9 maf [4.8 km^3]), New Mexico (2.0 maf [2.5 km^3]), Utah (1.0 maf [1.2 km^3]) and Wyoming (0.5 maf [0.6 km^3]) and additional 0.05 maf (0.06 km^3) to the portion of Arizona in the UCRB. The total allocation is 16.5 maf (20.3 km^3). The Colorado River Basin Project Act of 1967 authorized construction of the Central Arizona Project (CAP) to deliver water from the Colorado River to central Arizona and made the CAP water supply subordinate to the Colorado River appropriation to California during periods of water shortages.

Over-allocation of the Colorado River (20.3 km^3) results from the allocation being determined in 1922 after a period of above average flow (22.2 km^3/yr) relative to the current ~100 yr average flow (18.3 km^3/yr). The past 15 years since 2000 have been extremely dry with average flow of 15.2 km^3/yr (2000 – 2014) at Lee’s Ferry and reservoir storage sharply declined from a peak of 66.5 km^3 (2000) to 40.1 km^3 (2004). Reservoir storage in 2014 (38.7 km^3) represents 44% of reservoir capacity (87.2 km^3) and 69% of long-term reservoir storage (56.1 km^3), raising concerns about water reliability.

Section 3. Data Sources

Well hydrographs and groundwater depletion maps in the Central Valley: California State Groundwater Elevation Monitoring (CASGEM):

http://www.water.ca.gov/groundwater/maps_and_reports/index.cfm

Water deliveries to Kern County and water level hydrographs: obtained from contacting Kern County Water Agency: http://www.kcwa.com/

Water level hydrographs: available online at Arizona Groundwater Site Inventory:

https://gisweb.azwater.gov/waterresourcedata/gwsi.aspx

Arizona Dept. of Water Resources: http://www.azwater.gov/azdwr/

California Dept. of Water Resources: www.water.ca.gov

Central Arizona Project (CAP) water deliveries from the Colorado River (1999 – 2015):

http://www.cap-az.com/departments/water-operations/deliveries

Managed Aquifer Recharge and Conjunctive Use facilities in Arizona as of 2014:

http://www.azwater.gov/azdwr/WaterManagement/Recharge/documents/ALLAMAUSFandGSFList02.07.2014.pdf

Managed aquifer recharge facilities in California are listed in California Dept. of Water Resources (2015), California's Groundwater Update 2103: A compilation of Enhanced Content for California Water Plan Update 2013, *California Dept. of Water Resources, 90 p.*

http://www.waterplan.water.ca.gov/topics/groundwater/index.cfm

Arizona Active Management Area budgets:

http://www.azwater.gov/AzDWR/WaterManagement/Assessments/

Arizona Dept. of Water Resources, Hydrology Division, AMA regional GW models:

http://www.azwater.gov/azdwr/Hydrology/Modeling/default.htm

Kern Water Bank Authority: http://www.kwb.org/

Arvin Edison Water Storage District: http://www.aewsd.org/

California surface reservoir storage: California Division of Safety and Dams:

http://www.water.ca.gov/damsafety/damlisting/index.cfm

Section 4. Composite Groundwater Level Hydrographs

Composite groundwater level hydrograph were developed for the Active Management Areas (Phoenix, Pinal, and Tucson AMAs) with access to water deliveries from the Central Arizona Project (CAP) aqueduct. We compared composite hydrographs for the AMAs with irrigated areas that do not have access to CAP water (McMullen/Ranegras, Gila Bend, San Simon, and Willcox basins) (Figs. 2, 7). The number of hydrographs included in each composite varies annually and ranges from a maximum of 48 in San Simon Basin to 800 in Tucson AMA. The following procedure was used to develop composite groundwater level hydrographs in the LCRB.

1. Isolated Nov-March groundwater level observations
2. Removed groundwater levels flagged for issues such as pumping wells and no observations
3. Calculated average groundwater level for each region and anomaly based on the mean for the period of record
4. Removed several obvious outliers, mostly typo data entry errors
5. Removed years with fewer observations
6. Calculated mean anomaly for each year
7. Area weighted GW level changes based on areas of different regions

During data processing the following issues were identified. The number of observations were variable for each year which were attributed to two clear reasons,
1. change in data agency from USGS to Arizona Dept. of Water Resources in the mid-1980's and
2. as yet unavailable observations from Tucson Water agency after 2012.
There are also occasional years with fewer observations during 1990, 1993, and 1996. The number of hydrographs were also low in the Tucson AMA in 2013 (107) and 2014 (109).

An average groundwater level anomaly was produced for each Active Management Area and the nonmanaged areas (Fig. 7).

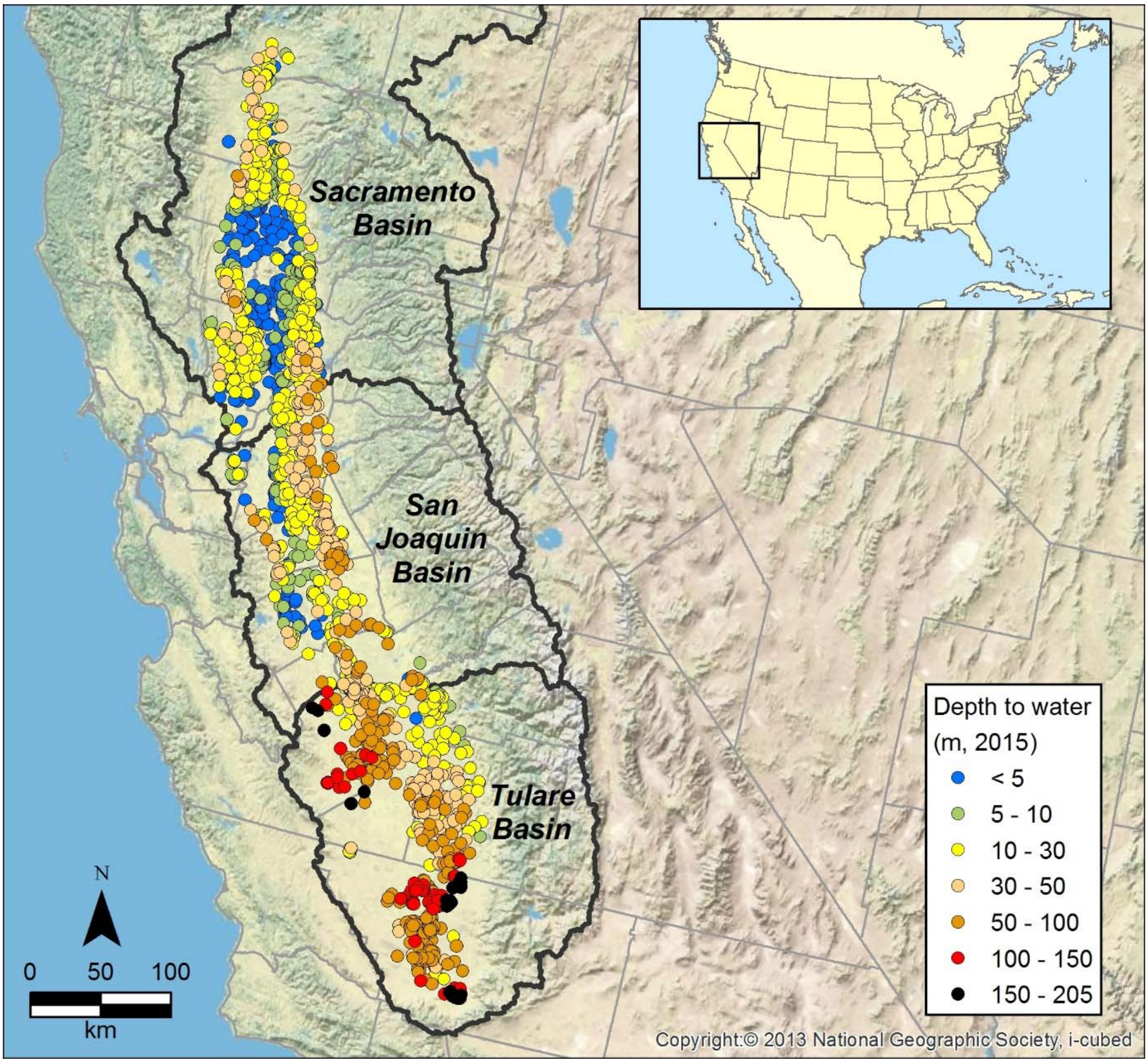


Figure S6. Depth to water table based on water level data monitored in spring 2015. Data source: California Statewide Groundwater Elevation Monitoring (CASGEM, (http://www.water.ca.gov/groundwater/maps_and_reports/index.cfm).

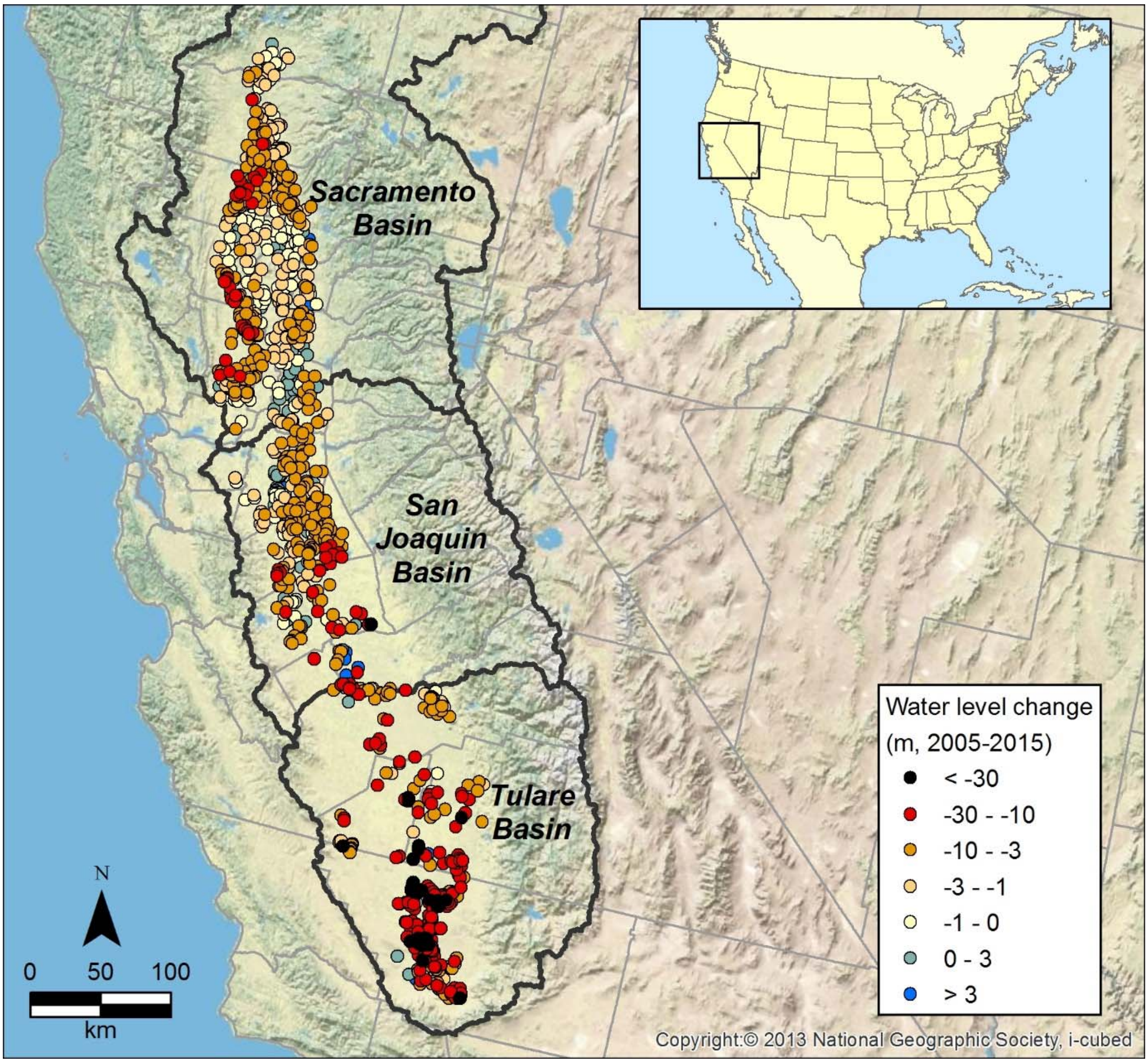


Figure S7. Change in water levels from spring 2005 to spring 2015. Data source: California Statewide Groundwater Elevation Monitoring (CASGEM, (http://www.water.ca.gov/groundwater/maps_and_reports/index.cfm).

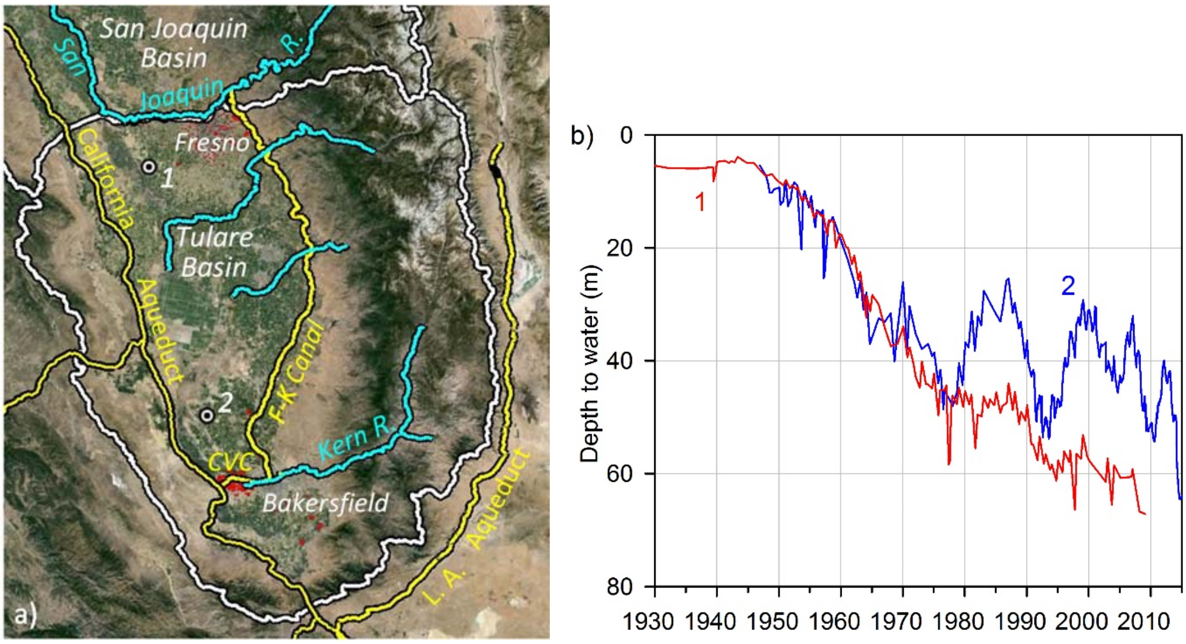


Figure S8. a) Locations of representative hydrographs and b) time series of hydrographs showing declines in the early 1900s with some wells showing recovery in the mid-1960s and 1970s with imported water from N California. Data source: California Statewide Groundwater Elevation Monitoring (CASGEM, (http://www.water.ca.gov/groundwater/casgem/), Kern County Water Agency (KCWA, http://www.kcwa.com/) Groundwater Database. Hydrograph 1 is attributed to demand continually exceeding supply from recharge (Well ID 15S18E30L001M). Hydrograph 2 is north of main area of MAR systems and shows impacts of conjunctive use with groundwater depletion during droughts and partial recovery during wet periods (Well ID 27S23E10J001M).

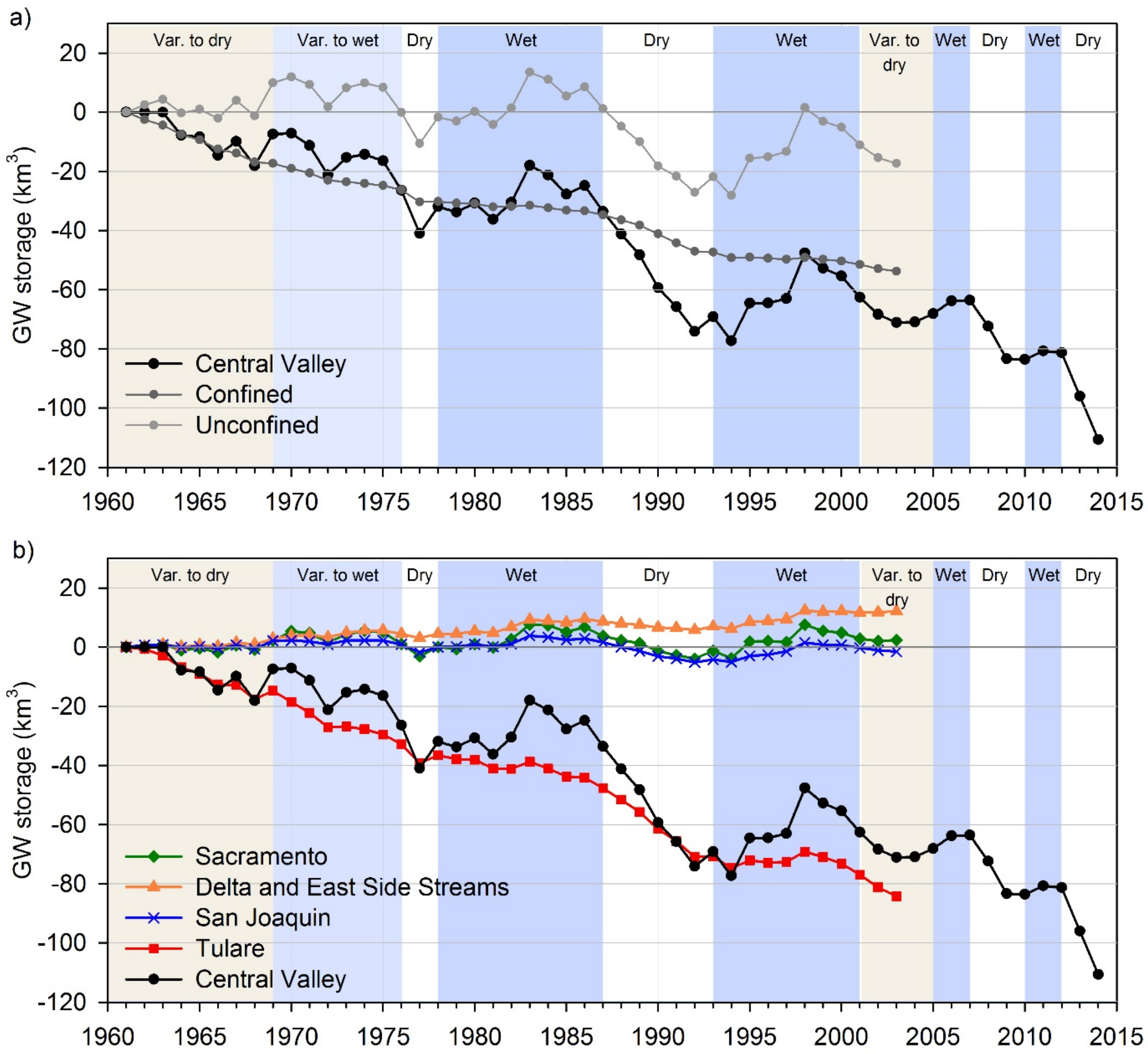


Figure S9. a) Simulated groundwater storage change in the Central Valley, including depletion in the unconfined and confined portions of the aquifer up to 2003 (modified from Faunt, 2009). Storage data beyond 2003 are unpublished. Storage depletion is dominant during drought periods (1976-1977; 1987-1992) with partial recovery during intervening wet periods. b) Simulated groundwater storage change in sub-basins of the Central Valley up to 2013 and total depletion up to 2013 (modified from Faunt, 2009). Total depletion in the Central Valley is dominated by depletion in the Tulare Basin. Storage depletion is dominant during drought periods (1976-1977; 1987-1992) with partial recovery during intervening wet periods. Prevailing climatic conditions are indicated by shaded areas in both figures.

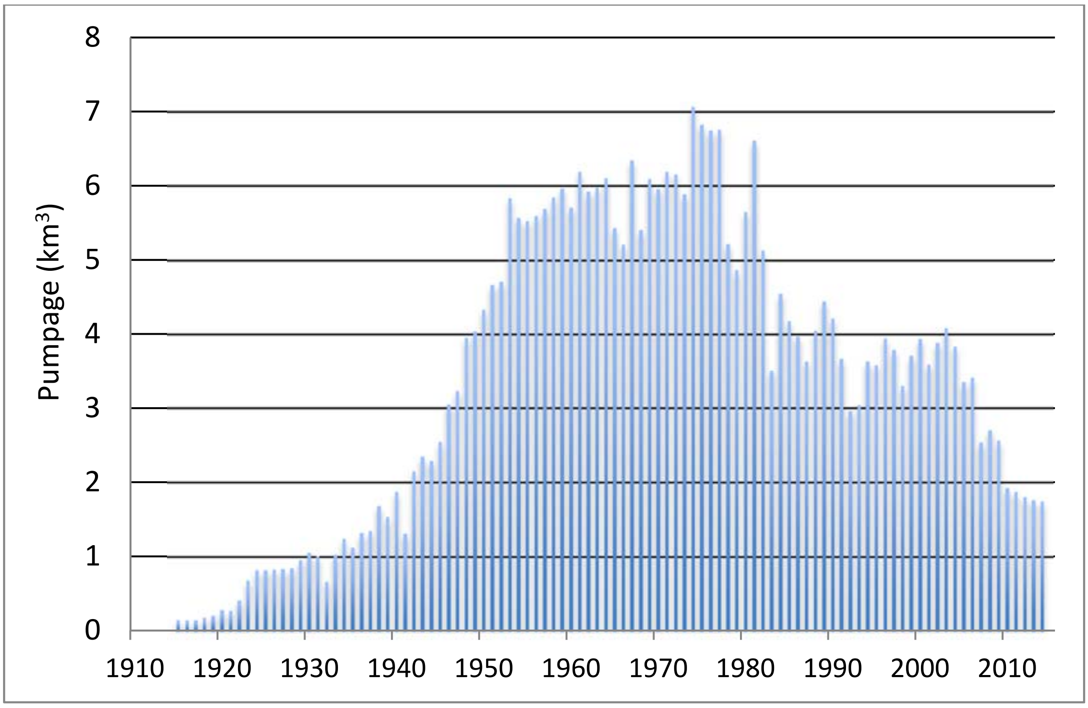


Figure S10. Temporal variations in groundwater withdrawals in Arizona (extended from Leake et al., 2000)[4]. Pumpage from Phoenix AMA ends in 2006 and Pinal AMA in 2009. Data from the latest year was extended to 2014. Data source: pumpage for non AMA areas, http://az.water.usgs.gov/projects/9671-9DW/. Pumpage for AMAs simulated in regional groundwater models[5,6,7] Withdrawals do not include domestic and stock uses and withdrawals in parts of AMAs that are not included in the groundwater flow models primarily including some municipal and agricultural withdrawals in the Phoenix AMA. Omissions from other AMA models are primarily by small users.

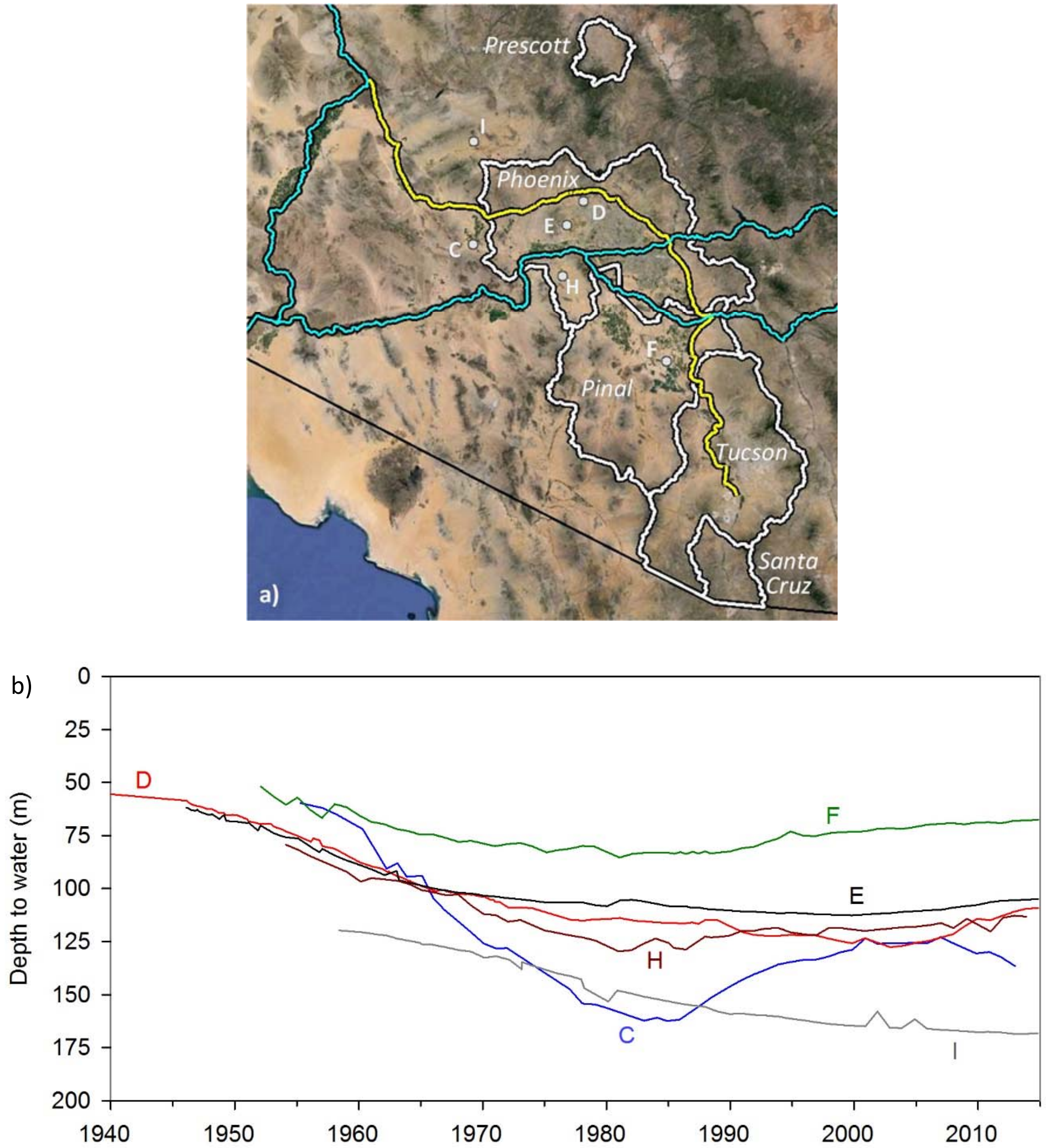


Figure S11. a) Locations of long-term monitoring wells and b) long- term monitoring time series of representative groundwater level hydrographs for south central Arizona[8]. Well locations are shown as white symbols. Well identification numbers are well C: C-01-09 11DCB, well D: B-04-01 09BCD, well E: B-02-02 04DCB, well F: D-07-07 34CDD2, well H: C-02-02 27CCC, and well I: B-08-10 36BBB.

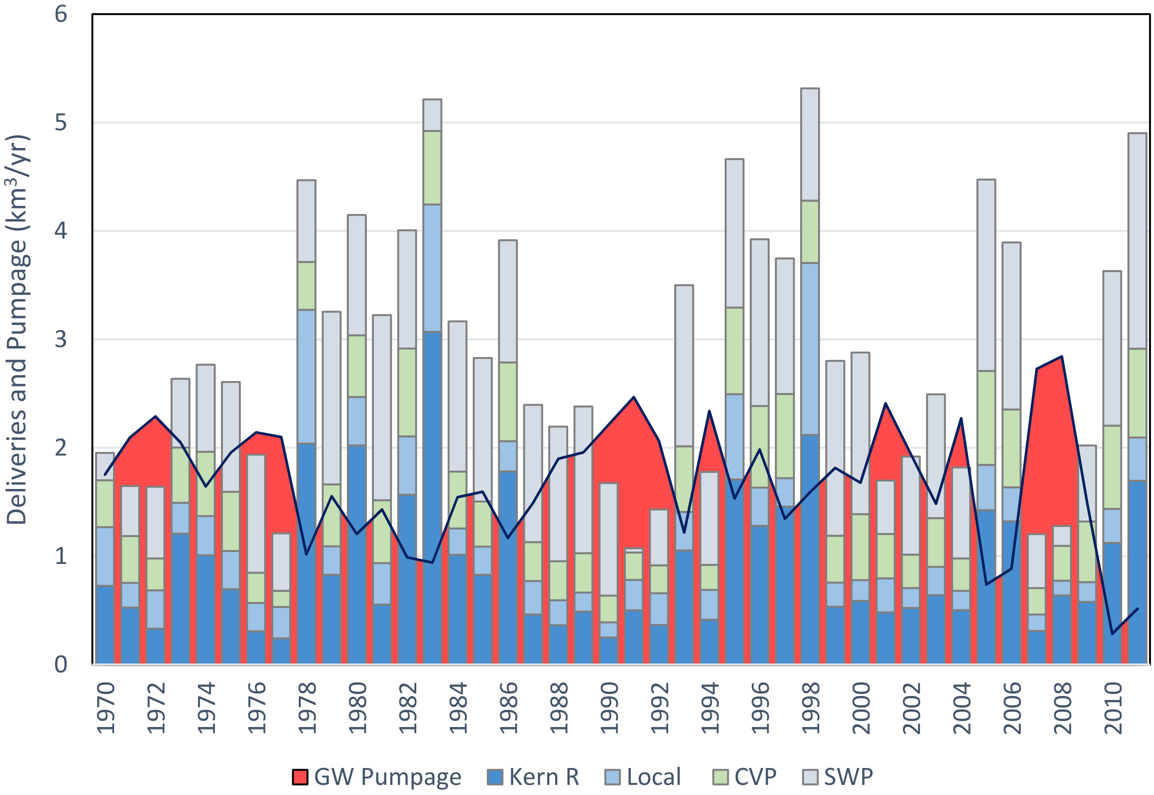


Figure S12. Source of water for irrigation, conjunctive use, and managed aquifer recharge in Kern County, including Kern River water, local rivers, Central Valley Project (CVP) and State Water Project (SWP) imported water, and groundwater pumpage[9]. Mean values are 33% Kern River, 11% other local rivers, 17% CVP, and 36% SWP.

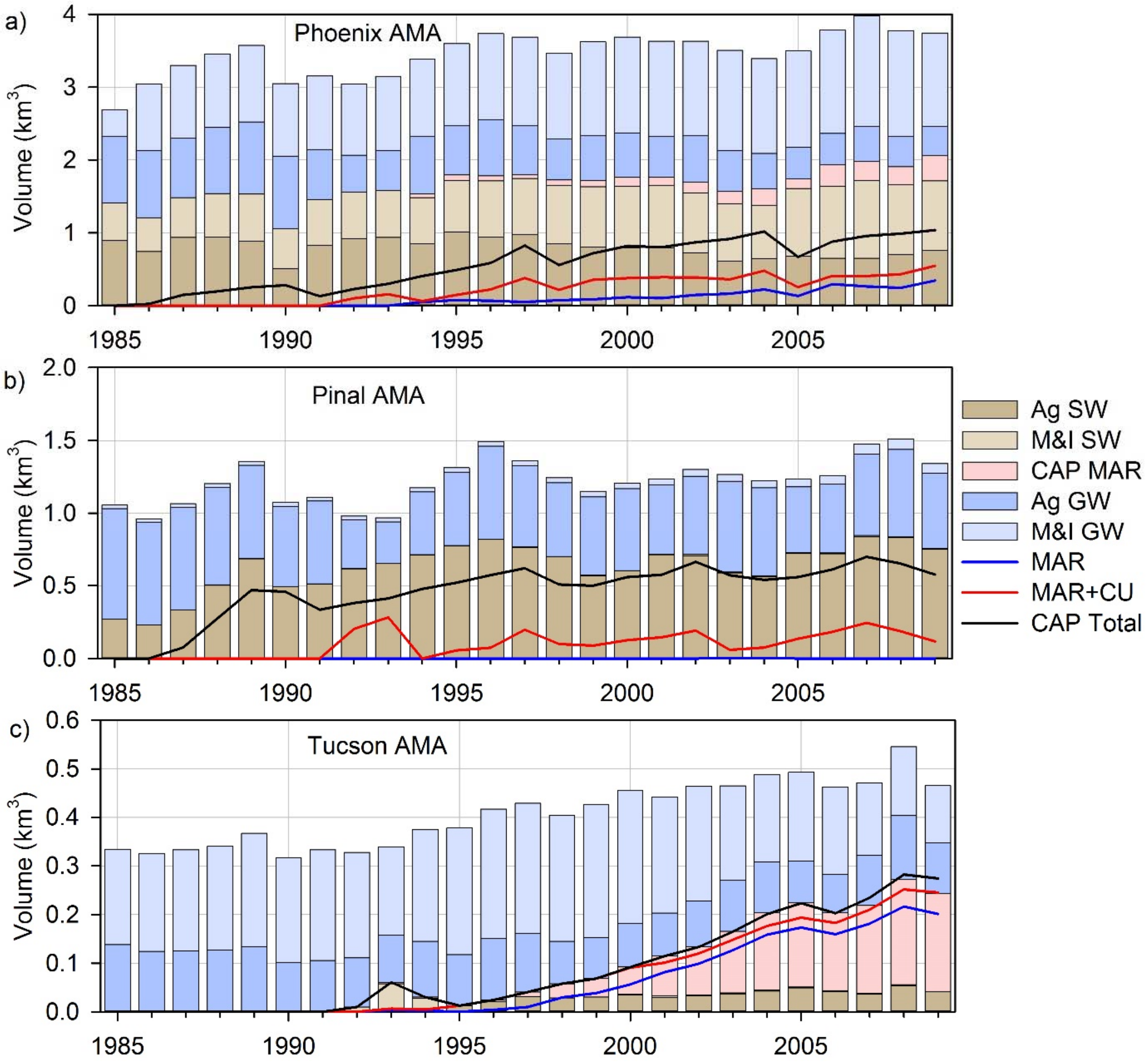


Figure S13. Comparison of annual deliveries from the Central Arizona Project (CAP) relative to total water budgets (including CAP) for a) Phoenix, b) Pinal, and c) Tucson active management areas (AMAs). CAP total deliveries include Managed Aquifer Recharge (MAR) to spreading basins, conjunctive use (CU), and irrigation. Ag, agricultural irrigation; SW, surface water; M&I, municipal and industrial; CAP, Central Arizona Project; MAR, managed aquifer recharge; GW, groundwater; CU, conjunctive use.

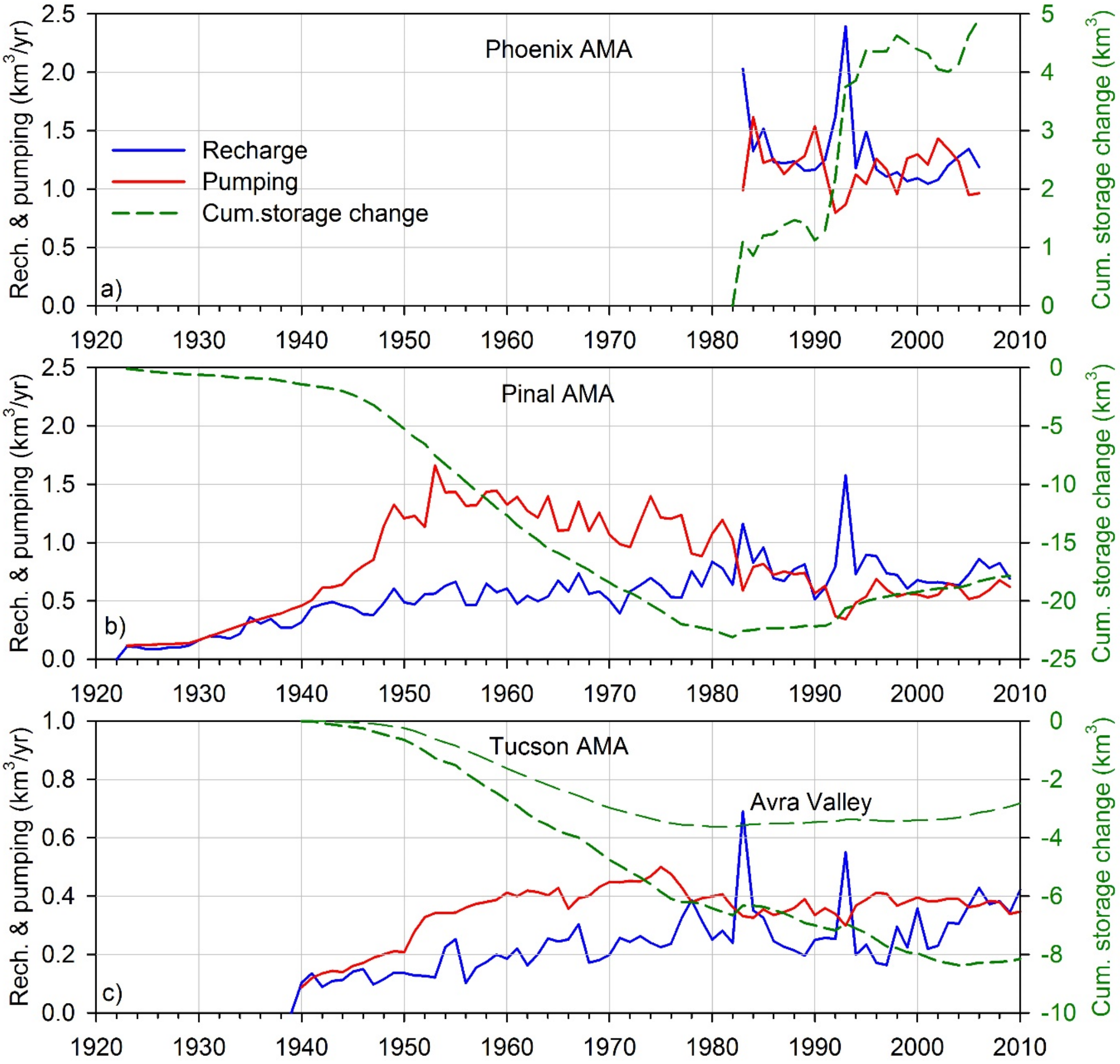


Figure S14. Water budgets from regional groundwater models for the a) Phoenix, b) Pinal, and c) Tucson Active Management Areas (AMAs), including recharge, pumping, and cumulative GW storage.[5,6,10]

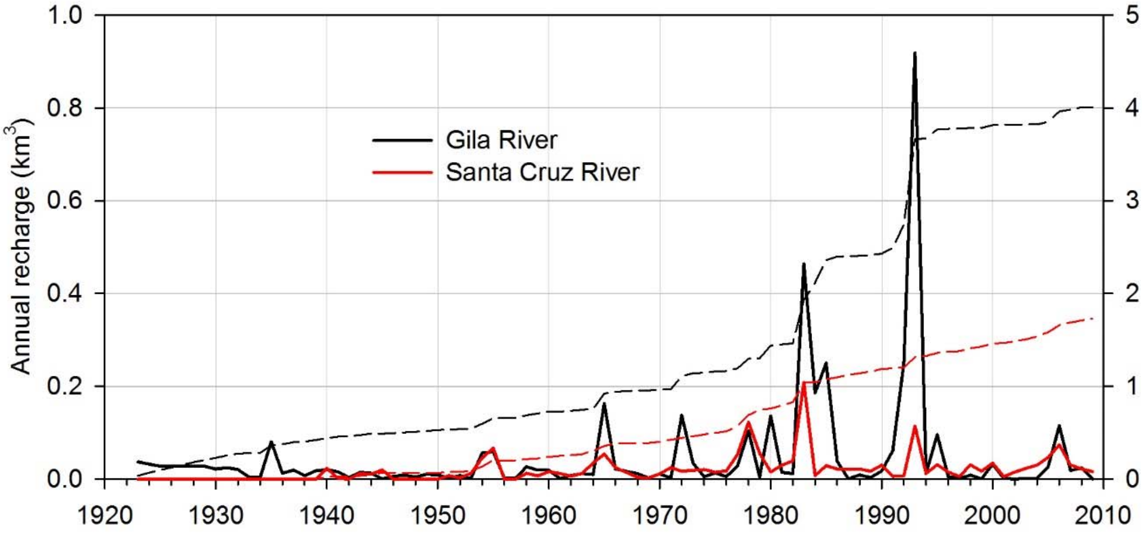


Figure S15. Simulated recharge in the Gila and Santa Cruz Rivers within the Pinal Active Management Area groundwater model[10]. Anomalously high recharge in 1983 and 1993 occur in response to elevated precipitation.

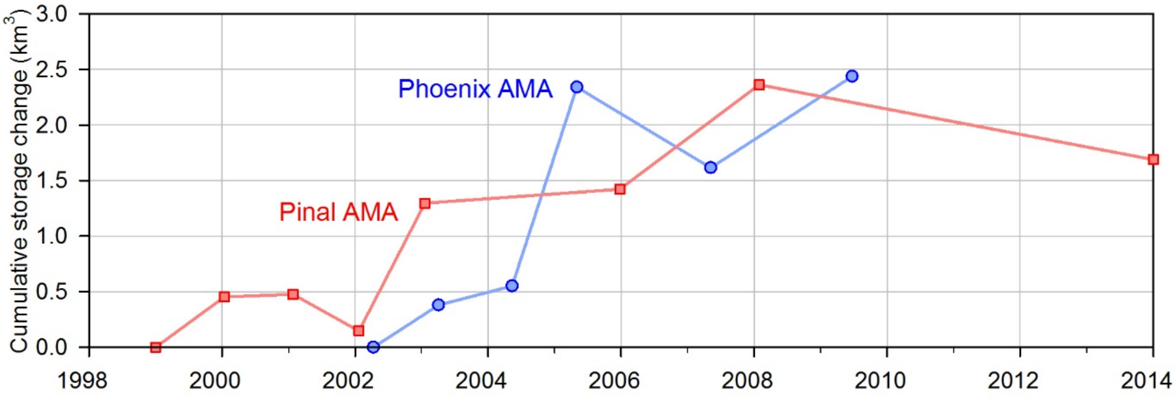


Figure S16. Change in groundwater storage based on synoptic ground-based gravity surveys in the Phoenix AMA and Pinal AMA[11].

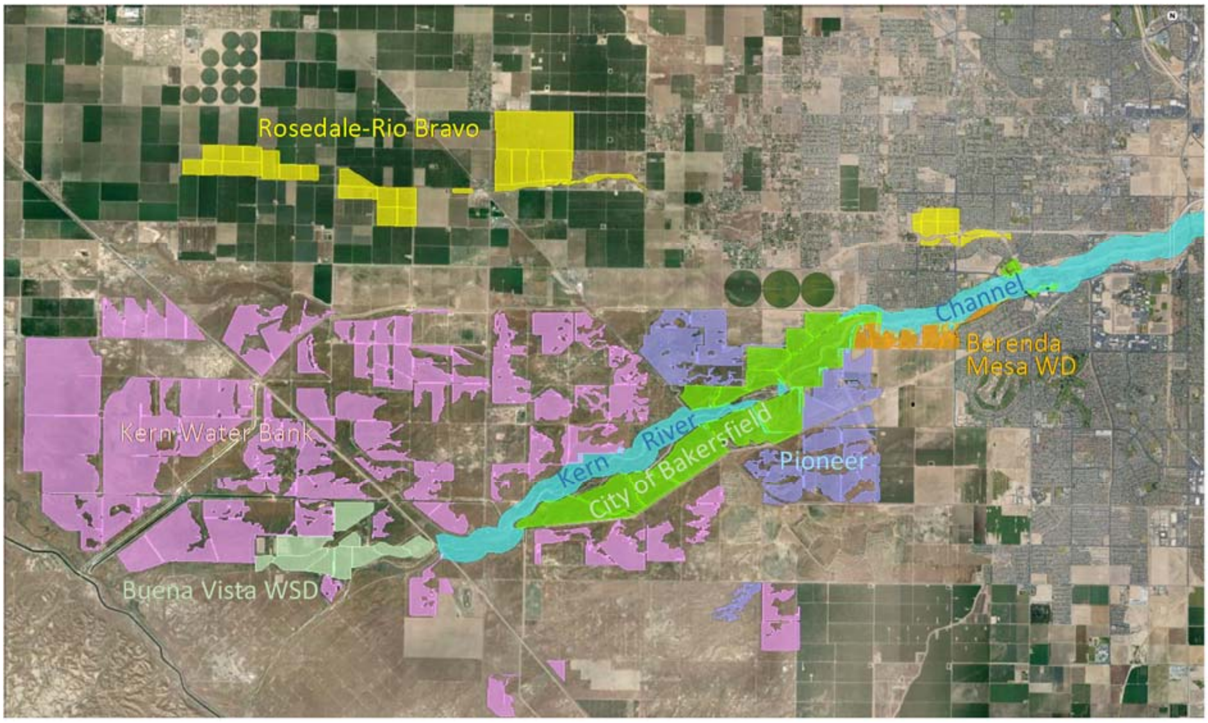


Figure S17. Spreading basins in the Kern Water Bank and adjacent water banks, including the Berenda Mesa Water District (WD), Buena Vista Water Supply District (WSD), City of Bakersfield (Kern River Channel), Pioneer, and Rosedale-Rio Bravo Water Supply District.

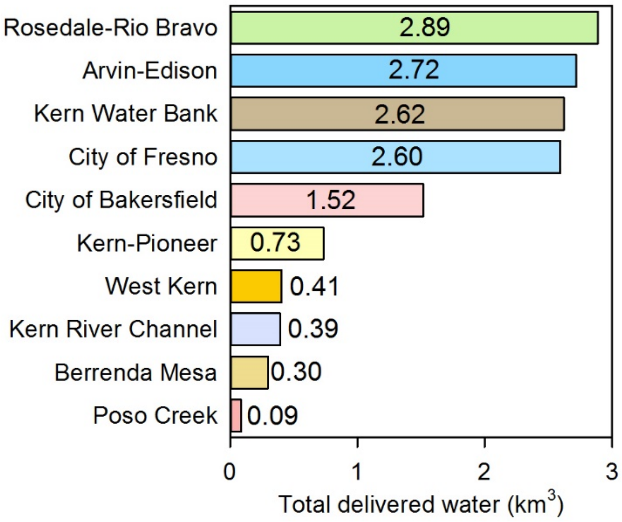


Figure S18. Total applied water (14.3 km^3) in different MAR systems in the southern Central Valley. The location of the majority of the MAR systems can be found in Fig. S17.

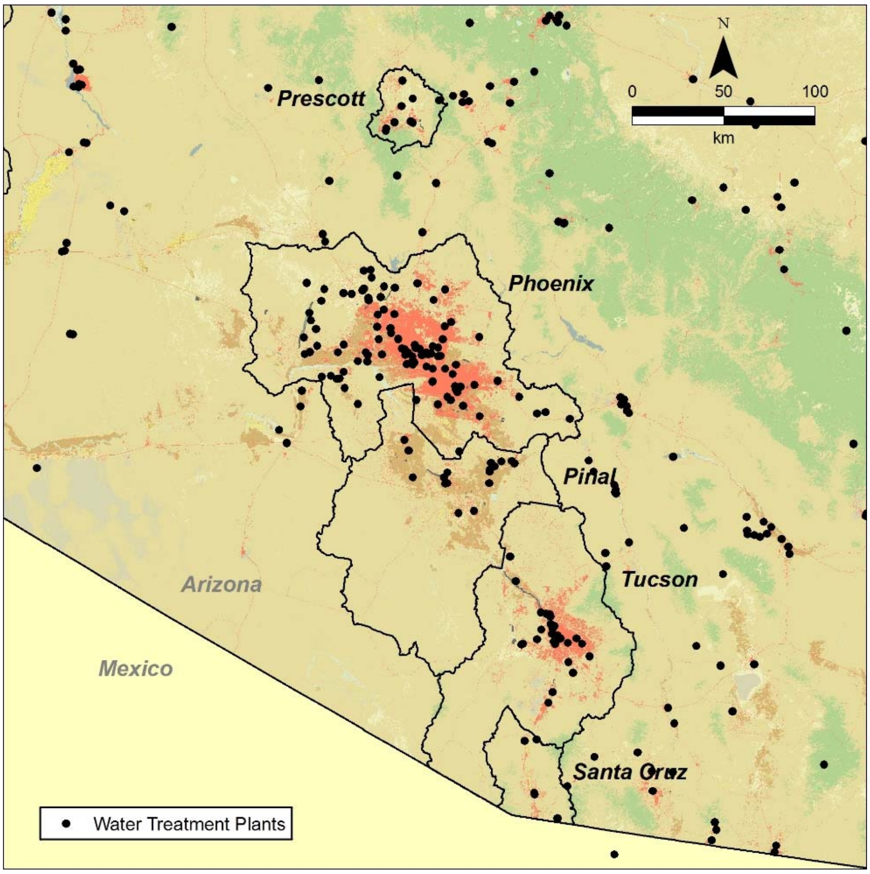


Figure S19. Distribution of waste water treatment plants in south central Arizona. There are a total of 365 waste water treatment facilities located in Arizona that are listed by the EPA (Prescott AMA: 29, Phoenix AMA: 104, Pinal AMA: 18, Tucson AMA: 33, Santa Cruz AMA: 6, remaining statewide: 175). Source of data: U.S. EPA Clean Watersheds Needs Survey 2008 database (CWNS database, http://water.epa.gov/scitech/datait/databases/cwns/)

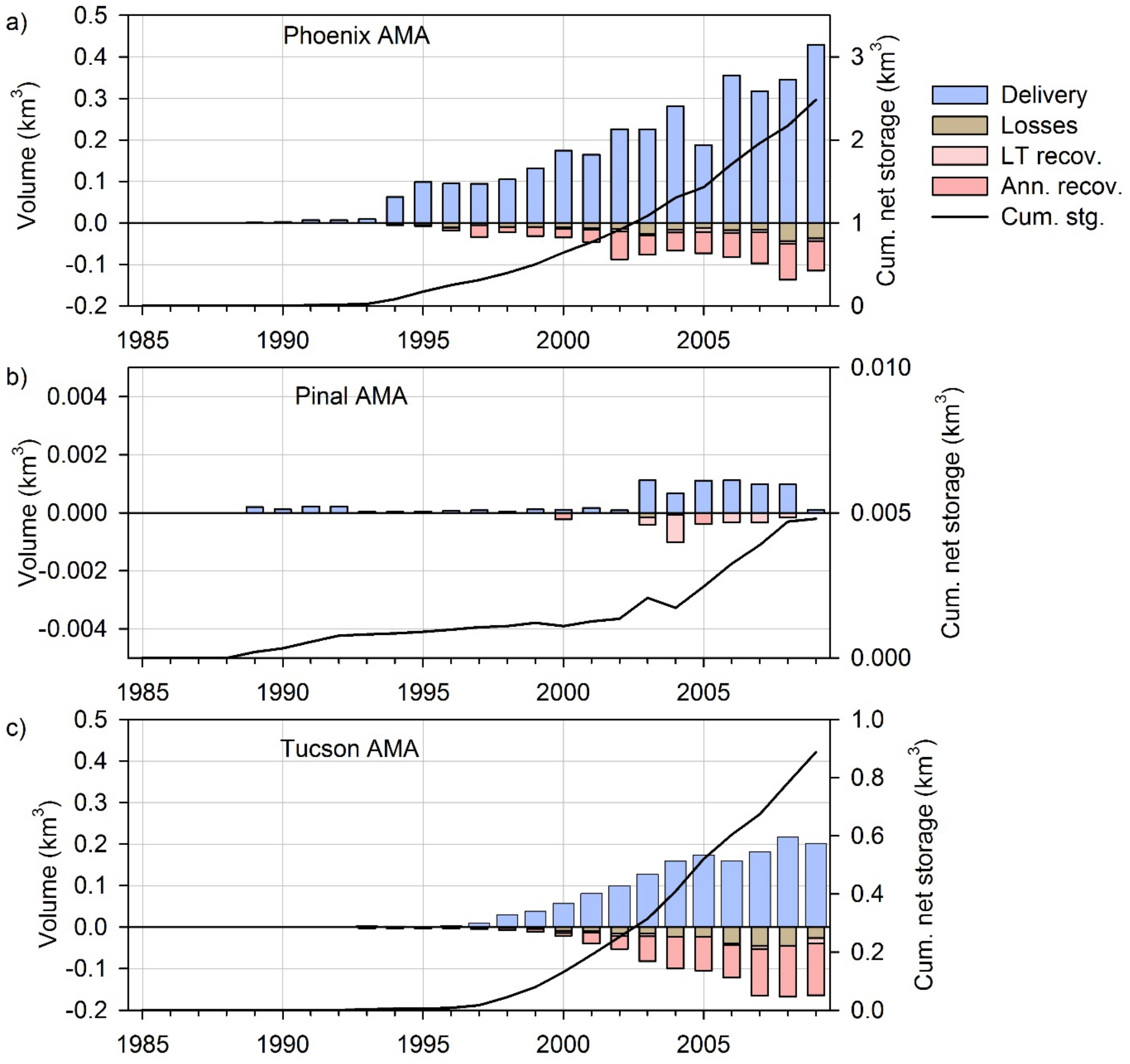


Figure S20. Deliveries versus recoveries for managed aquifer recharge systems in the a) Phoenix, b) Pinal, and c) Tucson Active Management Areas. Deliveries are derived from the CAP aqueduct. Long-term recovery (LT recov) includes recoveries beyond the year of spreading. Annual recoveries reflect recoveries in the same year as deliveries. Cumulative storage represents the net water input to the system.

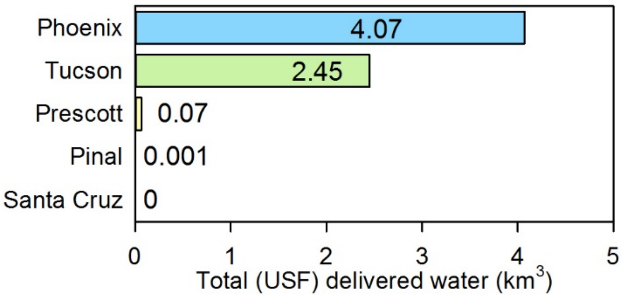


Figure S21. Total water delivered to MAR spreading basins (also termed underground storage facilities, USFs) in Active Management Areas (Phoenix, Tucson, Prescott, Pinal, and Santa Cruz AMAs) from the Central Arizona Project (CAP, 1994-2013) and other sources (1989-2009) including reclaimed water (municipal waste water) and Salt/Verde River water.

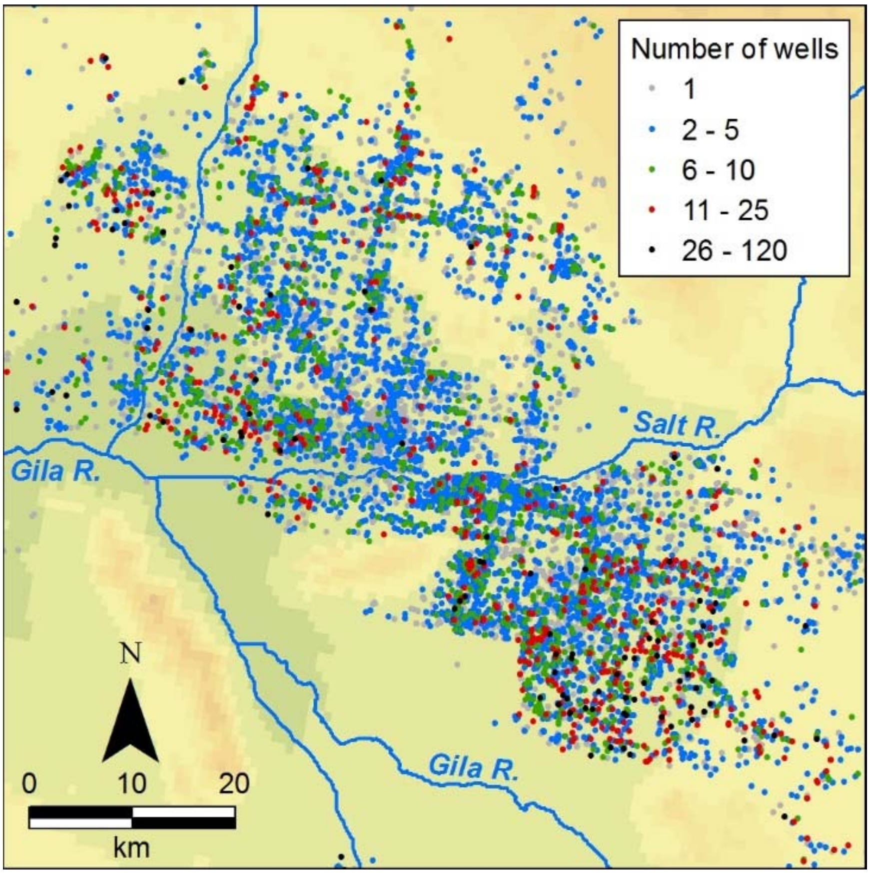


Figure S22. Location of dry wells in the vicinity of Phoenix. Source: Arizona Dept. of Water Resources[12].

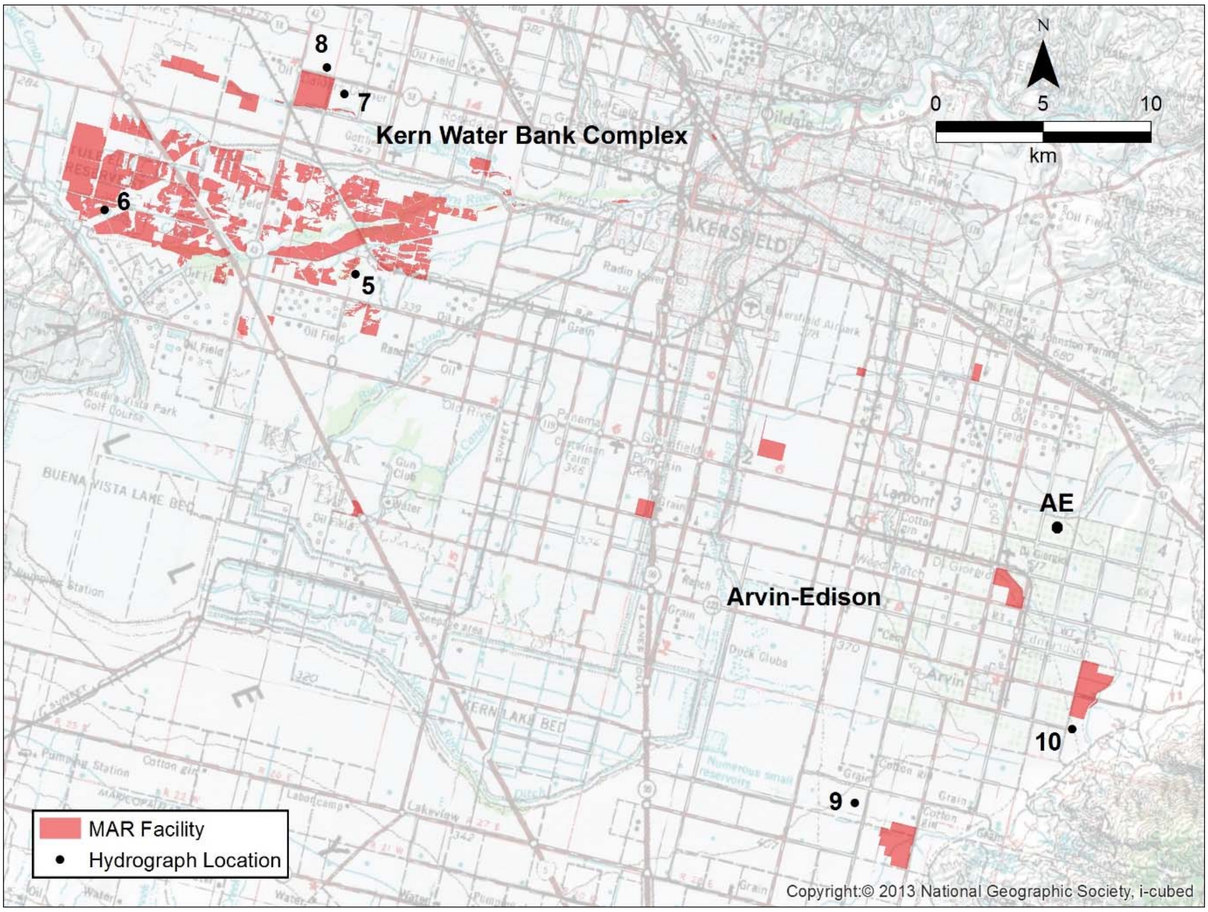


Figure S23. Location of monitoring wells near the MAR systems in the Central Valley. Hydrographs for locations 5-10 are shown in Figure 8b and for location AE is shown in Figure S26. Data for wells 5-10 were obtained from California State Groundwater Elevation Monitoring (CASGEM) and Kern County Water Agency. Well identification number are well 5: 30S26E21D001M, well 6: 30S25E19G001M, well 7: 29S26E30F001M, well 8: 29S25E24K001M, well 9: 32S29E17G002M, and well 10: 31S30E29N001M. Data for AE well were obtained from Arvin-Edison WSD.

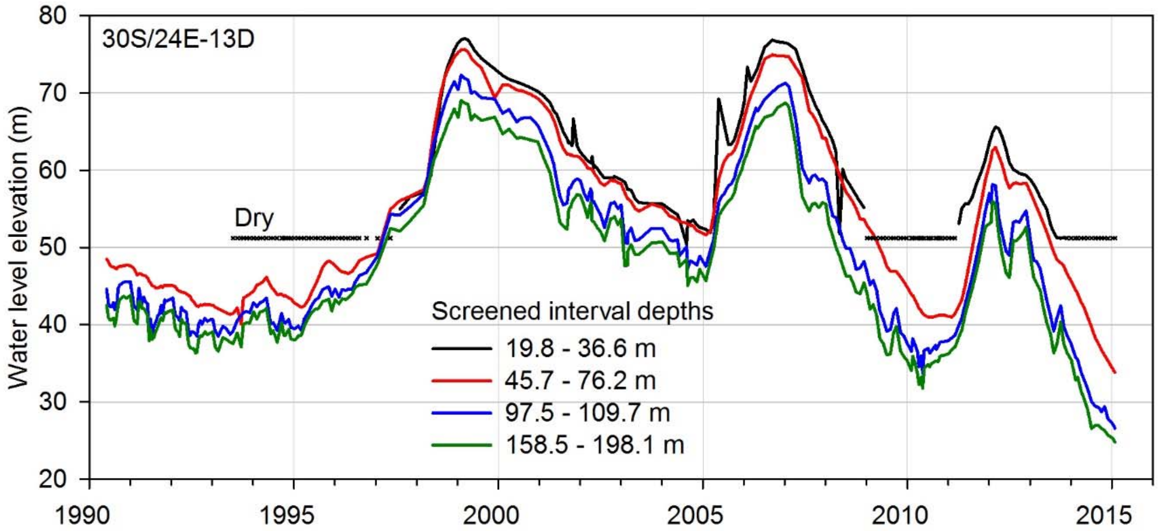


Figure S24. Nested wells screened at varying depths showing downward hydraulic gradient. This well (well ID 30S/24E-13D) is within the Kern Water Bank. Source of data: Kern County Water Agency Groundwater Database.

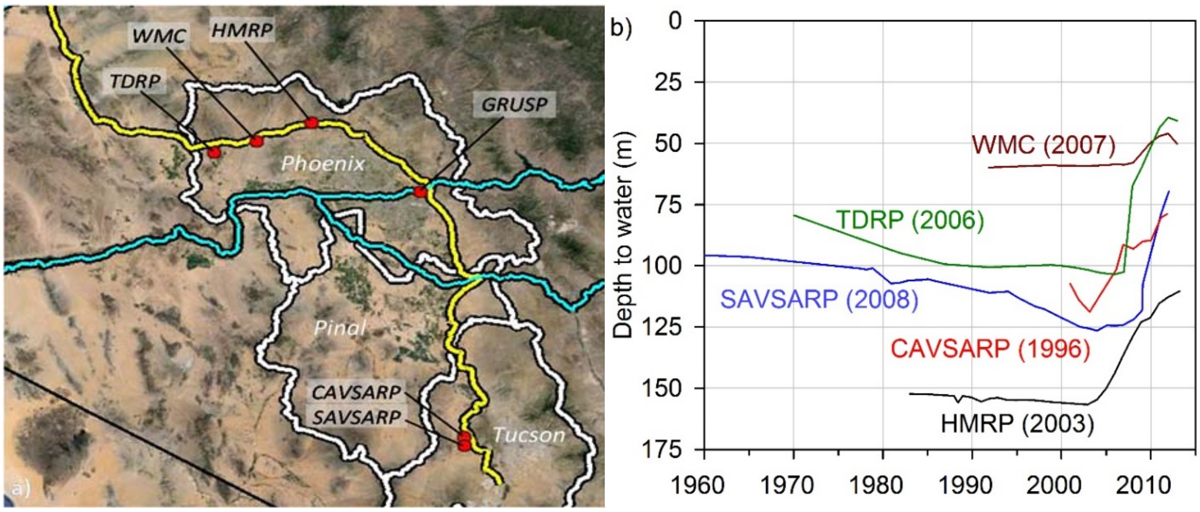


Figure S25. a) Locations of monitoring wells and b) time series of representative well hydrographs in the vicinity of spreading basins in the Phoenix Active Management Area (AMA) including the Tonopah Desert Recharge Project (TDRP), Hieroglyphic Managed Recharge Project, (HMRP) and West Maricopa Combine (WMC), and in the Tucson AMA, including the Southern and Central Avra Valley Recharge Projects (SAVSARP, CAVSARP). The year the MAR system began operation is shown in parenthesis. Well identification numbers are TDRP: 333146112560801, SAVSARP: 321034111132801, CAVSARP: 321312111141001, HMRP: 334603112252701, and WMC: 333724112423601. Source: https://gisweb.azwater.gov/waterresourcedata/GWSI.aspx

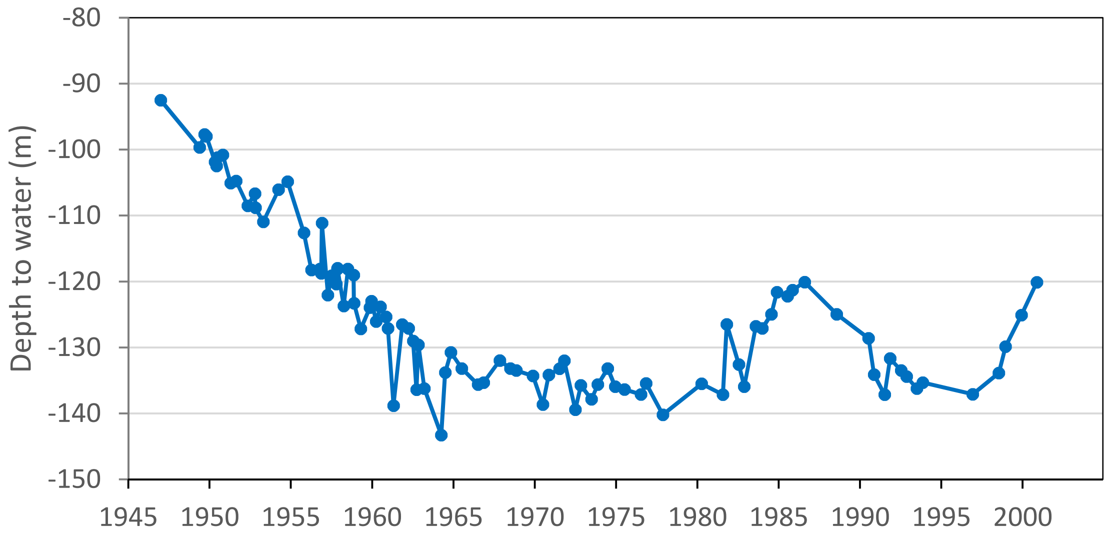


Figure S26. Long-term monitored water level hydrograph in the Arvin Edison Water Supply District.

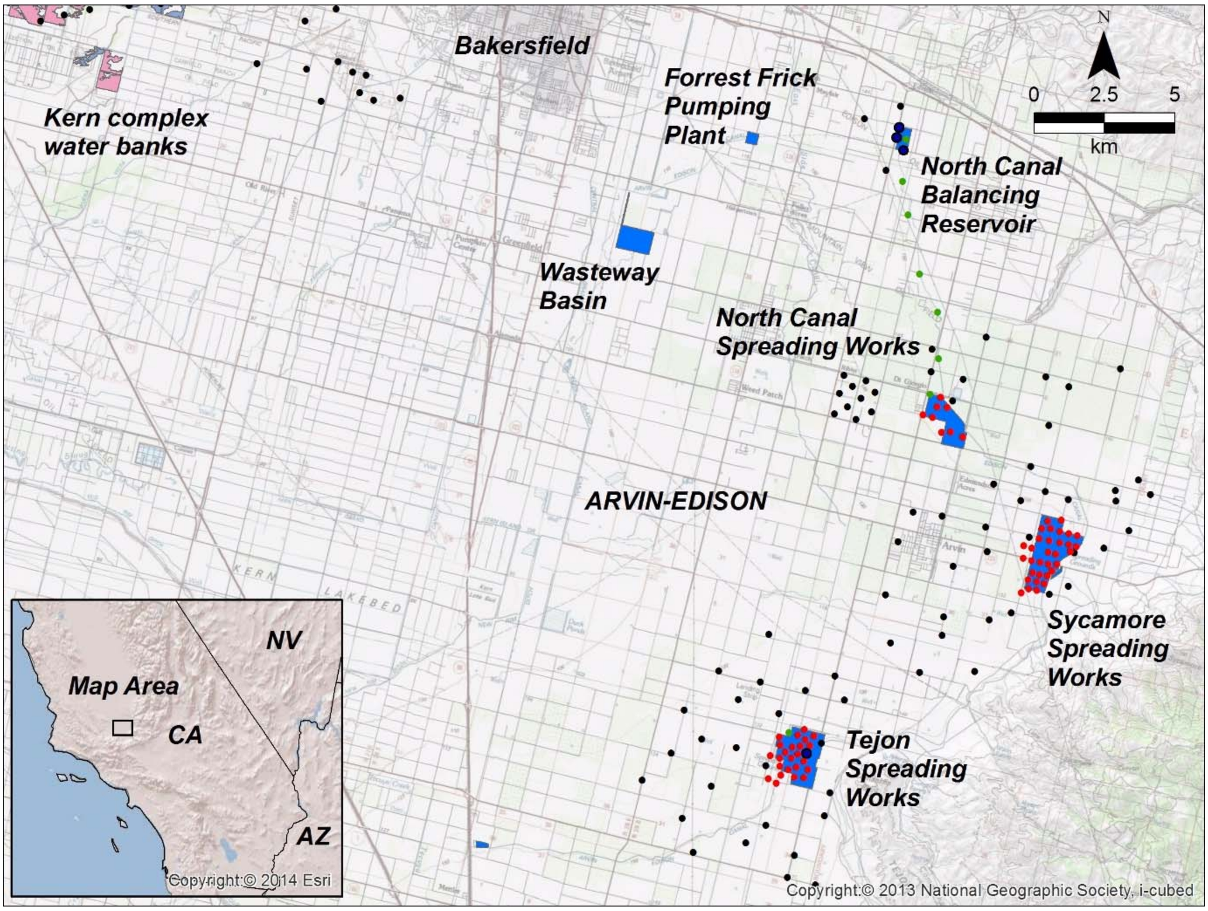


Figure S27. Location of Arvin Edison Water Supply District (AEWSD) and spreading basins, including Tejon (2.50 km^2 area), Sycamore (2.81 km^2 area) and North Canal (1.43 km^2 area). Tejon and Sycamore basins were constructed in 1966 whereas the North Canal spreading basin was added to the system in 2000. Off-channel balancing reservoirs (150,000–250,000 m^3) were installed to enhance operations. Point symbols represent locations of AEWSD withdrawal wells (red), AEWSD monitoring wells (green), and local withdrawal wells (black).

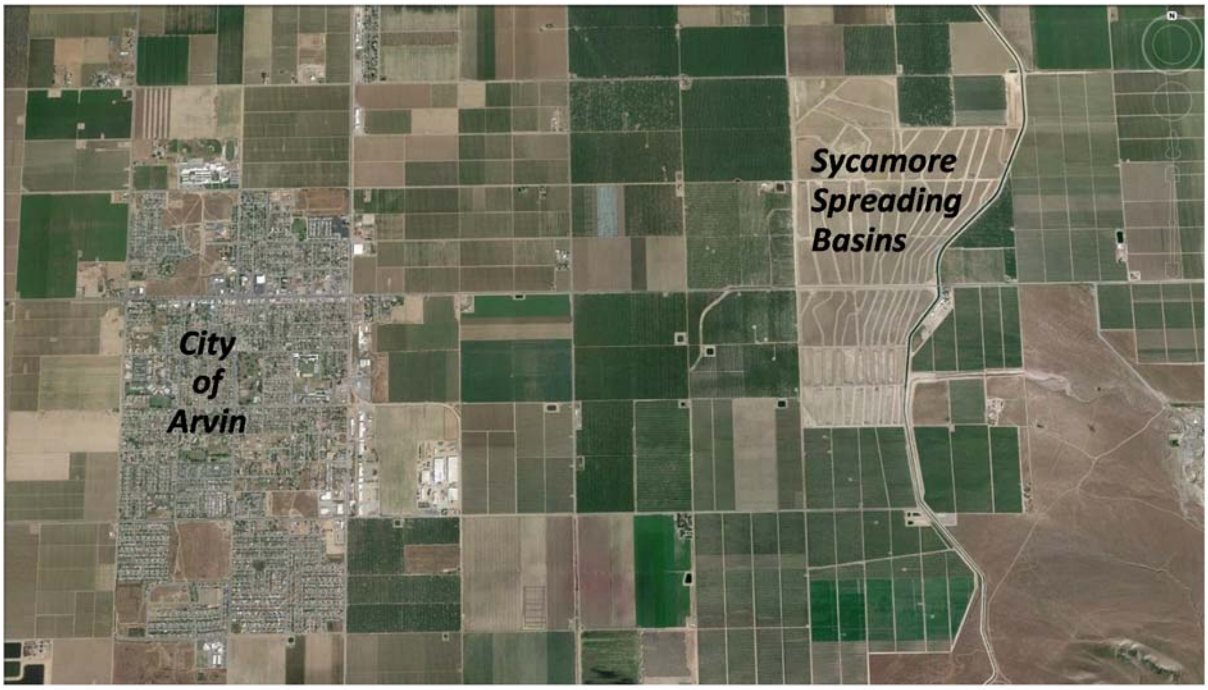


Figure S28. Location of the Sycamore spreading basins in Arvin-Edison Water Supply District on Google earth image. The City of Arvin (population ~20,300) is also shown.

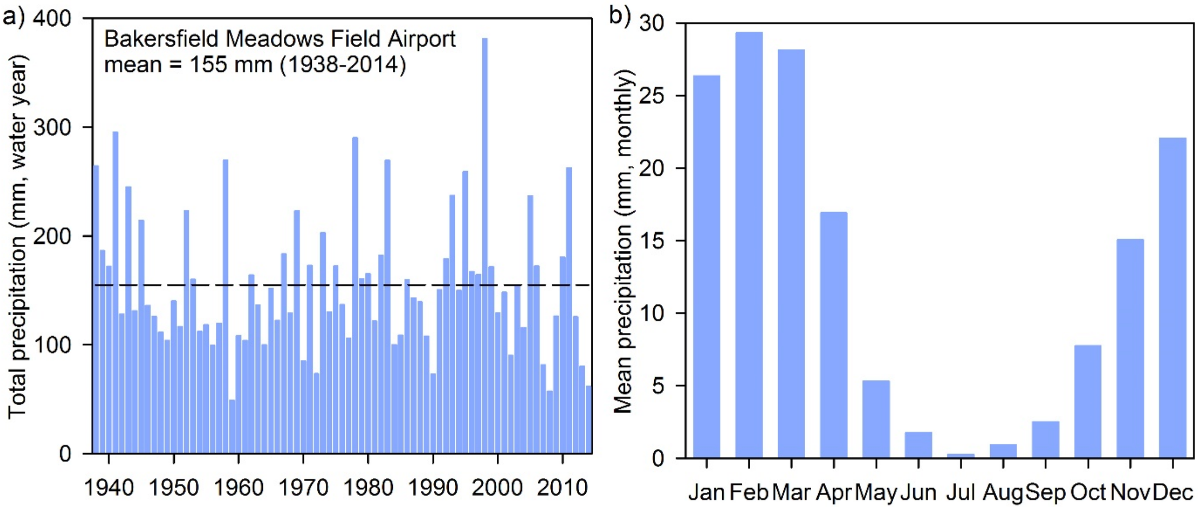


Figure S29. a) Annual precipitation and b) long-term (1938 – 2014) mean monthly precipitation at a gage in Bakersfield Meadows Field Airport (Station ID: USW00023155). Mean precipitation is 155 mm (1938 – 2014). Note large interannual variability in precipitation with lowest precipitation in 1959 (49 mm, 31% of long term mean) and highest precipitation in 1998 (381 mm, 246% of long-term mean). Precipitation occurs primarily in winter (89% from Nov through April). Source of data: U.S. NOAA National Climate Data Center (NCDC, https://www.ncdc.noaa.gov/cdo-web/).

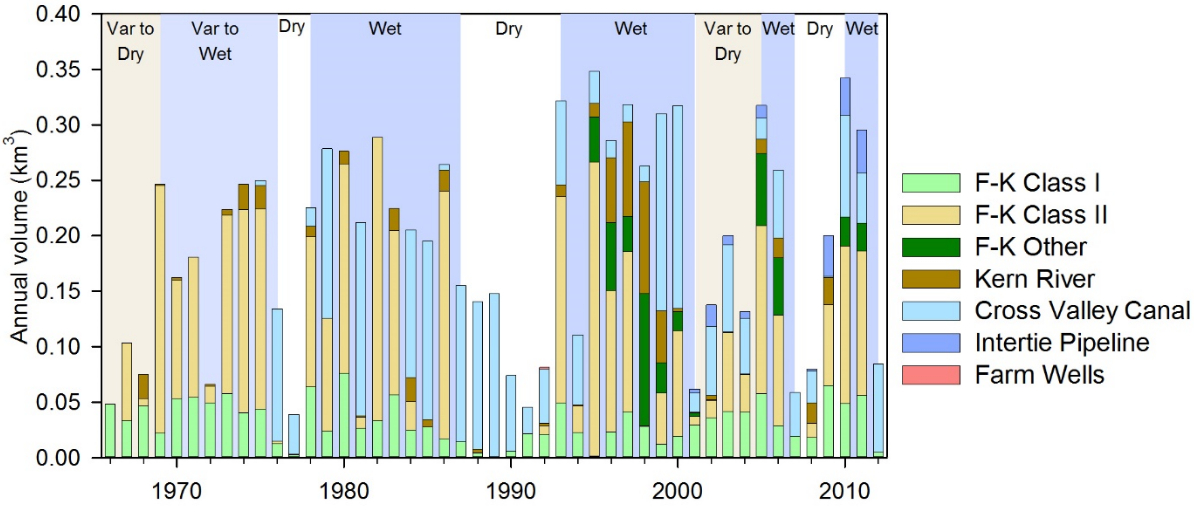


Figure S30. Source of water for spreading basins in Arvin Edison Water Supply District. F-K Class 1 is Friant-Kern Canal (part of Central Valley Project) and firm indicates a reliable source. F-K Class II refers to interruptible water supplies. Water from the Kern River is variable and infrequent, highest in 1996 – 1999. The Cross Valley Canal is the dominant water source during droughts. Prevailing climatic conditions are indicated by shaded areas.

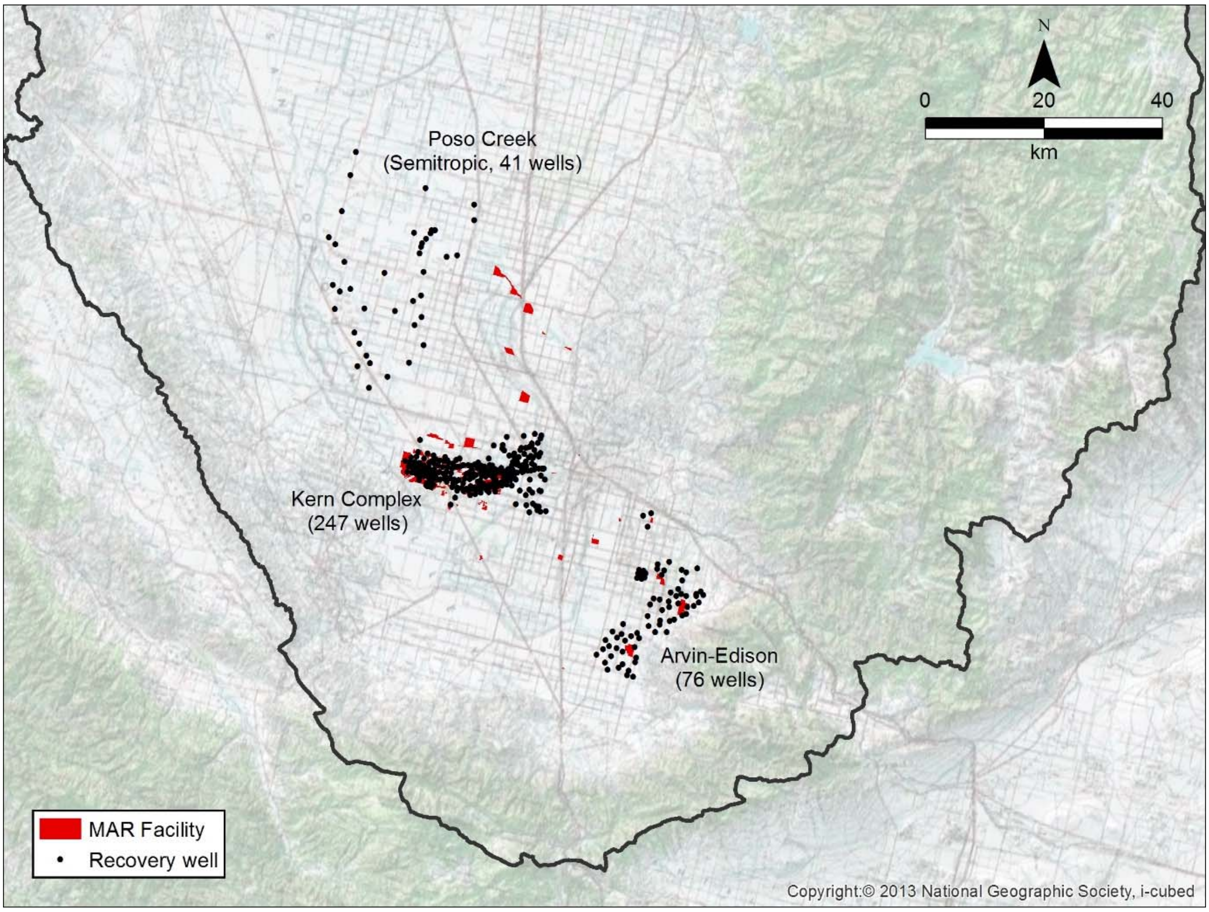


Figure S31. Locations of recovery wells near MAR systems in the Central Valley.

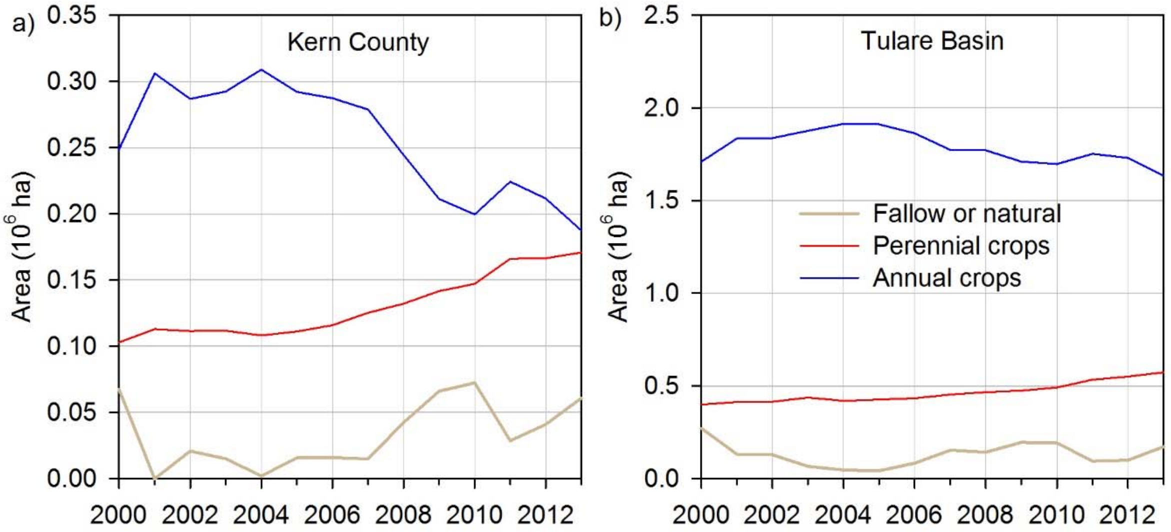


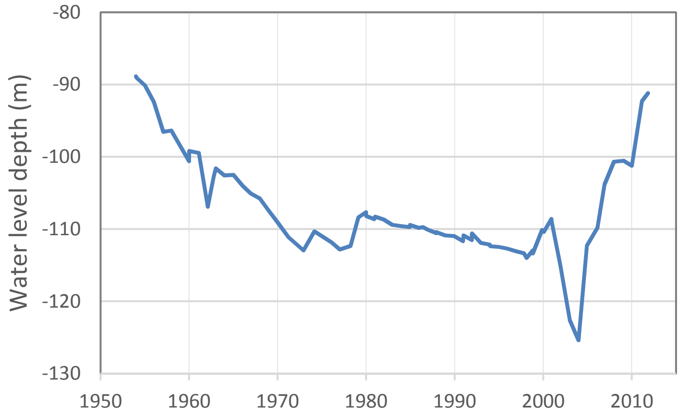
Figure S32. Recent variability of areas planted with perennial and annual crops in a) Kern County and in b) the Tulare Basin. Tulare Basin values represent the net totals for Fresno, Kern, Kings, and Tulare counties. Source of data: USDA National Agricultural Statistics Service (NASS, http://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS).

Section 5. Avra Valley Case Study

This section includes some additional details related to the Avra Valley case study to those provided in section 3.4b of the paper. The recent land use history of Avra Valley in the Tucson AMA provides an excellent case study to evaluate the impacts of MAR systems. Avra Valley (1400 km^2 in area) evolved from a major agricultural area after 1940, a water supply that augmented local groundwater in the Tucson in the 1990s, to a prominent receptacle for recharge at MAR and other types of recharge facilities after the mid-1990's. Agriculture was supported by groundwater withdrawals that far exceeded annual rates of groundwater recharge resulting in extensive storage loss as water-levels declined by as much as 30 m (Fig. S33). With the Arizona Groundwater Law of 1980, Avra Valley and the Adjacent Tucson Basin were grouped into the Tucson Active Management Area. The City of Tucson looked to Avra Valley as a water supply to help mitigate groundwater storage loss and land-subsidence in the Tucson area. This required purchasing water rights from senior water rights of Avra Valley Farms and modification of the Arizona Groundwater Law to allow interbasin groundwater transfers. With arrival of CAP water from the Colorado River to the Tucson basin, the city planned to directly distribute a blend of Colorado River water with local groundwater. Unfortunately, the change in water chemistry had undesirable effects on the delivery system and delivered water. This resulted in a local law that rejected direct use of CAP water but allowed indirect use through managed aquifer recharge (MAR) and later extraction. In response, the City of Tucson planned to use MAR systems, located primarily in Avra Valley, and eventually introduce a mixture of Avra groundwater and CAP water to the Tucson water distribution system. Gradual introduction would allow a gradual change in chemical response of the distribution infrastructure as the initially low percentages of Colorado River water became greater through time. The City of Tucson operates two MAR facilities that infiltrate CAP water in central and southern Avra Valley Storage and Recovery Projects (CAVSARP and SAVSARP). Other communities and agencies also added to use of Avra Valley as a recharge area with two MAR facilities that infiltrate CAP water in northern Avra Valley. A few farms also substitute CAP water for groundwater through permitted conjunctive use. In addition, enhanced infiltration of treated effluent in the ephemeral Santa Cruz River, which crosses northern Ava Valley, including at 3three facilities in the stream channel has been another source of increasing water supply in the area.

Groundwater withdrawals in Avra Valley have been simulated as much as 0.19 km^3/yr (150,000 acre-ft per year) since 1940 resulted in storage depletion of ~3.5 km^3 by about 1980 (Fig. S14c)[6]. Associated water-level declines were more than 30 m in Avra Valley. Storage and water levels began a slow recovery beginning about 1980 concurrent with a wet period that continued through the late 1990's (Figs. S14c, S34). Storage recovery rates increased after about 2000 following the establishment of two recharge facilities in central (CAVSARP) and southern Avra Valley (SAVSARP) and two smaller facilities near Marana in northern Avra Valley.

Artificial recharge of CAP water in Avra Valley began in 1996 at the CAVSARP facility, which currently includes 11 basins totaling 317 acres and 33 withdrawal wells, and at a facility in northern Avra Valley. Another facility began recharging CAP water along the Santa Cruz River channel in 2000. The SAVSARP facility began recharge operations in 2009 and includes nine basins totaling 226 acres and 11 withdrawal wells. Cumulative deliveries of CAP water for recharge in Avra Valley increased from about 0.1 km^3 before 2001 to about 2.3 km^3 before 2015 with an annual delivery rate of about 0.2 km^3 (Fig. S35), or about the maximum annual groundwater withdrawal rate that had previously occurred. Most of the deliveries are to the CAVSARP and SAVSARP facilities which received more than 1.5 km^3 before 2015. About 94% of the deliveries were credited as storage for future extraction with the remainder being credited to the aquifer and lost to evaporation. Recharge of CAP water has been augmented before 2015 through recharge of about 0.3 km^3 of effluent at two additional facilities in northern Avra Valley by 2015 and about 0.5 km^3 CAP water delivered to several farms in lieu of groundwater withdrawals. CAVSARP has reached maximum storage capacity and annual extraction rates of about 0.08 km^3, are slightly less than annual delivery rates, about 0.09 km^3. The City of Tucson plans on expansion of the CAVSARP facility storage capacity (Dick Thompson, Tucson Water Chief Hydrologist, verbal communication).



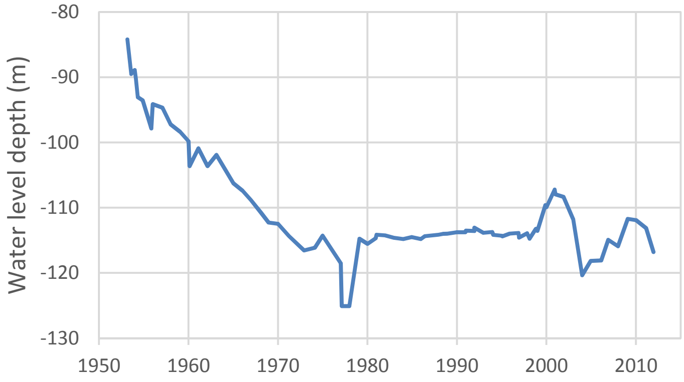


Figure S33. Water level hydrographs near the Central Avra Valley Storage and Recovery Project (CAVSARP). Groundwater levels declined in 1.2 – 1.4 m/yr from mid 1950s to early 1970s.

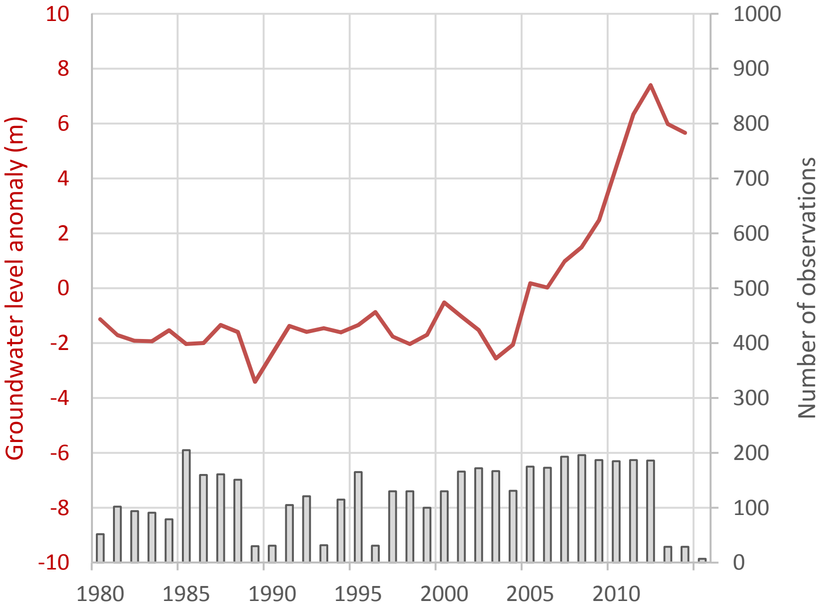


Figure S34. Composite hydrograph of the central and southern Avra Valley region (S. of latitude 32.5°) and number of well observations. Note low number of observations since 2013, reducing the reliability of the hydrograph.

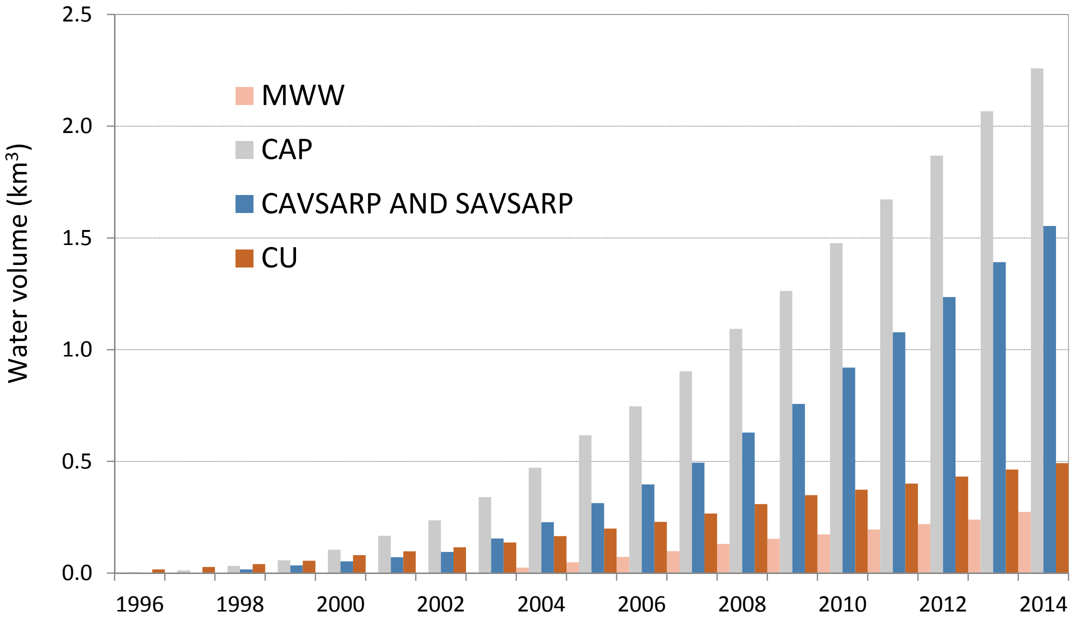


Figure S35. Water deliveries to the Avra Valley, including substitution of CAP water for groundwater (conjunctive use, CU), Central and Southern Avra Valley Storage and Recovery Projects (CAVSARP, SAVSARP), Central Arizona Project (CAP), and municipal waste water (MWW).

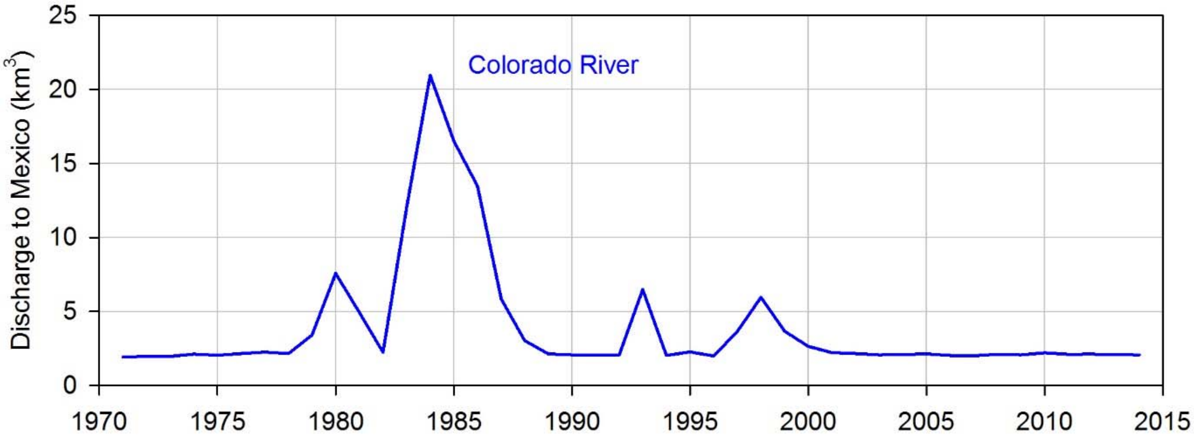


Figure S36. Colorado River annual total discharge from the US to Mexico. Source of data: US Bureau of Reclamation, Annual Water Accounting Reports (Boulder Canyon Operations Office, http://www.usbr.gov/lc/region/g4000/wtracct.html).

Table S1. Time periods of different intensities of El Niño Southern Oscillation (ENSO) events (http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml).

El Niño				*La Niña*		
Weak	*Mod*	*Strong*	*Very Strong*	*Weak*	*Mod*	*Strong*
1951-52	1963-64	1957-58	1982-83	1950-51	1955-56	1973-74
1952-53	1986-87	1965-66	1997-98	1954-55	1970-71	1975-76
1953-54	1987-88	1972-73		1964-65	1998-99	1988-89
1958-59	1991-92			1967-68	1999-00	2010-11
1968-69	2002-03			1971-72	2007-08	
1969-70	2009-10			1974-75		
1976-77				1983-84		
1977-78				1984-85		
1979-80				1995-96		
1994-95				2000-01		
2004-05				2011-12		
2006-07						

Table S2. Central Valley Hydrologic Model (CVHM) cumulative storage change results [13]. The CVHM was extended to 2013 but data for subbasins are only available to 2003. All values are in km^3 units.

Year	*Sacramento Valley*	*Delta and Eastside Streams*	*San Joaquin Valley*	*Tulare Lake*	*Central Valley*
1961	0.00	0.00	0.00	0.00	0.00
1962	-0.15	0.13	0.68	-0.63	0.03
1963	1.06	0.85	0.81	-2.78	-0.06
1964	-1.05	0.18	-0.09	-6.80	-7.76
1965	-0.37	0.76	0.22	-8.96	-8.35
1966	-1.71	0.23	-0.46	-12.60	-14.55
1967	0.65	1.49	0.68	-12.67	-9.85
1968	-0.83	0.93	-0.58	-17.59	-18.07
1969	2.17	2.87	2.28	-14.74	-7.42
1970	5.35	3.88	2.22	-18.53	-7.08
1971	4.79	4.15	1.95	-22.15	-11.26
1972	1.56	3.32	0.91	-27.03	-21.24
1973	4.35	4.91	2.24	-26.82	-15.31
1974	5.53	5.64	2.34	-27.78	-14.27
1975	5.14	5.69	2.26	-29.47	-16.38
1976	1.04	4.48	0.93	-32.80	-26.36
1977	-3.05	3.08	-1.80	-39.19	-40.96
1978	0.10	4.54	0.02	-36.53	-31.87
1979	-0.61	4.51	0.18	-37.85	-33.77
1980	1.01	5.35	0.93	-37.99	-30.69
1981	-0.14	4.79	0.17	-41.03	-36.21
1982	2.69	6.79	1.13	-41.05	-30.44
1983	7.62	9.27	3.87	-38.74	-17.97
1984	7.43	8.91	3.39	-40.99	-21.26
1985	5.17	8.40	2.42	-43.69	-27.70
1986	6.72	9.58	2.93	-44.04	-24.81
1987	3.76	8.63	1.68	-47.65	-33.58
1988	2.38	7.98	0.08	-51.62	-41.18
1989	1.34	7.52	-1.30	-55.77	-48.21
1990	-1.38	6.62	-3.08	-61.55	-59.38
1991	-2.75	6.43	-3.86	-65.64	-65.81
1992	-3.86	5.78	-5.14	-70.93	-74.15
1993	-1.23	7.01	-4.14	-70.80	-69.16
1994	-3.74	6.15	-5.01	-74.72	-77.33
1995	1.88	8.57	-2.97	-72.10	-64.62
1996	2.07	8.84	-2.57	-72.85	-64.51
1997	1.62	9.42	-1.43	-72.64	-63.02
1998	7.58	12.42	1.52	-69.14	-47.62
1999	5.49	11.95	0.79	-71.00	-52.78
2000	4.86	12.17	0.71	-73.15	-55.40
2001	2.86	11.69	-0.19	-76.97	-62.61
2002	2.06	11.78	-1.03	-81.19	-68.38
2003	2.38	12.14	-1.48	-84.20	-71.15
2004					-70.95
2005					-68.10
2006					-63.83
2007					-63.54
2008					-72.42
2009					-83.37
2010					-83.60
2011					-80.76
2012					-81.34
2013					-96.02

Table S3. Central Valley Hydrologic Model data, including precipitation input, surface water deliveries, and groundwater pumpage. All values are in km^3 units. Data modified from [13].

Year	*Precipitation*	*Surface water deliveries*	*Groundwater pumpage*
1962	17.6	13.3	13.9
1963	21.1	11.9	11.2
1964	12.2	11.2	15.0
1965	19.2	12.2	11.5
1966	13.4	11.9	15.9
1967	24.3	13.0	10.8
1968	13.7	11.5	15.7
1969	28.7	13.6	10.1
1970	22.6	12.7	13.2
1971	17.4	12.0	13.0
1972	9.9	12.6	15.9
1973	26.3	13.7	10.2
1974	21.6	14.3	9.7
1975	17.9	13.9	9.8
1976	11.5	11.8	13.0
1977	8.8	8.7	19.2
1978	30.4	13.0	8.3
1979	17.4	15.2	9.4
1980	22.8	14.5	7.7
1981	15.2	14.1	11.2
1982	27.4	13.7	6.1
1983	35.3	12.5	5.4
1984	16.8	14.9	8.9
1985	14.8	13.3	9.4
1986	24.3	13.9	7.2
1987	12.4	13.0	10.9
1988	15.8	11.6	12.1
1989	15.6	11.9	12.1
1990	12.5	10.3	14.4
1991	14.5	9.9	15.5
1992	16.9	9.7	15.1
1993	27.4	13.0	8.6
1994	14.4	11.9	11.7
1995	30.6	12.8	7.1
1996	21.1	14.6	8.0
1997	20.1	14.3	8.2
1998	37.2	11.0	5.6
1999	15.4	12.3	6.0
2000	19.2	12.5	6.0
2001	16.3	11.2	7.6
2002	15.9	11.6	8.8
2003	19.8	11.8	7.0
Average	19.4	12.5	10.6

Table S4. Sources of water for irrigation, conjunctive use, and managed aquifer recharge in Kern County [9].

Year	Kern River (km^3/yr)	Local rivers (km^3/yr)	CVP (km^3/yr)	SWP (km^3/yr)	GW pump. (km^3/yr)	Total Supplies
1970	0.73	0.54	0.43	0.25	1.75	3.71
1971	0.53	0.23	0.43	0.46	2.10	3.74
1972	0.33	0.35	0.29	0.66	2.29	3.93
1973	1.21	0.29	0.51	0.64	2.05	4.69
1974	1.01	0.36	0.59	0.80	1.64	4.41
1975	0.70	0.35	0.55	1.01	1.96	4.56
1976	0.31	0.26	0.28	1.09	2.14	4.08
1977	0.24	0.29	0.15	0.53	2.10	3.31
1978	2.04	1.23	0.44	0.75	1.02	5.48
1979	0.83	0.26	0.57	1.59	1.55	4.81
1980	2.02	0.45	0.57	1.11	1.20	5.35
1981	0.55	0.38	0.58	1.71	1.43	4.66
1982	1.57	0.54	0.81	1.09	0.99	4.99
1983	3.07	1.18	0.68	0.29	0.94	6.15
1984	1.01	0.24	0.52	1.38	1.54	4.71
1985	0.83	0.26	0.42	1.32	1.60	4.42
1986	1.78	0.28	0.73	1.13	1.17	5.08
1987	0.46	0.31	0.36	1.26	1.49	3.89
1988	0.36	0.23	0.36	1.24	1.90	4.09
1989	0.49	0.18	0.36	1.35	1.96	4.34
1990	0.25	0.14	0.25	1.04	2.22	3.89
1991	0.50	0.28	0.25	0.04	2.47	3.54
1992	0.37	0.29	0.26	0.52	2.06	3.50
1993	1.05	0.36	0.60	1.49	1.22	4.72
1994	0.41	0.28	0.23	0.86	2.34	4.12
1995	1.71	0.79	0.80	1.37	1.53	6.20
1996	1.28	0.35	0.75	1.54	1.98	5.91
1997	1.46	0.26	0.78	1.25	1.35	5.09
1998	2.12	1.59	0.58	1.03	1.59	6.91
1999	0.54	0.22	0.43	1.61	1.81	4.62
2000	0.59	0.19	0.61	1.49	1.68	4.56
2001	0.48	0.31	0.41	0.49	2.41	4.11
2002	0.52	0.18	0.31	0.90	1.94	3.86
2003	0.64	0.26	0.45	1.14	1.48	3.98
2004	0.50	0.18	0.30	0.84	2.27	4.09
2005	1.43	0.42	0.87	1.76	0.74	5.21
2006	1.32	0.31	0.72	1.54	0.88	4.78
2007	0.31	0.15	0.24	0.50	2.73	3.93
2008	0.64	0.14	0.32	0.18	2.84	4.12
2009	0.58	0.18	0.56	0.70	1.49	3.52
2010	1.12	0.31	0.77	1.43	0.28	3.91
2011	1.70	0.40	0.82	1.99	0.52	5.42

Table S5a. Information on Managed Aquifer Recharge facilities in the Phoenix AMA. MAR facilities are also termed Underground Storage Facilities in Arizona.

Facility Name	*Facility Type*	*Permitted (10^6 L/yr)*	*Permitted (af/yr)*	*Water Source*	*Permit Issued*
Phoenix AMA					
TARTESSO WRF	Spreading Basin	1,735.6	20,163	MWW	03/11/10
THE ESTATES AT LAKESIDE	Spreading Basin	5.8	67	MWW	08/25/06
SUPERSTITION MTNS. RP	Spreading Basin	2,152.0	25,000	CAP	11/08/11
VERRADO RECHARGE FACILITY	Spreading Basin	43.0	500	MWW	12/16/13
EL MIRAGE CONSTRUCTED RF	Spreading Basin	192.8	2,240	MWW	06/16/08
SECTION 11 RECHARGE FACILITY	Spreading Basin	109.9	1,277	MWW	03/29/10
CITY OF PHOENIX 6A-WELL 299	Spreading Basin	162.0	1,882	CAP	02/24/12
HASSAYAMPA	Streambed	6,886.5	80,000	CAP	04/18/13
CITY OF SURPRISE SPA-3 RWRF	Spreading Basin	366.4	4,256	MWW	01/09/12
CITY OF SURPRISE SPA-2 RWRF	Spreading Basin	192.8	2,240	MWW	11/22/11
VISTANCIA RECHARGE FACILITY	Spreading Basin	57.9	673	MWW	02/14/13
CITY OF PHOENIX 9A-WELL 300	Spreading Basin	91.2	1,060	CAP	01/10/12
QUEEN CREEK USP	Spreading Basin	2,272.5	26,400	CAP	02/25/13
CITY OF PHOENIX CCASR1 Well	Spreading Basin	249.9	2,903	CAP	07/14/14
GOODYEAR SAT PILOT	Spreading Basin	322.8	3,750	MWW	06/02/14
GRUSP	Spreading Basin	8,005.5	93,000	CAP, MWW, SW	03/13/12
NEELY RECHARGE FACILITY	Spreading Basin	192.8	2,240	MWW	11/21/14
SUN CITY WEST	Spreading Basin	482.1	5,600	MWW	12/16/13
CHANDLER INTEL	Spreading Basin	289.2	3,360	MWW	01/27/15
OCOTILLO SPRINGS	Spreading Basin	43.0	500	MWW	05/22/06
BEARDSLEY ROAD WRF	Spreading Basin	192.8	2,240	MWW	03/02/10
TUMBLEWEED PARK RF	Spreading Basin	964.1	11,200	MWW	03/15/10
PIMA UTILITY COMPANY USF	Spreading Basin	63.0	732	MWW	04/03/08
SCOTTSDALE WATER CAMPUS	Spreading Basin	1,851.9	21,514	CAP, MWW	12/07/08
SURPRISE SOUTH RECHARGE	Spreading Basin	694.3	8,066	MWW	04/18/13
KEN MCDONALD	Spreading Basin	292.7	3,400	CAP, SW	09/05/14
GILBERT RIPARIAN PRESERVE	Spreading Basin	376.1	4,369	CAP, MWW, SW	06/08/09
AVONDALE WETLANDS	Spreading Basin	1,721.6	20,000	CAP, MWW, SW	11/13/12
ANTHEM USF (DESERT HILLS)	Spreading Basin	43.0	500	CAP, MWW	12/16/13
AGUA FRIA	Streambed	8,608.1	100,000	CAP	02/13/12
AGUA FRIA	Spreading Basin	8,608.1	100,000	CAP	09/04/12
WESTWORLD	Spreading Basin	86.1	1,000	CAP	08/15/01
NORTH SCOTTSDALE AQUIFER RP	Spreading Basin	313.5	3,642	CAP	06/13/05
OCOTILLO ASR	Spreading Basin	964.1	11,200	MWW	01/28/10
HIEROGLYPHIC MTS.	Spreading Basin	3,012.8	35,000	CAP	09/04/12
SMCFD #1	Spreading Basin	202.5	2,352	MWW	05/20/13
CHANDLER HEIGHTS	Spreading Basin	192.8	2,240	MWW	10/29/09
NAUSP	Spreading Basin	2,582.4	30,000	CAP, MWW, SW	06/30/11
GOLD CANYON WWTP	Spreading Basin	96.4	1,120	MWW	04/14/03
ARROWHEAD RANCH	Spreading Basin	198.0	2,300	MWW	09/08/10
MUNICIPAL	Spreading Basin	192.8	2,240	MWW	11/30/04
FOUNTAIN HILLS	Spreading Basin	192.9	2,241	MWW	04/24/08
TONOPAH DESERT	Spreading Basin	12,912.1	150,000	CAP	07/27/09
GILBERT SOUTH	Spreading Basin	347.1	4,032	MWW	09/09/08
CAVE CREEK	Spreading Basin	771.4	8,961	MWW	10/06/08
Total		69,334.5	805,460		

MWW: Municipal Waste Water, CAP: Central Arizona Project, SW: Surface Water

Table S5b. Managed Aquifer Recharge facilities, also termed Underground Storage Facilities (USF) by the Arizona Dept. of Water Resources, in the Tucson, Pinal, and Prescott Active Management Areas.

Facility Name	*Facility Type*	*Permitted (10^6 L/yr)*	*Permitted (af/yr)*	*Water Source*	*Permit Issued*
Tucson AMA					
SAVSARP	Spreading Basin	6,456.1	75,000	CAP	12/24/14
CORONA DE TUCSON WRF	Spreading Basin	96.4	1,120	MWW	05/11/09
SADDLEBROOKE	Spreading Basin	179.9	2,090	MWW	12/02/13
PROJECT RENEWS	Spreading Basin	258.2	3,000	CAP	11/25/14
SWEETWATER	Spreading Basin	1,119.0	13,000	MWW	08/19/14
SANTA CRUZ MANAGED	Streambed	801.2	9,307	MWW	02/11/13
LOWER SANTA CRUZ	Spreading Basin	4,304.0	50,000	CAP	04/29/09
HIGH PLAINS RECHARGE PROJECT	Spreading Basin	30.1	350	MWW	06/10/09
AVRA VALLEY RECHARGE PROJECT	Spreading Basin	946.9	11,000	CAP	07/26/12
PIMA MINE ROAD RECHARGE PROJECT	Spreading Basin	2,582.4	30,000	CAP	06/16/08
CAVSARP	Spreading Basin	8,608.1	100,000	CAP	12/02/08
ROBSON RANCH QUAIL CREEK	Spreading Basin	192.8	2,240	MWW	12/17/03
LOWER SANTA CRUZ MANAGED	Streambed	3,701.5	43,000	MWW	02/11/13
SAHUARITA RECHARGE FACILITY	Spreading Basin	77.1	896	MWW	11/30/07
Total		29,353.8	341,003		
Pinal AMA					
AZ CITY SAN. DIST. RECHARGE FACILITY	Spreading Basin	96.4	1,120	MWW	05/23/12
SOUTHWEST WATER DIST.	Spreading Basin	96.4	1,120	MWW	07/25/07
SANTA ROSA UTILITY CO. USF	Spreading Basin	221.8	2,577	MWW	11/25/11
EJR RANCH RECHARGE FACILITY	Spreading Basin	23.4	272	MWW	11/25/11
ANTHEM AT MERRILL RANCH	Spreading Basin	289.2	3,360	MWW	03/29/10
SOUTHWEST WATER RECLAM.	Spreading Basin	96.4	1,120	MWW	10/17/08
ELOY DETENTION CENTER	Spreading Basin	234.7	2,726	MWW	11/17/11
CASA GRANDE CONSTRUCTED USF	Spreading Basin	180.8	2,100	MWW	04/18/13
CASA GRANDE MANAGED USF	Streambed	301.3	3,500	MWW	12/16/13
ELOY RECLAIMED WATER RECH.	Spreading Basin	192.8	2,240	MWW	04/09/12
SUN LAKES AT CASA GRANDE RF	Spreading Basin	29.3	340.4	MWW	02/25/08
Total		1,762.5	20,475		
Prescott AMA					
UPPER AGUA FRIA RECHARGE FACILITY	Spreading Basin	361.5	4,200	MWW	05/21/12
PRESCOTT RECHARGE FACILITY	Spreading Basin	619.8	7,200	MWW	05/18/09
OLD HOME MANOR RECHARGE FACILITY	Spreading Basin	96.4	1,120	MWW	05/22/06
Total		1,077.7	12,520		

MWW: Municipal Waste Water, CAP: Central Arizona Project, SW: Surface Water

Table S6. California Central Valley Delta system winter (Dec-Mar) outflows. Total Net Delta Outflow Index (NDOI) represents the total delta outflow volume. NDOI data were obtained from http://www.usbr.gov/mp/cvo/vungvari/deltaop1214.pdf. Excess NDOI represents the flow resulting from daily mean discharge rates that were simultaneously in excess of 170 m^3/s (6000 ft^3/s, the minimum environmental flow rate), and less than 400 m^3/s (14,000 ft^3/s, the maximum pumping capacity). Actual daily Delta export pumping was determined as the sum of Clifton Court, Tracy, and Contra Costa pumping. The San Luis Reservoir available storage values represent the storage capacity that remained in March of each water year (http://cdec.water.ca.gov/reservoir.html). The current system net available values represent the amounts of excess NDOI that might have been stored in San Luis Reservoir under current pumping and storage capacity limitations. The expanded system net available values represent the amounts of excess NDOI greater than the available San Luis Reservoir capacity.

Water Year	*Total NDOI Dec-Mar km³*	*Excess NDOI Dec-Mar km³*	*San Luis Reservoir available storage[1] km³*	*Current System Net Available km³*	*Expanded System Net Available km³*
2001	4.79	1.27	0.04	0.04	1.22
2002	6.72	1.29	-	-	1.29
2003	8.94	0.93	0.07	0.07	0.86
2004	12.84	1.02	-	-	1.02
2005	7.44	1.19	-	-	1.19
2006	27.32	1.58	-	-	1.58
2007	4.03	1.11	0.27	0.27	0.83
2008	5.03	1.57	0.40	0.40	1.18
2009	3.94	1.06	1.24	1.06	-
2010	5.63	1.29	0.37	0.37	0.92
2011	16.19	1.39	-	-	1.39
2012	3.57	1.11	0.31	0.31	0.80
2013	7.01	2.02	0.88	0.88	1.14
2014	2.51	0.60	1.43	0.60	-
2015	4.37	0.90	0.81	0.81	0.09
Total	120.3	18.3		4.8	13.5

[1] San Luis Reservoir conservation pool storage capacity = 2.48 km^3 (2,014,000 af)

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