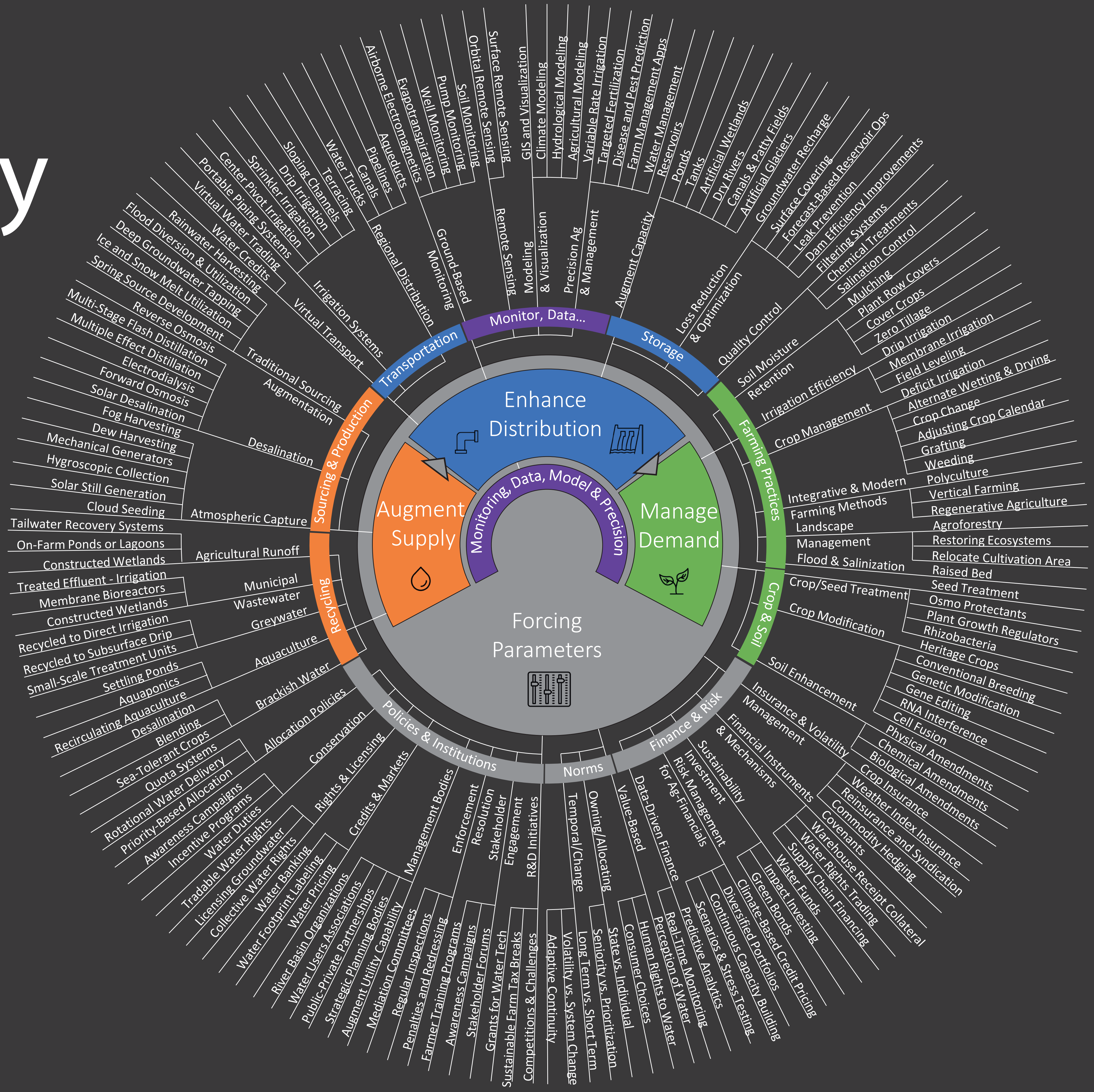
Water-Agriculture Nexus: Forefront of Climate Adaptation

Playbook for Volatile Future

Project Mizu

Solution Taxonomy



150+

Solutions to Understand Water-Ag Adaptation Landscape

Who we are

We are Project Mizu, an independent research group led by Agriculture and Water industry professionals studying at Stanford Graduate Schools of Business, Sustainability, and Engineering.

As a crop trader in Kansas, water engineer in Yokohama, and forestry financier in Nairobi, each of the lead authors experienced firsthand that the impact of climate change is most acutely felt through water stress and shifting weather patterns. Such risks are crucial for agriculture, which accounts for 70% of our freshwater use. As much as climate mitigation is urgent, we are committed to accelerating adaptation by responding to unprecedented shifts in weather patterns and water availability.

Many share the same concerns. Over the summer of 2023, we formed an interdisciplinary team of 30+ water engineers, agriculture experts, management consultants, and investment professionals to map the adaptation solutions in water and agriculture. We are fortunate to be advised by the world's leading researchers and practitioners.

World's First Playbook for Catalysts

This report distills over one thousand hours of research and interviews into a "playbook" that showcases breakthrough opportunities and winning strategies. Academic research, case studies, technology reports, and public guidelines are rarely designed as digestible, solution-to-system playbooks for catalysts such as entrepreneurs, investors, policymakers, and changemakers. We aspire to build a common language to link diverse disciplines.

To fill this gap, we interviewed experts and stakeholders. This report shares 1) a conceptual framework, 2) a solution taxonomy, 3) breakthrough opportunities, and 4) future scenarios to offer a practical overview. Our goal is to inform direct stakeholders, such as farmers, policymakers, and advisors, while inviting more entrepreneurs, investors, and changemakers to this multi-billion-dollar innovation whitespace. We need to sustain agriculture to feed 10 billion people, and update the multi-trillion-dollar agricultural supply chain.

To our knowledge, this is one of the world's first attempts in the water-agriculture adaptation space to map concrete solutions globally and to develop a comprehensive "playbook" for catalysts.

Out of Water, Out of Food. We Need a Playbook to Adapt Ahead of Time.

Our recommendations are not just about immediate adaptability and resilience. They are about envisioning and building a future where sustainable water-agriculture practices are the norm, not the exception. We must combine system-level solutions to ensure balanced demand meets resilient and equitable supply, mitigating the impact of climate change.

We hope this playbook will create an entry point to this complex field of the Water-Ag Nexus.

Project Mizu

Project Mizu Playbook

3 Trends in Water-Agriculture Adaptation Soluitons

Trend #1

Fix-all technologies (e.g., vertical farming, desalination) can reduce stress for high-value crops in confined geographies, but none are sufficiently scalable to cover major cereal crop production regions. They are not ready to protect our food security.

Trend #2

Lower-tech measures preventing leaks, preserving water, and recharging groundwater can be the most powerful interventions. Policy changes and water pricing can incentivize “low-hanging fruits” transition.

Trend #3

Climate change increases volatility in water supply, increasing the need to create and retrofit water storage and transport infrastructure systems. Risk simulations provide invaluable guidelines to identify vulnerabilities.

3 Steps to Climate-Proof Agriculture

Scaling innovations and updating infrastructure will take years, and that is why we should start now. In parallel, accelerate “low-hanging fruit” adaptations to mitigate the shocks.

Step 1: Accelerate farm-level adaptation to absorb the imminent water stress.

Step 2: Update infrastructure to the new weather patterns and water availability.

Step 3: Scale up innovative technologies to remove water constraints from agriculture.

Be Aware;

Scarcity vs. Diversity: Even in the best-case scenario where innovations are rapidly deployed, solutions are likely to be standardized and, therefore, monocultural. There is an inherent tradeoff between scalability and diversity.

Maladaptation Trap: Blind use of textbook solutions such as irrigation can backfire, incentivizing farmers to increase yields by withdrawing more water. Micro-level adaptation without safeguard structures may lead to system-level maladaptation.

Cost of Energy and Security: We can mainstream more technologies quickly when energy becomes cheaper and water stress intensifies. Water-Ag will be central to national security.

Adaptation Startups: Adaptation startups should align their team capacity, immediate market needs, and long-term impact. Missing one of the three will make them technically infeasible, commercially unsustainable, or zero impact.

Price of Water: Water footprint is the “next carbon credit,” where the market will price and trade risks and impact. People will soon realize “food trade” is a form of “water trade.” The belief that “water is free” is an illusion.

Testimonials

“The report does an exceptional job of addressing one of the most important, yet under-analyzed climate-change problems: the vulnerability of agriculture to changing water conditions. The authors provide a comprehensive and insightful picture of the novel technologies, governance structures, and transformative opportunities for addressing the problem. Their analysis and conclusions, moreover, are grounded in reality as a result of the multiple and diverse stakeholders whom they interviewed in developing the report. Everyone involved with the agriculture and water sectors will benefit from the analysis that the authors have performed. Having provided us with a roadmap forward, I look forward to seeing how the authors and others can use the blueprint to ensure a sustainable nexus between water and agriculture.”

Barton H. "Buzz" Thompson, Jr.

Robert E. Paradise Professor of Natural Resources Law, Stanford Law School
Professor of Environmental Behavioral Sciences, Stanford Doerr School of Sustainability
Senior Fellow & Founding Perry L. McCarty Director, Stanford Woods Institute for the Environment

"Project Mizu tackles the complexity of natural capital and sparks much-needed dialogue across fields. Their clear, motivating questions, and structured approach make for compelling and accessible reading. It offers a highly commendable guide for interdisciplinary collaboration."

Gretchen C. Daily

Bing Professor of Environmental Science, Stanford Department of Biology
Senior Fellow, Woods Institute for the Environment
Co-Founder and Director, Natural Capital Project

“Water scarcity and the potential for droughts as well as unusual heavy rainfall represent the most significant risks among the challenges posed by climate change, profoundly affecting millions of farmers and agrifood systems in numerous countries. Given that the majority of crop areas rely on rain, agriculture is heavily dependent on rainfall patterns, and any deviation can lead to severe consequences. Inconsistent and unpredictable rainfall may result in extended droughts in some regions, while others could face excessive rainfall and subsequent flooding. Both extremes have adverse effects on agricultural productivity and undermine agrifood systems. Furthermore, water scarcity often triggers conflicts and instability. This report approaches the issue of water with a fresh perspective. Project Mizu has undertaken substantial work to synthesize and interpret various sources, providing a comprehensive overview for practitioners worldwide.”

Taka Hagiwara

Representative in India
Food and Agriculture Organization of the United Nations (FAO)

"This report breaks down the complex interplay of the water-agriculture nexus, making it accessible to a broader audience. The absence of such a digestible narrative has limited collaborative actions among different stakeholders. This report creates avenues for entrepreneurs and fresh entrants, presenting a number of interesting opportunities."

Yoshihide Wada

Professor of the Climate and Livability Initiative and Center for Desert Agriculture
Biological and Environmental Science and Engineering
King Abdullah University of Science and Technology (KAUST)

“Greenhouse gas emission mitigation has a well-defined taxonomy. Adaptation, in contrast, remains largely undefined. This paper is a strong effort to develop a 'phylogenetic tree' for adaptation in water and agriculture. Their structured thinking and solution survey offer much-needed clarity. The team has done the groundwork to help climate entrepreneurs and investors identify low-hanging fruits and potential game changers. More work in other adaptation sectors is certainly needed.”

Peter Turner
Partner
Breakthrough Energy Ventures

“A complete and insightful exploration of water governance providing a clear roadmap for future policies and action. The comprehensive solution taxonomy was particularly interesting and illuminating.”

Brian Bartholomeusz
Executive Director of Innovation Transfer
Stanford TomKat Center for Sustainable Energy

"With its 30+ scientific and strategic contributors around the globe, Project Mizu's cross-disciplinary analysis and multi-layered recommendations offer a rare combination of breadth and depth on the topic of climate adaptation at the intersection of water and agriculture. No matter how you interface with water and agriculture (e.g. as an entrepreneur, financier, risk analyst, policy-maker, consumer, etc.) this report offers a grounding comprehensive overview and nuanced insights into the challenges and opportunities present today and in the future."

Keegan Cooke
Director
Stanford Ecopreneurship Programs

“Water and food – they are the basis of life yet we have over-used and degraded the ecosystems that sustain us. Project Mizu has pulled together a thoughtful, inclusive framework of solutions and rightly identifies the need for adaptation as climate change upends the water-agricultural complex. Many stakeholders have roles to play and can learn much from the recommendations in this report. Their call for actors in water/ag to lead transformational efforts is a hopeful message for us all”

Katie Vogelheim
Science Council Advisory Board Member
Conservation International

"This paper exemplifies Research Driven Ideation at its finest, with a remarkable commitment to comprehensive research on the Water-Ag Nexus. I am eager to see the innovative directions the team takes next to leverage their earned insights."

Scott Brady
Managing Partner
Innovation Endeavors

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Executive Summary

Water & Ag: Forefront of Climate Adaptation (Chapter 1)

Climate change exposes agriculture to water risks, and it is overlooked.

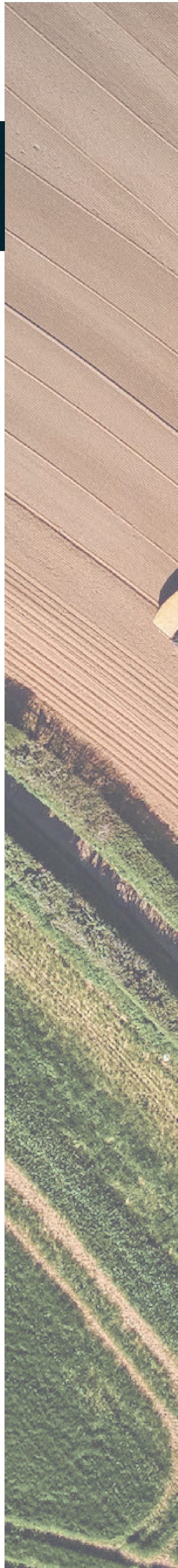
Our civilizations have always been designed around the availability of water. However, climate change is reshaping the "where," "when," and "how" of water accessibility, affecting everything from rain patterns and groundwater aquifers to glaciers and river flows. On the global average, each of us consumes approximately 1,000 gallons (3,785 liters) of water daily through direct use as well as indirect footprints, such as food production. Given the critical importance of water, any alteration in its distribution will dramatically shift its availability, forcing us into difficult allocation decisions.

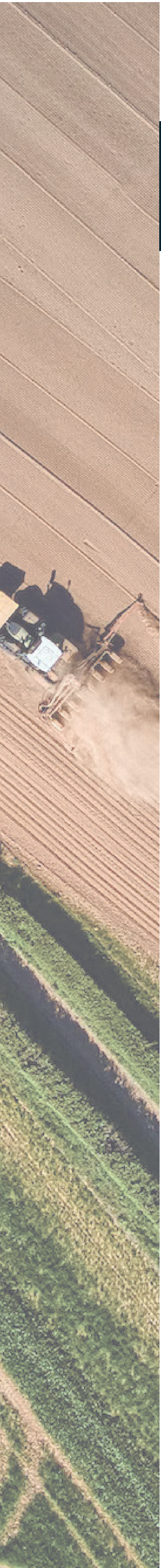
When discussing climate shocks, the conversation revolves around two factors: temperature and water. Imagine the recent weather-related crises: droughts, floods, heat waves, snowstorms, and sea level rise. The intertwining of temperature and water characterizes our experience of climate change and its impact on our livelihoods. Some regions will grapple with the paradox of heat waves and floods, while others may simultaneously face cold snaps and droughts.

Agriculture is particularly vulnerable because the sector accounts for 70% of freshwater consumption by humans. Water problems in agriculture can easily impact billions of livelihoods. 3.2 billion people live in agricultural areas with high water stress or frequent droughts. This scenario is set to intensify with the predicted escalation of unpredictable weather patterns and volatilities. For agriculture to nourish society, farmers need consistent and timely access to the right quantities of water. Therefore, the Water-Ag Nexus is one of the most crucial forefronts of climate change adaptation.

As climate change introduces more unpredictability, a growing population faces water shortages. **Traditionally, the water and agriculture sectors have been seen as risk-averse and resistant to change.** This caution makes sense. With thousands of years of trial and error, we have optimized agricultural production in most major geographies under stable climate conditions. However, with climate change introducing more instability, a growing population will face water challenges, and **avoiding difficult decisions is not a solution.** The need to feed a population of 10 billion sustainably means inaction is not an option.

We, Project Mizu, are a dedicated team of professionals and researchers examining the future of this intersection. This report presents the Solution Taxonomy, Solution System Framework, and future projections for the Water-Ag Nexus.





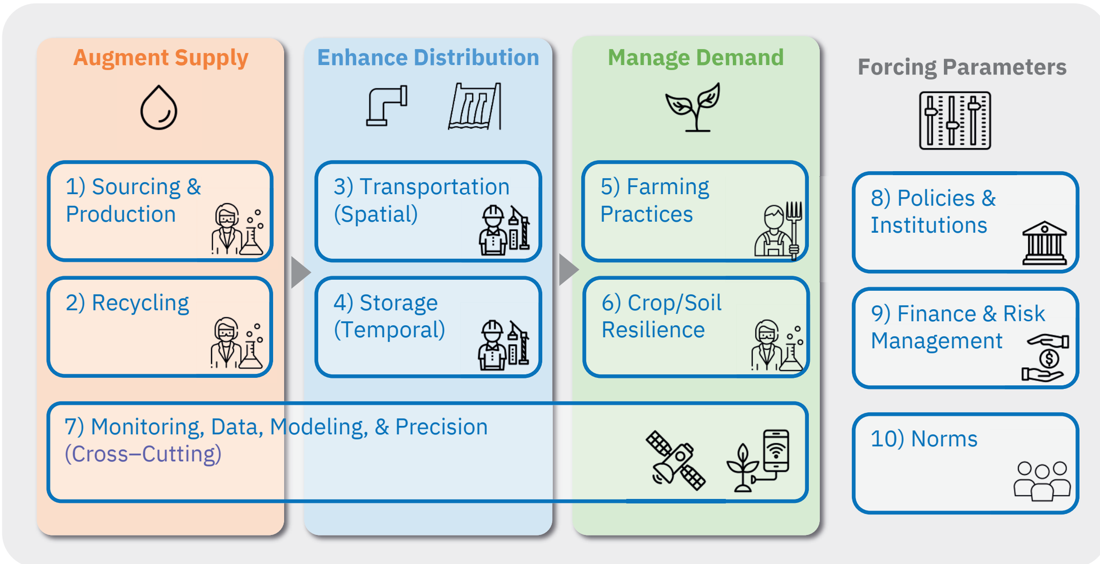
Common Language for Water-Ag Nexus

(Chapter 2 - 3)

The Water-Agriculture adaptation space, being vast and interdisciplinary, lacks a clear common language to address systemic challenges. Therefore, **our first task was to provide a map/ framework for the whole space** so that stakeholders could compare various solutions and discuss the best strategies on a common round table.

Exhibit 1

Our "Solution System Framework" provides the framework for navigating the solution space

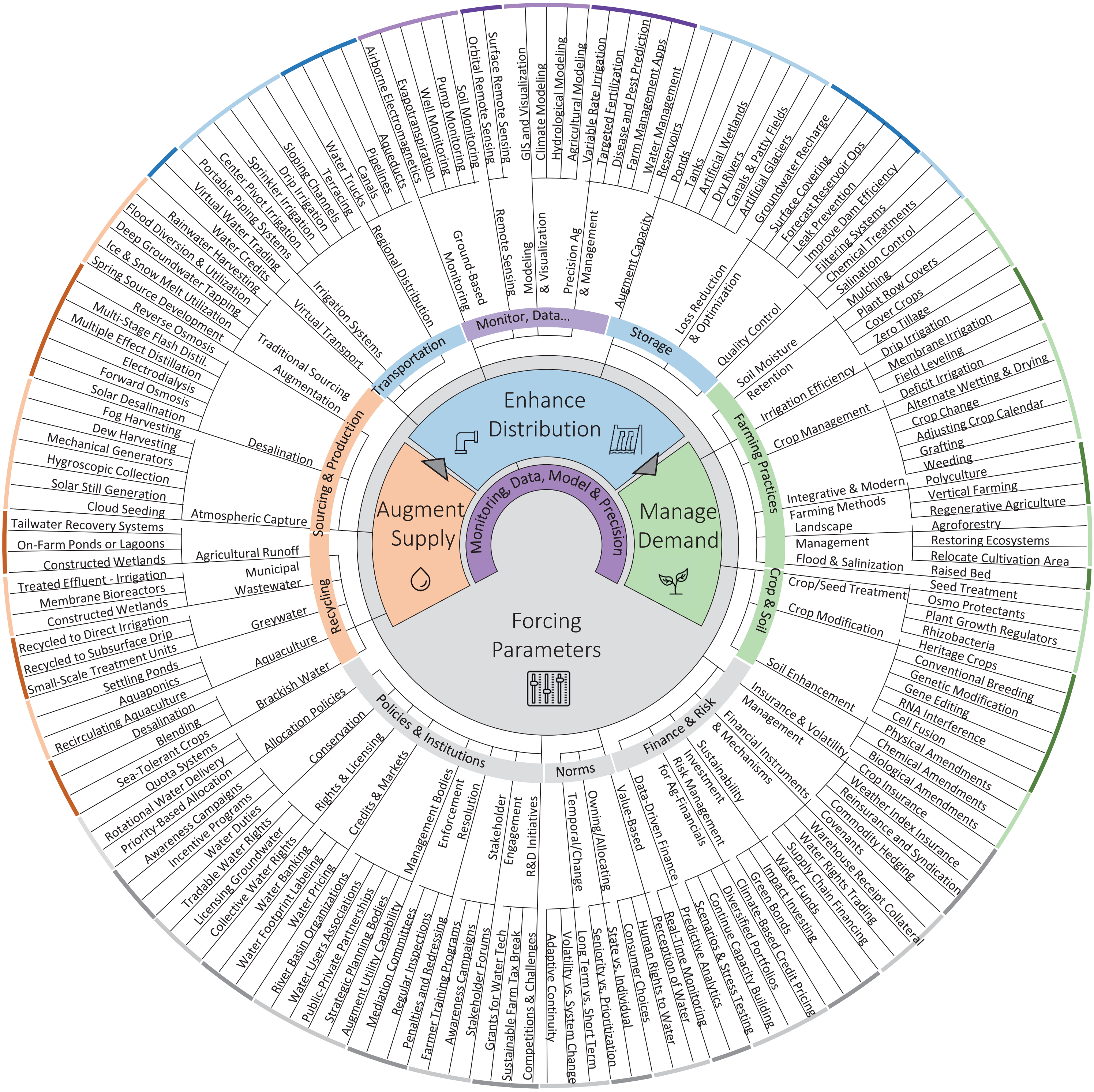


This is our Solution System Framework. We categorized the solution space into 5 categories: (1) Augment Supply (2) Enhance Distribution, (3) Manage Demand, (4) Monitoring, Data, Modeling, and Precision (Cross-Cutting), and (5) Forcing Parameters. Our Solution System Framework and Solution Taxonomy serve as a comprehensive map, enabling stakeholders from various disciplines to navigate the multifaceted challenges and solutions of the Water-Ag Nexus.

We leveraged our interdisciplinary networks to sweep potential solutions and categorized them according to the above 5 Solution Categories. **The Solution Taxonomy catalogs over 150 existing adaptation solutions worldwide.** We recognize that the Water-Ag Nexus varies based on specific actors and regions. Therefore, our approach offers a diverse collection of solutions—akin to a dictionary—rather than prescriptive recommendations.

Exhibit 2

The "Solution Taxonomy" catalogs over 150 existing adaptation solutions worldwide.



Playbook for the Future

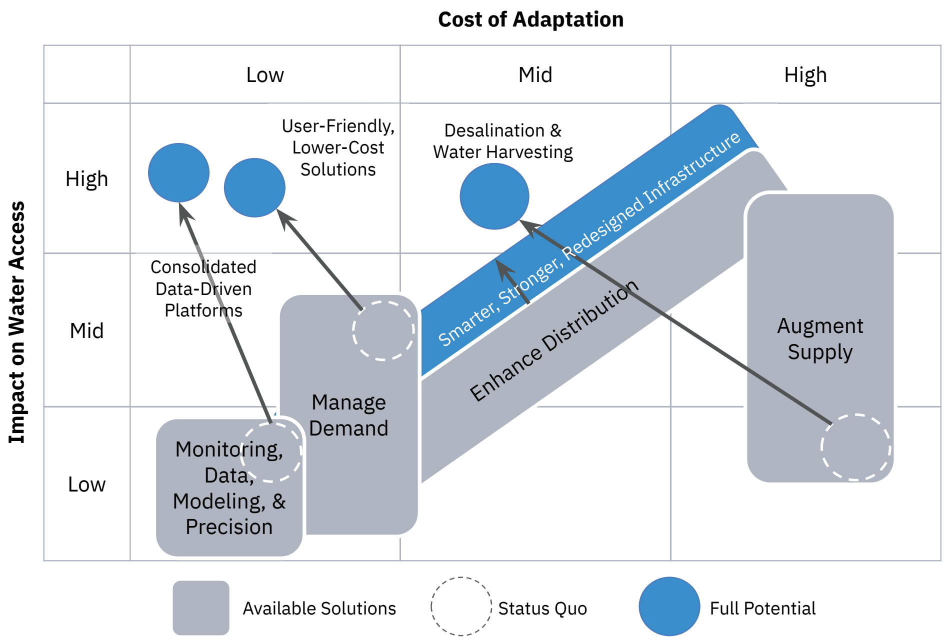
Findings & Recomendations (Chapter 4)

Our recommendations are not just about immediate adaptability and resilience. They are about envisioning and building a future where sustainable water-agriculture practices are the norm, not the exception. The immediate relief provided by farm-level interventions is only a step towards a long-term vision. We must combine system-level solutions to ensure balanced demand meets resilient and equitable supply, mitigating the climate risks.

Breakthrough Opportunities:

Exhibit 3

Arrows show the major Breakthrough Opportunities



» **Augmenting Supply:** Much like the energy and EV sectors that took decades to mainstream, desalination and water harvesting technologies are the areas to invest in now. While current technologies are expensive, energy-intensive, and unsuitable for vast agricultural regions like the US Midwest, Brazil, or Europe, reducing these costs and expanding their scale can lift water constraints in most regions. This could lead to a paradigm shift, especially as traditional water sources may dry up as a result of climate change. A resilient supply chain independent of precipitation will help in countering climate volatility.

» **Enhancing Distribution:** Distribution comes with its legacy of traditional infrastructure, which is hard to modify. But with volatile and severe weather events becoming more common, infrastructure needs to be more resilient in both hardwares and operational softwares. As climate change shifts water supply patterns such as rains, snows, and storms, some geographies will need to redesign their water infrastructure systems. We also need to overcome challenges in physical constraints and governance to ensure fairness in distribution.

Exhibit 4

Status quo and breakthrough enablers in water-ag

Solution Category	Status Quo	Breakthrough Opportunity	Enablers
Augment Supply	Infrastructure-heavy and capital-intensive. Water recycling and desalination have great potential but are expensive and unscalable for large-scale agriculture.	Scalable, economically viable desalination and water harvesting.	Growing uncertainty around natural water supply (precipitation volatility, groundwater depletion, etc.) will increase the costs of water. Significant long-term capital commitment is required.
Enhance Distribution	Various solutions are available from community ponds (small-scale, affordable) to dams and canals (mega-scale, expensive). Costs increase according to the scale.	Smarter software, stronger hardware, and redesigned infrastructure systems.	Climate change increases volatility in water supply, increasing the need for storage and transport. Extreme weather events will require physical reinforcements and operational flexibility. Governments need to consolidate collective political will to reoptimize water-ag infrastructure while securing investment capital.
Manage Demand	On-farm interventions, varying from CRISPR-enabled gene editing to soil moisture improvements, offer immediate, lower-capex solutions, especially in developed regions.	User-friendly, lower-cost farm-level solutions. In particular, the adaptive development of GMOs will help absorb climate shocks.	New climate conditions require new on-farm solutions. Farmer outreach will become a significant driver to accelerate adoption. This will be a consolidated effort by the private and public sectors.
Monitoring, Data, Modeling, & Precision	Numerous siloed solutions specialize across crops, regions, and challenges. Software is lower cost compared to hardware infrastructure. Decision process is not well integrated with data.	Consolidation of software/hardware platforms to integrate the farming and water decision process from monitoring to optimization.	Increasing climate uncertainties will create demand for integrated risk management and decision-making. Large corporations are well-positioned to lead this consolidation of data, analytics, and infrastructure.
Forcing Parameters	**Policy:** Water is recognized as one of the key stress areas for policymakers. However, it takes work to consolidate political will.	Water quota, water pricing, water trading/credit systems.	Water depletion in major agricultural regions leaves no choice but to enforce new governance regimes. Data will visualize these changes and accelerate decision-making.
	Finance & Risk Management: Water is recognized only in particular industries or geographies. Attentions are focused on wildfires and insurance.	Water accounting and climate risk assessments are integral to asset risk management.	Asset and commodity prices become increasingly volatile due to climate shocks and long-term weather pattern shifts. Data will be key to assessing and mitigating damages.
	Norms: Water is considered “free” and “ubiquitous.” In some areas, water-related disasters are changing people’s minds.	Consumer behavior changes to reduce water footprint through reduced meat consumption, food loss, and food waste.	Water scarcity will be widely recognized due to heatwaves, droughts, and other extreme events. Consumers feel the impact of weather volatility through rising food prices and government regulations.

- » **Managing Demand:** Farm-level interventions offer immediate relief and buffer from climate shocks. Direct interventions, like improved seeds and smart water management tools, do not require new infrastructure and can be adopted swiftly. We predict that user-friendly, lower-cost solutions will drive rapid adaptation on the ground, especially in emerging markets.
- » **Monitoring, Data, Modeling, & Precision (Cross-Cutting):** The agriculture sector is peppered with a range of data, monitoring, and analytics solutions tailored for specific needs. While this might be necessary for diversification, it has led to the development of siloed solutions. Much like what we have seen in the B2B SaaS market, we expect the consolidation of softwares and platforms for data-driven decision-making.
- » **Forcing Parameters:** Forcing Parameters set the context for entire water-ag system dynamics. Investments in R&D and scale-up efforts can increase the odds of successful adaptation. Policymakers, financial institutions, and the private sector play pivotal roles in forcing sustainable resource allocation while redirecting resources away from unsustainably-managed assets. Regulators will likely step in to balance individual benefits with system-level optimums. Individual efficiency gains can paradoxically damage overall water sustainability without enforceable water quota systems. Overarching governance, risk assessment, and external pricing are the keys.

Scenarios: Future of Water-Ag Nexus

Exploring the intersection of innovations and adoption reveals a variety of future scenarios. Each scenario depicts potential pitfalls and opportunities in global dynamics, inequalities, sustainability, and resilience. Balancing innovation with equitable adoption is crucial for avoiding detrimental monopolies and fostering an inclusive, sustainable adaptation that values diverse solutions and systemic harmony.

Exhibit 5

4 archetypes of futures imagined from innovation and adoption

Degree of Adoption \ Degree of Innovation	Low	High
High	Gradual Impoverishment	Technological Utopia
Low	Survival of the Fittest	Global Imbalace

» **Low Innovation - Low Adoption: Survival of the Fittest**

In this scenario, the world's response to climate shocks will remain stagnant and disparities among countries will grow. Affluent actors and nations monopolize resources and technology, escalating conflicts and leaving underprivileged entities more vulnerable to climate stressors. This scenario could occur when we only prioritize mitigation and take limited adaptation actions.

» **High Innovation - Low Adoption: Global Imbalance**
This pathway showcases how accelerated innovations can deepen global inequalities as privileged nations consolidate power and adaptation capabilities. Innovations in the hands of dominant nations may lead to international disputes, mass migrations, and potential governance instability due to the disproportionate capacities to tackle climate change. In this scenario, climate technologies become a power determinant just like in the defense sector.

» **Low Innovation - High Adoption: Gradual Impoverishment**
A universal adoption of existing solutions without disruptive innovations in this scenario could result in a gradual realization of climate repercussions. A uniform yet insufficient adaptation response is likely to lead to environmental tipping points where existing technologies can no longer absorb the intensified climate shocks.

» **High Innovation - High Adoption: Technological Utopia**
Here, rapid global adaptation and technological advancements enable substantial resilience against climatic anomalies. In this scenario, humanity successfully mitigates damages from climate change. At the same time, in order to execute rapid transformation globally, adaptation efforts may cause environmental imbalance by promoting monocultural evolution, potentially excluding diverse, localized solutions in favor of more universally applicable ones.

Recommendations: What Each of Us Can Do

» **Farmers: Brace for change and continue integrating innovative farming practices.**
Farmers can directly implement on-the-ground adaptation solutions to navigate the transient climatic conditions. Being proactive, farmers can integrate innovative farming practices and crop choices to enhance resilience to water variability. This adaptability protects their livelihoods from imminent risks and prepares them for the long-term impacts of climate change, enabling sustainable agriculture even as weather patterns and water access continue to shift. On the other hand, climate shocks will accelerate the "tipping points" that will disrupt farming, especially when farmers are lagging behind on sustainable water management.

» **Businesses: Grab billion-dollar opportunities to shield a trillion-dollar industry.**
Businesses, recognizing the intensification of climate shocks and water challenges, are well positioned to pioneer disruptions and improvements within the Solution System Framework. By aligning with farmers, governments, and food supply chain companies, they can create robust models that climate-proof their value chains, unlocking substantial economic opportunities and facilitating adaptation impacts that are crucial to safeguarding trillion-dollar agricultural assets globally. Businesses, especially startups, can capitalize on risk mitigation and upside maximization in the Water-Agriculture solution space.

» **Financial Sector: Manage uncertainties with data and capture upsides.**
Financial institutions will face increasing pressure to refine risk evaluation and impact measurement strategies to facilitate the capital transition to more sustainable assets. By adopting advanced modeling of water availability and usage, these institutions can inform asset pricing and manage volatility, allowing for more informed and resilient investment decisions, thus bolstering financial resilience against potential climate shocks.

» **Policymakers: Take charge in reforming water governance.**
Policymakers, despite the complexities and limited resources, can spearhead sustainable water and agriculture governance through effective system-level planning and pricing regimes. As a steward of shared natural resources such as water, policymakers are responsible for promoting transparent and inclusive multi-stakeholder discussions. Focused on optimized resource allocations and regulation frameworks, they can act as a catalyst for change, balancing immediate responses to climate shocks with long-term resilience strategies.

» **Researchers: Connect the dots for the rest of society as interdisciplinary facilitators.**
Researchers can champion the development and dissemination of interdisciplinary research, combining insights from social sciences, humanities, business, law, and engineering to form a multifaceted approach to challenges in the Water-Ag Nexus. By maintaining transparency, openness, and accessibility in their work, they can ensure that the solutions are not only technologically advanced but also socially equitable, economically viable, and readily implementable by various stakeholders. As climate shocks become daily events globally, researchers are expected not only to share their research findings within the academic communities, but also to communicate future scenarios and practical options with the rest of society.

» **Consumers: Don't take water for granted. Watch your water footprint.**
Consumers, as indirect beneficiaries of agricultural water, can leverage their influence to drive sustainable consumption patterns. By cultivating an awareness of the water footprint associated with their consumption choices, consumers can drive demand for sustainable agricultural practices. Even though such a realitys seems far off, consumers do have the power to drive a global movement towards water conservation and sustainable food production by promoting responsible and sustainable consumption.

Forget Ideology. Let's Deal with the New Reality.

- Water scarcity is no longer a looming challenge; it is our present-day reality. With recent weather pattern changes and volatilities, **we cannot accept the illusion that either mitigation or adaptation alone will suffice.** Both are crucial, especially in the water-agriculture domain.
- Adaptation is not about debating what or who caused climate change—**it is about responding to the tangible, unexpected events affecting stable agricultural production and food supplies.**
- Experts working in silos are not adequately equipped to handle the interlinked challenges within water and agriculture. This **absence of distinct ownership in water issues results in a plethora of isolated solutions attempting to solve these multifaceted issues.**
- This report is our first step to **contextualize innovations and interventions within the broader water-agriculture systems toward an integrated approach.**

1. Why Water-Agriculture is the Climate Adaptation Battlefield

1. Why Water-Agriculture?

The Battlefield for Climate Adaptation

"Climate change is more than a shift in temperature patterns; it alters the way water is distributed across our planet."

When we talk about extreme weather events such as droughts, floods, heat waves, snowstorms, and rising sea levels, we almost always encounter a dual focus on temperature and water. It is this interplay of heat and water that defines our experience of climate change, whether in the form of excess or shortage.

Climate change has already started to impact our ability to access water through short-term volatility and long-term shifts in the natural cycle of water distribution. A common view is that climate change simply means a rise in global temperatures, in other words, global warming. Yet, in reality, global warming is just a starting point that alters the water-heat dynamics of the entire planet.

Rising global average temperatures increase the atmosphere's ability to store water vapor, leading to more violent storm events with increased water volumes precipitating over shorter time periods. The world will also see longer durations between storm events, further shifting the dynamics of the entire planet. This means that the established patterns upon which humanity has assumed as given for thousands of years are changing. Climate change alters the seasonal patterns and weat-

World Bank estimates

9 of 10

climate change events are water-related

Over

70%

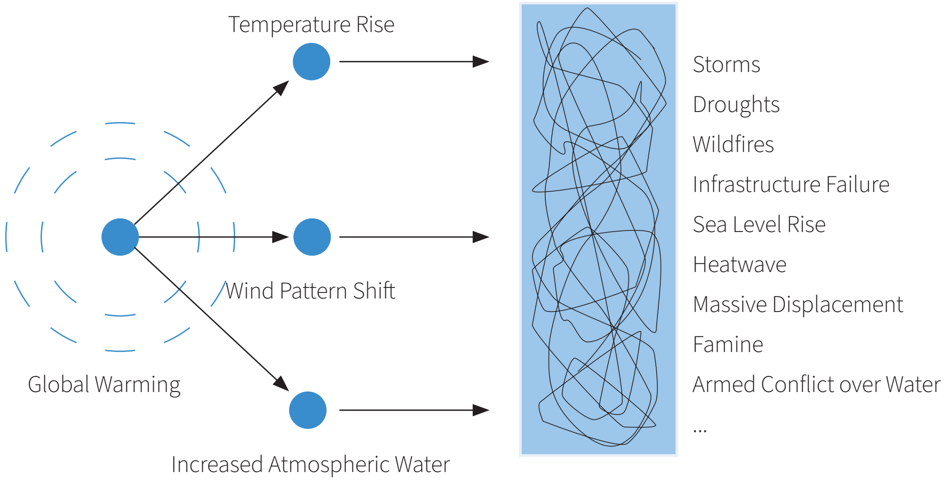
of fresh water use is in agriculture

80 %

of agriculture is rainfed

her baselines that have defined how humans have formed cities, farms, and, ultimately, civilizations. While billions of dollars are now invested in emission reductions to mitigate climate change, we also need to understand the potential consequences of these changes in our daily lives.

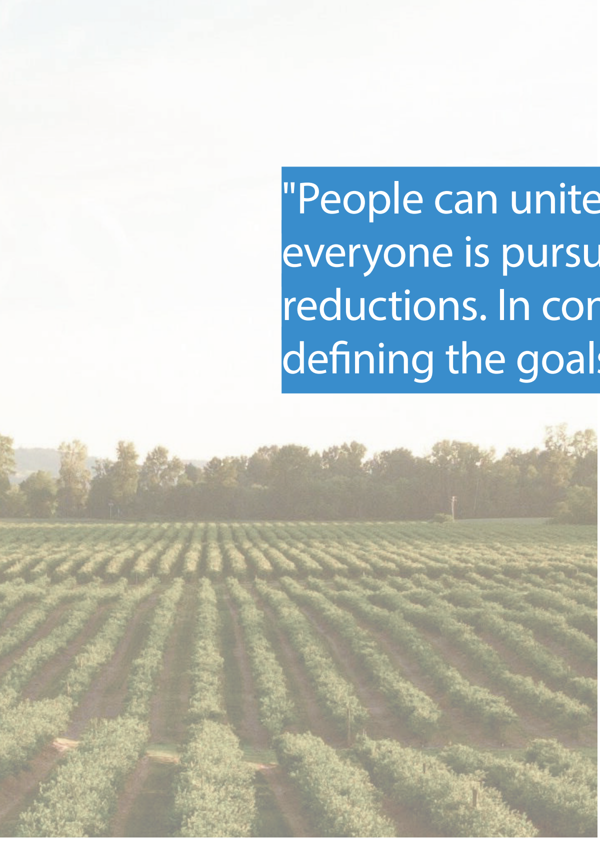
Exhibit 6
The "so what?" of global warming is intertwined



1.1 Adaptation as a Climate-Agriculture Rematching Exercise

This transformation has profound implications for agriculture, a sector that relies on 70% of the world's freshwater and has been developed to meet regional water availability over centuries through intricate supply chain operations. **Today, 3.2 billion people live in agricultural areas with water shortages or scarcity, while 1.2 billion people live in even more severely water-constrained areas.** Adapting to climate change in the nexus of water and agriculture is like solving a puzzle with moving pieces, a complex equation of "water-agriculture (re)matching."

Our efforts to engineer water solutions and optimize agriculture have, until now, operated on the assumption that weather patterns would largely remain the same every year, just as we expect seasons to repeat themselves. **Given that the World Bank estimates 9 out of 10 climate change events are water-related, there will be no such thing as "perpetuity" in weather patterns when it comes to water. In the face of climate change, we are required to adjust our behaviors, technologies, and investments in an increasingly unpredictable world where baseline**



"People can unite around mitigation targets because everyone is pursuing the same goals of emission reductions. In contrast, adaptation needs to start from defining the goals and priorities."

conditions change and weather volatility increases. Furthermore, the extra water stresses as a result of climate change are expected to increase and can push already water-stressed areas beyond the tipping points of no returns. For instance, California's 3-year droughts have reduced cropland by 752,000 acres, almost 10% of total crop areas, with expected losses of $1.7 billion. Combined with unsustainable water management, even the most valuable agricultural lands can lose their productivity after several years of droughts and heat waves.

To this point, adaptation feels like chasing a number of interconnected moving targets at the same time. It also requires us to optimize moving pieces from water distribution infrastructure to farmer behaviors on a global scale when almost all climate conditions are changing. The risks are significant, and (some) impacts and pattern shifts are foreseeable, providing a new space for innovative startups with climate solutions.

California's 3-year drought (2019-2022) alone have caused an estimated

-$1.7 bn

in losses

3.2 bn

people live in agricultural areas with high water shortages or scarcity

1.2 Responding to On-the-Ground Consequences of Climate Change

Unlike climate change mitigation, which is focused on the measurable goals of carbon emissions reductions, climate change adaptation requires us to imagine beyond the direct impact of climate change. Whenever we think about temperature increases and weather volatilities, we must ask ourselves, "So what?" Answering this question is not so easy, either. We need to rely on scientific projections and estimates to merely learn how our future weather patterns and water distribution will evolve. And then, we have to apply these simulations to specific crops, livelihoods, and socio-economic conditions.

The answer is almost always multifaceted, and there is unlikely to be a single solution that resolves these challenges. **People can unite around mitigation targets because everyone is pursuing the same goal of emission reduction. In contrast, adaptation needs to start with defining our goals and priorities**. Is that food security? Is that ensuring cultural heritage and diversity? Is that about protecting farmer livelihoods? Is that about making more profits? There are numerous questions that can arise, and the stakeholders need to align their views to tackle adaptation in sustainable water and agriculture use collectively.

Because it is so complex and nuanced, many of us tend to shy away from discussing the subject at all. However, that is the opposite of what we should do. Because it is complex and time-consuming, we should start now. The “so what” of climate change should be raised and discussed among as many stakeholders as possible so that we can respond to future changes. This report presents a bird’s-eye view of water-agriculture solutions for adaptation in the form of Solution System Framework and Solution Taxonomy. Our observations and analyses aim to offer a starting point for these open discussions about sustainable water and agriculture management.

1.3 Project Mizu: Interdisciplinary Challenges Require an Interdisciplinary Approach

Water's ubiquitous presence means that it has far-reaching implications for various fields in agriculture, from irrigation infrastructure and crop biology to legal systems, business models, and public health. Addressing this intertwined system requires an interdisciplinary approach. That is why our team consists of over 30 professionals, including management consultants, development experts, water engineers, and medical doctors, and has consulted with numerous researchers and experts to fully grasp this complicated relationship between water and agriculture.

In the face of these multifaceted challenges, no single expert can provide the solution. Instead, we must approach these interconnected systems holistically, leveraging a diverse and interdisciplinary team to systematically understand and address the complex nexus of water and agriculture. This report aims to offer an interdisciplinary common language for stakeholders to make sense of the “wicked problems” in water, agriculture, and climate. It is also our goal to provide a map for those who are exploring the next whitespace in climate actions.

This report represents an interdisciplinary effort to dissect the interconnected realms of sustainable water and agriculture in an era marked by the profound consequences of climate change. Rather than aiming to break new scientific ground or validate the effectiveness of specific technologies, our goal is to provide an approachable, straightforward framework to make sense of the entire adaptation solution space. The complexities of water and agriculture under the evolving pressures of climate change defy simple solutions. Our focus here is not on furnishing definitive answers but on offering an accessible starting point for multidisciplinary dialogues and creative thinking. We firmly believe that fostering such cross-sector collaboration is the only viable pathway to accelerate climate change adaptation on a global scale.

1.4 Report Structure

There is no single technology or solution that can address all the system challenges in water and agriculture. As such, we will take a holistic approach to map out the system structure, define key solution categories, and present tangible next steps to realizing a positive future. Each chapter in this report delves into a different aspect of the water-agriculture nexus, combining research, expert opinions, and potential solutions in the following order:

Comprehending and Navigating the Space
"Solution System Framework"

The conceptual mapping of existing solutions helps us understand the big picture when addressing the broad space of climate change adaptation. The Solution System Framework portrays the interactive dynamics between various solutions and enables us to apply system thinking in resolving water challenges in agriculture. This chapter will also share practical steps we can take to identify bottlenecks and opportunities to create system-level impacts in varying geographies and for different actors.

Sweeping the Landscape
"Water-Ag Adaptation Solutions Taxonomy"

The taxonomy summarizes the results of bottom-up research on individual water-ag solutions, defining over 150 solutions. This catalog will help us make sense of the diverse, interconnected space of the Water-Ag Nexus.

The Solution Taxonomy covers

150+

solutions to water-related challenges of climate adaptation in agriculture

Findings and Recommendations
"Playbook: So What Can We Do?"

The bottom-up survey of existing water-ag solutions puts us in a unique position to make observations and predictions. This chapter summarizes our findings and perspectives on how we can realize sustainable adaptation.

2. Framework: Comprehending and Navigating the Space

2. Solution System Framework

Mapping Is the First Step to Evaluate Water-Ag Adaptation Solutions

Accelerating adaptation in the Water-Ag sector begins with understanding existing solutions and mapping how these solutions interact. We recognize that there is not a singular answer, no "silver bullet" to our challenges. **While individual innovations may address segments of the problem, their efficacy often depends on how the broader system reacts.** For instance, a groundbreaking irrigation technique might work wonders on a small scale, but its widespread adoption could strain local water reserves.

Systemic changes can only be built upon a widespread consensus. Everyone involved needs to understand the current state of things and agree on a shared vision for the future. A common language, which is currently lacking, is crucial in bridging gaps in understanding. Often, the challenges we face in this transformation are nebulous, marked by transitions and unpredictability. These attributes add layers of uncertainty to an already complex situation, making it easy to lose sight of both the overarching goal and the immediate steps needed to get there.

Most recognize the complexity of the situation, but articulating that complexity is a heavy task in itself. Our “Solution System Framework” aims to address this disconnect between isolated solutions and systematic problems, advocating for a comprehensive view that incorporates varied components like Supply, Demand, Distribution, Cross-Cutting Optimization, and Forcing Parameters.

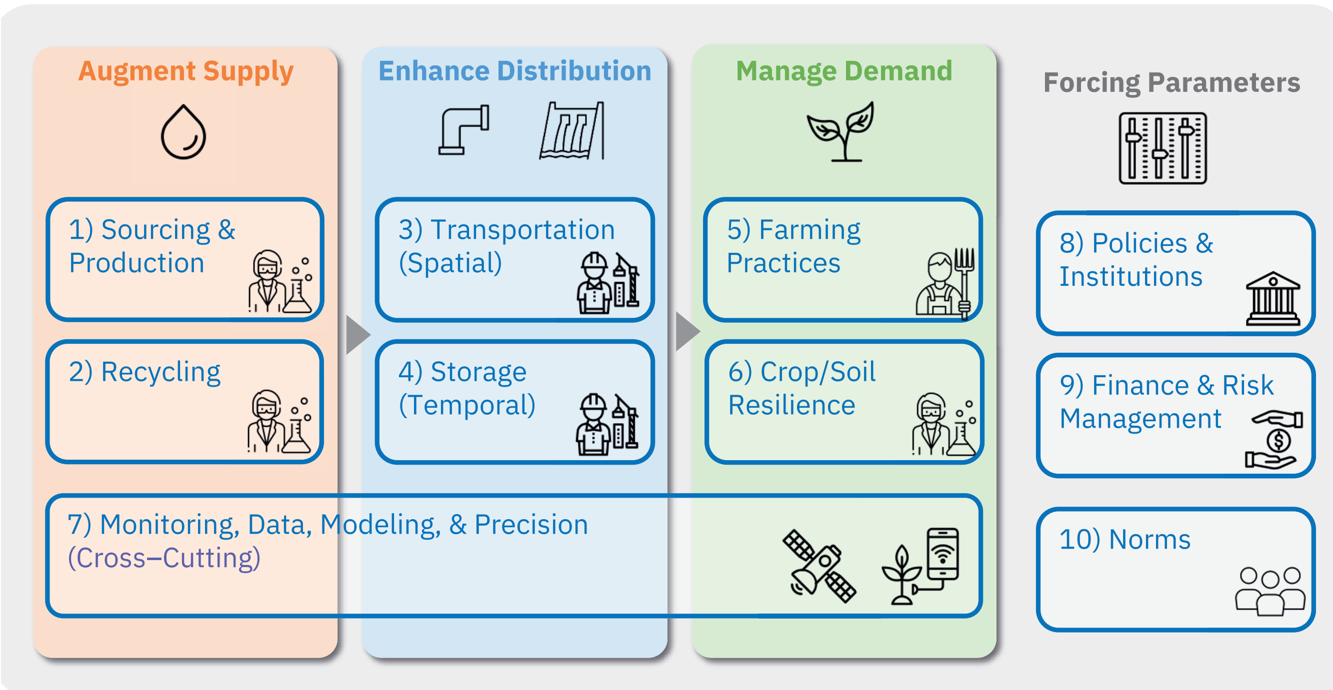
2.1 Solution System Framework

Any "playbook" should start with explaining the landscape and dynamics within the systems. The Solution System Framework provides a structured way to break down the multifaceted problems we face, turning them into tangible, addressable segments. In doing so, we take our first step towards meaningful change.

The Solution System Framework has been constructed to navigate the multifaceted and expansive juncture between water and agriculture. This framework serves as a guide for those aspiring to tackle this critical challenge, be they a startup conceptualizing sustainable innovations, a policymaker setting future strategies, or a researcher delving into systemic water challenges. All are invited to dive into the complex, dynamic systems of water and agriculture with the Solution System Framework.

Exhibit 7

"Solution System Framework" provides the framework for navigating the space



2.3 Pathways for Interventions

Stakeholders can address water challenges in agriculture through pathways of system interventions shown in this Solution System Framework. In order to achieve the most efficient water management in agriculture, we need to ensure reliable water supply (“Augment Supply”), optimize distribution mechanisms such as irrigation and dams (“Distribute”), and minimize water needs to grow crops in a sustainable way (“Manage Demand”), while updating formal and informal social institutions (“Forcing Parameters”).

In the Framework, Augment Supply, Distribute, and Manage Demand dictate the water supply-demand balance, driving toward an optimal and pragmatic equilibrium. Forcing Parameters Change represents the existing social systems and governs the supply-demand adjustments. Monitoring, Data, Modeling, & Precision (“Cross-Cutting Optimization”) serves as the conduit to interlink the balancing process and facilitates feedback cycles among stakeholders.

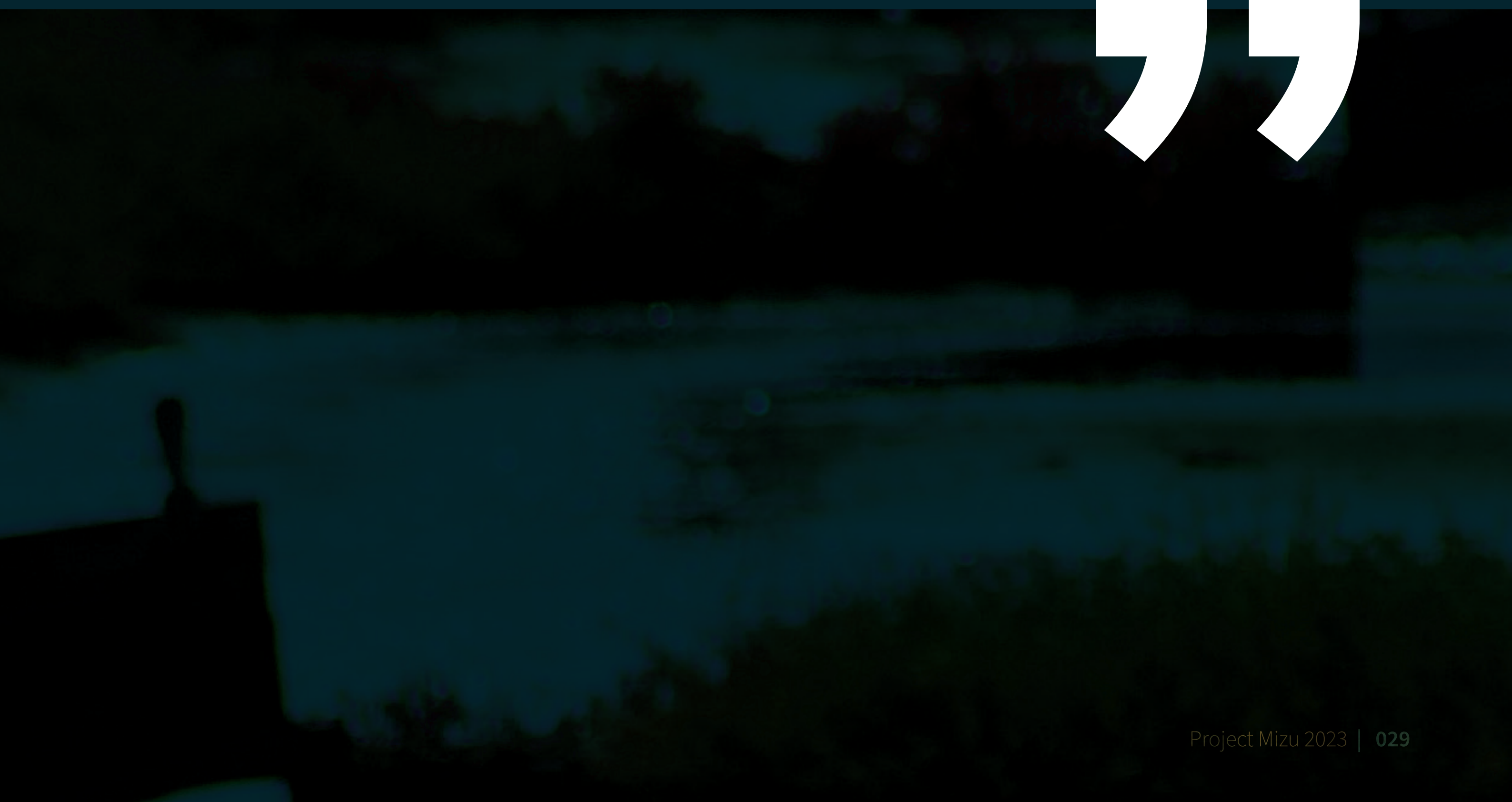
Exhibit 8

The 5 solution categories of our Solution System Framework

Solution Category	Definition
Augment Supply	The first area encompasses "Sourcing & Production" solutions, which focus on innovative ways to obtain and purify water sustainably. This involves exploring technologies in the category of "Recycling" and other methods that ensure a reliable and adaptable water supply.
Enhance Distribution	The second area emphasizes "Transportation" and "Storage" solutions to ensure the efficient and reliable movement of water. These interventions aim to optimize water distribution and storage systems, minimizing waste and maximizing accessibility by resolving “temporal”(i.e., preserving water until when it is needed) and “spatial” (i.e., moving water to places where it is needed) constraints regarding water.
Manage Demand	The focus is on "Farming Practices" and "Crop/Soil Resilience" interventions, which work toward reducing the overall water demand for agricultural production. By implementing water-efficient farming practices and cultivating resilient crops and soils, stakeholders can minimize water consumption while maintaining productivity.
Forcing Parameters	The fourth area involves strategic interventions related to "Policies & Institutions," "Finance & Risk Management," and "Norms." These interventions leverage policy, financial mechanisms, and societal norms to drive transformative changes in the water-agriculture landscape.
Cross-Cutting Optimization (Monitoring, Data, Modeling, & Precision)	"Monitoring, Data, Modeling, & Precision" solutions are essential for effective decision-making and precision agriculture. By leveraging advanced data analytics, modeling techniques, and precision technologies, stakeholders can gain valuable insights to optimize water use and agricultural practices across the system.

Adaptation is not about debating what or who caused climate change — it is about responding to the tangible, unexpected events affecting stable agricultural production and food supply.

”



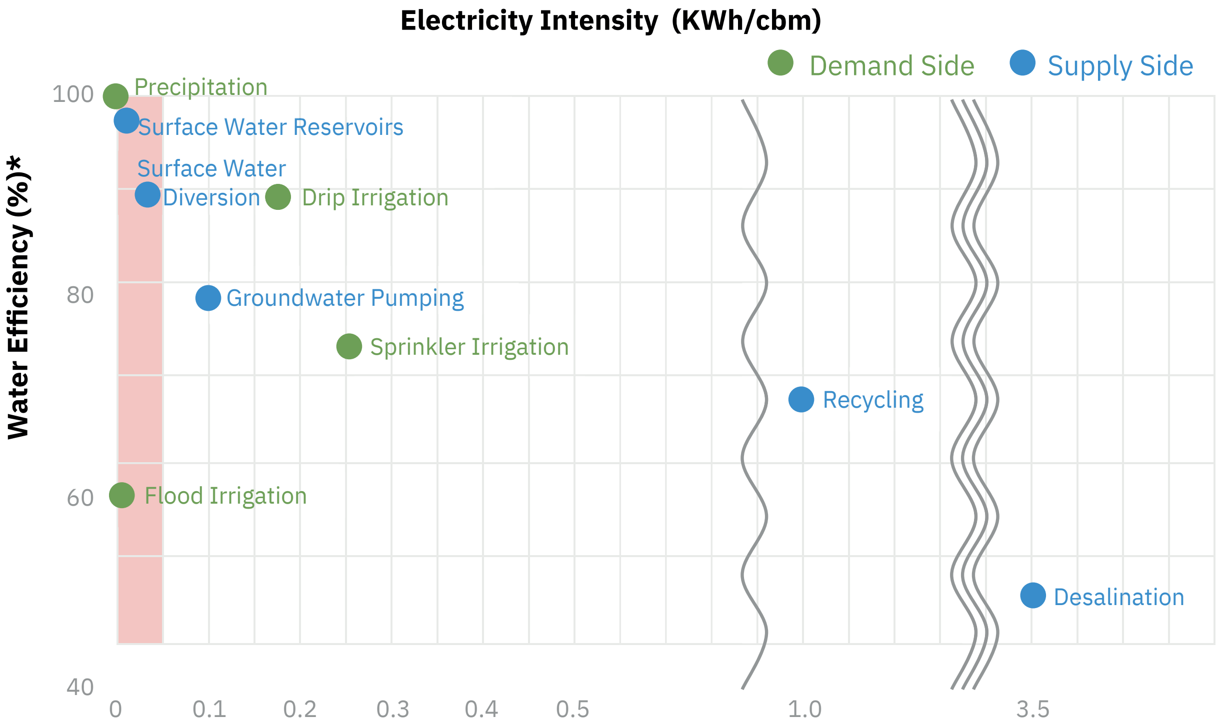
2.4 Paradox of Water Efficiency and Energy Use

To mitigate precipitation pattern change risk, we should invest in technologies to diversify water sources beyond our current reach.

The economic cost of water access is heavily dependent on its energy intensity. Given that water is among the commodities with the greatest per capita footprint, it is crucial to understand the energy intensity, cost structures, and water efficiency for each solution.

Exhibit 9 illustrates a mixed relationship between water efficiency and energy intensity. Typically, technologies that require more significant energy inputs deliver higher efficiency. However, the correlation is the opposite on the supply side: **solutions with minimal to zero electricity intensity, including surface water reservoirs and diversion, achieve superior water efficiency.** This counterintuitive phenomenon is not because our technologies are unsophisticated but because sources like reservoirs and surface water are more accessible to

Exhibit 9
The relation between electricity intensity and water efficiency



*Water efficiency measures the relationship between input water and output water for each technology. Refer to Dubreuil, et al (2012) for further details.
**Source: Kahil, et al. (2018). Expert interviews.

" The counterintuitive economic relationship between water efficiency and energy intensity illuminates why we tend to deplete the most available sources instead of diversifying our sources for long-term sustainability."

humans than groundwater or desalination. **The counterintuitive economic relationship between water efficiency and energy intensity illuminates why we tend to deplete the most available sources instead of diversifying our sources for long-term sustainability.**

On the demand side, different trends emerge. Drip irrigation, which offers superior water and energy efficiency, has witnessed growing adoption. In contrast, flood irrigation lags in water efficiency while being a zero-energy (i.e., near-zero cost) alternative to drip irrigation or sprinkler irrigation. Since most farmers only have limited economic means, adopting more efficient irrigation solutions is often out of their reach. The chart traces the cost-benefit calculations among farmers based on their crops, regions, and water scarcity. We cannot help but recognize the "wall of free water" between passive water sourcing (precipitation and flood irrigation) and engineered water sourcing (drip irrigation and sprinkler irrigation).

Climate change challenges the status quo by impacting low energy-intensity water sources, such as precipitation and surface water (see red highlight in Exhibit 9). The more accessible, energy-efficient water sources face heightened climate risks, as their primary water supply depends on precipitation. **Given that 80% of agricultural production is rainfed, shifts in precipitation patterns present a material risk to our food security.** This reliance on rainfed agriculture is even higher in Sub-Saharan Africa (95%) and Latin America (90%). Such a reality adds another reason to invest in alternative water sources outside our current economic considerations. **Decision-makers, therefore, need to evaluate (1) the total available volume for each water source, (2) the willingness to pay for water, and (3) the optimal diversification of water sources for climate resilience.**

90 %

of Larin American agriculture is rainfed

95 %

of Sub-Saharan African agriculture is rainfed

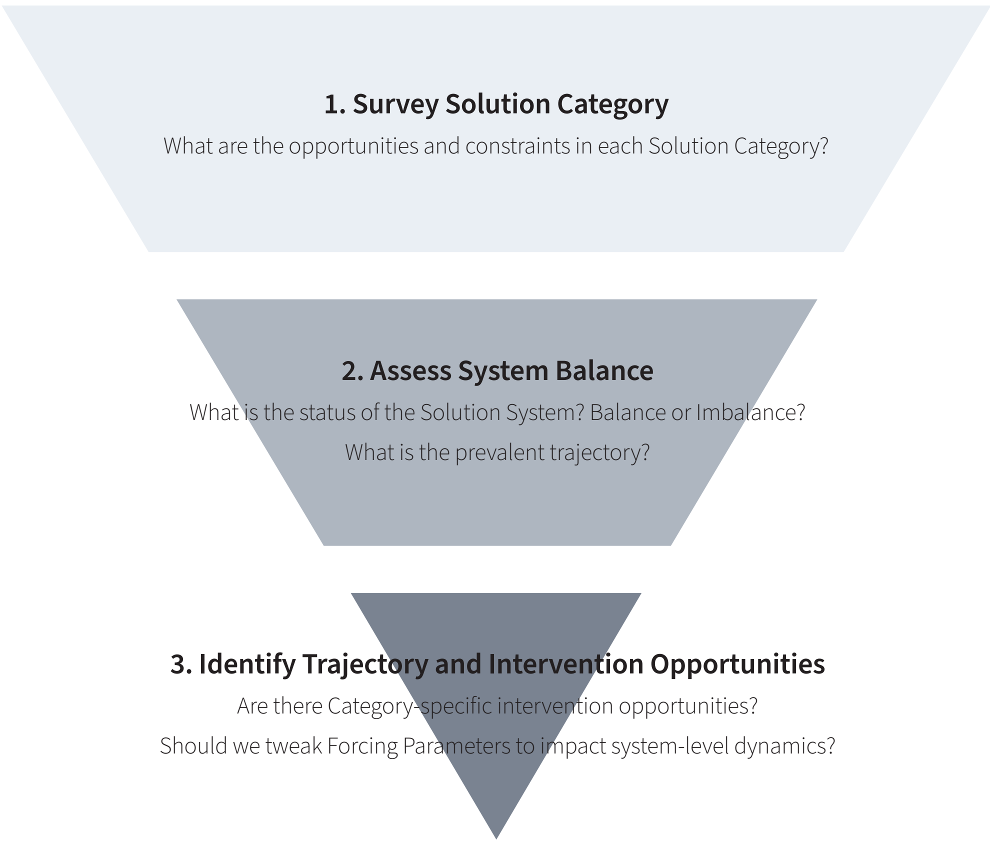
Applying the Framework for System Change

2.4 How Can We Apply the Framework to the Real World?

The Water-Ag system is almost too extensive for any single actor or expert to fully grasp. As such, it is vital to expand our thinking beyond the confines of specific stakeholders and areas of expertise, even to the extent that we start to feel unconformable. The Solution System Framework is designed to provide an analytical framework to identify the system-level challenges and opportunities to accelerate climate change adaptation in water and agriculture. Along with the Solution Taxonomy in the following chapter, the Solution System Framework aims to offer a “bird’s-eye view” of the entire Water-Ag Adaptation solution space. Although none of these Solution Categories may look entirely new to those who are already familiar with the relevant fields, mapping out inter-categorical dynamics as a whole system often provides us with a new perspective.

We tend to think about challenges from our personal and professional backgrounds and standpoints. For example, farmers are more likely to think about Managing Demand within their direct control, while policy-makers may emphasize Forcing Parameters and infrastructure components to Augment Supply and Enhance Distribution. Doubling down on problems and solutions in front of us, however, may not always yield positive results, especially where different Solution Categories are intertwined, and one change in one Solution Category can create unexpected impacts on the rest of the Solution System. Our Solution System Framework treats everything as equal so that everyone can intentionally take a step back from their fields of expertise and look at Solution Categories from the overall system perspective.

Exhibit 10
Narrowing down intervention opportunities



The first step is focused on the Solution Categories (i.e., Augment Supply, Enhance Distribution, Manage Demand, Cross-Cutting, and Forcing Parameters). Looking into each Solution Category, we should explore the trends, gaps, and potentials. The second step takes a bird's-eye view across Solution Categories, examining the supply-demand balance and the current capacity to adjust potential imbalances in the system. The final step extends the preceding analyses to make projections and identify intervention opportunities. The table "3 step questionnaires for systems change" offers more specific questions and research areas.

The step-by-step approach would allow us to break down the complex systems into multiple layers of tangible research questions. It also helps us mitigate the risks of maladaptation, a situation where well-intended adaptation efforts on the ground ultimately cause greater damages or unintended consequences at the system level. For instance, irrigation can enhance farm-level yields and increase farmer resilience but could also ramp up overall water usage and deplete water sources in the community.

Exhibit 11

3-step questionnaires for systems change

Step 1: Survey Solution Category	
» Current Capacity	What are the present capacities within the Solution Category? Are they stretched or are they capable of doing more to mitigate stress?
» Empirical Trends	What are the observable patterns and developments over time? Do you see innovations, incremental changes, or stagnation? What are causing these patterns?
» Climate Risks Exposure	How vulnerable is this Solution Category to climate change? Where and when would be "tipping points" at which the current Solution Category can no longer cope with climate risks?
» Challenges & Opportunities	What obstacles lie ahead, and where are the potential openings for progress?
Step 2: Assess System Balance	
» Supply-Demand Balance	Assess the current, short-term, and long-term equilibrium or any imbalances.
» Distribution Capacity	Examine the capacity for distribution, energy needs/efficiencies (if appropriate), and the pricing structures.
» Forcing Parameters	Identify any opportunities or constraints that can be leveraged to drive change.
» Maladaptation Risks	Are there any risks of maladaptation, where well-intended adaptation efforts in one Solution Category may deteriorate sustainability at the system level?
Step 3: Identify Trajectory and Intervention Opportunities	
» Current Trajectory	Where is the system headed now? Are there any feedback loops?
» Desired Direction	Where should the system be directed for optimal outcomes? Can the desired direction be a range of scenarios instead of a single ideal pathway? What does that mean to various stakeholders?
» Impact Opportunities	How should the interventions address ambiguity in the future trajectory? Are there any trickle-down effects or self-reinforcing feedback loops we can design?

2.5 Who Is in a Position to Lead the Transformation?

Upon applying the Solution System Framework to real-world situations, gaps and potentials will become evident at the system level. The next step is to see who is in the best position to fill these gap and think of means to encourage the transformation.

When searching “water sustainability” or “sustainable agriculture,” we encounter countless whitepapers and industry analyses. Given there is no singular entity that "owns'' these interdisciplinary challenges, positioning ourselves in the issue space itself presents a delicate task. Just as startups seek Product-Market Fit or Founder-Market Fit, effective climate change adaptation requires alignment between one’s capacity, short-term value proposition, and long-term system impact. True systems change opportunities are likely to arise when the following three factors align:

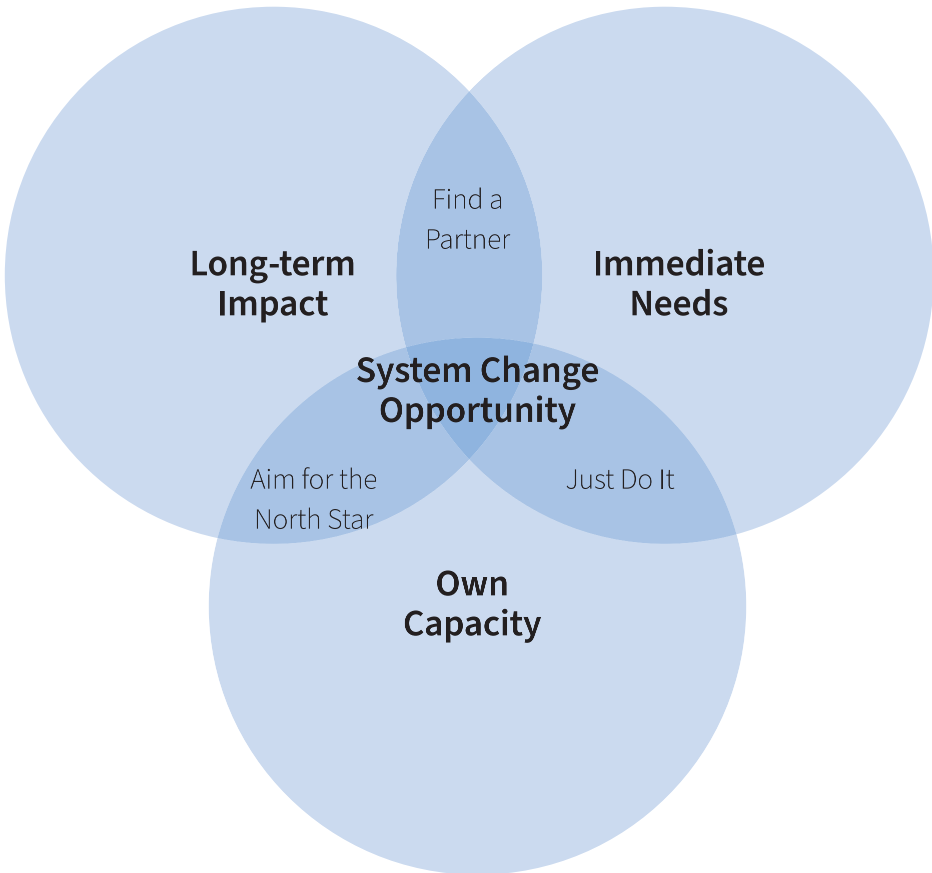
» **Own Capacity:** An entity's own capacity, expertise, and resources.

» **Long-Term Impact:** The potential to influence significant change beyond the narrow scope of problem-solving. This can take a longer timeframe and trickle down to other parts of the system.

» **Immediate Needs:** Identifying specific gaps and addressing them while rallying stakeholders willing to invest time, money, and effort.

Exhibit 12

The overlap of the 3 factors signifies the System Change Opportunity



In the journey to system change, challenges present themselves when one is only equipped with 2 out of the 3 factors. As the chart above highlights, we can call such situations the Three Cracks.

Exhibit 13

The Three Cracks of system change

The "Three Cracks"		
1 - Aim for the North Star	**2 - Find a Partner**	**3 - Just Do It**
Here, there is potential for significant impact and the capacity to influence it. Yet, the immediate needs are not met, often necessitating external pricing mechanisms like tax credits, subsidies, or even recognizing new value metrics.	An entity sees how an intervention can be of immediate benefit to users and have a long-term impact at the system level. Yet, it may lack the direct expertise to make it happen. This underscores the importance of finding the right partners who complement any missing expertise.	Solutions are immediately applicable and address direct needs. However, they operate within the existing system, limiting their long-term systemic impact. While these ad hoc adaptations still deliver a positive impact, a step-up approach is needed to initiate systems change in the long run.

These "Cracks" often pose barriers to a smooth transformation of the status quo. However, with the right strategies and collaborative efforts, they can be surmounted by critically reviewing what we have and do not have. As much as water-ag system changes are daunting tasks that fall beyond one's capacity, interdisciplinary collaborations can empower actors to reinforce their capacities collectively, making the journey towards systemic change more achievable.

3. Solution Taxonomy: Sweeping the Landscape

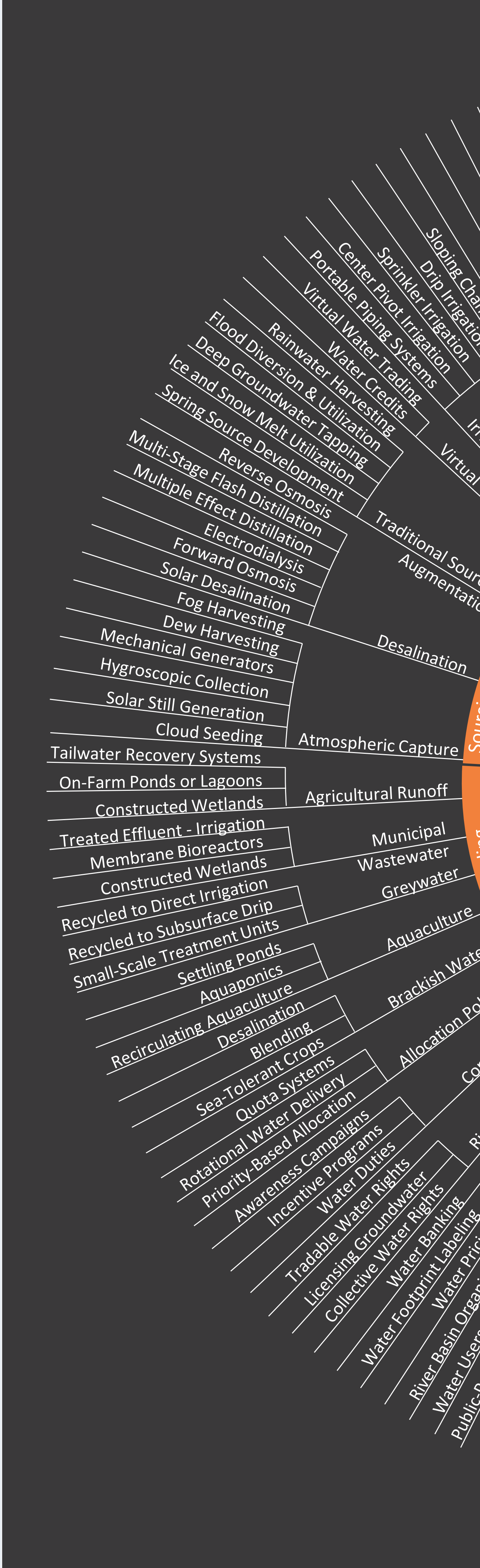
3. Solution Taxonomy

Understanding the Comprehensive Landscape

The Solution Taxonomy encapsulates over 150 solutions gathered and organized to address the multifaceted challenges within the Water-Ag Nexus. The goal of this taxonomy is not to evaluate solutions but to build a handy dictionary of diverse solutions.

Much like a dictionary, this chapter provides a structured compilation of potential interventions, technologies, and approaches to fortify water and agricultural systems against the consequences of climate change. The taxonomy is meant to serve as a resource for stakeholders across the spectrum, from policymakers and researchers to farmers and businesses, offering an encompassing view of available and emerging solutions in the domain.

By placing solutions in the context of the broader Water-Ag Nexus, we can contextualize isolated solutions and understand broader implications within the systems. This approach ensures that stakeholders can identify and select solutions that resonate with their unique circumstances, challenges, and objectives, enabling tailored, effective, and robust climate adaptation strategies. The Solution Taxonomy aims to serve as a toolbox for those tackling climate adaptation in the Water-Ag Nexus.



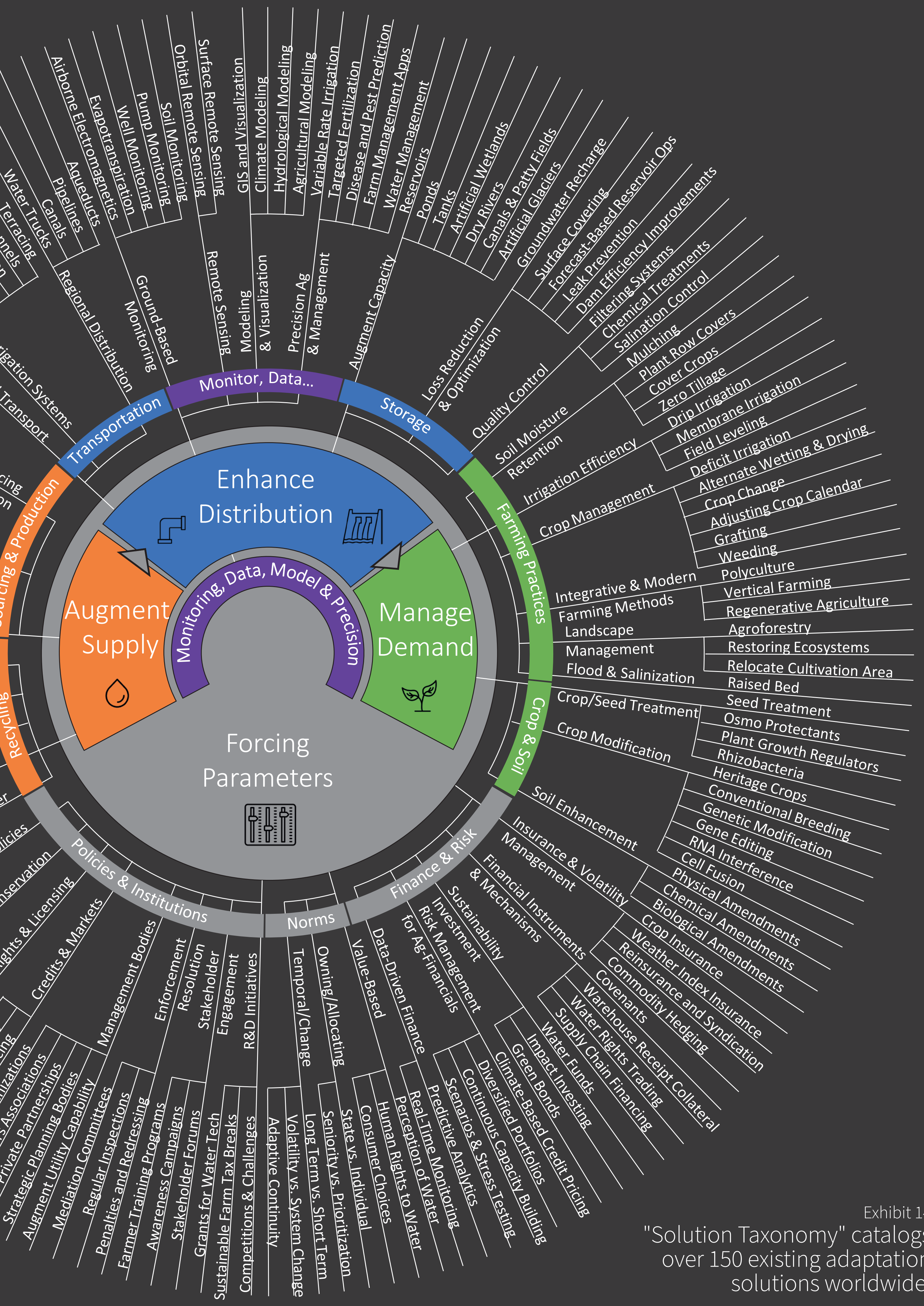


Exhibit 14
"Solution Taxonomy" catalogs over 150 existing adaptation solutions worldwide.

3.1 Augment Supply

3.1.1 Sourcing and Production

Sourcing & Production refers to the strategies, techniques, and technologies utilized to enhance water availability. By enhancing the available water supply, these methods aim to respond to water scarcity, inconsistent rainfall, drought, and other weather events that can impact crop production and overall food security.

The subcategories outlined below for augmenting water supply in agriculture can be grouped based on the primary source from which the water is derived: traditional sources, the ocean (desalination), or the air (atmospheric water capture).

1. Increasing Traditional Sourcing:

Increasing water production from traditional sourcing involves enhancing the water yield from sources that have historically been used for agricultural needs. These are sources that are naturally present and have been traditionally tapped into for water.

- **Rainwater Harvesting:** This method collects rain directly, making use of surfaces like rooftops to channel water into storage units. It capitalizes on precipitation events, turning them into quantifiable reservoirs for future agricultural use.
- **Floodwater Diversion and Utilization:** In areas prone to flooding, instead of letting floodwaters cause damage and then recede, they can be directly channeled to agricultural lands benefiting from silt deposition and direct water application.
- **Deep Groundwater Tapping:** Beyond the superficial water table, there are deeper reserves of groundwater. By drilling borewells and tube-wells, we can access these deeper, often untouched, water sources, which might provide a more consistent supply, especially in areas where surface water is scarce.
- **Ice and Snow Melt Utilization:** In colder climates or high-altitude areas, a significant amount of water is stored as ice or snow. Systems can be designed to capture the runoff from melting glaciers or snowfields, providing a seasonal boost to water supplies.
- **Spring Source Development:** Springs are natural sources of freshwater that emanate from the ground. By tapping into and channeling these springs, we can harness a continuous, and often clean, water supply for agriculture.

2. Desalination:

Desalination is the process of removing salts and other impurities from seawater or brackish water to produce freshwater, making it suitable for agricultural, industrial, and residential use. This approach is closely tied to energy usage, as often referred to as the Water-Food-Energy Nexus. The process is energy-intensive and therefore expensive, making it a challenging option for large-scale agricultural needs in most countries.

- **Reverse Osmosis (RO):** RO is the most common method for desalination. In RO, seawater is forced through a semipermeable membrane that allows water molecules to pass but blocks salts and impurities. The result is freshwater on one side and a highly concentrated brine on the other.
- **Multi-stage Flash Distillation (MSF):** MSF involves heating seawater in multiple stages. In each

stage, a portion of the water evaporates and is then condensed to produce freshwater. This method is particularly effective when combined with power plants where waste heat can be utilized.

- **Multiple-Effect Distillation (MED):** Similar to MSF, MED involves multiple stages of heating and evaporation. However, in MED, the steam produced in one stage is used to heat the next, making the process more energy-efficient.
- **Electrodialysis:** Used primarily for brackish water, electrodialysis involves using electrically charged membranes to separate positive and negative ions (salts) from the water. It is effective for waters with a lower salt content than seawater.
- **Forward Osmosis (FO):** FO is where water is drawn naturally across a membrane from a lower-concentration solution (seawater) to a higher-concentration solution. After this, the freshwater is separated from the high-concentration solution using another method, often with lower energy requirements than RO.
- **Solar Desalination:** Solar Desalination uses solar energy to heat seawater and produce steam. The steam is then condensed to produce freshwater. With the declining costs of solar panels and the abundance of sunlight in certain regions, this method is becoming more viable.

3. Atmospheric Water Capture:

Atmospheric water capture involves the condensation of water from atmospheric moisture. Given the high costs and relatively low volume yield, it is not the primary solution for traditional agricultural setups that demand substantial water volumes. However, this can be a powerful solution in areas with no traditional water sources, such as groundwater, surface water, and precipitation.

- **Fog Harvesting:** Utilized in areas with frequent fog but limited rainfall, large nets or mesh structures are erected to capture the moisture from the fog. As fog passes through these nets, water droplets form, coalesce, and are collected in storage tanks.
- **Dew Harvesting:** Similar in principle to fog harvesting, dew harvesting capitalizes on the condensation that forms during the cool hours of early morning or late evening. Structures or surfaces are designed to encourage and collect this dew.
- **Mechanical Atmospheric Water Generators (AWGs):** AWGs are devices that use electricity to cool the air and condense the moisture. The principle is similar to that of a dehumidifier but optimized to produce water suitable for drinking and agriculture. They can be scaled from small household units to larger industrial sizes.
- **Hygroscopic Material Collection:** Certain materials, known as hygroscopic materials, have the ability to attract and hold water molecules from the surrounding environment. These can be used to capture atmospheric moisture during humid conditions, after which the water is extracted from the materials, typically through a heating process.
- **Solar Still Atmospheric Water Generation:** A solar still captures and condenses moisture using the sun's heat. It consists of an enclosed space where air is heated by sunlight. As the air warms, it releases moisture, which then condenses on a cooler surface within the still, producing water.
- **Cloud Seeding:** Cloud Seeding involves introducing agents like silver iodide, potassium iodide, or liquid propane into clouds to stimulate the cloud particles and enhance the precipitation process, making clouds release their moisture as rain or snow more efficiently.

The viability of the solutions in this Solution Category hinges predominantly on price and energy expenditure. While they offer promise in regions with acute water scarcity and where the original cost of water is high, scalability remains a concern. For instance, desalinating to meet the vast demands of the whole US corn belt would pose significant challenges both in terms of cost and energy consumption. Additionally, the process of desalination generates brine, a by-product with high salinity that can have detrimental effects on marine ecosystems and soil quality when not managed appropriately, introducing another layer of environmental and sustainability concerns to the large-scale adoption of desalination solutions.

3.1.2 Recycling

Recycling encapsulates the solutions that treat and repurpose previously used water, ensuring its safe and efficient reuse in agricultural operations. Although Recycling is unlikely to fill the entire water supply, these technologies effectively complement the mainstream water supply and help balance the supply-demand challenges. In this section, we sub-categorize Recycling by the sources of the water being recycled.

1. Agricultural Runoff Recycling:

Refers to capturing, treating, and reusing water that runs off from agricultural fields due to irrigation or rainfall. Agricultural runoff recycling is efficient in that it keeps nutrients within the agricultural system, preventing contamination of other water bodies.

- **Tailwater Recovery Systems:** Captures and stores runoff from irrigated fields for reuse.
- **On-Farm Ponds or Lagoons:** Collects agricultural runoff, allowing contaminants to settle before reuse.
- **Constructed Wetlands:** Natural systems designed on farms to treat runoff before it is reused for irrigation.

2. Municipal Wastewater Recycling:

Involves treating municipal wastewater, which originates from household sewage, to a standard where it can be used for agricultural purposes.

- **Treated Effluent for Irrigation**: Directly using treated municipal wastewater for irrigation, especially for non-food crops.
- **Membrane Bioreactors (MBR):** Combines biological processes with membrane filtration for high-quality wastewater treatment.
- **Constructed Wetlands:** Utilizes plants, microorganisms, and natural processes to treat municipal wastewater.

3. Greywater Recycling:

Greywater recycling entails the collection, treatment, and reuse of non-toilet wastewater from household or office activities. The volume of recycled greywater may not suffice for extensive agricultural needs due to the large water volumes required. Nevertheless, in urban settings, greywater recycling can complement vertical farming where water requirements are relatively lower and the farms are situated close to the greywater source. This solution is most effective in regions where population is concentrated and external water inflow is limited.

- **Recycled Water to Direct Irrigation:** Using filtered greywater directly for landscape or garden irrigation.

- **Recycled Water to Subsurface Drip:** Distributes greywater below the soil surface, directly nourishing plant roots.
- **Small-Scale Treatment Units:** On-site systems that treat greywater to a standard suitable for garden or crop irrigation.

4. Aquaculture Wastewater Recycling:

This approach uses wastewater from aquaculture for agricultural irrigation, creating a symbiotic relationship between the two sectors. The rich nutrients in aquaculture wastewater provide essential nourishment to crops, enhancing soil fertility and crop yield. Conversely, the process of utilizing this water for agriculture helps in treating the wastewater, contributing to the sustainability and efficiency of aquaculture operations.

- **Settling Ponds:** These structures collect and filter solid waste from aquaculture systems, making the water suitable for agricultural irrigation.
- **Aquaponics:** This system connects aquaculture and hydroponics, allowing water and nutrients to cycle between fish and plants, ensuring efficient water use and providing nutrients for crops.
- **Recirculating Aquaculture Systems (RAS):** Closed-loop systems that continuously treat and reuse water within fish farms.

5. Brackish Water Recycling:

The reuse of mainly industrial effluents with a salinity level between that of seawater and freshwater, commonly redirected for agricultural applications after appropriate treatment. While this can be considered a subcategory for desalination, common practices on the ground often simply reuse salinated water from oil and gas operations. It is also important to recognize that these examples also involve a combination of salt level adjustments and crop optimization.

- **Brackish Water Desalination**: Techniques like reverse osmosis or electrodialysis to treat brackish water.
- **Blending:** Mixing brackish water with freshwater to achieve a suitable salinity level for certain crops.
- **Salt-tolerant Crops:** Growing crops (halophytes) that are naturally resistant to saline conditions.

In addressing water challenges, technological advancements in augmenting supply and recycling are making strides, though many solutions remain energy-intensive and costly, not yet achieving universal efficacy in ensuring water security. As the future looms, regions grappling with acute water scarcity might face a stark choice: resort to recycled water of lesser quality or confront severe shortages. To forestall this dilemma, immediate investments in recycling infrastructure and relentless innovation in technology are paramount, aiming for enhanced water quality and cost-effectiveness.

3.2 Enhance Distribution

Agriculture's water distribution challenge is twofold: availability varies across regions and over time, and these inconsistencies are set to amplify with climate change. The “Distribution” section explores "Transportation" for spatial distribution, ensuring water reaches where it's most needed, and "Storage" for temporal solutions, conserving water during abundance to use in lean periods.

3.2.1 Transportation (Spatial)

"Transportation" (spatial distribution) for agriculture refers to the systems and methods designed to move water from areas of abundance to scarcity. Transportation, such as irrigation, ensures crops receive the right amount of water irrespective of their original environmental constraints. The escalating extremes in weather patterns are intensifying this dichotomy between abundance and scarcity. This exacerbates the urgency to develop efficient water transportation networks to channel water to mitigate geographic water volatility.

1. Regional Distribution Network:

Infrastructure designed to encompass vast areas, connecting different regions to facilitate the distribution of water across expansive landscapes, bridging the gap between water-rich and water-scarce areas.

- **Aqueducts:** Elevated or ground-level channels that transfer water over long distances.
- **Pipelines:** Infrastructure for the long-distance conveyance of water, either above-ground or subterranean.
- **Canals:** Engineered waterways constructed to aid in the distribution of water across vast agricultural landscapes.
- **Water Trucks:** Mobile reservoirs used in severely dry areas or during emergencies to transport and dispense water to parched fields.

2. Irrigation Systems:

Systems specifically designed to provide water to agricultural lands, employing a variety of methodologies that leverage both gravity and pump assistance to facilitate efficient water distribution.

- **Terracing:** Creating flat, step-like platforms on slopes for the downward flow of water across multiple levels of farmland in hilly areas.
- **Sloping Channels:** Utilizing natural or artificially created slopes to guide water flow to downhill fields.
- **Drip Irrigation:** A network of tubes, pipes, and emitters to supply water directly to the plant roots.
- **Sprinkler Irrigation:** Replicating rainfall through overhead sprinklers for even water coverage.
- **Center Pivot Irrigation:** Automated systems with rotating sprinklers that irrigate in a circular pattern.
- **Portable Piping Systems:** Modular irrigation setups relocatable to different sections of a farm.

3. Virtual Water Transportation:

Virtual Water Transportation addresses spatial disparities in water availability by facilitating the non-physical adjustment of water demand. Market-based trading of water allocation ensures that regions with limited water resources can secure sufficient allocations without the need for tangible water movement.

- **Virtual Water Trading:** This involves the buying, selling, or leasing of water rights or allocations, enabling the redistribution of water resources without the actual physical transfer of water.
- **Water Credits**: Trading credits among regions or entities, allowing water-rich areas to earn credits that can be transferred to water-scarce regions, encouraging conservation and efficient usage.

Water transportation, especially over vast regions, necessitates strong government oversight. Leveraging gravity is cost-effective and essential for large-scale transport, but over-extraction from groundwater can lead to land subsidence, threatening our transport infrastructure.

3.2.2 Storage (Temporal)

"Water Storage" in agriculture resolves imbalances in temporal water distribution, where water is accumulated during periods of abundance and conserved for use during dry spells or periods of drought. This strategy is crucial in regions subject to significant water scarcity or variable rainfall patterns throughout the year. By balancing the temporal disparities in water availability, water storage strategies help sustain consistent agricultural activities, thereby bolstering agricultural productivity and ensuring food security. Storage also serves as a buffer to absorb climate shocks.

Effective water storage in agriculture fundamentally hinges on three pillars: capacity, efficiency, and quality.

1. Storage Capacity Improvement

- **Reservoirs:** Large-scale storage solutions, often formed by damming a river.
- **Ponds:** Smaller-scale storage solutions that can be artificially created.
- **Tanks:** Above- or below-ground containers for water storage of various sizes.
- **Artificial Wetlands:** Man-made systems that mimic natural wetlands for water storage.
- **Dry Rivers:** Temporary water storage solutions in arid regions during rain events.
- **Irrigation Canals and Paddy Fields:** Structures utilized for temporarily storing water in addition to their original uses.
- **Artificial Glaciers:** Creating ice structures in winter, such as ice stupas or glacier grafting, to store water that is gradually released in warmer months, providing a consistent water source for agriculture in high-altitude and arid regions.

2. Efficient Utilization and Loss Reduction

- **Groundwater Recharge (AgMAR):** Groundwater serves as a natural reservoir, storing water beneath the Earth's surface in saturated zones of soil and rock. Enhancing natural water infiltration into underground aquifers reinforces its storage and availability for agriculture. AgMAR is a method to intentionally flood crop land in order to recharge groundwater.
- **Surface Covering:** Synthetic covers over surface water bodies to reduce evaporation.

- **Forecast-Informed Reservoir Operations (FIRO):** A method using weather forecasts and data analysis to improve reservoir operations and water distribution.
- **Leak Prevention:** Techniques and technologies designed to prevent water loss from storage infrastructure.
- **Dam Storage Efficiency Improvements:** Strategies to maximize the volume of water stored in dams.

3. Quality Improvement and Contamination Control

- **Filtration Systems:** Systems that filter out impurities to keep the stored water clean and safe.
- **Chemical Treatments:** Techniques involving the use of specific chemicals to treat stored water, ensuring it is suitable for agricultural use.
- **Salination Control:** Strategies and technologies aimed at preventing, reducing, and managing salinization in soil and water.

When planning water storage for agriculture, it is critical to consider multiple objectives, such as energy production, conservation, and integrated systems like aquaponics. Reservoirs can generate hydroelectric power, conservation can enhance natural water storage and biodiversity, and aquaponics can use stored water for diverse, efficient food production. By aligning water storage with these broader goals, we can maximize the multifaceted benefits of our water resources.

3.3 Manage Demand

3.3.1 Farming Practices

Farming Practices encompass agricultural techniques to enhance water use efficiency, curtail water wastage, and ensure sustainable water management. By integrating these practices, farmers can buffer against the implications of water excess or scarcity, deter water pollution, and bolster agricultural adaptability.

1. Soil Moisture Retention Measures:

Techniques aimed at bolstering the soil's capacity to hold onto moisture, reducing the need for water.

- **Mulching:** Covering soil with materials like straw to conserve moisture and reduce evaporation.
- **Plant Row Covers:** Using covers to protect crops and retain soil moisture.
- **Cover Crops:** Growing specific crops, like clover, to enrich soil structure, boost organic content, and enhance moisture retention.
- **Zero Tillage:** Refraining from disturbing the soil and leaving crop residue on fields, thus preserving soil moisture.

2. Irrigation Efficiency Increase:

Approaches and technologies tailored to optimize water delivery and minimize wastage. It is important to note, efficient irrigation may not always result in system-level water savings. Empirical studies show farmers can capitalize on efficient technologies to enhance production, inadvertently increasing water consumption at the community level. Such efficiency gains can paradoxically elevate water use unless complemented by enforceable water quota/allocation systems.

- **Drip Irrigation:** Direct delivery of water to plant roots through a network of tubes, reducing evaporation and runoff.
- **Membrane Irrigation:** Using semipermeable membranes to distribute water, providing precise hydration while preventing soil salinization and water wastage.
- **Field Leveling:** Ensuring the agricultural field is level to enhance uniform water distribution, reduce water wastage, and ensure that every part of the field receives adequate water, thereby increasing irrigation efficiency.

3. Crop Management Measures:

Adjusting crop cultivation methods to bolster water conservation and optimize usage.

- **Deficit Irrigation:** Deliberately reducing water supply during certain crop growth stages to save water without significantly affecting yield.
- **Alternate Wetting and Drying (AWD):** A rice cultivation strategy where fields are alternately flooded and dried, promoting water efficiency compared to the traditional continuous flooding approach, without compromising yield significantly.
- **Crop Change:** Transitioning to drought-tolerant crops or varieties with lower water needs.

- **Adjusting Crop Calendar:** Modifying planting and harvesting schedules to align with periods of optimal water availability and conditions.
- **Grafting:** Joining plant tissues from two varieties, often to confer drought resistance.
- **Weeding:** Regular removal of unwanted plants, ensuring water is directed towards desired crops.

4. Integrative and Modern Farming Methods:

Merging traditional practices with contemporary techniques for holistic farming.

- **Polyculture:** Growing multiple crops simultaneously in a given area, enhancing biodiversity and water use efficiency.
- **Vertical Farming:** Stacked or inclined crop cultivation in controlled environments for water conservation and recycling.
- **Regenerative Agriculture:** A holistic farming practice that seeks to restore soil health, conserve water, and improve overall land resilience.

5. Landscape Management:

Interventions in broader land use patterns to promote water conservation and sustainable agriculture.

- **Agroforestry:** The integrated cultivation of trees, shrubs, and crops, to promote biodiversity and water retention.
- **Restoring Natural Ecosystems:** Revitalizing natural habitats to support water filtration, groundwater recharge, and ecosystem balance.
- **Relocate Cultivation Area:** Moving farming operations to locations with more favorable water availability or quality.

6. Flood and Salinization Defense:

Tactics devised to combat waterlogging, flooding, and salt accumulation, which can impair crop health.

- **Raised Bed:** Elevating the planting surface above the usual ground level to prevent waterlogging and enhance drainage.

Farm-level practices offer swift responses to evolving climate challenges, serving as immediate buffers. While they address immediate risks, their impact is often transient. Given the continuous and systemic effects of climate change on agriculture, collaboration among farmers, communities, and governments is vital. Engaging in landscape-level discussions ensures both short-term adaptability and long-term resilience, allowing stakeholders to harmonize immediate actions with foresight for sustainable agriculture.

3.3.2 Crop and Soil Resilience:

This approach targets enhancing the resilience of both crops and soil to tackle water-related challenges in agriculture. By strengthening the innate resistance and adaptability of crops and soil, it is possible to reduce dependency on water supplies, whether it is during periods of scarcity, flooding, or salination. The crop and soil adaptation methods are often researched, developed and implemented at the regional level in order to incorporate geographical nuances.

1. Crop and Seed Treatments:

- **Seed Treatment:** Applying protective coatings to seeds, mostly through chemicals or biological agents, to fend off pathogens and support successful germination even in challenging water conditions.
- **Osmoprotectants:** Chemical compounds used to assist plants in maintaining cell integrity under stressful drought or saline conditions.
- **Plant Growth Regulators:** Chemical substances that alter plant growth patterns, potentially increasing their resistance to drought.
- **Rhizobacteria:** Beneficial bacteria that enhance plant root systems, boosting growth and drought tolerance.

2. Crop Modification and Choice:

- **Heritage Crops:** Traditional crop varieties with inherent resilience to environmental stresses like drought and heat waves.
- **Conventional Breeding:** Utilizing traditional techniques of crossbreeding to select and propagate plants with desired traits, such as drought resistance.
- **Genetic Modification and Engineering:** Adapting a crop's genetic makeup to increase its resistance to challenges like drought or salinity.
- **Gene Editing:** Techniques like CRISPR are employed to introduce or amplify specific traits, including drought resistance.
- **RNA Interference:** This method suppresses certain genes, potentially those that might be disadvantageous under water stress conditions.
- **Cell Fusion:** Combining cells from diverse species to amalgamate beneficial traits.

3. Soil Enhancement:

- **Physical Amendments:** These are modifications to the soil influencing its structure, porosity, and water-holding capability. By adjusting the physical attributes of the soil matrix, such amendments affect water movement, aeration, and erosion control.
- **Chemical Amendments:** Incorporating substances into the soil that modify its nutrient content, pH, and ion exchange capacity. By targeting soil chemistry, these amendments adjust nutrient availability, pH balance, and, ultimately, water retention.
- **Biological Amendments:** Introducing living organisms or their derivatives that amplify soil's biological interactions. The focus here is on promoting symbiotic relationships, nutrient cycling, and microbial diversity, which together bolster soil health.

The strategies encompassed within crop and soil resilience have proven invaluable in today's agricultural landscape, playing an invaluable role in feeding a growing global population. It is important to note that these advancements, though exceptional, do not change the fact that crops need water for growth. While these technologies mitigate crop’s water footprint and water scarcity, we must continue to invest significant resources to develop and optimize these solutions to realize their full potential in future farming.

3.4 Cross-Cutting

3.4.1 Monitoring, Data, Modeling, and Precision

Tools, data analytics, and precision techniques provide a holistic perspective on the complex web of water-related issues in agriculture. This approach not only enriches our understanding of the issue space but also facilitates the process of refining interventions across water supply, distribution, and demand management.

1. Remote Sensing:

By assessing vast landscapes from afar, remote sensing gathers invaluable data with minimal intrusion.

- **Near-Surface Remote Sensing:** Drones or UAVs equipped with sensors for high-resolution data on soil moisture, crop health, irrigation specifics, and evapotranspiration rates.
- **Orbital Remote Sensing:** Satellites monitoring macro-environmental shifts, water availability, evapotranspiration over large areas, and land use patterns.

2. Ground-Based Monitoring:

Sensors placed directly in or on the ground offer firsthand data on various parameters.

- **Soil Monitoring:** Sensors measuring soil moisture, nutrient levels, and other vital parameters for crop health.
- **Pump Monitoring:** Instruments that monitor and control pump operations, ensuring optimal water usage and reducing waste.
- **Well Monitoring:** Systems that oversee groundwater levels and well health.
- **Evapotranspiration Measurement:** Ground sensors that specifically gauge the total amount of water being transferred from the land to the atmosphere, combining both evaporation and plant transpiration.
- **Airborne Electromagnetic Methods (AEM):** Advanced geophysical techniques used to map aquifer structures and understand groundwater movement.

3. Modeling and Visualization:

Harnessing digital tools to visualize, forecast, and transform raw data into actionable insights.

- **GIS and Visualization:** Geographic Information Systems (GIS) enable the spatial representation of data, helping stakeholders understand the geographic distribution and relationships of water-related factors in agriculture.
- **Climate and Weather Modeling:** Data-driven predictions of short-term weather patterns and long-term climatic shifts and their ramifications on water resources.
- **Hydrological Modeling**: Simulations of water movement, distribution, and quality within regions.
- **Agricultural Modeling:** Forecasts detailing crop responses to factors like water availability, pest occurrences, or fertilization decisions.

4. Precision Agriculture and Holistic Management:

Modern farming and water management relies on precision—every drop of water and grain of soil counts. Integrated digital tools guide these meticulous efforts.

- **Variable Rate Irrigation:** Customized water delivery based on precise field needs.
- **Targeted Fertilization:** Customized fertilizer applications informed by soil tests and remote sensing.
- **Disease and Pest Prediction:** Predictive analytics pinpointing potential disease or pest outbreaks.
- **Integrated Farm Management Apps:** Digital platforms collating data from multiple sources, offering insights and recommendations on optimizing irrigation, water transport, storage, and other farm operations.
- **Optimized Water Management Systems**: Leveraging data to ensure water is utilized efficiently throughout the farming process, from sourcing to distribution.

In the efforts to improve agricultural water management, a foundational principle remains true: we can only improve what we measure. The granular insights provided by robust monitoring can lead to seemingly minor yet profoundly impactful discoveries, like a broken sprinkler or a hidden leakage. Such oversights, if left unchecked, could negate broader water conservation strategies.

However, as valuable as this data-driven approach is, it is not devoid of challenges. The omnipresence of monitoring tools can sometimes invoke negative perceptions, with stakeholders feeling intrusively observed. Moreover, while a wealth of data and models are generated, there is a significant gap between acquiring this information and effectively integrating it into actionable decision-making. Bridging this gap and fostering a culture that respects both data privacy and utility is essential for the future of precision-based agriculture.

3.5 Forcing Parameters

"Forcing Parameters" sets the overarching contexts and frameworks for Augmenting Supply, Enhancing Distribution, and Managing Demand. This Solution Category delves into the critical underpinnings that drive, facilitate, or sometimes inhibit the tangible application of these strategies. It focuses on three categories: the policies and institutions that shape and guide action, the financial mechanisms and risk management tactics that ensure sustainable investments, and the societal norms that influence water-related behaviors and practices. Together, these parameters determine the effectiveness of all other adaptation measures.

3.5.1 Policies and Institutions

"Policies and Institutions" serves as a backbone in addressing water-related challenges in agriculture. This aspect focuses on designing, implementing, and upholding rules, regulations, and frameworks to ensure that water is utilized efficiently, equitably, and sustainably in agricultural practices. Policymakers and institutions often serve as conduits for farmers, stakeholders, civil society organizations, and communities to harmonize their efforts in the face of water scarcity and climate change.

1. Water Allocation Policies:

- **Quota Systems:** Assigning specific water quantities to different sectors or regions based on their needs, ensuring that vital agricultural areas receive priority during scarcity.
- **Rotational Water Delivery:** Assigning specific days or times when water will be supplied to different regions or sectors to balance demand.
- **Priority-based Allocation:** Giving water priority to staple food crops or areas of national food security importance.

2. Water Conservation Initiatives:

- **Public Awareness Campaigns:** Programs aimed at educating the public about the importance of water conservation in agriculture.
- **Incentive Programs:** Offering financial or other benefits to farmers who adopt water-saving technologies or practices.
- **Water Duties:** Water duties refer to legal limitations imposed on the amount of water that can be used for various purposes, including agriculture, to ensure the sustainable use of water resources. These can include regulations on water-intensive crops.

3. Water Rights and Licensing:

- **Tradable Water Rights:** A system where water rights can be bought, sold, or leased, promoting efficient use by allowing rights to be transferred to those who value them the most.
- **Licensing for Groundwater Extraction:** Regulating the amount of groundwater that can be extracted by farmers to prevent over-exploitation.
- **Collective Water Rights:** Assigning water rights to community groups or cooperatives rather than individuals, promoting shared management and conservation efforts.

4. Water Credits and Markets:

- **Water Banking:** Allowing users to 'deposit' unused water rights in a central 'bank' and 'withdraw' them or lease them out during times of need.
- **Water Footprint Labeling:** Labeling products based on the amount of water used in their production, promoting informed consumer choices.
- **Water Pricing:** Implementing pricing strategies that reflect the true value and scarcity of water, thus encouraging conservation.

5. Water Management and Strategic Planning Institutions:

- **River Basin Organizations:** Entities dedicated to managing water resources at the river basin level, ensuring equitable and sustainable usage across regions.
- **Water Users Associations:** Grassroots institutions that manage local water resources, with farmers playing a significant role in decision-making processes.
- **Public-Private Partnerships:** Joint initiatives between government agencies and private entities to finance, design, implement, and operate water infrastructure and services.
- **Strategic Water Planning Bodies:** Organizations dedicated to creating and implementing long-term water management goals in agriculture. These bodies, such as irrigation districts, focus on sustainable water use and conservation planning, ensuring balanced and efficient water resource utilization.
- **Utility Capability Augmentation:** By further advancing the adaptability and proficiency of water utilities, we can fortify the agricultural sector's response to water challenges. Through refined treatment and distribution practices, coupled with rigorous water quality assurance, utilities can play an instrumental role in amplifying agricultural water security and resilience.

6. Enforcement and Conflict Resolution Mechanisms:

- **Mediation Committees:** Bodies dedicated to resolving disputes related to water use, distribution, and rights, using collaborative dialogue to find a middle ground.
- **Regular Inspections:** Regular and ad-hoc checks of farms, storage units, and other facilities to ensure adherence to water regulations and preemptively identify potential points of contention.
- **Penalty and Redress Systems:** Clearly defined penalties for violations, which could range from fines to revoking licenses or permits, accompanied by mechanisms for affected parties to seek redress or appeal decisions.

7. Stakeholder Engagement and Training:

- **Farmer Training Programs:** Workshops and courses educating farmers about efficient irrigation techniques, sustainable practices, and new technologies.
- **Community Awareness Campaigns:** Programs aimed at the general public, emphasizing the importance of sustainable agricultural water use and how they can play a role.
- **Stakeholder Forums:** Regular meetings or forums where different stakeholders can voice concerns, share insights, and collaborate on solutions.

8. Research and Development Incentives:

- **Grants for Water Tech:** Financial support for startups or institutions working on groundbreaking water management or conservation technologies.
- **Tax Breaks for Sustainable Farms:** Offering reduced tax rates or other financial benefits for farms that adopt and demonstrate water-efficient practices.
- **Competitions and Challenges:** Hosting challenges that invite solutions to specific water challenges, with monetary rewards and recognition for the best innovations.

The water and agriculture sectors are shaped and influenced by local contexts. As such, it is imperative that policies and institutions are tailored to fit the unique intricacies of each region. In the face of climate change, our systems must maintain a continuously adaptive state, resiliently evolving to meet the ever-changing demands of the environment. This becomes even more complex when considering the delicate balance between individual water rights, often perceived as personal property, and the overarching needs of the agricultural system. Policies and institutions need to mainstream solutions that respect individuals' rights and well-beings while ensuring the sustainability of our shared resources.

3.5.2 Finance and Risk Management

"Finance & Risk Management" relates to the strategies, tools, financial instruments, and solutions established to ensure the financial stability and operational resilience of agricultural entities amidst water-related adversities. These measures offer fiscal and operational security to farmers and relevant stakeholders, ensuring that agricultural activities remain robust in the face of droughts, excessive rainfall, and other water-related challenges. By de-risking investments and reallocating capital, the financial sector can influence the fundamental economics of Water-Ag adaptation solutions.

1. Insurance and Volatility Management:

- **Crop Insurance:** Safeguards farmers from the financial setbacks of crop failure due to factors like drought or excessive rain.
- **Weather Index Insurance:** Offers payouts based on predetermined weather parameters, such as a lack of rainfall, rather than actual crop losses.
- **Reinsurance and Syndication:** Disperses insurance liability so that primary insurers can cater to more farmers, even in high-risk areas.
- **Commodity Hedging:** Provides farmers the ability to preset prices for their produce, shielding them from potential price fluctuations due to water-related events, commonly done using futures contracts.

2. Financial Instruments and Mechanisms:

- **Covenants:** Lenders may impose specific terms, such as mandating water-efficient practices, for farmers to qualify for financial assistance.
- **Warehouse Receipt as Collateral:** Farmers can utilize stored crops as collateral to obtain loans, enabling liquidity sometimes needed for resilience without the necessity of immediate sales.

- **Water Rights Trading:** Encourages efficient water use by facilitating the exchange of water rights among users.
- **Supply Chain Financing:** By capitalizing on their rapport with buyers, farmers can avail of better financing conditions. As incentives are aligned to achieve supply stability, parties could cooperate in financing adaptation.

3. Sustainable Investment Mechanisms:

- **Water Funds**: Investments directed towards water security and watershed conservation, distributing both risks and rewards across multiple stakeholders.
- **Impact Investing:** Channels capital to ventures, ensuring both monetary returns and tangible societal or environmental advantages.
- **Green Bonds and Loans:** Funds from these financial instruments are directed towards environmentally friendly projects, such as water conservation initiatives. They facilitate investments in sustainable water management through various market and direct lending platforms.

4. Risk Management for Ag-Financial Institutions:

- **Climate-Informed Credit Risk Assessment:** Adjusting credit models to incorporate future climate scenarios, ensuring that lending portfolios remain resilient.
- **Diversified Investment Portfolios:** Expanding investment across a range of sectors or geographic regions to minimize climate-induced risks.
- **Continuous Capacity Building:** Training staff to understand and act upon the evolving nature of climate risks in the agricultural sector.
- **Scenario Analysis and Stress Testing:** Employing these tools to evaluate the potential impact of varying climate change scenarios on loan portfolios and overall institutional health.

5. Data-Driven Financing and Risk Management:

- **Predictive Analytics:** Utilizes historical data and machine learning to foresee water-related risks, facilitating the adjustment of financial strategies accordingly.
- **Real-Time Monitoring Systems:** Systems that furnish immediate data on variables like rainfall or river levels, enabling more rapid financial and operational responses.

The financial sector has the potential to reshape the industry's entire landscape by allocating financial resources. As the challenges of adaptation intensify in an unpredictable future, financial institutions must lean heavily into current and reliable data and analysis. This ever-shifting agricultural horizon is not just about traditional practices; it is increasingly about utilizing sophisticated financial instruments, enacting proactive risk management, and leveraging real-time data for precision in decision-making.

3.5.3 Norms

Norms refer to the shared expectations or unwritten rules within societies that guide behavior and decision-making. In the context of water and agriculture, these norms influence how individuals, communities, and institutions perceive, value, and interact with water resources and other stakeholders in the ecosystem. By understanding and potentially shifting these norms, we can better address the myriad challenges posed by water scarcity, access, and quality in agriculture.

1. Value-Based Norms:

These norms stem from the inherent values, beliefs, and perceptions that societies or communities hold about water and its role in agriculture and ecosystems.

- **Perception of Water:** Traditionally, water might be seen as an endless resource, especially in regions with abundant rainfall. Shifting this perception to view water as precious and in high demand can lead to more conservative and efficient use. Solution: Public awareness campaigns, educational programs, and community dialogues to shift perceptions.
- **Human Rights to Water:** Recognizing access to clean water as a fundamental human right can prioritize its provision and equitable distribution. Solution: Formulation of laws, regulations, and implementation frameworks that uphold the right to water, ensuring fair access, especially in drought-prone regions.
- **Consumer Choices:** The types of food consumers value and choose to consume have significant implications for water use. For example, meat production is water-intensive. Additionally, reducing food waste can also lead to significant water savings. Solution: Awareness campaigns about water footprints of various food items and promote plant-based diets and initiatives to reduce food wastage.

2. Ownership and Allocation Norms:

These norms deal with who has water rights and how water is distributed.

- **Ownership (State vs. Individual):** This norm dictates whether water sources are seen as public goods managed by the state or private resources owned by individuals/entities. Solution: Water governance frameworks that clearly define ownership rights and responsibilities and ensure sustainable use.
- **Allocation Principles (Seniority vs. Prioritization):** While seniority may give water rights to those who have historically used a water source, prioritization might allocate water based on current needs or societal values. Solution: Adaptive water allocation policies that consider changing climatic conditions and societal needs, ensuring that critical requirements like drinking water and food production are prioritized.

3. Temporal and Change Norms:

These norms pertain to how societies perceive time and change in relation to water and agriculture.

- **Long-Term vs. Short-Term Thinking:** Prioritizing immediate water needs over long-term sustainability can lead to resource depletion. Conversely, long-term planning can ensure water availability for future generations but may limit short-term agricultural activity. Solution: Develop policies that promote water conservation in the short term while investing in sustainable infrastructure for the long term to cater to immediate needs without compromising future supplies.

- **Volatility vs. Systemic Change:** Understanding whether water challenges are due to temporary fluctuations or deep-rooted systemic issues can guide response strategies. Solution: Comprehensive water audits to discern the nature of challenges and crafting responsive strategies, whether they involve building water infrastructure for volatile periods or overhauling agricultural practices for systemic change.
- **Adaptive Continuity:** Recognizing that adaptation is not a one-off event but an ongoing state. Adaptation to water-related challenges requires continuous monitoring, learning, and adaptation to ensure resilience. Solution: Develop dynamic adaptive policies and frameworks that allow for frequent reviews and modifications based on new data or changing conditions.

In addressing water-related challenges within agriculture, it is imperative to understand that norms are not static. They evolve, much like the shared, transient, and variable nature of water itself. We also need to recognize trade-offs, balancing multiple stakeholders and ecological needs. Leveraging insights from behavioral science can be instrumental in designing effective interventions that shift norms, fostering sustainable water use for the generations to come.

4. Playbook for the Future: Findings and Recommendations

4. Playbook for the Future: Findings and Recommendations

So, What Can We Do?

The preceding chapters of this report represent a landscape overview surrounding the Water-Ag Nexus. While understanding the current dynamics is essential, it is equally important to ask, "so what?" As we turn to this final chapter, our focus shifts from laying the groundwork to delving deeper into the implications and prospective pathways stemming from our findings. To provide structure to this exploration, we approach this subject from three distinct angles:

4.1 Breakthrough Opportunities

Identifying where efforts and resources should be directed to drive the most significant impact and foster resilience.

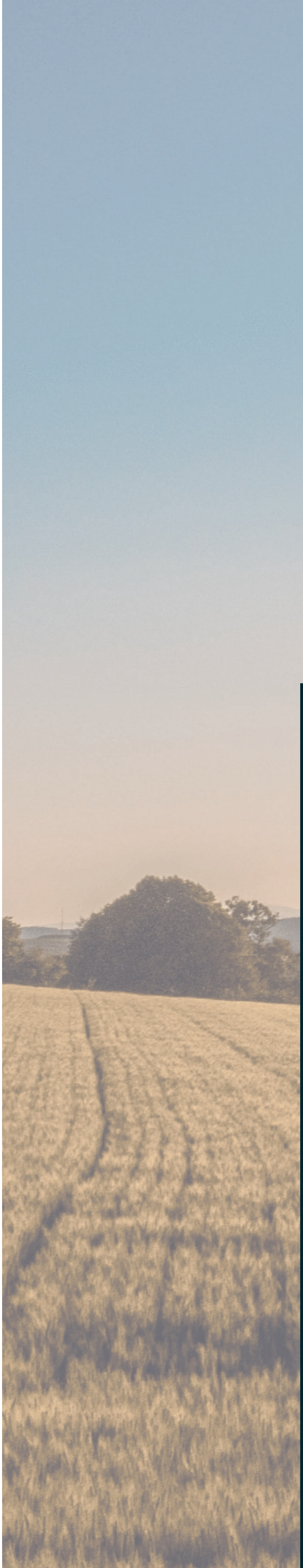
4.2 Range of Future Scenarios

Contemplating the possible futures that await the Water-Ag Nexus. This is not an exercise in precise prediction but rather an invitation to consider a spectrum of potential outcomes, both favorable and challenging.

4.3 Stakeholder Actions

Understanding how different actors, from policymakers to farmers, can make tangible shifts in their practices, collaborations, and perspectives to influence the future positively.

These angles are not about pin-point predictions or guaranteed pathways. They represent our initial forays into stretching the boundaries of what is conceivable, urging readers to join us in broadening the horizon of possibilities for the Water-Ag Nexus.



"There will be billion-dollar opportunities to safeguard trillion-dollar ag industry. Entrepreneurs, policymakers and financial institutions play crucial roles in allocating and reallocating resources to maintain sustainable, resilient value chains."

4.1 Breakthrough Opportunities

The Solution System Framework offers us a bird's-eye view of the Water-Ag Nexus. Then, where should we focus our investments to drive the system-level change? This section highlights our perspectives on each Solution Category. Although these observations are in no way definitive, this section aims to address key themes and questions that lay the foundation for future resilience.

Exhibit 15
Predicted shift in Solution Categories

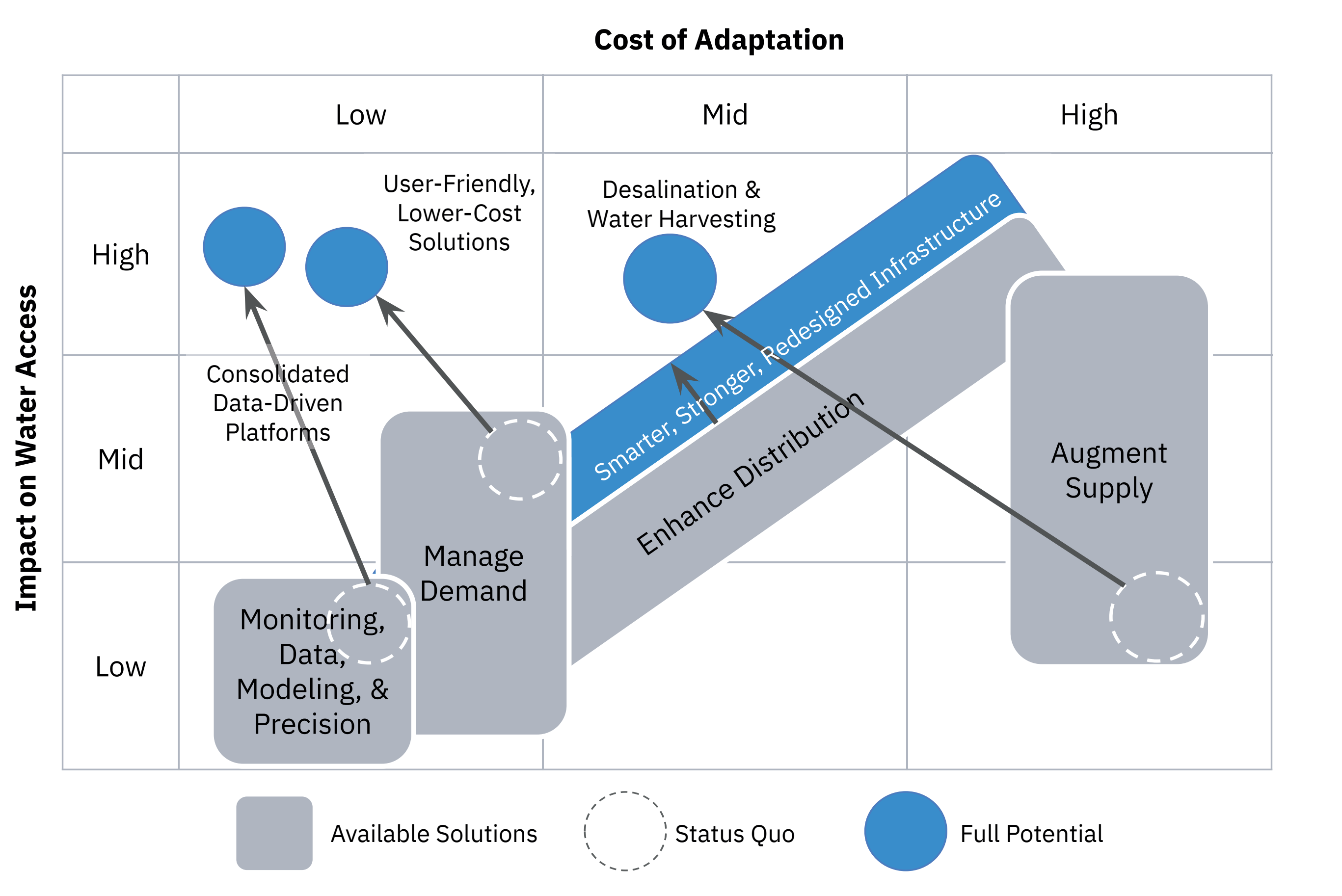
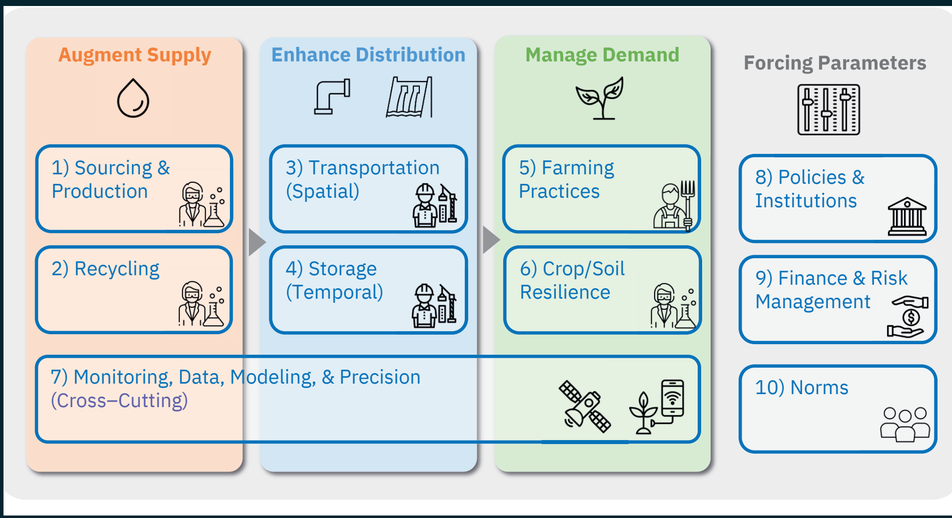


Exhibit 16

Breakthrough Opportunities for each of the "Solution System Framework" categories

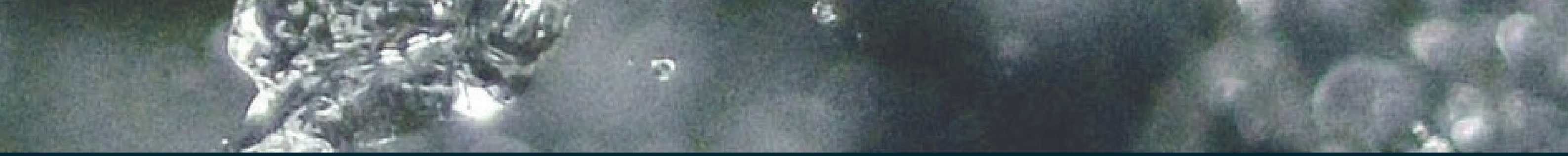


1. Augmenting Supply - Ubiquitous Water Access

Much like the energy and EV sectors that took decades to mainstream, **desalination and water harvesting technologies are the areas to invest in now.** While current technologies are expensive, energy-intensive, **and unsuitable for vast agricultural regions like the US Midwest, Brazil, or Europe, reducing these costs** and expanding their scale can lift water constraints in most regions. This could lead to a paradigm shift, especially as traditional water sources may dry up as a result of climate change.

We sometimes have the illusion that water is ubiquitous. This is simply untrue. The Solution System Framework shows that access to water is only possible through reliable water sourcing and distribution infrastructure. On Earth, only 2.5% of water is freshwater, and only 0.3% of such freshwater is easily accessible through surface water such as lakes, rivers, etc. The vast majority of freshwater is locked in glaciers, groundwater, and snow, requiring engineering to establish a stable water supply. As such, reinforcing access to freshwater will have a catalytic impact.

Given that a number of foundational technologies to "create freshwater" are already developed, scalability becomes the next frontier. In particular, innovations can dramatically improve cost saving and energy efficiency in order to reach a broader agricultural population, especially in rural regions with high water stress. For example, affordable desalination and water harvesting can allow farmers to bypass the need for complex distribution channels and remove the uncertainties around natural water sources. In some countries like Israel, recycling urban greywater for agriculture enhances water efficiency with fewer costs than desalination or water harvesting. Securing new water sources independent from precipitation and natural resources offers the ultimate resilience against climate volatility.



2. Enhancing Distribution - Smarter Software, Stronger Hardware, and Redesigned Infrastructure Systems

Distribution comes with its legacy of traditional infrastructure, which is typically hard to modify. However, with volatile and severe weather events becoming more common, **infrastructure needs to be more resilient in both their hardware and their operational software.** As climate change shifts water supply patterns, such as rains, snows, and storms, some geographies will face the need to redesign their water infrastructure.

The challenges in Enhancing Distribution are multifaceted. On one hand, **we grapple with physical constraints like energy and gravity.** On the other, **there is the intricate dance of building consensus,** which dives deep into governance and ensuring fairness in distribution. Can we reimagine our conventional irrigation infrastructure, much like how renewable energy sources have revolutionized power distribution? Furthermore, is it possible to retrofit existing infrastructure, such as dams, reservoirs, and water channels, to be smart, agile, and precise? Could we construct distributed micro-dams to create buffers, taking in excess water and releasing it when needed? **Key solutions could encompass the integration of advanced technologies in large infrastructure projects and championing more distributed, affordable systems.** The overarching goal is threefold: enhance efficiency, curtail loss, and develop buffers to counter supply-demand imbalances.

3. Managing Demand - Farm-Level Resilience

There are a number of opportunities to improve the water efficiency of agriculture at the farm level. Adaptation can scale up rapidly when solutions, backed by adequate policy and market support, are seen by individual farm asset owners as a cost-effective investment. The key to unlocking these opportunities is changing farmer behavior. Simply put, **we predict that user-friendly, lower-cost solutions will drive rapid adaptation on the ground, especially in emerging markets.**

Farm-level water demand control and resilience enhancements become the most realistic adaptation options as farmers grapple with immediate climate risks today. It is crucial to recognize that while augmenting supply and enhancing distribution are foundational upstream interventions, they also require long-term investments in infrastructure. Direct interventions at the farm level offer immediate relief from climate shocks, even if they do not fully address overarching supply-demand imbalances. The propagation of improved seeds and inputs does not necessitate new infrastructure, can be swiftly adopted, and make farms more resilient to climate anomalies. Smart water management practices, like deficit and drip irrigations, can help conserve water on the farm level. In the long run, however, focusing solely on the demand side without considering supply and distribution limits the sustainability of agricultural operations. **The farm-level interventions should be considered an extended buffer to absorb upstream shocks.**

4. Monitoring, Data, Modeling, & Precision - Platform Consolidation

The agriculture sector is peppered with a range of data, monitoring, and analytics solutions tailored for specific needs. While this might be necessary diversification, it has led to the development of siloed solutions. Much like what we have seen in the B2B SaaS market, **we expect consolidation of software and platforms for data-driven decision-making.**

The Monitoring, Data, Modeling, & Precision infrastructure guides transformation across the water-ag systems. The introduction of software and Internet of Things (IoT) solutions can greatly enhance the efficiency of agricultural operations and water utilization. With volatile weather patterns becoming the new normal, understanding the present and future state of climate and farmland becomes crucial. Among the broad spectrum of remote sensing and precision agriculture, the following sectors can directly help decision-makers across the value chain.

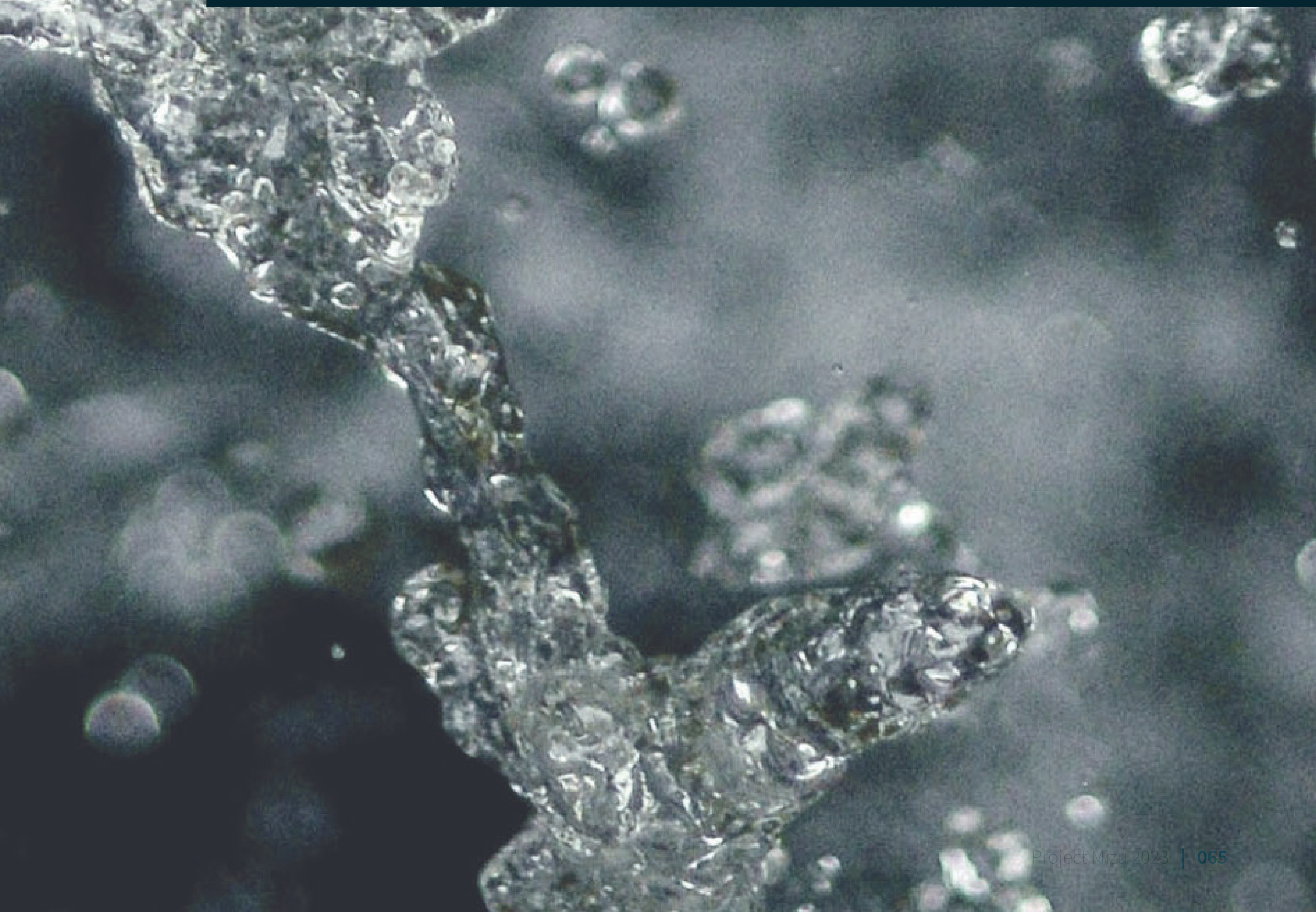
- **Accurate measurement** of water use through remote sensing
- **Risk simulation,** planning, and capital expenditure prioritization
- **Precision in decision-making** at the crop level
- **Farm-level adaptation** and reducing water leakage

5. Forcing Parameters - Allocation, Reallocation, and Governance

Forcing Parameters set the context for entire water-ag system dynamics, thus offering the most powerful interventions. **Investments in R&D and scale-up efforts can increase the odds of successful adaptation.** Just as early IT innovations were funded by governments, public institutions can spur transformation. In addition to directing resources toward more advanced solutions, **entities such as financial institutions and regulators can redirect efforts away from unsustainably managed assets.** Regulators, in particular, will likely step in to balance individual benefits with system-level optimums. For example, while efficient irrigation can increase yields, studies have shown it might lead to more water consumption at the aggregate level. Thus, individual efficiency gains can paradoxically damage overall water sustainability unless they are paired with enforceable water quota systems. The role of overarching governance is crucial when considering these Forcing Parameters.

Where are bottlenecks in the entire system? How can we combine solutions for maximum impact? Forcing Parameters may present answers to these intricate questions. **Forcing Parameters can also dictate the externality pricing around water and agriculture.** Despite the irrefutable value of water, only a limited number of countries charge the "full price" for water. Unlike in the carbon credit market, where intangible negative externalities are quantified and priced on a global scale, water markets remain relatively nascent and limited in geographic scope.

There is a palpable hesitancy to assign a cost to the shared risks of climate change, even when certain groups bear a disproportionate risk. **Policymakers and financial institutions must assess these risks, as they are in roles to allocate and reallocate resources to maintain sustainable, resilient value chains.** Integrating more data into system-level decisions is a practical step. We can also shift public narratives and make sustainable water-ag practices the new norm.



4.2 Future Scenarios

Possible Futures of Water-Ag Adaptation - 4 Archetypes

Conceptualizing various scenarios prompts us to stretch our imagination beyond common trajectories. Given countless intertwined variables shape issues in the Water-Ag Nexus, we must recognize these inherent ambiguities and fight the temptation to seek oversimplified solutions. This section presents 4 distinct future scenarios to shed light on the range of pathways we can take. We have to bear in mind that these scenarios are a starting point, a way to stimulate thought. They are not prescriptive blueprints but rather prompts meant to guide our individual and collective reflection.

We define scenarios based on the concept of "Adaptation." This can be distilled into two primary facets: the advancement of technological innovations and the extent of their adoption worldwide. Just as climate change mitigation requires both investments in novel technologies such as nuclear fusion and scale-up investments in traditional renewable energy sources, there is a clear need to channel resources into pioneering innovations and upscaling existing solutions. Based on the degree of success in 1) fostering innovations and 2) promoting adoption, we define 4 scenarios as illustrated in Exhibit 17.

Exhibit 17
4 archetypes of futures can be imagined from the degree of innovation and adoption

Adaptation = Innovation x Adoption

Degree of Adoption / Degree of Innovation	Low	High
High	Gradual Impoverishment	Technological Utopia
Low	Survival of the Fittest	Global Imbalace

Gradual Impoverishment

Low Innovation - High Adoption

This trajectory mirrors our current path, where most of our effort is about implementing known solutions to broader areas with limited disruptive innovations. In the face of obvious, acute pains, people will invest more resources to apply existing solutions globally. In addition to efforts by food producers, consumers may also need to accept constraints such as a limited variety of food supply options and reduced animal meat consumption to cut down water use. Although these disruptions will hurt people's livelihoods, these pains are not strong enough for nations to invest significant human, technological, and financial resources for innovations, compared to areas such as renewable energy. The situation can slide into dire straits, especially when we approach environmental tipping points, and existing technologies can no longer absorb the intensified climate shocks. In the long run, this scenario is likely to end up with a 'boiling frog' situation, where people are only gradually coming to terms with looming issues.

Technological Utopia

High Innovation - High Adoption

Arguably, this is the best possible scenario, where new technologies become accessible to those who need them. While extreme weather anomalies remain formidable challenges, advanced technologies and reinforced infrastructure would minimize exposures. We should also expect advanced farming techniques, driven by innovations from diverse industrial sectors from robotics to AI, to empower a reduced farming workforce to achieve more.

However, we should remember that the theoretical optimum at the system level may not guarantee inclusiveness for individual actors. For the vast majority of the agricultural value chain to be proofed of water risks within a short period of time, it is likely that some form of drastic, collective action is taken. For example, the world could see an aggregation of farming operations, deployment of a handful of powerful solutions instead of diverse solutions, and simple yet forceful policy on a global scale. The global-scale adaptation implies monocultural and potentially monopolistic evolution of the agriculture industry, which does not harmonize with diversity and inclusion. Governments and large corporations are the likely leads for such a formidable transition.

Survival of the Fittest

Low Innovation - Low Adoption

In this scenario, a myriad of possibilities emerge, though most are bleak. Farmers, especially those with limited resources, find it challenging to sustain their livelihoods due to the lack of support and adaptation strategies. While ample technologies exist to bridge the gap between water demand and supply in agriculture, their mainstream acceptance remains a challenge. The situation could escalate with intensified climate stressors on water and agriculture, causing conflicts among actors instead of collaborations. This stagnation might benefit affluent farmers and wealthier nations, driving up food prices and investments, but small-scale farmers and less resourceful countries would be left behind due to capital constraints. Some nations, especially in the high-latitude regions, benefit from increased agricultural productivity and water access, changing the international power dynamics.

Global Imbalance

High Innovation - Low Adoption

In this scenario, we would witness a disproportionate allocation of cutting-edge technologies and adaptation resources. The gaps in adoption may be a result of capital inequality, or it can be due to some regions' reluctance to change their traditions. The world becomes more nuanced, responding divisively to varying challenges of climate change. Regions near the equator suffer more from severe climate shocks, while high-altitude regions may even benefit from milder weather for agricultural production. Nations with economic stability and technological leadership are likely to consolidate power, leading to heightened global inequalities and unsustainability. The more productive some nations become, the more capacity they can leverage to accelerate adaptation for themselves and the rest of the world as they prefer. The disproportionality is likely to increase over time. The fallout of this scenario includes mass migrations, international disputes, and unstable global governance structures.

Risks and Opportunities:
Are We Ruthlessly Effective or Overly Simplistic?

The 4 scenarios paint a tapestry of risks and opportunities. Technological advancements without widespread adoption might cultivate global instabilities, reminiscent of protectionism around AI and big data in recent years. Conversely, merely following our current trajectory without nurturing innovations will expose us to intensified climate shocks. These uncertainties may undermine the foundation of our agricultural production. Moreover, relying solely on a limited selection of powerful solutions can blindside us to emerging problems and create a less inclusive world. When climate change threatens conventional ways of agriculture, small-scale farmers may be pushed out of the market, leading to monopolies by large-scale asset owners and even governments.

When thinking about the future of water and agriculture, we can envision both very positive and very negative outcomes. These 4 scenarios are not just mental exercises; they shed light on imminent challenges and pathways to progress. While risks are embedded in each narrative—from global power imbalances to ecological vulnerabilities—the horizon also presents unparalleled opportunities to deliver positive outcomes across the Solution System Framework. We are responsible for using technology wisely and spreading adaptation globally. Our success should not be measured simply by whether we accelerate innovations and adoptions. We must evaluate the balance of the speed, scale, and inclusiveness of our adaptation.

Exhibit 18

Varying degrees of losses will occur to different areas in each scenario

Type of Loss	Technological Utopia	Gradual Impoverishment	Global Imbalance	Survival of the Fittest
Economic Losses from Natural Disasters	Lower	Intermediate	Disparity	High
Food Insecurity	Low	Lower	Disparity	High
Damage to Farmer Well-being	Intermediate	Lower	Disparity	Higher
Cost to Apply Technologies	Lower	Low	High	Higher
Public Sector Ineffectiveness	Low	Low	High	Higher
Loss of Biodiversity	High	Higher	Intermediate	Higher
Loss of Water Quality	Lower	Higher	Disparity	High
Data & Monitoring Unavailability	Low	Lower	Intermediate	Higher
Loss in Culture	High	Disparity	Low	Higher
Damage to Global Businesses	Low	Intermediate	Low	Higher

4.3 Stakeholder Actions

At the juncture of a shifting agricultural landscape, understanding the roles of stakeholders, from farmers to policymakers, is essential. Each plays an indispensable role in forging a sustainable future in the ever-complex nexus of water and agriculture.

1. Farmers:

Farmers are the first ones to recognize shifts in water availability due to increasing weather volatility and water constraints. For farmers whose livelihoods are dependent on reliable access to water, high-level policy debates or multi-decade landscape planning may feel less urgent when there are a number of imminent risks to manage on the ground. However, keeping one's "head down" without being aware of the broader context is much riskier, especially when weather patterns and water access will continue to shift over time. With transient climatic conditions, farmers' decades of experience operating on particular farmlands may no longer be solely relied upon in managing farms they have known. It is also crucial to recognize the fact that most vulnerable farmers are the ones most exposed to climate shocks, especially in the global south and other less economically developed regions.

In the face of increasingly volatile weather patterns, farmers can consider multiple steps of adaptation. In the short term, farm-level adaptation measures will help absorb climate shocks by re-optimizing Farming Practices and Crop/Soil Resilience in the Solution System Framework. In the long term, however, farmers need to understand the broader system and prepare for the long-term impact of climate change. Their exposure to water scarcity, unexpected flooding, and extreme volatility will jeopardize the stable water supply by disrupting supply and distribution in the existing infrastructure.

Ultimately, the shifting water dynamics, along with increasing temperatures, are likely to dictate the new crop-region matching on a global scale, leading to a recalibration between agricultural production and geography. For example, the northward shift in global agriculture will enable new geographical regions to produce food and may cover up for the shortfalls in the conventional farming regions. The optimal farming regions of today might not remain so in the next two decades. Just like their ancestors who identified crops suitable for their landscapes, farmers need to reevaluate their crop portfolio, anticipating potential water abundance and shortages unique to each region.

Adaptation is never a one-off update to water and agriculture management. It will be a continued process of measuring, modeling, and testing. Under the shifting climate conditions, **sustainability today does not guarantee sustainability in a decade.**

2. Businesses:

Farmers, investors, and stakeholders are increasingly aware of water and agriculture risks emerging from climate change.

» **Intensifying Pains and Willingness to Pay for Water:** Even though the Water-Ag Nexus has been considered part of the "public" or "impact" sector with little willingness to pay, intensified climate shocks and water challenges can break through the stagnation. Opportunities for disruptions and improvements are prevalent in most categories in the Solution System Framework, especially when farmers, governments, and food supply chain companies recognize the need to climate-proof their value chain.

» **Billion-Dollar Opportunities to Safeguard a Trillion-Dollar Industry:** As the world gravitates towards sustainable water solutions in agriculture, businesses and innovators can take charge and enjoy substantial economic upside for those who successfully fill the gaps in the complex Water-Ag systems. It would not be surprising to see multi-billion-dollar businesses coming out of this space so as to safeguard trillions of dollars of agricultural assets at risk.

» **Identifying Socio-Environmental Tipping Points:** The question is not about "if" there are any tipping points; it is about "when" we will see irreversible shifts in the Water-Ag Nexus and "how" businesses can monetize these shifts with positive adaptation impact. Businesses should carefully anticipate and explore the tipping points in willingness to pay. Just like the recent surge in wildfires has made local residents, investors, corporations, and governments aware of the risks of heat waves within a couple of years, climate change will continue to cause physical, acute, and immediate pains in some regions. These upheavals can suddenly magnify the climate risks in water and agriculture that have historically been marginalized as negative externalities, creating opportunities for startups and private sectors to spearhead the response.

» **Potential Growth and Funding Opportunities:** As we stand on the brink of an unprecedented shift –where climate and water access will redefine agricultural conditions– global supply chains must evolve together. Agriculture, which contributes to 4% of global GDP and up to 25% in some nations, offers substantial economic potential. If private entities, from startups to major corporations, establish innovative business models, they can tap into vast growth and funding opportunities.

» **Rapid Disruption vs. Step-by-Step Risk Taking:** Considering the sector's paramount emphasis on safety and reliability, businesses should prioritize cautious progress over rapid disruption. While businesses possess the potential to rejuvenate stagnant systems, an incremental approach is preferable to radical transitions in cases where risk tolerance remains low and standard safety requirements are onerous.

» **Screening Fake Impact and Fake Markets:** In identifying opportunities, it is also essential to differentiate real impacts from superficial ones and avoid being swayed by the illusion of customer needs and markets. Like other business fields with public benefits, policy objectives do not automatically translate into successful business models. Businesses must confirm the existence of significant risks, urgent user needs, and genuine willingness to pay.

3. Financial Sector:

The financial sector holds considerable stakes in agricultural assets through loans, equity investments, insurances, and crop futures and derivatives, and thus, by extension, is exposed to the risks associated with them. Even though the financial sectors rarely take operational control of farmlands, financiers are in a unique position to promote the long-term sustainability of the agricultural sector through policies, covenants, and investment selection criteria.

While farmers are usually protected from shocks by government subsidies, financial institutions are exposed to the long-term value of their assets under management. Improving landscape governance and managing water footprints can bolster their financial resilience against potential climate upheavals. With increasing regulations and unpredictable climate events, investment trends should shift to reallocate their capital from less sustainable assets to more sustainable ones. In this respect, risk evaluation and impact measurement will be instrumental for financial institutions in steering this transition.

Beyond risk mitigation, financiers are well positioned to gain from emerging opportunities.

» **Informed Risk Return Calculations:** Advanced, long-term modeling of water availability and usage can inform asset pricing and volatility, guiding investment decisions and asset management.

» **Water Risk Products and Swaps:** The increased volatility necessitates the development of robust hedges to safeguard asset owners and investors.

» **Data-Driven Index-Triggered Insurances and Risk Pricing:** Integrating cutting-edge remote sensing and modeling with traditional insurance products enables more accurate pricing, aligning with the evolving market norms, and allowing for adaptive strategies rather than complete market withdrawal.

» **Water Credit Systems and Derivatives:** Similar to carbon credits, water credits can serve as innovative financial instruments, enabling investment in water conservation and management initiatives.

» **Bankable Water Investments:** The potential for direct and indirect investments in water through agricultural avenues is immense, with climate finance playing an important role in shaping the landscape.

» **Impact-Driven Sustainable Finance Products:** Instruments like perpetual bonds and social impact bonds underscore the growing importance of sustainability in financial decision-making.

» **Fiduciary Duty Regarding Water Footprint and Sustainability:** It will be imperative to integrate water footprint considerations and sustainability as part of fiduciary responsibilities.

» **Food-Security-Themed Investments:** These, especially when supported by public financing, can offer substantial returns while addressing critical global challenges.

By embracing these strategies and innovations, the financial sector can safeguard its interests. Furthermore, financiers can also contribute significantly to shaping a sustainable future in the Water-Ag Nexus by balancing profitability with responsibility. The synthesis of prudent financial management with sustainability can set the stage for long-lasting, impactful advancements in the agricultural sector, fostering food security and ecological balance.

4. Policymakers:

Policymakers face a daunting task with limited resources. Just as only a few countries charge the “full costs” of water to their users, there is a common expectation that water should be available, affordable, and high-quality, which imposes conflicting demands on policymakers who govern water. On one hand, policymakers need to deliver safe, high-quality water with little margin of error. On the other hand, they often do not have the capacity to invest in new solutions because the revenues generated from water are barely enough to run their day-to-day operations. Even if governments bear the authority to determine optimal systems and embark on adaptation measures, they are also pressured by the stakeholders to maintain the status quo and avoid risk taking. **Because water is so fundamental to our livelihoods, governments can be trapped among conflicting stakeholder interests.**

However, **this stagnation is likely to change when climate change increases the pressures for stakeholders** to adopt new solutions and governance regimes through weather volatilities, water shortage, and flooding. In these situations, policymakers will have opportunities to take steps toward sustainable water and agriculture governance from system-level planning to pricing regimes. Although effective policy interventions rely heavily on the local contexts, examples of key interventions include:

» **Monitoring, Measurement and Publication:** Understanding water usage will offer the starting point for multi-stakeholder discussions by removing information asymmetries across actors.

» **Building System-Level Optimization Strategies:** Given the multi-stakeholder nature of water governance, policymakers are in the position to oversee the entire system and map out the optimized resource allocations and regulation frameworks. Policymakers can also set investment priorities to reinforce the most vulnerable parts of the system.

» **Pricing Externalities:** Pricing externalities around water through permit systems, water markets, and fines can visualize the hidden costs of water and impact stakeholder behaviors.

» **Balancing Short-Term Response and Long-Term Resilience:** With greater risks of extreme weather events, policymakers need to balance responses between focusing on short-term climate shocks and long-term resilience.

» **Facilitating Stakeholder Dialogues:** Water is a scarce shared resource. As such, water allocation and planning can be the most challenging tasks for policymakers. By aligning interests and enforcing the collective optimum, policymakers can deliver system-level sustainability.

5. Researchers:

Research provides the crucial tools to bridge disparities. Theoretical research, with its pioneering technologies, amplifies the efficiency of each Solution Category, while applied research facilitates the incorporation of efficacious solutions into mainstream practices. Beyond generating advanced studies, research institutions play a pivotal educational role, exemplified by agricultural university extensions in the US, contributing to the practical and theoretical understanding of water and agriculture management.

Beyond the conventional realms of water and agriculture, an array of research domains, including the social sciences, humanities, business, law, and engineering, enrich the contextual landscape of this nexus. Water, being integral to a plethora of societal activities, and engineering, serving as the foundational backbone for on-the-ground implementations, converge to form a multifaceted approach to addressing challenges within this nexus. Within engineering, diverse specializations like water engineering, civil engineering, and hydrological modeling converge to optimize solutions in this space.

Mathematical optimization and modeling are indispensable for designing resilient infrastructure and operational strategies, contributing to the holistic understanding of water management. The societal implications of water decisions necessitate a broad consideration involving policy, business, economics, and the humanities. This comprehensive approach ensures that decisions made within the Water-Ag Nexus are not only technologically sound but also socially equitable and economically viable. Balancing technical advancements with societal needs provides a harmonious path forward in addressing the multifaceted challenges within the water-agriculture interface.

At the same time, **as specialization deepens, there is a risk that research becomes too isolated,** making it challenging for other stakeholders to implement. For society to adopt the latest research outcomes on the ground, it is crucial to keep research transparent, open, and widely accessible to other stakeholders. As much as researchers spearhead the pioneering work in developing solutions, they can also benefit from having interdisciplinary leaders who can seamlessly connect research and practical application. **Ultimately, the impact of research depends largely on our ability to foster interdisciplinary collaborations.**

6. Consumers:

Besides farmers, who are direct users of agricultural water, **consumers are indirect beneficiaries of agricultural water through the food they eat.** While this report delves into the technical solutions in water and agriculture, it is crucial to acknowledge the profound influence of consumer behaviors. Our consumption patterns leave an indelible watermark on the system. Just as trends like organic farming and food waste reduction have been consumer-driven, our awareness of the water footprint in what we consume can be a game changer. We cannot underestimate the potency of consumer-driven change, even though these are often perceived as less technical or “innovative.” Consumer awareness and behavior change remain a compelling force in steering the course toward sustainability.

4.4 Further Research Opportunities

This report has mapped the Water-Ag Nexus and provided a taxonomy of solutions with the aim of creating a common language. At the same time, we recognize the need for further research, such as quantitative data and qualitative assessments for individual solutions. The costs and benefits of the solutions we have presented are likely to vary by regional, socioeconomic, and environmental contexts. Without such nuances, we cannot offer quantified metrics for direct comparison or specific recommendations for prioritization. Further research could (1) identify contextual factors, (2) establish predictive models that estimate the costs and benefits of each solution, (3) conduct pilot studies to validate these predictions, and (4) create tools that provide decision-makers with quantified projections based on their specific needs and circumstances.

Water is a shared resource. There is often no clear owner for the issues in the Water-Ag Nexus.

This absence of distinct ownership in water issues results in a plethora of isolated solutions.

”

4.5 Call for Action

Forget Ideology
Let’s Deal with the New Reality

It’s not about believing in climate change—it’s about confronting and responding to the tangible, unexpected events affecting stable agricultural production.

We are now taking steady steps to mitigate climate change on a global scale. The flip side of this progress in mitigation is that we are considerably lagging in addressing the anticipated repercussions of climate change. With recent weather pattern changes and volatilities, **we cannot accept the illusion that either mitigation or adaptation alone will suffice.** Both are crucial, especially in the water-agriculture domain.

Adaptation is not about debating what or who caused climate change—it is about responding to the tangible events affecting stable agricultural production and food supply. Losing access to the right volume of water in the right place at the right time is a symbolic example of severe consequences of climate shocks. A unified focus on “survival” aligns everyone’s interests, offering a shared goal to bridge the gaps at the practical level, not at the ideological level. Actions to achieve water and agriculture sustainability may vary for each country, depending on their economic and legal frameworks, but a collaborative, interdisciplinary approach is universally essential. Our report aims to ignite conversations across various stakeholders about future possibilities and challenges.

Stakeholders need to make forward-looking adjustments in order to respond to the shifting reality. This transition is a complex and dynamic journey, requiring system-thinking tools to extend our imagination beyond our individual expertise. Deciphering interdependencies between social, environmental, and engineering factors in the Water-Ag Nexus requires a diverse range of expertise, from hydrology and WASH (Water, Sanitation, and Hygiene), to biology, law, policy, and business. Water systems affect a diverse range of stakeholders, from local communities to policymakers and interest groups, making it intricate. Experts working in silos are not adequately equipped to handle the interlinked challenges within water and agriculture. **Given water is a shared resource, there is no clear owner for the issues in the Water-Ag Nexus.**

This absence of distinct ownership in water issues results in a plethora of isolated solutions attempting to solve these multifaceted issues. While every individual problem might have a specialized, technical resolution—whether it is in engineering, biology, policy, or finance—such isolated solutions can adversely impact broader water management. Solutions need to be interdisciplinary and integrated with the broader system to make a meaningful impact. **This report concentrates on contextualizing innovations and interventions within the broader water-agriculture systems.**

Every actor in the water-ag sector has the potential to lead transformational efforts.

Entrepreneurs are pivotal in introducing transformative technological, social, and business innovations. Similar to their role in various industries, they have the ability to disrupt system stagnation with bold, innovative ideas in technology, society, and business. Moreover, intrapreneurs can transform traditional sectors from inside, such as public infrastructure managers and farm operators, with the latest innovations. By leveraging their front-line perspective of the challenges, intrapreneurs can act as catalysts for widespread transformation.

Policymakers, investors, and citizens also hold responsibilities as stewards of these systems, with the potential to implement new water governance regimes to hasten change. They have the capacity to support and endorse risk taking and devise innovative governance structures to accelerate change and elevate successful new ideas. For farmers and consumers, behavioral change is inevitable. They are the primary ones to experience the shifts due to the increase in unusual and disruptive events impacting stable agricultural production and food supply chain management. Their concerns and willingness to adapt can become the driving force behind a global shift towards sustainable water-ag systems.

In the face of accelerating climate change, water scarcity is no longer a looming challenge; it is our present-day reality. As the global population grows, the urgency to address water shortages and sustainably to meet our agricultural needs is more pressing than ever. **While the intrinsic conservatism of the water and agriculture sectors is understandable, given the monumental stakes, the urgency of our times demands transformative actions.** It is not just about avoiding mistakes but proactively forging solutions to meet the demands of nearly 10 billion people by mid-century. This journey necessitates a collective commitment to innovation, dialogue, and meaningful action. Our framework, taxonomy, and analytical tools are not just a contribution; they are a clarion call. It is our hope that they catalyze the informed, nuanced, and bold conversations we need today for a sustainable tomorrow.

Project Mizu

4.6 Project Mizu Playbook

3 Trends in Water-Agriculture Adaptation Soluitons

Trend #1

Fix-all technologies (e.g., vertical farming, desalination) can reduce stress for high-value crops in confined geographies, but none are sufficiently scalable to cover major cereal crop production regions. They are not ready to protect our food security.

Trend #2

Lower-tech measures preventing leaks, preserving water, and recharging groundwater can be the most powerful interventions. Policy changes and water pricing can incentivize “low-hanging fruits” transition.

Trend #3

Climate change increases volatility in water supply, increasing the need to create and retrofit water storage and transport infrastructure systems. Risk simulations provide invaluable guidelines to identify vulnerabilities.

3 Steps to Climate-Proof Agriculture

Scaling innovations and updating infrastructure will take years, and that is why we should start now. In parallel, accelerate “low-hanging fruit” adaptations to mitigate the shocks.

Step 1: Accelerate farm-level adaptation to absorb the imminent water stress.

Develop → Deploy

Step 2: Update infrastructure to the new weather patterns and water availability.

Step 3: Scale up innovative technologies to remove water constraints from agriculture.

Be Aware;

Scarcity vs. Diversity: Even in the best-case scenario where innovations are rapidly deployed, solutions are likely to be standardized and, therefore, monocultural. There is an inherent tradeoff between scalability and diversity.

Maladaptation Trap: Blind use of textbook solutions such as irrigation can backfire, incentivizing farmers to increase yields by withdrawing more water. Micro-level adaptation without safeguard structures may lead to system-level maladaptation.

Cost of Energy and Security: We can mainstream more technologies quickly when energy becomes cheaper and water stress intensifies. Water-Ag will be central to national security.

Adaptation Startups: Adaptation startups should align their team capacity, immediate market needs, and long-term impact. Missing one of the three will make them technically infeasible, commercially unsustainable, or zero impact.

Price of Water: Water footprint is the “next carbon credit,” where the market will price and trade risks and impact. People will soon realize “food trade” is a form of “water trade.” The belief that “water is free” is an illusion.

5. Team and Acknowledgements

5.1 Project Mizu

An Interdisciplinary Team for Interdisciplinary Problems

32

professionals

We are Project Mizu, a collaborative effort of 32 pro bono researchers committed to climate adaptation in the water-agriculture nexus. Our diverse team, including consultants, medical doctors, and WASH experts, echoes the interdisciplinary nature of the challenges we tackle.

With over 15 weeks of intense meetings and 5 months of research, we bring together unique insights from various industries to develop a holistic view of these issues. Our research within this report embodies our dedication to fostering sustainable and resilient water and agricultural systems amidst a changing climate.

7
Members with Water Experience

10
Members with Agriculture Experience

14
Members with Climate Experience

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Members from **8** Financial Institutions

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This report encapsulates the collective insights and dedicated research of the Project Mizu team members. Each member has worked independently from their professional or personal affiliations. Findings and perspectives shared in this report do not in any way reflect the viewpoints or official policy of their respective professional affiliations or any other organizations they are associated with. Various measures have been taken to ensure the accuracy and reliability of the information provided, however, the authors assume no responsibility for any errors or omissions, or for the results obtained from the use of this information. This report is intended for informational and analytical purposes.

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