Policy Brief

New research shows that groundwater levels are declining at rapid and accelerating rates in many global aquifers. It also reveals cases where depleted aquifers have recovered after human interventions.

Background

Groundwater is a vital water resource globally, providing drinking water to billions of individuals and supplying nearly half of all water used for irrigation. Excessive withdrawals can, however, deplete groundwater resources.

Rapid and accelerating groundwater decline

A new study analyzed millions of groundwater levels in 170,000 wells in over 40 countries to identify groundwater level changes over time. Two of the findings of the study are:

1. Rapid groundwater declines are widespread, especially in arid climates with extensive croplands.
2. In many of these cultivated drylands, groundwater declines have accelerated over the past 40 years.

Consequences of groundwater decline

Rapid and accelerating reductions in groundwater levels can lead to undesirable outcomes including (a) seawater intrusion, which can contaminate coastal aquifers, (b) land subsidence, which can damage infrastructure and flood coastal communities, (c) streamflow depletion, which can reduce water availability to downstream water users, including wildlife, and (d) wells running dry, which can impair access to clean and convenient fresh water.

Table 1. Observed rates of 21st century groundwater decline

Country	Aquifer system	Median rate of decline (m/year)
Afghanistan	Central Kabul Basin	0.73
Chile	Central Santiago Basin	0.63
China	Northcentral Piedmont (North China Plain)	0.75
India	Northwest Jaipur Alluvium & Mendha Basin	1.68
Iran	Rashtkhar Aquifer	2.62
Iran	Western Qazvin Plain	1.74
Mexico	Calera Aquifer	1.01
Morocco	Central Souss Basin	1.04
Saudi Arabia	Eastern Saq Aquifer	1.30
Spain	Cingla-Cuchillo Aquifer	1.60
USA	Cuyama Valley	1.45
USA	Chowchilla Basin (California Central Valley)	1.02

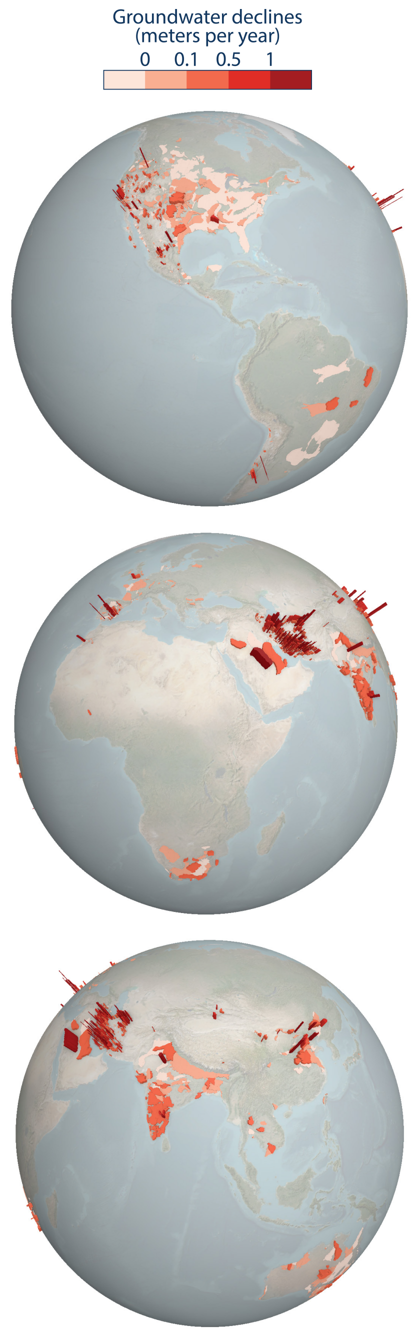


Fig. 1. 21st century groundwater declines. Dark red indicates rapid declines, and light brown indicates that groundwater did not decline. Rapid declines are evident in areas of the western US (top), Saudi Arabia and Iran (middle) and northern China (bottom).

Ram-Saq Aquifer, Saudi Arabia

Addressing groundwater depletion

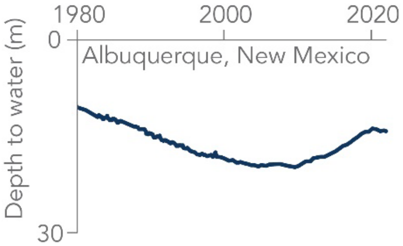
The research highlights cases where groundwater-level declines were reversed by interventions, such as (1) policy changes, (2) inter-basin water transfers, or (3) managed aquifer recharge.

Intervention 1) Policy change

The implementation of new or altered policies has, in some cases, led to groundwater recovery. For example, in Bangkok (south Thailand), groundwater level declines of the 1980s and 1990s were reversed after the implementation of regulations designed to reduce groundwater pumping.

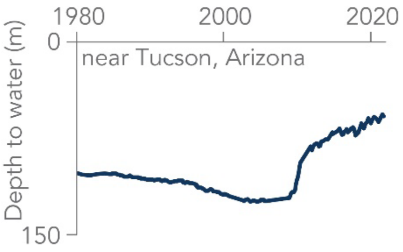
Intervention 2) Alternative water source

Substitution of groundwater for another water source has enabled some depleted aquifers to recover. For example, in Albuquerque (western US), groundwater levels are recovering after an inter-basin transfer of surface water alleviated groundwater demand.



Intervention 3) Managed aquifer recharge

Managed aquifer recharge involves intentionally replenishing aquifers, via infiltration ponds or injection wells. For example, in the Avra Valley of Arizona (west of Tucson in the southwestern US), a depleted aquifer is being refilled by water that has been diverted from the Colorado River.



Jasechko, S. et al. Rapid groundwater declines in many aquifers globally but cases of recovery. *Nature* https://doi.org/10.1038/s41586-023-06879-8 (2024)


San Joaquin Valley, California

Albuquerque, USA

In Albuquerque, long-term groundwater declines were reversed after the city increased its withdrawals of surface water derived from an inter-basin water transfer, reducing groundwater withdrawals and enabling managed aquifer recharge projects.

Background

Albuquerque is located in the western US (35.1°N, 106.6°W). Municipal groundwater withdrawals from the local aquifer system (the Santa Fe aquifer system) increased by a factor of 4 between the late 1950s and the year 2000, leading to groundwater level declines (Fig. 1).

Intervention

In 2008, Albuquerque increased withdrawals of surface waters from a river that runs through the city[1] (the "Rio Grande"), taking advantage of an inter-basin transfer of river water from the Colorado River Basin into the Rio Grande Basin (inter-basin transfer project known as the "San Juan-Chama Project"). Consequently, demand for groundwater declined, leading to a 67% reduction in total groundwater withdrawals from 2008 to 2016 (ref.[1]). The city has also operationalized managed aquifer recharge projects (e.g., "Bear Canyon Recharge Project") that divert water supplied by the San Juan-Chama Project into the aquifer via injection wells or infiltration ponds[2].

Outcome

After the inter-basin surface water transfer alleviated groundwater demand, groundwater levels rose in parts of the Albuquerque Basin (Fig. 1). This increased groundwater is available to Albuquerque as an emergency water supply, should surface water supplies be contaminated or become limited during drought[1].

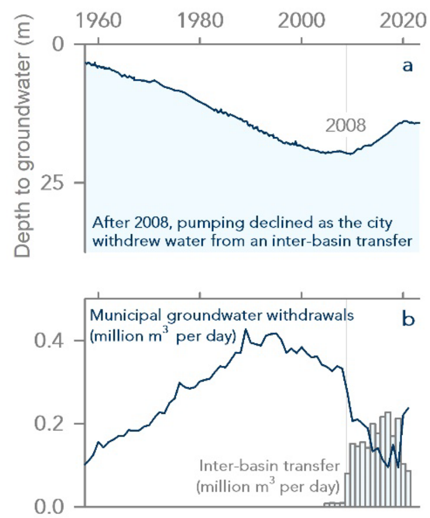


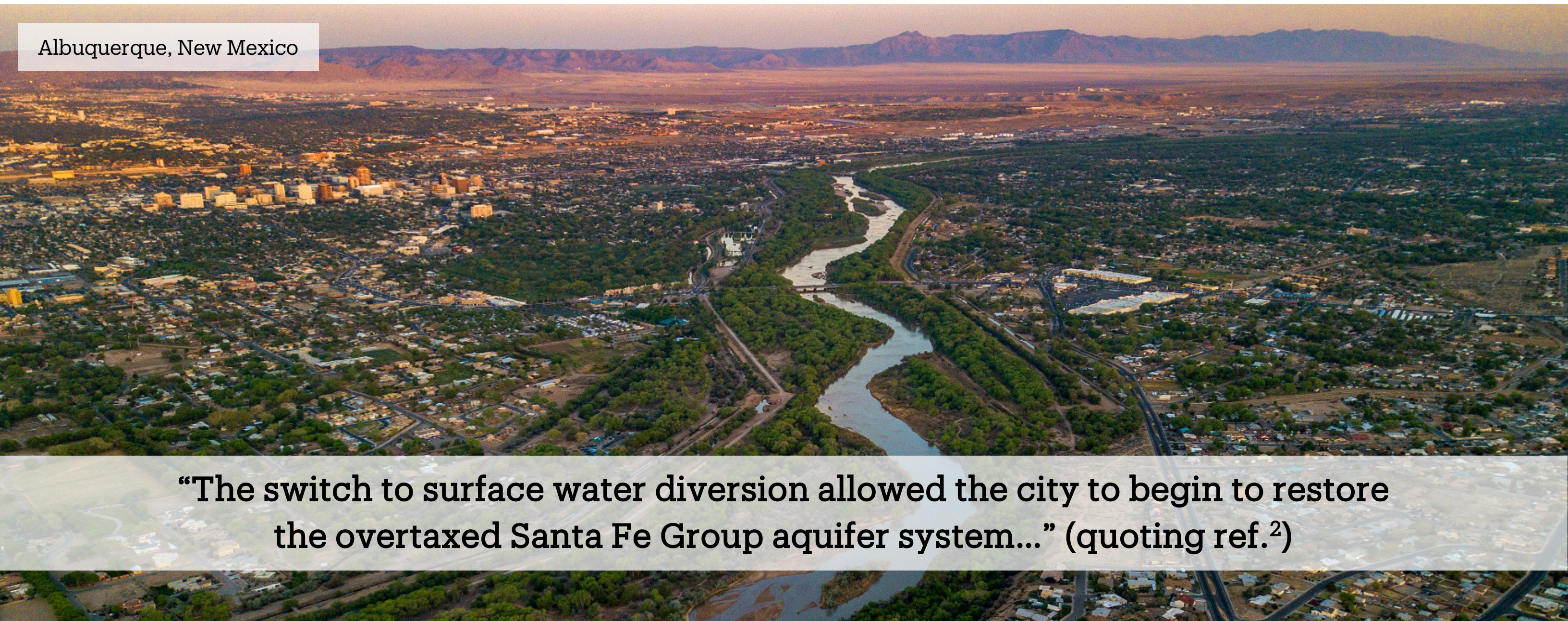
Fig. 1. (a) Groundwater level change over time in a monitoring well in Albuquerque, New Mexico (35.140°N, 106.632°W; data compilation and processing described in ref.[3]). **(b)** Municipal groundwater withdrawals in Albuquerque (line at top of panel b). In 2008, Albuquerque increased its withdrawal of surface water from a river that runs through the city (the Rio Grande; see bars at base of panel b). These river withdrawals were enabled by an inter-basin surface water transfer project located upstream of the city, which transfers water from the Colorado River Basin into the Rio Grande (withdrawal data from refs.[1,4]). After this transfer, groundwater pumping declined and levels rose.

[1] Galanter, A. E., Curry, L. T. S. U.S. Geological Survey Scientific Investigations Map 3433, 1 sheet, 13-p. pamphlet. Available via: https://doi.org/10.3133/sim3433 (2019).

[2] Miller, K., Burson, M., Kiparsky, M. An urban drought reserve enabled by state groundwater recharge legislation: The Bear Canyon Recharge Project, Albuquerque, New Mexico. Case Studies in the Environment 5, 1-10 (2021).

[3] Kennedy, J. R., & Bell, M. T. Measuring basin-scale aquifer storage change and mapping specific yield in Albuquerque, New Mexico, USA, with repeat microgravity data. Journal of Hydrology: Regional Studies, 47, 101413 (2023).

[4] Jasechko, S., Seybold, H., Perrone, D., Fan, Y., Shamsudduha, M., Taylor, R.G., Fallatah, O., Kirchner, J.W. Rapid groundwater declines in many aquifers globally but cases of recovery. Nature https://doi.org/10.1038/s41586-023-06879-8 (2024).



"The switch to surface water diversion allowed the city to begin to restore the overtaxed Santa Fe Group aquifer system…" (quoting ref.[2])

Avra Valley, USA

West of Tucson, multi-decadal groundwater depletion trends were reversed after the implementation of managed aquifer recharge via expansive infiltration ponds.

Background

The Avra Valley is located west of Tucson (a city within the state of Arizona) in the southwestern US (32.2°N, 111.2°W). Groundwater levels declined throughout much of the late 20th century[1], coinciding with increased groundwater withdrawals for irrigation after the year 1945 (ref.[2]).

Intervention

In 2008, managed aquifer recharge commenced at the Southern Avra Valley Storage and Recovery Project, leading groundwater levels to rise in the southern part of the Avra Valley (near the monitoring well depicted in Fig. 1). Farther north, another managed aquifer recharge project (the "Central Avra Valley Storage and Recovery Project") began several years prior. These managed aquifer recharge projects are supplied by water diverted from the Colorado River via the "Central Arizona Project."

Outcome

As managed aquifer recharge projects were implemented, groundwater levels rose (Fig. 1). Carruth and colleagues[1] state that "…long-term water-level declines have stabilized or reversed since 2000 at most areas in Tucson Basin and Avra Valley." Little to no land subsidence occurred during the 21st century[1], highlighting that addressing groundwater level declines likely also addressed the issue of land subsidence, which occurred throughout much of the late 20th century[1].

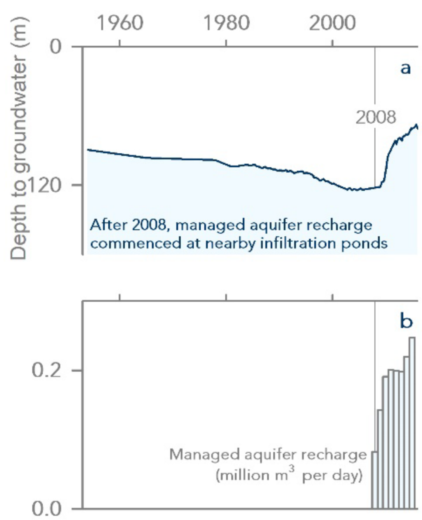
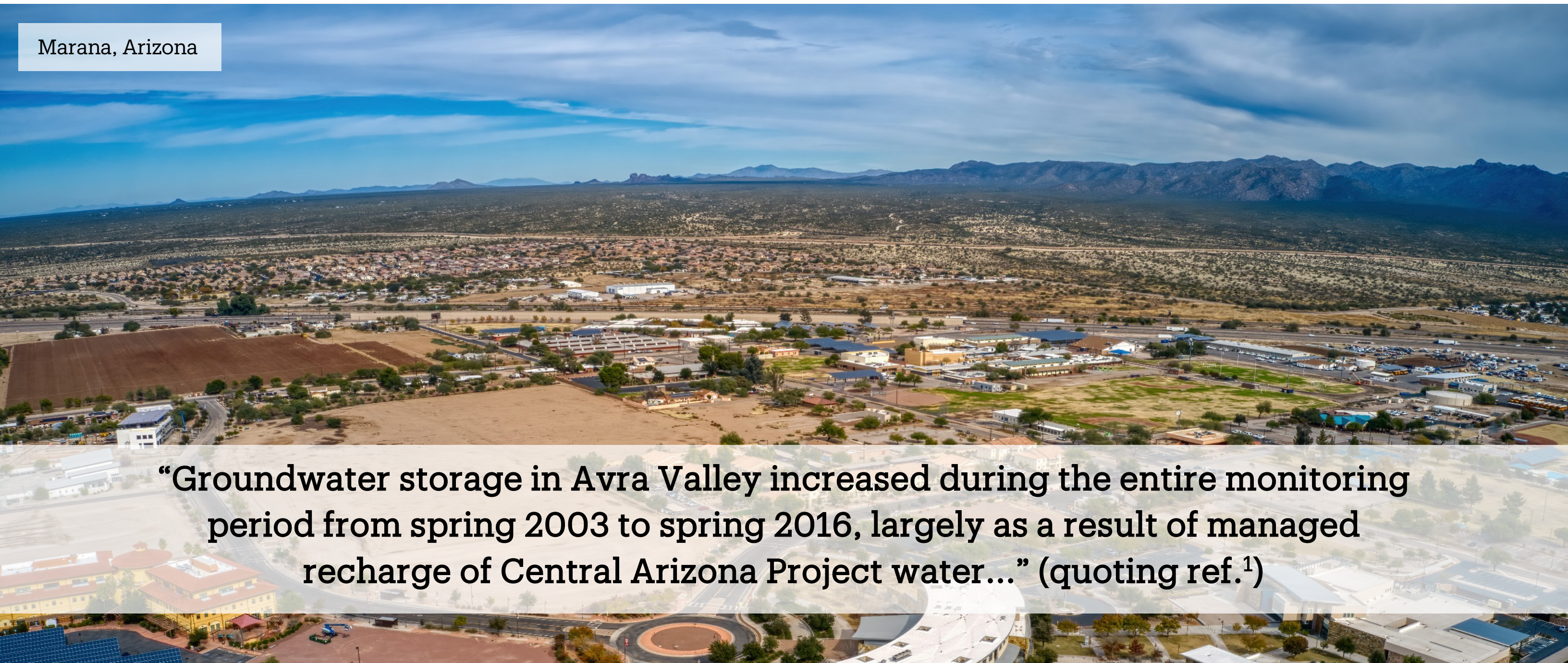


Fig. 1. (a) Groundwater level change over time in a monitoring well (32.162°N, 111.217°W). The well is located just south of the Southern Avra Valley Storage and Recovery Project, which began managed aquifer recharge in 2008 (ref.[1]). **(b)** Groundwater recharge via the Southern Avra Valley Storage and Recovery Project[1] (bars at base of panel b). After 2000, managed aquifer recharge took place, and, after decades of decline, groundwater levels rose (groundwater level data compilation and analyses from ref.[3]).

[1] Carruth, R. L., Kahler, L. M., & Conway, B. D. Groundwater-storage change and land-surface elevation change in Tucson Basin and Avra Valley, south-central Arizona--2003-2016. Scientific Investigations Report 2018-5154, 46 pp. https://doi.org/10.3133/sir20185154 (2018).

[2] Hanson, R. T., & Benedict, J. F. Simulation of ground-water flow and potential land subsidence, upper Santa Cruz Basin, Arizona. US Geological Survey Water-Resources Investigations Report 93-4196, 47 pp. https://doi.org/10.3133/wri934196 (1994).

[3] Jasechko, S., Seybold, H., Perrone, D., Fan, Y., Shamsudduha, M., Taylor, R.G., Fallatah, O., Kirchner, J.W. Rapid groundwater declines in many aquifers globally but cases of recovery. Nature, https://doi.org/10.1038/s41586-023-06879-8 (2024).



Marana, Arizona

"Groundwater storage in Avra Valley increased during the entire monitoring period from spring 2003 to spring 2016, largely as a result of managed recharge of Central Arizona Project water…" (quoting ref.[1])

Bangkok, Thailand

In Bangkok, groundwater levels recovered after the implementation of policies designed to reduce groundwater withdrawals in parts of the city.

Background

Bangkok is located in southeast Asia (13.8°N, 100.6°E). Historically, there are two main groundwater users: (i) the Metropolitan Waterworks Authority, and (ii) private wells for industries and other uses. (i) From 1980-2000, pumping by the Metropolitan Waterworks Authority was largely eliminated as the Authority switched to surface water from the Chao Phraya[1,2]. However, (ii) total pumping doubled from 1980-2000 due to substantial increases in withdrawals from private wells, inducing groundwater declines (Fig. 1).

Intervention

In 1983, a "Cabinet Resolution" created (a) a cap on total groundwater withdrawals within "Critical Zones" (meaning applications for new wells could be denied[2]), and (b) a groundwater withdrawal charge system, meaning pumping came at a cost. The groundwater charge was in place by 1985 but the fee was nominal[1], and private withdrawals nearly doubled[1,2] from 1985-2000. But, from 2000-2006, increased fees in the existing charge system and the implementation of an added "groundwater conservation fee" increased total fees per unit of pumped groundwater by a factor of ~4 over just 6 years; by 2006, pumping had declined to a rate similar to that of the early 1980s (refs.[1,3]).

Outcome

As groundwater withdrawals declined from 2000-2012, groundwater levels rose (Fig. 1). Since the early 2000s, land subsidence has slowed[4], suggesting that the recovering groundwater levels have helped address land subsidence.

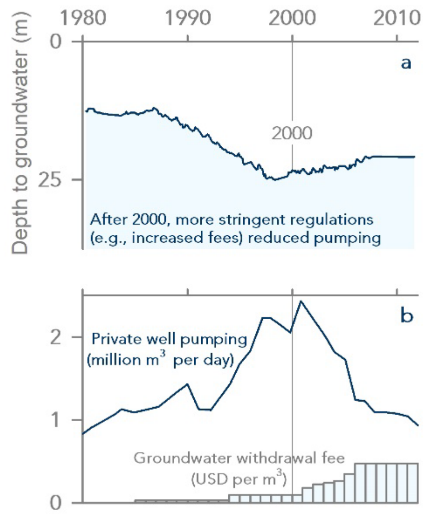


Fig. 1. **(a)** Groundwater level change over time in a monitoring well in Bangkok, Thailand (14.195°N, 100.527°E). **(b)** Groundwater withdrawals from private wells[3] (line at top of panel b) and withdrawal fees[2,4] (bars at base of panel b). From 2000-2013, groundwater withdrawal fee rose and total withdrawals declined by ~70%, and, after decades of decline, groundwater levels rose from 2000-2013 (groundwater level data compilation and analyses described in ref.[5]).

[1] Buapeng, S. & Foster, S. Controlling groundwater abstraction and related environmental degradation in metropolitan Bangkok – Thailand. World Bank Case Profile Collection No. 20. (World Bank, 2008).

[2] Endo, T. Sinking cities and governmental action: institutional responses to land subsidence in Osaka and Bangkok. In: Taniguchi, M. (eds) Groundwater and Subsurface Environments. Springer, Tokyo. Groundwater and Subsurface Environments: Human Impacts in Asian Coastal Cities. Chapter 14, pp. 271-288 (2011).

[3] Phoban, H., Seeboonruang, U., & Lueprasert, P. Numerical modeling of single pile behaviors due to groundwater level rising. Applied Sciences, 11, 5782 (2021).

[4] Lorphensri, O., Nettasana, T., & Ladawadee, A. Groundwater environment in Bangkok and the surrounding vicinity, Thailand. In: Shrestha (Eds.) Groundwater environment in Asian cities: Concepts, Methods and Case Studies. Butterworth-Heinemann, Chapter 11, pp. 229-262 (2016).

[5] Jasechko, S., Seybold, H., Perrone, D., Fan, Y., Shamsudduha, M., Taylor, R.G., Fallatah, O., Kirchner, J.W. Rapid groundwater declines in many aquifers globally but cases of recovery. Nature, https://doi.org/10.1038/s41586-023-06879-8 (2024).

Coachella Valley, USA

In California's Coachella Valley, groundwater level declines were reversed after (i) new managed aquifer recharge projects were implemented, (ii) imports of surface water were increased, and (iii) tiered water pricing led to lower groundwater demand.

Background

The Coachella Valley is located in southern California (southwestern USA; 33.7°N, 116.2°W). Groundwater withdrawals have occurred since the early 1900s, leading to groundwater level declines in the 20th century[1,2].

Intervention

From 2006-2009, the Coachella Valley Water District implemented several interventions, including (i) increased "groundwater substitution" (ref.[1]), where the "Mid Valley Pipeline" provided access to an alternative water source (specifically, recycled water and surface-water diverted from the Colorado River[1]), reducing the demand for groundwater, (ii) tiered-rate pricing for water use (multi-tiered rate with inclining block structure[3]), where an allocation for water users is set and usage beyond this budget is priced at a higher cost per unit water[3], and (iii) managed aquifer recharge (e.g., the "Thomas E. Levy Groundwater Replenishment Facility").

Outcome

By 2010, these interventions were in place, and groundwater levels stabilized or rose in parts of the Valley[1]. Land subsidence rates have slowed or stopped in some areas, too, though they have continued even in some of the places where groundwater levels have rebounded, highlighting the important role of geologic heterogeneity on the connections between land subsidence and groundwater level changes.

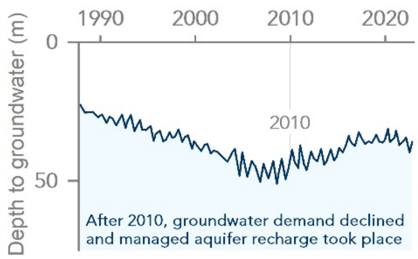


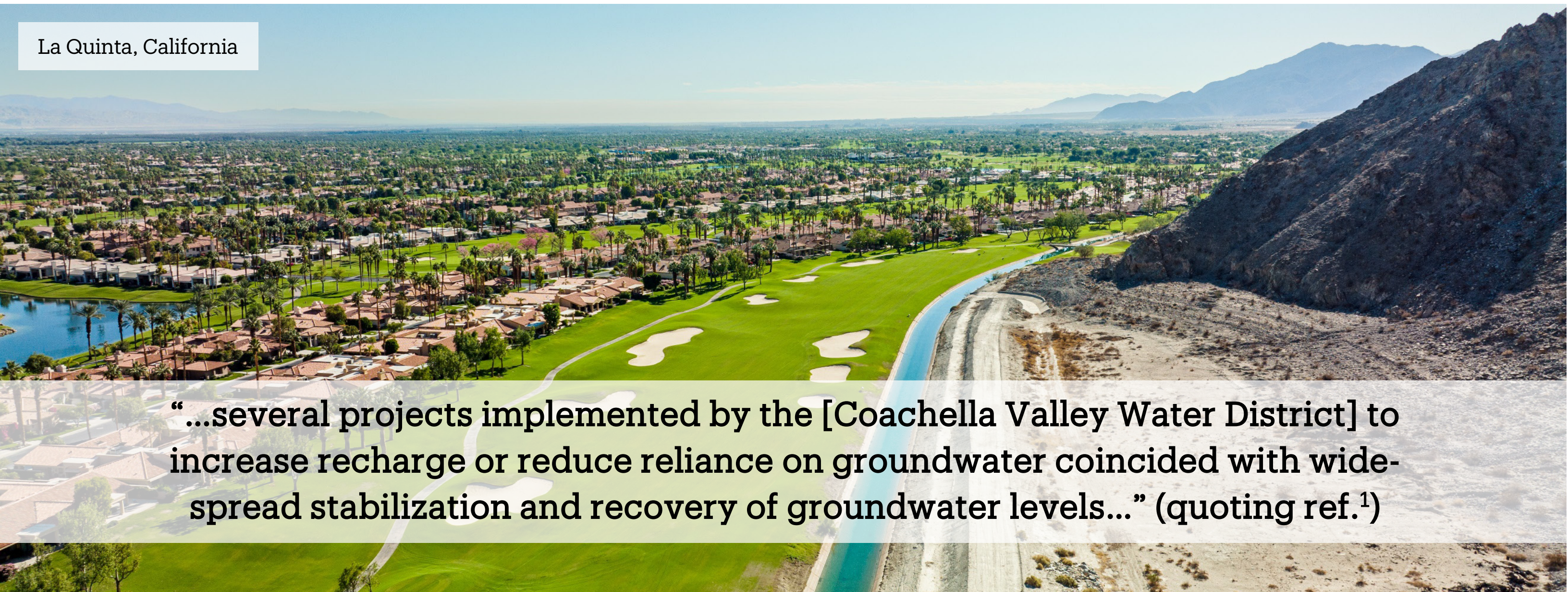
Fig. 1. Groundwater level change over time in a monitoring well (33.654°N, 116.253°W). The well is located on the west side of the Coachella Valley (ref.[1]). Groundwater levels declined in the 1980s and 1990s, but recovered from 2010-2023. After 2010, groundwater demand fell as transported surface water substituted for groundwater use, and as tiered-pricing was implemented. Further, managed aquifer recharge occurred at new sites. After decades of decline, groundwater levels rose (groundwater level data compilation and analyses from ref.[4]).

[1] Sneed, M., & Brandt, J.T. Mitigating land subsidence in the Coachella Valley, California, USA: an emerging success story. Proceedings of the International Association of Hydrological Sciences, 382, 809-813 (2020).

[2] Thomas, B.F., Famiglietti, J.S. Sustainable groundwater management in the arid southwestern US: Coachella Valley, California. Water Resources Management, 29, 4411 4426 (2015).

[3] Coachella Valley Water District (2023). 5.05.010 Tiered rates policies. Accessed Dec-10-2023 via https://cvwd.district.codes/CVWDC/5.05.010

[4] Jasechko, S., Seybold, H., Perrone, D., Fan, Y., Shamsudduha, M., Taylor, R.G., Fallatah, O., Kirchner, J.W. Rapid groundwater declines in many aquifers globally but cases of recovery. Nature, https://doi.org/10.1038/s41586-023-06879-8 (2024).



La Quinta, California

"...several projects implemented by the [Coachella Valley Water District] to increase recharge or reduce reliance on groundwater coincided with wide-spread stabilization and recovery of groundwater levels..." (quoting ref.[1])

El Dorado, USA

In El Dorado (Arkansas, USA), groundwater levels declined from 1940-2000 as industries pumped considerable groundwater. Funded by a fee imposed on large groundwater users, new infrastructure was installed to transport water from a nearby river to the area, reducing groundwater demand and allowing the aquifer to recover.

Background

El Dorado is a town in southern Arkansas, in the southern USA (33.2°N, 92.7°W). Groundwater withdrawals from a confined aquifer (the "Sparta Aquifer") led groundwater levels to decline by ~60 m from 1940-2000 (Fig. 1; refs.[1,2]).

Intervention

In 1999, Act 1050 empowered new "Critical Groundwater Conservation Boards." In Union County in 1999, this Board created a fee structure (0.063 USD per m^3 of groundwater pumped), which incentivized local industries to develop infrastructure to access an alternate water supply instead of groundwater[2]. By 2005, requisite infrastructure (e.g., 48-inch diameter pipeline, pumps) had been installed to divert water from the Ouachita River to local industries, and groundwater withdrawals fell by 50% or more[2].

Outcome

After the water diversion infrastructure became operational, groundwater withdrawals declined and groundwater levels rose.

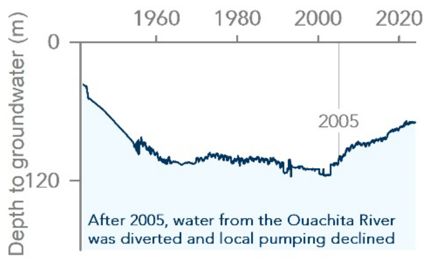
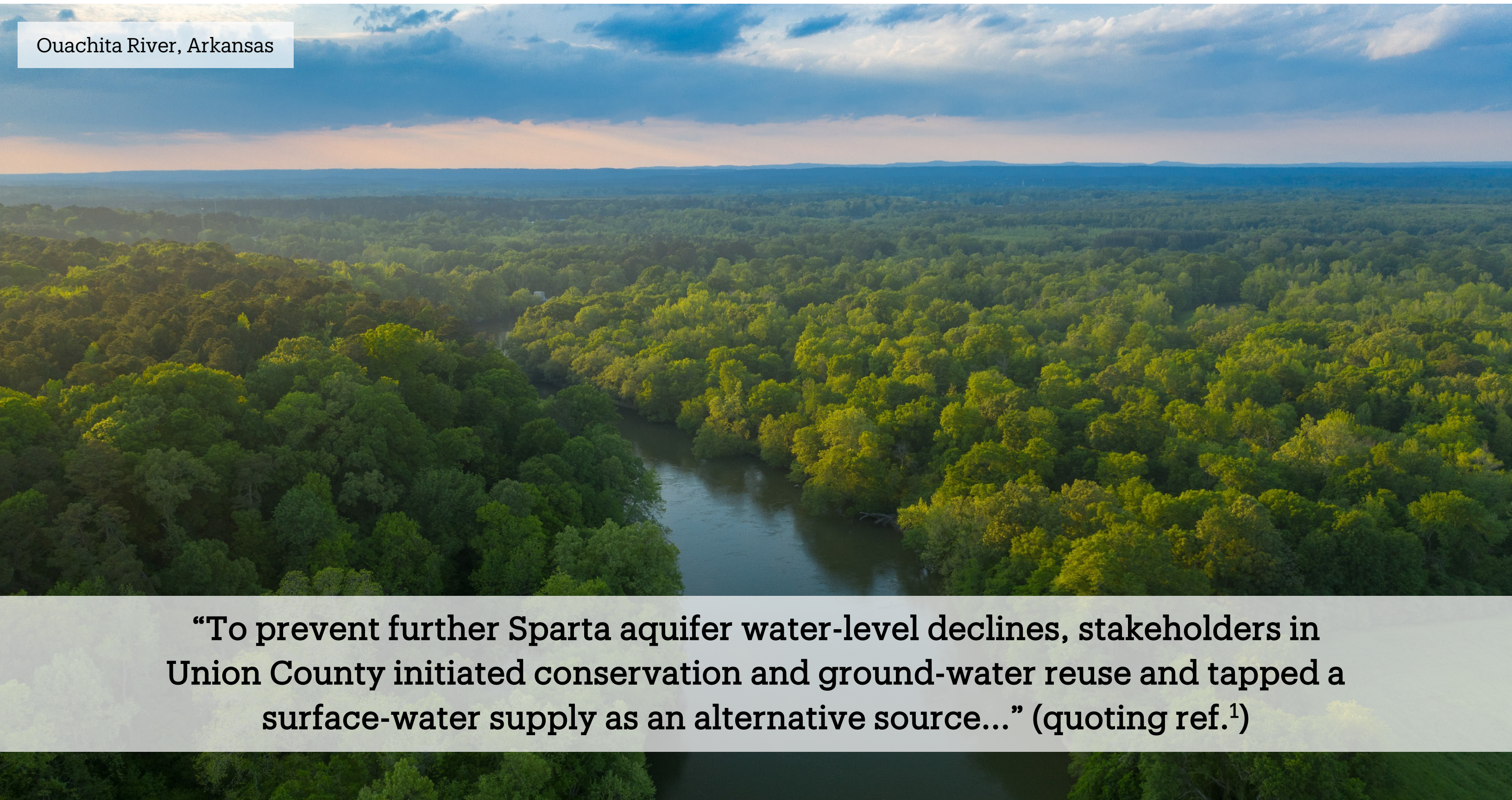


Fig. 1. Groundwater level change over time in a monitoring well (33.244°N, 92.691°W). After 2005, the transport of river water to local industries led to a decline in groundwater demand, as these newly available surface water diversions substituted in for groundwater. After decades of decline, groundwater levels rose from 2005-2023 (groundwater level data from ref.[3]).

[1] Freiwald, D.A., & Johnson, S.F. Monitoring of Sparta aquifer recovery in Southern Arkansas and Northern Louisiana, 2003–07: U.S. Geological Survey Fact Sheet 2007–3102, 4 pp. (2007)

[2] Johnson, S. Sparta Aquifer Recovery South Arkansas & North Louisiana "We're Not California – but We Coulda' Been". Presentation at the Red River Valley 92nd Annual Convention, Shreveport, Louisiana. Accessed December 10, 2023 via www.rrva.org/02272017/Ground Water Conservation & Development.pdf (2017).

[3] US Geological Survey webpage accessed December 10, 2023 via https://waterdata.usgs.gov/monitoring-location/331438092411901/#parameterCode=72019&period=P7D&showMedian=true



"To prevent further Sparta aquifer water-level declines, stakeholders in Union County initiated conservation and ground-water reuse and tapped a surface-water supply as an alternative source…" (quoting ref.[1])