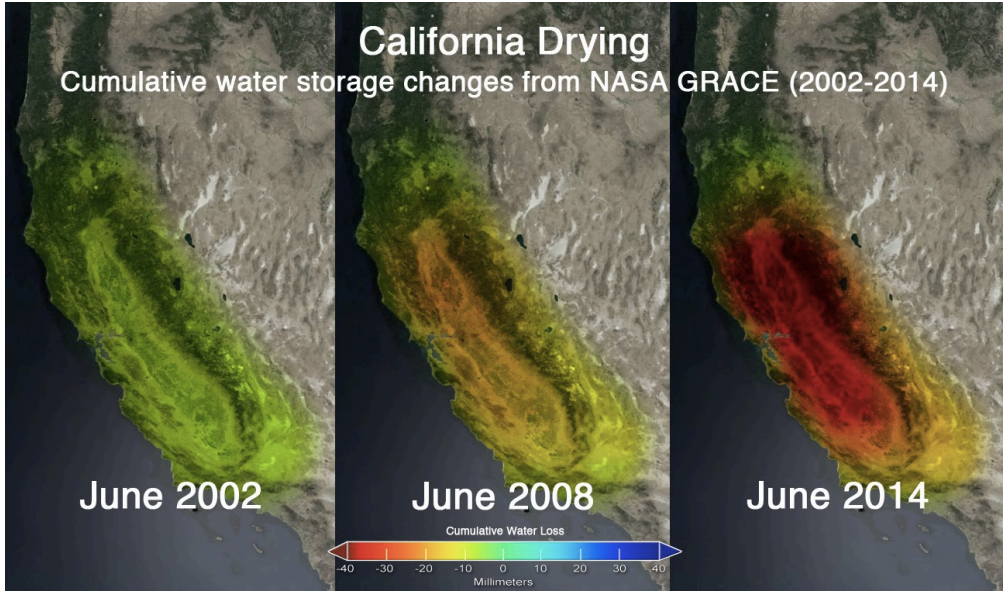


From animation prepared for 60 Minutes, November 16, 2014

Groundwater depletion as viewed from space: Implications for water, food, and human security

Julie Ann Wrigley Global Futures Laboratory
Arizona State University

Jay Famiglietti
Global Futures Professor
School of Sustainability, College of Global Futures

PCAST, Understanding Groundwater, 12-01-2023

Groundwater is rapidly disappearing from the world's aquifers because of little or no oversight

The United States is no exception: groundwater depletion in the Central Valley and in the southern half of the Ogallala aquifer, driven primarily by overpumping for irrigation, threatens not only our water security, but our food security as well

Its disappearance also threatens the resilience and climate adaptation capacity of desert cities like Phoenix, where cuts to Colorado River water will place increasing stress on a dwindling resource

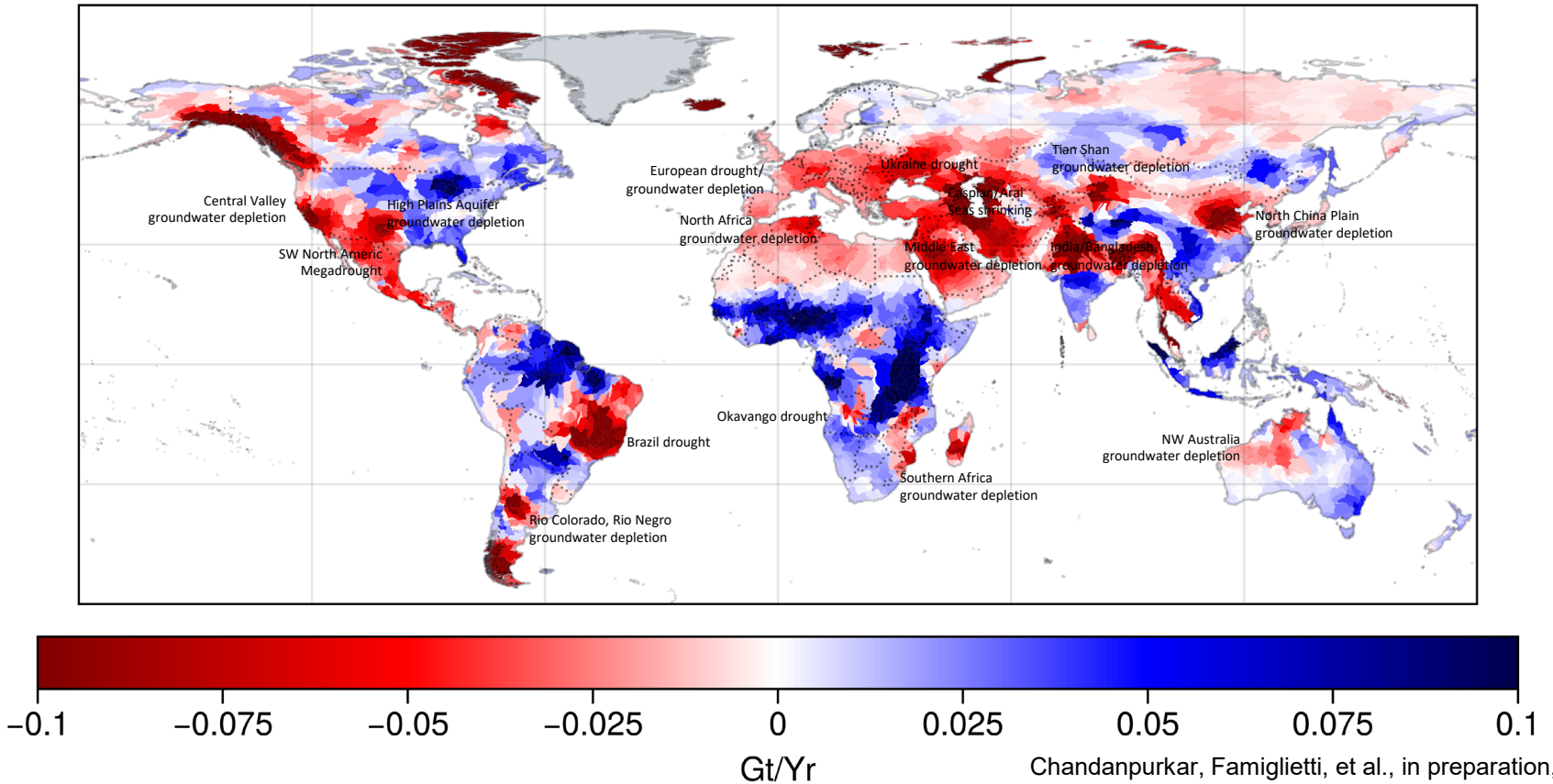
The rapid pace and extensive scale of the groundwater crisis has far outstripped the pace and scale of the response by the US (and also by the rest of the world)

Far greater awareness of the importance of groundwater, extensive exploration, and new management paradigms and policies, including at the national scale, are key to preserving groundwater for generations to come

This is an all hands on deck moment for groundwater sustainability

The global picture from NASAGRACE/FO (2002-2023)

Trends in total water storage

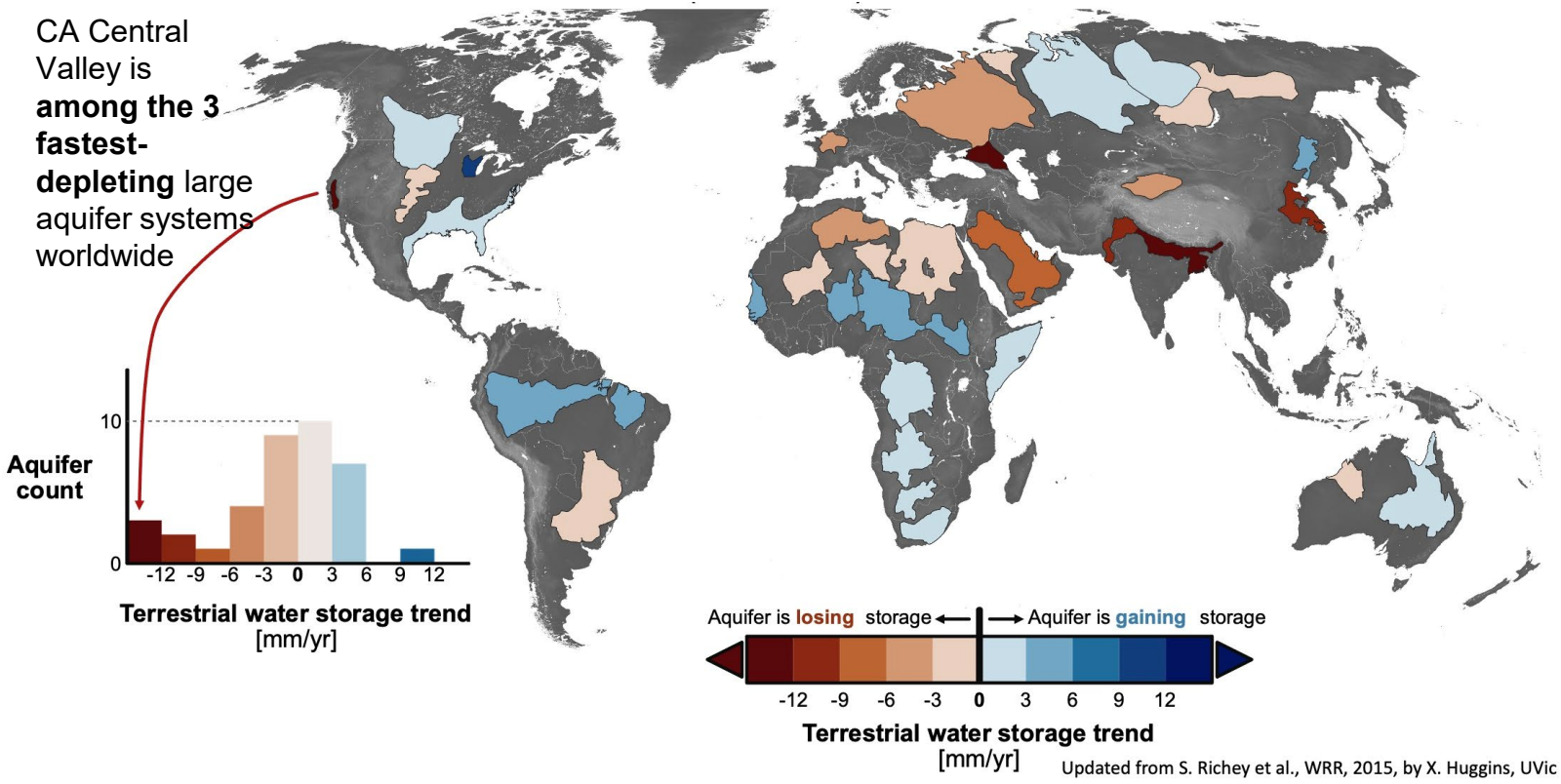


Chandanpurkar, Famiglietti, et al., in preparation, 2023

The global picture from NASAGRACE/FO (2002-2023)

Trends in total water storage in the world's large aquifer systems

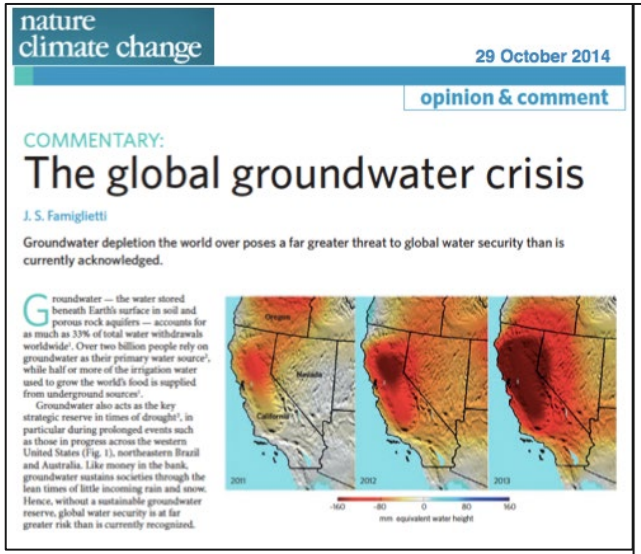
CA Central Valley is **among the 3 fastest-depleting** large aquifer systems worldwide



Updated from S. Richey et al., WRR, 2015, by X. Huggins, UVic

The global picture from NASA GRACE/FO (2002-2023)

The global groundwater crisis



nature climate change

29 October 2014

opinion & comment

COMMENTARY:

The global groundwater crisis

J. S. Famiglietti

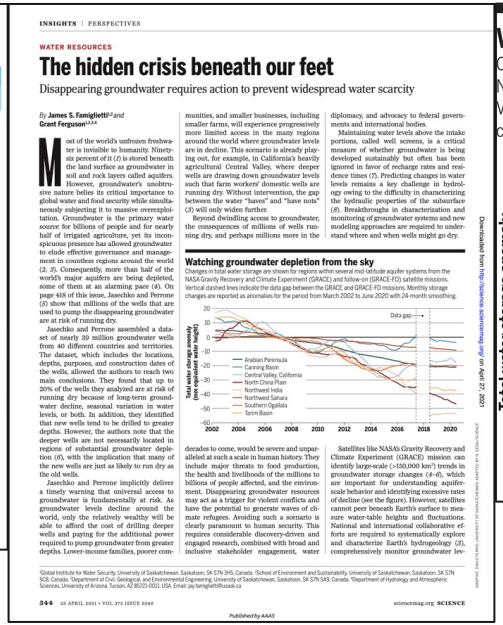
Groundwater depletion the world over poses a far greater threat to global water security than is currently acknowledged.

Groundwater — the water stored beneath Earth's surface in soil and porous rock aquifers — accounts for as much as 33% of total water withdrawals worldwide[1]. Over two billion people rely on groundwater as their primary water source[2], while half or more of the irrigation water used to grow the world's food is supplied from underground sources[3].

Groundwater also acts as the key strategic reserve in times of drought[4], in particular during prolonged events such as those in progress across the western United States (Fig. 1), northeastern Brazil and Australia. Like money in the bank, groundwater sustains societies through the lean times of little incoming rain and snow. Hence, without a sustainable groundwater reserve, global water security is at far greater risk than is currently recognized.

Oregon
Nevada
California
2011
2012
2013
−160 −80 0 80 160
mm equivalent water height

Famiglietti, Nature Climate Change, October 29, 2014



INSIGHTS | PERSPECTIVES

WATER RESOURCES

The hidden crisis beneath our feet

Disappearing groundwater requires action to prevent widespread water scarcity

By James S. Famiglietti[1,2] and Grant Ferguson[3,4,5]

Most of the world's unfrozen freshwater is invisible to humanity. Ninety-six percent of it (1) is stored beneath the land surface as groundwater in soil and rock layers called aquifers. However, groundwater's unobtrusive nature belies its critical importance to global water and food security while simultaneously subjecting it to massive overexploitation. Groundwater is the primary water source for billions of people and for nearly half of irrigated agriculture, yet its inconspicuous presence has allowed groundwater to elude effective governance and management in countless regions around the world (2, 3). Consequently, more than half of the world's major aquifers are being depleted, some of them at an alarming pace (4). On page 418 of this issue, Jasechko and Perrone (5) show that millions of the wells that are used to pump the disappearing groundwater are at risk of running dry.

Jasechko and Perrone assembled a dataset of nearly 39 million groundwater wells from 40 different countries and territories. The dataset, which includes the locations, depths, purposes, and construction dates of the wells, allowed the authors to reach two main conclusions. They found that up to 20% of the wells they analyzed are at risk of running dry because of long-term groundwater decline, seasonal variation in water levels, or both. In addition, they identified that new wells tend to be drilled to greater depths. However, the authors note that the deeper wells are not necessarily located in regions of substantial groundwater depletion (6), with the implication that many of the new wells are just as likely to run dry as the old wells.

Jasechko and Perrone implicitly deliver a timely warning that universal access to groundwater is fundamentally at risk. As groundwater levels decline around the world, only the relatively wealthy will be able to afford the cost of drilling deeper wells and paying for the additional power required to pump groundwater from greater depths. Lower-income families, poorer communities, and smaller businesses, including smaller farms, will experience progressively more limited access in the many regions around the world where groundwater levels are in decline. This scenario is already playing out, for example, in California's heavily agricultural Central Valley, where deeper wells are drawing down groundwater levels such that farm workers' domestic wells are running dry. Without intervention, the gap between the water "haves" and "have nots" (3) will only widen further.

Beyond dwindling access to groundwater, the consequences of millions of wells running dry, and perhaps millions more in the decades to come, would be severe and unparalleled at such a scale in human history. They include major threats to food production, the health and livelihoods of the millions to billions of people affected, and the environment. Disappearing groundwater resources may act as a trigger for violent conflicts and have the potential to generate waves of climate refugees. Avoiding such a scenario is clearly paramount to human security. This requires considerable discovery-driven and engaged research, combined with broad and inclusive stakeholder engagement, water diplomacy, and advocacy to federal governments and international bodies.

Maintaining water levels above the intake portions, called well screens, is a critical measure of whether groundwater is being developed sustainably but often has been ignored in favor of recharge rates and residence times (7). Predicting changes in water levels remains a key challenge in hydrology owing to the difficulty in characterizing the hydraulic properties of the subsurface (8). Breakthroughs in characterization and monitoring of groundwater systems and new modeling approaches are required to understand where and when wells might go dry.

Satellites like NASA's Gravity Recovery and Climate Experiment (GRACE) mission can identify large-scale (>150,000 km²) trends in groundwater storage changes (4–6), which are important for understanding aquifer-scale behavior and identifying excessive rates of decline (see the figure). However, satellites cannot peer beneath Earth's surface to measure water-table heights and fluctuations. National and international collaborative efforts are required to systematically explore and characterize Earth's hydrogeology (3), comprehensively monitor groundwater lev-

Watching groundwater depletion from the sky

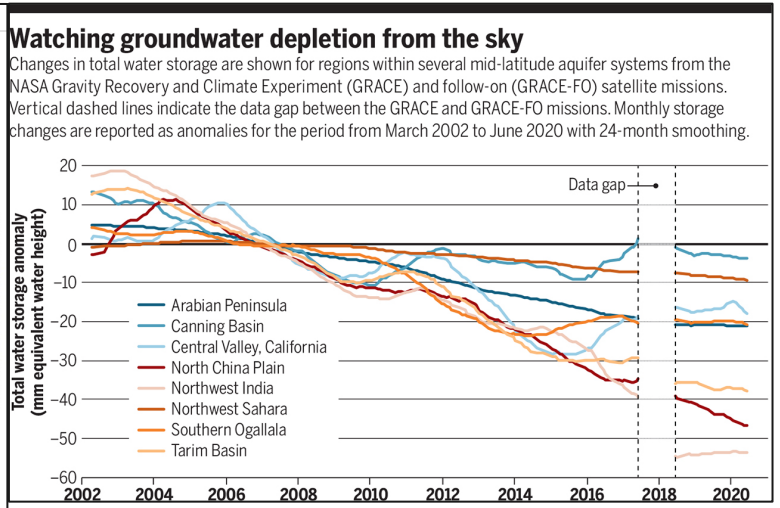
Changes in total water storage are shown for regions within several mid-latitude aquifer systems from the NASA Gravity Recovery and Climate Experiment (GRACE) and follow-on (GRACE-FO) satellite missions. Vertical dashed lines indicate the data gap between the GRACE and GRACE-FO missions. Monthly storage changes are reported as anomalies for the period from March 2002 to June 2020 with 24-month smoothing.

Data gap
Arabian Peninsula
Canning Basin
Central Valley, California
North China Plain
Northwest India
Northwest Sahara
Southern Ogallala
Tarim Basin
Total water storage anomaly (mm equivalent water height)
20 10 0 −10 −20 −30 −40 −50 −60
2002 2004 2006 2008 2010 2012 2014 2016 2018 2020

[1]Global Institute for Water Security, University of Saskatchewan, Saskatoon, SK S7N 3H5, Canada. [2]School of Environment and Sustainability, University of Saskatchewan, Saskatoon, SK S7N 5C8, Canada. [3]Department of Civil, Geological, and Environmental Engineering, University of Saskatchewan, Saskatoon, SK S7N 5A9, Canada. [4]Department of Hydrology and Atmospheric Sciences, University of Arizona, Tucson, AZ 85721-0011, USA. Email: jay.famiglietti@usask.ca

Published by AAAS

Famiglietti and Ferguson, Science, April 23, 2021



Watching groundwater depletion from the sky

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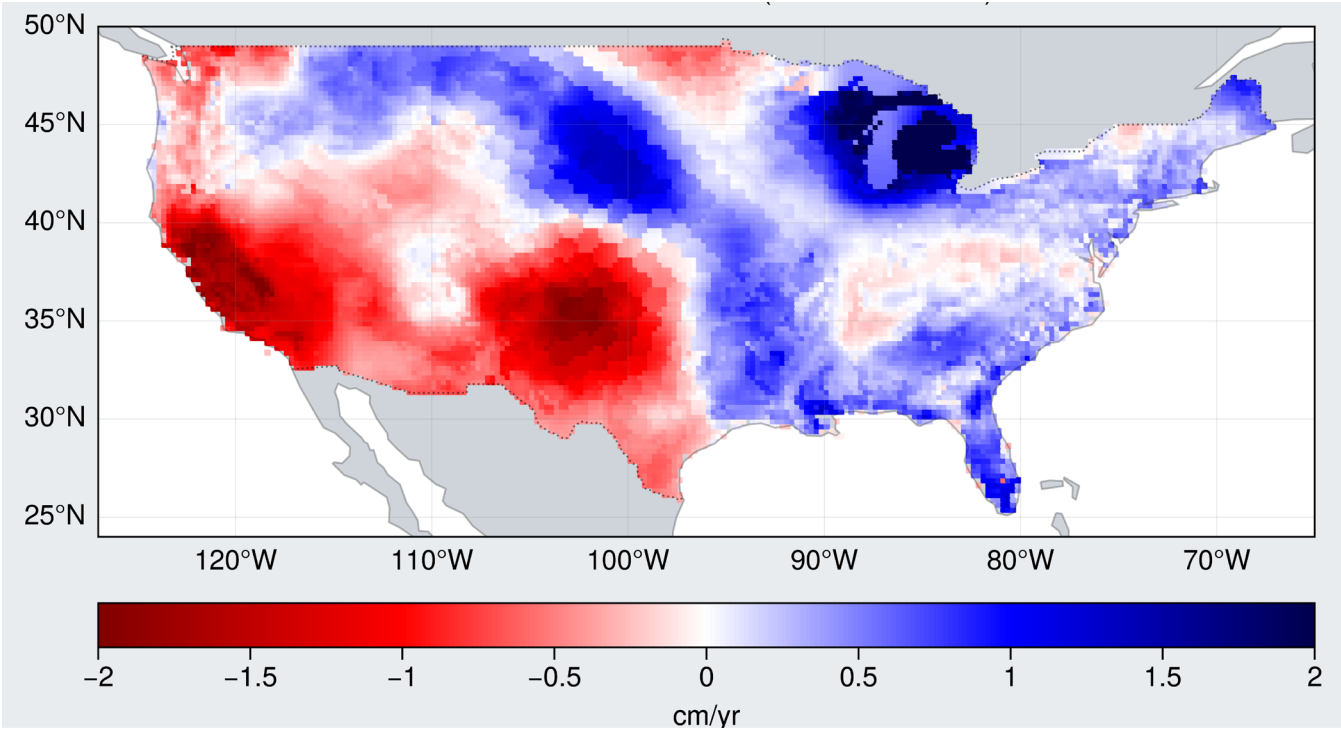
Famiglietti and Ferguson, Science, April 23, 2021

The US picture from NASA GRACE/FO (2002-2023)

Trends in total water storage

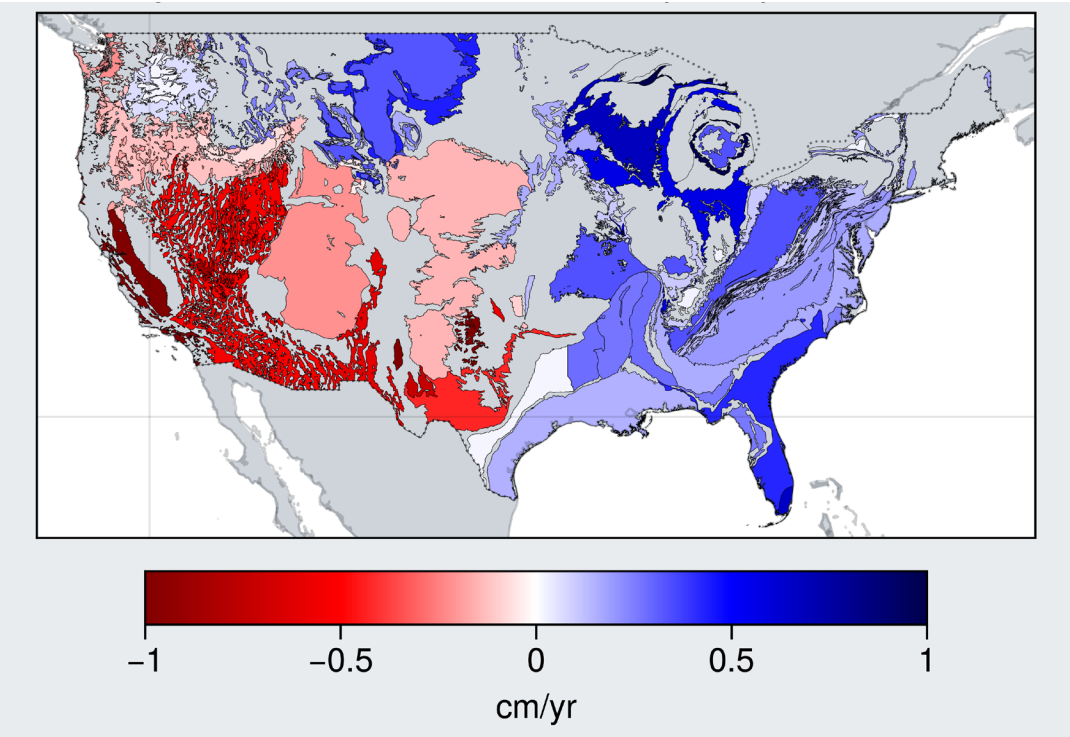


Chandanpurkar, Famiglietti, et al, 2023, in preparation; courtesty of H. Chandanpurkar and K. Abdelmohsen

The US picture from NASA GRACE/FO (2002-2023)

The groundwater crisis at home

Groundwater storage trends in the principal aquifers of the US



Chandanpurkar, Famiglietti, et al, 2023, in preparation; courtesty of H. Chandanpurkar

Critically, GRACE/FO only measures the change in storage, not the absolute amount.

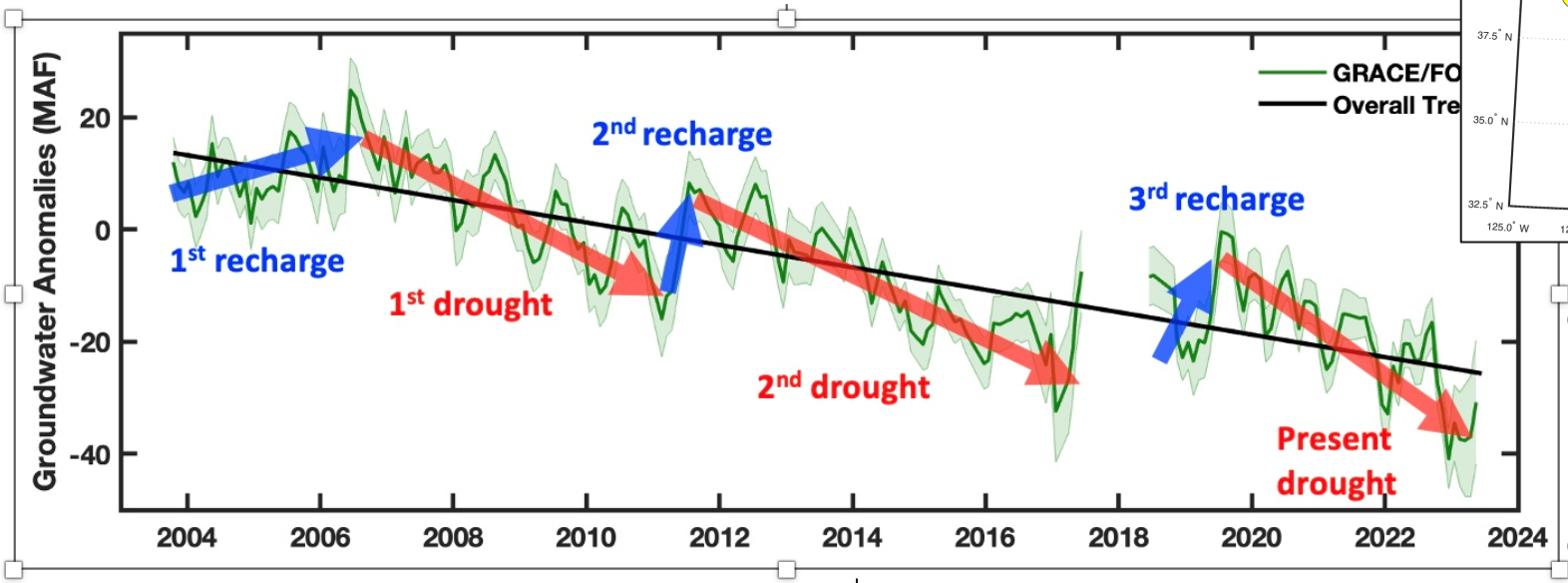
In most aquifers in the US and around the world, we actually do not know how much groundwater we have.

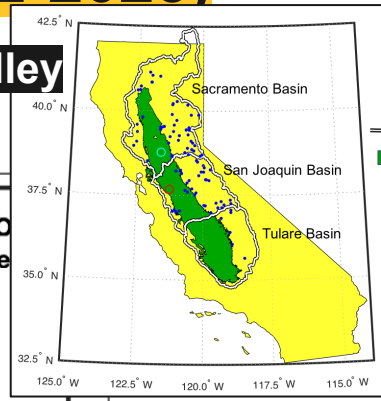
The US (and the rest of the world) needs a major exploration effort to characterize the shallow crustal ‘water environment’, including how much groundwater is there, how much is accessible, and how its quality varies with depth.

If water were oil, this would already have been done.

Regional studies of groundwater depletion (2002-2023)

Groundwater depletion has been accelerating in California's Central Valley





SGMA implementation targets sustainability by 2042

Updated from Liu, Famiglietti, et al., Dec. 2022, by Pang-Wei Liu, NASA/GSFC

Julie Ann Wrigley Global Futures Laboratory
Arizona State University

Arizona Water Innovation Initiative

Accelerates the work ASU is doing in water: engineering, hydrology, law, policy and management

Technological developments, partnerships and applied research

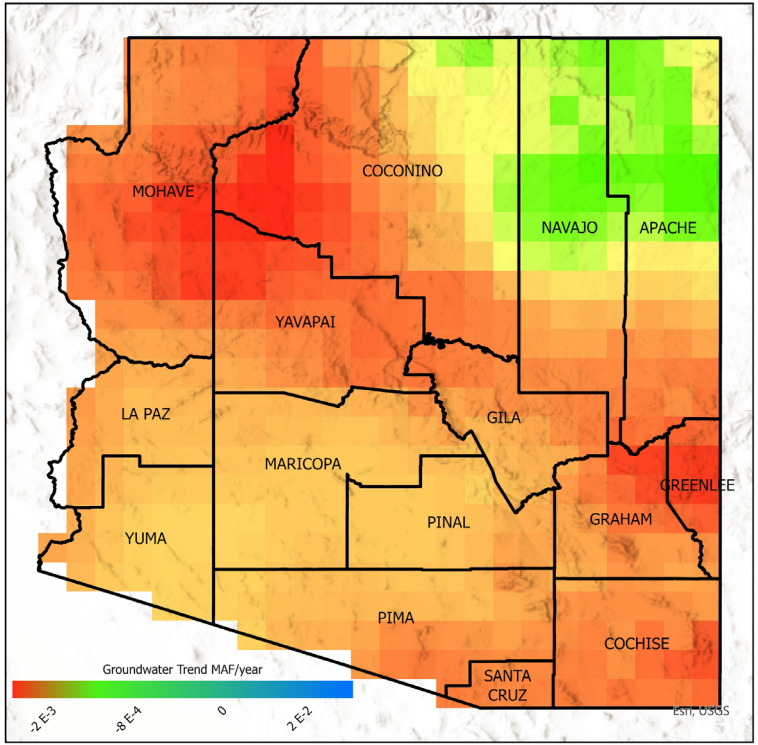
Deep engagement, co-developed research, raising public awareness, catalyzing change

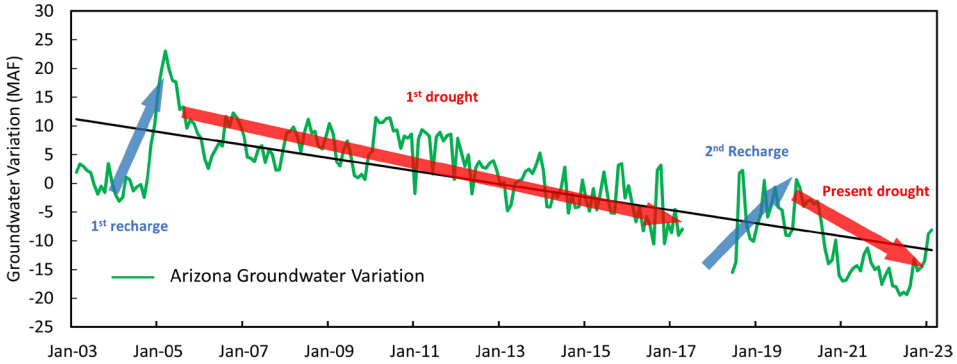
What are the pathways to economic growth and water sustainability in Arizona?

How can this type of effort help the rest of the US, and the world?

Regional studies of groundwater depletion (2002-2023)

Estimating groundwater storage changes in Arizona





Courtesy K.Abdelmohsen and H. Chandanpurkar

Regional studies of groundwater depletion (2002-2023)

The future of groundwater in Arizona

- Groundwater is likely Arizona's most precious, and undervalued, natural resource
- It is only managed in less than 25% of the state by area
- Most of the Active Management Areas are not on track to meet their 2025 sustainability goals… after 45 years
- Groundwater management is needed across the entire state in order to sustain this transgenerational resource for generations to come
- We need to seize the 'moment' in Arizona with a very 'water-forward' governor, willing partners in the state agencies, industry, and universities, and the urgency driven by future Colorado River allocation cuts

Closing Thoughts (and pleas for help)

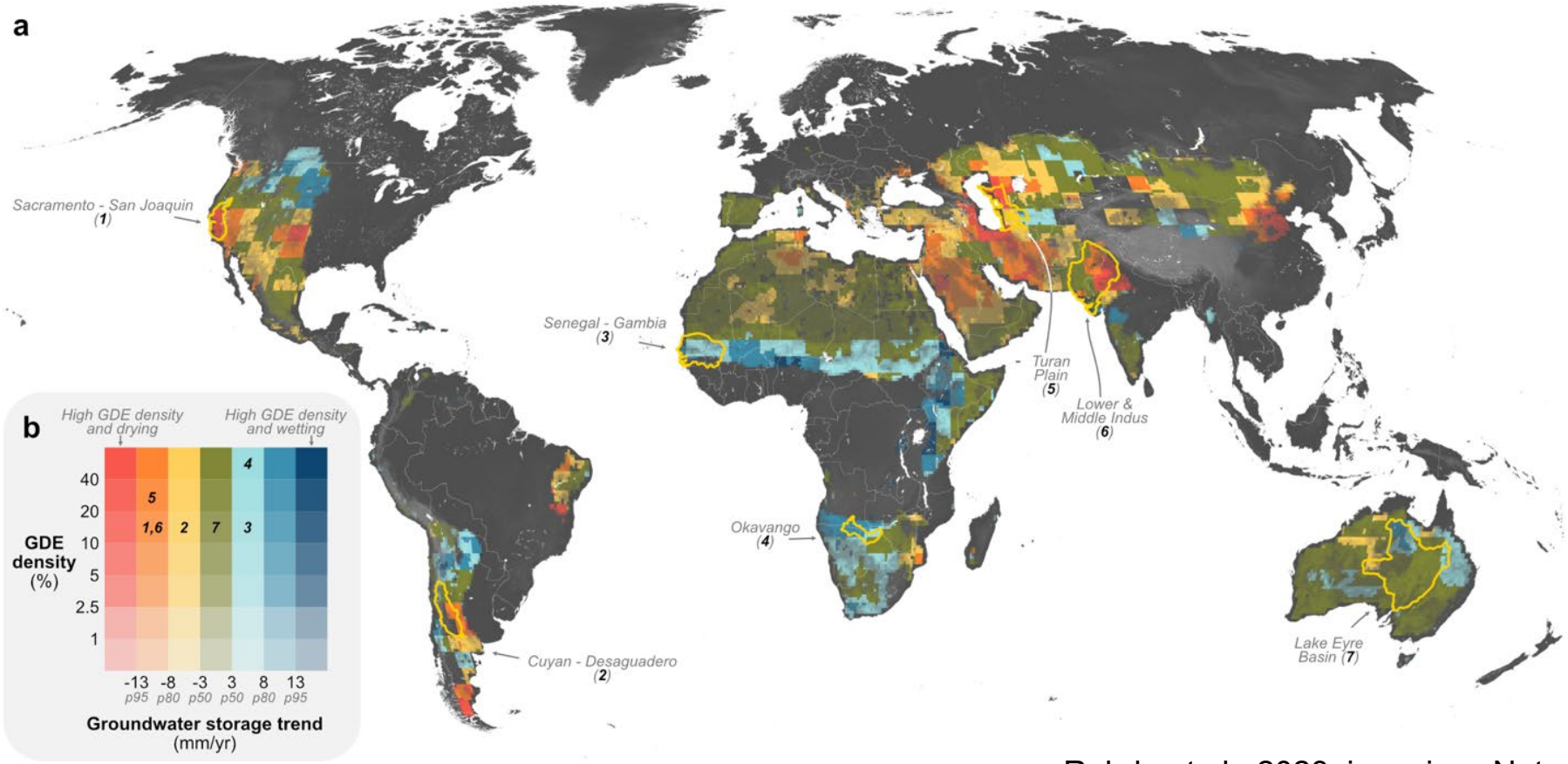
Transdiscplinary engagement with the private sector, government, civil society, and researchers/academia will be critical to chart pathways to groundwater sustainability

Awareness, education, and science communication are of paramount importance at all levels…but we need this and more

”Water is the new carbon”

We desperately need to understand how disappearing groundwater will impact food production and food systems in the US. NASEM’s Board on Agriculture and Natural Resources (BANR) is proposing a 2-year study on ‘groundwater security for food security’. We need your help to find sponsors to make this a reality. Please contact BANR Director Robin Schoen, RSchoen@nas.edu

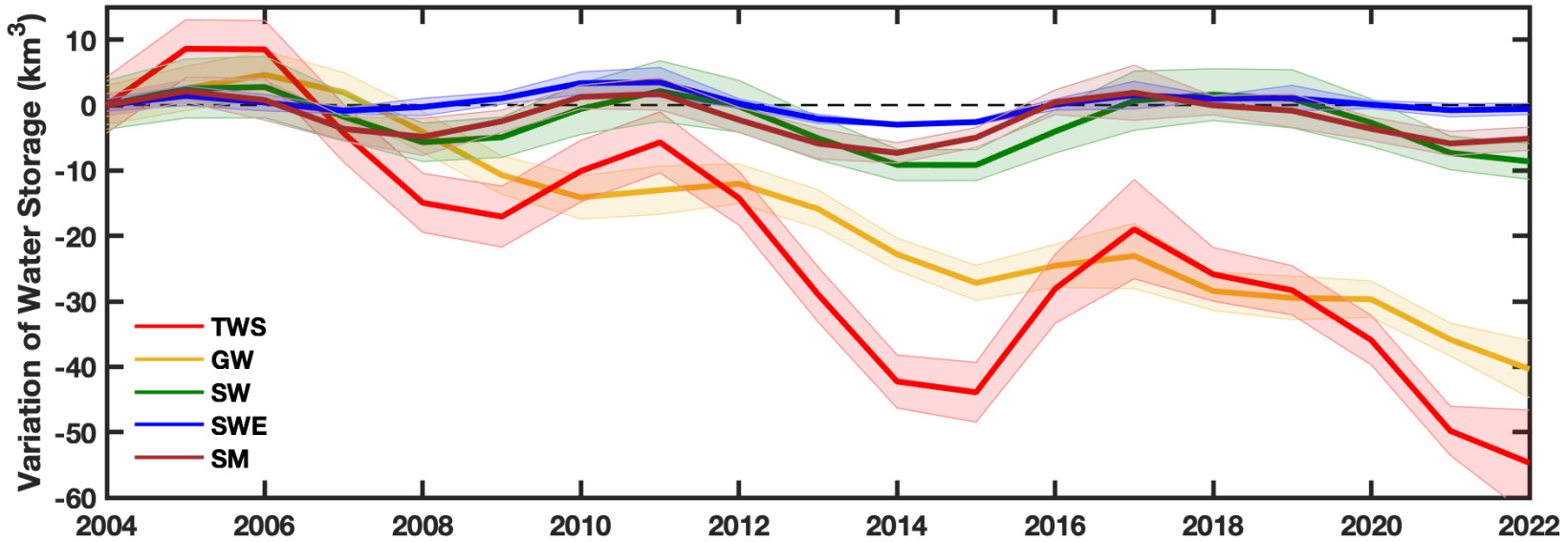
Groundwater Depletion is a Threat to GDE's



Rohde et al., 2023, in review, Nature

Elevating the water dialogue

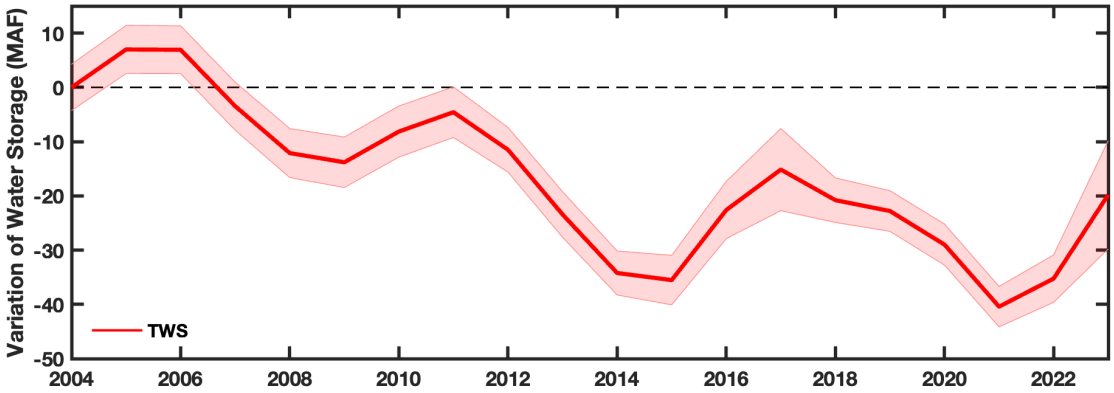
Science communication is essential

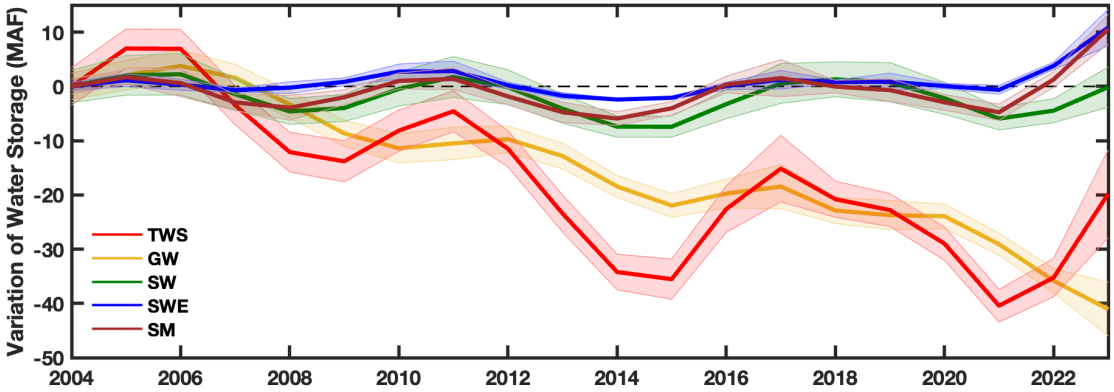


2004 2010 2016 2022

Note: The groundwater trend is based on data from the GRACE and GRACE Follow-On satellite missions. A gap in readings from August 2017 through September 2018 occurred between missions and is indicated by a dashed line. Source: Pang-Wei Liu and Jay Famiglietti By Nadja Popovich/The New York Times

New York Times, Feb 28, 2023



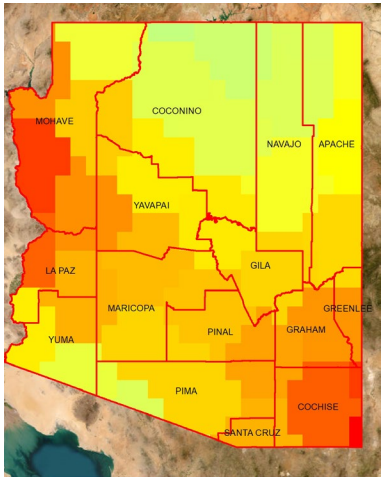


- Remind that the 2023 groundwater calculation is only to June, while other terrestrial water components on the surface are still at high level.
- We expect to see higher groundwater level after we include all year of data.

Research plans for Arizona

Revisting, updating, improving our 2014 study ten years later

GRACE data



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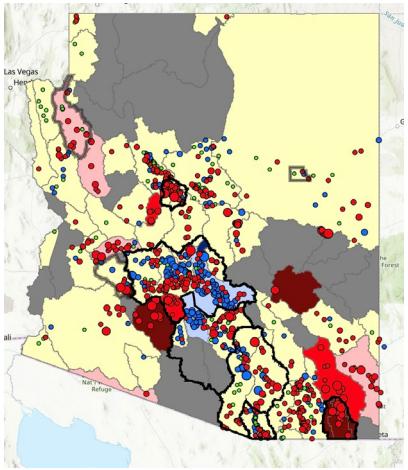
Ground-based observations



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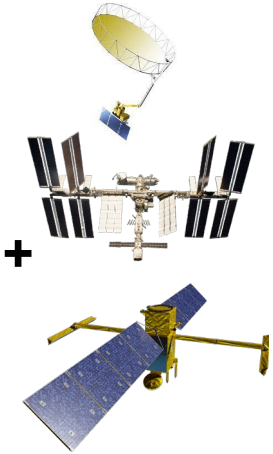
Other satellites,
Advanced computer models



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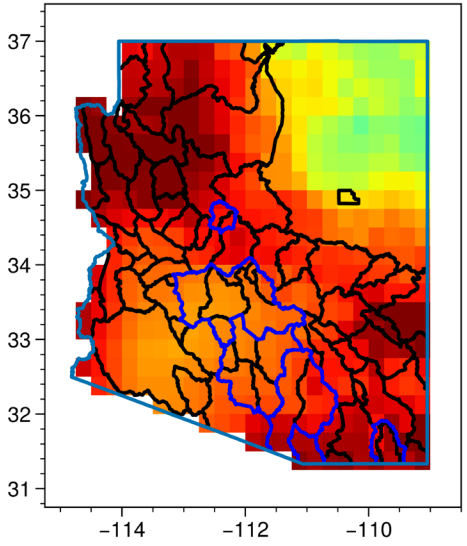
Best available maps of surface and groundwater changes



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Revisting,

AGU PUBLICATIONS

Geophysical Research Letters

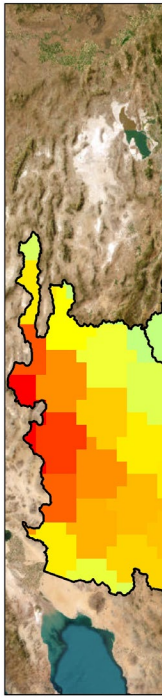
RESEARCH LETTER

10.1002/2014GL061055

Groundwater depletion during drought threatens future water security of the Colorado River Basin

Stephanie L. Castle[1,2], Brian F. Thomas[1,2,3], John T. Reager[1,2,3], Matthew Rodell[4], Sean C. Swenson[5], and James S. Famiglietti[1,2,3]

[1]UC Center for Hydrologic Modeling, University of California, Irvine, California, USA, [2]Department of Earth System Science, University of California, Irvine, California, USA, [3]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [4]Hydrological Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [5]Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado, USA



Key Points:
- Groundwater depletion in the Colorado River Basin is greater than we thought
- As GW disappears, the basin will struggle to supply water to the seven basin states
- It is time to bring groundwater under the water management umbrella

Supporting Information:
- Readme
- Figure S1
- Figure S2
- Figure S3
- Figure S4

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J. S. Famiglietti,
jfamigli@uci.edu

Citation:
Castle, S. L., B. F. Thomas, J. T. Reager, M. Rodell, S. C. Swenson, and J. S. Famiglietti (2014), Groundwater depletion during drought threatens future water security of the Colorado River Basin, *Geophys. Res. Lett.*, *41*, 5904–5911, doi:10.1002/2014GL061055.

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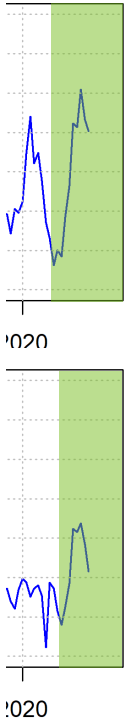
Published online 29 AUG 2014

Abstract Streamflow of the Colorado River Basin is the most overallocated in the world. Recent assessment indicates that demand for this renewable resource will soon outstrip supply, suggesting that limited groundwater reserves will play an increasingly important role in meeting future water needs. Here we analyze 9 years (December 2004 to November 2013) of observations from the NASA Gravity Recovery and Climate Experiment mission and find that during this period of sustained drought, groundwater accounted for 50.1 km^3 of the total 64.8 km^3 of freshwater loss. The rapid rate of depletion of groundwater storage (-5.6 ± 0.4 km^3 yr^{-1}) far exceeded the rate of depletion of Lake Powell and Lake Mead. Results indicate that groundwater may comprise a far greater fraction of Basin water use than previously recognized, in particular during drought, and that its disappearance may threaten the long-term ability to meet future allocations to the seven Basin states.

1. Introduction

Over a decade, drought in the Colorado River Basin (Basin; Figure 1) has exposed the vulnerability [*Bureau of Reclamation*, 1975; *Barnett and Pierce*, 2008] of the most overallocated river system in the world [*Christensen et al.*, 2004]. Recently, the U.S. Bureau of Reclamation acknowledged the potential challenges [*Bureau of Reclamation*, 2012] to meeting future surface water allocations to the seven Basin states (Figure 1), noting that the contribution of local supplies, including groundwater withdrawals, will be required to offset anticipated shortages. While the need to exploit groundwater resources to meet Basin water demands has long been recognized [*Bureau of Reclamation*, 1975], withdrawals required to meet current demands remain undocumented and are uncertain in the future. In particular, water management under drought conditions



2020

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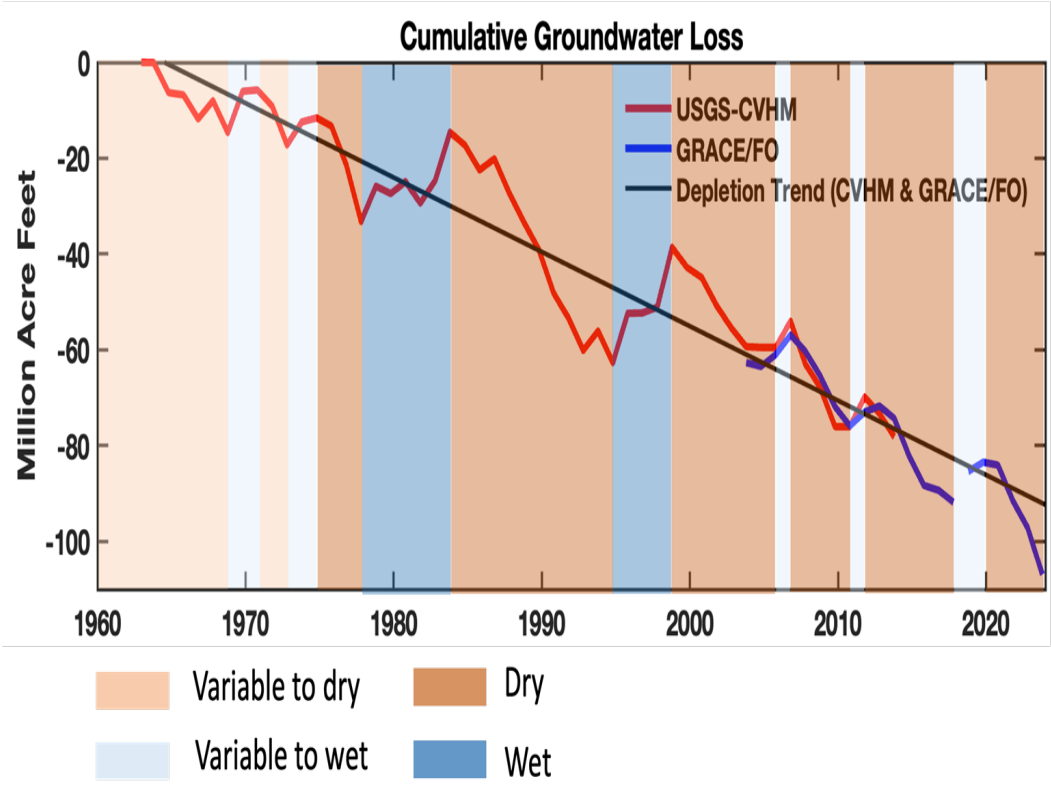
Courtesy K.Abdelmohsen

Regional studies of groundwater depletion

Groundwater depletion has been accelerating in California's Central Valley



Updated from Liu, Famiglietti, et al., Dec. 2022, by Pang-Wei Liu, NASA/GSFC