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WATER STORIES

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Technology/MIT's efforts towards a water-secure future

Water Security for All

Water and sanitation infrastructure built in the twentieth century, which has significantly reduced mortality, is one of the greatest engineering achievements of the time. Today, even greater innovation is needed to guarantee access to clean water for current and future populations

JOHN H. LIENHARD V

He is the Abdul Latif Jameel Professor of Water and Mechanical Engineering at MIT. During three decades on the MIT faculty, Lienhard's research and educational efforts have focused on heat and fluid flow, water purification and desalination, and thermodynamics.

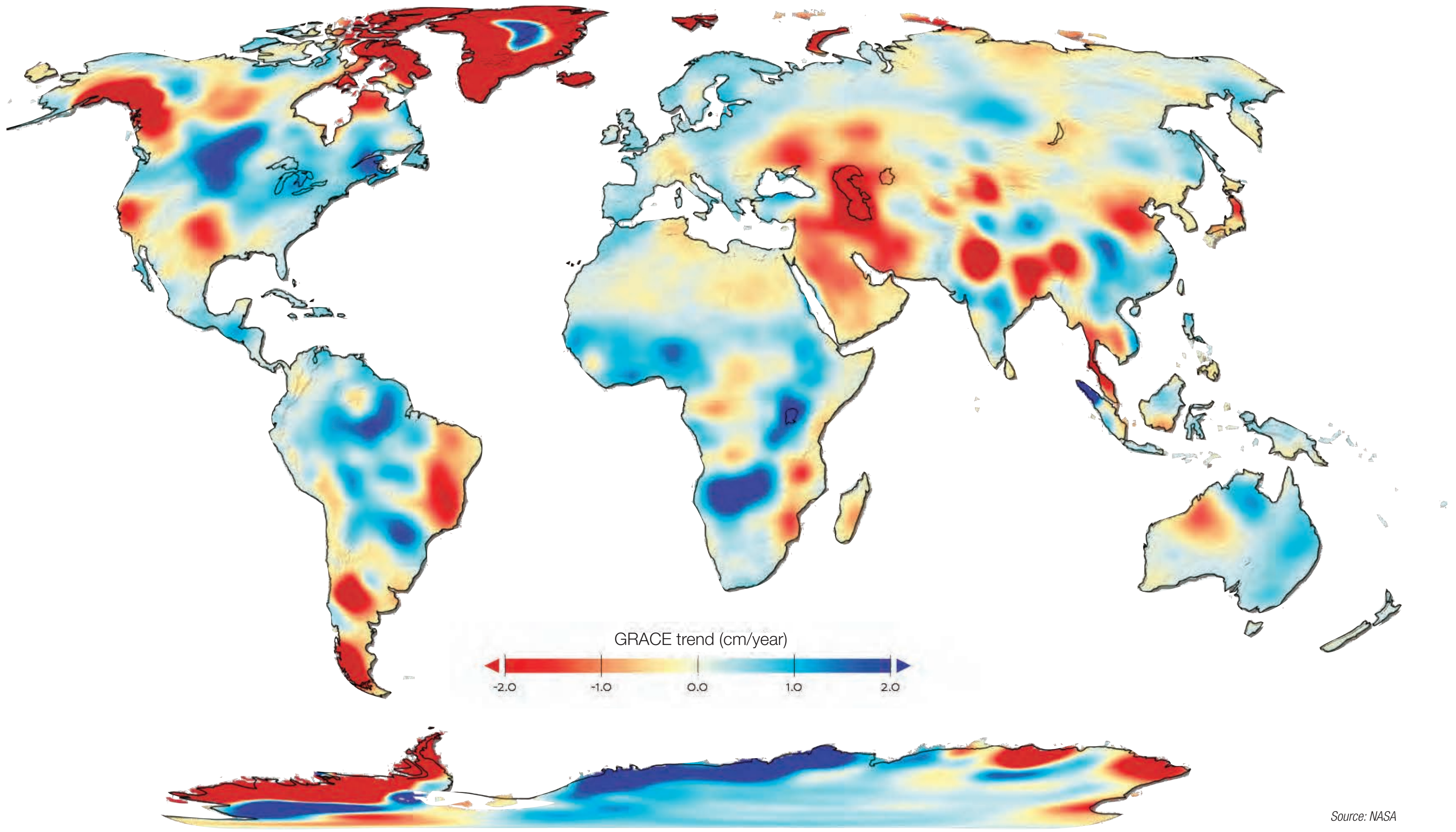
In 1943, the psychologist Abraham Maslow proposed a universal hierarchy of human needs. He framed this need as a pyramid comprised of five horizontal layers. The layers range upward, from safety, through love and belonging, then to esteem, finally to self-actualization at the top. But at the very base of his pyramid, serving as its foundation, Maslow placed our physiological needs, including air, water and food. Without that foundation, higher levels of human achievement are impossible.

Humans have created many technologies to support these basic needs. Examples range from millennia-old water jugs, wells and aqueducts to the industrial water treatment and desalination facilities that now feed municipalities across the globe. Indeed, the water and sanitation infrastructure built in the 20th century—which greatly decreased mortality and raised our quality of life—is one of the greatest engineering achievements of the era.

Today, we need even greater technical innovation to ensure that current and future populations have reliable access to clean water. Our rapidly expanding cities demand more fresh water than local watersheds can provide. Our industries and dwellings still release wastes into our rivers and streams. The intensifying climate crisis is altering historical precipitation patterns worldwide, straining the existing infrastructure, food production and ecosystems upon which we depend. Arid regions are particularly stressed, although water scarcity is now a global phenomenon.

At the Massachusetts Institute of Technology, where I am based, researchers from diverse fields are driving toward solutions. They are creating new technologies, better poli- →

A rendering of a recreational space that also serves as a stormwater-filtering wetland for the city of Los Angeles, California by a multi-disciplinary MIT research team from the Department of Civil and Environmental Engineering as well as the Department of Architecture. This team developed a design framework for modular and scalable urban wetlands that can be adapted to a variety of urban settings for more efficient stormwater treatment while providing ecosystem services and recreational spaces.



Source: NASA

Based on satellite data collected over a period of 14 years by a NASA Earth observation mission called Gravity Recovery and Climate Experiment (GRACE), the map shows how the availability of fresh water in the world is changing. High latitude regions, tropical areas and low latitudes are becoming more humid, while at the same time middle latitudes (the arid and semi-arid belt in the middle) are becoming drier.

cies and novel business models, many specific to a local cultural context. MIT's Abdul Latif Jameel Water and Food Systems Lab (J-WAFS) is fueling much of that work through seed grants, commercialization support, and industrial partnerships. In this article, I highlight a few of these efforts to ensure a water-secure future for everyone.

Water for agriculture

Agriculture uses much more water than cities and towns—roughly seven to eight times more. This high demand, coupled with poor stewardship of dwindling resources and the consequences of climate change, makes our food systems vulnerable.

For example, agricultural irrigation most often uses surface water. In areas such as Southern Australia, however, long-term drought and wildfires have shrunk surface water supplies and lowered water quality. Farmers there have experienced a 300 percent increase in water costs, cutting sharply into profit margins. Irrigation has also overdrawn groundwater resources. In parts of India and in the irrigated High Plains of the U.S., over-pumping and excessive use of pesticides and fertilizers have led to sinking water tables and drinking water contamination. In Egypt, a rising population strains the Nile River—the agricultural lifeline of the country—and the Grand Ethiopian Renaissance Dam, a hydropower project, threatens to reduce Nile water flow while it fills. Managing supplies like these more effectively is essential to long-term food and water security.

Low cost and water-efficient irrigation technology can protect farmers of all incomes across the globe. At MIT, professor Amos Winter in mechanical engineering is developing low-pressure, solar-powered drip-irrigation systems that can reduce a farm's water consumption by as much as 60 percent. His work is aimed at farmers in India and other developing parts of the world where irrigation may rely on inefficient diesel pumps or traditional flood irrigation.

What about food crops that are better adapted to climate stress? Advanced biological science enables faster and more effective crop breeding than is possible by the traditional, slow path of hybridization. MIT's David Des Marais, a professor of civil and environmental engineering, and Caroline Uhler, a professor of computer science, are working on a J-WAFS-backed project to find the genetic foundations of plant tolerance to the stresses of heat and drought. With machine learning, they aim to find the gene networks that impart drought resistance to certain grasses similar to wheat and rice. Their research will guide accelerated hybridization of food crops, through precise gene editing. These new strains should produce more grain from less water and ensure that crops survive our increasingly variable climate.

Apart from supply-side solutions, better demand management is essential. For example, one-third of the grain grown in the world simply feeds livestock. And some foods, particularly beef, require much more water to produce. For those who are not vegetarians, even a small movement toward a more plant-based diet can help reduce burden on water and on agricultural lands.

Water for people

What of the 10 percent of fresh water used across the globe for drinking, washing, and domestic purposes? Water for human consumption and household use faces an array of challenges: the vast trend of urbanization, rising population and evolving standards of living. Urban areas usually draw their water from a surrounding watershed—rivers or lakes and the lands that feed them. But other resources must be tapped when populations exceed what can reliably be drawn nearby.

Desalination

Over the last half-century, desalination plants have had a growing role in offsetting fresh water scarcity. Yet, this technology has ancient origins. In antiquity, seawater was directly boiled, and the steam was condensed to make fresh water. That vaporization consumed a great deal of fuel. Today's most efficient desalination plants don't use heating at all. Instead, they pressurize seawater behind thin polymer membranes. The pressure drives fresh water through the membranes, in a process called reverse osmosis (RO).

Through technology improvement, desalination's energy use has fallen dramatically. But this kind of improvement has limits. Desalination can never be "zero energy" because water must be pumped and pretreated and because thermodynamics sets a minimum energy to separate water from salt water. Even so, cost and carbon footprint continue dropping as processes improve. Most importantly, RO plants are electrically powered and fit easily into a low-carbon electrical grid (perhaps based on solar or wind power, as noted in a 2016 J-WAFS study). Planners throughout the Middle East are looking to large-scale, renewably-powered RO as the primary choice for many new desalination plants.

A community-scale example is Brazil's Água Doce program, launched in 2004. This government effort promotes sustainable use of brackish groundwater in rural communities. Água Doce has deployed more than 600 small desalination plants across semi-arid eastern Brazil. Today, hundreds of thousands of people receive potable water through the program. The program's goals include community empowerment, environmental sustainability and building technical capacity. Likewise, MIT research has created several small-scale solar-driven desalination technologies. Those systems use not only RO, but also electrodialysis and high-performance solar stills.

Purification and sensing

Clean water supplies depend on effective water purification and wastewater treatment. Constant vigilance is required. For example, aging infrastructure or changing envi-

J-WAFS-funded research under the direction of T. Alan Hatton, Ralph Landau Professor of Chemical Engineering at MIT, has resulted in the development of a new method for removing even extremely low levels of unwanted compounds from water. The new method relies on an electrochemical process that can selectively remove organic contaminants such as pesticides, chemical waste products, and pharmaceuticals.

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ronmental conditions can contaminate drinking water with heavy metals. In response, researchers are focusing on new technologies to remove lead, arsenic, uranium and other elements from water. At MIT, Tim Swager, a professor of chemistry, is designing polymers that can selectively remove mercury and lead ions from water. Julia Ortony, a professor of materials science and engineering, has made self-assembling nanoribbons that capture arsenic. And Zachary Smith, a professor of chemical engineering, is applying metal-organic frameworks to selectively remove boron, an essential micronutrient for both plants and animals which becomes toxic at high concentrations.

Industrial micropollutants are also a target of novel technologies. These harmful chemicals often have low concentrations. Conventional water treatments don't remove them. Alan Hatton, a professor of chemical engineering at MIT, has created chemically tunable electrodes that capture specific organic pollutants. Professor Patrick Doyle, also in chemical engineering, is developing a special hydrogel for water treatment. This gel can be "tuned" to selectively absorb organic contaminants from industrial and agricultural wastewater.

Low income areas that lack reliable water infrastructure need affordable, open-sourced technologies to test and clean water. Susan Murcott, an environmental engineer at MIT, has devoted her career to accessible technologies for water, sanitation and health in developing countries. Most recently, she has created a low-cost, portable test kit for *E. coli* in drinking water. She has deployed these kits in Nepal by working with J-WAFS, the MIT-Nepal Initiative, led by history professor Jeffrey Ravel, and the Nepalese NGO Environment and Public Health Organization (ENPHO). This new kit is poised to reach millions of Nepalese citizens who are otherwise threatened by waterborne disease.

MIT researchers in mechanical engineering and MIT D-Lab (an MIT center that approaches international development with a design mindset) have worked in both rural northern India and in Delhi's slums to develop an affordable water filtration system. Their technology exploits the natural filtration capabilities of xylem tissue from coniferous trees. The research team formed these technologies into culturally adapted products by working closely with on-the-ground partners. And they have released the design as an open-source technology. The result? Small entrepreneurs in India will soon commercialize the xylem-filtration devices, manufacturing them locally and selling them in their communities.


Women from a mountainous village in the Bageshwar district of Uttarakhand, India, participate in a design workshop facilitated by J-WAFS-funded researchers from MIT D-Lab and the MIT Department of Mechanical Engineering in order to develop prototypes for a wood xylem-based household water filter. The workshop was conducted to uncover the needs and design preferences of potential users for the household water filters the team is developing.

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Water management

Ensuring greater resilience for our water systems will require comprehensive water management. At the urban scale, one key aim is to improve stormwater management. Ground water should be replenished, and run-off of pollutants into surrounding ecosystems should be prevented. In 2017, a team of MIT civil engineers and landscape architects released design frameworks for urban stormwater wetlands that achieve these goals. Their designs provide natural water treatment, flood protection, water storage, wildlife habitat, and attractive urban parklands. Reducing waste in our existing water systems is also essential. Water efficiency standards, such as for low-flow toilets and showerheads, have resulted in enormous water savings where they have been adopted. In arid climates, grass lawns are being replaced by xeriscapes to eliminate landscape irrigation. Effective detection and control of leaks in urban water pipes cuts waste: in many parts of the world, water leakage from buried pipes amounts to 20 to 50 percent of the initial supply! One MIT startup, WatchTower Robotics, deploys floating robots to inspect water pipes from the inside. Technologies like this can detect leaks that may otherwise be very difficult to locate and can identify problems with pipes before they are catastrophic. An estimated 240,000 water main breaks per year in the U.S. alone waste over seven trillion liters of treated drinking water. Preventive maintenance can save water, energy and money. Conserving water also means achieving greater circularity in our consumption through wastewater reuse. In California, the Orange County Water District's groundwater replenishment system reclaims wastewater that would previously have been discharged into the Pacific Ocean. The wastewater is treated by microfiltration, RO, ultraviolet light and hydrogen peroxide, making water clean enough to meet state and federal drinking water standards. The clean water is pumped into injection wells and recharge basins. These replenish the deep aquifers of north and central Orange County's groundwater basin, from which potable supply is drawn. Likewise, Singapore's National Water Agency, PUB, has been extremely effective in rallying public support for water reuse. Used water is treated to a potable standard and branded NEWater. Five NEWater recycling plants supply 40 percent of Singapore's current water need. PUB expects to increase NEWater capacity to meet up to 55 percent of water demand by 2060.

Outlook

Assuring safe, sufficient and sustainable water for everyone is among the 21st Century's most urgent challenges. Water supply is a daily hardship for billions of people already. Climate change and population growth are expanding water scarcity and water-driven conflict. We need to bring our best efforts, not only in engineering and technology, but also in integrated water management and collaboration across disciplines, institutions, states, and nations. Working together, we can secure the future of our communities and farms and the prosperity of our economies for decades to come.