n 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 policies, and 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.

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Water Security for All

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

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.

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are becoming drier. and semi-arid belt in the middle) time middle latitudes (the arid and low latitudes are becoming latitude regions, tropical areas in the world is changing. High availability of fresh water (GRACE), the map shows how and Climate Experiment mission called Gravity Recovery over a period of 14 years the Grand Ethiopian Renaissance High Plains of the U.S., over-pump- strains the Nile River—the agricul- bles and drinking water contamina- fiers have shrunk surface water supplies and lowered water quality.  Farmers have experienced a 100 percent increase in water costs, coming sharply into profit margins. Irrigation has also drained nearby. Over the last half-century, desalina- tions exceed what can reliably be draw their water from a surrounding watershed—rivers or lakes and the lands that feed them. But other re- sources must be tapped when popula- tions 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 operation 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 process drives fresh water through the membranes, in a process called reverse os- mosis (RO). Through technology improvement, desalination’s energy use has fallen dramatically. But this kind of im- provement has limits. Desalination can never be “zero energy” because water must be pumped and pressur- ized and because thermodynamics sets a minimum energy to separate water from salt water. Even so, cost and car- bon footprint continue dropping as processes improve. Most important ly, RO plants are electrically powered and fit easily into a low-carbon elec- trical grid (perhaps based on solar or wind power, as noted in a 2016 J- WAFS study). Plans throughout the Middle East are looking to large- scale, seawater-powered RO as the primary choice for many new desalina- tion plants. A community-scale example is Brazil’s Agua Doce program, launched in 2004. This government-effort pro- motes the installation of small freshwater desalination plants in rural communities. Agua Doce has deployed more than 600 small desalination plants across semi-arid and eastern Brazil. Today, hun- dreds of thousands of people receive potable water through the program. The program’s goals include com- munity empowerment, environmen- tal sustainability and building tech- nical capacity. Likewise, MIT re- search has created several small-scale solar-driven desalination technologies. These systems use not only RO, but also electrodialysis and high-perfor- mance solar stills. Purification and sensing Clean water supplies depend on ef- fective water purification and wastewater treatment. Constant vig- ilance is required. For example, ag- ing infrastructure or changing envi- ronment
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.

Environmental 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 Oort, a professor of materials science and engineering, has made self-assembling nanoparticles that capture arsenic. And Zachary Smith, a professor of chemical engineering, is applying metal-organic frameworks to selectively remove mercury, 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 concentration. 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 often have untested open-sourced technologies to test and clean water. Susan Munkittrick, 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 with local partners in India and in Dalhousie’s aims to develop an affordable water treatment system. Their technology exploits the natural filtration capabilities of xylem tissue from coniferous trees. The team is transforming these technologies into culturally adapted products by working closely with urban-ground partners. And they have released the design as an open-source technology. Hopefully, entrepreneurs in India will soon commercialize the xylem-filtration devices, manufacturing them locally and selling them in their communities.

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 design provides natural water management, flood protection, water storage, wildlife habitat, and attractive urban landscapes. 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 pipe networks, 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. Recovering 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 membrane filtration, 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 15 percent of water demand by 2060.

Outlook

Aiming 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 firms and the prosperity of our economies for decades to come.