San Luis Rey
MUNICIPAL WATER DISTRICT
5328 Highway 76 • Fallbrook, California 92028

AGENDA

Regular Meeting of the
San Luis Rey Municipal Water District
Wednesday, September 16, 2020 - 4:00 p.m.

at the

Pankey Ranch Office
5328 Highway 76
Fallbrook, California 92028

Writings distributed less than 72 hours prior to this meeting are available for public inspection at the District's General Counsel's office, 2361 Rosecrans Ave., Suite 475, El Segundo, CA 90245, or call 424-269-3351 if you would like a copy sent to you.

*** COVID-19 NOTICE ***

Consistent with Executive Orders No. 25-20 and No. N-29-20 from the Executive Department of the State of California, this Board Meeting will not be physically open to the public as the Board Members will be teleconferencing into the meeting.

Two ways to participate in the Meeting:

- **Call**: 408-638-0968 (Meeting ID: 884 7389 0466) (Password: 7307083)
- **Video**:https://us02web.zoom.us/j/88473890466?pwd=N3RmZHBoRTJqZnFaUEJTV1dFQWZGZz09

How to submit Public Comment: Members of the public may provide public comment by sending comments to the District's General Counsel's Office by email at aespinosa@awattorneys.com. Please submit your written comments as early as possible, preferably prior to the start of the meeting or if you are unable to email, please call Alondra Espinosa 424-269-3351 by 3:30 p.m. on the date of the meeting. Email comments must identify the Agenda Item Number in the subject line of the email. The public comment will be entered into record and provided to the Board Members. All comments should be a maximum of 500 words, which corresponds to approximately 3 minutes of speaking time.

- **CALL MEETING TO ORDER**
- **ROLL CALL**
- **APPROVAL OF THE AGENDA**

1. **ADDITIONS OR CHANGES ON THE AGENDA**

2. **ITEMS RECEIVED TOO LATE TO BE ON AGENDA**

   Recommendation: Determine the need to take action on item(s) that arose subsequent to the agenda being posted (Adoption of this recommendation requires a two-thirds vote of the Board members present at the meeting or, if less than two-thirds of the Board members are present, a unanimous vote).

- **PUBLIC COMMENT**
  Any person may address the Board at this time upon any subject not identified on this Agenda, but within the subject matter covered by the San Luis Rey Municipal Water District; however, any matter that requires action will be referred to staff for a report and action at a subsequent Board meeting. As to matters on the Agenda, an opportunity will be given to address the Board when the matter is considered.

3. **CONSENT CALENDAR ITEMS**
   These are items to be acted upon without discussion, unless a request is made by a member of the Board, the Staff, or the Public to discuss a particular item. All consent calendar items are approved by a single motion.

   A. **APPROVAL OF MINUTES**
   Regular Meeting of June 17, 2020
   Adjourned Meeting of July 15, 2020
   Adjourned Meeting of August 19, 2020

B. APPROVAL OF THE DEMAND LIST

4. ACTION CALENDAR ITEMS

All action items are placed on the Agenda so that the Board may discuss and take action, if the Board is so inclined.

A. BIENNIAL REVIEW OF DISTRICTS CONFLICT OF INTEREST CODE

Recommendation: Staff recommends that no changes be made to the District's 2016 Conflict of Interest Code at this time and authorize President Victor Pankey to sign the 2020 Local Agency Biennial Notice.

5. REPORTS

The following agenda items are reports. They are placed on the agenda to provide information to the Directors and the public. There is no action called for in these items.

A. SAN LUIS REY WATERSHED COUNCIL – Oral Report by President Victor Pankey

B. AB-3030 PLAN - Oral Report by Vice President William Pankey

C. GROUNDWATER SUSTAINABILITY ACT UPDATE -Oral Report by President Victor Pankey

6. DIRECTORS' COMMENTS

Comments by Directors concerning District business that may be of interest to the Board. Directors' comments are placed on the Agenda to enable individual Board members to convey information to the Board and the Public. There is no discussion or action taken on comments made by Board members.

7. INFORMATION ITEMS

These items are included for the Board's information only. If action is required on any informational item, it will be placed on a subsequent agenda.

A. DELTA

09/09/2020, forbes.com, *Climate Change May Bring Unexpected Benefits to San Francisco Bay-Delta*

09/06/2020, californiaglobe.com, *California's Three Delta Entities: What's the Difference?*

09/03/2020, courthouosenews.com, *Judge to Decide if San Francisco Bay Salt Ponds are Protected US Waters*

B. WATER SUPPLY

09/04/2020, calmatters.org, *New Approach Needed to Protect Health of California's Rivers*

09/03/2020, weforum.org, *As Much as Half of the World's Water Supply is Being Stolen, Report Finds*

09/02/2020, regionalchnage.ucdavis.edu, *Sustainable for Whom? The Impact of Groundwater Sustainability Plans on Domestic Wells Executive Summary*

09/2020, pacinst.org, *Ending Conflicts Over Water: Solutions to Water and Security Challenges*

C. WATER MATTERS OF INTEREST

09/10/2020, waterfm.com, *City of Anaheim, Brown and Caldwell to Partner on PFAS Removal Project*

09/10/2020, californiawaternewsdaily.com, *Helix Replaces Dock at Lake Jennings*

09/07/2020, sandiegouniontribune.com, *Bill Will Strengthen and Expand Carlsbad Fish Hatchery Program*

09/05/2020, wateronline.com, *Adapting to the New Normal in a Post COVID Water Sector*

09/03/2020, sdcwa.org, *Support Rate Relief at MWD*

09/03/2020, villagenews.com, *FPUD Approves Additional LAFCO Deposit*

09/02/2020, jdsupra.com, *Supreme Court of California Weigh in on Blanket Categorization of Well Construction Permit Approvals as Ministerial*

8. ADJOURNMENT

Adjourn to October 21, 2020, at 4:00 p.m.

Upon request, this agenda will be made available in appropriate alternative formats to persons with disabilities, as required by Section 202 of the Americans with Disabilities Act of 1990. Any person with a disability who requires a modification or accommodation in order to participate in a meeting should direct such request to the District Assistant Secretary at (949) 223-1170 at least 48 hours before the meeting, if possible.

SAN LUIS REY MUNICIPAL WATER DISTRICT
BOARD OF DIRECTORS MEETING
MINUTES OF THE REGULAR MEETING
JUNE 17, 2020

(Any agenda reports and demand list produced at the regular meeting of June 17, 2020 regular meeting, were received, filed, and made part of these minutes on file at the General Counsel's Office.)

CALL MEETING TO ORDER

President Victor Pankey called to order the Regular Meeting of the Board of Directors of the San Luis Rey Municipal Water District ("District") at 4:00 p.m.

ROLL CALL

Present: President Victor Pankey, Vice-President William Pankey, Secretary Thomas F. Veysey, Director Christian Zaleschuk

Absent: Director Helga Fritz

APPROVAL OF THE AGENDA

1. ADDITIONS OR CHANGES ON THE AGENDA

There were none.

2. ITEMS RECEIVED TOO LATE TO BE ON AGENDA

There were none.

PUBLIC COMMENT

There were no public comments.

3. CONSENT CALENDAR ITEMS

A motion was made by Vice President William Pankey, seconded by Secretary Thomas F. Veysey, and unanimously carried by the directors present to approve the consent calendar consisting of the minutes of the Regular Meeting of March 18, 2020, April 15, 2020, and May 20, 2020 and the Demand List.

4. ACTION CALENDAR ITEMS

A. FIXED ASSET QUESTIONNAIRE 2020

The Directors held a general discussion regarding the Fixed Asset Questionnaire 2020. There we Directors asked regarding the District's contact information.

Alondra Espinosa, Corporate Secretary, arrived at the meeting.

A motion was made by Director Christian Zaleschuk, seconded by Secretary Thomas F. Veysey, and unanimously carried by the directors present to approve the signing of the Fixed Asset Questionnaire and authorize staff to forward it to the County of San Diego.

B. ANNUAL LETTER TO THE PROPERTY OWNERS

The Directors held a general discussion regarding the revisions to the annual letter to the District's property owners. The Directors approved and/or requested the following revisions: (1) remove or update Pauma Valley Community Services District information on page 5.

A motion was made by Vice President William Pankey, seconded by Secretary Thomas F. Veysey, and unanimously carried by the directors present to approve the letter subject to the changes discussed.

C. BUDGET FOR FISCAL YEAR 2020-2021

The Directors held a general discussion regarding budget for fiscal year 2020-2021. A motion was made by Vice President William Pankey, second by President Pankey, and unanimously carried by the directors present to aprrove

A motion was made by Secretary Thomas F. Veysey, seconded by Director Christian Zaleschuk, and unanimously carried by the directors present to approve Resolution 2020-1, approving and adopting the budget for fiscal year 2020-2021.

5. <u>REPORTS</u>

A. SAN LUIS REY WATERSHED COUNCIL
President Victor Pankey reports that there is nothing to report.

B. AB-3030 PLAN
President Victor Pankey reports that there is nothing to report.

C. GROUNDWATER SUSTAINABILITY ACT UPDATE
President Victor Pankey reports that there is nothing new to report.

6. <u>DIRECTORS' COMMENTS</u>

Vice President William Pankey asked President Victor Pankey regarding the signatures on documents and checks. President Victor Pankey provided a report regarding the District's insurance.

7. INFORMATION ITEMS

President Victor Pankey reported that the articles provided were good.

8. ADJOURNMENT

Adjourn to July 15, 2020, at 4:00 p.m.

SAN LUIS REY MUNICIPAL WATER DISTRICT

DRAFT

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Victor Pankey, President

Approved by the minutes of
The Board of Directors
Meeting of ______________

SAN LUIS REY MUNICIPAL WATER DISTRICT
BOARD OF DIRECTORS
MINUTES OF THE ADJOURNED REGULAR MEETING
ON JULY 15, 2020

The regular meeting of the San Luis Rey Municipal Water District's Board of Directors, scheduled July 15, 2020, at 4:00 p.m., was canceled. The next regular meeting of the Board will be August 19, 2020, at 4:00 p.m., at the Pankey Ranch Office, 5328 Highway 75, Fallbrook, California 92028.

SAN LUIS REY MUNICIPAL WATER DISTRICT

DRAFT

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Victor S. Pankey, President

Approved by the minutes of
The Board of Directors
Meeting of _______________

SAN LUIS REY MUNICIPAL WATER DISTRICT
BOARD OF DIRECTORS
MINUTES OF THE ADJOURNED REGULAR MEETING
ON AUGUST 19, 2020

The regular meeting of the San Luis Rey Municipal Water District's Board of Directors, scheduled August 19, 2020, at 4:00 p.m., was canceled. The next regular meeting of the Board will be September 16, 2020, at 4:00 p.m., at the Pankey Ranch Office, 5328 Highway 75, Fallbrook, California 92028.

SAN LUIS REY MUNICIPAL WATER DISTRICT

DRAFT
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Victor S. Pankey, President

Approved by the minutes of
The Board of Directors
Meeting of ______________

SAN LUIS REY MUNICIPAL WATER DISTRICT
DEMAND LIST FOR PAYMENT
As of September 11, 2020

Vendor	Invoice	Work Performed	Period	Amount	Fund	Account
Aleshire & Wynder, LLC	06/22/20 57843	General District Services	June 2020	3,701.25	0	550010
Aleshire & Wynder, LLC	07/14/20 58098	General District Services	July 2020	425.00	0	550010
County of San Diego	07/01/20 LC20-44	LAFCO FY 2020-21	2020	28.74	0	502000
Total:				4,154.99		

Fund 0 – District General Fund
Fund 1 – Gregory Canyon First Supplement
Fund 2 – Gregory Canyon Mitigation
Fund 3 – Latent Powers
Fund 4 – Deannexation

2020 Local Agency Biennial Notice

Name of Agency: San Luis Rey Municipal Water District

Mailing Address: 5328 Highway 76, Fallbrook, CA 92028

Contact Person: William Pankey, Vice -Presider Phone No. 949-250-5436

Email: sanluisreymwd@yahoo.con Alternate Email: bill@pankeyllc.com

Accurate disclosure is essential to monitor whether officials have conflicts of interest and to help ensure public trust in government. The biennial review examines current programs to ensure that the agency's code includes disclosure by those agency officials who make or participate in making governmental decisions.

This agency has reviewed its conflict of interest code and has determined that *(check one BOX):*

☐ **An amendment is required. The following amendments are necessary:**

(Check all that apply.)

- ☐ Include new positions
- ☐ Revise disclosure categories
- ☐ Revise the titles of existing positions
- ☐ Delete titles of positions that have been abolished and/or positions that no longer make or participate in making governmental decisions
- ☐ Other *(describe)* ______________________

☐ **The code is currently under review by the code reviewing body.**

☑ **No amendment is required.** (If your code is over five years old, amendments may be necessary.)

Verification **(to be completed if no amendment is required)**

This agency's code accurately designates all positions that make or participate in the making of governmental decisions. The disclosure assigned to those positions accurately requires that all investments, business positions, interests in real property, and sources of income that may foreseeably be affected materially by the decisions made by those holding designated positions are reported. The code includes all other provisions required by Government Code Section 87302.

DRAFT

______________________ ______________

Signature of Chief Executive Officer *Date*

All agencies must complete and return this notice regardless of how recently your code was approved or amended. Please return this notice no later than **October 1, 2020**, or by the date specified by your agency, if earlier, to:

(PLACE RETURN ADDRESS OF CODE REVIEWING BODY HERE)

PLEASE DO NOT RETURN THIS FORM TO THE FPPC.

Climate Change May Bring Unexpected Benefits To San Francisco Bay-Delta

Linh Anh Cat

The San Francisco Bay-Delta is literally threatened from all sides: rising sea levels from the ocean, disruptions to sediment supply from upstream, and within the Bay-Delta itself, development and other land use changes have left only a tiny fraction (5%) of marshland untouched.

Under climate change, coastal wetlands across the world, like the Bay-Delta, are disappearing. The rivers that feed coastal wetlands sediment which provide habitat for wildlife and form the structure of the ecosystem are transporting about a third less sediment, on average. Less sediment supply contributes to increased erosion of the ecosystem.

These delicate ecosystems provide several benefits to humans, such as protecting our shorelines, maintaining water quality, preventing damaging floods, and providing a peaceful place to recreate. In addition, they provide habitat for birds, fish, and other wildlife and play an important role in nutrient cycling, particularly carbon storage.

A recent study by scientists at the U.S. Geological Survey used historical streamflow and sediment data to calibrate models in order to predict what will happen to the Bay-Delta under varying levels of climate change.

In the future, California will continue to get about the same amount of rain, however, storms will be less frequent but more powerful. Therefore, streamflow will increase and the faster speed of the water will carry more sediment into the bay.

Rivers draining through the Sacramento Valley make their way to the Bay-Delta, and these waterways will likely experience higher peak streamflows. The new models projected that faster waters will carry 39 to 69 percent more sediment down to the Bay-Delta by 2100.

Unfortunately, the increased transport of sediment will bring a increased amount of pollutants. However, there are some silver linings to the projected sediment transport into the Bay-Delta:

Scientists think the higher sediment levels in the Bay-Delta will reduce impacts from sea level rise by raising the level of the Bay-Delta in concert with sea level rise, potentially reducing the amount of erosion exacerbated by rising oceans.

Turbidity, or how difficult it is to see through cloudy water, may increase, providing habitat for fish that can hide more easily from predators.

Ecosystems around the world face different challenges from climate change. While there are silver linings to the climate change impacts in the San Francisco Bay-Delta, this is not the case when we look at global climate change as a whole.

Understanding how local areas will experience climate change is key to effective natural resource management and to guide the best areas to invest our efforts in order to adapt to and mitigate climate change in our communities.

Follow me on Twitter or LinkedIn.

CALIFORNIA GLOBE

California Bay Delta water (Photo: USGS)

California's Three Delta Entities: What's the Difference?

Committed to the protection and health of the Sacramento-San Joaquin Delta in California.

By Chris Micheli, September 6, 2020 7:51 am

California has three Delta-related entities: Delta Protection Commission, Delta Protection Advisory Committee, and Delate Stewardship Council. What's the difference?

Delta Protection Commission

Public Resources Code Division 19.5, Chapter 3, Section 29735, added in 1992, created the Delta Protection Commission, which consists of 15 members as follows:

- One member of the board of supervisors, or his or her designee, of each of the five counties within the Delta whose supervisorial district is within the primary zone shall be appointed by the board of supervisors of each of those respective counties.
- Two elected city council members selected and appointed by city selection committees, from the appropriate regions in each of the following areas:
  - One from the south Delta, consisting of the County of San Joaquin.
  - One from the west Delta, from either the County of Contra Costa or the County of Solano, on a rotating basis.
- One elected city council member selected and appointed by city selection committees, from regional and area councils of government from the north Delta, consisting of the Counties of Yolo and Sacramento.
- One member each from the board of directors of three different reclamation districts that are located within the primary zone who are residents of the Delta, and who are elected by the trustees of reclamation districts. Reclamation district members must come from specified areas of the Delta.
- The Secretary of Food and Agriculture, or the secretary's sole designee.
- The executive officer of the State Lands Commission, or the executive officer's sole designee.
- The Secretary of the Natural Resources Agency, or his or her sole designee.
- The Secretary of Transportation, or his or her sole designee.

Public Resources Code Section 29703.5 sets forth the following legislative findings and declarations:

"(a) The Delta Protection Commission created pursuant to Section 29735 provides an existing forum for Delta residents to engage in decisions regarding actions to recognize and enhance the unique cultural, recreational, and agricultural resources of the Delta. As such, the Commission is the appropriate agency to identify and provide recommendations to the Delta Stewardship Council on methods of preserving the Delta as an evolving place as the Delta Stewardship Council develops and implements the Delta Plan.

"(b) There is a need for the five Delta counties to establish and implement a resources management plan for the Delta and for the Delta Stewardship Council to consider that plan and recommendations of the Commission in the adoption of the Delta Plan."

According to the Delta Protection Commission, it is committed to the protection and health of the Sacramento-San Joaquin Delta in California. "We protect, maintain, enhance and enrich the overall quality of the Delta environment and economy. We do this with a focus on agriculture, heritage, recreation, and natural resources while remaining mindful of the importance of the Delta to all Californians."

Delta Protection Advisory Committee

According to the Delta Protection Advisory Committee (DPAC), it provides recommendations to the Delta Protection Commission on diverse interests within the Delta, including the Delta's ecosystem, water supply, socioeconomic sustainability, recreation, agriculture, flood control, environment, water resources, utility infrastructure, and other Delta issues. This fifteen-member committee is appointed by the Commission and meets regularly. Its members serve three-year terms.

Delta Stewardship Council

Water Code Division 35, Part 3, Chapter 1, which was added in 2009, in Section 85200 establishes the Delta Stewardship Council as an independent agency of the state. The Council consists of seven voting members. Four members are appointed by the Governor and confirmed by the Senate. One member is appointed by the Senate Committee on Rules; one member is appointed by the Speaker of the Assembly; and, one member is the Chairperson of the Commission. The Council is required to meet once a month in a public forum, and at least two meetings each year must take place at a location within the Delta.

According to the Delta Stewardship Council, it was created in legislation to achieve the state-mandated co-equal goals of the Delta. Those two, co-equal goals are to provide a more reliable water supply for California and protect, restore and enhance the unique cultural, recreational, natural resource, and agricultural values of the Delta.

The Council took effect on February 3, 2010 and is required by state law to develop and enforceable, long-term sustainable management plan for the Delta to ensure coordinated action at the federal, state and local levels. Its adopted "The Delta Plan" in 2013 that includes regulatory policies, as well as recommendations.

Author Recent Posts

Chris Micheli

Chris Micheli is a lobbyist with Aprea & Micheli, as well as an Adjunct Professor of Law at the University of the Pacific McGeorge School of Law.

Judge to Decide If San Francisco Bay Salt Ponds Are Protected US Waters

NICHOLAS IOVINO September 3, 2020

Environmental groups and California sued the EPA over its finding that the Redwood City Salt Ponds south of San Francisco are not considered "waters of the United States" protected by the Clean Water Act. (Photo by Kenneth Lu, 2013 available via Flickr)

SAN FRANCISCO (CN) — A Justice Department lawyer urged a federal judge Thursday to uphold the Trump administration's finding that vast salt ponds slated for redevelopment along the San Francisco Bay are not protected "waters of the United States."

"This isn't in any way, shape or form resembling the tidal environment that it used to be in the early 1900s," Justice Department lawyer Andrew Doyle argued in a telephonic hearing Thursday morning.

California and a coalition of environmental groups sued the Environmental Protection Agency one year ago, challenging the agency's March 2019 finding that the 1,365-acre Redwood City Salt Ponds south of San Francisco fall outside the jurisdiction of the Clean Water Act.

The EPA's decision deprives California of the right to review redevelopment plans for the site to ensure they comply with state water quality rules. It also means California cannot require a potential development project there to include wetlands restoration, public recreation access or other conditions related to water quality.

The area was converted into a salt extraction site starting in 1901 and further developed over the next century. Cargill Corporation, the nation's largest private company, acquired the site in in 1979.

In 2009, developers proposed building 12,000 new housing units on the site. Amid opposition from environmentalists pushing for wetlands restoration of the area, developers withdrew that proposal in 2012.

In November 2016, the EPA's Region 9 office in San Francisco issued a draft decision finding 1,270 acres of the salt ponds are "waters of the United States" because tidal channels within the site were part of traditionally navigable waters of San Francisco Bay before the Clean Water Act was passed in 1972.

In March 2019, the Trump administration's EPA reversed course, issuing a final decision that the salt ponds are not "waters of the United States" because they were converted to fast lands — a legal term for land subject to just compensation for government taking — before 1972.

During a hearing on dueling motions for summary judgment Thursday, California Deputy Attorney General Tatiana Gaur argued the EPA failed to justify its abrupt about-face despite previously requiring dredge and fill permits at the site that are exclusively for areas protected under the Clean Water Act.

"Those permits can only be issued for discharges in the salt pond if those salt ponds were waters of the United States," Gaur argued. "That was the position of the agency."

Defending the EPA's position, Doyle told U.S. District Judge William Alsup that March 2019 was the first time the agency took an official position on whether the salt ponds are considered protected U.S. waters.

"No decision was made in reference to those permits," Doyle argued.

Representing Save the Bay and other environmental groups, attorney Eric Buescher of Cotchett Pitre & McCarthy said the EPA committed a clear legal error in finding the salt ponds are "fast lands" because fast lands can only be dry upland areas that are "above the high-water mark."

"The record clearly shows the site was and is at intertidal elevation," Buescher said.

Upon prodding by Judge Alsup, Buescher acknowledged he could only find cases in which courts said sites above a high-water line are considered upland and not subject to Clean Water Act jurisdiction. He could not cite a case in which a court found areas below the high-water mark can never be considered upland.

"If we were to go there today and break open the dike that separates the pond from the bay, which way would the water flow?" Aslup asked.

"It would ebb and flow in each direction," Buescher answered.

Doyle countered that no court has established a "bright-line test" for what is considered "fast land."

"It's a site-specific inquiry," he argued.

Doyle said the EPA made its decision based on findings that the salt ponds don't import water from the bay except in very limited circumstances.

Representing real estate developer Redwood City Plant Site, attorney Tom Boer of Hogan Lovells told Alsup that bay water has not overtaken the site since salt beds were constructed in 1951. However, he acknowledged that "pickle" — mostly evaporated water containing salt — did flow into the site through a transbay pipeline over a period of years and as recently as 2011.

"What you're telling me is after the CWA, water from the bay came into these pools through a pipe," Alsup said.

"It came into one cell at the salt site for the quick dissolve operation," Boer replied.

After about 70 minutes of debate, Alsup took the arguments under submission and said he would issue a ruling "in due course."

Other plaintiffs in the lawsuit include San Francisco Baykeeper, Committee for Green Foothills and Citizens' Committee to Complete the Refuge.

POSTED INMY TURN

New approach needed to protect health of California's rivers

BY GUEST COMMENTARY
SEPTEMBER 4, 2020

The Sacramento River. Photo via iStock

IN SUMMARY

In the face of climate change, biodiversity loss and conflict over water, California urgently needs to rethink how it manages water for the environment.

By Ted Grantham and

Ted Grantham is an adjunct fellow at the [PPIC Water Policy Center] and an adjunct professor in the department of environmental science, policy and management at the University of California, Berkeley, tgrantham@berkeley.edu.

Jeffrey Mount, Special to CalMatters

Jeffrey Mount is a senior fellow at the [PPIC Water Policy Center], mount@ppic.org. They are coauthors of [Making the Most of Water for the Environment: A Functional Flows Approach for California's Rivers], which informed this piece.

Dams, diversions, and land conversion have substantially altered California's rivers and disrupted the processes that sustain ecosystem health. The result is a crisis for native fish and wildlife and the loss of many benefits we derive from river ecosystems.

Of the state's more than 125 native fishes, seven species are already extinct and 100 are in decline, including half of California's salmon and steelhead species. In the face of the changing climate, biodiversity loss and continuing conflict over water, California urgently needs to rethink how it manages water for the environment.

In some of the state's rivers, the law requires the protection of "environmental flows" – water left in rivers to protect salmon and other sensitive species. Commonly, these requirements prescribe minimum flows, usually water released from dams or limits on water diversions for other uses. Unfortunately, this minimum flow approach fails to preserve the natural variation needed to maintain ecosystem functions, such as the movement of sediment, maintenance of water quality, and environmental cues for species migration and reproduction.

In our new report, we recommend moving away from minimum flow standards to the use of "functional flows" – the seasonal components of river flow that sustain the biological, chemical and physical processes upon which native freshwater species depend. This approach doesn't mandate restoring natural flows or historical ecosystem conditions. Instead, it focuses on preserving key functions that maintain ecosystem health and are broadly supportive of native fish and wildlife.

A functional flows approach also requires physical habitat improvements – such as barrier removal, channel restoration, and floodplain reconnection projects – to restore critical interactions between flowing water and land.

Too often, physical habitat restoration is not coordinated with changes in environmental water management. Aligning functional flows with physical habitat restoration – rather than a flows-only or habitat-only approach – brings a greater environmental return on investment. It also creates opportunities for multi-benefit projects that meet the needs of people and the environment.

Functional flows can be implemented in a variety of ways, including by modifying dam operations, altering the timing and location of diversions, and managing discharges of wastewater and stormwater to rivers and streams. But creative changes in governance are also needed to put functional flows into practice.

We recommend the allocation of an "ecosystem water budget" - a fixed volume of water for the environment, overseen by an independent trustee - to be flexibly managed for functional flows. This flexibility would support cooperative solutions among water users and, critically, would allow for adapting to new information and changing conditions.

In some cases, functional flows will require more water for the environment, with corresponding declines in water supply for other purposes. Yet, by maximizing the benefits of environmental water, this approach provides greater assurances that water is being used effectively. A fixed water budget also brings greater certainty over supply reliability for other water users.

Improvements in ecosystem health would also deliver significant public benefits, including better water quality and recreational opportunities. It would also reduce the likelihood of disruptions from new Endangered Species Act listings. Actions taken now to improve ecosystem health for all native species - not just those currently protected - can pay off in the future by avoiding additional regulatory burdens.

Sustainable management of water resources is one of California's - and indeed the world's - grand challenges. California will continue to face intense competition over water resources, forcing difficult decisions over how to allocate water to protect freshwater ecosystems for all uses, not just water supply. A functional flows approach enables a more efficient and effective use of environmental water, and can be an important tool in managing the state's rivers for an uncertain, but certainly changing, future.

Jeffrey Mount has also written about how California should stop relying on the Endangered Species Act in managing the environment and Delta outflow explained.

WORLD ECONOMIC FORUM

As much as half of the world's water supply is being stolen, report finds

Agriculture is leading illegal water extraction across the world.

Image: Henning Bagger/Ritzau Scanpix/via REUTERS

03 Sep 2020

Douglas Broom
Senior Writer, Formative Content

This article is part of the **Sustainable Development Impact Summit**

- Global water supplies are under stress from rising populations.
- Agriculture is mainly to blame for illegal water abstraction.
- Climate change is adding to the number of water crises across the globe.

As much as half the world's water supply is being stolen, with agriculture responsible for much of that, according to a new study.

Writing in the journal Nature Sustainability, an international team of researchers says thieves steal between 30% and 50% of the planet's water supply every year. Overhauling legal and political frameworks could protect precious water supplies, they say.

The theft of water takes various forms, including using treated drinking water without paying for it, and taking water from natural sources in breach of environmental guidelines. Agriculture, which accounts for 70% of global water use, is often to blame. The report found that social attitudes and uncertainty over future supply help drive the crime.

A 'challenge for humanity'

While water theft does take place in richer nations, those stealing water are often poor and vulnerable people in developing countries, according to the paper. Combined with a lack of data, this has led to the issue being under-researched.

So the team, led by the University of Adelaide, developed a novel framework and model to help study the issue. They applied this to three examples of water theft: growing marijuana in California; cultivating strawberries in Spain; and cotton farming in Australia. In the Spanish case study, water was being taken from an area protected for migratory birds.

Although the study calls for tougher penalties for stealing water, the authors note that where people understand water regulations and believe everyone else is obeying the rules, water theft is much lower.

"Water crises constitute a challenge for humanity," says the report, urging authorities to recognize the urgency of the situation. "When regulators fail to understand the value of water, inadequate prescribed penalties increase the risk of theft."

The authors say that improved monitoring technology will play a major role in helping to tackle the issue.

Water stress is rising

The world's water supplies are under increasing strain. The global population tripled in the 20th century and rising living standards have further stimulated demand. Climate change is accelerating the problem of water stress across the planet.

Water is the primary medium through which the world will feel the effects of climate change, according to United Nations Water. It says water availability is becoming less predictable, with flooding and droughts both increasing.

More than 2 billion people live in countries suffering high levels of water stress, and by 2040 a quarter of the world's children will be living in areas of extreme water stress. Water scarcity could lead to the displacement of up to 700 million people by 2030, the UN predicts.

Global response

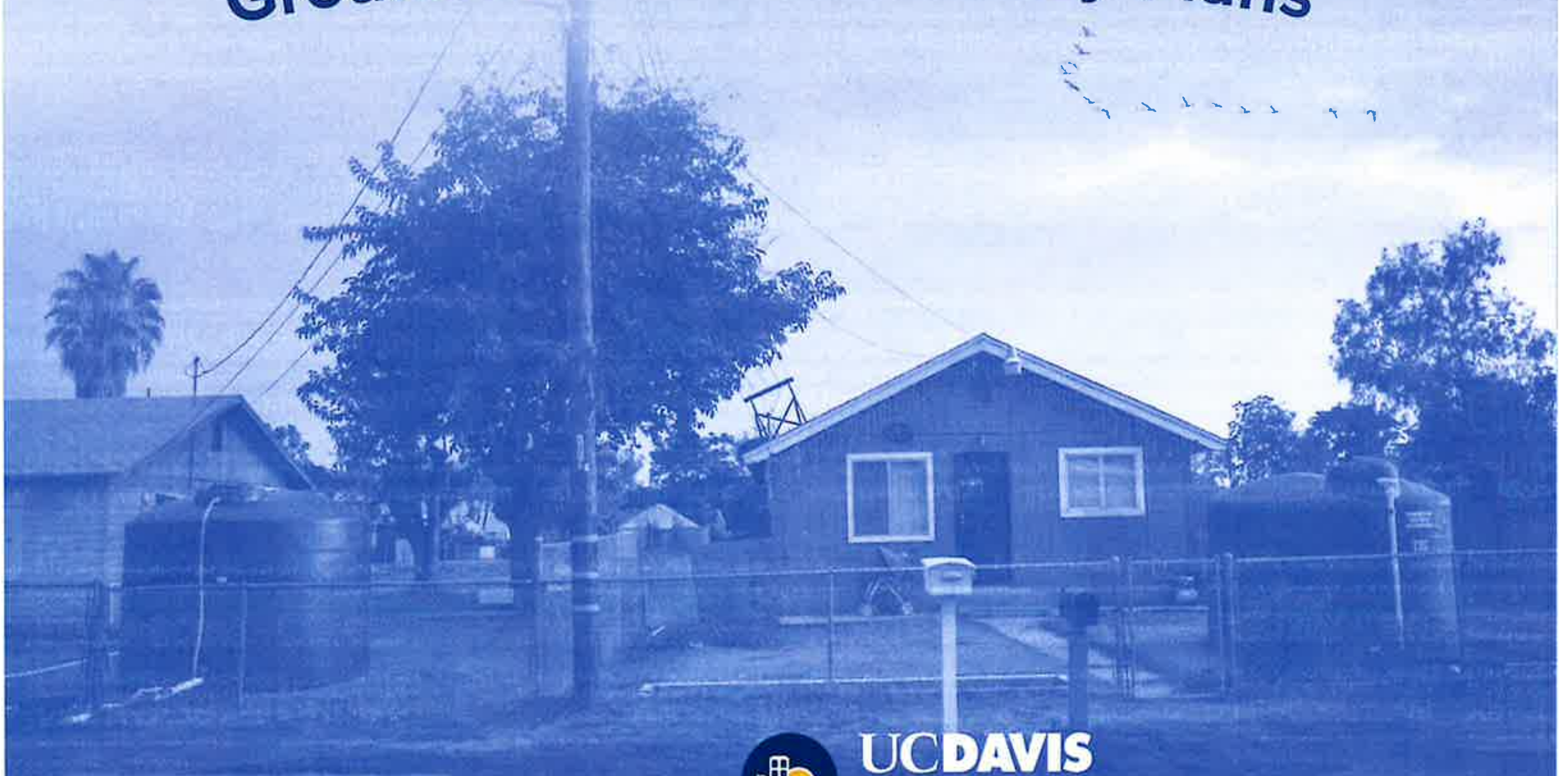
Data compiled by the World Water Council says that, overall, domestic consumption only accounts for 10% of worldwide water usage, with industry taking 20% and evaporation from reservoirs claiming a further 4%. The rest is down to agriculture.

The World Economic Forum's Global Water Initiative was launched in response to a warning from scientists that the gap between global water supply and demand would widen to 40% by 2030.

SUSTAINABLE FOR WHOM?

EXECUTIVE SUMMARY

The Impact of SGMA's Groundwater Sustainability Plans



UC DAVIS
Center for Regional Change

EXECUTIVE SUMMARY

INTRODUCTION

Studies estimate that 1.5 – 2.5 million Californians rely on domestic wells to meet their household water needs (Johnson and Belitz 2015; Dieter et al. 2018; Pace et al. 2020). But because domestic wells are often shallow, they are also often sensitive to changes in groundwater levels. As such, sustainable groundwater management has an important role to play in safeguarding the health and safety of residents and the achievement of California's recognized Human Right to Water.

The concept and meaning of 'sustainable groundwater management' is broadly contested. This is because the way sustainability is implemented deeply affects the health and productivity of the interconnected social, economic, and physical systems that rely on aquifers. Historically, 'sustainable yield' has been defined as the amount of water able to be extracted from a groundwater system without undesirable results (Todd 1961). The vagueness of 'undesirable results', however, led to a push to explicitly include harm to the interconnected socio-economic systems as a component of undesirable results (Freeze and Cherry 1979) . Theoretically, sustainable yield under this definition combines the needs of society and the physical constraints of aquifers, with the goal of maximizing long-term use and minimizing harm to the physical and social systems (Sophocleous 1997; 2000; Gleeson, Alley, et al. 2012). However, the task of minimizing social harm has been interpreted differently by various interest groups (Rudestam and Langridge 2014). A general definition of social harm and sustainability more broadly can also mask the vast disparities between social groups (based on race, ethnicity, class and other factors) as they experience the impacts of water distribution and management. Given the ambiguity of defining sustainability, it is important to understand how this concept is defined in local contexts and what impacts its definition has on different users when it is applied in policy.

Historical groundwater management in California over the twentieth century was not sustainable, but rather, extractive in nature (Gleeson, Wada, et al. 2012). Chronic aquifer depletion has lowered groundwater levels and made shallow domestic wells vulnerable to losing access to water. From 2012 to 2016, during the worst drought in California's recorded history, rapid groundwater level decline caused domestic well failure (Jasechko et al. 2017; Feinstein et al. 2017; Gailey, Lund, and Medellín-Azuara 2019; Pauloo et al. 2020), loss of groundwater dependent ecosystems (The Nature Conservancy 2014), and subsidence (Liu et al. 2019). During this drought, the state received reports of more than 2,500 household well failures, primarily located in low-income communities and communities of color in the San Joaquin Valley. Although extreme, these impacts are not new, as disparities in access to drinking water in disadvantaged communities have persisted for decades (Pannu 2018; London 2018).

The loss of drinking water access challenges the feasibility of accomplishing the goals set forth in AB 685 (CA SWRCB 2012), or California's Human Right to Water. This bill outlines California's commitment to ensuring clean, affordable, and accessible drinking water for every Californian, and requires state agencies to consider the Human Right to water in policies that concern domestic well users. But as disproportionate impacts to disadvantaged communities during the recent drought have clearly shown, AB 685 remains aspirational; significant work is needed to realize this vision for all Californians.

One such area of significant work involves how California manages groundwater as a vital, shared, and scarce resource. During the 2012-2016 drought, the legislature passed the Sustainable Groundwater Management Act (SGMA) to establish a new framework for groundwater management in California. Under SGMA, Groundwater Sustainability Agencies (GSAs), created from existing public agencies, specify their definitions of sustainability. GSAs must also prevent six different 'undesirable results', including chronic groundwater overdraft[1]. These undesirable results are codified, and their prevention implemented, in Groundwater Sustainability Plans (GSPs). These documents establish a path to sustainability by setting Measurable Objectives (MO) and Minimum Thresholds (MT) for six indicators of sustainability related to undesirable results that are significant and unreasonable. A MO represents optimal conditions, and a MT is a threshold beyond which significant and unreasonable results will occur for environmental, social, or economic uses of groundwater. This analysis in this report is focused on the MTs set for lowering of groundwater levels.

Although SGMA intends to lead California towards a future of groundwater sustainability, the design of the law and the ambiguity of groundwater sustainability means that 'sustainability' will be determined locally by GSAs. Hence, it is critical to understand how local agencies assess sustainability via GSPs, based on their established MOs and MTs, as well as the spatial boundaries of their monitoring networks. The detrimental and inequitable impacts of the 2012 - 2016 drought, and the prospect of additional, longer, and more severe droughts forecasted under climate change (Rhoades, Jones, and Ullrich 2018; Swain et al. 2018), intensifies the importance of decisions made by GSAs, which will directly affect the state's ability to advance the Human Right to Water.

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[1] Under SGMA, undesirable results specifically include reduction of groundwater storage, lowering of groundwater levels, seawater intrusion, degraded water quality, land subsidence and depletion of interconnected surface water.

To provide this information, this report analyzes 41 GSPs in 19 critical priority subbasins in California (in the San Joaquin Valley, Central California, and the Central Coast) to assess monitoring well coverage and the impact of MTs on domestic well failure. We find that GSPs range in lateral spatial coverage (33 - 100 %) and coverage of domestic wells (43 - 100%) within their boundaries. Overall, estimated domestic well failure rates are on par with a management regime of "business as usual" or status quo groundwater extraction (Pauloo et al. 2020). Results suggest that 1,000 - 6,000 wells are at risk of failure in critical priority basins under proposed MTs. In what follows we present the research methodology, key results, and a set of policy recommendations to assist the achievement of sustainable groundwater management in California that is compatible with the state's efforts to achieve the human right to water.

METHODOLOGY

This report examines the minimum thresholds (MTs) set for lowering of groundwater levels in 41 GSPs submitted to the Department of Water Resources for review in January 2020. These GSPs are located within 19 of 20 critically overdrafted basins in the state and, in this study, are separated into three 'regions' - San Joaquin Valley, Coastal, and Central (Figure 1). Because a domestic well requires a certain water level for operation and some require shallower water levels than others, MTs have important implications for well production and operation throughout the state. One lens to understand different definitions of groundwater sustainability (and undesirable results) is to translate GSA's local definitions into local impacts, as they are required to do as well[2]. This study defines the impacts as the extent of domestic well failure that separates undesirable results from the sustainable operating range as represented by MT groundwater levels.

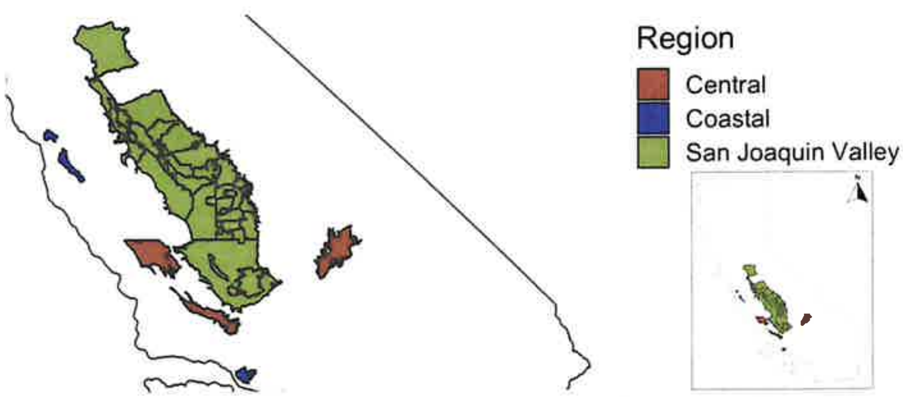

Figure 1. Map of GSPs for critical priority basins analyzed in this study, categorized by region in California.

[2] 23 CCR **§354.26** (b) The description of undesirable results shall include the following: Potential effects on the beneficial uses and users of groundwater (CA DWR 2014).

MTs are set at monitoring wells located within a GSP area. The monitoring network is used to understand basin conditions and when to best implement mitigation measures when a MT is exceeded. Importantly, each monitoring well most accurately represents groundwater conditions in a specific radius around that well. Having sufficient monitoring wells in the appropriate locations is critical to accurately represent conditions across a basin; the capacity to measure groundwater sustainability defined by MOs and MTs is only as robust as the spatial density of the monitoring well network. It is paramount, therefore, to have enough monitoring wells in the appropriate locations to accurately represent conditions across a basin. For example, if production wells are too far from a monitoring well and left outside of a monitoring network, it will be challenging to measuring groundwater sustainability at these wells, which will in turn problematize implementation of management actions if and when minimum thresholds are exceeded.

DWR guidelines for a monitoring network suggests that optimal monitoring networks range from 2 to 10 monitoring wells per 100 mi2 depending on the amount of pumping and complexity of the geology (Heath 1976; DWR 2010; Hopkins 2016). In other words, a monitoring well can represent 10 - 50 mi2 of lateral extent. (In this study, we do not include vertical monitoring zones, which depend on local geologic properties including the porosity, hydraulic conductivity, and connectivity of sediments.) To approximate DWR's guidelines of lateral coverage, 36 mi2, or township-level, buffers are set around each monitoring well with the MT specified in a GSP, also consistent with basins pumping in excess of 5,000 acre-feet/year (Hopkins 2016). The total area of the buffer is compared to the area of the GSP in order to assess the percentage of monitoring network coverage. The buffer area is also compared to the location of domestic wells within a GSP, in order to understand the percentage of domestic wells that fall within the monitoring network. In this study, we focus on the unconfined and the semi-confined aquifer in which domestic wells tend to be screened, thus we only consider monitoring wells with MTs set above 400 ft in the coverage metric, as deeper water levels are likely below confining sediments.

To understand how MTs might affect domestic wells, we interpolate a theoretical groundwater surface that approximates how deep the groundwater level is likely to be across the study area using MTs specified in GSPs. The extent of the buffer is considered the maximum distance an interpolation can be performed without significant uncertainty. This surface represents a hypothetical estimation of what the groundwater level may look like if the water level reaches the level of the minimum thresholds.

Declining groundwater levels pose a threat to groundwater wells, particularly shallow ones. Moreover, pumps are susceptible to reduced water production and mechanical damage as the groundwater above the pump falls within the net positive suction head (Tullis 2007), but for the purposes of this modeling exercise, we assumed no reduction in efficiency as this level is approached. Rather, we consider the estimated pump location and total completed depth as 'failure thresholds'. If levels fall below the pump, the well will not produce water unless the pump is lowered so it can be re-submerged. If water levels drop below the bottom of the well entirely, the well must be deepened or a new one constructed to reach groundwater.

This study calculates a range for the percent of potential domestic well failures using the MT surface described above and both the total completed depth of wells and their estimated pump locations (Pauloo et al. 2020). To calculate the lower bound on the number of wells vulnerable to failure under proposed MTs, we assume wells fail when the MT drops below the total completed depth of the well, in other words, when there is no water in the well at all (Figure 2). Although more localized studies done by GSAs can estimate the average retirement age in their region, this study assumes a 30-yr well retirement age and only includes domestic wells constructed on or after 1990. This is consistent with calibrated well retirement ages determined by Gailey, Lund, and Medellín-Azuara (2019) and Pauloo et al. (2020) in their respective regional analyses of domestic well vulnerability[3].

We estimate the upper bound by comparing which wells have pump depths that are equal to or higher than the interpolated MT water level (Figure 2). Because estimated pump locations for domestic wells are not available in the Central and Coastal regions, the upper bound of well failures is only calculated for San Joaquin Valley subbasin GSPs (35 of 41 GSPs). Although this estimate is not available for all GSPs, it is extremely important because water levels near or below pump depths render wells unable to produce water thus depriving the well-dependent residents of drinking water and water for other essential household uses. For this reason, this estimate of the upper bounds of well-failure is most reflective of immediate water access conditions in residences. By contrast, the lower bound estimate using the total completed depth represents longer-term impacts to water security that can only be remedied by increasing the depth of the well.

[3] One recent study of 26 GSPs in the San Joaquin Valley relied on an underlying domestic well dataset (Pace et al. 2020) that did not assume any retirement age; the study authors also had to exclude 25% of well completion reports (13,000/45,000) due to missing information. The authors estimated 4,000 – 12,000 partial or completely dewatered domestic well by 2040 (Water Foundation and EKI 2020).

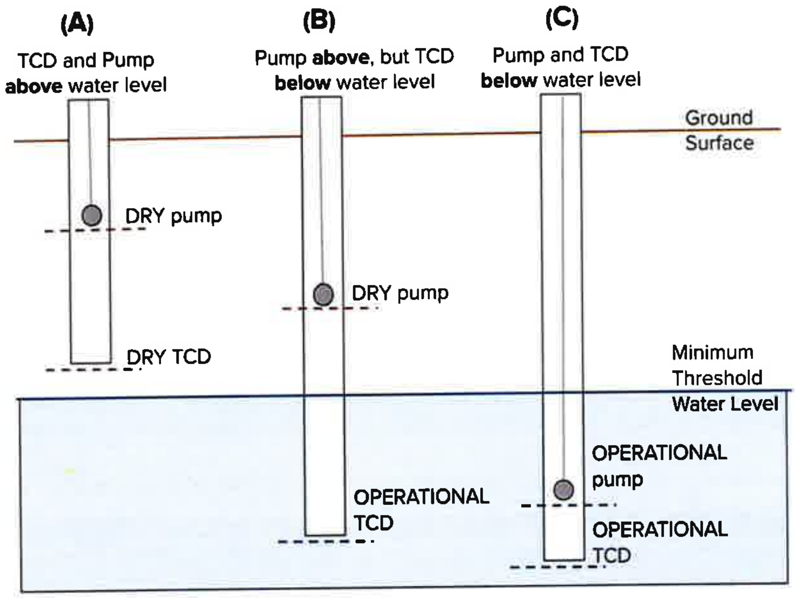

Figure 2. Conceptual model of well failure determination. Pump location used to determine well failure in SJV only.
(a) failing well according to both pump location and TCD.
(b) failing well according to pump location but active according to TCD.
(c) active well according to both pump location and TCD.

Finally, we estimate a range of the number of people reliant on domestic wells to estimate how many people rely on wells vulnerable to these MTs. The average household size is 3 people and domestic wells can support 1 – 4 households. Thus, we multiply the range of people reliant on one domestic well (3 – 12 people) by the number of wells vulnerable to MTs to obtain the range of people likely affected by MTs.

RESULTS

1. Domestic wells will likely go dry if MT groundwater levels are exceeded

Across all 41 GSPs analyzed, 10% of domestic wells have total completed depths that are vulnerable to future dewatering if water levels reach MT levels (lower bound of dry well estimate). This statewide measurement, although useful in some respects, obscures important regional differences. Comparing critically overdrafted basins among the three study regions, the SJV stands out as having the most extreme potential impacts to water access in domestic wells (Figure 3).

Percentages alone can be misleading, as shown in Figure 3 and Table 1. Figure 4 conveys the same findings as a *quantity* of vulnerable domestic wells by GSP. In Coastal and Central Basins, less than 100 wells have total completed depths that are vulnerable to potential dewatering. In the San Joaquin Valley, in contrast, nearly 800 wells would need to be deepened (if possible) in order to access water because their total completed depths are above the MT water table (Figure 4).

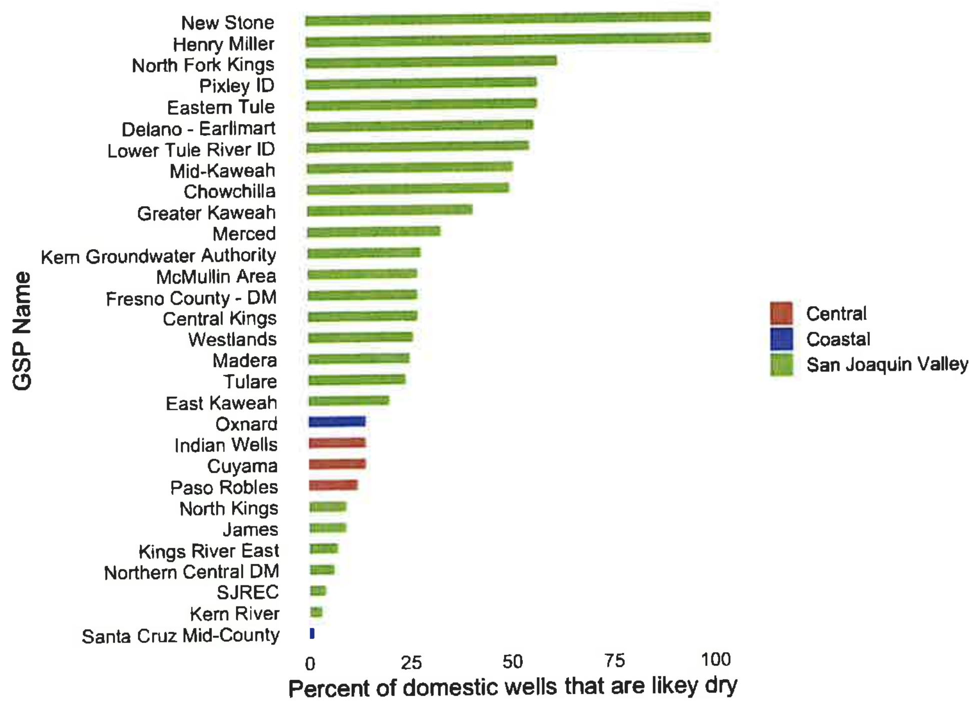

Figure 3. Percent of domestic wells vulnerable to MTs based on ***total completed depths*** *by GSP (y axis) and region (color).*

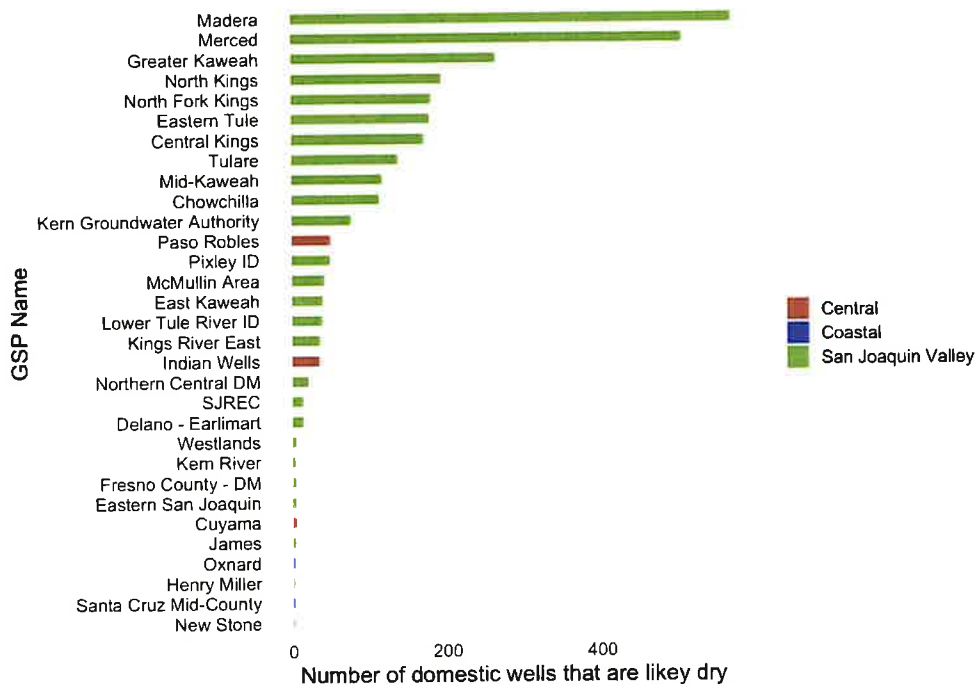

*Figure 4. Count of domestic wells vulnerable to MTs based on **total completed depths** by GSP (y axis) and region (color).*

	Total Completed Depth (TCD)			Pump Location		
	Average Well Failure (%)	Count of Well Failure (#)	Range of People Affected (#)	Average Well Failure (%)	Count Well Failure (#)	Range of People Affected (#)
San Joaquin	11%	765	2,295 - 9,180	61%	5,420	16,260 - 65,040
Coastal	4%	3	9 - 36	NA	NA	NA
Central	13%	89	267 - 1,068	NA	NA	NA

*Table 1. Summary of the percent (rounded) and number of domestic wells and people vulnerable to MTs based on **pump location and total completed depth (TCD).***

Table 1 also includes both the count and percentage, to better understand the quantity of vulnerable domestic wells in each GSP. In the San Joaquin Valley GSPs, 11% of, or 765 domestic wells have total completed depths above the minimum threshold surface. Using the upper estimate, however, 61% of domestic wells have estimated pump depths above the minimum threshold surface, indicating that about two thirds of wells are likely to fail at the MTs set by the GSAs, and assuming no mitigation measures are taken (e.g., pump lowering, well deepening). In other words, approximately 5,400 domestic wells in the San Joaquin Valley would at minimum need their pumps lowered in order to continue to function. The Merced GSP has the most wells with pump locations vulnerable to MTs (about 1,400 or 94%), potentially affecting a quarter of all domestic wells in the SJV.

There is significant variability in domestic well failure across SJV GSPs. Some areas have no wells whose pump locations are vulnerable to MT water levels, while others have 80 – 100% of their wells vulnerable to the MT water level. Most notably, Merced, North Fork Kings, and Eastern Tule GSPs set MTs where greater than 90% of the domestic wells in their management areas pumps at risk of dewatering (Figure 5), totaling about 1,800 wells.

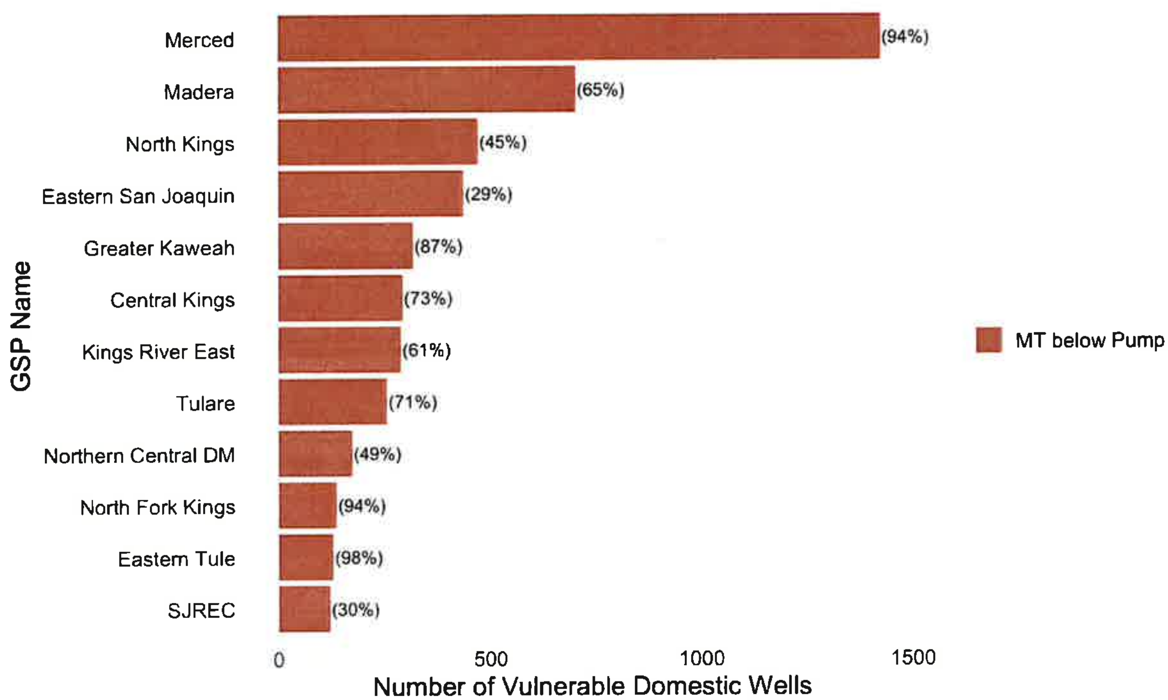

*Figure 5. Number of domestic wells in the San Joaquin Valley vulnerable to MTs based on **pump location**. Percents in parentheses represent the proportion of domestic wells vulnerable within each GSP. Shown are the 12 GSPs that cover 90% of domestic wells in the SJV.*

To understand how these results could affect disadvantaged communities (those with incomes less than 80% of the state median) specifically, we intersected domestic wells with vulnerable pumps with two different disadvantaged community (DAC) census geometries: 1) DWR's Disadvantaged Community Census Places (places) layer which uses 2016 ACS income data (DWR 2016a) and 2) DWR's Disadvantaged Census Block Groups (block groups), which also uses 2016 ACS income data (DWR 2016b)[4].

There are 203 CDPs within SJV GSPs, 132 of which are disadvantaged communities. 58 of these 132 disadvantaged community CDPs contain domestic wells completed after 1990 within their boundaries, totaling approximately 1,300 wells. Of those wells,

[4] In California, a disadvantaged community (DAC) is one with an average median household income (MHI) of less than 80% of California's overall MHI. DWR's 2016 DAC income threshold is $51,026 (80% of $63,783).

approximately 400 (30%) are vulnerable to dewatering at set minimum thresholds spread across 58 unique communities (Figure 6). These wells are located throughout many GSPs, but are concentrated in Merced, North Kings, Madera, and Eastern San Joaquin GSPs.

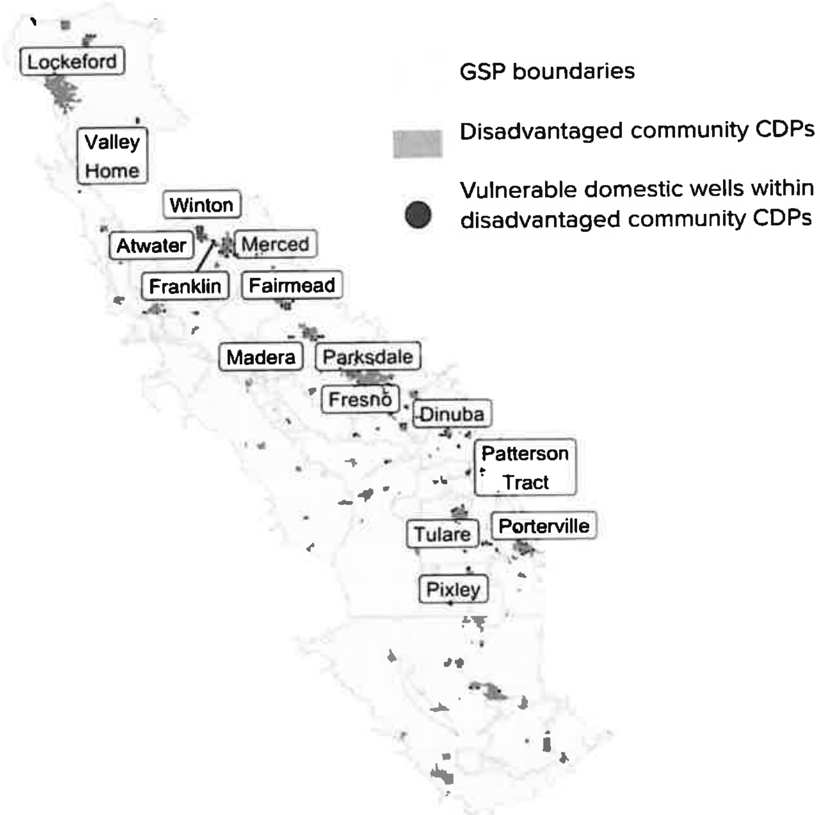

Figure 6. Disadvantaged community CDPs with domestic wells whose pumps are vulnerable to MTs. Labeled are disadvantaged communities with more than 5 vulnerable domestic wells within their boundaries.

There are 1,885 block groups within the SJV GSPs and 1,118 are classified as disadvantaged. Disadvantaged block groups make up 60% of the area within SJV GSPs. Within disadvantaged block groups, there are approximately 6,300 domestic wells completed after 1990; about 2,100 (30%) of which have pumps vulnerable to MTs (Figure 7). These 2,100 domestic wells comprise nearly 40% of all vulnerable wells within the SJV, indicating that if water levels decline, GSAs need to be prepared to support and fund enhanced mitigation efforts for vulnerable domestic wells that supply households in low-income communities, in particular.

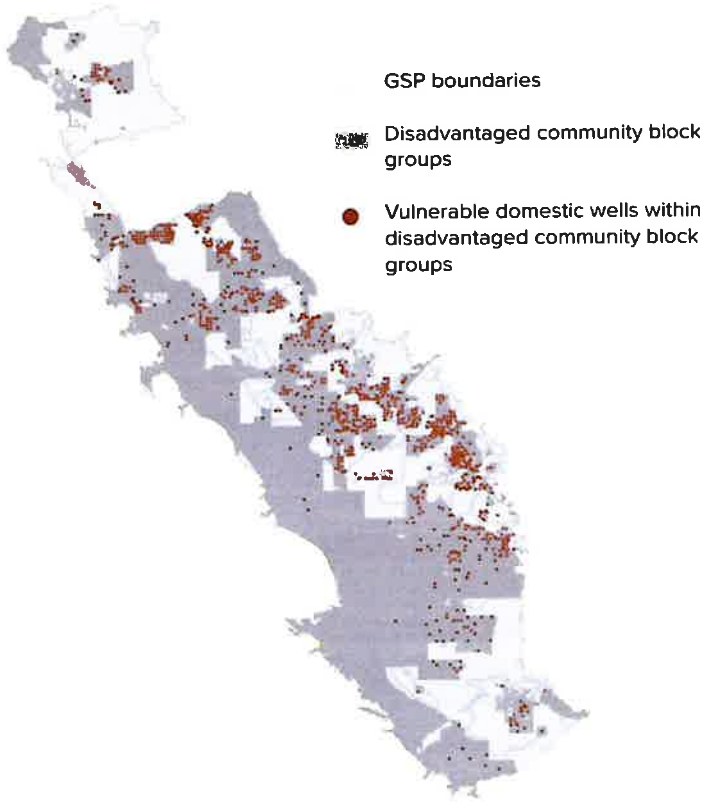

Figure 7. Disadvantaged community block groups with domestic wells whose pumps are vulnerable to MTs.

2. Monitoring networks cover most – but not all – domestic wells

Monitoring networks are essential to understanding and ensuring the longevity of sustainable water levels in a basin. They provide an understanding of groundwater levels at specific locations and, if water levels are recorded over time, can demonstrate long term trends at that location. In this report, proposed GSP networks are used as a proxy for the extent of the GSPs' ability to define sustainability and monitor progress towards that goal.

What percent of GSP management areas are included in current GSP monitoring networks?

Across all three regions and in most GSPs the established monitoring networks do not completely cover management areas (Figure 8). In other words, the networks do not have enough monitoring wells spread across their land area to represent groundwater conditions for all parts of the basin they manage. Coverage percentages, however, vary between plans and between regions. In the San Joaquin Valley, monitoring networks cover an average of 86% of the total management area but range from 33% to 100% coverage of individual GSPs (Table 2). Monitoring networks in coastal basins cover an average of 95%, ranging from 86% to 99% of their management areas. The excluded areas are found mostly along the edges of the basins, as well as in the central section of

Salinas Valley. Finally, the monitoring networks in the Central basins cover an average of only 41% of the total area in the region. Indian Wells' monitoring network extends over 24% of its basin area, with Paso Robles covering 33%, and Cuyama covering 67%.

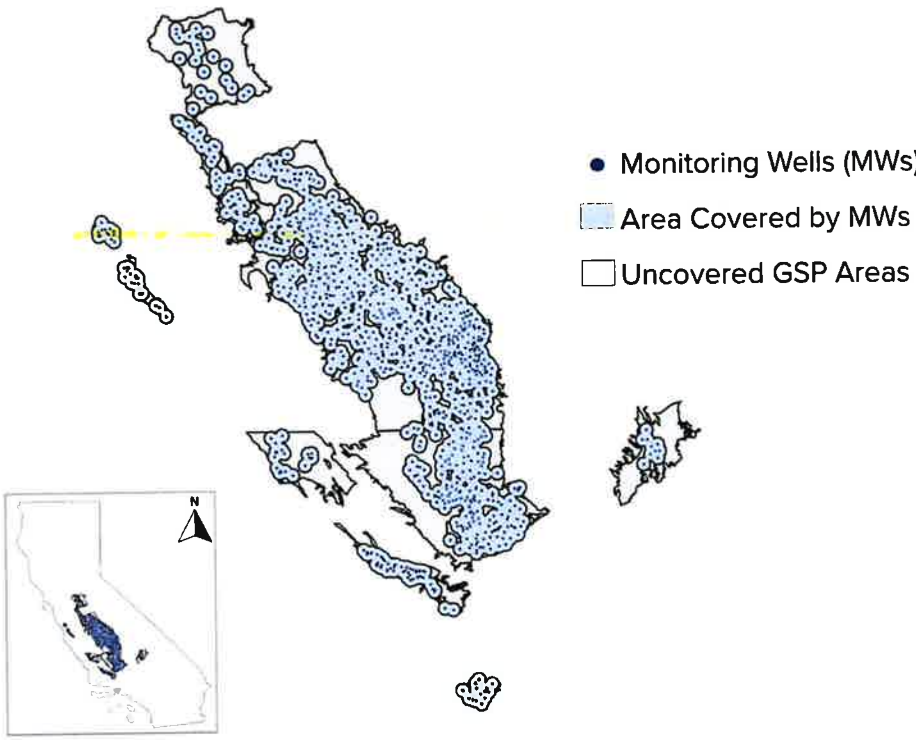

Figure 8. GSP monitoring networks wells with 36 mi² circular buffers consistent with (Heath 1976), indicating the areas covered and uncovered by monitoring wells.

What percent of domestic wells are included in current GSP monitoring networks?

Changes in groundwater levels are often driven by groundwater pumping, and thus such areas require close monitoring. Among the different types of wells, domestic wells are relatively shallow in depth, and thus the most vulnerable to the placement of MTs. Because they are the most vulnerable, a monitoring network is needed to cover areas with domestic wells. Overall, most domestic wells are included within the coverage areas of GSP monitoring networks, but for those that are left out, inadequate monitoring network coverage challenges basin-wide sustainability planning and a meaningful well failure assessment.

Monitoring network coverage of domestic wells varies by region and plan. Across all SJV GSPs, 92% of domestic wells fall within a monitoring network (Table 2). Four GSPs have monitoring networks that cover less than 80% of their domestic wells, with Eastern San Joaquin covering the fewest domestic wells, 43% of domestic wells in their subbasin. In coastal basins, domestic wells are also partially covered. In Salinas and Pleasant Valley, 65% and 83% of domestic wells are covered. All domestic wells are covered in Santa Cruz and Oxnard GSPs. Central basins don't cover most of their area, but they do cover on average 80% of domestic wells, with Paso Robles covering 75%, Indian Wells covering 78%, and Cuyama covering 88%.

	Average Area Covered (%)	Range Area Covered (%)	Average Domestic Wells Covered (%)	Range Domestic Wells Covered (%)	Number Domestic Wells Covered (#)
San Joaquin	86	33 - 100	92	43 - 100	15,000
Coastal	95	86 - 99	86	65 - 100	300
Central	41	24 - 67	80	75 - 88	700

Table 2. Summary of the percent and number domestic wells covered by GSP MTs by region.

It is important to note, however, that because GSPs have markedly different numbers of domestic wells in their management areas, similar percentages of domestic well coverage can mean very different things depending on the number of wells in different GSPs. For example, in Salinas where 68% of domestic wells are covered, about 40 domestic wells fall outside of the monitoring network and in Pleasant Valley, with 66% coverage, only 2 domestic wells are excluded and the San Joaquin River Exchange Contractors cover 78% of their basin, or about 500 domestic wells.

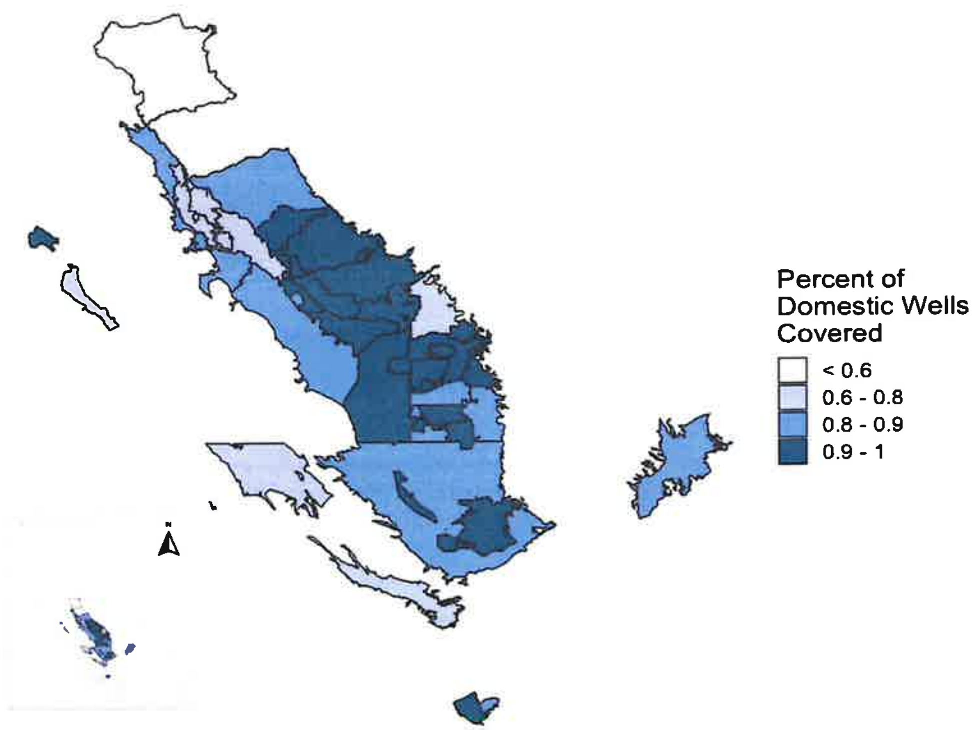

Figure 9. Map of the percent of domestic wells that fall within the GSP monitoring networks.

3. Policy Recommendations

Local definitions of sustainability defined by MTs differ by GSP and therefore, the potential implications for domestic well failure also differ among GSPs. Although GSPs set different MTs, what they all have in common is setting these MTs below current groundwater levels and even recent drought lows. This means that groundwater levels will decline in most subbasins, and that thousands of domestic wells are vulnerable. We now propose and discuss several recommended actions to address these risks.

A. *DWR can and should reject plans that are forecasted to cause significant well failure, and that lack sufficient mitigation plans.*

California state water agencies such as DWR have the regulatory power to reject groundwater plans. The Department of Water Resources can decide that minimum thresholds (MTs) set in GSPs may cause significant and unreasonable impacts to domestic wells and ask GSAs for revisions. If local GSPs are persistently insufficient, DWR has the power to intervene and manage groundwater basins in place of GSAs. State agencies should use the results presented in this report and similar studies to inform that intervention and management. Ultimately, if the state and GSAs cannot agree on what constitutes a significant and unreasonable impact, the state may overrule the GSAs on grounds of upholding the Human Right to Water.

B. *Robust and well-funded mitigation programs are needed to address inevitable domestic wells failure.*

Mitigation programs that do not monitor for or protect domestic wells with water supply contingency plans are in violation of the Human Right to Water. The responsibility of funding and providing clean water to residents who lose access to their domestic wells should not fall to other government programs, like the State Water Board's SAFER program. Instead, these costs should be paid locally, as they are a direct result of local decisions in defining groundwater sustainability. See Self Help Enterprises, Leadership Counsel for Justice and Accountability, and Community Water Center (2020).

C. *Additional studies on the socio-economic profile of populations dependent on domestic wells should be conducted to ensure that California meets its commitment to the Human Right to Water.*

Many low-income people and people of color live in disadvantaged communities and rely on vulnerable domestic wells. These same households and communities often lack the financial and political capital to influence groundwater planning and definitions of sustainability. Analyses of these disparities are important to develop effective and equitable policy solutions. In addition, it is impossible to understand these disparities without knowing how many people are reliant on domestic wells. Furthering studies done by Johnson and Belitz (2015) and Pace et al. (2020) can shape decision making and mitigation actions in a robust way.

D. *Use more than one metric for assessing impact to domestic wells.*

Understanding the total completed depth of a well gives the lowest, most conservative, estimate of well failure under MTs. Performing an analysis of this kind with full understanding of the pump locations of domestic wells provides a more realistic, usually higher, well failure estimate. However this parameter is difficult to ascertain, and well owner participation in a future study would help reduce the uncertainty inherent in this approach.

E. *Improve the extent and density of monitoring networks.*

Sustainability can only be managed where there are sufficient monitoring networks. GSAs can improve their understanding of domestic well vulnerability and ability to respond to undesirable results by adding more monitoring wells across their area, especially in areas where domestic wells are present. Nonprofit advocacy groups provide a framework for establishing monitoring networks and management actions that protect domestic wells and mitigate well failure. See Self Help Enterprises, Leadership Counsel for Justice and Accountability, and Community Water Center (2020)

F. *Understand the distribution of domestic well ages, depths, and pumping capacities.*

The analyses in this report are limited by a lack of information about exact pump locations in all basins and an inadequate understanding of domestic well retirement ages. 1990 is likely an underestimation of the average retirement age of domestic wells. When assessing impacts to domestic wells, GSAs should make a concerted effort to gather data on the wells, including the age, pump location, and total completed depth of all domestic wells. More complete domestic well data will inform assessments of the impacts of MTs, which can then be used to define more reasonable MTs that protect domestic wells. Furthermore, this data may be used to inform other critical management questions. For instance, can strategic siting of managed aquifer recharge reduce the vulnerability of domestic wells to failure (Maples, Fogg, and Maxwell 2019).

G. *Require monitoring well construction details, groundwater contours, and SMCs to be included in the public data portals.*

It is incredibly challenging to understand the impacts of MOs and MTs when the data is provided exclusively in pdf form as is the case in current GSPs. For greater transparency, all data that is able to be made public should be available in formats that are easily accessible to the public.

In conclusion, GSAs can improve GSPs to better protect vulnerable domestic wells and their users by ensuring monitoring networks offer adequate coverage in areas where domestic wells are present, understanding attributes of domestic wells in their area (i.e., location, age, depth, pump location), and redefining sustainability through resetting their MOs and MTs. In this way California can make bold strides towards meeting its visionary policy on the Human Right to Water.

AUTHORS

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PREFERRED CITATION

Bostic, Darcy; Kristin Dobbin; Rich Pauloo; Jessica Mendoza; Michael Kuo; Jonathan London. 2020. *Sustainable for Whom? The Impact of Groundwater Sustainability Plans on Domestic Wells.* UC Davis Center for Regional Change.

ACKNOWLEDGEMENTS

We would like to thank Water Foundation and Microsoft AI for Earth for their funding of this project. Thank you to Leadership Counsel for Justice and Accountability, Self Help Enterprises, Community Water Center, Amanda Fencl, Mark Lubell, Graham Fogg, Alvar Escriva-Bou, and Helen Dahlke for their input and advice. Thank you to Chelsea Jimenez for designing this report.

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ENDING CONFLICTS OVER WATER

Solutions to Water and Security Challenges

PETER GLEICK, CHARLES ICELAND, AND AYUSHI TRIVEDI

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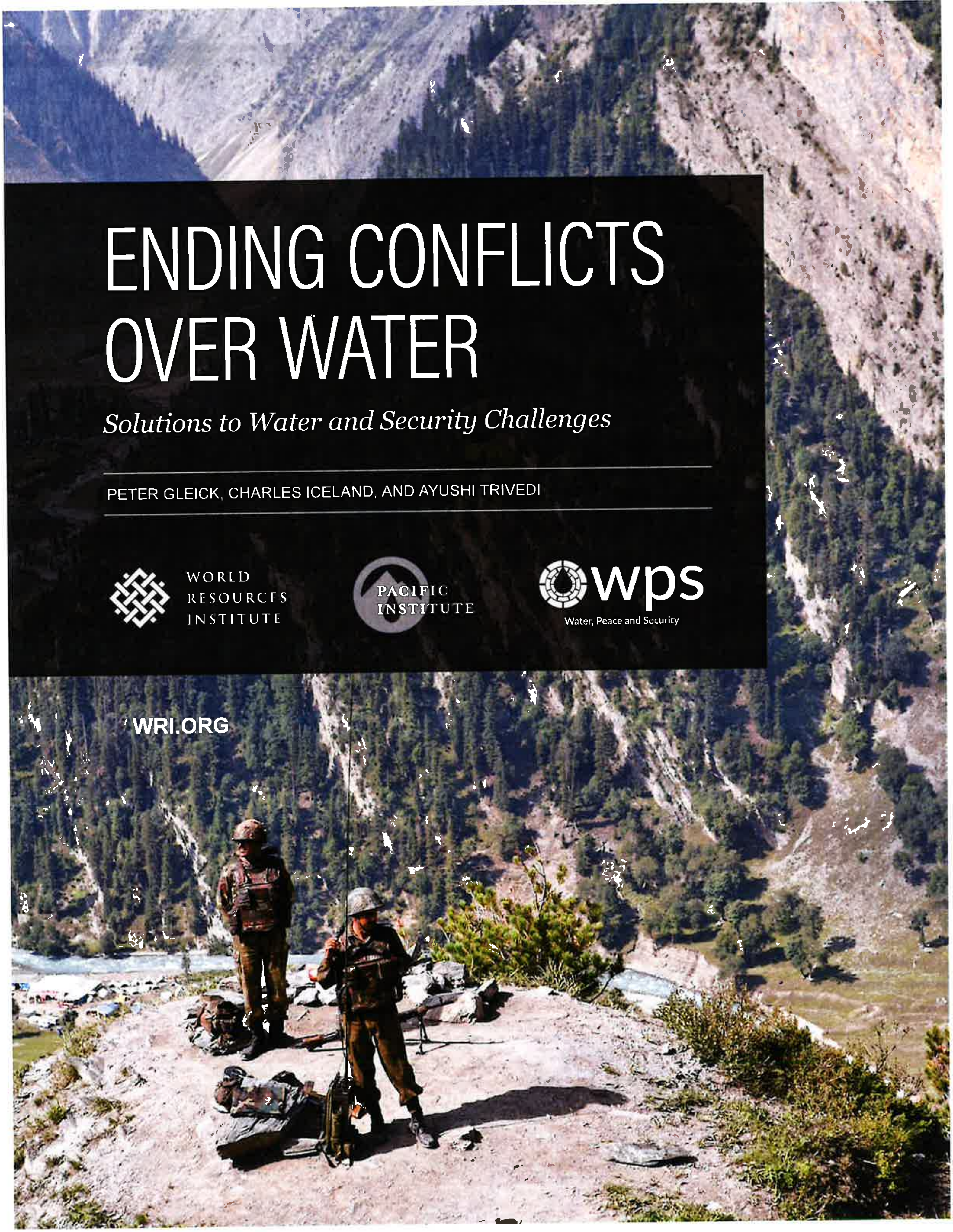

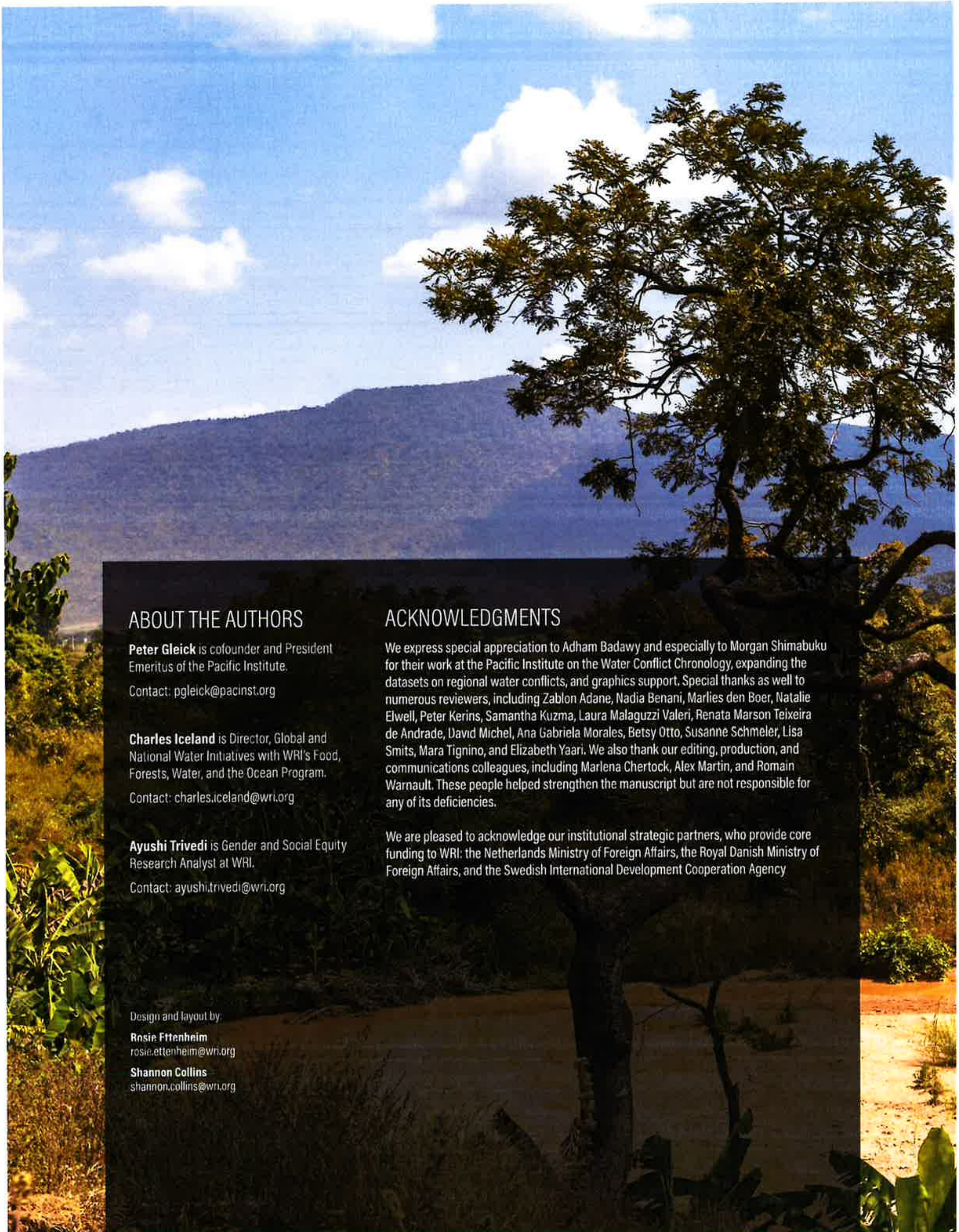

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ACKNOWLEDGMENTS

We express special appreciation to Adham Badawy and especially to Morgan Shimabuku for their work at the Pacific Institute on the Water Conflict Chronology, expanding the datasets on regional water conflicts, and graphics support. Special thanks as well to numerous reviewers, including Zablon Adane, Nadia Benani, Marlies den Boer, Natalie Elwell, Peter Kerins, Samantha Kuzma, Laura Malaguzzi Valeri, Renata Marson Teixeira de Andrade, David Michel, Ana Gabriela Morales, Betsy Otto, Susanne Schmeier, Lisa Smits, Mara Tignino, and Elizabeth Yaari. We also thank our editing, production, and communications colleagues, including Marlena Chertock, Alex Martin, and Romain Warnault. These people helped strengthen the manuscript but are not responsible for any of its deficiencies.

We are pleased to acknowledge our institutional strategic partners, who provide core funding to WRI: the Netherlands Ministry of Foreign Affairs, the Royal Danish Ministry of Foreign Affairs, and the Swedish International Development Cooperation Agency

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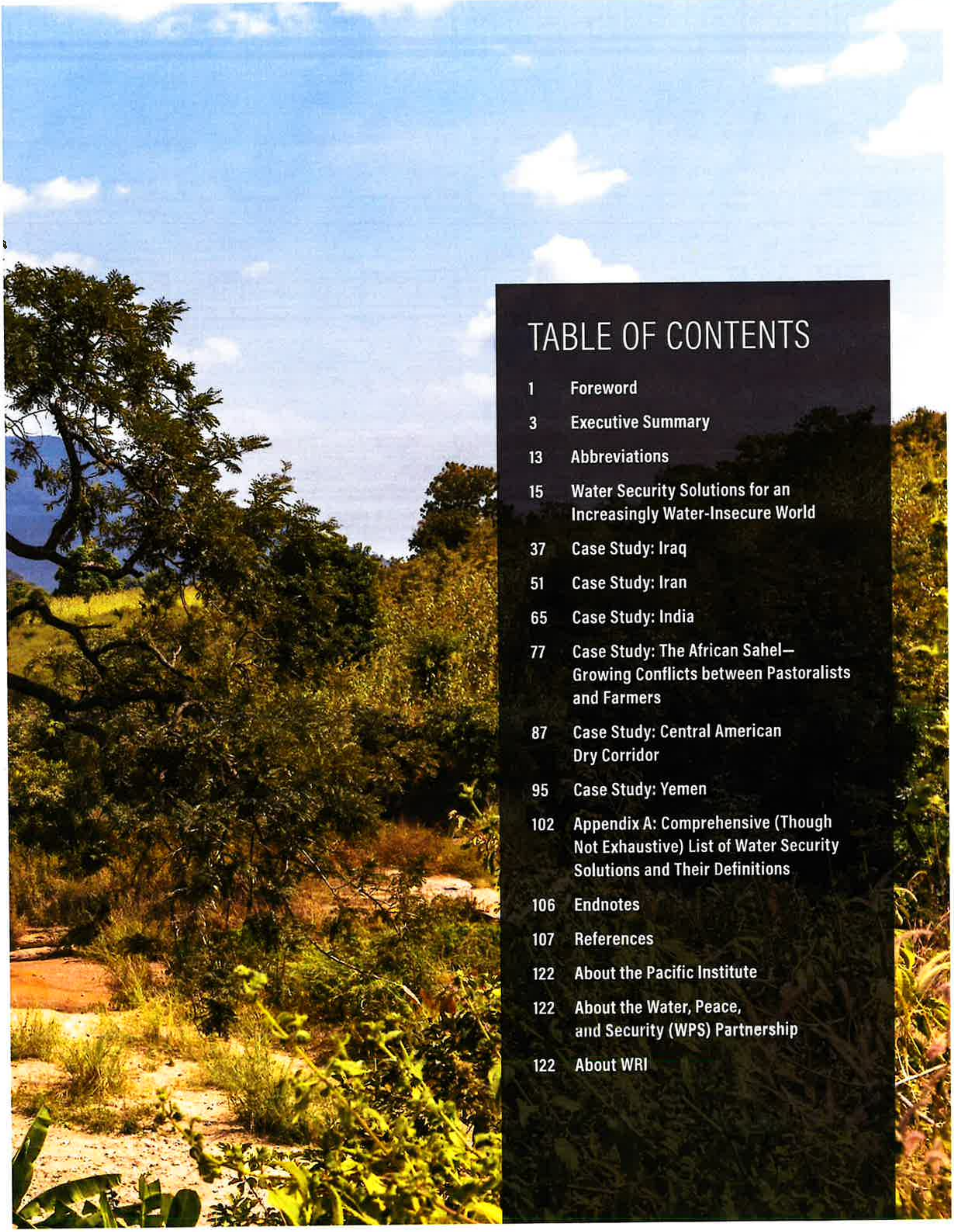

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FOREWORD

Recent analysis from the World Resources Institute found that 17 countries, home to a quarter of the world's population, face extremely high water stress. Billions of people face other growing water challenges as well, including highly polluted water, increasingly erratic rainfall leading to more severe droughts and floods, and lack of access to safe and affordable drinking water. These water challenges lead to increased insecurity, migration and a growing risk of violent conflict, especially in developing countries that lack the financial, technical and governance capacities to deal with these problems. These challenges—already urgent before the COVID-19 crisis—have been revealed by the crisis to be a matter of life or death for hundreds of millions of people who cannot follow the simple injunction to "wash your hands" because they lack clean, reliable water.

This report explores some of the thorniest water crises taking place across the developing world. In southern Iraq, severe water quality problems have triggered social unrest and violent protests. Recent droughts in India have prompted an exodus of farmers from the countryside in Maharashtra and dried up the reservoirs serving the city of Chennai. Across the African Sahel, there are violent conflicts between farmers and pastoralists over water and productive land resources. In Yemen, urban water systems have been targets of persistent attacks during the ongoing conflict in the country.

While intensifying water challenges and the threats they pose to security are well documented, relatively few solutions have been presented. In this report, WRI, the Pacific Institute and the Water, Peace and Security (WPS) Partnership offer potential solution sets to water challenges in key water-insecure hotspots around the world. Drawing on the report's six in-depth case studies—from Iraq, Iran, India, the African Sahel, Central America and Yemen—as well as other recent research, the authors identify strategies to reduce water-related security risks. These solutions are organized into four broad categories: natural resources, science and engineering approaches; political and legal tools; economic and financial tools; and policy and governance strategies.

Most water problems are unique, idiosyncratic and local in nature. Each problem may therefore require solutions that are uniquely suited to local circumstances. For instance, in Iran, declining water availability in rural areas is undermining rural livelihoods and forcing migration to cities. Solutions, such as placing limits on overall water usage in water-scarce agricultural regions while switching to more efficient irrigation technologies, cultivating less water-intensive crops and improving groundwater management, would greatly increase the sustainability of agriculture and improve rural livelihoods. This would, in turn, reduce migration pressures. In contrast, water infrastructure in Yemen has often been a target or casualty of war. Solutions in this case include strengthening and promoting international humanitarian laws and agreements on the protection of water systems and other infrastructure in times of war.

The framework presented in this report provides decision-makers with options for tailoring solution sets to unique water challenges. It is intended for global development, diplomacy, defense and disaster response experts, as well as for national- and river basin-level decision-makers charged with addressing natural resource–based conflict, migration and other forms of insecurity.

This report is research for action. It provides the evidence, examples and solution-oriented analysis that decision-makers need to avert water crises around the world. As the costs of inaction rise, policymakers should work to overcome barriers to implementation by increasing political will and recognizing the benefits of improved water resources management, drought response, flood prevention and access to safe, reliable and affordable water for all.

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EXECUTIVE SUMMARY

Water insecurity throughout much of the world is growing as populations grow, economies expand, and climate change begins to impact the hydrological cycle. In many places, this growing water insecurity is combining with other societal stressors to produce violent conflict or trigger destabilizing migration. While the incidence of water-related conflict appears to be growing, there are many solutions that can be implemented to reduce water risks and avoid conflict. We examine six crisis regions throughout the developing world and propose sets of solutions for each that we believe could successfully address water challenges and enhance security.

HIGHLIGHTS

- Across the globe, the risks and incidences of water-related conflict and political instability appear to be on the rise, and the factors that drive such conflict and instability seem to be intensifying.
- Conflict and instability are rarely caused by any single factor, such as a water crisis. Instead, water crises should be seen as contributing factors that influence the risks of conflict and political instability.
- A number of risk drivers are common to many of today's water-related conflicts and instability, among them population growth, economic expansion, severe and prolonged drought and climate change, pollution, upstream infrastructure development, inefficient water use in agriculture, poor water resources management, and weak institutions.
- Just as no single driver causes conflict, no single solution will eliminate water insecurity problems. Fortunately, a wide variety of solutions are available. Through in-depth case studies, we illustrate how these solutions could be implemented in practice.
- We identify here several dozen strategies to reduce water-related conflicts, but no such list of solutions can be exhaustive. We have organized them into four broad categories: (1) natural resources, science, and engineering approaches; (2) political and legal tools; (3) economic and financial tools; and (4) policy and governance strategies.
- Despite the apparent complexity of many water and security challenges, potential solutions are not difficult to identify, once the key drivers of risk are correctly understood. Solutions are likely difficult to implement for a number of reasons, however, among them the political and economic trade-offs inherent in proposed solutions, problems generally associated with collective action (such as the "free rider" problem), a lack of sufficient financial resources and/or technical capacity, the presence of social or cultural barriers, and the existence of widespread and entrenched corruption.

Context

Water insecurity is a growing threat to humanity. Across the globe, the risks and incidences of water-related violence appear to be on the rise, and the factors that drive such conflicts seem to be increasing. Nonviolent water insecurity also appears to be increasing, from chronic drought leading to loss of rural livelihoods and destabilizing migration in the African Sahel and Central America, to megacities like Chennai and São Paulo facing the prospect of running out of water (Chennai's four main reservoirs actually did run out of deliverable water in June 2019).

Water insecurity is proliferating due to a number of key risk drivers. Population growth and economic expansion are sharply increasing water demand in many regions of the world. Water supply is expected to decrease in the mid-latitude regions of the world because of climate change, which is also expected to alter the timing of water availability and increase the severity of droughts and floods. We are already witnessing increasingly severe and prolonged droughts in many parts of the world. As temperatures rise due to climate change, the amount of water required to irrigate agriculture is projected to increase due to higher rates of evaporation and crop transpiration. Increasing pollution, in many places because of inadequate or nonexistent wastewater treatment, is rendering vast amounts of local water unusable. In many increasingly water-stressed river basins, upstream countries are building dams and siphoning off water with little or no consultation with their downstream neighbors. Much of the world's irrigated agriculture still uses highly inefficient flood irrigation schemes, rather than more efficient sprinkler or drip irrigation technologies. Many water-intensive crops are planted in areas of very high water stress. Most planning and water use around the world takes place without regard to how much water is sustainably available, causing groundwater levels to drop, rivers and lakes to dry out, and local ecosystems to collapse. The destruction of natural habitat further impairs surface water and groundwater quality. Poor land management practices are contributing to soil erosion and desertification, decreasing the amount of arable land available.

Although water risks are growing worldwide, many risk-reducing solutions are available (see Appendix A). We will explain how the solutions in Appendix A can be implemented through the six case studies we present below, which look at a broad range of water and security challenges in Iraq, Iran, India, the African Sahel, Central America, and Yemen.

About This Report

Purpose of the report. The purpose of this report is to illustrate and discuss how water-related challenges can be successfully addressed through comprehensive sets of "solutions." We present six case studies from around the world where water-related challenges are helping to drive conflict or instability, or where water systems are being targeted during conflict.

Roadmap for the report. Each of the case studies begins with a description of the factors driving these water-related challenges. We then describe the conflict or crisis itself. We conclude each case study by proposing solutions that could successfully address the water-related challenges. Each case study is summarized in the opening chapter ("Water Security Solutions for an Increasingly Water-Insecure World"), with details presented in the full case studies that follow. The opening chapter also includes a structured discussion of water security solutions, drawing on both the case studies and other recent research. Importantly, this structured discussion includes examples of the solutions being put into practice.

Intended audience for the report. This report, like our shorter introductory assessment (Gleick and Iceland 2018), is intended for professionals in the diplomacy, defense, development, and disaster-response fields, as well as for transboundary- and national-level decision-makers who want to address water and security at a strategic level. Civil society organizations and the private sector are important secondary audiences, as their participation is vital in many of the solutions we present.

Our Research Approach

In "Water, Security, and Conflict" (Gleick and Iceland 2018), we describe many types of water and security challenges and classify them under broad headings and subheadings; in this report, we move from describing problems to proposing possible solutions. Because there are few instances of integrated (or successful) solutions to water and security challenges in the developing world (or anywhere, for that matter), we have taken the novel approach of describing recent examples of water-related conflict or instability around the world and then proposing sets of solutions that we believe would reduce water-related risk.

We selected six countries or regions of the world currently facing severe water and security challenges and conducted extensive research to describe both the problems themselves and the major drivers of risk. We wished to learn what was driving the problems because we believe that the most effective solutions target the root causes of a problem rather than its symptoms. Our research yielded six case studies—for Iraq, Iran, India, the African Sahel, Central America, and Yemen—where we examine recent and ongoing instances of water-related conflict or instability and their key drivers. In conducting our research, we reviewed journal articles and think-tank pieces; analyses prepared by local sources and subject matter experts, practitioners, and government agencies; assessments prepared by international organizations; contemporaneous news articles; global and national databases, statistical analyses, and models; UN conventions and protocols; and monographs. We selected these case studies because they are both current and illustrative of a broad spectrum of problems.

At the end of each case study, we propose solutions that target the major drivers of risk. If one of the drivers of risk is the lack of effective transboundary water-sharing agreements, for example, we propose that such an agreement be negotiated or strengthened. If a driver of risk is the use of inefficient flood irrigation systems, we highlight the possible role of regional water demand caps and the implementation of agricultural water-efficiency improvements such as shifts to sprinkler or drip irrigation systems. Once we completed the six case studies, we developed a comprehensive list of all the solutions we proposed, broken down into four broad categories: (1) natural resources, science, and engineering approaches; (2) political and legal tools; (3) economic and financial tools; and (4) policy and governance strategies. We also drew on our prior research of other recent water crises (those described in "Water, Security, and Conflict," for example) and solutions that we believe would have contributed to reducing the risks in those cases. This comprehensive—though not exhaustive—list of solutions is included in Appendix A, which also provides brief definitions for each solution.

Most of the solutions included in Appendix A have been implemented elsewhere throughout the world. Some of the more novel solutions (e.g., "dietary choices") are under discussion by think tanks and other expert groups but have not yet been implemented on any large scale. The sets of solutions we propose in each case study have of course not been implemented; they are simply our recommendations based on our analysis of the problems and their principal drivers. The significance of this report is in offering a comprehensive list of water security solutions and illustrating how different combinations of these solutions—if successfully implemented—could mitigate the risk of water-related instability.

The solutions in Appendix A are by necessity generic. We do not indicate whether they are technically feasible in any given situation, or cost-effective, or politically viable, and so on. That assessment must still be done for each specific region. We do not prioritize any of these solutions. These are all issues that need to be addressed on an individual, case-by-case basis, and adapted to varying social, economic, and political contexts.

Results

In this section, we provide short summaries of our case study findings, including a brief description of the problem (e.g., conflict, migration due to water scarcity), its major drivers, and the priority solutions that we recommend implementing.

Iraq case study summary

Exceedingly poor water quality in southern Iraq triggered demonstrations against the government; demonstrations that turned violent.

Water as trigger of conflict:

- Reduced flows in the Tigris and Euphrates Rivers allow salt water to flow upstream from the Persian Gulf, ruining sources of fresh water and agricultural lands in southern Iraq.
- Untreated sewage is released throughout Iraq into the Tigris and Euphrates Rivers, further impacting water quality.

- In 2018, roughly 120,000 people in Basra were hospitalized after drinking polluted water.
- In mid-to-late 2018, demonstrations turned violent. Protesters were frustrated with lack of access to clean water and electricity. They also protested poor employment prospects and corruption in government.
- After going dormant for a while, violent protests resumed in October 2019 throughout much of Iraq, leading to the prime minister's resignation.

Drivers of risk:

- Growing population and water demand in all countries that share the Tigris-Euphrates basin.
- New upstream dams and water diversions in Turkey, Iran, and Syria.
- Climate change and worsening drought.
- Inefficient water use in agriculture and urban areas.
- Poor governance.
- Corruption.
- Destruction of water infrastructure over decades of violence.

Solutions:

- Repair and expand water delivery and sewage treatment systems in major cities.
- Develop comprehensive transboundary water-sharing agreements with other countries sharing the Tigris-Euphrates basin based on open and transparent data, including agreements that would increase flows into Iraq.
- Limit water use in water-stressed regions of Iraq.
- Enhance water-efficiency in agriculture and urban settings.
- Take steps to adapt to a hotter and dryer future, as climate change–related impacts worsen.
- Root out pervasive corruption. Although this is exceedingly difficult, it is critical for reforming and improving water management institutions and restoring public trust.

Iran case study summary

Overuse of water relative to available supplies led to internal tensions and violent conflicts over access to scarce water throughout much of the country. Water scarcity also led to disputes with neighboring countries over use of water in shared river basins.

Water as trigger of conflict:

- Communities in eastern Iran and western Afghanistan that share flows of the Hirmand/Helmand River have reported violence over water allocations and use.
- Severe droughts and internal water diversions from one region of Iran to another, followed by severe rains and floods, have led to major fluctuations in the levels of Lake Urmia, protests from Iraq over dust levels, and concerns about water availability in tributaries of the Tigris River.
- Internal protests over diversions of water between Iranian provinces have turned violent.
- In southwestern Iran, adjacent to the Persian Gulf, poor water quality due to pollution and salinization has led to violent protests. The problems are similar to those in Basra, just across the Iran-Iraq border.

Drivers of risk:

- A rapidly growing population in a region with only modest renewable water resources.
- Water sources that are extensively shared with neighboring countries, but without effective multinational/transboundary agreements to govern management and use of water in those river basins.
- Worsening impacts of severe droughts and floods.
- Construction of dams, water diversions and pipelines, and economic subsidies for agricultural communities have helped Iran develop deep expertise in hydrology and water institutions, but they also have contributed to social concern and unrest over perceived inequalities in access to water.

- Water-resources management currently prioritizes human withdrawals of water over the ecological impacts on Iran's wetlands and internal lakes.

Solutions:

- Restructure agriculture to improve water-use productivity and reduce the pressure for internal redistribution of water.
- Pursue open discussions with neighboring countries to create or update treaties providing for joint management of shared water resources.
- Strengthen governance by establishing independent water institutions and management agencies insulated from political infighting among regional entities.
- Pursue water management approaches that reach out to and consult with key stakeholders.

India case study summary

Recent drought conditions throughout India have sparked violent and nonviolent demonstrations and marches, led to disputes between states over scarce water supplies, left urban dwellers without water, and forced rural inhabitants to flee their towns and villages.

Water as trigger of conflict:

- Numerous recent violent and nonviolent protests over access to water.
- In Bengaluru, protesters rioted in 2016 after the Supreme Court ordered the state of Karnataka to release more water to downstream Tamil Nadu.
- In 2017, political conflict between the states of Madhya Pradesh (MP) and Gujarat over sharing of water from the Narmada River was accompanied by deadly protests in MP over insecure farm incomes made worse by drought.
- In 2019, 50,000 farmers in Maharashtra staged a peaceful march on Mumbai over unmet water-related demands on government.
- Chennai, India's sixth-largest city, ran extremely low on water in 2019 following deficient rainfall in 2017 and 2018. Competition for access to scarce water supplies (which had to be trucked in) led to some violence.

Drivers of risk:

- Chronic water stress throughout much of the country (water demands are too high relative to available supply).
- Very pronounced seasonal variability in rainfall, making the country highly vulnerable to failures of the monsoons.
- Very large population, which is expected to continue growing until about 2060.
- Inefficient water use in agriculture.
- Food loss and waste.
- High vulnerability associated with extreme poverty.
- Poor water governance and conflicts between national and state-based policies.

Solutions:

- Improve water-use efficiency in agriculture.
- Increase water storage.
- Protect ecosystems and establish and implement minimum river-flow commitments.
- Establish water-use limitations in high water-stress areas.
- Establish or strengthen interstate water-sharing agreements.
- Increase water prices (along with subsidies to protect the poor).

- Improve water management.
- Raise the status of women in society.
- Reduce population pressures.

African Sahel case study summary

Increasing scarcity of water and land resources has led to more frequent and intense violence between local farmers and pastoralists.

Water as trigger of conflict:

- Violence between farmers and herders in various regions of the Sahel goes back many years, but it has escalated since 2018.
- In the first nine months of 2018 alone, over 1,700 violent deaths attributed to these conflicts were reported in western and central Nigeria.
- In March 2019 and continuing in 2020, violence escalated in Mali, where conflict among Fulani herders, Dogon and Bambara farmers, and Bozo fishers in the Mopti region led to several hundred deaths. The violence in this part of Mali revolves around use of and access to watercourses and land, sharing of resources, and the seasonal migration of livestock, but it also has a growing ethnic and religious component.
- In April 2019, failure to adequately address the violence led to the collapse of Mali's government and the resignation of the prime minister.

Drivers of risk:

- Competition for water and land in the Sahel has long pitted farmers against nomadic pastoralists.
- In the past few years more violence has been reported for many reasons:
    - Expansion of settled communities as populations have grown
    - Appropriation of watering holes and lands formerly used by nomadic groups
    - Damage to crops by cattle
    - Changes in hydrology and climatology that push herders further south in search of adequate water and grazing land
    - Weakening of traditional conflict-resolution approaches such as payment of compensation and local mediation
    - Growing religious extremism among the different cultural groups

Solutions:

- Because so many of the disputes between herders and farmers revolve around access to water resources and grazing land, strategies are needed to reduce inequitable water and land rights and clarify political and economic control of water.

- In Nigeria, Mali, and Ghana, some communities are seeking to set aside permanent grazing areas, protected migration pathways, and water reserves to reduce herding challenges and uncertainties about seasonal conditions.
- Some observers have recommended more efficient irrigation systems and expanded water catchment and water conservation policies to improve water availability.
- Policies to expand soil restoration and reforestation and to improve farming and tilling practices have also been identified as reducing tensions between farmers and herders.
- Under certain circumstances, local community security groups and peacekeepers can provide both local protection as well as opportunities for mediation, though there is a risk that armed groups not under the control of formal governmental structures can worsen vigilantism and sectarian violence.

Central America case study summary

Five years of drought in the "Central American Dry Corridor" have forced many subsistence farmers to abandon their lands and migrate to regional cities or to the United States in search of work to support themselves and their families.

Water as trigger of migration:

- Severe drought and acute food insecurity over the past five years in Central America's "Dry Corridor" have forced many subsistence farmers and families to leave their farms in search of new opportunities. Many of these farm families have decided to migrate to the United States.
- By 2018, the number of Central Americans crossing the U.S. border (specifically, from Guatemala, Honduras, and El Salvador) surpassed the number from Mexico (Shear et al. 2019), exacerbating political tensions in the United States over this issue.
- A 2018 U.S. Customs and Border Protection report documented this severe food insecurity problem and its link to U.S. migration (NBC News 2019; *Scientific American* 2019).

Drivers of risk:

- The frequency and intensity of drought has been increasing in recent years. There is a documented drying trend in the region.
- Populations have been growing significantly in some of the affected countries.
- Many affected farmers live well below the poverty line and lack resources to adapt to changing climate conditions.
- Few government services are available to help these farmers adapt to changing climate conditions or to assist them during times of acute food insecurity.

Solutions:

- Agricultural extension services can help farmers determine optimal crops for their regions, when they should be planted, and how yields can be maximized under changing climate conditions. They can also help farmers increase water-use efficiency and reduce postharvest food loss.
- Data and information services can help farmers identify optimal dates for planting various crops, reducing the uncertainty associated with changing weather patterns.
- Early warning systems can give farmers advance notice of extreme weather.
- Reforesting land in the region may help moderate temperature and absorb rainfall, thereby stemming crop losses.
- These countries can strengthen disaster-response policies and social safety net programs to backstop other more proactive, resilience-building measures.
- These countries should consider taking measures to elevate the status of women and reduce population pressures.
- In order to address migration pressures more generally, these countries will need to expand economic opportunities in the manufacturing and services sectors to accommodate migration from rural areas to urban areas.
- The countries must take aggressive measures to curb gang violence.

Yemen case study summary

Water infrastructure in Yemen has been regularly targeted for destruction as a way to gain military advantage over and apply pressure on opposing parties.

Water as casualty of conflict:

- Unlike the other cases, in Yemen we look at water systems as casualties of conflict, rather than water-scarcity or quality problems as triggers of conflict.
- The splintering and disintegration of Yemen has been underway for decades but has worsened with the onset of civil war. The current conflict began in March 2015 over competing claims about who represents and controls the official government.
- Because of Yemen's strategic location at the intersection of the Red Sea and Arabian Sea, and because of the religious and ideological tensions splintering the area, the conflict has since expanded to include major outside and proxy groups.
- A major current challenge is the apparent effort to weaken opposing forces through widespread targeting of civilian infrastructure, especially energy and water systems. There has been an intensive series of attacks, largely in the form of air strikes, on water utilities, water purification plants and distribution systems, wells and water tankers, pipelines, and water drilling equipment.
- Between the start of the civil war in 2015 and 2019, there have been over 100 recorded attacks on water-related infrastructure. These attacks have led to a huge increase in the numbers of people without access to safe water and sanitation and have contributed directly to massive disease outbreaks that began in 2016 and continue today.

Drivers of risk:

- Where civilian infrastructure is thought to be of strategic or economic importance, the moral, ethical, and legal constraints that are supposed to protect civilians often fail. This has been the case in Yemen over the past several years.
- Much of the heavily populated regions of Yemen suffer from high or extremely high levels of water stress, and groundwater tables have been falling in and around the major cities. Warring parties have seized on this vulnerability and sought to exploit it—at the expense of Yemen's civilians.

Solutions:

- International laws of war—also called international humanitarian laws—explicitly include protections for a wide range of civilian infrastructure, including water systems.
- These laws prohibit intentional attacks targeting civilians and require that accidental or collateral damages in war not be excessive compared to military advantages gained.
- The failure of these laws to protect water systems in Yemen suggests that they are either inadequate or inadequately enforced.
- Clarification or expansion of protections afforded by existing laws of war is needed. Countries and groups not currently bound by existing international laws should be encouraged to abide by the existing conventions (Gleick 2019b).
- Some efforts could be made to harden water systems or improve the ability to repair them in the event of damage or destruction, but no level of hardening can protect civilian water systems from intentional efforts to destroy them.

While solutions to water and security challenges can usually be identified, they are often difficult to implement for a number of reasons, among them the political and economic trade-offs inherent in the proposed solutions (i.e., the fact that some members of society will "lose" as a result of the proposed solutions), problems generally associated with collective action (such as the "free rider" problem),[1] lack of sufficient financial resources and/or technical capacity, the presence of social or cultural barriers, and the existence of widespread and entrenched corruption. There is extensive literature addressing ways to overcome each of these types of barriers, but a discussion of these approaches is beyond the scope of this report.

Conclusions and Recommendations

More and more countries throughout the world are confronting water insecurity as water demands increase and water supplies decrease and/or become more erratic. In addition, pollution is rendering many sources of water supply unfit for use in many or all applications. In many parts of the developing world, lack of access to safe and affordable water for drinking, hygiene, and household use adds to the burden caused by underlying water quantity and quality challenges.

While solutions exist on paper, they are often difficult to apply politically. As these challenges to social stability grow, we need to mobilize the political will and economic and technical capacity to effectively address them. This will require concerted efforts involving the international community; national, state, and local governments; competing water users; and other key stakeholder groups.

Among the first things needed to confront these challenges are data and information systems that can help monitor conditions and provide early warning of potential problems. It is very important for the international community and affected countries to have as early a warning as possible that water risks are growing and that crises may be at hand. As examples, the Water, Peace, and Security (WPS) partnership has developed a global conflict early warning tool that identifies high-risk areas based on indicators such as rainfall, crop health, poverty levels, population growth, and so on (WPS Global Early Warning Tool 2019). The U.S. Agency for International Development and its partners have developed the Famine Early Warning System Network (FEWS NET) to give advance notice of food shortages.

Once high-risk areas are identified, the international community should have rapid response teams that can assist at-risk countries. These teams can catalyze the identification and implementation of solutions by helping global, regional, national, state, and local leaders better understand the nature of the problem(s), the major drivers of risk, and potential ways to address the problem. The WPS partnership, for example, has developed tools to conduct local-level rapid analyses for hotspot areas, capacity-building and training modules for decision-makers and resource managers, approaches for convening relevant stakeholders and establishing legitimate decision-making processes, and approaches to dispute resolution.

Most solutions require significant funding. The rapid response teams should therefore have the backing of development banks, bilateral aid agencies, the private sector, and other sources of funding that can furnish needed grants or loans. Funds should be set aside by these organizations specifically to address emerging water and security crises.

The challenge of collective action is significant, but it can be overcome if and when societies recognize the benefits of needed changes and the perils of continuing with "business as usual." Consensus on collective action is the product of national (or global, regional, state, or local) dialogues. Such consensus enables the rewarding of compliance with desired actions (e.g., with tax breaks) and the imposition of penalties for noncompliance (in the form of fines, criminal penalties, etc.).

After reading some of the case studies, the problems may seem insurmountable and the solutions unattainable. Most complex problems can be broken down and tackled piece by piece, however. We have tried—in the six case studies we present—to identify the key underlying drivers of the problems and let these sets of drivers guide the identification of priority solutions.

Abbreviations

BAU	business as usual
bcm	billion cubic meters
FAO	Food and Agriculture Organization of the United Nations
FEWS NET	Famine Early Warning System Network
GAP	Southeastern Anatolia Project (from the initials in Turkish)
GRACE	Gravity Recovery and Climate Experiment
IDB	Inter-American Development Bank
IFAD	International Fund for Agricultural Development
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
ISIS	Islamic State of Iraq and Syria
km	kilometer
m^3	cubic meters
m^3/p/yr	cubic meters per person per year
MENA	Middle East and North Africa
mm	millimeters
MP	Madhya Pradesh
MSP	minimum support price
NAIS	National Agricultural Insurance Scheme
NASA	National Aeronautics and Space Administration
NIC	U.S. National Intelligence Council
OAS	Organization of American States
OECD	Organisation for Economic Co-operation and Development
ONEA	Office National de l'Eau et de l'Assainissement (National Water and Sanitation Office, Burkina Faso)
TDS	total dissolved solids
WFP	World Food Programme
WHO	World Health Organization
WPS	Water, Peace, and Security

SECTION I

WATER SECURITY SOLUTIONS FOR AN INCREASINGLY WATER-INSECURE WORLD

This report examines six countries and regions throughout the developing world where water resource problems have undermined human security and led to violent conflict or otherwise destabilized society. Our research identifies factors driving these crises and recommends comprehensive sets of solutions to alleviate them. Through the examination of these crises and other recent research, we offer a comprehensive list of water security solutions organized into four broad categories: natural resources, science and engineering approaches; political and legal tools; economic and financial tools;
and policy and governance strategies.

In recent years, a wide range of water-related factors have contributed to political instability, human dislocation and migration, agricultural and food insecurity, and violence. Demand for water has grown as populations and economies expand, while the availability and quality of water resources is increasingly influenced by industrial activities, water pollution, and human-induced climate change (Gleick and Iceland 2018). While water-related factors have posed challenges to human civilizations throughout history, water-related violence appears to be increasing (Gleick 2019b) as pressures on water resources have grown, undermining water access and quality, and as broader political violence spills over into the civilian water-services sector.

Although water risks are increasing worldwide, there are many strategies to reduce water conflicts and improve water security. Identifying and understanding these strategies, where they might be most effectively applied, and how to overcome barriers to implementing them is vital to efforts to move away from conflict and toward cooperation.

Based on an analysis of six recent water and security case studies and other recent research, this report offers a comprehensive list of water security solutions and illustrates how different combinations of these solutions—if successfully implemented—could help to mitigate the risk of water-related instability.

Solutions to water and security challenges can be described and categorized in many ways. Here, we describe four broad categories of strategies:

1. Natural resources, science, and engineering approaches
2. Political and legal tools
3. Economic and financial tools
4. Policy and governance strategies

Natural resources, science, and engineering approaches. This category includes measures that reduce pressures on water resources by increasing supply, improving the efficiency of water use and decreasing demand, and improving water quality. Water users can pursue water-efficiency and conservation technologies and policies, new centralized or decentralized sources of water, treatment technologies, and data collection and information systems that improve water management.

Political and legal tools. Political and legal measures can improve water management and use or resolve disputes. Examples include water-use limitations or demand caps, transboundary and subnational water-sharing agreements, international humanitarian laws, human rights law, and land and water-rights reform.

Economic and financial tools. Pricing, markets, and other economic approaches can influence both water supply and demand, address water disputes and tensions, and improve management. Some options include innovative utility pricing strategies, reduction or elimination of harmful subsidies, and social safety net programs that protect basic human needs.

Policy and governance strategies. Some conflicts over water result from failures of water management, weak or ineffective governments and institutions, inappropriate or missing policies, or out-of-date approaches. Options for improving water management in this category include governance approaches; reduced corruption; more stakeholder and community engagement; integrated water, food, and energy strategies; and policies that address demographic trends and challenges.

Report Roadmap

We present six case studies from around the world where water-related challenges are helping to drive conflict or instability, or where water systems are being targeted during conflict. Each of the case studies begins with a description of the factors that are driving these water-related challenges. We then describe the conflict or crisis itself. We conclude each case study by proposing solutions to address the water-related challenges. Each case study is summarized in this opening chapter, with details presented in the full case studies that follow. This chapter also offers information and insights on solutions to water security challenges, both from the case studies and from other recent research. Importantly, this discussion of solutions includes examples of the solutions being put into practice.

Definitions

Water security

The case studies prepared for this project address a broad set of security issues related to freshwater resources. The term *security* has different meanings and connotations to different communities. For purposes of this report, we define water security as the capacity of a population to

- safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socioeconomic development;
- protect against water pollution and water-related disasters; and
- preserve ecosystems, upon which clean water availability and other ecosystem services depend (Gleick and Iceland 2018).

Water scarcity and water stress

Water scarcity. Metrics of water scarcity developed by Malin Falkenmark et al. (1989) indicate that regions with rainfall of 500 to 1,000 cubic meters per person per year (m^3/p/yr) face chronic water scarcity; regions with less than 500 m^3/p/yr face fundamental constraints to human development and well-being.

Water stress. Water stress measures the ratio of total water withdrawals to available renewable surface and groundwater supplies. Higher values indicate more competition among users. Values between 40 and 80 percent indicate "high" water stress. Values above 80 percent indicate "extremely high" water stress (Hofste et al. 2019a).

Forms of conflict

Water-related security challenges include localized crises in the form of water scarcity, contamination, or excess, up to and including larger-scale challenges associated with agricultural and food security, population displacements, and transboundary water disputes. These are cases where water scarcity or disputes over control of water **trigger** conflict. A second set of water-related conflicts involves the use of water resources or water systems as **weapons**. A third category of conflict includes water resources or water systems as **casualties** of conflict. These categories are taken from the Water Conflict Chronology work done at the Pacific Institute. Cases in the second and third categories are often ignored in the water-conflict literature, but they are growing in number and show both the value of safe water and sanitation systems for the functioning of stable communities and the challenges communities face when such systems are not available (Gleick 2019b). As a result, it is vital that any assessment of water and security issues address the trends in these categories of cases and strategies for reducing these risks.

For purposes of this report, we define three forms of conflict as follows:

- **Trigger**: Water as a trigger or root cause of conflict, where there is a dispute over the control of water or water systems, or where economic or physical access to water, or scarcity of water, triggers violence. For example, a series of massacres in central Mali, fueled by conflict over land and water resources, caused 50,000 people to flee their homes in 2019.
- **Weapon**: Water as a weapon of conflict, where water resources, or water systems themselves, are used as an instrument of violence. For example, the Islamic State in 2014 deliberately contaminated drinking water with crude oil in the Balad district of the Salahaddin Governorate. Poisoned water supplies were also reported in Aleppo, Deir ez Zor, Raqqa, and Baghdad.
- **Casualty**: Water resources or water systems as a casualty of conflict, where water resources or water systems are targets or casualties of violence. For example, many water supply, treatment, and distribution systems have been hit in Yemen during air raids in recent years. (Gleick 2019a; Gleick 2018).

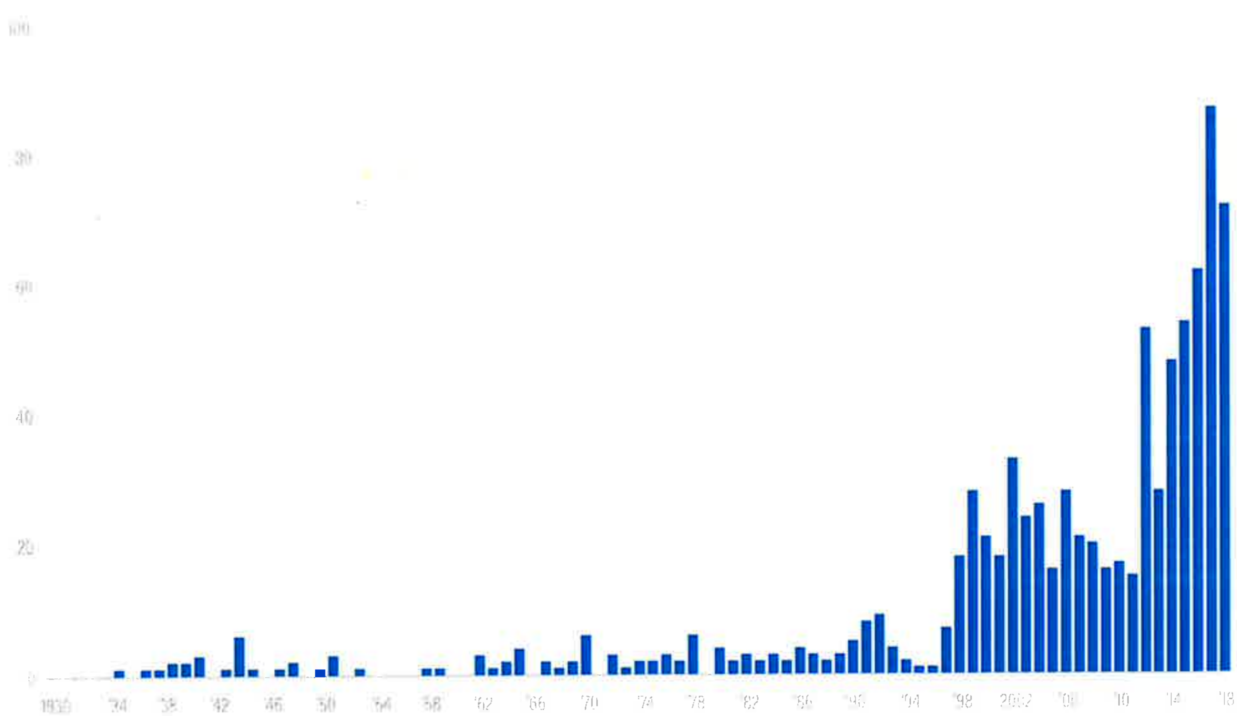
Water security challenges

In "Water, Security, and Conflict" (Gleick and Iceland 2018), we described various categories of water-related challenges that have triggered instability or violence over water, including (1) scarcity primarily due to diminished water supply or diminished water quality, (2) scarcity primarily due to increased water demand, and (3) disruptions from extreme floods. These and other pathways can combine with social and political factors to produce a crisis, especially where governance or states are weak (Sadoff et al. 2017). The exact nature of the crisis varies from case to case. In some cases, the crisis comes in the form of politically destabilizing or violent conflict. In other cases, the crisis comes in the form of large-scale, destabilizing migration or famine. Sometimes it is a large-scale public health crisis. Recently we even witnessed a large city of several million people run out of water, requiring inhabitants to wait in long lines for drinking water, raising tensions, and leading to instances of violence over water. The crisis, of course, can also be a combination of the above. Understanding pathways and timelines, as well as the complex interaction of multiple factors at work in a crisis, is vital to help policymakers design effective policy responses.

Water security solutions

Water problems do not necessarily lead to conflict—in fact, violence associated with water systems and problems is the exception, not the rule. But the risks and incidences of water-related violence appear to be on the rise (see Figure 1) and the factors that play into such conflicts seem to be increasing (although we acknowledge that some of the increase in water conflict event data is likely due to improved reporting and dissemination of news in the internet era).

Figure 1 | The Trend in Incidences of Violence Associated with Water Resources and Water Systems, 1930 to 2018



Source: Gleick (2018), October 2019 update.

The purpose of this report is to address the growing problem of water-related conflict and other forms of instability by exploring solution sets that can reduce risk and enhance security. Water solutions can be especially attractive because they offer a platform for slowly building trust between conflicting parties even as other drivers of hostilities remain (for additional insights on leveraging water diplomacy as a force for peace, see SDC 2020). Table 1 includes a comprehensive set of water security solutions derived from our analysis of six case studies and other recent research. The table also maps the applicability of these solutions to different forms of water conflict; namely, water as a trigger, weapon, or casualty of conflict. We discuss these solutions in greater detail below.

Table 1 | Water Security Solutions: Forms of Conflict and Types of Response

TYPES OF RESPONSES	APPLICABILITY OF THE RESPONSES TO DIFFERENT FORMS OF CONFLICT[a]		
Natural Resources, Science, and Engineering Approaches	**Trigger**	**Weapon**	**Casualty**
Water efficiency and conservation improvements	●		
Traditional water supply expansion measures (i.e., "hard" measures)	●		
New centralized sources of water (wastewater treatment and reuse, stormwater capture, desalination, etc.)	●		
New decentralized sources of water (rainwater capture, graywater reuse, etc.)	●	●	●
Reduction in nutrient and pesticide pollution from agriculture (crops and livestock)	●		
Improved water capture and storage (surface and groundwater)	●		
Ecosystem and soil restoration	●		
Data collection and information systems	●		
Agricultural extension services	●		
Leak-detection technologies and reduced water losses	●		
Joint scientific exchanges	●		
Protection and hardening of civilian water infrastructure		●	●
Water, sanitation, and hygiene (WASH) infrastructure and services	●		
Political and Legal Tools	**Trigger**	**Weapon**	**Casualty**
Improvement and enforcement of international humanitarian laws and human rights laws		●	●
Water and land rights reform	●		
Legal ecological flow commitments	●		
Water-use limitation and demand caps	●		
Food security policies, open global food market access	●		
Disaster-response policies (e.g., for droughts and floods)	●		
Human right to water and sanitation and the right to a healthy environment	●	●	●
Multistakeholder peacekeeping groups	●	●	●

Table 1 | Water Security Solutions: Forms of Conflict and Types of Response (Cont.)

Political and Legal Tools	Trigger	Weapon	Casualty
Strengthened national environmental laws			
Training for militaries in international humanitarian law			
Water-sharing agreements: subnational			
Water-sharing agreements: transboundary			
Interbasin transfer agreements			
Economic and Financial Tools	Trigger	Weapon	Casualty
Access to water development financing			
Alternative crops			
Alternative landscaping			
Reduction in food loss and waste			
Water, food, and agricultural subsidies			
Water prices			
Water markets			
Insurance strategies for farmers			
Social safety net programs			
Dietary choices			
Policy and Governance Strategies	Trigger	Weapon	Casualty
Decentralization of water management			
Cross-agency collaboration			
Stakeholder and community engagement			
Immigration and emigration policies (intranational and international)			
Gender equality			
Population policies			
Urban and rural development policies			
Improved governance (intranational and international)			
Reduced corruption			
Improved water management			

Note: [a] In most cases, the applicability of these responses to different forms of conflict is relatively intuitive and straightforward. Three types of response can be applicable to all three forms of conflict. These include (1) solutions that decentralize water infrastructure or water management, (2) solutions that generally foster agreement among water users, and (3) solutions that involve peacekeepers

Source: Authors.

Water-Related Instability and Conflict: Summaries of Case Studies

The best way to illustrate how these solutions can be applied in practice is by presenting a number of recent case studies. We have developed six in-depth case studies for this report. Summaries of the six in-depth case studies are presented below, with the full case studies included in the chapters that follow.

Iraq

Drivers of risk. There are numerous drivers of water-related risk in Iraq. Growing populations and water demand in all countries in the region are putting mounting pressure on the shared waters of the Tigris and Euphrates Rivers. Together, these rivers account for over 98 percent of all water used in Iraq (Abd-El-Mooty et al. 2016). New upstream dams and water diversions in Turkey, Iran, and Syria are reducing flows to Iraq. Drought and climate change are also reducing water supply. Inefficient water use is common in both agricultural and urban systems. Poor governance and corruption are preventing improvements in the infrastructure for clean water supply and wastewater treatment, as well as in holding polluting industries accountable. And decades of violence have taken a toll on Iraq's water infrastructure.

Water as trigger of conflict. Reduced flows in the Tigris and Euphrates allow salt water to flow upstream from the Persian Gulf, ruining sources of freshwater supply (and productive land) in southern Iraq. The pollution of freshwater sources by salt water is compounded by the fact that most of Iraq's sewage is released into the Tigris and Euphrates untreated. Beginning in July 2018, thousands of people began demonstrating in southern and central Iraq, protesting against poor services, including undrinkable water and chronic power outages, along with concerns over unemployment, corruption, and perceived Iranian interference in local affairs. These demonstrations turned violent, with security forces using live ammunition, tear gas, and water cannons on the crowds. The protests escalated in Basra—where water conditions were especially bad—in late August and early September 2018, with the protesters targeting "pretty much every government office, bureaucrat, political party, and armed group in the city that wields any power and influence" (*Vox* 2018). Around this time, nearly 120,000 people in the Basra area were hospitalized after drinking polluted water (AFP News 2019), with officials warning of a possible resurgence of cholera in the region (*New Arab* 2018). After dying down for a few months, violent protests over unemployment, corruption, and lack of services (including clean water and electricity) erupted anew across many Iraqi cities in October 2019.

Solutions. There are many steps Iraq can take to lower water risk and the incidence of water-related violence. Investments in repairing and vastly expanding water and sewage systems in the major cities are critically needed and would help address concerns about government corruption and lack of basic services. In addition, there remains a critical need for comprehensive transboundary water-sharing agreements for the Tigris and Euphrates Rivers that will increase water flows into Iraq, water-use limitations in areas of Iraq where demand is too high relative to supply, and water-efficiency improvements in both agricultural and urban settings. Iraq also needs to take steps to adapt to a hotter and dryer future, as climate change impacts have already begun to manifest themselves. We discuss these and other measures in greater detail in the case study.

Iran

Drivers of risk. Iran faces a complex set of water-related problems driven by a growing population in a region with only modest renewable water resources (extensively shared with neighboring countries), internal disputes over water allocations and management, and the worsening impacts of both severe droughts and floods.

Water as trigger of conflict. Traditional approaches to water management, including the construction of dams, water diversions and pipelines, and economic subsidies for agricultural communities have helped Iran develop deep expertise in hydrology and water institutions, but they also have contributed to social concern and unrest over perceived inequalities of access to water. Agricultural subsidies have also distorted economic incentives and price signals, driving inefficient and unsustainable water use, groundwater overdrafts, and cropping patterns divorced from actual hydroclimatic conditions. In addition, Iran has prioritized human withdrawals of water over the ecological impacts of these withdrawals on its lakes and wetlands.

Several examples of conflicts and violence over water resources in Iran have arisen in recent years. Communities in eastern Iran and western Afghanistan that share flows of the Hirmand/Helmand River have reported violence over allocations and water use. Severe droughts and internal water diversions from one region to another, followed recently by severe rains and floods, have led to major fluctuations in the levels of Lake Urmia, protests from Iraq over dust levels, and concerns about water availability in tributaries of the Tigris River. Internal protests over diversions of water between Iranian provinces have turned violent.

Solutions. New strategies to address concerns over water could include efforts to restructure agriculture to improve water-use productivity and reduce the pressure for internal redistribution of water; open discussions with neighboring countries over joint management of shared water resources, including new or updated treaties; water allocations to ecosystems; and improved independent water institutions and management agencies insulated from political infighting among regional entities.

India

Drivers of risk. India is one of the most water-stressed countries in the world (Hofste et al. 2019b; Gassert et al. 2014). More than half of India's total area faces high to extremely high levels of water stress (Shiao et al. 2015). In addition, India's seasonal variability of water supply is very pronounced (Aqueduct Water Risk Atlas 2019): about half of India's rain falls in just 15 days, and over 90 percent of river flows occur in just four months (Briscoe and Malik 2006). Many years, the monsoon fails, worsening scarcity, as it did in Tamil Nadu in 2018, when this contributed to the drying up of Chennai's reservoirs. Other drivers of water risk include high population, unsustainable and wasteful water use, vulnerability to extreme weather, food loss and waste, and a complex and outdated water management regime.

Water as trigger of conflict. Over the past several years, drought and disputed control of water have been central to highly publicized protests by farmers and urban dwellers in India and pitted Indian states against one another. When the Indian Supreme Court ordered the state of Karnataka to release water from its reservoirs to relieve drought-stricken farmers in neighboring Tamil Nadu in September 2016, protest riots broke out in Karnataka's capital, Bengaluru, until thousands of police were deployed to restore order (Gleick and Iceland 2018). Drought in 2017 led to a conflict over how much water should be released from the Indira Sagar reservoir in Madhya Pradesh (MP) to the downstream Sardar Sarovar reservoir in Gujarat, and five people were reported killed during protests in MP over insecure farm incomes made worse by repeated drought and crop failures (CNN 2017). Severe drought in 2019 prompted over 50,000 farmers in Maharashtra to begin a 180 kilometer (km) peaceful march to Mumbai to protest unfulfilled demands on the government, including "complete loan waiver[s], compensation, relief and insurance for crop damage in situations like drought, a higher minimum support price (MSP) for crops, land rights, irrigation facilities, and pension schemes for farmers among others" (Mitra 2019). In June 2019, in the wake of deficient rainfall in 2017 and the failure of the monsoon in 2018, Chennai—India's sixth-largest city—ran out of water and was left dependent on water tanker trucks for basic drinking water and sanitation needs (*India Today* 2019a). Several instances of violence were reported among residents fighting over water rations (CNN 2019; *Time* 2019; *The Wire* 2019). Monsoonal rains arrived in the weeks and months after the Chennai reservoirs ran dry, but the city will remain vulnerable to future droughts until significant water resource management improvements are implemented.

Solutions. The complexity and diverse nature of water challenges in India means that no single solution or set of solutions can be applied universally, but there are many options to lower water risk and water insecurity. These measures include increasing water-use efficiency and conservation in agriculture, increasing water storage, protecting ecosystems and implementing ecological flow commitments, establishing water-use limitations in oversubscribed watersheds and aquifers, creating or strengthening interstate water-sharing agreements, increasing water prices, improving water management, improving water services within cities and providing more drinking water access points for poor residents, elevating the status of women in society, and reducing population pressures. The India case study provides details on these and other options.

African Sahel

Drivers of risk. Competition for water and land in the Sahel has long caused tensions between farmers and nomadic pastoralists. In the past few years more violence has been reported for many reasons: an expansion of settled communities as populations have grown; appropriation of watering holes and lands formerly used by nomadic groups; damage to crops by cattle; changes in hydrology and climatology that push herders further south in search of adequate water and grazing land; the weakening of traditional conflict-resolution approaches, such as payment of compensation and local mediation; and growing religious extremism among the different cultural groups (McGregor 2017; Patience 2016; Sulaiman and Jaafar-Furo 2010).

Water as trigger of conflict. Violence between farmers and herders in Kenya, Tanzania, Nigeria, Mali, Ghana, and other countries in Africa goes back many years, but it has escalated since 2018. In the first nine months of 2018 alone, over 1,700 violent deaths were attributed to these conflicts in western and central Nigeria (Adeoye 2018; Institute for Economics and Peace 2018; Toromade 2018b). In March 2019, violence escalated in Mali, where conflict among Fulani herders, Dogon and Bambara farmers, and Bozo fishers in the Mopti region led to several hundred deaths. The violence in this part of Mali revolves around use of and access to watercourses and land, sharing of resources, and the seasonal migration of livestock, but it also has a growing ethnic and religious component (Diop 2019; Hackleton 2019). Failure to adequately address the violence led to the collapse of Mali's government and the resignation of the prime minister in April 2019 (Al Jazeera News 2019b).

Solutions. Because so many of the disputes between herders and farmers revolve around access to water resources and grazing land, strategies are needed to reduce inequitable water and land rights and clarify political and economic control of water. In Nigeria, Mali, and Ghana some communities are seeking to set aside permanent grazing areas, protected migration pathways, and water reserves to reduce herding challenges and uncertainties about seasonal conditions. Some observers have recommended more efficient irrigation systems and expanded water catchment and water conservation policies to improve water availability. Policies to expand soil restoration, reforestation, and improve farming/tilling practices have also been identified as beneficial for reducing tensions between farmers and herders. Under certain circumstances local community security groups and peacekeepers can provide both local protection as well as opportunities for mediation, though there is a risk that armed groups not under the control of formal governmental structures can worsen vigilantism and sectarian violence.

Central America

Drivers of risk. *Central American Dry Corridor* is a relatively new term for a region increasingly at risk from frequent and devastating droughts, especially during El Niño years. Ecologically speaking, it is a "tropical dry forest region on the Pacific side of Central America that stretches from the Pacific Coast of Chiapas, Mexico, to the western part of Costa Rica and western provinces of Panama." During El Niño years, "precipitation drops by 30%–40%, with long periods of heatwaves during which there is hardly any rainfall" (FAO 2017). In recent years, droughts have been increasingly frequent and intense (FAO 2017). Between 40 and 50 percent of the region's inhabitants live in rural areas, many well below the poverty line. Little infrastructure and few services are available to help these communities when severe droughts (or floods) hit the region (FAO 2017). Populations in most Central American countries have been growing significantly over the past few decades.

Water as trigger of migration. Severe drought, together with other impacts of a changing climate, such as shifting rainfall patterns, frosts, and new pests, have contributed to significant crop losses and sharp increases in migration from Central America to the United States. By 2018, the number of Central Americans crossing the U.S. border (specifically from Guatemala, Honduras, and El Salvador) surpassed the number from Mexico (Shear et al. 2019). There are other powerful drivers of migration from Central America to the United States, including gang-related violence and better economic opportunities more generally.

Solutions. A number of solutions can lower drought-related risk and insecurity in the Dry Corridor. Agricultural extension services can help farmers determine optimal crops for their regions, when they should be planted, and how yields can be maximized under changing climate conditions. They can also help farmers become more water efficient and reduce the incidence of postharvest food loss and waste. Data and information services can help farmers identify optimal dates for planting various crops, reducing the uncertainty associated with changing weather patterns. Early warning systems can give farmers more time to prepare for extreme weather (Arcanjo 2018). Anecdotal evidence suggests that reforesting land in the Dry Corridor can help moderate temperature and absorb rainfall, thereby stemming crop losses (Blitzer 2019; Shapiro and Blitzer 2019). And Dry Corridor countries can strengthen disaster-response policies and social safety net programs to backstop other, more proactive, resilience-building measures. Raising the status of women in society and reducing population pressures would ease demand-side pressures on water resources. In order to address migration pressures more generally, these Central American countries will need to expand economic opportunities in the manufacturing and services sectors, as well as take aggressive measures to curb gang violence. Additional solutions are discussed in the Central America case study.

Yemen

Drivers of risk. Unlike in the other countries and regions studied, where tensions and violence over water are associated with disputes over access to or control of water, the Yemen case study provides insight into the vulnerability of built water-supply and sanitation systems to conflicts that start for other reasons, especially in regions where water

resources are very scarce (water has been a trigger of many conflicts in Yemen; however, our case study focuses on water as a casualty of conflict). Numerous examples of intentional attacks on water infrastructure, including wells, dams, irrigation systems, water treatment and distribution plants, and energy facilities critical for the operation of built water systems, can be found throughout history, from ancient times through the major wars of the 20th century to the present. Where civilian infrastructure is thought to be of strategic or economic importance, the moral, ethical, and legal constraints that are supposed to protect civilians often fail. This has been the case in Yemen over the past several years.

Water as casualty of conflict. The splintering and disintegration of Yemen has been underway for decades but has worsened with the onset of civil war (Gleick 2019b). The current conflict began in March 2015 over competing claims about who represents and controls the official government. Because of Yemen's strategic location at the intersection of the Red Sea and Arabian Sea, and because of the religious and ideological tensions splintering the area, the conflict has expanded to include major outside and proxy groups. A major current challenge is the apparent effort to weaken opposing forces through widespread targeting of civilian infrastructure, especially energy and water systems. There has been an intensive series of attacks, largely in the form of air strikes, on water utilities, water purification plants and distribution systems, wells and water tankers, pipelines, and water drilling equipment. Between 2015, when the civil war began, and 2019, there were over 100 recorded attacks on water-related infrastructure (Pacific Institute 2019). These attacks have led to a huge increase in the numbers of people without access to safe water and sanitation and contributed directly to massive disease outbreaks that began in 2016 and continue today.

Solutions. International laws of war—also called international humanitarian laws—explicitly include protections for a wide range of civilian infrastructure, including water systems. These laws prohibit intentional attacks targeting civilians and require that accidental or collateral damages in war not be excessive compared to military advantages gained (Geneva Water Hub 2019).

Most humanitarian constraints on actions during conflict, like the Geneva Convention and Protocols, were negotiated to address interstate wars, not subnational or civil wars. Nonetheless, the 1977 Second Additional Protocol focuses on non-international armed conflicts and includes provisions on the protection of water infrastructure (see Articles 14 and 15). The United Nations (1977) noted back then that the vast majority of casualties of armed conflicts since 1945 resulted from subnational conflicts. The same is true today. Data from the Water Conflict Chronology show the dominant role played by intrastate civil war or civil unrest (see Figure 21 in the Yemen case study).

Improvements in the legal sphere include making it clear that the protections afforded by existing laws of war apply to subnational disputes. Nonstate armed groups should be encouraged to abide by the existing conventions and customary obligations (Gleick 2019; Geneva Water Hub 2019). In addition, the militaries and military arms of all countries and groups should be trained in the rules of international humanitarian law and human rights law protecting water infrastructure (Tignino 2020). Finally, these laws need to be enforced by the international community, especially when violated by nonstate actors such as the "Islamic State of Iraq and Syria" (ISIS), or else they will continue to be ignored.

Other solutions include hardening water systems or improving the ability to repair them in the event of damage or destruction, but no level of hardening can protect civilian water systems from intentional efforts to destroy them.

Water Security Solutions: A Structured Discussion

In this section, we discuss water security solutions within the framework provided in Table 1 and provide examples for each major category.[2] Short definitions of all solutions in Table 1 are provided in Appendix A. The solutions in Table 1 are by necessity generic. We do not indicate whether they are technically feasible in any given situation, or cost-effective, or politically viable, and so on. We do not prioritize any of these solutions. These are all issues that need to be addressed on an individual, case-by-case basis.

Just because solutions exist does not mean that they are easily implemented. In many cases, implementation faces significant barriers. For instance, one needs to build up political will for significant social change. Those who lose out may need to be somehow compensated. Mechanisms to prevent "free riding" may need to be developed.

Some of the solutions in Table 1 can support, complement, or supplement each other, or one solution. One solution may be needed for another to be effective. For example, a well-functioning system of water rights is likely required for water markets to operate. Or a cap on total water usage in a water-stressed region may be needed to support the objectives of water-use efficiency measures.

By the same token, there are potential tensions or trade-offs between some of the solutions in Table 1. For example, improved water capture and storage could undermine efforts to promote legal ecological flow commitments.

Now we turn to a discussion of the solutions in Table 1, category by category.

Natural resources, science, and engineering approaches

Water efficiency and conservation improvements. Constraints on the availability of new or traditional supplies have led to a focus on improving the productivity of water use (sometimes called "water-use efficiency," "water productivity," or "conservation") and the strategy of reducing demand for water without harming industrial and agricultural production or human well-being. When water was abundant and inexpensive, technologies and practices for water use paid little attention to efficiency. Today, however, technological, economic, and policy tools for reducing waste and inefficiencies are often available at lower costs than finding new supplies (Cooley et al. 2019). In Iraq, for example, it is estimated that only about a third of treated water actually reaches customers—system losses total about 68 percent (Alwash et al. 2018). It is likely easier and cheaper for Iraq to find and cut losses in its urban water systems than to find new sources of water supply. These kinds of improvements are available in every sector of the economy and include investment in improved irrigation application technologies, improvements in industrial processes, and investment in infrastructure and technologies that can reduce preconsumer food loss, to name a few. Increasing water prices can help incentivize water-efficiency and conservation improvements (water pricing is discussed more below). It is also important to note that more efficient systems do not necessarily lead to lower water use, as efficiency gains are often used to expand production. This is why efficiency improvements need to be accompanied by water-use limitations, demand caps, or redirection of water allocations in highly water-stressed regions (more on water-use limitations and demand caps below).

Large-scale disruptive technologies can revolutionize how we live, how we produce goods and services, and how we consume those goods and services. While they are difficult to anticipate, there is one set of technologies and processes that we as natural resource experts should keep an eye on. As a result of rapid advances in precision biology, we have begun to synthesize proteins to produce—for example, ground meat substitutes. Such advances could eventually revolutionize global food production and consumption systems and dramatically reduce global food prices. The implications for global natural resource use, including much less land and water use, as well as much less waste production, could be enormous (Tubb and Seba 2019).

Traditional water-supply expansion. When tensions over water arise due to scarcity, the historical response has been to expand water supplies through traditional approaches of building dams, withdrawing water from lakes and rivers, moving water from distant watersheds with aqueducts and pipelines, or tapping groundwater systems. There are regions of the world where such carefully designed and built infrastructure can still provide important water-supply benefits, but such options are increasingly expensive, ecologically fraught, or unviable due to resource limitations. In parts of India, for example, the combination of very high water stress, monsoonal rainfall patterns, and low water-storage capacity makes local populations exceedingly vulnerable to drought. In these areas, water-storage dams may be needed to reduce human vulnerability to acceptable levels.

It is important to note, however, that natural systems such as forests, floodplains, and soils contribute to sustainable water supply and protect against extreme weather. Where possible, such "green infrastructure" should be used with or instead of traditional physical infrastructure like dams, levees, reservoirs, treatment systems, and pipes both because it can be less costly and because it encourages the preservation of ecosystems and the many services they provide humankind (Browder et al. 2019). In Florida, for example, a local water supply authority skims water from the Peace River during wet periods, and then treats and injects the water into an aquifer for later withdrawal during a dry period (National Ground Water Association 2020).

New centralized and decentralized sources of water (wastewater treatment and reuse, stormwater capture, desalination, etc.). As water limits become increasingly evident and where traditional centralized systems are unavailable, uneconomic, or otherwise limited (Gleick and Palaniappan 2010), there has been a shift toward identifying and developing new supply options, such as advanced treatment and reuse of wastewater and improved capture and storage of stormwater. Windhoek (Namibia) and Singapore, for example, have both made substantial and early commitments to advanced water reuse. Israel and California are making major investments in water reuse for agriculture, groundwater recharge, and some urban uses. In regions where absolute water scarcity is severe, and where economic and financial resources are available, investments in seawater desalination technology can provide high-value urban and industrial water supply. Examples where desalination has been aggressively pursued include the Gulf States, Israel, parts of Spain, and various small island nations where natural rainfall is limited and no rivers or lakes of adequate size exist. These kinds of alternative sources can be centralized or decentralized, providing different scales of access to water.

Data collection and information systems. New in situ and remote-sensing monitoring tools can help farmers apply the right amount of water at the right time in the right places. New sensors for detecting leaks can help urban utilities reduce losses of high-quality water. Accurate smart meters can help water users understand their water use and improve efficient use. Open data platforms can permit regions and countries sharing transboundary water resources to resolve disputes.

Agricultural extension services. Agricultural extension services can help farmers determine optimal crops for their regions, when they should be planted, and how productivity can be maximized under changing climate conditions. They can also help farmers become more water-efficient and reduce postharvest food loss and waste, as has been demonstrated in the Central American Dry Corridor (Arcanjo 2018).

Joint scientific exchanges. Open communication and sharing of information between scientific organizations and research communities can provide a mechanism for identifying and advancing technical and policy solutions to pressing challenges. Many international river basin treaties explicitly set up joint scientific committees to share information and provide a forum for discussing and resolving water disputes (Schmeier 2013; Caponera and Nanni 2019). During the Cold War, the Pugwash organization helped U.S. and Soviet scientists share information and ideas, including advancing what ultimately became the Partial Test Ban Treaty signed by the United States and Soviet Union. Pugwash was awarded a Nobel Peace Prize in 1995 for these efforts to reduce the threat of nuclear war. Iranian and U.S. hydrologists and water specialists have met periodically, under the auspices of the two countries' national academies of science, including a workshop on "Science as a Gateway to Understanding" (National Research Council 2008, 2005).

Water, sanitation, and hygiene (WASH) infrastructure and services. Many people in developing countries (and even in some developed countries) lack sufficient access to safe, reliable, and affordable water for drinking, hygiene, and household use in or near their homes. Many also lack access to safe, reliable, and affordable sanitation services. A recent analysis of 15 cities found that "vast segments of the urban population in the global south lack access to safe, reliable and affordable water. On average, almost half of all households in the studied cities still lack access to piped utility water." The analysis highlights four areas for cities to improve water access: (1) extending the formal piped water network, (2) addressing causes of intermittent water service, (3) pursuing strategies to make water affordable, especially for low-income households, and (4) supporting informal settlement upgrading (Mitlin et al. 2019).

Political and legal tools

Improvement and enforcement of international humanitarian law. International humanitarian law sets rules and standards for the protection of civilians and critical infrastructure during armed conflicts. In particular, the 1977 Protocols to the Geneva Convention prohibit intentional attacks on drinking water systems, irrigation works, and other water-related infrastructure. Further, militaries are to avoid attacking such installations so as not "to leave the civilian population with such inadequate food or water as to cause starvation or force its movement" (United Nations 1977; Tignino 2016). As described in the Yemen case study, where numerous attacks on civilian water systems have been reported, greater enforcement of international laws and improved training for militaries are needed to reduce violations of these protections (Gleick 2019a).

Water and land rights reform. Where conflicts arise because of disputes over access to water and land, as described in the case study of violence between herders and farmers in Africa's Sahel region, strategies for addressing inequitable water and land rights and for clarifying issues of political and economic control of water are needed. In Nigeria, Mali, and Ghana, some Fulani communities have asked national and regional politicians to allocate permanent grazing areas, protected migration pathways, and water reserves as a way to clarify land and water-use rights and reduce herding challenges and seasonal migration (Odebode et al. 2012). Reforms like these are often unpopular because they are perceived to constitute government-imposed reallocation of land and water or because of concerns that set-aside land and water are poor quality, inaccessible, or already in use (McGregor 2017), but without clarity over water and land rights violence will continue.

Water and land rights reform is also urgently needed in many countries where policies of agricultural self-sufficiency are being pursued, often with disastrous consequences. In Iran, for example, the large national population and overall limits on water availability make it unlikely the country can be reliably self-sufficient in food production. Despite these limitations, the government has pursued policies of agricultural self-sufficiency since the 1979 revolution. By subsidizing agricultural inputs, including water, electricity, and fertilizers, providing farmers with guaranteed price floors for some 20 crops, and providing consumers with subsidies for bread and grains, Iran's agricultural sector has expanded beyond the point of sustainable water availability (Michel 2019), causing groundwater tables to decline and rivers and lakes to run dry. Iran needs to modify agricultural support policies to bring water demand in line with available supplies. The international community also needs to do its part by guaranteeing Iran's ability to import food.[3]

Legal ecological flow commitments, strengthened national environmental laws. Some tensions over water are related to ecological problems associated with human extractions of water. In Iran, the desiccation of Lake Urmia, and the drying of the central Gavkhouni marshes, the Hawizeh marshes along the Iraq-Iran border fed by the Tigris and Karkheh Rivers, and the Sistan and Hamoun marshes in the east have each contributed to local protests over water policy and allocations. Similar problems are common in other countries and regions. In India and China, many lakes and rivers are drying up as a result of overabstraction of water, extreme weather, or a combination of factors. In many countries, ecosystem degradation and destruction has led to the loss of productive agricultural land (e.g., through the hardening and/or loss of topsoil). Many wealthier countries mitigate these types of risks by imposing minimum environmental flow requirements (OECD 2015). The international community can help poorer countries establish their own environmental flow requirements—as well as ecosystem and soil protection policies—through technical assistance programs.

Water-use limitations and demand caps. Water-allocation strategies and water-demand caps can be essential components of water management. There has been, nevertheless, a dearth of information on how these approaches can be implemented across a wide range of contexts. To fill this gap, the Organisation for Economic Co-operation and Development (OECD) conducted a survey of allocation regimes in 27 OECD and key partner countries in 2015. The survey found that most of these countries had some kind of explicit and enforceable limit (or "cap") on abstractions (OECD 2015). Such enforceable use limitations are valuable for managing water users, preventing declines in water tables and the drying up of rivers, and minimizing conflict (groundwater abstraction has seen more limited regulation and enforcement than surface water abstraction).

Food security policies, open global food market access. National priorities that push for food self-sufficiency contribute to pressures on domestic water resources. A key alternative—the reliance on foreign markets for food imports—can reduce local pressure on water resources but increase pressures on economies and local employment, and expose consumers to global food market price shocks, as happened in 2007–8 and 2010–12. In addition, dependence on world food markets increases the perception and possibility of outside political pressures through embargoes and imposed sanctions. The international community can prevent the imposition of external economic sanctions on food and encourage open access to international food markets. It should be noted that some countries may be forced to prioritize food self-sufficiency due to hard currency limitations. For instance, Ethiopia is contemplating expanding lowland wheat production for food security, employment, and better management of hard currency.

Multistakeholder peacekeeping groups. Because a growing number of conflicts over water result from subnational disputes rather than interstate disputes, special attention must be paid to strategies focused on the local level. When governments are weak or ineffective, there is both an opportunity and a risk that local groups will self-organize to provide security in the form of militias or other informal armed groups. The risk is that armed groups not under the control of formal governmental structures can devolve rapidly into vigilantism and sectarian violence. Under the right circumstances, however, such groups can play a role in reducing the risks of conflict. In central Nigeria, violence between herders and farmers has led to the formation of groups of peacekeepers, including representatives of both pastoralists and farmers, who provide local law enforcement and adjudicate disputes. While groups like this traditionally operate outside of formal government control, they can be beneficial in places where governments have few other options and where adequate local trust exists (Bearak 2018; Sahara Reporters 2018).

Water-sharing agreements: subnational, national, and transboundary. Many major watersheds are shared by two or more political entities, including local, regional, and multinational ones. In these circumstances, water management and sharing agreements based on the principles, rights, and obligations of both local and international law apply. The long history of cooperative transboundary water agreements on specific rivers or for distinct watersheds, described extensively by Aaron Wolf et al. (2003), provides tools and models for nations or regions that want to share water resources (Wolf 1997; Giordano et al. 2014; Subramanian et al. 2014). This means addressing conflicting demands through joint monitoring systems, data sharing, and technical cooperation. Joint river basin commissions created by transboundary water agreements, like the Mekong River Commission, the International Boundary and Water Commission between the United States and Mexico, and others, can provide a mechanism for resolving conflicts when they arise.

Despite the successes of such water-sharing agreements, many watersheds still lack them, or current ones are inadequate to deal with new challenges, such as the effects of climate changes on hydrology. In the Middle East, for example, where many water-related conflicts continue to occur, key watersheds such as the Tigris and Euphrates, the Nile, and the Hirmand/Helmand have either no agreements or incomplete or weak ones on data collection and sharing, levels of withdrawals, seasonal standards for river flows, and rules to govern management of large dams and other infrastructure. In Asia, growing tensions over the control and management of the waters of the Mekong could partly be addressed if the countries that share the basin agreed to a comprehensive treaty. When feasible, efforts to initiate, restart, or finalize agreements would be valuable.

At a global scale, efforts to develop fundamental principles for transboundary watershed management led to the drafting, adoption, and entry into force of the 1997 UN Convention on the Law of Non-navigational Uses of International Watercourses (United Nations 1997). This convention establishes standards and principles for best practices around joint basin management, data sharing, and conflict resolution, and, while not universally accepted, the fundamental concepts in the convention are widely respected and apply at multiple scales (Gleick and Iceland 2018). Moreover, since 2016, the Convention on the Protection and Uses of Transboundary Watercourses and International Lakes is also open to all UN member states. Two African countries, Senegal and Chad, are parties to this agreement (McCaffrey 2019; Boisson de Chazournes 2013; Boisson de Chazournes and Tignino 2015). In 2018, recommendations of the Global High-Level Panel on Water and Peace for the first time included specific recommendations on improving transboundary water cooperation on both surface and groundwater resources as well as on the respect for international humanitarian law in protecting water infrastructure (Tignino 2020).

How should transboundary water-sharing agreements be negotiated and who should be involved? Negotiations can take place between official negotiators operating in their formal capacities—this is referred to as "Track 1" diplomacy. But nongovernment actors can also take part in diplomacy. This is referred to as "Track 2" diplomacy. Finally, government negotiators can discuss issues informally ("Track 1.5"). Actors can also be included from international organizations and third parties, such as the United Nations, the World Bank, and bilateral aid agencies. While including all these types of actors and processes can complicate matters, it also ensures that all dimensions of the situation get addressed, including both the costs and benefits of alternative water management regimes (Klimes and Yaari 2019).

Economic and financial tools

Access to water development financing. Inadequate water infrastructure and management systems in many countries contribute to growing tensions over water. While the failure to develop such systems has many causes, an important one is the inability to deploy sufficient capital for water development. Improving access to financing for such systems, including green bonds, microfinance and microinsurance approaches, international lending, and more, can help alleviate this problem but requires more funding for water, and mechanisms to allocate this funding to the regions of greatest need must be improved.

Water prices; water, food, and agricultural subsidies; water markets. Water prices rarely reflect the true costs of providing reliable water. Outdated subsidies may contribute to inefficient water use and high levels of water stress. Markets that permit more efficient reallocation of water are rare and difficult to implement equitably. Each of these areas offers opportunities to improve the quality of water services and access. Prices for water can be designed not only to reflect the full cost of service in order to pay for current operation and maintenance costs but also to provide reliable streams of financing for improving and expanding water infrastructure. Pricing structures should also protect access to safe and adequate water and sanitation—a basic human right—for poor and disadvantaged communities through carefully designed subsidy and safety-net programs. More generally, water pricing should reflect societal values of efficiency (economic values), inclusiveness (social values), and sustainability (environmental values) (High Level Panel on Water 2018).

In Ouagadougou (Burkina Faso), ONEA, the utility responsible for water and wastewater services, provides piped water to 94 percent of the city's population (including most of its poor), almost 24 hours per day. It also performs very well financially, with positive cash flows and low nonrevenue water (i.e., water lost through leaks or theft). ONEA and a handful of other water utilities in Africa have been identified by the World Bank as examples of companies that can both serve the poorest and maintain financial viability (Iceland 2017).

Agricultural subsidies that promote inefficient water allocations and demand should be redesigned or eliminated. In India, for example, various types of government subsidies make it easier and cheaper to pump groundwater (Parvaiz 2016). In areas where groundwater tables are falling, those subsidies should be modified to encourage more sustainable use of water. The creation of some forms of water markets may also help communities regulate, allocate, and efficiently use limited water resources.

Other economic/social tools. Changes in social priorities, cultural norms, and behavior can also reduce unsustainable use of water. For example, changes in preferences for outdoor landscaping can greatly reduce household use of water in regions where outdoor water use is a large component of total use (California Department of Water Resources 2020). Changes in dietary preferences, such as away from water-intensive red meat consumption, can dramatically reduce water consumption (Ranganathan et al. 2016). Addressing large-scale food loss and waste can increase the total amount of food available for consumption while reducing water and other natural resource and climate change pressures in the agricultural sector (Lipinski et al. 2013).

Policy and governance strategies

Improved water management. Water scarcity, poor water quality, limited access, or inequitable allocation is often a trigger of violence. As a result, strategies to improve water management and use can reduce the underlying tensions associated with peak water constraints (Gleick and Palaniappan 2010). Because of the connections between water and almost every part of the economy, such water management approaches must be integrated with energy decisions, allocations and management of land, agricultural policies, and economic development choices. It is no longer sufficient to leave decisions about water to a narrow set of engineers or water-utility planners. And because so many water resources cross political boundaries, modern water management requires a degree of political cooperation not traditionally achieved. Just as the inclusion of diverse economic sectors and transboundary actors strengthens water management, so too does the inclusion of women, due to their significant and unique roles in water management and in agricultural production (more on this topic in the "gender equality" section below). Improved water management can also provide broader benefits, including better engagement with and education of local communities, reduced corruption and internal governmental conflicts over water policy, and strengthening of environmental agencies.

Decentralization of water management. Where water management is heavily centralized—as it is in many parts of the world—the reliance on centralized water agencies and large-scale construction can be balanced with decentralized, soft-path approaches of water efficiency, alternative nontraditional supplies, improved economics, and regional, decentralized water basin approaches. Writing about Iran, Kaveh Madani (2014) notes that "such a management paradigm recognizes the interrelated dynamics of the water sector with other sectors, cures the problem causes rather than its symptoms, manages water rather than controlling it, and benefits from effective non-structural (soft) solutions (e.g. regulations, institutions, taxation,

monitoring, population control) as much as it benefits from structural (hard or engineering) solutions (e.g. dam construction, water diversion, using irrigation sensors)."

Stakeholder and community engagement. Broad-based engagement of water users, communities, and other stakeholders in water-resources management is required in order to make informed and legitimate decisions. Such engagement is needed now more than ever, with climate change and growing demands on natural resources bringing more and more people into competition with one another. An example of a successful effort to engage stakeholders is the Restoration Initiative in Kenya's Tana Delta. Tensions between local farmers and pastoralists over increasingly scarce water and land reached a high point in 2012, when 286 people died in local clashes between these communities. By bringing communities together to participate in land-use decisions, the Restoration Initiative has helped over 100 villages restore and better manage natural resources and thereby reduce local tensions (UNEP 2019).

Gender equality. When women influence water management, studies show their communities get measurably better outcomes—including better-functioning water systems, expanded access, economic and environmental benefits, and equitable distribution, especially in times of scarcity (Morna 2000; Mommen et al. 2017; Kholif and Elfarouk 2014; UNDP and Gender and Water Alliance 2006; Lecoutere et al. 2015). However, women's participation in decision-making roles is often restricted by their lower status in society and the discrimination they face in their homes and communities. These restrictions are often compounded by other social characteristics like age, class, and religion (O'Neil and Domingo 2015). Breaking such country-specific structural, social, legal, and economic barriers (Campbell et al. 2006) is essential to elevating women's status and enabling them to participate actively in water resource decision-making.

Improvements in women's education, economic and political participation, and safety are also correlated with reduced inter- and intrastate violence (Hudson et al. 2012; Caprioli 2000) and lead to

lower levels of conflict (Melander 2005) and more peaceful and stable outcomes (Hudson et al. 2012) and help achieve other Sustainable Development Goals (UN Women 2018). Similarly, research shows that gender-inclusive peace processes produce longer lasting, more robust agreements that are less likely to be broken (Troell and Yaari 2019; Krause et al. 2018; UNSC 2000).

Population policies. Rapidly growing populations in many developing countries are putting significant pressure on fixed or diminishing water resources, raising tensions among user groups and often leading to conflict and violence. Socially responsible policies are therefore needed in many parts of the world to improve access to information and strategies for family planning. Experience from a wide range of countries shows that fertility rates can drop rapidly when a combination of technical, educational, and social interventions is pursued (Iceland 2017; Searchinger and Hanson 2013):

- *Increasing secondary education rates for girls while maintaining rates for boys*—This may involve improving access to and quality of educational opportunities by reducing distance to school, building safe and inclusive learning environments, providing sanitation facilities and transport, ending child marriage and early marriage, and addressing violence against girls and women.
- *Increasing acceptance of and access to reproductive health services and family planning options*—This includes concerted efforts to address early marriage and childbearing practices and women's lack of autonomy in reproductive decision-making, promoting more integrated services for family planning, and addressing cultural barriers like preference for sons and religious barriers related to family size, both of which restrict access to reproductive health services.
- *Reducing infant and child mortality*—This includes improving immunization programs, improving mother and child nutritional health programs, improving sanitation services, and addressing administrative and budgetary challenges in public health.

For these interventions to work, they must be accompanied by a set of cultural or social interventions that promote gender equality (UNFPA 2018). Eliminating discrimination against women and giving them more agency at the household and community levels are key enabling conditions for interventions to work. They can be achieved through collective efforts by state and nonstate actors, instilling a cultural change that corrects the power imbalance between men and women.

In a similar vein, it is important to engage young men and women in water-related security discussions, considering the youth population bubbles in many of the areas most acutely affected by water security challenges (Yaari 2020).

Immigration and emigration policies (intranational and international). The UN Refugee Agency's annual number of "persons of concern" keeps climbing, year after year. These "persons of concern" include refugees, internally displaced people, asylum-seekers, and others displaced by political and environmental factors, and by extreme disasters. At the end of 2018, this number had grown to almost 75 million globally (UNHCR 2019). Individual nation-states and the international community need to develop improved, humane approaches for dealing with intranational and international migrants, even as the COVID-19 crisis is shutting down much travel across international borders. As these numbers grow, regional pressures on water resources may also worsen. The Syrian civil war, for example, pushed very large numbers of refugees into Jordan, worsening water shortages and putting new pressures on already unsustainable groundwater use (Dakkak 2017).

Reduced corruption. The water sector is particularly vulnerable to corruption for a number of reasons, including the existence of large infrastructure contracts and large flows of public money, asymmetric power dynamics between water suppliers and customers, and monopoly control of markets. Reducing and eradicating corruption in the water sector can lead to improved water and wastewater service delivery, reduced costs, and other tangible benefits. Initiatives such as the Water Integrity Programme can help reduce corruption by promoting transparency, accountability, and participation in water resources management and service delivery. This program is active in almost 40 countries and has earned strong political endorsements in the regions in which it's active (Water Governance Facility 2020).

Conclusions and Recommendations

No matter how dire the water and security challenge, potential solutions are available. But solutions can require money, advanced technical experience, or complex managerial skill sets. In many cases they require sufficient political will to overcome challenges associated with political and economic trade-offs, social or cultural barriers, entrenched corruption, and/or collective action.

Here are recommendations for getting ahead of and reducing risks, before water problems devolve into full-blown crises:

1. Monitoring and early warning. Establish global monitoring systems for key indicators associated with water-related conflict, migration, and other water-related crises (cities running out of water, large-scale disease outbreaks, famine, etc.). The Water, Peace, and Security (WPS) partnership, for example, has developed a machine learning–based Global Early Warning Tool that identifies potential high-risk areas based on indicators such as rainfall, crop health, poverty levels, population growth, and so on (WPS Global Early Warning Tool 2019). The U.S. Agency for International Development (USAID) and its partners have developed the Famine Early Warning System Network (FEWS NET). It is very important for the international community and affected countries to have as early a warning as possible that water risks are growing and that crises may be at hand.
2. Rapid response teams. Once high-risk areas are identified, the international community should have rapid response teams in place that can offer assistance to at-risk countries. These teams can catalyze the identification and implementation of solutions by helping regional, national, state, and local leaders better understand the nature of problems, the major drivers of risk,

and potential ways to address the problems. The WPS partnership, for example, has developed tools to conduct local-level rapid analyses for hotspots, capacity-building and training modules for decision-makers and resource managers, guidance for convening relevant stakeholders and establishing legitimate decision-making processes, and approaches to dispute resolution.

3. Sources of funding. Most solutions require significant funding. The rapid response teams should therefore have the backing of development banks, bilateral aid agencies, and other sources of funding that can furnish grants or loans. Funds should be set aside by these organizations specifically to address emerging water and security crises. The private sector and public-private partnerships may also have a role to play in achieving these solutions.

4. Stakeholder dialogues. The challenge of collective action is significant, but it can be overcome if and when societies recognize the benefits of needed changes and the perils of continuing with "business as usual." Consensus on collective action is the product of global, transboundary, national, state, or local dialogues. Consensus enables the rewarding of compliance with desired actions (such as tax breaks) and the imposition of penalties for noncompliance (fines, criminal penalties, etc.). There are many ways to conduct dialogues. When dialogues occur amid tensions or conflicts, they can occur through formal or informal diplomatic processes (in the case of transboundary problems) or through discussions organized by civil society and other third parties, such as the United Nations, the World Bank, and bilateral aid agencies (Klimes and Yaari 2019).

5. Incremental steps. After reading some of the case studies, the problems may seem insurmountable and the solutions unattainable. Most complex problems can be broken down and tackled piece by piece, however. We have tried—in the six case studies presented—to identify the key underlying drivers of the problems and let these sets of drivers guide the identification of priority solutions.

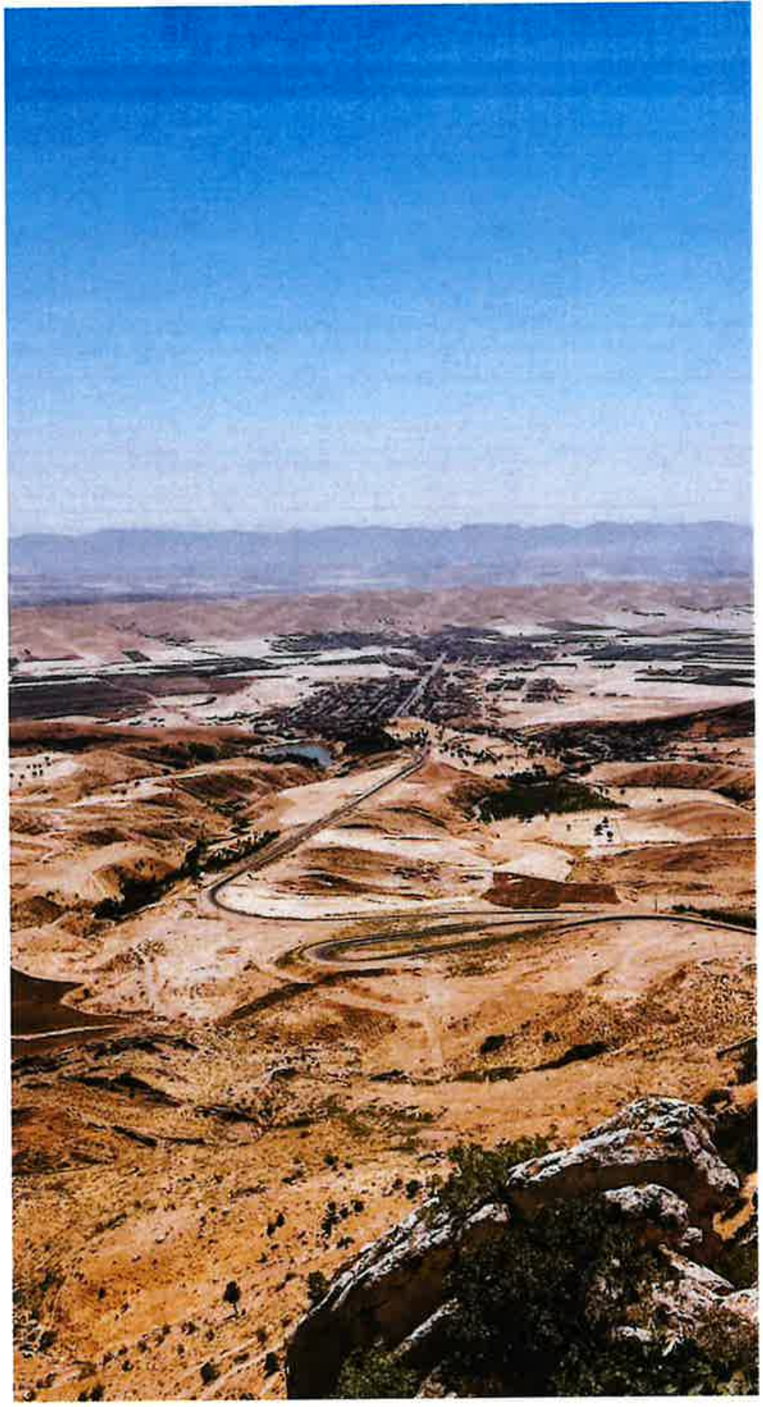
It may be possible to develop general guidance that helps decision-makers move systematically from problem identification to analysis of drivers to identification of priority solutions—a "priority solution identification protocol," as one of our colleagues has suggested. This certainly deserves further research and consideration.

SECTION II

CASE STUDY IRAQ

Charles Iceland

Exceedingly poor water quality in southern Iraq was one of several issues that triggered demonstrations against the government, which turned violent and contributed to the resignation of the prime minister. Decreasing water flows in the Tigris and Euphrates Rivers, agricultural runoff, and lack of wastewater treatment have been identified as major drivers of the crisis. Solutions include large-scale investment in wastewater treatment infrastructure; river-basin agreements that specify levels of withdrawals by each country, set seasonal standards for river flows, and provide rules to govern the management of large dams and other infrastructure; and policy measures that make the demographic shift of people from rural to urban areas easier and more successful. These and other solutions could help mitigate water-related conflict in Iraq.



Mesopotamia, the land between the Tigris and Euphrates Rivers, was the cradle of some of the world's earliest civilizations. These civilizations were able to develop here because of the region's abundant freshwater resources. Modern-day Iraq, however, now faces an existential threat as pressures mount on these two rivers, which together provide over 98 percent of water used in Iraq (Abd-El-Mooty et al. 2016). Much of the problem stems from a combination of upstream dams and water diversions in Turkey, Iran, and Syria, long-term persistent drought, and Iraq's own use of its water resources. A near constant state of warfare in the country since the early 1980s and economic sanctions in the 1990s have worsened challenges with water institutions, infrastructure, and management. We begin with an analysis of water-related conflict drivers in Iraq, continue with a discussion of recent conflict triggered in part by water resource problems, and conclude with an exploration of possible solutions to Iraq's water resource problems.

Geography/Climatology/Hydrology

The Tigris-Euphrates river system is Iraq's lifeblood. The two rivers originate within 50 miles of each other in the mountains of eastern Turkey. They travel southeastward through Syria and Iraq until they meet and empty into the Shatt al-Arab waterway in the southeastern corner of Iraq, which in turn flows into the sea. Figure 2 depicts the Tigris and Euphrates river basin and its catchments. Many dams in Turkey, Iran, Syria, and Iraq regulate the flows of the two rivers, which are further influenced by man-made watercourses and off-river storage reservoirs in Iraq.

Iraq's geography has four main regions: the desert in the south and southwest, the highlands in the north and northeast along Iraq's borders with Iran and Turkey, the uplands between the two rivers in the northern part of the country, and the alluvial plain, also between the two rivers, beginning north of Baghdad and extending south to the sea (U.S. Library of Congress, Federal Research Division 2006).

Climate throughout much of Iraq is sunny, hot, and dry during the summer, and cool and wetter during the winter. Temperatures are cooler in the northern mountain areas, and more humid near the gulf. During summer heat waves, temperatures can approach 50 degrees Celsius (120 degrees Fahrenheit). Apart from the mountainous northern areas, the terrain consists mostly of broad plains, with reedy marshes and large flooded areas along the Iranian border in the south (WeatherOnline 2019; CIA 2019).

Drivers of Risk

We provide a quick overview of the major drivers of water risk and water-related conflict in Iraq in the following paragraphs. The goal is to provide some context for the recent protests and violence over water. And we'll see in this case that water has served not only as a trigger of conflict but also as a casualty and weapon of warfare.

Expanding upstream dams and diversions

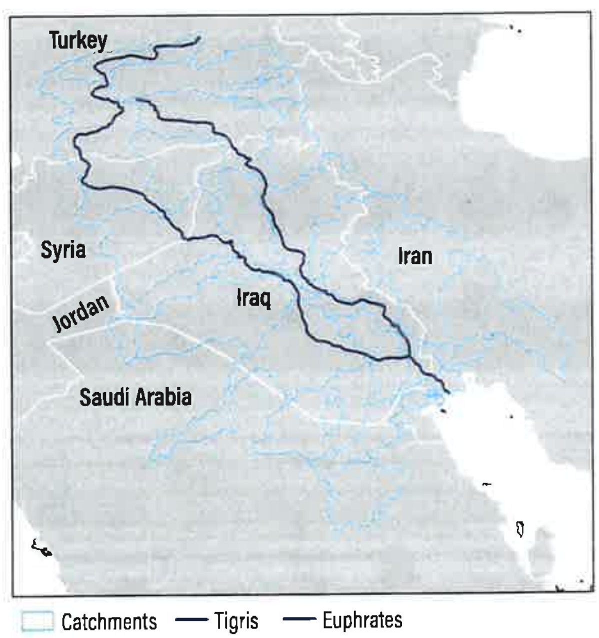
As we noted above, the Tigris and Euphrates account for over 98 percent of water used in Iraq. But much of that water comes from upstream countries. Patrick MacQuarrie (2004) estimates the combined annual flow of the two rivers at 84.2 billion cubic meters (bcm), of which 65.7 bcm come from Turkey (78.1 percent), 11.2 bcm from Iran (13.3 percent), 6.8 bcm from Iraq (8.1 percent), and 0.5 bcm from Syria (0.5 percent).

Looking at only the Euphrates, about 98.6 percent originates in Turkey. About 65 percent of the flow of the Tigris comes from Turkey and the remainder from Iraq and Iran through its tributaries (MacQuarrie 2004), making Iraq highly dependent on its upstream neighbors for this vital resource.[4] These neighbors in turn have been damming and diverting these waters for their own uses. Turkey began building a network of 22 hydroelectric and irrigation dams along the rivers in 1975. This network is known as the Southeastern Anatolia Project (Turkish: Güneydoğu Anadolu Projesi, GAP). The massive Atatürk Dam on the Euphrates River was completed in 1992. Turkey began filling the latest of these dams, the Ilisu on the Tigris River, in June 2018.

If the GAP dams were only for generating hydropower, there would be less for Iraq to worry about. But GAP has been designed and used in part for irrigation. Ibrahim Yuksel (2006) notes that the GAP package of 22 dams includes "19 hydroelectric power plants and the irrigation facilities to serve 1.7 million hectares of land." Arda Bilgen (2018) reports that as of 2017, "74% of the energy projects and 26.4% of the irrigation projects under the GAP umbrella had been completed," increasing the withdrawal and consumption of water from the Euphrates River.

Iran, an upstream riparian along the Tigris, has also been building dams and diversions. The Daryan Dam on the Sirwan River, for example, was completed in 2017 and has as its primary purpose the "supply [of] up to 1.378 billion cubic meters of water annually to the 48 km-long Nosoud Water Conveyance Tunnel where it will irrigate areas of Southwestern Iran" (Fanavary Novin Niroo Co. 2016). The Iraqi Civil Society Solidarity Initiative (2016) protested the construction of this dam and diversion project, arguing that "the reduced water flows of the Sirwan River, known as the Diyala River in Iraq, will . . . have significant negative impacts on people and communities further downstream in Central and Southern Iraq." Diversion projects such as this one have been raising alarm in Iraq, as they threaten to further reduce flows of water into its territory.

Figure 2 | The Tigris and Euphrates River Basin and Its Catchments



Source: Hofste et al. (2019a), Harvard WorldMap.

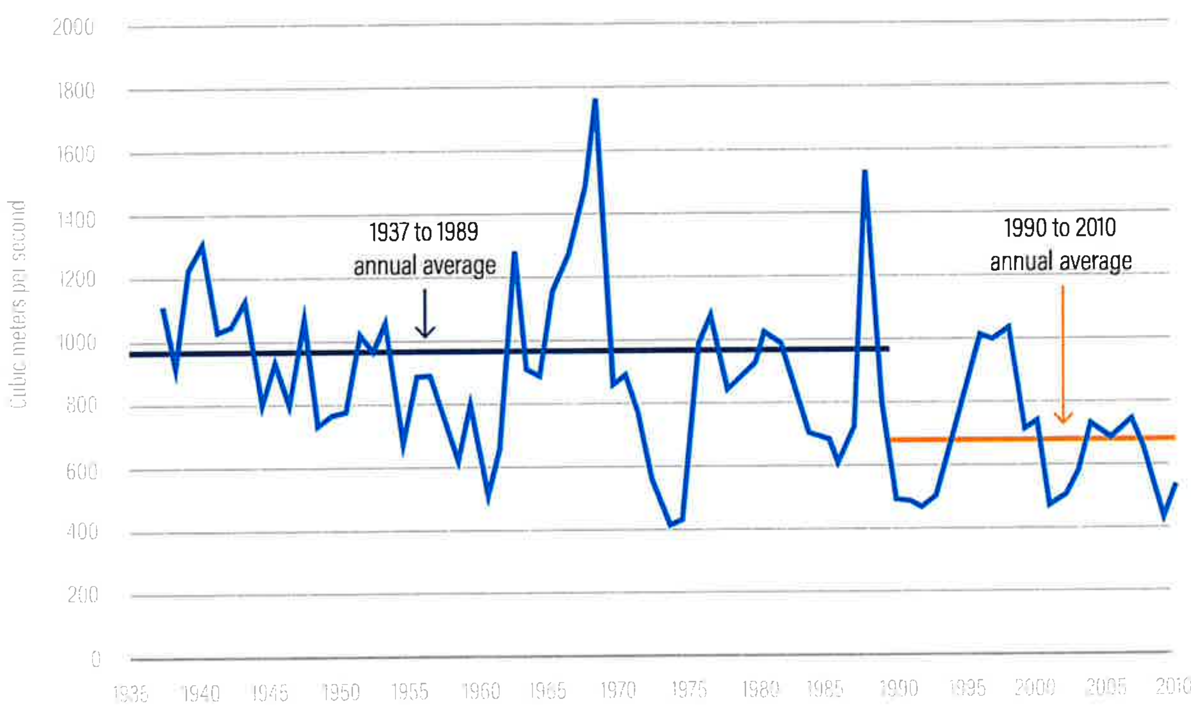
Reliable data on long-term flows of the Tigris and Euphrates are hard to find because measurements are not taken or the data are not publicly released. Figure 3, however, shows an estimate of average annual flows of the Euphrates River from 1937 to 2010 measured at Jarabulus, Syria, just downstream of the Turkish-Syrian border. As this figure shows, average flows have been dropping over this period (Gleick 2014).

Figure 4 illustrates the dramatic impact of reduced river flows on the size of the reservoir impounded by Iraq's largest dam. Between 1999 and 2018, the surface area of the Mosul Dam reservoir contracted by 63 percent (Iceland et al. 2018).

Worsening drought and climate change

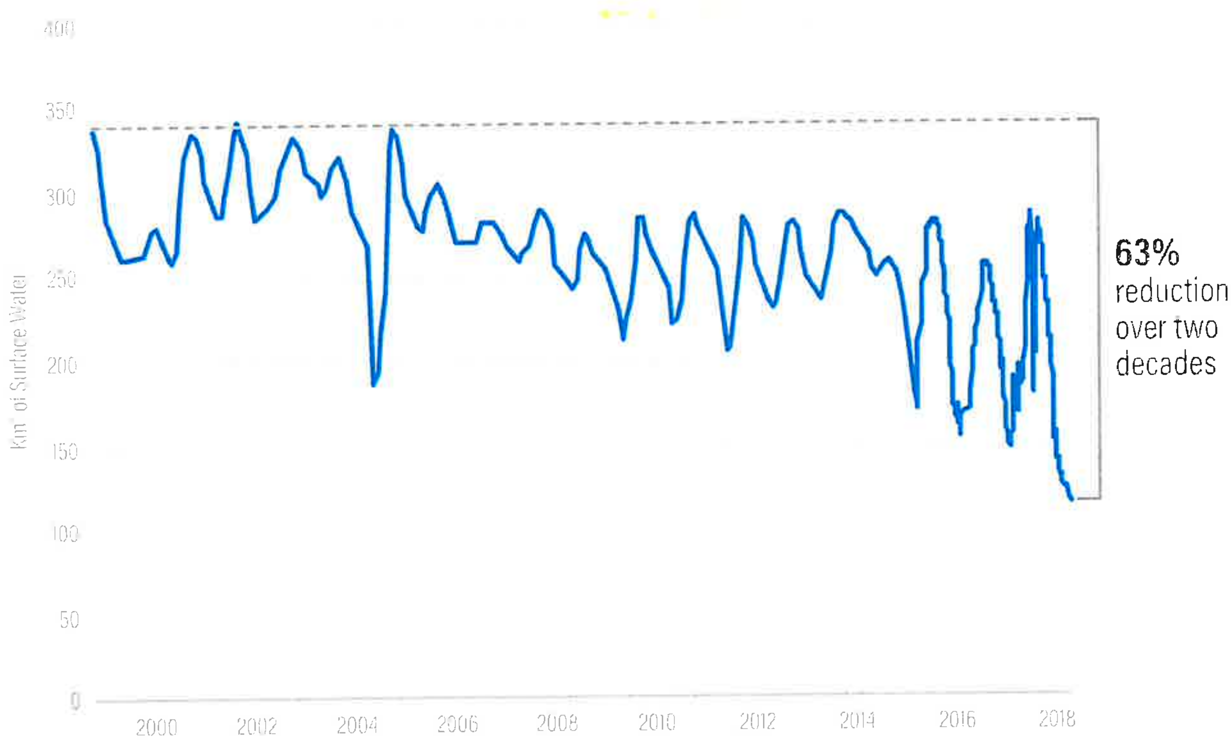
Iraq has faced severe drought in recent years, contributing to decreases in surface water flows and a growing reliance on groundwater. U.S. National Aeronautics and Space Administration (NASA) (2013) remote-sensing satellites documented large-scale groundwater losses in the Tigris and Euphrates basins during a severe drought that began in 2007. The UN Inter-agency Information and Analysis Unit (2010) reported that the 2007–9 drought affected 40 percent of Iraq's cropland, and that livestock was decimated. Severe drought struck again in 2018. Midway through the year, Iraq's Ministry of Water Resources, citing high tempera-

Figure 3 | Annual Average Discharge of the Euphrates River Measured at Jarabulus Just Downstream of the Turkey-Syria Border, 1937–2010



Sources: Data from UN-ESCWA (2013); graphic from Gleick (2014).

Figure 4 | The Surface Area of the Mosul Dam Reservoir Has Shrunk by 63 Percent over the Past Two Decades



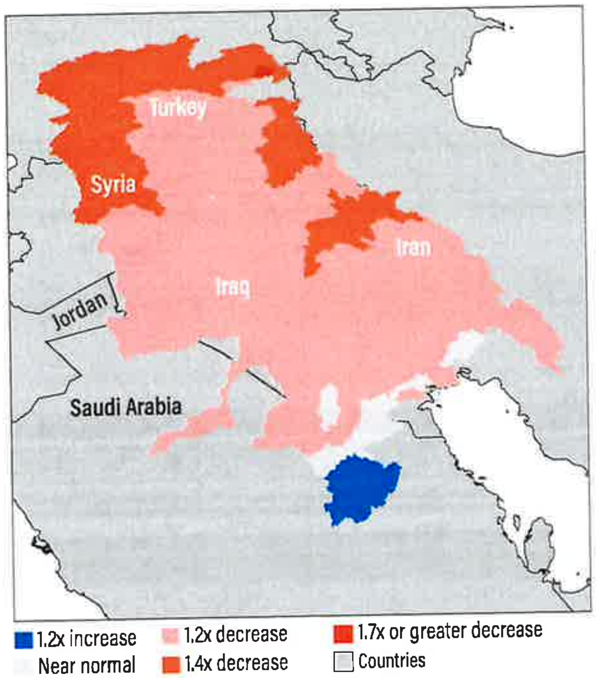
Source: Iceland et al. (2018).

tures and insufficient rains, announced that the country only had enough water to irrigate half its farmland that summer (*Seattle Times* 2018).

Growing evidence supports the observation that recent droughts in the Tigris-Euphrates basin have been influenced or worsened by climate change. A.A. Azooz and Shamil Talal (2015) evaluated primary data for four Iraqi cities: Baghdad (1887–2013), Mosul (1900–2013), Basra (1923–2013), and Kirkuk (1935–2013). Their analysis found significant evidence of climate change, including temperature increases and precipitation decreases. Looking more regionally, Martin Hoerling et al. (2012) found that "a change in wintertime Mediterranean precipitation toward drier conditions has likely occurred over 1902–2010 whose magnitude cannot be reconciled with internal variability alone." Hoerling et al. further note that "the land area surrounding the Mediterranean Sea has experienced 10 of the 12 driest winters since 1902 in just the last 20 years." Looking specifically at the Tigris-Euphrates basin, data offered by Hoerling et al. reveal that many of the basin's high rainfall areas have experienced significant recent drying.

The basin's hydrology is likely to continue worsening with climate change. Figure 5 shows projected water supply decreases throughout most of the basin between 2010 and 2040 under a business-as-usual (BAU) scenario (Gassert et al. 2015).

Figure 5 | Projected Change in Water Supply in the Tigris-Euphrates Basin from Baseline through 2040 under BAU Scenario



Note: Aqueduct future projections/water supply/change from baseline to 2040/BAU scenario.

Source: Gassert et al. (2015).

Rapidly growing population

Figure 6 shows that Iraq's population has grown very rapidly in recent decades—from 7.3 million in 1960 to 40.4 million in 2019 (World Population Review 2019). Growing population pressure on fixed (or declining) water and land resources is adding significantly to Iraq's security risks. As population grows, the per capita availability of fresh water drops. In Iraq, the availability of renewable fresh water—even ignoring changes in water supply due to climate or upstream uses—has dropped from 4,868 m^3/capita/yr in 1992 to 2,348 m^3/capita/yr in 2017 (FAO 2016a).

With around 24 percent of women married before they are 18 years old, and a fertility rate of 4.2, double the replacement rate of 2.1 (UNFPA 2017), Iraq's gender and cultural norms contribute to the growing population numbers. Factors associated with high fertility rates also include inadequate provision of education and health services for girls and women, and high infant mortality rates. In Iraq, as of 2016, more girls dropped out of secondary school than boys (UNICEF 2017a). Infant and maternal mortality rates remain acutely high, with overall health indicators being among the worst in the Arab region (USAID 2019a).

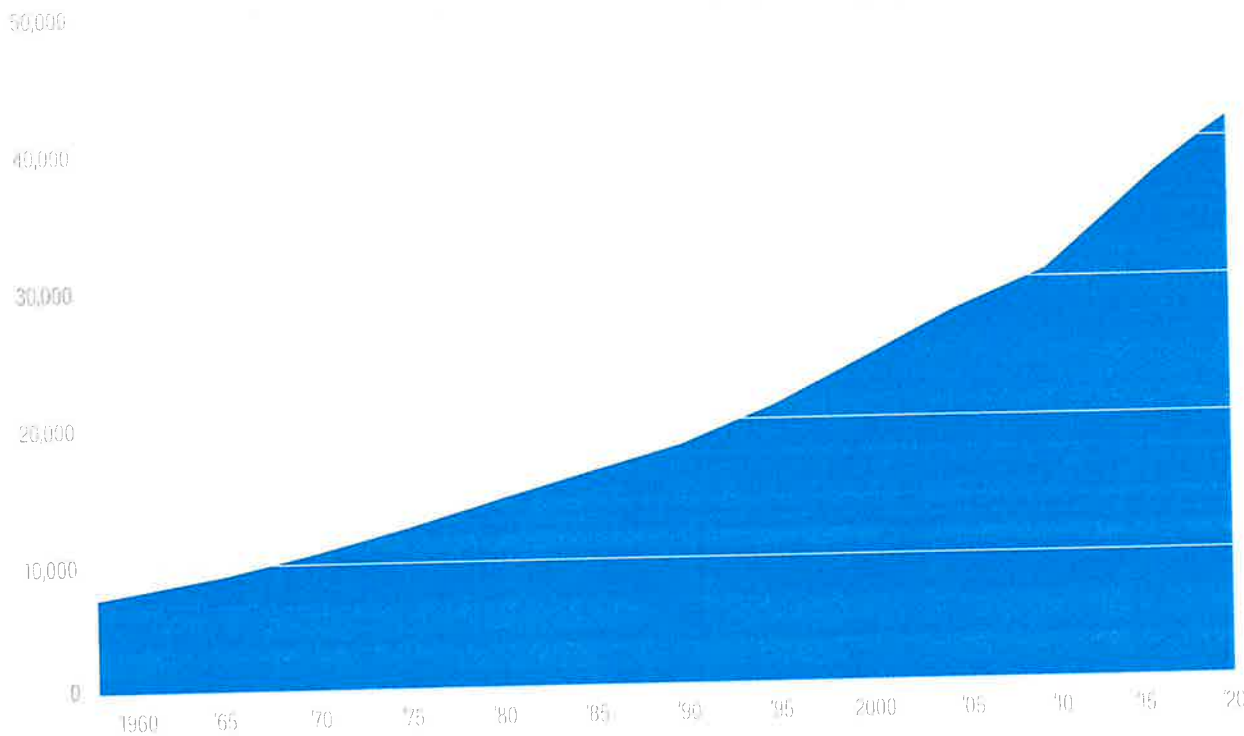
Low water-use efficiency in agriculture

Agriculture accounted for over 90 percent of total water withdrawals in Iraq in 2016, industry accounted for 5 percent, and municipalities accounted for 3 percent (FAO 2016a). Irrigated summer crops include rice, corn, dates, cotton, vegetables, fruits, legumes, and alfalfa. Irrigated winter crops include wheat and barley. Most irrigation uses highly inefficient flood irrigation methods, with a substantial amount of water lost to unproductive evaporation. While the water-use efficiency of flood irrigation is traditionally assumed to be between 30 percent and 40 percent, one study notes it is probably closer to 20 percent or less. Low levels of investment in and maintenance of irrigation systems have greatly compounded the problem of inefficient agricultural water use (FAO 2012). On top of all this, the ongoing regional conflicts have greatly worsened farmer access to irrigation (FAO 2018a). More on the role of conflict below.

High water losses from urban water systems, inefficient urban water use

In 2006, only about 32 percent of Iraq's treated water actually reached customers (i.e., water system losses of 68 percent) (Alwash et al. 2018). The United Nations in Iraq also notes that due to exceedingly low water tariffs and a lack of awareness of water scarcity, water use per capita in Iraq is almost twice the international standard (UN Iraq 2013). Such highly inefficient urban use of water adds unnecessary pressure on already scarce water resources. Reducing wasteful use requires accelerated financial investment in infrastructure and public campaigns to increase awareness of water scarcity and the need to use water more efficiently.

Figure 6 | Iraq Population, 1960–2019 (Thousands)



Source: World Population Review (2019).

Increasing water and soil salinity, soil erosion, and land desertification

Salt contaminates both drinking water and cropland. Ancient Mesopotamia declined for this very reason. Jared Diamond (2003) argues that "irrigation agriculture [in Mesopotamia] led to salinization, both by releasing salt buried deep in the ground and by adding salt through irrigation water. After centuries of degradation, areas of Iraq that formerly supported productive irrigation agriculture are today salt pans where nothing grows."

Historically, periodic floods in the Tigris-Euphrates basin helped mitigate the problem by flushing salts from the soil and depositing new layers of silt and clay. But with upstream dams and water diversions greatly diminishing these periodic floods, salinity problems are worsening. Today, an estimated 74 percent of Iraq's cropland suffers from some degree of damaging soil salinity (Alwash et al. 2018).

Diminishing river flows in the Tigris, Euphrates, and Karun Rivers have also permitted salt water from the Persian Gulf to advance up the Shatt al-Arab waterway (below the confluence of the Tigris and Euphrates Rivers), ruining productive farmland and drinking water sources in southern Iraq (Abdullah et al. 2016; Al-Wazzan 2018; Bloomberg 2018).

Mesopotamian marshlands under great pressure

These iconic marshlands in the lower floodplains of the Tigris and Euphrates in southern Iraq are the largest wetlands in the Middle East. They support a diverse array of wildlife and provide sustenance to local human populations. By the year 2000, these wetlands had shrunk by about 90 percent (Wetlands International 2016). In the decades leading up to the year 2000, new infrastructure, including dams, canals, and reservoirs, greatly reduced flows of water into the marshlands. Beginning in the 1990s, Saddam Hussein drained large areas of the marshlands at least in part to punish antigovernment Marsh Arabs (NASA Earth Observatory World of Change n.d.). Following the fall of Saddam's regime, about 40–60 percent of the marshes were reflooded. Today, however, they are again under great pressure due to reduced river flows in the Tigris and Euphrates Rivers and growing salinity (RTD Documentary Channel 2019).

Crippling levels of water pollution

In 2013, the United Nations reported that water quality for domestic and agricultural use in Iraq was poor and violated both national and World Health Organization (WHO) guidelines. Organic pollution (as measured by biochemical oxygen demand) was more than three times the national limit, having grown at an "alarming" rate between 2005 and 2010. Inorganic pollution by dissolved salts (as measured by total dissolved solids, or TDS), especially in the Euphrates River, grew from 457 parts per million in the 1980s to 1,200 ppm in 2009 (UN Iraq 2013). TDS of over 1,200 ppm are generally considered "unacceptable" by the WHO. Generally speaking, water pollution grows significantly worse south of Baghdad (Alwash et al. 2018).

Poor or nonexistent wastewater and solid waste management further pollutes water. One source notes that only 14 of 252 cities in Iraq have wastewater treatment plants (as of 2006). These plants serve 8 percent of the population. Most sewerage systems need "replacement, rehabilitation and upgrading." About 70 percent to 83 percent of sewage water is directly discharged to rivers. In addition to these massive problems, Iraq suffers from wartime contamination of water and soil by chemicals used by militaries (Al-Ansari et al. 2018).

Poor governance, corruption

Transparency International's (2013) report about Iraq notes that "massive embezzlement, procurement scams, money laundering, oil smuggling and widespread bureaucratic bribery have led the country to the bottom of international corruption rankings, fueled political violence and hampered effective state building and service delivery."[5] Corruption in Iraq hasn't improved in the five years since that report was published. Iraq currently ranks 168th of 180 countries in Transparency International's (2018) Corruption Perceptions Index. The demonstrations and violence discussed in the next section responded not only to a lack of clean water but also to poor government services and corruption more generally.

Wartime destruction of water infrastructure

Most of the discussion of water problems in Iraq up to this point involves an analysis of water risks as potential *triggers* of conflict. But water systems in Iraq have also served as weapons or been casualties of warfare (Gleick 2019b). Iraq has been involved in war and violence for over three decades, including devastating wars with Iran, the first Gulf War after Saddam Hussein invaded Kuwait, the war with the United States and allied forces starting in 2003, and the recent conflicts with extremist groups, including ISIS. Each of these conflicts has included destruction of civilian water and wastewater systems and limited Iraq's ability to repair and improve water service infrastructure. The Food and Agriculture Organization of the United Nations (FAO 2018a) notes that the recent war with ISIS (2014–17) had devastating effects on water and agricultural systems in much of northwestern Iraq, including "destruction of and damage to water systems, irrigation facilities and other agricultural infrastructure, disruption of value chains and losses of personal assets, crop and livestock production and food supplies."

In September 2018, Amnesty International conducted research in rural portions of northwestern Iraq that had been under ISIS control. While some of the destruction of water and agricultural infrastructure was considered collateral damage from the fighting (i.e., water systems were a casualty of war), much of the rest of the destruction

amounted to deliberate attempts to undermine the livelihoods of people living in rural communities (i.e., water systems were leveraged as a weapon of war). Amnesty International (2018) reported that "some of the clearest examples of this are related to irrigation wells. These wells were often sabotaged with rubble, oil, or other foreign objects. Blockage was often accompanied by theft and/or destruction of the pump, cables, generators and transformers. [ISIS] also burnt or chopped down orchards and pulled down and stole vital electricity lines." Gleick (2019b) provides a detailed discussion and extensive chronology of water as a weapon or casualty of conflict in Syria, Iraq, and Yemen from 1980 to 2018. Amnesty International and others consider these acts possible violations of international law, including laws covering war crimes and crimes against humanity (Amnesty International 2018; Gleick 2019b).

Water woes used in rural communities to recruit jihadists

Observers report systematic attempts by ISIS and related extremist groups to use growing water problems in rural Iraq to recruit desperate farmers and pastoralists. According to one source, beginning around 2009, following severe droughts and other water-related crises, jihadists could be seen recruiting desperate farmers in rural villages. As Peter Schwartzstein (2017) reported, the jihadists would often use disinformation about the origins of water problems to sow additional enmity between Sunnis and Shia: "The jihadists expertly exploited the desperation in Iraq's agricultural heartland by rationalizing its inhabitants' woes. They spread rumors that the Shia-dominated government was delaying crop payments and cutting off water to Sunni farmers. In fact, the lack of rain wasn't due to climate change, but really a man-made ploy designed to drive Sunni landowners from their rich fertile fields, their emissaries suggested."

Gender and social equity-related aspects of water scarcity in Iraq

Poorer residents, especially those living in informal housing settlements with inadequate access to safe water and sanitation services, are the most vulnerable during a water crisis. In Basra, over 300,000 residents were not connected to a proper water or sewage network during the crisis, exposing them to high risk of unsafe water and related health dangers. Some of these communities resorted to illegally tapping water pipes that ran under their homes, worsening the overall water-supply crisis. These vulnerable communities are also the least able to afford hospitalization and other health costs resulting from exposure to unsafe water supplies (Human Rights Watch 2019).

Women and girls in Iraq are also disproportionately affected by water scarcity. For instance, as primary water collectors, women and girls spend up to three hours per day on average on water collection (Central Statistical Organization Iraq et al. 2018). Reductions in water supply increase this burden, which has been known to negatively affect women's education, economic participation, and personal safety (UNICEF 2016). Women's control over resources and participation in decision-making related to water resources is also restricted by cultural barriers, precluding their ability to adequately respond to issues of growing water scarcity and land degradation (Vilardo and Bittar 2018).

Water as Trigger of Conflict

Beginning on July 8, 2018, as temperatures rose to nearly 50 degrees C, thousands of people demonstrated in central and southern Iraq protesting against poor services, including water shortages, contaminated water, and chronic power outages; high and growing rates of unemployment; rampant corruption; and perceived Iranian interference in local affairs. These demonstrations turned violent, with security forces using live ammunition, tear gas, and water cannons on the crowds. At least 14 people had been killed by July 22. The protests took place in Basra, Najaf, Maysan, Dhi Qar, and Karbala, with smaller protests in Baghdad (Al Jazeera News 2018a).

The protests escalated in Basra in late August and early September 2018, with the protesters targeting "pretty much every government office, bureaucrat, political party, and armed group in the city that wields any power and influence" (*Vox* 2018). Online videos showed water coming out of faucets that was yellow, brown, or even black—too salty and polluted to wash clothes, let alone drink. By mid-October, the number of cases of poisoning from polluted water in Basra reached about 120,000, with officials warning of a possible resurgence of cholera in the region (*New Arab* 2018). After dying down for a few months, violent protests over unemployment, corruption, and lack of services (including clean water and electricity) erupted anew across many Iraqi cities in October 2019.

Solutions

In this section, we discuss some of the major responses we recommend to improve water-related security in Iraq.

Table 1 in the opening chapter of this report includes four broad categories of water security solutions:

1. Natural resources, science, and engineering approaches
2. Political and legal tools
3. Economic and financial tools
4. Policy and governance strategies

We will discuss priority responses within each category in turn but note that other responses may well be applicable in specific circumstances.

Natural resources, science, and engineering approaches

Water efficiency and conservation improvements. As per capita and total water availability decrease over time, water-use efficiency improvements can help Iraq generate the goods and services it requires with less water. In the agricultural area, this means shifting to more water-efficient irrigation systems. In urban areas, fixing leaks and reducing the amount of water that is unaccounted for while improving the efficiency of current water-use technologies from toilets and washing machines to industrial water use can increase productivity while decreasing water needs. As we noted above, it has been estimated that only about 32 percent of Iraq's treated water actually reaches customers (i.e., water system losses of 68 percent). Iraq needs to invest in and maintain improved water delivery infrastructure and technologies.

New centralized sources of water (desalination, stormwater capture, wastewater treatment and reuse, etc.). Iraq's significant water pollution problems require large-scale investment in wastewater treatment infrastructure and very significant improvement in solid waste management. Repairing and expanding water treatment technology can now include new approaches for expanding water reuse, capturing more stormwater, and, in the coastal regions in the south, perhaps building desalination systems for high-value urban uses.[6]

Data collection and information systems. A core principle for sustainable water management and transboundary water cooperation is that data on water quantity and quality should be collected and shared. Together with the other Tigris and Euphrates riparians, Iraq needs to develop water information systems that can measure baseline conditions and monitor progress toward goals.

Political and legal tools

Water-sharing agreements: transboundary. Formal agreements on how to manage, allocate, and share transboundary water resources, such as the Tigris and Euphrates Rivers, can help reduce disputes and tensions over water supply. At present, none of the major shared rivers in the region have river basin agreements that specify levels of withdrawals by each country, set seasonal standards for river flows, and provide rules to govern the management of large dams and other infrastructure. There are no functional multinational councils for the Tigris-Euphrates basin where disputes concerning the watershed can be heard, and no comprehensive data collection or sharing of basic water conditions. Efforts to initiate or restart negotiations on such agreements would help Iraq and all the other countries in the region develop sustainable plans for water and land use and increase domestic security. And because insecurity easily crosses national borders, such agreements increase the security of all the riparian nations (Gleick and Iceland 2018).

Water-use limitation and demand caps. Caps on total water usage in areas where water demand is high relative to expected supply can provide incentives for improving water-use efficiency in all sectors (addressed below). Water supply varies from year to year, so drought conditions need to be factored into these calculations. Governments can then engage with local stakeholders to identify the best ways to reduce total water demand to levels set by the caps.

Food security policies, open global food market access. The agricultural sector in Iraq has declined significantly over decades of conflict and economic sanctions. Today, about half of the cereals consumed in Iraq are imported, and about 2.4 million people require food security assistance (Bandiera et al. 2018). Many countries in the Middle East and North Africa (MENA) have tried to pursue food security by expanding domestic production, but food security and food self-sufficiency are not synonymous, especially if the latter is pursued in an unsustainable manner. The international community can boost food security in the MENA region and in other water-scarce countries by guaranteeing their ability to import food. If global food prices spike, the international community should help vulnerable countries stabilize prices to ensure that the poor can continue to afford food.

Legal ecological flow commitments. Restoring ecological health in the region's limited wetlands can serve political, public health, and environmental needs and reduce tensions over polluted waters. Wetlands improve water quality and provide food and services for local populations. As we noted above, part of the water pollution problem in Iraq is high levels of water salinity. These levels can be reduced by increasing river flows.

Human right to water and sanitation and the right to a healthy environment. In keeping with the human right to water and sanitation, and Iraq's intended nationally determined contributions (under the UN Framework Convention on Climate Change), the government could look to expand service delivery infrastructure across the country, especially for informal residents and other unconnected communities. This will not only help prevent illegal tapping and exorbitant increases in water prices during crises but also help mitigate water-quality problems related to unsafe waste and sewage management.

Economic and financial tools

Cropping patterns. In water-scarce and drought-prone areas, switching to high-value, water-efficient, and drought-resistant crop varieties may permit farmers to generate more income or yield per unit water applied. Iraqi researchers, for example, recently worked alongside international experts to develop a new drought-tolerant wheat variety that has increased yields fourfold (IAEA 2016).

Water prices, water subsidies. Exceedingly low water prices and a lack of awareness of water scarcity contribute to very high per capita water use in Iraq and lead to underinvestment. Iraq needs to consider raising water prices while showing progress in improving the services provided. Proper pricing helps finance water infrastructure investment and maintenance, and conveys to users that water is scarce and should be used efficiently. If prices for water rise toward the full cost of service, care must also be taken to provide appropriate subsidies and price protection for poorer communities for basic water and sanitation needs.

Policy and governance strategies

Reduced corruption. Corruption significantly hampers Iraq's ability to grow economically and provide basic services to its people. Rooting out pervasive corruption, although extremely difficult, is critical for reforming and improving water management institutions and restoring public trust.

Urban and rural development policies. Across the world, experts are anticipating a large net migration of people from rural to urban areas. If these migrants can find gainful employment in cities, this would take pressure off agriculture to provide livelihoods for them. Government could do a lot to help make this demographic shift easier and more successful. Assuming that Iraq is left with fewer and wealthier farmers, and more consolidated farmland, this could make the transition from water-wasting flood irrigation systems to more water-efficient but more expensive sprinkler and drip irrigation systems easier. However, consolidation of agriculture into larger units can also have adverse local and social consequences.

Population policies and gender equality. As noted above, Iraq's population has grown very rapidly in recent decades. Iraq could consider policies to reduce population growth and thereby lessen expected increases in water stress. Experience from a wide range of countries shows that fertility rates can drop rapidly when the following three strategies are pursued (Iceland 2017; Searchinger and Hanson 2013):

- *Increasing secondary education rates for girls while maintaining rates for boys*—This may involve improving access to and quality of educational opportunities by reducing distance to school, building safe and inclusive learning environments, providing sanitation facilities and transport, ending child marriage and early marriage, and addressing violence against girls and women.
- *Increasing acceptance of and access to reproductive health services and family planning options*—This includes concerted efforts to address early marriage and childbearing practices and women's lack of autonomy in reproductive decision-making, promoting more integrated services for family planning, and addressing cultural barriers like preference for sons and religious barriers related to family size, both of which restrict access to reproductive health services.
- *Reducing infant and child mortality*—This includes improving immunization programs, improving mother and child nutritional health programs, improving sanitation services, and addressing administrative and budgetary challenges in public health.

Enabling conditions need to be put in place for the above strategies to work. As we have mentioned, cultural norms and the status of women contribute to high fertility rates and the prevalence of child marriages in Iraq. In general, higher fertility rates indicate women's low status in a society (Caprioli 2005). Elevating women's status can help facilitate fertility rate reductions, lead to lower levels of conflict (Melander 2005), and help achieve other sustainable development outcomes (UN Women 2018).

Like other countries throughout the world, Iraq faces specific challenges to gender equality entrenched in its legal and political systems that are interlinked with religious and cultural norms. As a result, "women are marginalized and unable to contribute fully economically, socially and politically" (Vilardo and Bittar 2018). Breaking these and other structural barriers (Campbell et al. 2006) will sustainably raise women's status.

Conclusions

When we look at the totality of water problems in Iraq, we see rising demand for water while water supplies dwindle, water infrastructure that is in disrepair or absent altogether, and water quality that ranges from poor to unusable. In this kind of environment, livelihoods are jeopardized, food insecurity rises, and economic development and public health are at risk. Disaffection with government increases, as does the risk of violence, and many rural inhabitants are forced to migrate to cities, where jobs are already scarce.

Lack of safe, affordable, clean water has contributed to recent tensions and violence in southern and central Iraq, and the trends point to growing water-related instability. Although Iraq's water-related challenges can at times appear overwhelming, solutions exist. Numerous measures can be taken, including a range of technical, political, economic, and policy approaches. Iraq will need to work in close partnership with domestic stakeholders, with its regional neighbors, and with the international community to implement these solutions.

SECTION III

CASE STUDY IRAN

Peter Gleick

Increasingly scarce water supplies in Iran led to internal tensions and violent conflicts over access to water. Water scarcity also led to disputes with neighboring countries over use of water in shared river basins. A rapidly growing population, policies that promote food self-sufficiency (and with it significantly increased water use), and increasing temperatures and extreme weather have been identified as major drivers of the crisis. Solutions include improved agricultural water-use efficiency, ecological flow commitments to protect at-risk river and lake environments, transnational agreements on shared rivers, and increased participation of women and local groups in water management. These and other solutions could help mitigate water-related conflict in Iran.

Iran, like many countries in semiarid and arid regions of the world, faces growing challenges with sustainable water availability, management, and use. Iran's water and wastewater community has noted for several years the growing mismatch between water supply and demand, increasing water stress for a large number of urban centers and rural communities, declining groundwater levels due to agricultural overdraft, and the challenges of a changing climate (Al Jazeera News 2016; Karami 2015a; Madani 2016; Yazdanpanah et al. 2016). These stresses, combined with both internal political tensions and unresolved issues with neighboring countries, threaten to worsen and expand water-related conflicts. In this case study, we look at the range of hydrological, climatological, demographic, and socioeconomic factors that play a role in Iran's water challenges.

Geography

Iran is located in western Asia[7] and shares extensive borders with Pakistan and Afghanistan in the east; Turkmenistan, Azerbaijan, and Armenia along the north; Turkey and Iraq in the west; as well as long coastlines along the Persian (or Arabian) Gulf in the south and the Caspian Sea in the north. The country's topography includes highland and mountainous regions in the northwest and low-lying deserts, with a large central plateau.

Hydrology/Climatology/Water Use

Iran has a highly diverse climate and hydrology. The country is highly arid in the east, with moderate precipitation in the north and west. Summers are long, hot, and dry; winters are short and cool. Annual average precipitation is around 250 millimeters (mm) per year but varies greatly from less than 50 mm per year in central Iran to over 1,000 mm per year in the Caspian Sea area (Mesgaran and Azadi 2018), with two-thirds of rainfall occurring between November and March.

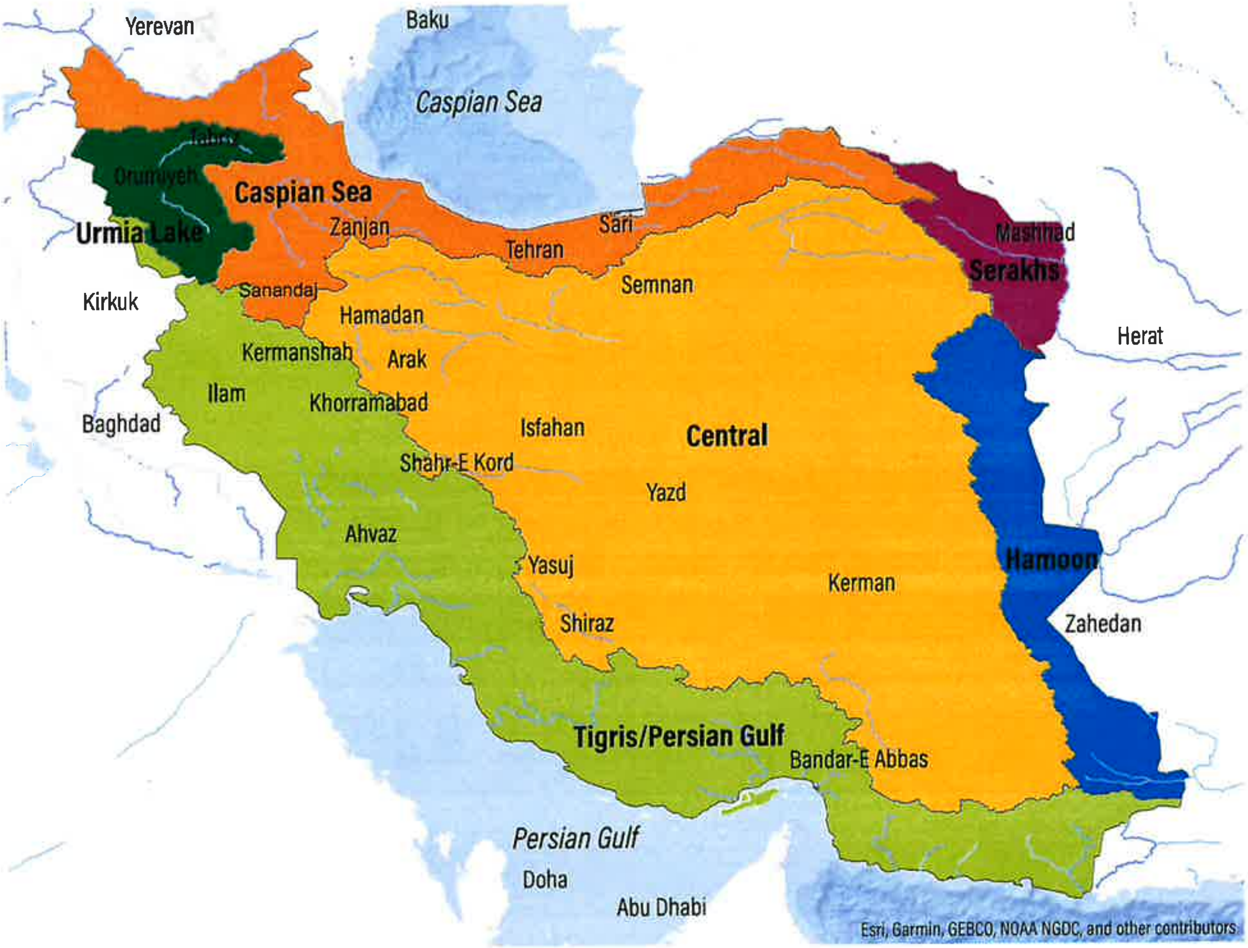
Iran has few major rivers, and river flow is highly variable, both within each year and interannually. Figure 7 shows the major watersheds of Iran. The highland plateau experiences internal or endoreic runoff. Rainfall in the north drains to the Caspian Sea; rainfall in the south drains to the Persian (or Arabian) Gulf; and rainfall in the east contributes to the Hirmand/Helmand and Harirud watersheds, shared with Afghanistan.[8] The Hirmand River provides important flows for population centers in eastern Iran but has suffered from decreasing flows in recent years due to both drought and human abstractions in both Afghanistan and Iran. Perhaps the most important internal river is the Zayandeh-Rud, which receives runoff from rain and snow in the Zagros Mountains and provides water supply for the city of Isfahan and the central region of the country. But water withdrawals from the river cause it to dry up seasonally, and transfers in and out of the river have had unintended consequences (Gohari et al. 2013).

Overall, Iran is considered a water-scarce country, with important regional differences in both supply and demand, as measured by both total and per capita availability of renewable fresh water (see Table 2). As we note in the next section, demographic factors, including both population size and distribution, also have contributed to metrics of scarcity.

By some estimates, Iran is already using over 80 percent of its reliable renewable fresh water, with agriculture comprising around 90 percent of total use and groundwater providing around 60 percent of current demand (Fanack Water 2016). In addition, however, the World Bank reports that a quarter of all water withdrawals in Iran should be considered nonrenewable—above what is replenished by nature (Sengupta 2018). Much of this nonrenewable water is groundwater overdraft. Governments have overallocated water rights and imposed few regulatory constraints on groundwater use. Subsidies for both energy and water also contribute to inefficient use and unrestricted pumping.

Groundwater, which is recharged by rainfall and surface runoff from wetter regions, has always played an important part in Iran's water development. Ancient groundwater systems, called *qanats*, were pioneered here and permitted groundwater resources to be extracted and moved long distances using only gravity, but in the past several decades, massive investment in pumping and groundwater irrigation systems has contributed to overdraft and unsustainable groundwater use, declining groundwater levels, and salinization of aquifers.

Figure 7 | Major Watersheds of Iran



Source: Map prepared by M. Shimabuku, Pacific Institute (2019).

Table 2 | Renewable Water Availability and Use in Iran (as of 2016)

Total Renewable Water Availability	100 to 137 billion cubic meters (bcm) per year
Total Water Withdrawals	93 bcm per year
Per Capita Water Use	1,215 cubic meters/person/year

Note: These data do not include the direct use of water in rainfed agriculture or the important regional differences in different watersheds, where total use can exceed reliable renewable water availability from unsustainable groundwater overdraft.

Sources: Different sources have different estimates for natural renewable water availability. The lower estimate here comes from the Iranian Ministry of Energy (Madani et al. 2016). Other estimates come from Mesgaran and Azadi (2018) and FAO (2018b).

Drivers of Risk

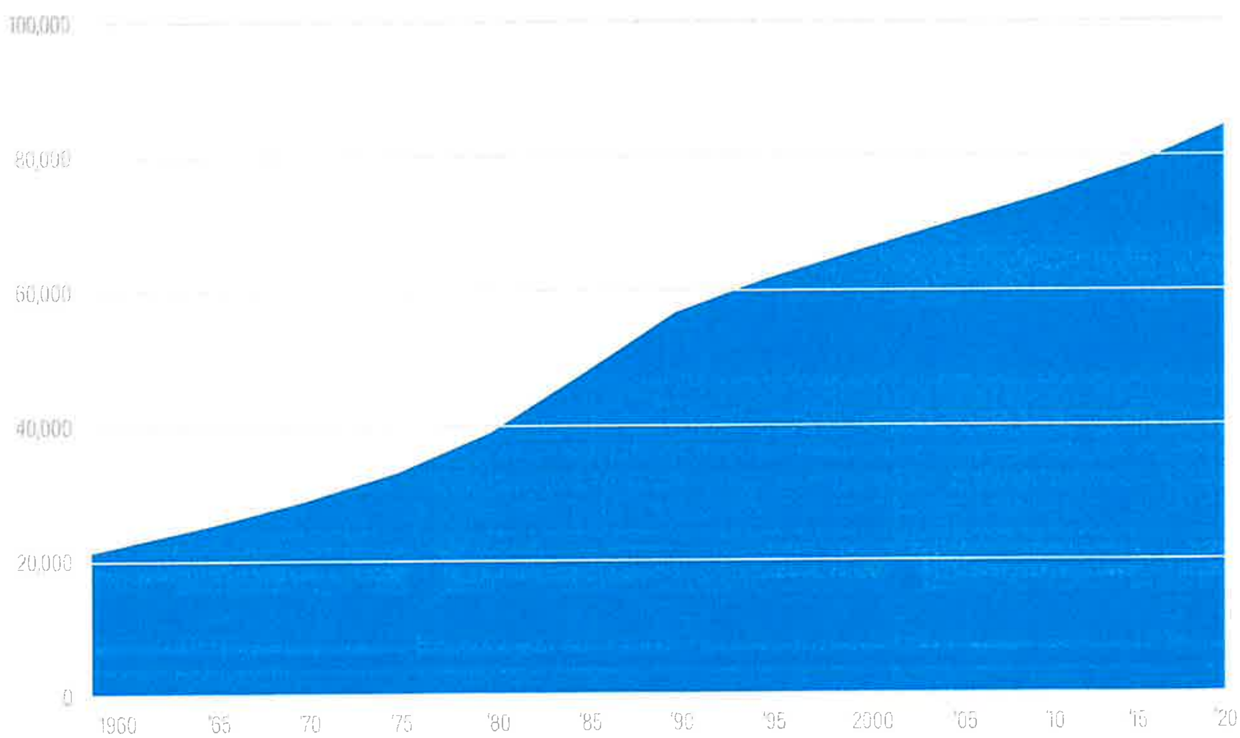
Water is rarely the sole factor behind violence, though there are numerous historical examples where water scarcity has helped trigger violence, government instability, or social unrest (Gleick 2019b). Many regions of the world suffer from short- or long-term water scarcity and use diverse tools of technology, governance, and management to reduce the consequences of scarcity. Challenges associated with water in Iran have many complex, interwoven drivers, including climatological and hydrological factors and a range of demographic, economic, management, and sociopolitical ones. Of special interest to people working on water management and water security are instances where traditional water management and policy tools fail and violence occurs. This section describes a set of factors driving water risk and water-related conflict in Iran.

Demographics

Iran is the second-largest country in the Middle East by both area (after Saudi Arabia) and population (after Egypt) (Madani 2014). Iran's population as of 2019 is almost 83 million people (Figure 8), with an annual growth rate of around 1.2 percent. A substantial majority of the population is urban, with over 8 million living in the capital, Tehran, and around 15 million in the greater Tehran area. As in all the countries of the region, population growth has been extremely rapid, doubling between 1980 and the present, and more than half the current population is younger than 35 (United Nations, Department of Economic and Social Affairs, Population Division 2017).

One obvious and significant consequence of rapid increases in population is a comparable decline in per capita availability of water. As shown in Figure 9, Iran's renewable available water decreased from

Figure 8 | Iran Population, 1960–2019 (Thousands)



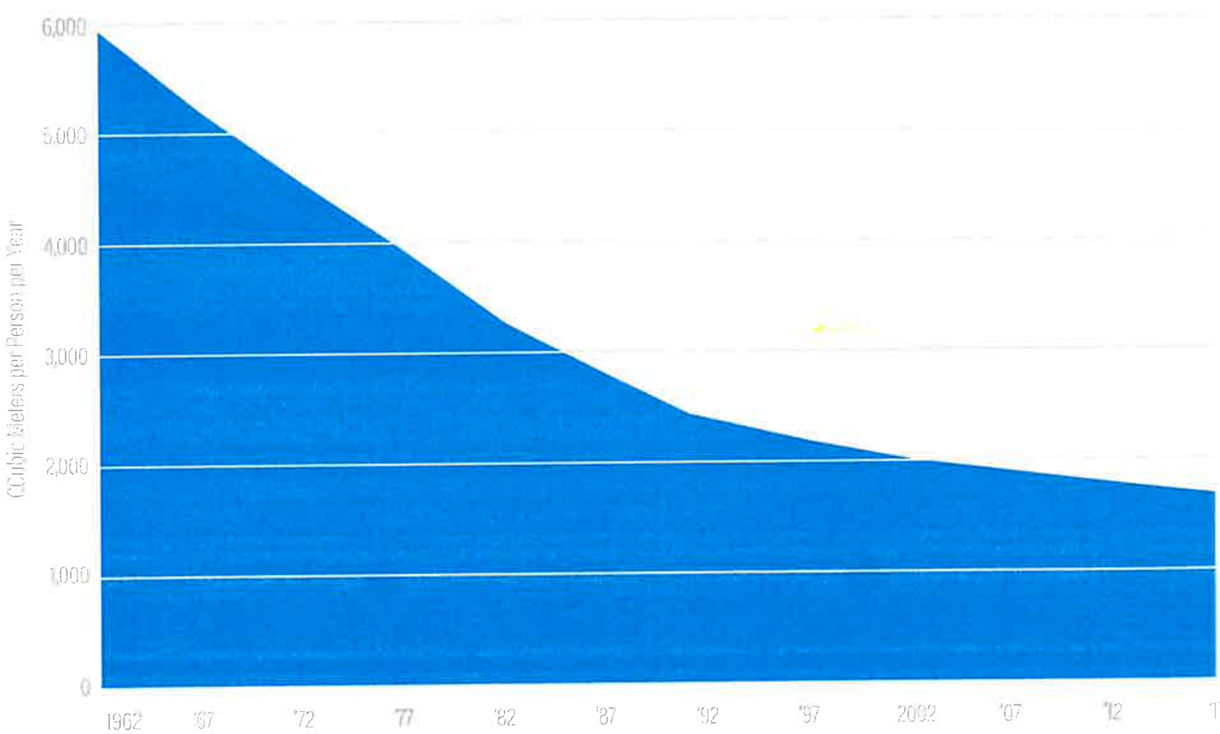
Source: World Population Review (2019).

around 6,000 cubic meters per person in 1960 to under 2,000 m³/p/yr by 2016, using UN data; Iranian authorities report that per capita availability is already under 1,500 m³/p/yr (Gohari et al. 2013). While this measure is an imperfect indicator of actual water availability, it shows the role that population growth plays in pressures on water.

As in some countries, though less so in Iran, women face severe direct consequences of water quality and quantity challenges in rural areas without reliable centralized water supply (Lansky et al. 2017). Women have been active in some of the public protests over water shortages, scarcity, and policy inaction (AFP News 2018; Lipin and Sajjadi 2018).

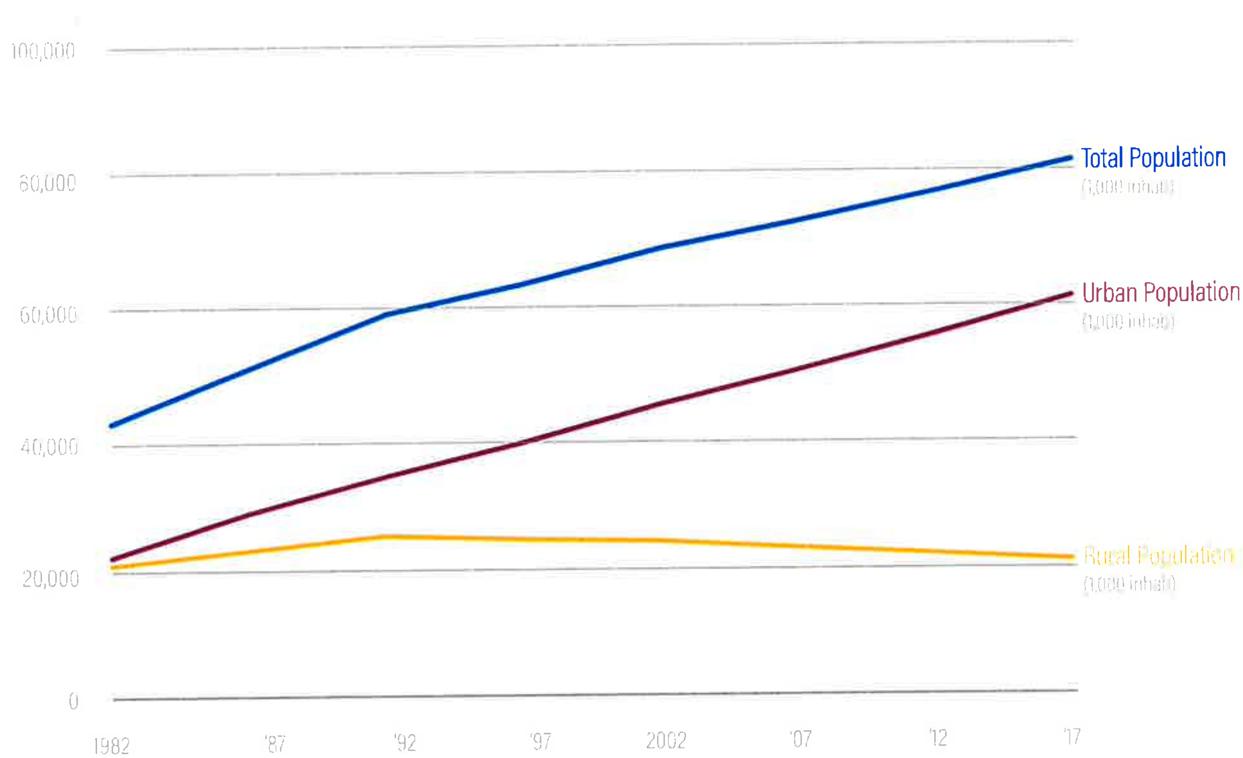
Associated with difficult demographic factors is the population shift from the countryside to cities. In 1982, Iran's population was equally divided into urban and rural areas; by 2017, 75 percent of the country's population was urban and only 25 percent rural (FAO 2018b) due to internal migration driven by economic and social factors. As Figure 10 shows, the entire growth in population between 1982 and the present has occurred in cities. New environmental issues are now contributing to internal migration. The idea of environmentally induced migration is not new (Reuveny 2007; Swain 1996). In Iran, declining water availability has been acknowledged as a threat to rural ways of life. In April 2015, Issa Kalantari, at that time the advisor on water and the environment to Iran's vice president and as of mid-2019 vice president and head of Iran's Department of Environment, said that if water management did not improve, Iran could experience mass migration of tens of millions of people from rural to urban centers (Karami 2015b; Shaddel 2017).

Figure 9 | Iran's per Capita Water Availability, 1960–2017



Source: FAO (2018b).

Figure 10 | Iran's Urban and Rural Population (1,000 People), 1982–2017



Source: FAO (2018b).

Urban and agricultural water management and use

As in many countries, and the world, the vast majority of water used in Iran goes to the agricultural sector. Growing urban populations and calls for ecological water protections, noted above, however, are increasing demand in direct competition with the agricultural sector, adding to political tensions. As we have noted, while parts of Iran receive generous precipitation during parts of the year, the large population and overall limits on water availability make it impossible for the country to be reliably self-sufficient in food production. Despite these limitations, the government has pursued policies of agricultural self-sufficiency since the 1979 revolution. By subsidizing agricultural inputs, including water, electricity, and fertilizers, providing farmers with guaranteed price floors for some 20 crops, and providing consumers with subsidies for bread and grains, Iran's agricultural sector has expanded beyond the point of sustainable water availability (Michel 2019), causing groundwater tables to decline and rivers and lakes to run dry. Figure 11 shows that water stress is high or extremely high throughout most of Iran.

Extreme weather and changing climate

Extreme heat and drought are long-time hazards in the Middle East and North Africa, and cultures there have developed a wide range of approaches for adapting to them. Nevertheless, increasingly complex and difficult social, demographic, economic, and political factors, combined with growing weather extremes, are making the region more vulnerable than it was in the past (Hoegh-Guldberg et al. 2018).

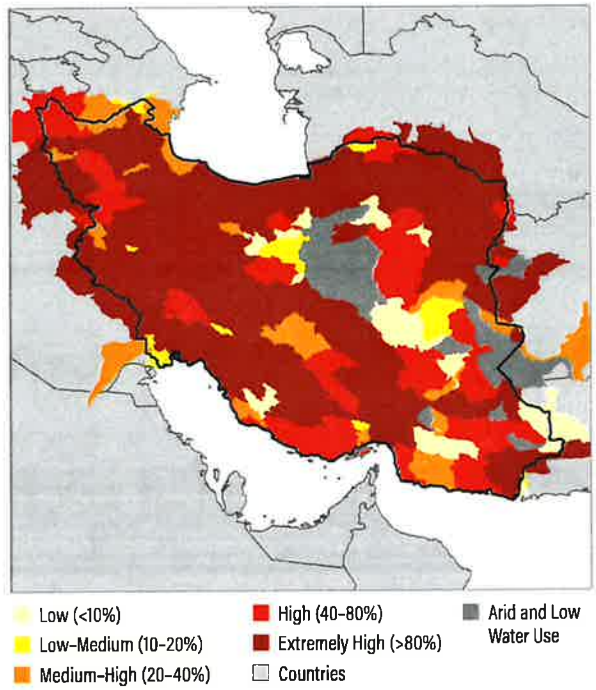
Recent extreme weather in the region, including extensive droughts, have contributed to a series of connected challenges, including decreases in water availability and reductions in hydropower generation within the country (Bizar 2018). At the same time, higher summer temperatures have increased water and power demands (Salahudden 2018). Even without the additional complication of human-caused climate change, such extreme conditions are more difficult to address given the demographic and water-management factors mentioned above.

The longer-term problem of human-induced climate change is an additional and growing challenge. Assessments by climate scientists have long projected increasing temperatures and growing precipitation and runoff deficits in the region in coming years (Christensen et al. 2013; Seneviratne et al. 2012). Recent observed trends in severe drought, rising temperatures, and reductions in precipitation are being linked to anthropogenic climate change (Cook et al. 2016) with impacts on agriculture and the displacement of populations from rural areas (Kelley et al. 2015; Saeidi et al. 2017). In 2015, the head of Iran's Environmental Protection Agency, Masoumeh Ebtekar, warned of the challenges of changes in temperature and precipitation for the region (Karami 2015a). While detailed regional climate assessments always come with a range of projections, the Iranian region as a whole has already seen statistically significant increases in temperature and is highly likely to experience continued warming (Habibi Mohraz et al. 2016), increased water demand as a result of higher temperatures (Ashraf et al. 2019; Vaghefi et al. 2019), changes in the timing of river runoff, especially in the few high-altitude areas where snowfall and snowmelt occur, and potentially a decline in overall rainfall (Sengupta 2018).

Water as Trigger of Conflict

The long-run consequences of these demographic, management, and climatological factors for conflicts over water depend on how severe they become and how communities, governments, and individuals prepare and react. Independently of the water issue, a series of protests began in major population centers in Iran in early 2018 and spread to other regions (Sengupta 2018). Many of these protests were expressions of concern and frustration about broader economic and political conditions and the economic impacts from international economic sanctions, high inflation rates, and inconsistent regulatory policies. But the failure of provincial and national governments to provide reliable basic water services or address concerns about water allocations and management have been noted as an additional driver of both local anger and violence and growing tensions with neighboring Iraq, Turkey, and Afghanistan. For some time, each of these nations has pointed the finger at neighboring countries for its water problems, increasing the political tensions in the region (Majidyar 2018). There are already indicators and evidence that conflicts over water in the region are worsening, giving us some insight into the nature and severity of the problem. Below, we describe some of the core tensions over water within Iran and with neighboring countries.

Figure 11 | Baseline Water Stress in Iran



Source: Hofste et al. (2019a).

Lake Urmia

A highly visible symptom of Iran's water problem is the rapid and dramatic fluctuation (both desiccation and reflooding) of Lake Urmia in the northwestern corner of the country that includes the provinces of East and West Azerbaijan, Kurdistan, and Kermanshah (Figure 8). Lake Urmia was originally one of the world's largest saltwater lakes by area, but in recent years it has shrunk to a few percent of its original size (Ashraf et al. 2019; Khazaei et al. 2019). Like other terminal lakes around the world—including the Salton Sea, the Aral Sea, and the Dead Sea—the size and extent of Lake Urmia depends on two simple factors: how much water flows into it from rivers and how much water is lost due to evaporation. When more water comes in than goes out, terminal lakes grow. When losses exceed inflows, they shrink.

In the Lake Urmia basin, a combination of factors contributed to the shrinking of the lake, including drought and the extensive damming and diversion of upstream water, which reduced inflows, and rising temperatures and climate change, which worsened evaporation from the lake's surface (Erdbrink 2018; Fathian et al. 2015). As the water disappeared, the salts on the lake bed have become exposed and the lake's ecosystem has been destroyed (Madani 2014; Zeinoddini et al. 2015). Salts mobilized by storms have the potential to damage nearby agricultural lands and crop productivity and contribute to population displacements (Madani 2014). Potential socioeconomic impacts of the lake's shrinking also include deteriorating health outcomes and livelihood prospects, impacting millions of inhabitants in surrounding villages (UNDP Iran 2019; Femia and Werrell 2012). Several protests in Tabriz in 2011 over the worsening conditions in the lake were violent, with at least one death, several injuries, and many arrests reported (Dehghan 2011; EuroNews 2011; Mackey 2011).[9] Continued fluctuations in lake levels warrant continued observation.

Central and southern Iran

In central Iran, there have been ongoing disputes over increasing diversions of water to Isfahan province from the Zayandeh-Rud, central Iran's longest river, originating from springs in the province of Chaharmahal and Bakhtiari (YJC 2015). The river used to terminate in the Gavkhouni wetland, a Ramsar site, but little flow now reaches it. Lawmakers from the provinces of Chaharmahal and Bakhtiari and Khuzestan, where the water originates, have regularly warned that the effort to increase diversions could worsen water-related conflicts (Bodaghi 2018; YJC 2015). The Isfahan Chamber of Commerce recently estimated that 2 million people—40 percent of the local population—have suffered economic losses as a result of the drying up of the river (CNA 2017).

In 2013, farmers in eastern Isfahan Province seeking additional water after severe drought fought with police and special forces after a water pipeline that diverts water to neighboring Yazd was destroyed (Al-Monitor 2013; Associated Press 2013). Several injuries and arrests were reported. These disputes reemerged in 2018 in a series of violent confrontations when facilities diverting water out of Isfahan in central Iran to the neighboring province of Yazd were again sabotaged, damaging reservoirs, pipes, and transfer facilities (Radio Farda 2018). In southcentral Iran in August 2018, clashes over water escalated in Bushehr Province along the Shapur River, when the government attempted to remove unauthorized irrigation pumps from the river. Iran's interior minister reported 20 water-related protests, including one that left at least one person dead and several injured (EuroNews 2018a). At the end of 2018, 18 parliamentary representatives from Isfahan announced they would resign in protest over what they considered unfair regional allocations of water and the failure of the central government to address water problems (EuroNews 2018b). The lawmakers were protesting the government's decision to take Isfahan Province's water transfer projects out of the official budget.

Western Iran-Iraq border

A combination of many factors—including long-term drought, drying wetlands in both Iraq and Iran, years of war in Iraq and Syria, construction of major dams such as the Ilisu project in Turkey, abandonment of farmlands, and exposure of dust flats from desiccated lakebeds—has contributed to growing water scarcity and severe dust storms in western Iran and neighboring Iraq, prompting protests in 2015 (Dehghan 2015). Increased oil and gas development, including water diversions and extractions around the Hoor-al-Azim wetland at the border of Iran and Iraq, have also led to social concerns (Zalaki et al. 2017). In 2017, President Hassan Rouhani traveled to Khuzestan Province to address public anger over air pollution caused by the dust storms, and late 2017 and early 2018 saw antigovernment protests driven, in part, by water and environmental problems (Bengali and Mostaghim 2017; Majidyar 2018). In 2018, violence and injuries were reported associated with protests in the city of Khorramshahr along the Iran-Iraq border and the Tigris/Euphrates River. Residents in this largely Arab city were protesting dirty, salty water as well as growing economic hardship (Associated Press 2018).

The Caspian Sea and water diversions

In recent years, the Caspian Sea, the world's largest inland saltwater sea, has become a focus of disputes over boundaries, water pollution and diversions, oil and gas extraction, and a deteriorating ecosystem. Several of Iran's northern provinces border the Caspian Sea, which the country shares with Kazakhstan, Russia, Azerbaijan, and Turkmenistan. Political efforts to negotiate solutions have produced three sets of agreements, including the 2003 Framework Convention for the Protection of the Marine Environment of the Caspian Sea (the "Tehran Convention"), protocols on pollution prevention and ecosystem protection, and in August 2018 a broader Convention on the Legal Status of the Caspian Sea (Akhmadiyeva and Abdullaev 2019). Despite these efforts, there are still no comprehensive agreements on water management in the Caspian Sea or surrounding territories.

The revival of a proposal in 2018 to divert and desalinate water from Mazandaran Province on the Caspian Sea through a 200 km pipeline to Semnan Province on the central plateau of Iran has been met with intense political opposition from representatives of the provinces of Gilan, Mazandaran, and Golestan (Deutsche Welle Farsi 2018). President Rouhani has repeatedly called for implementation of the diversion, despite some opposition from the country's Deputy Environment Directorate (Deutsche Welle Farsi 2019; Payvand News, Radio Farda 2019).

Shared Iranian-Afghan watersheds

Long-standing water disputes center on the management and allocation of waters shared between Iran and Afghanistan, including the Hirmand (called the Helmand in Afghanistan) and the Harirud. The Hirmand River originates in the Hindu Kush mountains northwest of Kabul, drains around 40 percent of Afghanistan, and flows into Sistan marshes and Hamun lakes in both southwestern Afghanistan and Iran's Sistan and Balouchestan Province. While most of the river's watershed lies within Afghanistan, cities in eastern Iran rely on Hirmand River flows for much of their water supply. In northeast Iran, the Harirud river basin provides irrigation and domestic water for over 3 million Iranians, including urban supply for Iran's second-largest city, Mashhad.

A formal agreement on sharing water from the Hirmand was signed by Afghanistan and Iran in 1973, guaranteeing Iran an average flow of 26 cubic meters per second, providing for data collection and exchange, and creating a basin commission. This is the only agreement between the two countries that specifically sets water allocations and follows earlier recommendations from the conclusions of the 1951 Helmand River Delta Commission (Hearns 2015). That treaty also established the current Helmand Commission, responsible for providing oversight of the provisions, but there have been few meetings and little active cooperation on data sharing or monitoring in recent years.

Around 2003, Iran joined a UN partnership to protect the Hamun lakes, and an Iran-Afghan commission was created to negotiate sharing of Hirmand River flows. In late 2010 energy ministers from Iran, Afghanistan, and Tajikistan established a water council to discuss water sharing (Houk 2011). There is no water-sharing agreement on the Harirud with Afghanistan.

The signed agreements are often touted as a positive example of managing a shared international river basin in a region with few positive examples, but disputes over the Hirmand's waters have persisted (Dehgan et al. 2014). Between 1999 and 2001, during severe drought, the Taliban-led government in Afghanistan was accused of cutting off the flow of the river to Iran, raising tensions in the region and reinforcing the Iranians' perception of their vulnerability to political manipulation of the watershed (Dehgan et al. 2014). In 2011, a military confrontation erupted between Iranian and Afghan border units over Iranian attempts to enter Afghanistan to increase water releases into an irrigation canal (Goes et al. 2016). There have also been reports that attacks on Afghanistan dam construction sites are encouraged or supported by Iran. Both the provincial governor and the police chief of Farah, Afghanistan, have publicly accused Iran of providing arms, explosives, and training for these attacks (Houk 2011). In the Harirud basin in 2015, at least 10 people were reported killed in disputes between Iran and Afghanistan over access to water where the river forms the shared border (Karimi and Hulpachova 2015).

These problems are continuing: in 2018 Iran again argued that new water projects in Afghanistan have dramatically cut flows into Iran on both the Harirud and Hirmand Rivers (*Financial Tribune* 2018). Ongoing drought in Sistan and Balouchestan Province has heightened tensions over water, worsened by a sectarian factor: the province has a sizeable Sunni majority, in contrast to Iran's Shia majority. This dispute has pitted members of parliament from Sistan and Balouchestan Province against the Foreign Ministry (Bodaghi 2018).

Solutions

In this section, we discuss some of the major responses we recommend to improve water-related security in Iran.

Table 1 in the opening chapter of this report includes four broad categories of water security solutions:

1. Natural resources, science, and engineering approaches
2. Political and legal tools
3. Economic and financial tools
4. Policy and governance strategies

Below we discuss a few of the most relevant and important approaches, with the understanding that other approaches in our solutions table may also be valuable and worth pursuing.

Natural resources, science, and engineering approaches

Improved agricultural water-use efficiency. A core driver of overall Iranian water use is the large demand by agriculture. Inefficient farm water use, the choice of water-intensive crops,

lack of modern irrigation practices, or insufficient groundwater management are all common challenges in water-scarce regions (Gleick et al. 2011). Improvements in each of these areas could reduce farm water demand and improve the livelihoods of the agricultural community, which could help reduce internal migration away from rural areas. The potential to increase water-use productivity in Iranian agriculture has not been assessed in detail, but experience in other regions suggests that agricultural water use can readily be reduced by 10 to 20 percent or more without reducing yields through switching to modern irrigation technologies, soil-moisture monitoring, and improved delivery systems (Al-Faraj et al. 2016; Nazari et al. 2018). Improvements in agricultural productivity should be coupled with restrictions on total water use in order to free up water for ecological restoration and urban needs. National priorities around Iranian food self-sufficiency also contribute to pressures on water. The international community has a role to play here by preventing the imposition of external economic sanctions on food and encouraging open access to international food markets. While current sanctions exempt food, medicine, and humanitarian supplies, measures targeting financial activities have deterred many banks from doing business with Iran, slowing imports of grain and other humanitarian supplies (Gardner 2019).

Joint scientific exchanges. Even during times of political tension, sharing of information between scientific organizations and research communities can keep lines of communication open and help identify technical and policy solutions to pressing challenges. During the Cold War, the Pugwash organization helped U.S. and Soviet scientists share information and ideas. Pugwash was awarded a Nobel Peace Prize in 1995 for these efforts to reduce the threat of nuclear war. Iranian and U.S. hydrologists and water specialists have met, for example, during the 2002 joint Iranian-American Workshop on Water Conservation, Reuse, and Recycling, sponsored by the two nation's academies of science (National Research Council 2005). In 2007, the U.S. National Academies and the Iranian Institute for Advanced Studies in Basic Science held joint U.S.-Iranian workshops on the topic "Science as a Gateway to Understanding" (National Research Council 2008). More recently, U.S. and Iranian experts have met to address a wide range of environmental challenges, including the decline of Lake Urmia (National Academies of Sciences, Engineering, and Medicine 2018). The European Union and Iran are also involved in partnerships and cooperation in areas of science, technology, and research through the EU Horizons 2020 Program (European Union 2018b) and an effort focused on sustainable development, including water (European Union 2018a).

Political and legal tools

Legal ecological flow commitments, strengthened environmental laws. Some of the tensions over water are related to ecological problems associated with human extractions of water, including the fluctuations of Lake Urmia; the drying of the central Gavkhouni wetland, the Hawizeh marshes along the Iraq-Iran border fed by the Tigris and Karkheh Rivers, and other wetlands in the southwest; and worsening conditions in the Sistan and Hamoun marshes in the east. Iranian government agencies could set up a wide range of protections of rare and critically threatened natural ecosystems, including some guaranteed ecosystem water allocations (Farashi and Shariati 2017; Sajedipour et al. 2017). Iran has already begun to address some of these problems with international partners and local communities like farmers and women's groups (UNDP Iran 2019).

Water-sharing agreements. Water development projects must consider the needs of domestic populations as well as those of neighboring nations when water resources are shared internationally. Core principles, rights, and obligations are set out under a variety of international laws and strategies, including river basin treaties and UN declarations. For the watersheds Iran shares with Afghanistan, Iraq, Turkey, and the nations around the Caspian Sea, this means addressing conflicting demands in the watersheds through joint monitoring systems, data-sharing, and technical cooperation around both variable water quantity and quality. Joint river basin commissions, like the one set up for the Hirmand/Helmand basin (but not for the Harirud or other shared watersheds) and those developed in other regions of the world (the Mekong River Commission, the International Boundary and Water Commission between the United States and Mexico, etc.), permit knowledge-sharing and, if functioning properly, provide a mechanism for resolving conflicts when they arise (Dehgan et al. 2014).[10]

Economic and financial tools

Water prices, water markets, other economic tools. As in much of the world, water and energy prices in Iran do not reflect the true costs of providing reliable water and energy. Inappropriate agricultural subsidies lead to inefficient water allocations and demand and should be revisited. Conversely, the use of proper pricing approaches can increase the efficiency of water use and improve water practices in all sectors, including the agricultural sector (Tahamipour et al. 2015). If prices for water rise toward the full cost of service, care must also be taken to provide appropriate subsidies and price protection for poorer communities for basic water and sanitation needs. The creation of some form of water market may also help regulate, allocate, and efficiently use limited water resources. When water is properly priced, individual and community incentives rise to invest in more water-efficient technologies and practices.

Assuming Iranian food prices rise along with rising water prices, care must be taken here as well to continue providing subsidies enabling poorer communities to meet basic food needs. Access to global food markets could relieve price pressures on Iranian food. It is important to bear in mind that Iranian food security is at risk if nothing is done to improve unsustainable water use.

Policy and governance strategies

Improved water management and governance. Water management in Iran has long relied on centralized water agencies and focused on large-scale hard centralized water infrastructure construction. More appropriate strategies include decentralized, soft-path approaches of water efficiency, alternative nontraditional supplies, improved economics, and regional, decentralized water basin approaches. As Kaveh Madani (2014) has noted, "Such a management paradigm recognizes the interrelated dynamics of the water sector with other sectors, cures the problem causes rather than its symptoms, manages water rather than controlling it, and benefits from effective non-structural (soft) solutions (e.g. regulations, institutions, taxation, monitoring, population control) as much as it benefits from structural (hard or engineering) solutions (e.g. dam construction, water diversion, using irrigation sensors)."

Improved water management can also provide broader benefits linked to improved governance, including more decentralized control of water, better engagement and education of local communities, reduced corruption and internal government conflicts over water policy, and strengthening of environmental agencies.

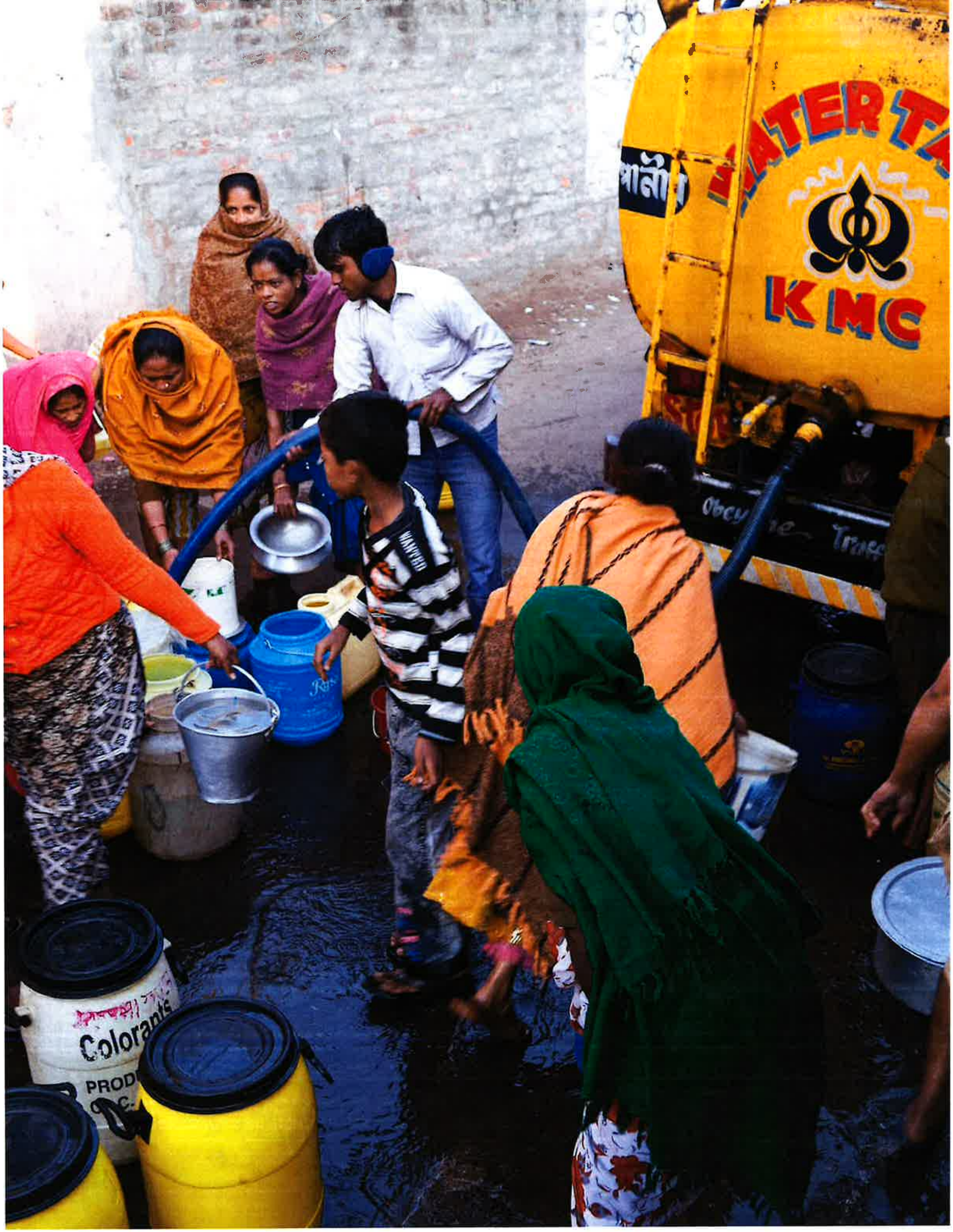
Gender equality, stakeholder and community engagement. When women influence water management, studies show that their communities get measurably better outcomes—including better-functioning water systems, expanded access, economic and environmental benefits, and equitable distribution, especially in times of scarcity (Morna 2000; Mommen et al. 2017; Kholif and Elfarouk 2014; UNDP and Gender and Water Alliance 2006; Lecoutere et al. 2015). However, women's participation in decision-making roles is often restricted by their lower status in society and the discrimination they face in their homes and communities. These restrictions are often compounded by other social characteristics like age, class, and religion (O'Neil and Domingo 2015). Breaking such country-specific structural, social, legal, and economic barriers (Campbell et al. 2006) is essential to raising women's status and enabling them to actively participate in water-resource decision-making.

Improvements in women's education, economic and political participation, and safety are also correlated with reduced inter- and intrastate violence (Hudson et al. 2012; Caprioli et al. 2005; Caprioli 2000), and lead to lower levels of conflict (Melander 2005), more peaceful and stable outcomes (Hudson et al. 2012), and help achieve other Sustainable Development Goals (UN Women 2018).

Summary

Iran faces a complex and growing set of water challenges associated with a disparity between reliable renewable water availability and water demand, internal disputes over the control, allocation, and distribution of water, conflicts with neighboring countries over shared watersheds, declining groundwater levels and deteriorating aquatic ecosystems, and problems associated with climate change. These stresses, combined with both internal and international political tensions, threaten to worsen and increase the risk of water-related conflicts. In this case study, we have looked at the range of hydrological, climatological, demographic, and socioeconomic factors that play a role in Iran's water conflicts, including examples of recent violence over water.

A wide range of strategies are available to reduce the risks of water conflicts, both broadly applicable approaches and some tailored specifically in the Iranian context. These include technological, economic, institutional, and legal approaches summarized here and explored in more detail in the opening chapter of this report prepared for the Water, Peace, and Security partnership (WPS 2019). No single approach will eliminate water problems or the related political complications that can result, but integrated water management approaches can be very effective.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SECTION IV

CASE STUDY INDIA

Charles Iceland

Recent drought conditions throughout India have precipitated violent and nonviolent demonstrations and marches, led to disputes between states over scarce water supplies, left urban dwellers without water, and forced rural inhabitants to flee their towns and villages. Population size and growth rates, unsustainable water use for irrigation, and outmoded water-resources management regimes have been identified as major drivers of the crisis. Solutions include improved data collection and information systems, green and gray water-storage systems and water-use limitations in high-stress areas. These and other solutions could help mitigate water-related insecurity in India.

For its population and size, India is one of the most water-stressed countries in the world (Hofste et al. 2019b; Gassert et al. 2014). About 54 percent of India faces high to extremely high levels of water stress. In addition, India's seasonal variability of water supply is very pronounced (Aqueduct Water Risk Atlas 2014): about 50 percent of the country's rain falls in just 15 days, and over 90 percent of river flows occur in just four months (Briscoe and Malik 2006). Many years, the monsoon fails (i.e., monsoon season rainfall is significantly below normal). India is the world's largest user of groundwater, which accounts for 80 percent of the nation's drinking water and nearly two-thirds of its irrigation needs (Committee on Restructuring the CWC and the CGWB 2016). Groundwater stress in the northern part of the country is among the highest in the world (Gleeson et al. 2012; Aqueduct Water Risk Atlas 2014). Conversely, there is also a problem with too much water—periodic severe flooding kills many people and upends lives and livelihoods.

Access to water, sanitation, and hygiene is relatively low in India. Estimates for the year 2017 (Figure 12) show relatively large percentages of the population lacking access to at least basic sanitation and hygiene services.[11] And a relatively significant percentage of the population lacks access to at least basic drinking water service.[12]

There are other water risks as well. We will discuss these risks, their drivers, the types of insecurity and conflict they help produce, and possible risk-mitigating "solutions" in the following pages.

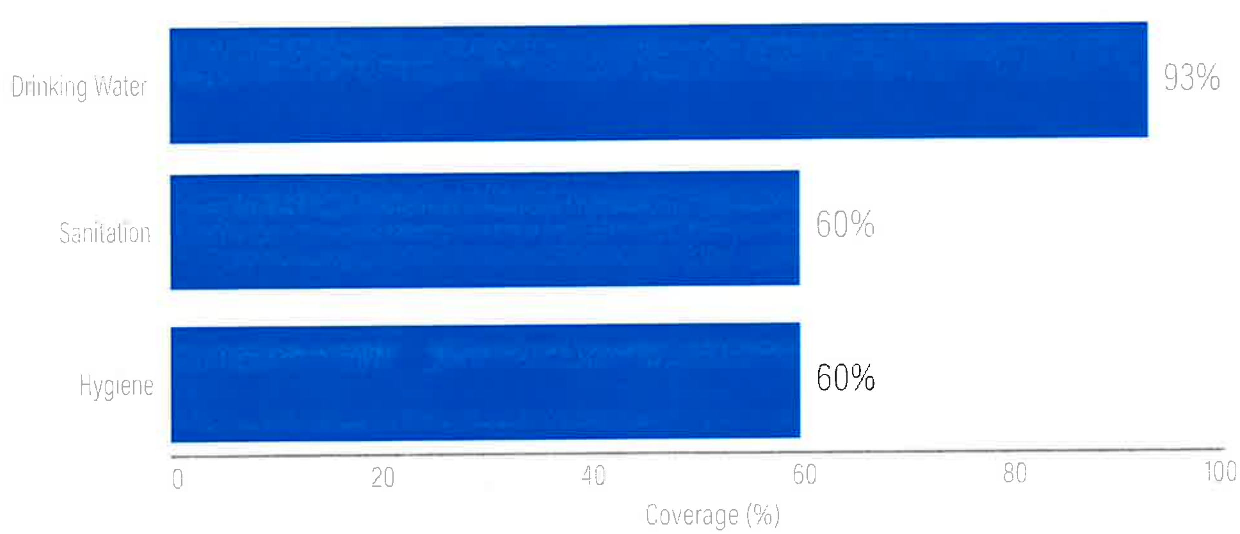
Scope

Water, security, and conflict in India is too vast a subject to address in this report. We do not address important international (or "transboundary") issues (for example, between Pakistan and India, or India and Bangladesh)—there is a great deal written on these subjects elsewhere. Nor do we explore important urban or industrial water issues in any depth. Our focus here is on local and regional risks, insecurity, and conflicts associated with agricultural water use in India.

Drivers of Risk

We have witnessed many instances in recent years of chronic water stress and episodic drought affecting farmers and agriculture throughout India. As is true worldwide, agriculture is vulnerable to the vagaries of weather and water availability, but water stress and drought in India seem to be expanding. In some parts of India, farmers counting on irrigation water have been cut off and advised not to plant. In other parts of India, recur-

Figure 12 | India Water, Sanitation, and Hygiene Coverage (2017)



Source: WHO/UNICEF JMP (n.d.).

ring drought forces farmers and family members to migrate to cities in search of jobs and livelihoods. In still other parts of India, tens of thousands of farmers have marched almost 200 km to a state capital to press for relief from drought. What is driving these problems?

Population and population growth

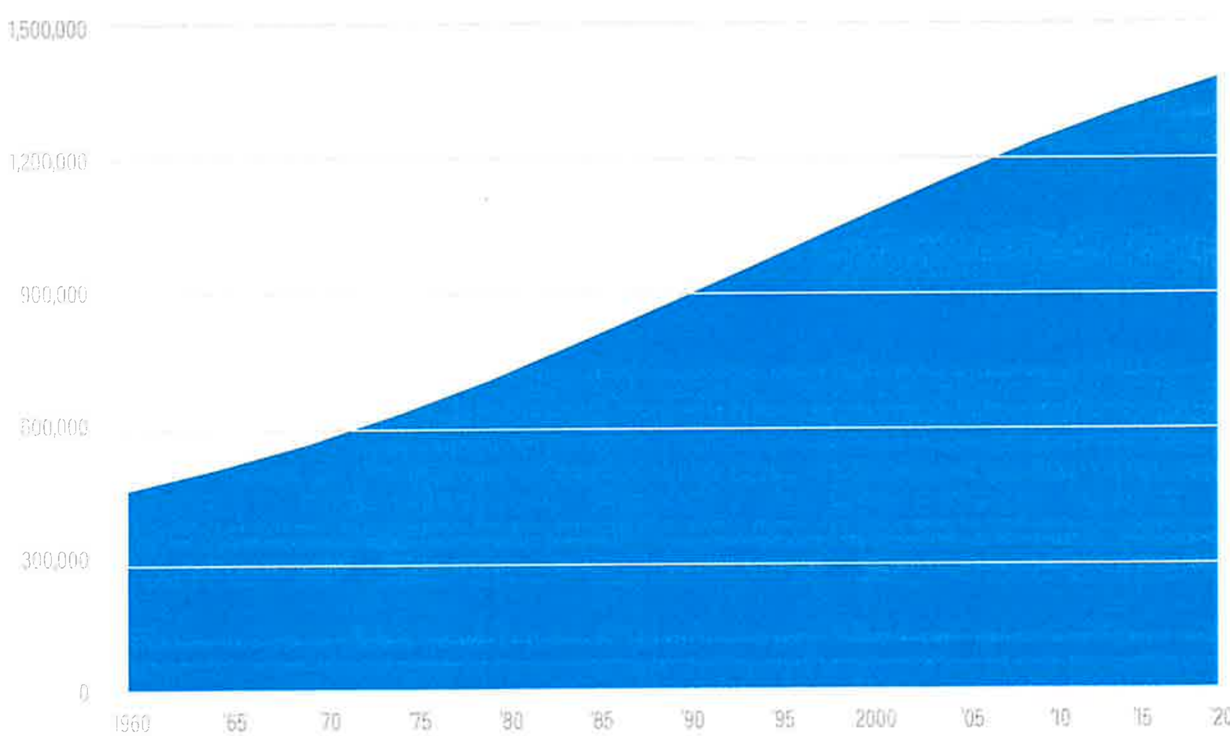
Population size and population growth rates are key drivers of water risk, especially in India. India's population has more than tripled since 1960 (Figure 13). Total population in 2020 stands at almost 1.4 billion and will soon surpass that of China. Population growth rates are slowing down, however, and projections are that India's population will likely peak around 2060 at around 1.7 billion people. More people means decreased water availability per capita. In addition, only about a third of India's population is urban, meaning that large numbers of Indian farmers are affected by water scarcity and drought.

India's population growth is directly related to a variety of socioeconomic issues such as inequitable access to health and education services, high maternal and infant mortality, bias against girl children, child marriage, and other concerns related to gender inequality (Yadavar and Raman 2020; Raina 2017).

Unsustainable water use

Figure 14 provides an overview of water stress across India, defined here as the ratio of water demand to water supply (Hofste et al. 2019a). Most of Figure 14 is shaded red or dark red, indicating high or extremely high stress. India, in short, is using a very high fraction of total water availability; indeed, in many places across India, total water use exceeds natural renewable, recharge and groundwater tables are falling, meaning that water is being pumped out of the ground faster than it can be replenished.

Figure 13 | India Population, 1960–2020 (Thousands)

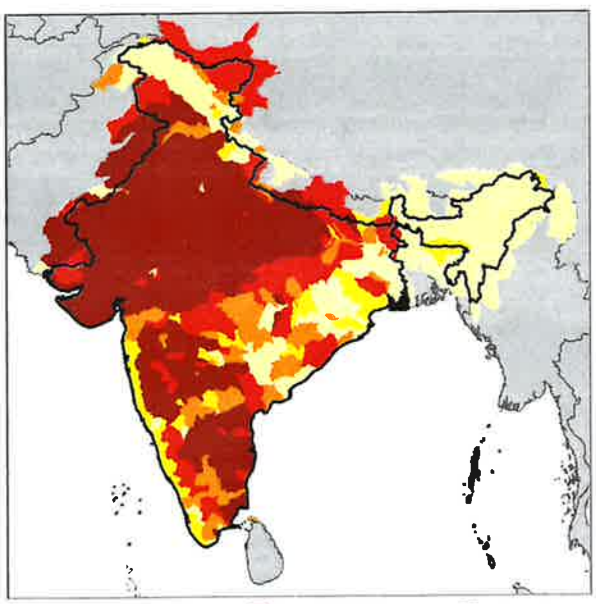


Source: World Population Review (2020).

The latest results from remote sensing through NASA's Gravity Recovery and Climate Experiment (GRACE) satellites indicate that northern and eastern India lost significant amounts of groundwater between 2002 and 2016 (Rodell et al. 2018). These groundwater losses were mostly due to overabstraction of groundwater to irrigate crops. Jay Famiglietti, one of the authors of the NASA-GRACE study, notes that "although the trends in groundwater are confined to the northern part of India and into Bangladesh, it is really a national problem in the sense that, especially in northwestern India, that region grows food for the nation." The problem is not only one of food security, however, but also of employment and livelihoods. One source observes that "although agriculture comprises only 17 percent of India's Gross Domestic Product, it employs more than half of the workforce" (Jain 2018).

Many observers attribute agricultural overabstraction of groundwater in India to government policies designed to curry favor with rural voters. Amit Kar, an economist at the Indian Council of Agricultural Research, attributes groundwater shortage to "government policies such as free electricity for irrigation, credit facilities and subsidies for digging wells and buying pumping equipment, as well as heavily subsidized diesel fuel for pumps" (Parvaiz 2016).

Figure 14 | Baseline Water Stress in India



Source: Hofste et al. (2019a).

Often-inefficient use of agricultural water

Experts also point to wasteful use of water for planting thirsty crops such as rice, wheat, and sugar in water-scarce and/or drought-stricken areas. Rice, for example, requires about four times as much water as maize, pulses, or oilseeds. Cultivation of such crops is driven in part by the national government's program to purchase staple foods like rice, wheat, and sugar as part of its Public Distribution System. The government then sells these foods to citizens at subsidized prices (Parvaiz 2016).

In addition to planting water-intensive crops, the vast majority of India's irrigation consists of inefficient flood irrigation. In 2004, irrigation in India was 97 percent flood irrigation, 2 percent sprinkler irrigation, and 1 percent drip irrigation (FAO 2016a). By 2015, sprinkler and drip irrigation as a percent of total area sown was estimated at 5.5 percent (Grant Thornton 2016). To the extent that India can shift to less water-intensive crops and to sprinkler and drip irrigation, it will be possible to maintain or expand agricultural production while reducing water stress.

Vulnerability to drought

John Briscoe and R.P.S. Malik (2006) have noted that "whereas arid rich countries (such as the United States and Australia) have built over 5,000 cubic meters of water storage per capita, and middle-income countries like South Africa, Mexico, Morocco, and China can store about 1,000 cubic meters per capita, India's dams can store only 200 cubic meters per person. India can store only about 30 days of rainfall, compared to 900 days in major river basins in arid areas of developed countries." Unfortunately, India's per capita water storage capacity has not increased significantly in the years since (Ministry of Environment, Forest and Climate Change 2018). The combination of very high water stress, a monsoonal rainfall pattern, and low

water-storage capacity makes India exceedingly vulnerable to drought. The failure of the monsoon to fully materialize in any given year can spell ruin for poor farmers living hand-to-mouth. At the same time, political, economic, and environmental constraints on expanding traditional dam storage projects make it urgent to explore other, nonstructural strategies (see below) for reducing drought vulnerabilities.

Food loss and waste

FAO estimates that, by weight, about 32 percent of all food produced in the world in 2009 was lost or wasted; by calorie, the figure was about 24 percent (Lipinski et al. 2013). In South and Southeast Asian countries, per capita food loss and waste is about 120 kilograms per year. The majority of that loss and waste is at the preconsumer stage (Gustavsson et al. 2011). Addressing food loss and waste could greatly reduce the amount of water required to meet food needs (see Mekonnen and Hoekstra 2011 for detailed information on the water footprint of crops and crop products).

Outmoded water-resources management regimes

In the mid-20th century, the development of vast irrigation systems helped power the Green Revolution in India. Millions of people avoided starvation, stunted growth, and other effects of malnutrition. In the 21st century, however, the Green Revolution and India's water resources are suffering a crisis of sustainability (Committee on Restructuring the CWC and the CGWB 2016). In their July 2016 report, the seven-member Committee on Restructuring the Central Water Commission and the Central Ground Water Board, led by Mihir Shah, laid out "India's Water Crisis" in stark terms:

- "If the current pattern of demand continues, about half of the demand for water will be unmet by 2030
- Water tables are falling in most parts of India
- There is fluoride, arsenic, mercury, even uranium in our groundwater
- Recent droughts and persistent farmers' suicides underscore the gravity of the situation
- Climate change poses fresh challenges as more extreme rates of precipitation and evapo-transpiration exacerbate impacts of floods and droughts
- Cities produce nearly 40,000 million litres of sewage every day and barely 20 percent of it is treated
- Only 2% of our urban areas have both sewerage systems and sewage treatment plants
- More intense, extreme and variable rainfall, combined with lack of proper drainage, means that every spell of rain becomes an urban nightmare as roads flood and dirty water enters homes and adds to filth and disease.
- It is no wonder then that conflicts across competing uses and users of water are growing by the day."

The water-resources management paradigm that helped drive past successes now appears to be part of the problem.

Water as Trigger of Conflict

Drought drives conflict between Karnataka and Tamil Nadu

Water scarcity and drought often spark heated competition and conflict among Indian states, especially Karnataka and Tamil Nadu, which share the Cauvery River (Iceland 2017). In September 2016, when the Indian Supreme Court ordered Karnataka to release water from its reservoirs to relieve drought-stricken farmers in neighboring Tamil Nadu, protest riots erupted in Karnataka's capital city, Bengaluru. Thousands of police were deployed to restore order, at least two people died, and others were injured. Over 400 people were arrested (Gleick 2018). Karnataka argued that millions of its farmers needed the water due to the severe impact of the drought on the state's water storage—42 percent of its 3,600 irrigation tanks had been left dry (BBC News 2016).

Conditions in Tamil Nadu, meanwhile, worsened. In January 2017, the Indian Meteorological Department announced that the northeast monsoon of October–December 2016 had been Tamil Nadu's worst since 1876. The state government officially declared a drought in January 2017, following 144 farmer suicides between October and December (Waghmare 2017). In March 2017, a group of Tamil Nadu farmers demanding loan waivers, revised drought packages, better prices for their produce, and a committee to handle the sharing of Cauvery River water staged a 40-day protest in Delhi to draw the central government's attention to their demands (Govindarajan 2017; Balachandran 2017).

Chennai—India's sixth-largest city—runs dry

In mid-June 2019, news that Chennai, a city of 4.9 million people and the capital of Tamil Nadu, had run out of water shocked the world. It was reported that four large reservoirs supplying India's sixth-largest city had dried up (*The Guardian* 2019). This resulted in schools, hotels, restaurants, and other businesses shutting down. Information technology companies asked employees to work from home, and residents formed long lines to receive small amounts of water from government tankers. Instances of violence were reported among residents fighting over rations (CNN 2019; *Time* 2019; *The Wire* 2019). Monsoonal rains arrived in the weeks and months after the Chennai reservoirs ran dry, but the city will remain vulnerable to future droughts until significant water resource management improvements are implemented. The impacts of, and in some cases even the responses to, the crisis were inequitable, with poor and marginalized populations suffering disproportionately (Trivedi and Chertock 2019).

Drought in central India pits Madhya Pradesh against Gujarat

The Narmada River flows east to west through the Indian state of Madhya Pradesh (MP), then through the state of Gujarat before emptying into the ocean. Drought in 2017 led to a conflict over how much water should be released from the Indira Sagar reservoir in MP to the downstream Sardar Sarovar reservoir in Gujarat (Iceland et al. 2018).

At the end of 2017, Indira Sagar's peak reservoir water level was 33 percent lower than average, as seen in Figure 15. Releasing more water would have further reduced this MP reservoir's supply during the critical summer period. Because Gujarat's Sardar Sarovar reservoir didn't get its allocated amount of water from Indira Sagar, however, its level fell at an alarming rate. The Sardar Sarovar reservoir is the drinking water source for about 30 million people, almost half of Gujarat's total population, and the irrigation water source for more than 1 million farmers (Sardar Sarovar Narmada Nigam Ltd. 2019).

On March 15, 2018, the government of Gujarat stopped supplying water for irrigation, and the state minister appealed to farmers not to sow summer crops (*Indian Express* 2018). The low water level also curtailed Sardar Sarovar's ability to generate electricity.

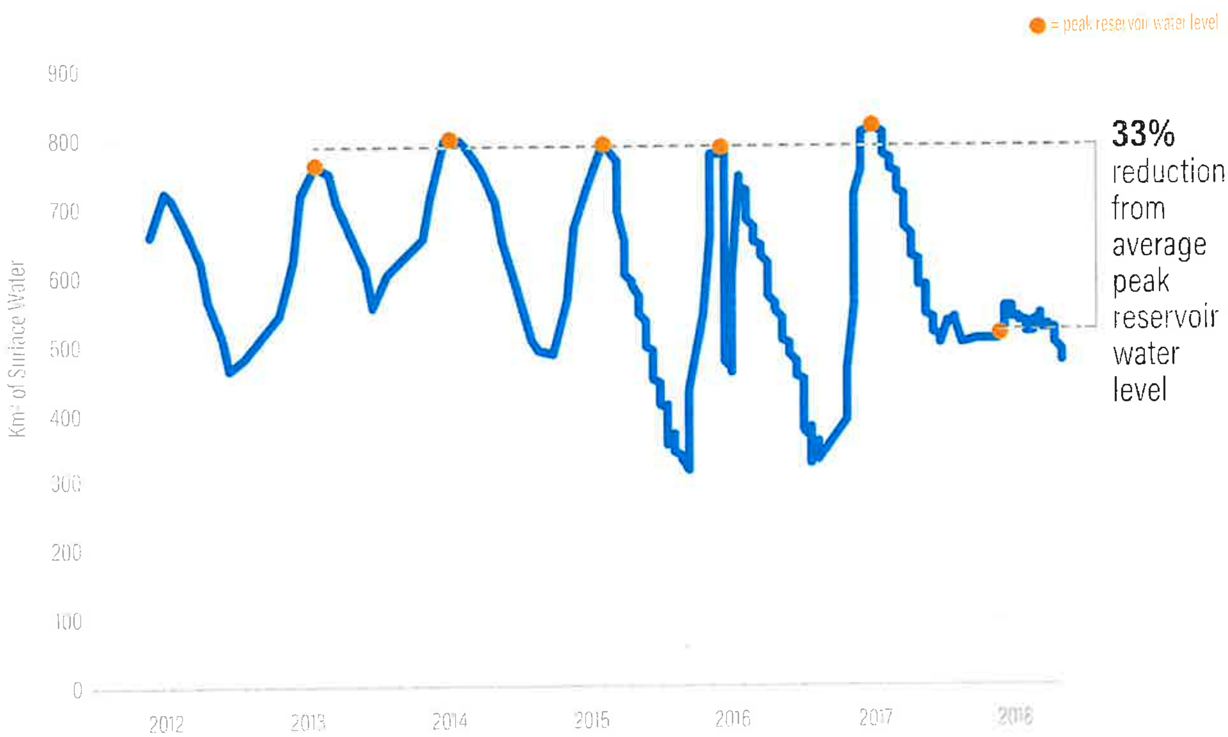
In upstream MP, according to reports, the state's chief minister came under political pressure to not release more water from its reservoir, as that could adversely impact the livelihoods of its water users. This was a sensitive political issue prior to assembly elections set for the year's end. Reports noted that local farmers were already on edge—western MP had been the "epicenter of violent farmer unrest" in mid-2017 (Noronha and Maburkar 2018). On June 6, 2017, police had opened fire on protesting farmers in Mandsaur district, killing five (*LiveMint* 2017).

Drought in Maharashtra sparks mass protests by farmers

During the second half of 2018, Maharashtra experienced back-to-back summer and winter droughts for the first time since 1972. Both the main southwest monsoon (June to September) and the smaller winter monsoon (October to December) produced deficient rainfall in the region (Haq 2019). On February 21, 2019, over 50,000 farmers in Maharashtra began a 180 km peaceful march to Mumbai to protest unfulfilled demands on the government, including "complete loan waiver[s], compensation, relief and insurance for crop damage in situations like drought, a higher minimum support price (MSP) for crops, land rights, irrigation facilities, and pension schemes for farmers among others" (Mitra 2019).

The following day, protest leaders halted the march following successful negotiations with the Maharashtra government. "Besides accepting the demands raised by the farmers, the [All India Kisan Sabha] said the government has assured that water flowing in Maharashtra's rivers like Nar, Par, Damanganga and Pinjal will be transferred to the Godavari basin through lift irrigation and used in drought-hit areas of the state." This was the second time in a year that Maharashtra farmers had taken to the road in mass protest to seek concessions from their state government (*India Today* 2019b). Nor did these protests occur in isolation. In fact,

Figure 15 | Indira Sagar Dam Surface Water Area between 2012 and 2018



Source: Iceland et al. (2018).

data from the National Crime Records Bureau show that India saw an almost eightfold increase in "agrarian riots" between 2014 and 2016 (these Maharashtra protests, it should be reiterated, were peaceful). "These riots include[d] conflict over land and water, resources that have come under stress from weather-related shocks and inadequate policy response" (Srinivas 2018).

Drought's impact on women in India

Male migration due to depleting water resources and drought has severely impacted women in affected communities. Women and girls are primary water collectors in India (UNICEF and WHO 2017); taking over their husbands' roles adds to their workload. In addition, women comprise over 42 percent of the agricultural labor force in India, despite owning less than 2 percent of the country's farmland (India Human Development Survey, as cited in Mehta 2018), which greatly limits their access to resources, credit, technology, irrigation, and other inputs (Purohit 2018; Pachauri 2019). These limitations, together with restrictive practices regarding inheritance and social norms stigmatizing widows exacerbate the impacts of water stress and drought on rural women. Little to no attention is given to their social security, skill development, or livelihood options (PRCWD and HLRN 2017; Ramesh 2017). Beyond such direct impacts on women and girls, gender inequality is also associated with more intrastate conflict (Caprioli 2005).

Solutions

In this section, we discuss some of the major responses available to improve water-related security in India. This discussion provides a strategic overview of solutions and is not intended to be detailed or exhaustive.

Table 1 in the opening chapter of this report includes four broad categories of water security solutions:

1. Natural resources, science, and engineering approaches
2. Political and legal tools
3. Economic and financial tools
4. Policy and governance strategies

We will discuss priority responses within each category in turn.

Natural resources, science, and engineering approaches

Data collection and information systems. To the degree they are absent, India needs to develop information systems for water quantity (surface water and groundwater) and water quality that can measure baseline conditions and monitor progress toward achieving water sustainability objectives. These data and information systems should be transparent and accessible to the public in order to restore confidence in the system. Robust data and information systems are also a prerequisite for other strategies described below, including water-use limitations and demand caps, water pricing mechanisms, improved water rights and allocations, and water rights trading.

Traditional water-supply expansion. When tensions over water arise due to scarcity or demand exceeding supply, the historical response has been to expand water supplies through traditional approaches of building dams, withdrawing water from lakes and rivers, moving water from distant watersheds with aqueducts and pipelines, or tapping groundwater systems. In some regions of the world, such carefully designed and built infrastructure can still provide important water-supply benefits, but such options are increasingly expensive, ecologically risky, or constrained by resource limitations. In parts of India, for example, the combination of very high water stress, monsoonal rainfall patterns, and low water-storage capacity makes local populations exceedingly vulnerable to drought. In these areas, water-storage dams may be needed to reduce human vulnerability to acceptable levels.

It is important to note, however, that natural systems such as forests, floodplains, and soils can also contribute to clean, reliable water supply and protect against floods and drought. Where possible, such "green infrastructure" should be used in combination with or instead of traditional "gray infrastructure" (such as dams, levees, reservoirs, treatment systems, and pipes) both because it can be less costly and because it encourages the preservation of ecosystems and the many services they provide mankind (Browder et al. 2019).

It is also worth noting that Prime Minister Narendra Modi has revived a long-debated plan to siphon water from "surplus" rivers to "deficit" rivers through a countrywide network of linked rivers (see, for example, Bhardwaj 2017). This massive project carries tremendous environmental and ecological risks, however. As of early 2020, six projects have been under examination by government authorities (Ramakrishnan 2020).

Water efficiency and conservation improvements. Constraints on the availability of new or traditional supplies have led to a focus on improving the productivity of water use (also called "water-use efficiency," "water productivity," or "conservation") and the strategy of reducing demand for water without harming industrial and agricultural production or human well-being. When water was abundant and inexpensive, technologies and practices for water use paid little attention to efficiency. Today, however, broad technological, economic, and policy tools for reducing waste and inefficiencies are often available at lower costs than finding new supplies (Cooley et al. 2019). Options are available in every sector of the economy and include investment in improved irrigation application technologies, improvements in industrial processes, and investment in infrastructure and technologies that can reduce preconsumer food loss, to name a few. Of course, increasing water prices will further incentivize water-efficiency and conservation. It is also important to note that more efficient systems do not necessarily lead to lower water use, as efficiency gains are often used to expand production. This is why efficiency improvements need to be accompanied by water-use limitations or demand caps in highly water-stressed regions.

Improved water capture and storage (surface and groundwater). As we noted above, India only has water storage capacity equal to 200 cubic meters per person, as compared with 5,000 cubic meters in developed countries and 1,000 cubic meters in middle-income countries. India will likely need to increase water storage capacity in many places, ideally in ways that do not compromise ecological conditions. For this reason, it may be best to consider "green" water storage options, such as measures to increase groundwater infiltration. Such green water storage systems may also be less expensive than traditional "gray" infrastructure options.

Political and legal tools

Water-use limitations and demand caps. Caps on total water usage in areas where water demand exceeds expected supply can provide incentives to improve water-use efficiency in all sectors. Water supply varies from year to year, so drought conditions need to be factored into these calculations. River basin authorities and state and local governments in India could set such caps and then engage with stakeholders to identify the best ways to reduce total water demand to levels set by the caps.

Disaster-response policies (e.g., for droughts and flooding). Chronic water-stress conditions throughout most of India make it relatively easy for drought to plunge affected areas into crisis. To the extent that India can reduce water-stress levels, this will also increase its resilience to drought. To reduce flood risks, the government could invest in additional flood protection measures, especially green infrastructure. It could also prohibit settlement and development in high-risk areas.

Water-sharing agreements: subnational. While states have exclusive power over water in India, Parliament, under the Indian constitution, has the power to legislate and regulate *interstate* rivers in the public interest. The Indian constitution also provides for adjudication of disputes over water of interstate rivers (Ministry of Water Resources 2013). Notwithstanding these legal provisions, it is clear that strong interstate water-sharing agreements need to be enacted, or existing agreements strengthened.

Economic and financial tools

Alternative crops. Thirsty crops such as rice, wheat, and sugar are grown in water-scarce and drought-prone areas. Switching to less water-intensive crops, such as maize, pulses, and oilseeds, could save large amounts of water. One way to incentivize farmers to switch crops would be by making changes to the government's Public Distribution System, which currently subsidizes demand for water-wasteful crops (rice, wheat, and sugar).

Water, food, and energy subsidies. Various types of government subsidies make it easier and cheaper to pump groundwater. In areas where groundwater tables are falling, those subsidies should be cut back appropriately.

Water prices. To the extent that the government can raise water prices without disproportionately burdening the poor, this would help attain a few key objectives, including signaling the true value of water, improving water-use efficiency, and reducing water loss and waste.

Reduction in food loss and waste. We have noted that about a third of all global food production (by weight) is lost or wasted. Assuming comparable loss and waste in India, substantial water savings would result from reducing food loss and waste. Lipinski et al. (2013) provides information on a wide range of approaches for reducing food loss and waste (improving availability to farmers of agricultural extension services, improving access to low-cost handling and storage technologies, etc.).

Insurance strategies for farmers. Implementing more effective disaster-response policies in the face of extreme climatic and hydrologic events would significantly enhance rural security. While government insurance schemes exist in India, a 2017 report by the Comptroller and Auditor General of India (2017) found that "the coverage of small and marginal farmers under [the National Agricultural Insurance Scheme (NAIS)] was very low and ranged between 2.09 per cent to 13.32 per cent of the total number of small and marginal farmers." The report found that the percentage of farmers who willingly signed up for crop insurance schemes (as opposed to those mandatorily enrolled) was particularly low, ranging from 0 to 5 percent of total insured farmers under the modified NAIS, and between 1 and 10 percent under the Weather-Based Crop Insurance Scheme (*DownToEarth* 2017). Clearly, these insurance programs are not providing value to farmers and need to be substantially improved and coverage significantly expanded.

Policy and governance strategies

Population policies and gender equality. As we noted above, India's population growth rate is slowing, and its population will likely peak around 2060 at around 1.7 billion people. Population policies can help slow and reverse population growth rates: experience from a wide range of countries shows that fertility rates can drop rapidly when the following three strategies are pursued (Iceland 2017; Searchinger and Hanson 2013):

- Increasing educational opportunities for girls, while maintaining rates for boys
- Increasing access to reproductive health services, including family planning
- Reducing infant and child mortality

Enabling conditions need to be put in place for the above strategies to work. In general, higher fertility rates indicate a low status of women in a society (Caprioli 2005). Raising their status can help reduce fertility rates. Elevating women's status can also lead to lower levels of conflict (Melander 2005) and help achieve other sustainable development outcomes (UN Women 2018).

Improvements in women's status are also related to reducing the barriers they face in accessing land and other resources, which tend to amplify women's vulnerability to drought (Tandon and Sharma 2006). While some institutional reform efforts have sought to remove these restrictions, such as the inheritance rights law, additional efforts are required to bridge the gap between legal prescription and actual implementation of social change (Sircar and Pal 2014). Breaking these and other structural barriers will enable a sustained increase in women's social status (Campbell et al. 2006).

Urban and rural development policies. As we have noted, about two-thirds of India's population currently resides in rural areas. Experts are anticipating a large net migration of people from rural to urban areas. If these migrants can find gainful employment in cities, this would take pressure off agriculture to provide livelihoods for them. Government could do a lot to help make this demographic shift easier and more successful. Assuming that India is left with fewer and wealthier farmers, and more consolidated farmland, this could facilitate the transition from water-wasting flood irrigation systems to more water-efficient but more expensive sprinkler and drip irrigation systems.

Stakeholder and community engagement. We briefly touched on the need for such engagement above. Here we need to add that marginalized farmers with small landholdings, including women farmers, who tend to be even further marginalized, need to become actively involved in water resource management decision-making. Forty-two percent of farmers in India are women (Mehta 2018) who are rarely granted any formal recognition in decision-making processes, limiting their participation in government initiatives.

Improved governance. The complex local, state, and federal systems for managing water could be improved to focus on sustainable water strategies that particularly contribute to reducing tensions over access, control, and management of water. Some of the suggestions discussed above and highlighted by the Committee on Restructuring the Central Water Commission and the Central Ground Water Board (2016) can lead to improved water governance in India.

Summary

In many parts of India, agriculture uses too much water relative to long-term renewable supply. Groundwater levels in many parts of India are falling as a result, and surface water systems are overallocated. Much of India's agricultural water use is inefficient, with most irrigators still using flood irrigation systems instead of more efficient sprinkler or drip irrigation systems. Experts also point to wasteful use of water for planting thirsty crops such as rice, wheat, and sugar in water-scarce and/or drought-stricken areas. Cultivation of such crops is driven in part by the national government's program to subsidize staple foods like rice, wheat, and sugar.

Several factors make India highly vulnerable to extreme weather. Monsoons bring rainfall in very compressed time periods, making any deviation from normal monsoon patterns highly consequential for farmers. In addition, there is very little water storage capacity in India, making it nearly impossible to use excess water from one year to help tide people over during drought conditions in years that follow. Finally, many farmers are very poor and live hand-to-mouth, with few reserves to help them through even short periods of difficulty.

Management of water resources is generally poor, and states tend to compete for scarce supplies instead of devising water-sharing plans that could help spread the wealth and the pain. India's population has increased dramatically over the past few decades, and it is poised to supplant China as the world's most populous nation, putting further pressure on water systems and contributing to violence over scarcity.

The size and complexity of water challenges in India means that no single solution or set of solutions can be applied universally, but there are many options that can lower water risks and water insecurity. These measures include increasing water-use efficiency and conservation in agriculture, increasing water storage (green water storage infrastructure is far preferable to traditional dams and reservoirs), protecting ecosystems and implementing ecological flow commitments, establishing water-use limitations in oversubscribed watersheds and aquifers, increasing water prices, improving water management, and implementing socially responsible population policies to help slow and reverse population growth rates.

SECTION V

CASE STUDY THE AFRICAN SAHEL: GROWING CONFLICTS BETWEEN PASTORALISTS AND FARMERS

Peter Gleick

Across the African Sahel, violent conflicts pit farmers against pastoralists over increasingly scarce water and productive land. Rapidly growing populations in the countries of the Sahel; extreme weather, climate change, and land degradation; and rising religious extremism have been identified as major drivers of the crisis. Solutions include policies to expand soil restoration and reforestation and improve tilling practices; water and land rights reform; and multistakeholder peacekeeping groups. These and other solutions could help mitigate water-related conflict in the region.

The risk of violence over resources, including water, is a growing concern. That risk is a function of many complex and interacting factors and is recognized to result from an accumulation and combination of natural resource conditions, the strength or weakness of governmental and institutional systems, the level and type of development, and existing social and political contexts. Combined, these factors contribute to what the World Bank and others describe as "fragility," where states or institutions "lack the capacity, accountability, or legitimacy to mediate relations between citizen groups and between citizens and the state, making them vulnerable to violence" (Sadoff et al. 2017). For water resources and systems, violence is the result of comparably similar and complex factors.

Table 3 | Water Withdrawals by Sector (Percentage)

	AGRICULTURE	INDUSTRY	MUNICIPAL
Benin	45%	23%	32%
Burkina Faso	51%	3%	46%
Cabo Verde	93%	1%	6%
Chad	76%	12%	12%
Côte d'Ivoire	38%	21%	41%
Djibouti	16%	0%	84%
Eritrea	95%	0%	5%
The Gambia	39%	21%	41%
Ghana	65%	10%	25%
Guinea	51%	10%	39%
Guinea-Bissau	76%	6%	18%
Liberia	8%	37%	55%
Mali	98%	0%	2%
Mauritania	91%	2%	7%
Niger	67%	1%	6%
Nigeria	44%	16%	40%
Senegal	93%	3%	4%
Sierra Leone	22%	26%	52%
Somalia	99%	0%	0%
South Sudan	36%	34%	29%
Sudan	96%	0%	4%
Togo	34%	3%	63%

Note: Data from FAO (2016a) AQUASTAT database, including a mix of measured and modeled data for various years. Excludes direct use of rain by agriculture.

One example is the increasing violence over access to water and land between traditional herder/pastoralist communities and expanding fixed agriculture in Africa, where modern political borders and land-use practices are coming into conflict with long-standing traditional practices.

As an example of these conflicts, this case study provides a history of violence between herders and farmers over water and land in sub-Saharan Africa during the past decade, with a focus on tensions between the Fulani community—an ethnic/tribal group spread throughout the Sahel region of Africa—and its neighbors. Similar conflicts have been reported widely among different communities of herders and farmers.

Hydrology/Climatology/Water Use

The hydrology and climatology of the sub-Saharan region is arid and semiarid and highly variable. The region receives low overall precipitation, with rainfall increasing toward the south. Rainfall is often concentrated from May to October, when temperatures and evaporation are highest, with a dry cooler season in December through February. The region is also subject to high interannual variability in precipitation, with extended years of below-average rainfall.

Water withdrawals in the region are shown by country and sector in Table 3. Agricultural water-use data do not include water for rainfed agriculture, which is critically important in the region. Total and per capita water withdrawals are shown by country in Table 4 .

Drivers of Risk

As noted in Gleick and Iceland (2018), tensions over water resources can lead to violence when complex factors interact and when traditional approaches to peaceful resolution of disputes fail. Below we describe a series of these factors relevant for the historical and ongoing tensions in Central and Western Africa involving pastoralist and farming communities. We do not attribute the examples of violence below to any single cause, nor do we think that is appropriate: tensions resulting from factors like drought, land degradation, growing population pressures, access to water sources, animal grazing practices, and land access are all contributing to disruption of local agricultural and livestock economies.

The role of water, however, is not negligible and has been noted and addressed by others. For example, Bola Tinubu, a former governor of Lagos state in Nigeria, argued that the current tensions in the region were not predominantly religious or political but driven by water scarcity and desertification in the northern part of the country, which forces herders south. He also identified climate changes as playing a role (CuteNaija 2018).

Geography and ethnography

The Fulani people live in Sahelian Central and West Africa, widely dispersed across 21 countries from Mauritania, Senegal, the Gambia, and Chad through parts of Egypt and Sudan to the Red Sea coast, with large populations in Ghana, Nigeria, Senegal, and Guinea (Figure 16). The Fulani have historically been nomadic pastoralist (cattle) communities but also include settled farmers, merchants, and influential politicians and members of the ruling class. Leading Fulani have included presidents of Nigeria (including Muhammadu Buhari, president since mid-2019), Senegal, and

Table 4 | Total and Per Capita Water Withdrawals

	YEAR OF DATA	WITHDRAWALS 10^9 CUBIC METERS/YEAR	PER CAPITA WITHDRAWALS CUBIC METERS/PERSON/YEAR
Benin	2001	0.13	17.53
Burkina Faso	2005	0.818	57.35
Cabo Verde	2001	0.022	48.31
Chad	2005	0.8796	81.6
Côte d'Ivoire	2005	1.549	82.12
Djibouti	2000	0.019	25.49
Eritrea	2004	0.582	132.1
The Gambia	2000	0.0905	69.19
Ghana	2000	0.982	49.63
Guinea	2001	0.5533	60.71
Guinea-Bissau	2000	0.175	127.6
Liberia	2000	0.1308	42.59
Mali	2006	5.186	376.9
Mauritania	2005	1.35	405.6
Niger	2005	0.9836	67.7
Nigeria	2010	12.47	74.12
Senegal	2002	2.221	213.8
Sierra Leone	2005	0.2122	39.36
Somalia	2003	3.298	370.2
South Sudan	2011	0.658	59.92
Sudan	2011	26.93	714.1
Togo	2002	0.169	32.87

Note: Data from FAO (2016a) AQUASTAT database, including a mix of measured and modeled data for various years. Excludes direct use of rain by agriculture.

the Gambia, a secretary-general of the Organization of Petroleum Exporting Countries, and a deputy secretary-general of the United Nations.

Many Fulani are Muslim, but the long-standing tensions over water and land have not historically had a strong religious component. While that may be changing because of recent changes in the dynamics of religious fundamentalism, this case also highlights the importance of resource issues.

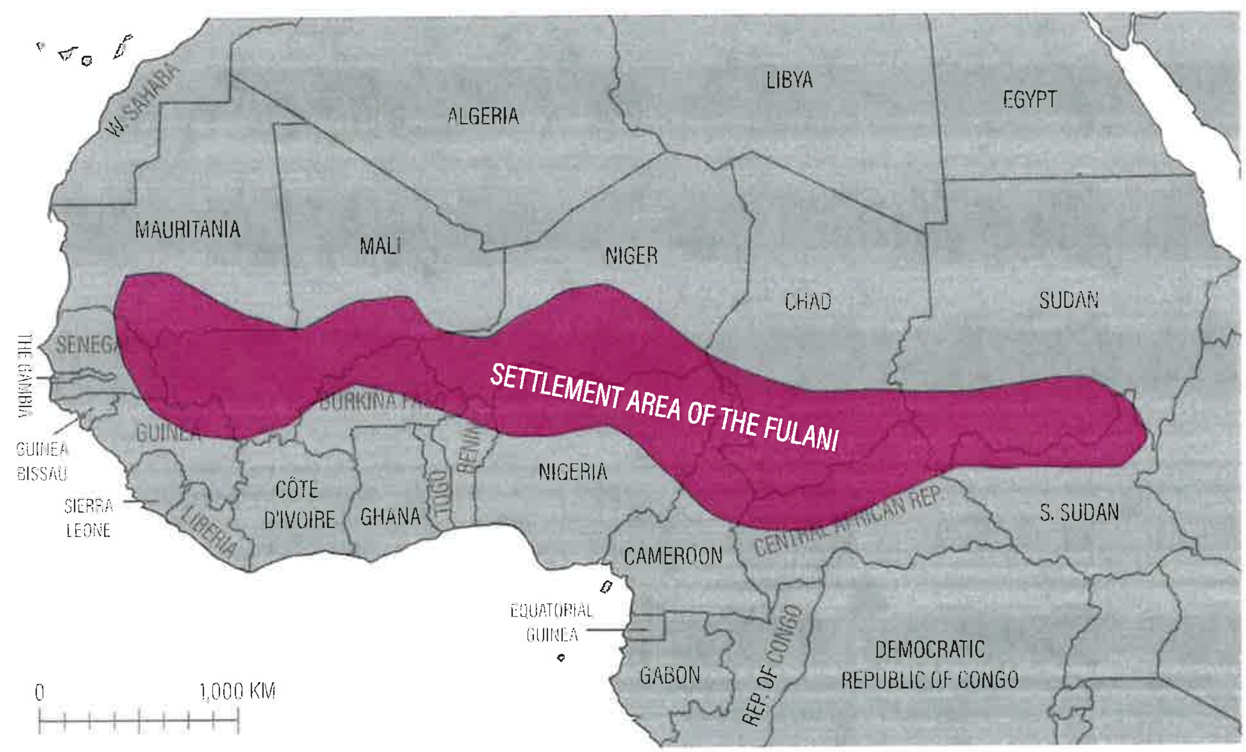
Demographics and social factors

Populations in the countries of the Sahel are growing rapidly, putting more pressure on fixed land and water resources. Nigeria, in particular, has seen a massive growth in population, from 59 million in 1972 to 182 million in 2015, but all of the countries in the region have grown by three to four times over the past four decades (Table 5).

The current population of Fulani is difficult to estimate because of challenges in measuring the size and distribution of pastoral, nomadic communities, the lack of systematic censuses, and the many countries where Fulani are present. Common estimates range from between 25 to 50 million, with very large population increases over the past few decades—in parallel with overall population growth in developing countries around the world.

Wealth in Fulani communities has traditionally been measured by the size of animal (typically cattle) herds. This factor, combined with growing human populations, puts added pressure on limited land and water resources, but problems are worsened when added to the growing populations of other groups also looking for access to permanent land and water rights. Among the consequences of these factors are loss of seasonal pastures, destruction of fixed agricultural crops, and competition for limited water resources.

Figure 16 | Approximate Distribution of Major Fulani Populations across Central/Northern Africa



Source: McGregor (2017).

A related demographic challenge contributing to political tensions is access to traditional seasonal migration routes as populations have grown and pressure over control and access to resources has worsened. In recent years, land and water grants to fixed farming communities, especially in Nigeria, Burkina Faso, and Ghana, have led to efforts to curtail the movement of Fulanis or to force them to abandon traditional nomadic practices and settle on fixed lands.

Extreme weather, climate change, land degradation

Growing desertification and degradation of wetlands, loss of traditional grazing lands, changes in weather and climate patterns, and disruption of natural aquatic systems and fisheries also play a role in recent resource pressures. The loss of traditional springs and streams in the northern Sahel has pushed herders south to the savannahs in central Nigeria (McNeill and Akwagyiram 2018). The severe loss and degradation of wetlands in the Sahel is receiving increased attention as a factor in involuntary and disruptive human migration. A recent assessment of these trends argues that these migratory pressures are now affecting regional and even European politics (Wetlands International 2017).

By some estimates, Nigeria is also losing 2,000 km^2 of crop and grazing lands every year to desertification in the north, dislocating pastoralists (*Daily Trust* 2013). Some of the Fulani herdsmen now in Ghana were pushed out of Burkina Faso as the availability of pastureland there decreased (McGregor 2017).

Assessments of rainfall trends in Nigeria over the last three decades have noted a long-term decline in average precipitation (Ekwe et al. 2014; McNeill and Akwagyiram 2018) (Figure 17). Changes in water availability, temperature, and crop productivity have led some observers to argue that long-term climate change and impacts on water resources are contributing to the violence (Botchway 2017; Folami and Akoko 2010; Folami and Folami 2013; Irabogu 2016). Joachim Ezeji (2016), a Nigerian water researcher, argues that a root cause of the conflict is "current water management practices in Nigeria, which . . . [are] not robust enough to cope with the impacts of climate change, especially [on] water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems."

Table 5 | Population of Select Countries in North Central Africa, 1972 and 2015 (Thousands)

	1972	2015
Benin	3,039	10,880
Côte d'Ivoire	5,748	22,702
Ghana	9,084	27,410
Liberia	1,497	4,503
Nigeria	58,829	182,202
Burkina Faso	5,825	18,106
The Gambia	475	1,991
Mali	6,147	17,600
Niger	4,753	19,899
Senegal	4,485	15,129

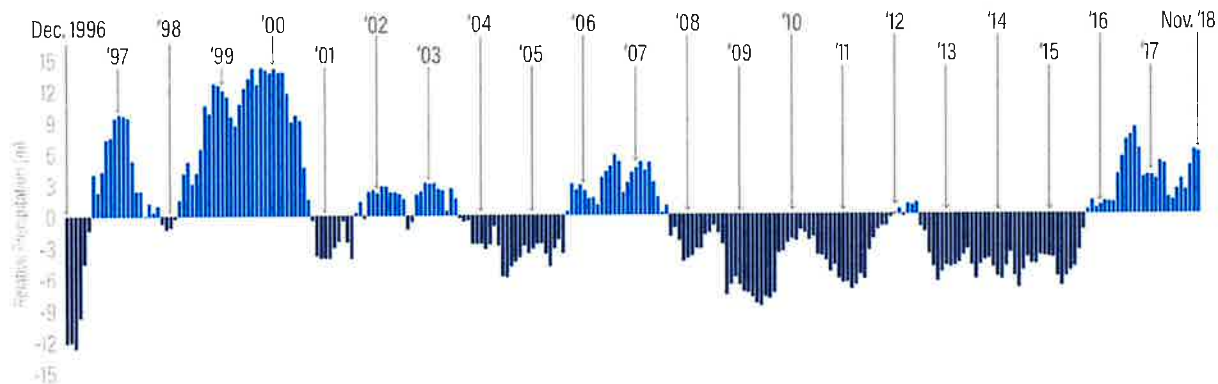
Note: Data on population from FAO (2018b).

Others have also identified climate factors as a contributor to resource-related tensions, while observing that more data and evidence on a regional level are needed (Gleick 2014; Hsiang and Burke 2014; Hsiang et al. 2013).

Religion

The Fulani are primarily Muslim; southern Nigerian farmers are mostly Christian. Religious factors have been known to play a role in the disputes between Fulani herders and farmers, but until recently this has been a relatively minor issue. Severe violence associated with the Islamist group Boko Haram, however, has sensitized the entire region to religious extremism. Beginning around 2016, groups from both communities began using religious differences to inflame tensions and to frame the violence in religious terms. After herders attacked a community in Nigeria's Kaduna State, a local pastor described the violence as an Islamic holy war against Christians and tried to link the Fulani with Boko Haram, contributing to retaliatory attacks against the Fulani (*Vanguard News, Nigeria* 2016). There are also reports of Islamic

Figure 17 | Long-Term Changes in Precipitation in Nigeria



Note: Moving 12-month precipitation totals compared to the 1996–2018 annual averages.

Source: McNeill and Akwagyiram (2018).

jihadist groups in Mali taking advantage of resource factors by protecting and aligning with herders and nomadic Fulani communities (Institute for Economics and Peace 2018). Unlike in Nigeria, where the national government is relatively strong, recent violence in Mali has led to growing links between Fulani communities and jihadist groups because of long-standing clashes with both separatist and loyalist Tuareg groups over land and access to water (Al Jazeera News 2019b; Hackleton 2019; McGregor 2017).

Water as Trigger of Conflict

While tensions between farmers and nomadic pastoralists have existed for many years, many regions of central and western Africa have reported increasing violence for several related reasons: growing populations have led to an expansion of settled communities and appropriation of lands formerly used by nomadic groups; damage to fixed crops by cattle have led to a cycle of anger and violence between farmers and herders; changes in the hydrology and climatology of the Sahel are pushing livestock herders further south in search of water and grazing land; traditional conflict-resolution approaches are weakening, including payment of compensation and local mediation; and weapons are increasingly available (McGregor 2017; Patience 2016; Sulaiman and Jaafar-Furo 2010).

These factors also lead to secondary problems and the risk of feedbacks. With growing insecurity and violence, farms have been abandoned, agricultural production and food scarcity have worsened, younger people have moved to cities, and local economies have been damaged. These kinds of feedbacks are known to contribute to worsening state security and fragility and the risk of state failure (Sadoff et al. 2017). When cultural and religious elements are added, what may originate as a resource and economic dispute can evolve into a more intractable and fractious conflict.

Box 1 lists major examples of violence over access to water and land between herders or pastoralists and farmers since 2011 through early 2019. As these data show, this violence is not limited to one region or a limited number of groups but is widespread across the Sahel. While this case study focuses on the severe challenges involving the Fulani, we must not lose sight of related issues in other regions.

Overall, growing numbers of deaths have been attributed to violence between herders and farmers. In the first nine months of 2018 alone, over 1,700 violent deaths attributed to Fulani militia groups in western and central Nigeria were reported in the 2018 Global Terrorism Index report (Adeoye 2018; Institute for Economics and Peace 2018; Toromade 2018b)—more than were attributed to Boko

BOX 1 | SUMMARY OF CONFLICTS BETWEEN HERDERS AND FARMERS IN AFRICA OVER WATER AND LAND, 2011–19

2011: Four farmers are killed in the Pangani river basin in Tanzania in violence between herders and farmers over diminishing water resources and disputes over destruction of crop land by cattle (Makoye 2012).

2012: Violence along the border between Mali and Burkina Faso flares up between Dogon villagers and nomadic Fulani herders after a water- and land-sharing agreement is revoked (Xinhua News 2012).

2012: Kenyan Pokot herders cross the border with Uganda seeking water and grazing land, leading to violence and the deployment of 5,000 Ugandan soldiers (Bii 2012).

2012: Violence between farmers and pastoralists in Tanzania's southeastern Rufiji Valley leads to several deaths and many injuries. It is worsened by prolonged drought and disputes over access to water in the southern regions of Lindi and Mtwara (Makoye 2012).

2012–13: Extensive violence over water occurs in Kenya between Pokomo farmers and Orma cattle herders, with more than 100 deaths reported (AFP News 2012). The conflict is worsened by Kenyan and foreign investment in land for food and biofuel cultivation that puts pressure on local resources.

2013: Fighting between Borana herders and the agricultural Burji community in Kenya and Ethiopia kills at least 56 people. The violence is rooted in historic clan rivalries as well as economic and political competition for water and pasture. Clashes between the two communities date back to the 1960s (Khalif and Doya 2014).

2013: Tanzanian herders attempt to take control of a water source in the village of Makenya, leading to violence with local farmers (Makoye 2013).

2014: Tiv/Agatu farmers and Fulani herdsmen clash in Nigeria over access to grazing land and water points. In April 2014, President Goodluck Jonathan orders military intervention in Benue, Nassarawa, and Plateau in order to reduce the violence. During 2014, at least 1,000 people are reported killed in violence between herders and farmers over water and land (AllAfrica 2014; McAller 2014).

2015: Dozens are killed in Somalia in several local land and water disputes in the Hiiraan region and in Garowe (Abdirahman 2015; Hiiraan Online 2015).

2015: Clashes between pastoralists and farmers over water access expand in Kenya (Langat 2015).

2017: Violence increases in the Sudan over water and land access. Eleven people are injured in South Kordofan in clashes between farmers and herdsmen over access to water. Thirty-eight people are reported killed and another 30 are injured in fighting between local clans over water, grazing land, and border areas in Gogrial West, Warrap, South Sudan. Elsewhere local militia, allegedly supported by the Sudan People's Liberation Army, attack Kenyan herders who cross the border in search of water and pasture (SBS News 2017).

2018: Continuing violence between Fulani and Dogon communities in Koro, Mali, leads to at least 25 deaths (eNCA Media 2018).

2018: In September 2018, several deaths are reported in violence between Fulani herders and a farming community in central Nigeria. This is part of a massive increase in reported violence between Fulani herders and farming communities over land and water resources in central Nigeria (VOA 2018).

2018: In October 2018, more than a dozen people are killed in northern Kenya near Marsabit when water and land conflicts between pastoralists and farmers turn violent (Abdi 2018).

2019: In late March, over 150 people are massacred in central Mali in an escalation of conflict between Fulani herders, Dogon and Bambara farmers, and Bozo fishers over access to water and land. The conflict now has a growing ethnic and religious component (BBC News 2019; Hackleton 2019). This violence has continued to grow.

Source: Data from Pacific Institute (2019).

Haram extremists, who are mostly active in the northeastern part of the country. The violence is not one-sided: in Nigeria, the state's inability to resolve the conflicts or provide strong security has led to a cycle of violence by informal militias on both sides, including anti-Fulani vigilante groups.

In March 2019, violence in the region expanded, with a major escalation in Mali, where a series of attacks in the Mopti region led to the massacre of around 160 people, including Fulani herders, Dogon and Bambara farmers, and Bozo fishers. The violence in this part of Mali has a long history, which revolves around use and access to watercourses and land, sharing of resources, and the seasonal migration of livestock, but it now has a growing ethnic and religious component (Diop 2019; Hackleton 2019). The government's failure to adequately address the violence led to the government's collapse and the resignation of the Malian prime minister in April 2019 (Al Jazeera News 2019b).

Solutions

A wide range of strategies are available to reduce the risks of conflicts over water resources. Table 1 in the opening chapter of this report includes four broad categories of water security solutions:

1. Natural resources, science, and engineering approaches
2. Political and legal tools
3. Economic and financial tools
4. Policy and governance strategies

Not all are applicable to all kinds of water-related conflicts, and not all are applicable given the diverse social, cultural, physical, and economic characteristics of regions where water violence occurs. Below we describe a subset of top approaches that are relevant in the case of the water- and land-related violence described here, with the understanding that other solutions included in Table 1 may also be valuable and worth pursuing.

Disputes over access to land and water are not new. Where governments are weak, land and water rights are poorly defined or inequitably allocated, or resource pressures are high, the risk of violence increases. In the western United States in the late 1800s, similar disputes between traditional migratory cattle ranchers and increasingly fixed landowners led to violence over fencing practices and access to grazing and water sources (Gard 2010).

Natural resources, science, and engineering approaches

Water efficiency and conservation improvements, ecosystem and soil restoration. Some regional observers have recommended that water catchment and water conservation policies such as increased water storage and improved irrigation systems be developed at local levels (CuteNaija 2018). In Nigeria, policies to expand soil restoration efforts, reforestation, and improve tilling and other farming practices have also been identified as beneficial for reducing tensions between farmers and herders by improving long-term water availability and quality and the health of pasture lands.

Political and legal tools

Water and land rights reform. Because so many of the disputes between herders and farmers revolve around access to water resources and grazing land, reallocating these resources can help reduce the inequitable nature of access to both water and land and can clarify issues of political and economic control. In Nigeria, Mali, and Ghana some Fulani communities have asked national and regional politicians to allocate permanent grazing areas, protected migration pathways, and water reserves to clarify land and water-use rights and reduce herding challenges and seasonal migration. Regions with larger populations of Fulani have tried to include such reserves in development plans, but such reserves are limited in size and a comprehensive solution has yet to be put in place or enforced, in part because of disagreements over policy (Odebode et al. 2012).

Grazing reserves are seen as a way to allocate land, and potentially water, rights to pastoralists, but they are not popular on either side, for several reasons: they are seen as a government allocation of land from one community to another; Fulani herders complain that the lands identified for reserves are of poor quality, inaccessible, or already in use; and many legislators are on record as opposing this approach as a land grab (McGregor 2017).

Conflicting land and water laws in the different countries also play a role. In Nigeria, laws against some forms of grazing have led to the criminalization of nomadic groups and the arrest of hundreds of herders, inflaming tensions. In late 2017, Benue State implemented a prohibition against open grazing, greatly raising tensions in the region. That, in turn, led to recent calls to loosen these restrictions and establish clearer land allocations for cattle reserves (CuteNaija 2018; Toromade 2018a).

Multistakeholder peacekeeping groups. When governments are weak or ineffective, there is both an opportunity and a risk that local groups will self-organize to provide security, sometimes in the form of militias. The danger in these cases is that armed groups not under the control of formal governmental structures will devolve rapidly into vigilantism and sectarian violence. Under the right circumstances, however, such groups can play a role in reducing the risks of conflict: in central Nigeria, violence between herders and farmers has led to the formation of groups of peacekeepers, informally known as Barkin Ladi's vigilantes, who include both herders and farmers and provide local law enforcement by building trust and adjudicating disputes.

Policy and governance strategies

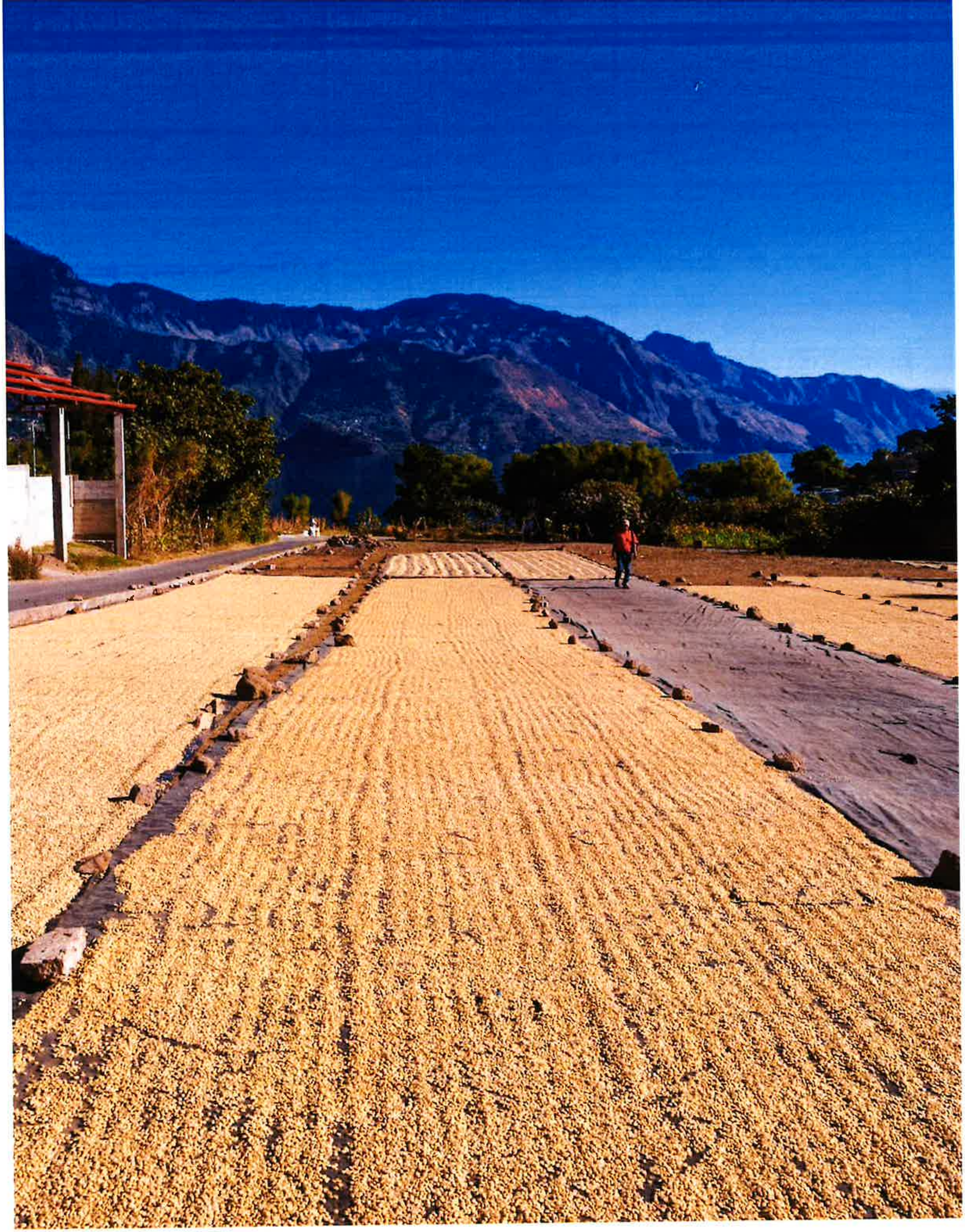
Stakeholder and community engagement. While such militia groups traditionally operate outside of formal government control, they can be beneficial in places where governments have few other options. For the Barkin Ladi group, the inclusiveness is supported by local officials. "No one will accuse them of being partisan or conniving with one tribe against the other," said Yakubu Dati, a spokesman for the state government. "That is what we want, that is what this administration is all about, and we are doing everything to encourage other vigilante groups to emulate that so that peace can return permanently" (Bearak 2018). Similarly, the official Nigerian military efforts in the region support the local volunteers, provide at least some training, and coordinate with them. Whether such groups can continue to offer local security will depend on their commitment to nonpartisan mediation, whether they can continue to draw volunteers from all the affected groups, the quality of support from the central government, and whether water and land conditions further deteriorate (*Sahara Reporters* 2018).

In another example of the governance challenges in the region, the growing violence in Mali in 2019 and the inability of the central government to protect civilians led to the firing of senior military officers, the resignation of the prime minister, and a major government shakeup (Al Jazeera News 2019a, 2019b).

Conclusions

Reliable and consistent access to water resources and land for economic survival, such as grazing, is vitally important for traditional herder communities in Africa. Growing populations, increasing control and privatization of land, and expanding rural settlements and fixed agriculture are all contributing to rising tensions between herders and settled farmers throughout Africa, but especially for Fulani communities in sub-Saharan Africa, including parts of Nigeria, Mali, and surrounding countries. Combined with other factors, including economic and political disparities and growing religious tensions between Muslim and Christian communities, water-related violence is on the increase, with a sharp uptick in severe violence in the past few years.

As with all water-related violence, there are myriad strategies to reduce the risks of conflict, including improved water management, and in the case of herder-farmer conflicts, mechanisms to resolve land and water rights disputes and strategies to ensure access to needed resources. The complexities of managing diverse cultural, social, and religious factors complicates implementing effective solutions, however, and without broad regional efforts to address land and water access, violence over these resources seems likely to worsen in the near term.



SECTION VI

CASE STUDY CENTRAL AMERICAN DRY CORRIDOR

Charles Iceland

Five years of drought in the Central American Dry Corridor have forced many subsistence farmers to abandon their land and migrate to regional cities or the United States in search of work to support themselves and their families. A regional drying trend over several decades in Central America and the Caribbean, rapidly growing populations in the region, and extreme poverty have been identified as major drivers of the crisis. Solutions include strengthened disaster-response policies, agricultural extension services, and planting crops that are better suited to evolving climate conditions. These and other solutions could help mitigate destabilizing migration in the region.

The Central American Dry Corridor is a tropical dry forest region on the Pacific side of Central America. While it stretches all the way from southern Mexico down to Panama, the areas of greatest vulnerability—and therefore of greatest concern—are in Guatemala, Honduras, El Salvador, and Nicaragua (FAO 2017). The term *Central American Dry Corridor* wasn't even used prior to 2009, but the area has quickly become known for its frequent and devastating droughts, especially during El Niño years. During such years, "precipitation drops by 30%–40%, with long periods of heatwaves during which there is hardly any rainfall" (FAO 2017). Between 40 and 50 percent of the region's inhabitants live in rural areas, many well below the poverty line. Few services are available to help these people when extreme weather hits the region (FAO 2017). This case study is different from the others in this report in that we are looking at destabilizing migration instead of conflict as an end point. We first explore the region's recent struggles with drought, then discuss the role of drought in growing migration from this region to the United States. We conclude with some possible risk-mitigating "solutions."

Drought in the Region: Present, Past, Future

As of mid-2019, the Central American Dry Corridor was in the throes of a severe five-year drought. The drought began in 2014 and accelerated in 2015, becoming the worst to hit the region in 30 years. By mid-2016, the drought had ravaged 50–90 percent of crop harvests, leaving 1.6 million people in the area food insecure and 3.5 million in need of humanitarian assistance (FAO 2016b). In September 2018, the World Food Programme warned that 2 million Central Americans risked hunger, following lower-than-average rains in the critical crop-growing months of June and July. "Miguel Angel García, regional director in Central America for Action against Hunger, said poor crop harvests caused already vulnerable families to incur a spiral of debt and sell off land. 'The loss of harvests is linked in many cases to the loss of land or the sale of other assets that families have,' he said" (Moloney 2018). By early 2019, many news outlets were reporting that climate disruption or climate change was one of several factors driving increasing Central American migration to the United States (other factors cited included extreme poverty, gang violence, and family reunification) (see, for example, Wernick 2019; Blitzer 2019; and Shapiro and Blitzer 2019).

But is the region's climate really changing, and, if so, is this due to climate change or to periodic natural climate fluctuations? An April 2006 study (Neelin et al. 2006) found evidence of a statistically significant regional drying trend in Central America and the Caribbean in observational datasets from 1979 to 2003 (satellite) and from 1950 to 2002 (land station). That this drying trend is the result of climate change has not yet been definitively established, but that question is largely academic, as the problem must be faced regardless.

As for the impacts of climate change on *future* temperature and precipitation in the region, a December 2009 report noted Intergovernmental Panel on Climate Change (IPCC) projections of a mean warming in Central America between 1980–99 and 2080–99 of 1.8°C to 5.0°C (USNIC 2009). The report also noted that Central America was likely to experience a decrease in rainfall in the future. In its latest report (Hoegh-Guldberg et al. 2018), the IPCC lists Central America as one of several global regions that can expect decreases in runoff (i.e., surface water supply) as a result of 2°C of global warming.

All three WRI-Aqueduct future scenarios show decreases in water supply across parts of Central America between baseline and 2040. Figure 18 depicts one of these scenarios (Gassert et al. 2015).

The manifold risks associated with drought are not, of course, simply a function of the drought itself (i.e., the "hazard"); they are also a function of how many people or assets lie in the drought's path (i.e., the "exposure") and how able these people or assets are to withstand the drought (i.e., the "vulnerability").

We know the "hazard" is increasing. We also know that the "exposure" is increasing.

- The population of Guatemala more than tripled between 1965 and 2017, from 4.9 million to 16.9 million.

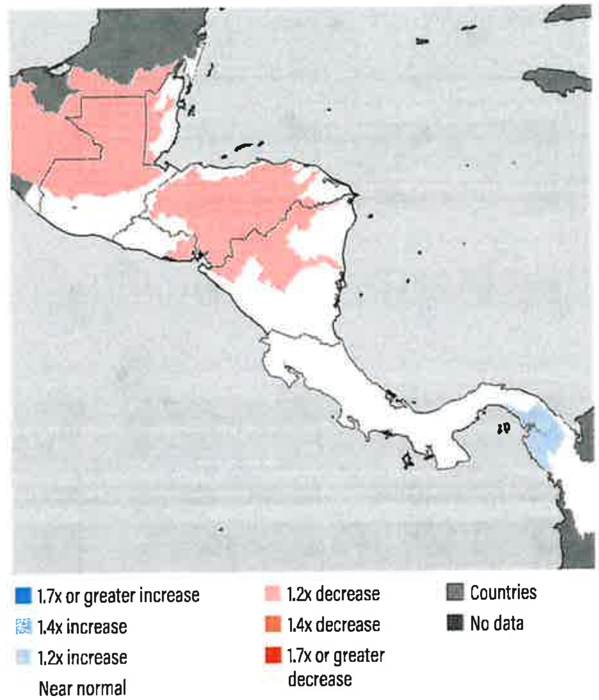
- The population of Honduras quadrupled between 1965 and 2017, from 2.3 million to 9.3 million.
- The population of El Salvador doubled between 1965 and 2017, from 3.2 million to 6.4 million.
- The population of Nicaragua tripled between 1965 and 2017, from 2.1 million to 6.2 million (Google 2019).

Many socioeconomic factors play a role in the rising population rate, such as lack of access to health and education services, inadequate family planning services, and gender inequality. About 2 million Guatemalan children and young adults between the ages of 15 and 24 are not in school, and about half of all Salvadorian children drop out before secondary school (USAID Guatemala 2018; USAID 2019b). This region sees the highest rates of unwanted pregnancies in the world, as well as poor maternal and prenatal care services (GTR 2017). These services are especially inaccessible for the marginalized indigenous and poorer women (World Bank 2018). Patriarchal cultural and social norms in the Dry Corridor countries tend to restrict women's access to economic assets and hamper their upward social mobility. For instance, even as gender equality is prescribed in the country's inheritance laws, women represent only 6.5 percent of all landowners in Guatemala. In Nicaragua, only 13 percent of women have access to land and 5 percent have access to formal credit. They make 35 percent less than men for equal value of work in El Salvador and have been excluded from any of the benefits associated with agrarian reforms (FAO n.d.).

Finally, we know that the vulnerability is high. Many people in the Dry Corridor live in extreme poverty, relying solely on what they can grow for food. Most do not have access to irrigation, which could help improve social and economic resilience during a drought. Most do not have access to agrarian experts (through extension services), who could teach them how to better cope with a changing climate.

Women are even more vulnerable than men due to their constrained access to social, natural, economic, educational, and nutritional resources. When crops fail, male household members often migrate to nearby cities in search of work, leaving female household members to both tend to the

Figure 18 | Projected Change in Water Supply in Central America from Baseline through 2040 under "Optimistic" Scenario



Note: Aqueduct future projections/water supply/change from Baseline to 2040/ Optimistic scenario.

Source: Gassert et al. (2015).

crops and fulfill their domestic responsibilities. Even under these difficult circumstances, women's work is barely recognized. In Guatemala and El Salvador, for example, 52 percent of women work in rural areas, and only 20 percent of these women receive remuneration (FAO et al. 2018; Welsh 2018; Ramírez 2011; World Food Program USA n.d.).

During severe droughts and floods, Central American agricultural workers and their families often decide to migrate north. The U.S. National Intelligence Council (NIC) predicted in 2009 that "the inability of countries in the region to adapt and recover from severe climate events . . . will continue to promote migration outside the region, in particular, to the United States and Canada. The large number of immigrants coming to the United States in the past 20–25 years will facilitate this movement."

The Role of Drought in Growing Migration from Central America to the United States

The U.S. National Intelligence Council was correct in its 2009 forecast. Severe drought, together with other impacts of a changing climate, such as shifting rainfall patterns, frosts, and new pests, *have* contributed to significant crop losses and sharp increases in migration from Central America to the United States. If anything was wrong in the NIC forecast, it is the *speed* with which these climate change impacts have occurred—the report was billed as a forecast out to 2030 (it is clear that gang violence and other factors are also driving migration from Central America to the United States, but we do not know the relative importance of each driver).

As of early–mid-2019, aggregate migration numbers along the southwestern border of the United States had begun to spike, following years of decline. In addition, the share of Central American migrants was growing, while the share of Mexican migrants was commensurately decreasing. By 2018, the number of Central Americans crossing the U.S. border (specifically, from Guatemala, Honduras, and El Salvador) surpassed the number of Mexicans (Shear et al. 2019).

Many media reports explained the role of drought and a changing climate in driving this migration. An October 2018 article in *National Geographic,* for example, observed that "data from Customs and Border Patrol show a massive increase in the number of Guatemalan migrants, particularly families and unaccompanied minors, intercepted at the U.S. border starting in 2014. It's not a coincidence that the leap coincides with the onset of severe El Niño–related drought conditions in Central America's Dry Corridor, which stretches through Guatemala, Honduras, and El Salvador."

The same article described the plight of one Guatemalan farmer:

> Eduardo Méndez López lifts his gaze to the sky, hoping to see clouds laden with rain. After months of subsisting almost exclusively on plain corn tortillas and salt, his eyes and cheeks appear sunken in, his skin stretched thin over bone. The majority of his neighbors look the same.
>
> It's the height of rainy season in Guatemala, but in the village of Conacaste, Chiquimula, the rains came months too late, then stopped altogether. Méndez López's crops shriveled and died before producing a single ear of corn. Now, with a dwindling supply of food, and no source of income, he's wondering how he'll be able to feed his six young children.
>
> "This is the worst drought we've ever had," says Méndez López, toeing the parched earth with the tip of his boot. "We've lost absolutely everything. If things don't improve, we'll be forced to migrate somewhere else. We can't go on like this". (Steffens 2018)

In an attempt to better understand the relationship between drought and migration in the Dry Corridor of Guatemala, Honduras, and El Salvador, the World Food Programme (WFP), the Inter-American Development Bank (IDB), the International Fund for Agricultural Development (IFAD), the Organization of American States (OAS), and the International Organization for Migration (IOM) commissioned a study of families where members had left the country since the last El Niño episode (2014–16). The study's findings, published in mid-2017, found that poverty and unemployment were the most common causes of emigration, followed by problems associated with agricultural losses due to drought, high temperatures, and pests. One of the main goals of emigration was to generate income and send remittances back home, to repay debts, support families, and make investments for a better life. While violence was also cited as a reason for emigration, this was limited largely to people interviewed in El Salvador (WFP et al. 2017).

Solutions

By April 2019, the U.S. immigration system appeared to be reaching a breaking point. Many Central American migrants were simply walking up to the border, surrendering to U.S. border patrol agents, and requesting asylum. Smugglers were advising many of them that as long as they brought a child, they would be quickly released and allowed to stay in the United States for years while their asylum cases were processed (Shear et al. 2019). The Trump administration was said to be making things worse by threatening to "close the border," as this was simply communicating to would-be migrants that it was "now or never."

Taking a step back, what would make sense for both U.S. immigration policy *and* many migrants would be to create conditions in which these migrants could stay in or return to their countries. It has been documented in many news articles that many of these migrants would have preferred to stay on their farms, and that migration was a last-ditch, desperate option.

Table 1 in the opening chapter of this report includes four broad categories of water security solutions:

1. Natural resources, science, and engineering approaches
2. Political and legal tools
3. Economic and financial tools
4. Policy and governance strategies

Below, we discuss some of the major responses we recommend to improve water-related security in the Central American Dry Corridor. This discussion provides a strategic overview of solutions and is not intended to be detailed or exhaustive.

Natural resources, science, and engineering approaches

Data collection and information services. Data from weather stations can help farmers identify optimal dates for planting various crops, reducing the uncertainty associated with changing weather patterns. Early warning systems can give farmers more time to prepare for extreme weather. These approaches have been tested and/or implemented in Honduras and Guatemala (Arcanjo 2018).

Ecosystem and soil restoration. As discussed above, the risks associated with drought and a changing climate are a function of three things: the hazard (i.e., the drought or other biophysical factors), the exposure (i.e., how many people or assets lie in the drought's path), and the vulnerability (i.e., how able these people or assets are to withstand the drought).

Can we reduce the hazard? Generally speaking, there is not a lot that a single country can do to reduce the incidence of drought or temperature changes—mitigating global climate change requires concerted efforts by many countries worldwide. Anecdotal evidence suggests, however, that reforesting land in the Dry Corridor can help moderate temperature and absorb rainfall, thereby stemming crop losses (Blitzer 2019; Shapiro and Blitzer 2019). More research can help us better document the microclimate benefits of reforestation and other forms of "regreening" in the Dry Corridor.

Agricultural extension services. Meanwhile, agricultural extension services can help farmers determine optimal crops for their regions, when they should be planted, and how yields can be maximized under changing climate conditions. They can also help farmers become more water-efficient and reduce the incidence of postharvest food loss and waste. These approaches have been tested and/or implemented in Guatemala (Arcanjo 2018).

Political and legal tools

Disaster-response policies (e.g., for droughts and flooding), social safety net programs. The Dry Corridor countries need to strengthen disaster-response policies and social safety net programs to backstop other, more proactive, resilience-building measures. In early 2019, the WFP and FAO issued requests on behalf of these countries for millions of dollars from the international community to deliver food assistance to more than 700,000 people (FAO 2019).

Economic and financial tools

Alternative crops. We can reduce vulnerability by planting crops that are better suited to evolving climate conditions. A recent *New Yorker* article noted an example of a village in the highlands of western Guatemala where coffee and citrus could now be planted, whereas three years earlier it would have been "impossible" to cultivate such crops (Blitzer 2019; Shapiro and Blitzer 2019). Another source notes regional initiatives to develop more climate-resilient crops. "These are typically crops that may have been grown in the region centuries ago, and are more resilient to dry weather" (Arcanjo 2018).

Policy and governance strategies

Urban and rural development policies. Can we reduce the exposure of Dry Corridor countries to drought? There are two obvious ways to reduce exposure: short-term through emigration, and long-term by reducing population growth. Migration has been a key adaptation measure since time immemorial. The problem comes when migration is so heavy that it destabilizes societies. National governments of Dry Corridor countries—with help from the international community—need to identify policies and practices that can best handle increasing migration from rural areas to regional towns and cities.

Another option, short of migration from rural to urban areas, is to engage in part-time work in nearby villages and towns. There are many examples throughout the world where farmers work part of their time (or part of the year) in agriculture and part of their time in basic service jobs in nearby towns.

Population policies and gender equality. We have already noted the significant population increases in Dry Corridor countries between 1965 and 2017. To the degree possible, these countries should implement policies to reduce population growth. Experience from a wide range of countries shows that fertility rates can drop rapidly when the following three strategies are pursued (Iceland 2017; Searchinger and Hanson 2013):

- Increasing secondary education rates for girls while maintaining rates for boys. This is also important to address the high prevalence of school dropout and unemployment rates in the countries (Fippin 2019).
- Increasing acceptance of and access to reproductive health services and family planning options, specifically addressing the high adolescent and unwanted pregnancy rates in the countries.
- Reducing infant and child mortality.

Certain *enabling conditions* need to be put in place for the above strategies to work. One of them is improving the low status of women in society, which will not only help achieve the above-mentioned education and health outcomes but also contribute to improving the countries' social and economic outcomes (World Bank 2018).

A recent analysis of agricultural, food security, and climate change policies and programs in Dry Corridor countries has found that fewer than half of these policies meaningfully include gender considerations (Gumucio et al. 2016). These policies and programs should incorporate gender considerations to specifically address women's heightened vulnerability to drought and other water-related risks. Improving gender equality will increase the effectiveness of many of these policies and programs.

Summary

Severe drought, together with other impacts of a changing climate, such as shifting rainfall patterns, frosts, and new pests, have contributed to significant crop losses and sharp increases in migration from Central America to the United States. By 2018, the number of Central Americans crossing the U.S. border (specifically, from Guatemala, Honduras, and El Salvador) surpassed the number from Mexico (Shear et al. 2019). It should be noted that there are other powerful drivers of migration from Central America to the United States, including gang-related violence, better economic opportunities in the United States generally, and the presence of family members already in the United States.

A number of solutions can lower drought-related risk and insecurity in the Dry Corridor. Agricultural extension services can help farmers determine optimal crops for their regions, when they should be planted, and how yields can be maximized under changing climate conditions. They can also help farmers become more water-efficient and reduce the incidence of postharvest food loss and waste. Data and information services can help farmers identify optimal dates for planting various crops, reducing the uncertainty associated with changing weather patterns. Early warning systems can give farmers more time to prepare for extreme weather (Arcanjo 2018). Anecdotal evidence suggests that reforesting land in the Dry Corridor can help moderate temperature and absorb rainfall, thereby stemming crop losses (Blitzer 2019; Shapiro and Blitzer 2019). And Dry Corridor countries can strengthen disaster-response policies and social safety net programs to backstop other more proactive, resilience-building measures.

SECTION VII

CASE STUDY YEMEN

Peter Gleick

During the war in Yemen, belligerents have sought to weaken and destroy opposing forces by targeting civilian infrastructure, including water and energy systems. The assaults on these systems have led to a huge increase in people lacking access to safe water and sanitation and contributed directly to massive disease outbreaks. Solutions include improvement and enforcement of international humanitarian and human rights laws, expanding humanitarian laws to subnational conflicts, and taking measures to protect or harden civilian water infrastructure. These and other solutions could help mitigate these human rights abuses.

While most assessments of the links between water and conflict have focused on water as a trigger for violence through disputes over control and access to water resources, another major category of water conflicts has been growing in importance: water as a casualty or target of conflict. The Water Conflict Chronology (Gleick 2018) catalogs events that involve the targeting of water resources and water infrastructure during violence, regional and civil conflicts, and interstate war. Perhaps the most extreme example of this has been the violence in Yemen that intensified with the onset of civil and regional conflict in 2015 involving internal parties and external actors (both directly and through proxy powers). This case study analyzes the extensive targeting of water infrastructure in Yemen as an example of water and water systems becoming casualties of conflict and offers recommendations for reducing the risk of such attacks.

The Physical Environment: Geography, Climate, Hydrology, Water Use

Yemen is on the southern edge of the Arabian Peninsula, bordered by Saudi Arabia in the north, the Arabian Sea in the south, the Red Sea in the west, and Oman in the east. The country has large variations in elevation and geography, from broad, flat, dry, and hot coastal and inland plains in the east to cooler and wetter mountains in the west. A substantial extreme desert also runs between the mountains and the eastern plateau, and in the north and east a major desert is shared with Saudi Arabia. Several small islands are located off the coast in the Red Sea and Arabian Sea.

Yemen's climate ranges from semiarid to hyperarid, with a spring and summer wet season and persistently high temperatures. In the western mountains, higher rainfall levels of between 300 mm to around 1,000 mm/year provide most of the runoff that feeds seasonally flowing wadis in the coastal areas and provides much of the country's water. Most of the country's area, however, is hyperarid desert receiving less than 100 mm/year of rain. Because of the extreme nature of Yemen's hydrology, drought risks are high, floods can occur during wet season storms, and overall water availability for human use is highly variable.

Measured on a per capita basis, the FAO (2016a) AQUASTAT data indicate that average renewable water availability (including both surface and groundwater) in Yemen is on average less than 125 m^3/p/yr—one of the lowest in the world. These data reflect current climatic conditions and do not account for anticipated climate changes. Simple metrics of scarcity developed by Falkenmark et al. (1989) suggest that regions with 500 to 1,000 m^3/p/yr face chronic water scarcity; regions with less than 500 m^3/p/yr face fundamental constraints to human development and well-being. Reviews

and discussions of more integrated approaches to defining water scarcity, including hydrologic, social, and economic factors, also note the extreme vulnerability of this region (Jaeger et al. 2013; Showstack 2011). Because of Yemen's variable hydrology and limited development of modern water infrastructure, the population is largely dependent on a mix of formal and informal water systems, including local wells, private water providers, urban groundwater withdrawals, rainfall capture and use, seasonal irrigation, and small-scale local desalination systems for some industrial and urban uses. Further complicating Yemen's water challenges has been long-term unsustainable overdraft of Yemen's groundwater, especially around the major cities, like Sana'a.

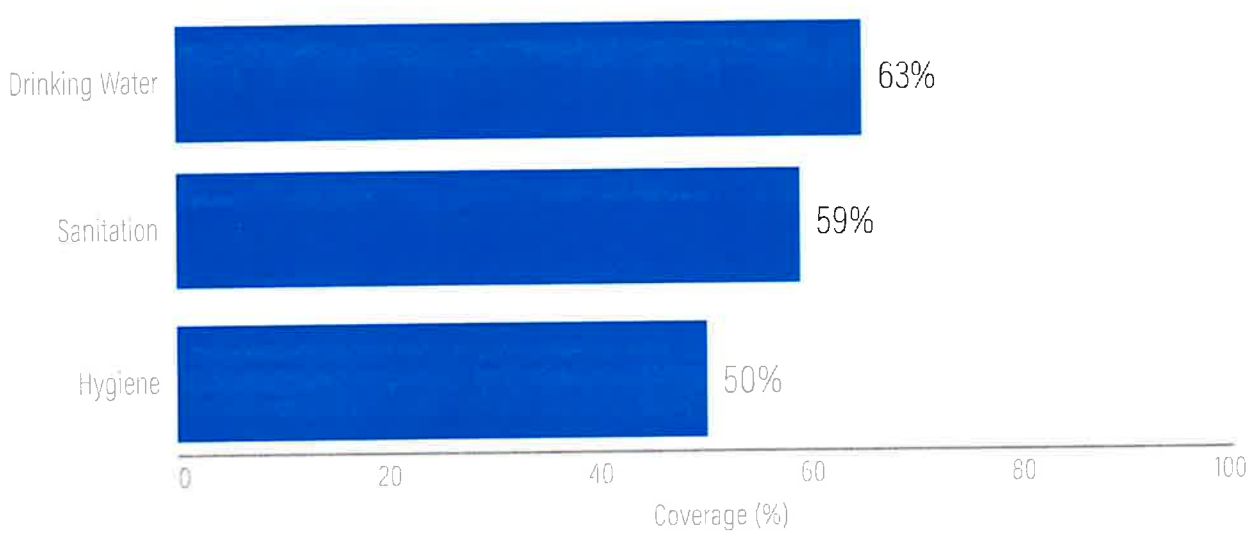
Access to water and sanitation, even prior to the onset of the war in 2015, has always been low in Yemen. Estimates for the year 2017 (Figure 19) show large percentages of the population without access to basic drinking water, sanitation, and hygiene services.[13]

Demographic, Economic, and Social Factors

As of mid-2020, the population of Yemen was estimated to be just under 30 million, with the vast majority under 20 years of age. Figure 20 shows the population of Yemen between 1960 and 2020. The population remains largely rural but with a few large cities mostly concentrated in the western part of the country, including the capital region of Sana'a, with around 4 million people. The population growth rate is high, around 2.3 percent annually, and overall population has gone from around 5.3 million in 1960 to its present size. Yemen is almost entirely Islamic (FAO 2018a).

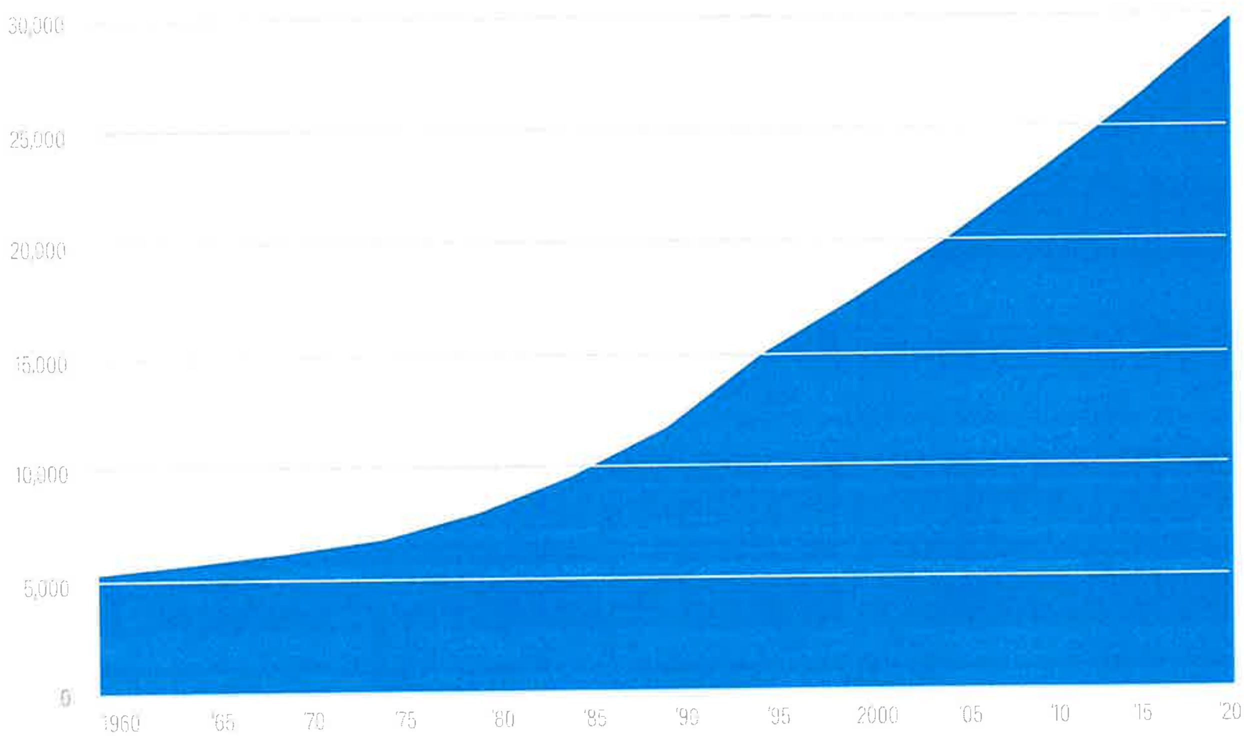
Yemen is one of the poorest nations in the world and even without the current conflict faces difficult long-term economic challenges. The economy is largely based on agriculture and the export of oil but is highly dependent on imports of all major goods, food, and fuel. The ongoing war has severely

Figure 19 | Yemen Water, Sanitation, and Hygiene Coverage (2017)



Source: WHO/UNICEF JMP (n.d.).

Figure 20 | Yemen Population, 1960–2020 (Thousands)



Source: WHO/UNICEF JMP (n.d.).

reduced Yemen's ability to export goods, damaged civilian and industrial infrastructure, and put pressure on international funding (Moyer et al. 2019).

Drivers of Risk

Geography and ethnography

The splintering and disintegration of Yemen has been underway for decades but has worsened with the onset of civil war (Gleick 2019a). The current conflict, involving internal and external actors, began in early March 2015 over differing claims about who represents and controls the official government. Because of the strategic location of Yemen at the intersection of the Red Sea and Arabian Sea, and because of the religious and ideological tensions splintering the area, the conflict has since expanded to include major outside and proxy groups, including Iran, Saudi Arabia, other Gulf States, factions from ISIS and Al-Qaeda, the United States, France, and others, including logistical and weapons support. Several billion dollars in arms sales by both the United States and the United Kingdom to Saudi Arabia have fueled the violence, and the media has reported direct attacks by U.S. air forces (Starr and Cohen 2017). By mid-2019, tens of thousands of deaths from military action had been reported, along with tens of thousands more civilian deaths from famine and disease.

The civil war and attacks on civilian infrastructure

The key driver of water-related security concerns in Yemen appears to be an effort to weaken and destroy opposing forces through widespread targeting of civilian infrastructure, including energy and water systems. Between the start of the war and early 2019, the Pacific Institute's Water Conflict Chronology has recorded over 100 attacks on water utilities, water tanks, water treatment plants, wells, well-drilling equipment, and desalination plants, most conducted by the Saudi Arabian/UAE/Gulf States coalition, but with water-related attacks reported by all parties (Kennedy 2017; Watson 2018; Yemen Data Project 2019). Continuing reports of intensive attacks on civilians and civilian infrastructure have led human rights organizations to ask whether international laws of war are being violated (Human Rights Watch 2016, 2015; Keaten 2018; Miles 2015).

The attacks on Yemen's water systems have led to a huge increase in the number of people without access to safe water and sanitation and contributed directly to massive disease outbreaks that began in 2016 and continue today. Collapsing civilian health, water, and sanitation systems have deprived 14.5 million people of reliable access to clean water and sanitation (Camacho et al. 2018; UNICEF 2017b; UNICEF and WHO 2019; Strategic Foresight Group 2019). By mid-2019, cholera had killed over 3,000 people, mostly children, and sickened more than 1.5 million (Al Jazeera News 2018b; Federspiel and Ali 2018). In just the first four months of 2019, the World Health Organization estimated over 220,000 cases of cholera, with 470 deaths (WHO and UNICEF 2019).

Solutions

Many strategies can reduce the targeting and destruction of water infrastructure. Table 1 lists these strategies (and definitions for each are included in Appendix A). Not all are applicable to all kinds of water-related conflicts, and not all are applicable given the diverse social, cultural, physical, and economic characteristics of regions where water violence occurs. Here we describe a subset of top approaches that are most relevant to the targeting of civilian water systems during local or large-scale wars, with the understanding that other approaches described in Table 1 may also be valuable and worth pursuing.

Political and legal tools

Improvement and enforcement of international humanitarian laws and human rights laws. International laws of war—or international humanitarian laws—explicitly include protections for a wide range of civilian infrastructure, including water systems. These laws prohibit attacks intentionally targeting civilians and require that accidental or collateral damages in war not be excessive compared to military advantages gained. These laws have a long history, extending back more than a century (Gleick 2019b). The most important of these laws include the Fourth Geneva Convention (UN Documents 1949), which prohibits deliberate or indiscriminate destruction of property belonging to individuals, nations, or other public authorities, and especially the 1977 Protocols to the Geneva Conventions (United Nations 1977). The Protocols limit means and methods of warfare that cause superfluous injury or unnecessary suffering, prohibit indiscriminate attacks on civilians and civilian infrastructure, and explicitly prohibit attacks on "drinking water installations and supplies and irrigation works, for the specific purpose of denying them for their sustenance value to the civilian population."

Sowers et al. (2017) describes additional international agreements, statements, and guidelines that also limit attacks on civilian infrastructure like water treatment and delivery systems. Here are two examples:

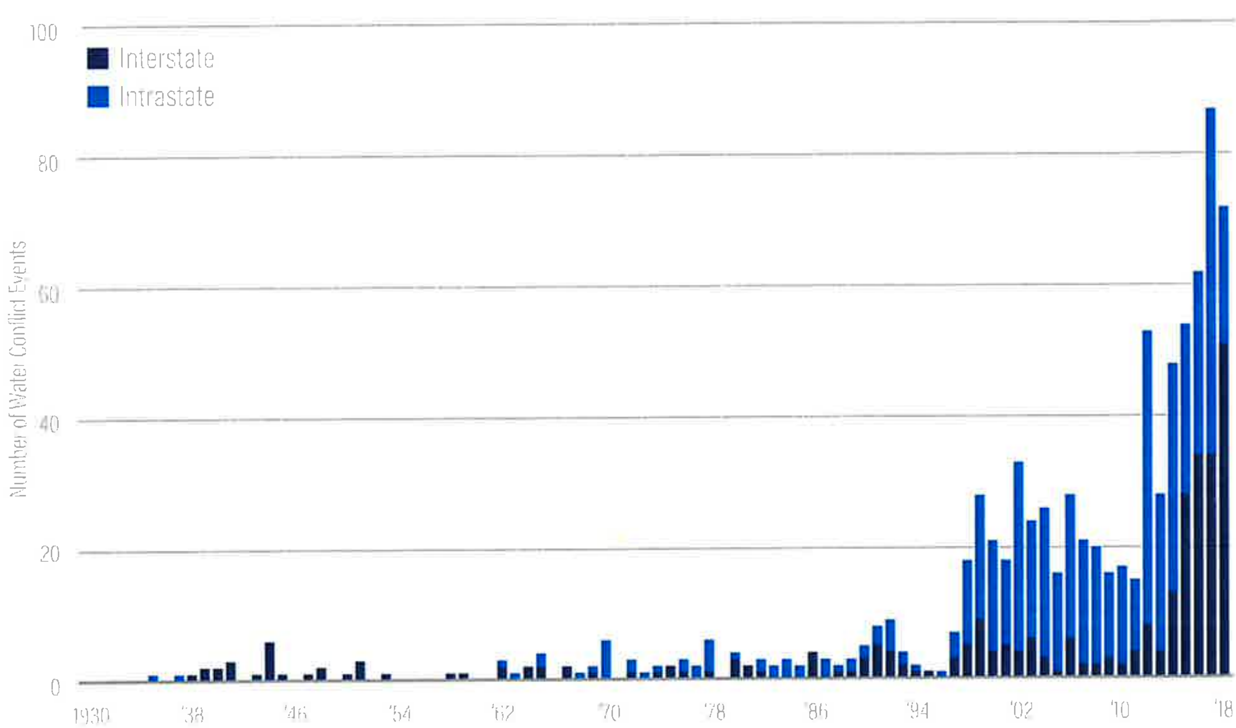
- The 1990 Cairo Declaration on Human Rights in Islam states that it is prohibited "to destroy crops or livestock, to destroy the enemy's civilian buildings and installations by shelling, blasting or any other means" (CDHRI 1990, Article 3(b)).
- According to the Rome Statute of the International Criminal Court, "Intentionally directing attacks against civilian objects, that is, objects which are not military objectives," constitutes a war crime in international armed conflicts (ICC 1998, Article 8(2)(b)(ii)).

Soft law documents such as the Geneva List of Principles on the Protection of Water Infrastructure, published under the leadership of the Geneva Water Hub (2019) in consultation with a wide group of experts, also play an important role in raising awareness of the obligations of international humanitarian law, human rights law, and international water law in protecting access to safe water by civilian populations during and after armed conflicts. As a result of the severe public health consequences of failing to have reliable access to safe and affordable water and sanitation, the International Committee of the Red Cross (ICRC 1994) has long argued for stronger international humanitarian laws to protect water systems and civilian experts who manage them.

Lack of enforcement worsens the current trend. Governments and international legal institutions should prosecute violations of international humanitarian laws that protect water resources and water systems, but such enforcement is almost nonexistent. Until tribunals prosecute violations of international laws of war, there is little disincentive for such acts.

Expanding humanitarian laws (laws of war) to subnational conflicts. Most humanitarian constraints on actions during conflict, like the Geneva Convention and Protocols, were negotiated to address interstate wars, not subnational or civil wars. Nonetheless, the 1977 Second Additional Protocol focuses on non-international armed conflicts and includes provisions on the protection of water infrastructure (see Articles 14 and 15). The United Nations (1977) noted back then that the vast majority of victims of armed conflicts since 1945 resulted from subnational conflicts. This remains true today. Data from the Water Conflict Chronology show the dominant role played by intrastate civil war and civil unrest (Figure 21). Improvements in the legal sphere include making it clear that the protections afforded by existing laws of war apply to subnational disputes. Nonstate armed groups should be encouraged to abide by existing conventions and customary obligations (Gleick 2019b; Geneva Water Hub 2019).

Figure 21 | Trends in Interstate and Intrastate Water Conflict Events, 1930 to 2018



Source: Gleick (2019b).

Natural resources, science, and engineering approaches

Protecting and hardening civilian infrastructure can provide some limited resilience in the face of attacks on water systems. In 2017, the UN Security Council called on member states to explore ways to assess vulnerabilities, interdependencies, and capabilities of critical infrastructure in the context of potential attacks, including cyberattacks, encouraging states to improve the resilience and reliability of such infrastructure (UNSC 2017). These kinds of actions can provide modest protection in the face of incidental or collateral damage and offer the ability to more quickly recover from damage, but no level of physical protection can prevent destruction from intentional targeted attacks.

Conclusions

While incidents of water-related violence are often thought to be related to disputes over access to and control of water, a growing number are direct and indirect attacks on water and sanitation systems in conflicts that may have started for any number of other, more traditional, reasons, including political, economic, and ideological ones. The most current and extreme example of this is the ongoing violence in Yemen that began in 2015 and continues as of this writing. This case study has highlighted over 100 recorded attacks on civilian water infrastructure during the regional war there, including attacks on water treatment plants, wastewater systems, water tankers and wells, and water distribution systems.

The quantity and persistence of these attacks suggest that this civilian infrastructure is being intentionally targeted, or that the attackers are not taking care to separate civilian from military targets, both of which are explicit violations of international laws of war. Should that prove to be the case, the international community has an obligation to either improve enforcement of these international laws or to clarify the laws to strengthen protections for civilians. A step in this direction has been taken with the Geneva List of Principles on the Protection of Water Infrastructure presented at the 33rd International Conference of the Red Cross and Red Crescent in December 2019. The humanitarian implications of these kinds of attacks are clear: in Yemen thousands of deaths and millions of cases of water-related diseases have occurred because of the increased inability to provide safe water and sanitation for millions of Yemeni civilians.

In addition to improving and enforcing legal protections for civilian water infrastructure, modest improvements can be made when designing and building such systems that would make them more resilient in the event of conflicts, but ultimately no amount of hardening can protect water systems from intentional efforts to destroy them, highlighting the importance of legal and political protections.

APPENDIX A

Table A1 | Comprehensive (though Not Exhaustive) List of Water Security Solutions and Their Definitions

WATER SECURITY SOLUTIONS	DEFINITION
Natural Resources, Science, and Engineering Approaches	
Water efficiency and conservation improvements	Using less water per unit of output.
Traditional water supply expansion measures (i.e., "hard" measures)	Developing large-scale infrastructure typically used in past decades, such as dams, aqueducts, pumping stations, and so on. Tapping of additional sources of surface water and groundwater.
New centralized sources of water (wastewater treatment and reuse, stormwater capture, desalination, etc.)	With the advent of "peak water" conditions in certain geographies, developing innovative large-scale ways of extending existing sources of supply, capturing and storing rainfall that had gone unused, converting sources of polluted or saline water to clean fresh water, or using low-quality, polluted, or saline water in certain applications (instead of high-quality or potable fresh water).
New decentralized sources of water (rainwater capture, graywater reuse, etc.)	With the advent of "peak water" conditions in certain geographies, options exist for innovative, small-scale ways to expand existing sources of supply, such as capturing and storing rainfall that had gone unused, converting sources of polluted or saline water to clean fresh water, or using low-quality, polluted, or saline water in certain applications (instead of high-quality or potable fresh water).
Reduction in nutrient and pesticide pollution from agriculture (crops and livestock)	Increasing supply of clean fresh water by preventing agricultural water pollution or reducing or eliminating sources of pollutants used in agriculture.
Ecosystem and soil restoration	Increasing the supply of clean fresh water by improving the potential of natural landscapes and soil to retain water and/or filter out pollutants.
Data collection and information systems	Increasing the efficiency, fairness, and sustainability of clean freshwater use by collecting, analyzing, and distributing data and information openly and transparently.
Agricultural extension services	Building the capacity of smallholder farmers to improve yields, increase sustainability, and/or reduce costs through government-funded training programs. Such services could include helping farmers determine optimal crops for their regions, improve yields, increase water use efficiency, reduce postharvest losses, and so on.
Leak-detection technologies and reduced water losses	Reducing water losses between a water treatment plant and customers, through leaks, theft, inaccurate metering, and so on.
Joint scientific exchanges	Exchanging information and knowledge among scientists of different countries through conferences, online communication, and so on.
Protection and hardening of civilian water infrastructure	Vulnerabilities of water infrastructure during and after armed conflicts can be modestly reduced by improvements in design and construction, and by developing programs to rehabilitate and restore services in the event of disruptions.
Water, sanitation, and hygiene (WASH) infrastructure and services	Providing access to safe, reliable, and affordable water for drinking and household use, and to ensure good hygiene. Providing access to safe, reliable, and affordable sanitation services.

Table A1 | Comprehensive (though Not Exhaustive) List of Water Security Solutions and Their Definitions (Cont.)

WATER SECURITY SOLUTIONS	DEFINITION
Political and Legal Tools	
Improvement and enforcement of international humanitarian laws and human rights laws	International law has provisions to protect civilian water systems during armed conflicts, but such laws are either inadequate or inadequately enforced. In particular, non-international conflicts are less well covered by current international laws of war and should be more explicitly included.
Water and land rights reform	Reforming user rights to water and land to make these rights clearer and more transparent, efficient, and equitable, and make water and land use more sustainable. Includes reform of rights that are discriminatory against women.
Legal ecological flow commitments	Laws and regulations mandating that enough surface water and groundwater be left available in rivers, lakes, aquifers, and the like to support the local ecology (as it exists today or in the recent past). These ecological flow commitments should ideally address both the amount and timing of flows (e.g., the amounts of water needed during high-flow and low-flow times of the year).
Water-use limitation and demand caps	Limiting or capping water use in a given region. These limits help ensure that water savings from efficiency improvements are not "squandered" through expansion of water use. Such limits should ideally be consistent with ecological flow commitments. Stopping use of water altogether for certain activities.
Food security policies, open global food market access	Enacting national policies that help ensure that urban and/or rural communities experiencing food crises have access to affordable quantities of food for sustenance. Enacting international agreements that help ensure that nations experiencing food crises have access to affordable quantities of food for sustenance through global food markets or otherwise.
Disaster-response policies (e.g., for droughts and floods)	Enacting policies that provide assistance to communities affected by severe droughts, flooding, and other types of disasters, including sufficient water for drinking and sanitation, and sufficient food for health and sustenance.
Human right to water and sanitation and the right to a healthy environment	The United Nations declared a formal human right to water and sanitation in 2010, but enforcing that right in the context of water-related violence has not been very successful. In addition, efforts should be made to closely connect the rights to water and sanitation to the right to a healthy environment.
Multistakeholder peacekeeping groups	Under the right circumstances, local or international peacekeeping groups can play a role in reducing the risks of conflict over water. This can include community-scale groups.
Strengthened national environmental laws	Enacting environmental laws that protect ecosystems and water resources from destruction, degradation, pollution, and unsustainable use. The leading edge of such law includes the granting of legal rights to rivers (Tignino 2018).
Training for militaries in international humanitarian law	Understanding and enforcing international laws of war partly requires that militaries and armed groups understand these laws and are subject to them. This requires improvements in training, specifically in the protection of water systems.

Table A1 | Comprehensive (though Not Exhaustive) List of Water Security Solutions and Their Definitions (Cont.)

WATER SECURITY SOLUTIONS	DEFINITION
Political and Legal Tools (cont.)	
Water-sharing agreements: subnational	National, state, and/or local agreements that efficiently, equitably, and sustainably share water resources between or among different groups of water users (e.g., two different states, or agricultural vs. urban users). This includes addressing any conflicting demands through joint monitoring systems, data sharing, technical cooperation, and/or agreed-upon judicial and arbitration mechanisms.
Water-sharing agreements: transboundary	International agreements between two or more nations that efficiently, equitably, and sustainably share water resources. This includes addressing any conflicting demands through joint monitoring systems, data sharing, technical cooperation, and/or agreed-upon diplomatic, judicial, and arbitration mechanisms.
Interbasin transfer agreements	Agreements between two basins or watersheds that specify how and under what circumstances water will be transferred from one to the other (via aqueducts, artificially constructed water channels, etc.).
Economic and Financial Tools	
Access to water development financing	Providing national water resource authorities and related entities (e.g., agricultural authorities, municipal authorities, private sector actors) who otherwise cannot access capital to finance needed investments with access to such capital. Providers of such capital include the World Bank, the Asian Development Bank, the African Development Bank, and so on.
Alternative crops	Switching crop production to crops that require less water per unit of output or that do better in drought conditions or under higher temperatures.
Alternative landscaping	Switching from more water-intensive plants (e.g., grass) to less water-intensive plants (e.g., cacti).
Reduction in food loss and waste	Saving water, land, and energy by reducing the amount of food lost at each stage of production, and reducing the amount of food wasted after purchase.
Water, food, and agricultural subsidies	Reducing or eliminating subsidies that lead to wasteful water use. Increasing subsidies where needed to help the poor and vulnerable afford water and food.
Water prices	Increasing water prices to enable greater levels of investment and maintenance in the water sector, and to signal to water users that water is a scarce commodity and needs to be used more efficiently. All this while safeguarding basic water for all in alignment with the human right to water and sanitation.
Water markets	Creating water markets can facilitate the reallocation of water to more profitable uses. Such markets need to be regulated in order to safeguard other public policy objectives.
Insurance strategies for farmers	Developing insurance programs that would blunt the economic impact of drought on farmers should drought conditions traverse certain predefined thresholds (e.g., rainfall levels x percent below normal over y number of months).

Table A1 | Comprehensive (though Not Exhaustive) List of Water Security Solutions and Their Definitions (Cont.)

WATER SECURITY SOLUTIONS	DEFINITION
Economic and Financial Tools (cont.)	
Social safety net programs	Implementing government programs that provide food and/or funds to rural (and in some cases urban) inhabitants in times of severe drought or flooding conditions.
Dietary choices	Reducing overconsumption of calories and animal-based foods (especially beef) so as to reduce the use of water (and land and energy).
Policy and Governance Strategies	
Decentralization of water management	Shifting the management of water resources from central and state governments to local governments, villages, water user associations, and so on.
Cross-agency collaboration	Collaborating on water-related issues across government agencies at international, national, state, and local levels. One of the goals of this strategy would be the production of efficient and coherent policies among economic sectors, both nationally and internationally (e.g., through international trade policies).
Stakeholder and community engagement	Involving all significant stakeholders in water resource decision-making (civil society, economic actors, ethnic groups, women's groups, youth groups, etc.).
Immigration and emigration policies (intranational and international)	Anticipating migration patterns under chronic (e.g., increasing water stress) and acute (e.g., severe drought) water conditions, and developing plans to facilitate and accommodate such migration, and/or creating conditions that would limit such migration (by creating agricultural extension services, developing social safety nets, etc.).
Gender equality	Raising the status of women in society to be on a par with men's status; among other things to enable them to influence water management and thereby help their communities achieve measurably better water outcomes.
Population policies	Incentivizing reductions in population growth through humane policies (through improved access to family planning services, reduction in child mortality rates, etc.).
Urban and rural development policies	Anticipating future levels of migration from rural to urban settings and developing policies to facilitate and accommodate such migration.
Reduced corruption	Reducing dishonesty, fraud, and the like by government officials for private gain.
Improved governance	Any additional improvements to the manner of governing not captured above.
Improved water management	Any additional water management measures not captured above.

Source: Authors.

ENDNOTES

1. "The Free Rider Problem occurs when there is a good (likely to be a public good) that everyone enjoys the benefits of without having to pay for the good. The free rider problem leads to under-provision of a good or service and thus causes market failure" (*Intelligent Economist* 2020).

2. The categories in Table 1 and the decision to include specific solutions within each category are, to a certain extent, arbitrary—one could have chosen to organize these solutions in other ways, and arguments can be made to include certain solutions in different categories. For us, the importance of Table 1 is not its specific structure; it's the provision of a structure that can be used to organize thinking around solutions to very complex sets of problems.

3. While current sanctions exempt food, medicine, and humanitarian supplies, measures targeting financial activities have deterred many banks from doing business with Iran, slowing imports of grain and other humanitarian supplies (Gardner 2019).

4. FAO (2008) AQUASTAT provides somewhat different figures, with Turkey contributing 89% of the Euphrates's annual flow and 51 percent of the Tigris's flow. But the point remains the same: Iraq, as the downstream riparian, is highly dependent on its neighbors for its water supply.

5. Transparency International (2013) is a summary prepared by the U4 Helpdesk, which is described in the document as follows: "U4 is a web-based resource center for development practitioners who wish to effectively address corruption challenges in their work. Expert Answers are produced by the U4 Helpdesk—operated by Transparency International—as quick responses to operational and policy questions from U4 Partner Agency staff."

6. Desalination can also be a "decentralized" source of water, with small solar-powered systems providing fresh water in small coastal villages and in remote inland villages where water is too salty or polluted to drink. See, for example, Peters (2019).

7. Using the UN regional definitions (UNSD 2019).

8. This river is called the Hirmand in Iran and the Helmand in Afghanistan. Because this case study focuses on Iranian water challenges, we use the Iranian terminology. Similarly, we refer to the Persian Gulf here in line with the recommendations of the Specialized Group for Experts on Standardization of Geographical Names, of the UN Social Economical Council (United Nations 2006).

9. David Michel (2020) notes that the tensions around Lake Urmia, and the 2011 demonstrations in particular, have an ethnic dimension related to Azeri nationalism, with demonstrators accusing Iran of strangling the lake. Like the conflicts with Arab populations in the southwest and Baloch in the east, many water conflicts in Iran pit the ethnic periphery against the Persian center.

10. David Michel (2020) notes that Tehran and Baghdad concluded a 1975 accord on their transboundary rivers and specified division of the minor watercourses. This agreement stipulated a future joint commission to allocate the major rivers, but this work was never completed. Iran and Turkmenistan equally share the Harirud from their jointly constructed and operated Dosti Dam. And, by joint protocol, Turkey supplies Iran with a guaranteed minimum flow on the Sarisu River (UNECE 2011; UNESCWA and BGR 2013).

11. According to WHO/UNICEF JMP, basic sanitation service includes "use of improved facilities which are not shared with other households," and basic hygiene service includes "availability of a handwashing facility on premises with soap and water." See https://washdata.org/monitoring/sanitation and https://washdata.org/monitoring/hygiene.

12. According to WHO/UNICEF JMP, basic drinking water service includes "drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing." See https://washdata.org/monitoring/drinking-water.

13. According to WHO/UNICEF JMP, basic drinking water service includes "drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing"; basic sanitation service includes "use of improved facilities which are not shared with other households"; and basic hygiene services includes "availability of a handwashing facility on premises with soap and water." See https://washdata.org/monitoring/drinking-water, https://washdata.org/monitoring/sanitation, and https://washdata.org/monitoring/hygiene.

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The initiative is intended to become an open network that can bring together knowledge, capacities and activities directed at speeding up and scaling up preventative action in the context of water stress-induced conflict, migration or other forms of social destabilization. To this end, the consortium collaborates with a growing number of other institutions, including Oregon State University, Pacific Institute and New America. More information about WPS can be found at https://waterpeacesecurity.org/.

ABOUT WRI

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SEPTEMBER 10, 2020
BY WFM STAFF

City of Anaheim, Brown and Caldwell to partner on PFAS removal project

The City of Anaheim, California, has enlisted Brown and Caldwell to provide owner advisory services for the design-build delivery of multiple groundwater treatment plants. The new facilities will play a key role in Anaheim's compliance with recent state Per- and polyfluoroalkyl substances (PFAS) regulations and ensure water supplies continue to meet state and federal quality standards.

Following the nation's largest PFAS pilot program undertaken by the Orange County Water District to identify a local remedy to remove trace amounts of the manmade chemicals from groundwater, Anaheim is installing multiple groundwater treatment plants to eliminate PFAS from local groundwater supplies. The heat and water-resistant chemical properties of PFAS make them difficult to remove through chemical and biological processes in conventional water and wastewater treatment, therefore new, technologically advanced plants are required. The total construction budget of the groundwater treatment plants program is $80 million to $100 million, delivered in three phases, and three design-build projects, over five years.

RELATED — Transformational Treatment in Tuscon: Groundwater Remediation Achieved through a 25-Year CERCLA-to-Drinking Water Program

Earlier this year, Orange County water agencies took more than 40 drinking water wells in north and central Orange County out of service, temporarily resulting in increased reliance on costlier water supplies imported from Northern California and the Colorado River. Long-term, county water agencies are constructing new treatment facilities to remove PFAS from drinking water wells and provide a local supply as explained by Anaheim Public Utilities Assistant General Manager Michael Moore:

"This is an important project for Anaheim to alleviate our reliance on imported water supplies. With many of our wells shut down, we are developing groundwater treatment options to be able to use affordable, safe, and dependable local groundwater for the long-term benefit of customers."

As owner advisor, Brown and Caldwell will assist Anaheim in the planning, procurement, and construction of the groundwater treatment plants. The firm's responsibilities include procurement planning, project technical requirements definition, evaluating the best available delivery method, procurement support to identify and select design-build entities, and construction oversight.

"We applaud Anaheim for their forward-thinking approach to navigating the regulatory landscape and providing their customers with a quality, affordable water supply," said Brown and Caldwell Project Manager Rod Pope. "We look forward to collaborating with Anaheim's leadership and the chosen design-build entities to make this project a success."

Presently, Anaheim is defining the projects and performing pilot testing for the first phase of projects. Design, construction, and commissioning of the new facilities is expected to start by spring 2021 and be complete by spring 2023.

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CARLSBAD

Bill will strengthen and expand Carlsbad fish hatchery program

Research assistant Michael Page loads cultured juvenile white seabass into a transport tank. (*Photo by* Mark Drawbridge)

Cultivation will replenish depleted ocean native species

By PHIL DIEHL

SEP. 7, 2020 | 6 PM

A bill passed by the state Legislature and headed to the governor's desk for his signature will strengthen and expand a marine fish hatchery program in Carlsbad, the only one of its kind on the West Coast.

The new legislation by Assemblywoman Tasha Boerner Horvath will update the program and allow it to breed more of the native California species that have been depleted by commercial and recreational fishing over the years.

"At a time when climate change continues to put strains on the world's oceans, we need to be finding more innovative ways to balance our commercial and sport fishing industries with the need to safeguard against over-fishing," Boerner Horvath said in a news release. "This bill gives us a shot at securing a sustainable fishing future by equipping us with the tools needed to become effective stewards of our marine resources."

White seabass have been the main focus of what's officially called the Ocean Resources Enhancement and Hatchery Program since The Leon Raymond Hubbard Jr. Marine Fish Hatchery opened in Carlsbad in the mid-1990s. Hubbard, who died in 1983, was a prominent business, civic and political leader who served on the San Diego City Council from 1973 to 1977. The building is on the north shore of Agua Hedionda Lagoon, across the water from the Encina power plant and the Carlsbad Desalination Plant.

The new legislation, AB 1949, expands the scope of the program to include research on all species of marine fish that have an economic impact on California.

"This legislation will allow for the state to continue to invest in the science and research necessary to adapt to inevitable changes in the marine environment and usher in new productivity at this amazing facility," said Bill Shedd of the Coastal Conservation Association of California, chairman of the hatchery program's advisory panel.

California halibut initially were included in the hatchery program, but the efforts shifted to a single species after a few years, said Mark Drawbridge, director of the program for the Hubbs-Seaworld Research Institute.

"There just wasn't enough funding to do all that is needed for two species at once," Drawbridge said. "There is so much involved in raising the fish and making sure they are healthy."

Fish bred at the hatchery are tagged with microscopic piece of stainless steel wire placed in their cheek, he said. White seabass sold in commercial markets are scanned with sensors to look for the tagged fish. Recreational fisherman are asked to save the heads of the species and return them to a collection point, such as Helgren's Sportfishing at the Oceanside harbor, where the heads are stored in a freezer for the survey.

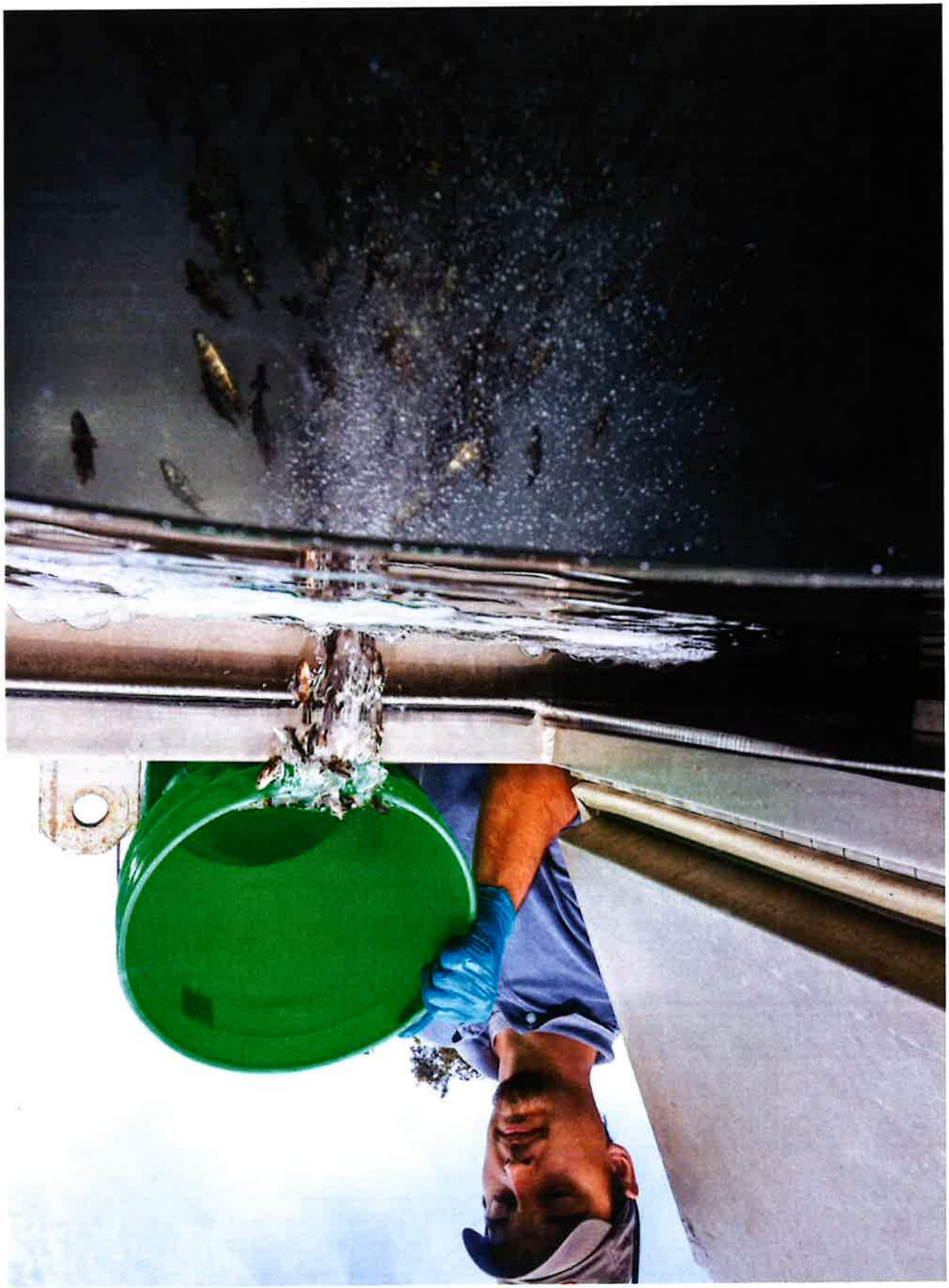
Surveys so far have not been as productive as researchers hoped, Drawbridge said. Only about one tag turns up in every 300 fish scanned, but there could be many reasons for that. Researchers are studying the possibility that some of the tags become demagnetized or are shed by the fish.

Ideally, the hatchery would produce up to 10 percent of the white seabass caught, he said.

The hatchery produces about 100,000 fish a year, Drawbridge said. When they are about 3 inches long, the fish are placed in cages in the ocean along the Southern California coast. They grow to 8 or 10 inches long in the cages before they are released into the open water. The larger fish have a better chance of surviving on their own.

White seabass take about five years to reach the legal size for catch, which is a minimum length of 28 inches or about five pounds. The largest hatchery-bred fish ever caught was 20 years old and weighed about 20 pounds, Drawbridge said.

Wild white seabass can grow to 90 pounds, but it's rare to catch one over 60 pounds, he said.



The Court found that the ability of the County to determine on a case-by-case basis whether a prescribed statutory standard set-off distance was appropriate conferred significant discretion on the County in some cases, rendering its blanket categorization of permit approvals as ministerial improper. In particular, the Court noted that Standard 8.A specifically states that an adequate set-off distance may depend on several variables, and explicitly allows for set-off distances to be increased or decreased based on the "the opinion of the enforcing agency [...]" regarding the level of protection needed, which "allows County to shape a well construction project in response to concerns that could be identified by an environmental review." The Court found that the County's ability to require a different well location, or deny a permit, was sufficient authority to render a permit discretionary when the County is elected to alter a project under Standard 8.A. The Court also found that the County's lack of ability to impose mitigation measures under Chapter 9.36 did not affect its determination that permits issued under the Chapter could be discretionary.

However, the Court rejected plaintiffs' contention that all permit approvals should be blanket classified as discretionary, as there are some circumstances under which the ordinance does not allow the County any discretion. Instead, the Court was careful to hold that County may find permit approvals to be a ministerial action on a case-by-case basis when the record supports such a classification.

In rejecting the County's argument that the interpretation of County ordinances should be left to the County, as it is the party best situated to determine intent and meaning, the Court reasoned that the portions of the County ordinance relevant to the case were those that merely incorporated State standards by reference. Since the agency that promulgated the standards was not a County agency, the Court held that the CEQA guidelines and precedent supporting deference to an agency's determination of what is ministerial or discretionary were not relevant. Furthermore, the Court suggested that its position on discretion may be different if it were reviewing a particular permit issuance decision, but the County's claim here was that the ministerial exemption applied to an entire category of permits as a matter of law.

The *Protecting Our Water and Environmental Resources* decision is instructive to governmental entities or project proponents attempting to determine whether project permits are discretionary. While the Court notes that the blanket categorization of a category of permits is technically permissible, its holding demonstrates that such categorizations will be scrutinized and will be found to be improper if the permitting agency has any ability to deny or modify a project based on any concerns that could properly be the focus of CEQA analysis. It appears that Courts will be far more lenient and deferential to permitting agencies if ministerial categorizations are made for particular permits on a case-by-case basis.

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[1] The standards particularly addressed by the Court are state standards taken from Sections 8.A, 8.B, 8.C, and 9 of State Department of Water Resources Bulletin No. 74.