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An insidious issue has been growing along the Central Coast and throughout the state of California for decades: groundwater overdraft. In response to this growing threat and 2014 legislation designed to put an end to chronic overdraft, many basins have identified managed aquifer recharge (MAR) as an essential supply-side tool for managing water resources. MAR promotes infiltration using natural or engineered infrastructure and available water, thereby improving water balance.



Distributed MAR is an even newer concept, relying on catchment systems spread throughout a groundwater basin rather than centralized in a single location. However, areas most suitable for MAR––spaces with suitable geology to which water can be efficiently routed for infiltration––are often located on land that water management agencies cannot freely access. The individuals, businesses, or outside agencies that do own or manage these areas are not sufficiently incentivized to



nature water

Article

https://doi.org/10.1038/s44221-023-00141-1

**Recharge net metering (ReNeM) is a novel, cost-effective management strategy to incentivize groundwater recharge**

Received: 27 December 2022

Accepted: 7 September 2023

Published online: 18 October 2023

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Managed aquifer recharge, which uses available water to augment groundwater resources, holds promise as a strategy to reduce chronic groundwater overdraft. However, water management agencies often confront hurdles when implementing managed aquifer recharge. Favourable sites for recharging water are often located on private land, and common-pool resource conflicts frequently disincentivize voluntary private participation. We introduce recharge net metering (ReNeM), a conceptually novel, market-based mechanism to help overcome these barriers and achieve multiple extractive and non-extractive benefits from improved groundwater management. ReNeM enables an agency to incentivize practices that enhance infiltration and groundwater recharge. Here we formalize the basis for incentivizing recharge and conduct a multi-party cost–benefit analysis of an operating ReNeM programme in California's Pajaro Valley. Calculations show that water supply from ReNeM can be achieved at a lower cost than many viable alternatives and can produce multiple benefits for collaborating entities and stakeholders.

Unsustainable groundwater management is a growing global concern with unsettling environmental, economic and social implications[1–3]. Achieving sustainable groundwater management typically requires reducing extraction and increasing available supply[4]. Managed aquifer recharge (MAR), which uses available water (for example, stormwater, excess flood water and recycled water) and engineered or natural infrastructure for infiltration, can enhance aquifer replenishment by augmenting locally available supplies, thus contributing to an improved water balance[5,6]. Distributed MAR—catchment systems spread throughout a groundwater basin rather than centralized in a single location—holds promise as a low-cost strategy to collect and infiltrate stormwater[7–10]. However, distributed MAR also poses unique challenges[11,12]. First, infiltration and recharge conditions can be highly heterogeneous, with favourable conditions present across only a fraction of the landscape, including sites located on private land or in areas not accessible to management agencies[6,13]. Second, although components of distributed MAR can be affordable, purchasing or leasing disbursed land assets can be cost prohibitive or politically challenging[14–16].

The objective of this analysis is to introduce recharge net metering (ReNeM), a market-based mechanism that incentivizes groundwater supply augmentation using distributed MAR and to use a case study of ReNeM's deployment in California's Pajaro Valley to demonstrate the programme's cost-effectiveness. Similar to net energy metering, which compensates programme participants with at-home solar power systems for the energy they feed into the grid[17], ReNeM incentivizes the construction and operation of MAR projects on private property by compensating rechargers based on the measured quantity of water each project infiltrates. ReNeM payments offset direct costs of project operation and land opportunity costs to rechargers—costs that might otherwise be barriers to voluntary action. As currently deployed in the

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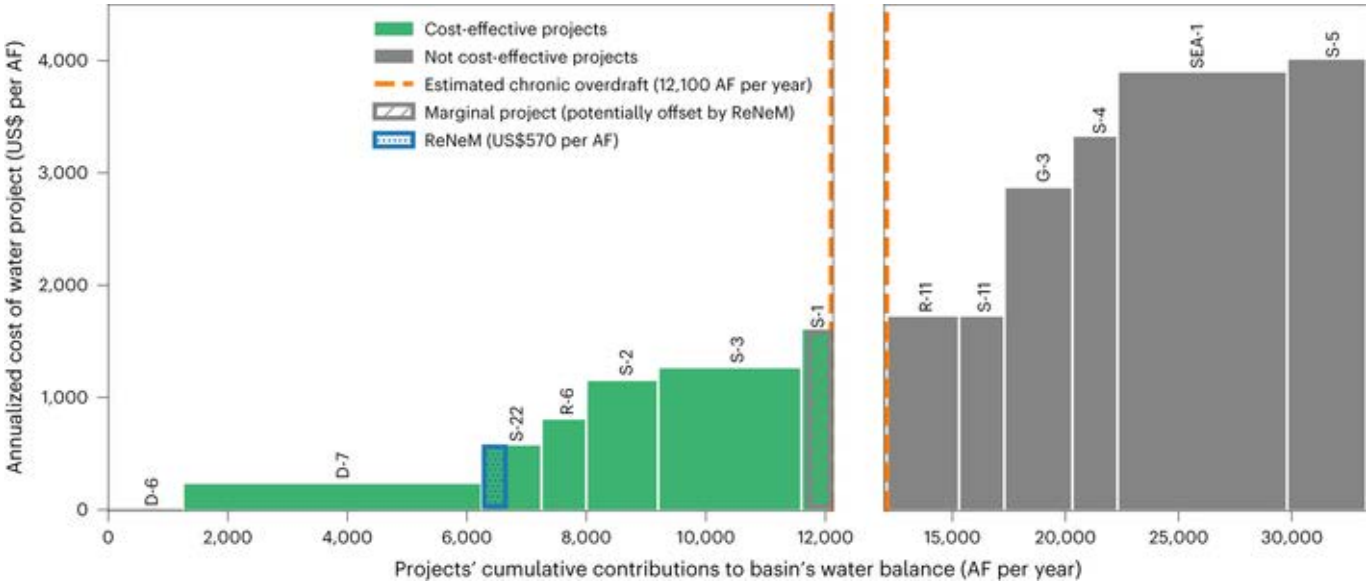
participate in MAR.

Enter recharge net metering (ReNeM), a conceptually novel market-based mechanism similar to net energy metering that financially incentivizes groundwater supply augmentation using distributed MAR by subsidizing private parties who conduct recharge on their land. In this way, ReNeM addresses some of the political challenges and transaction costs that can hinder other forms of groundwater management.

Our new paper, published in *Nature Water*, showcases a case study of ReNeM deployed in California's Pajaro Valley by developing a method to evaluate its economic performance based on cost-benefit analysis. Results show:

## ReNeM can reduce groundwater overdraft at lower cost per acre foot than most other management actions.

Results showed that, at $570 per acre foot of water, ReNeM cost less than all other management options at the Pajaro Valley's disposal. These include both surface water storage and other groundwater recharge efforts. Only narrow instances of increased recycled water deliveries and improvements in irrigation efficiency cost less.




## All parties to the ReNeM program receive significant net benefits.

ReNeM produces significantly more benefits than the costs it imposes. Over 25 years at its current modest level of implementation, , ReNeM is projected to generate net benefits equivalent to ~$1.9 million.  ~86% of that amount ($1.63 million) is projected to accrue to the basin as resource enhancement and ~14% ($270,000) paid to program participants who host projects on their land.

## ReNeM is highly adaptable and capable of producing substantial net benefits under a range of circumstances.

ReNeM aligns the interests of agency and landowner participants in ways that other methods do not. Unlike groundwater banking, ReNeM has the potential to support environmental improvements and sustain groundwater supplies. Crucially, ReNeM may contribute to environmental and social benefits which, while not quantified in our analysis, can help deliver broader water management benefits that are typically difficult to provide such as regional stream base flow augmentation, water quality improvements, enhanced aquatic conditions, and community engagement in groundwater stewardship. Particularly when combined with groundwater protections or extraction limits, ReNeM's adaptability gives agencies the capacity to balance

different water uses, limit the withdrawal of recharged water, and support groundwater users in the basin.

Groundwater overdraft demands creative, cooperative solutions like ReNeM. Our research indicates that ReNeM may hold promise for many other basins across California and the west. Water managers can use our paper's methodology to assess the program's viability in their own management setting and roll out an incentive-based groundwater recharge program fit to local needs.

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Reference: Bruce, M., Sherman, L., Bruno, E., Fisher, A.T., and Kiparsky, M. Recharge net metering (ReNeM) is a novel, cost-effective management strategy to incentivize groundwater recharge. *Nature Water* 1, 855–863 (2023).