REPORT TO THE PRESIDENT

Science and Technology to Ensure the Safety of the Nation's Drinking Water

Executive Office of the President

President's Council of Advisors on Science and Technology

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Professor, Environmental Science and Engineering
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Harvard University

Staff

Ashley Predith
Executive Director

Jennifer L. Michael
Program Support Specialist

Diana E. Pankevich
Science Policy Consultant

PCAST Science and Technology to Ensure the Safety of the Nation's Drinking Water - Working Group

Working Group members participated in the preparation of an initial draft of this report. Those working group members who are not PCAST members are not responsible for, nor necessarily endorse, the final version of this report as modified and approved by PCAST.

Working Group Co-Chairs

Rosina Bierbaum
Professor, School of Natural Resources and Environment, University of Michigan
Roy F. Westin Chair in Natural Economics, School of Public Policy, University of Maryland

Christine Cassel
Planning Dean
Kaiser Permanente School of Medicine

Working Group

Matthew Davis
Division Head, Academic General Pediatrics and Primary Care
Director, Smith Child Heath Research Program
Ann & Robert H. Lurie Children's Hospital of Chicago
Northwestern University Feinberg School of Medicine

John P. Holdren*
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

Ed Penhoet*
Director
Alta Partners
Professor Emeritus, Biochemistry and Public Health
University of California, Berkeley

Bob Perciasepe
President
Center for Climate and Energy Solutions

Joan Rose
Laboratory Director/Principal Investigator
Homer Nowlin Chair in Water Research
Department of Fisheries and Wildlife
Michigan State University

Maxine Savitz*
Honeywell (ret.)

Orren Schneider
Manager, Water Technology
American Water

Daniel Schrag*
Sturgis Hooper Professor of Geology
Professor, Environmental Science and Engineering
Director, Harvard University Center for Environment
Harvard University

Chad Seidel
DeRISK Center Technology Director
University of Colorado Boulder

Nancy Sutley
Chief Sustainability and Economic Development Officer
Los Angeles Department of Water and Power

Paul Westerhoff
Professor & Senior Advisor on Science and Engineering to the ASU Vice Provost
Arizona State University

Staff

Diana E. Pankevich
Science Policy Consultant

Bruce Rodan
Assistant Director
Environmental Health
Office of Science and Technology Policy

Ashley Predith
Executive Director

* denotes PCAST member

Executive Summary

Americans have come to expect access to safe and affordable drinking water as a fundamental right and integral part of sustaining public health. And, indeed, public drinking-water systems in the United States provide safe, high-quality drinking water most of the time in most places. But public confidence regarding the quality of their drinking water has been shaken lately by a series of high-visibility crises that have resulted in temporary drinking-water-system closures and do-not-use advisories. These high-profile crises highlight the long-term, national challenges to maintaining high-quality drinking water, resulting particularly from continuing and legacy pollution of source waters and an aging infrastructure that is in need of significant repair and modernization.

As part of the Administration's response to concerns about the safety of the Nation's drinking water, underscored by the revelations about lead in tap water in Flint, Michigan, President Obama asked his President's Council of Advisors on Science and Technology (PCAST), in March 2016, how science and technology (S&T) could more effectively be brought to bear on the challenge of ensuring the safety of the Nation's drinking water. PCAST was not asked to address non-S&T dimensions of the provision of safe drinking water, such as Federal-State-local responsibilities and interactions, management issues (unless directly related to advancing S&T opportunities), and financing of drinking-water infrastructure, nor was it asked to address safety of bottled water.

Following preliminary exploration of the S&T issues around safe drinking water, PCAST organized a day-long national workshop of drinking-water experts from Federal agencies, public water systems, academia, the medical community, and civil society to help shape the inquiry. A working group reflecting that diversity of expertise was then constituted—comprising six members of PCAST and seven of the outside experts who participated in the workshop—to conduct the study. The findings and recommendations reported here have been reviewed and approved by the full PCAST and are the responsibility of PCAST alone.

In the remainder of this Executive Summary, we provide a brief overview of characteristics of the national drinking-water system and the challenges it presents, turning finally to a set of key findings and recommendations that follow from them.

The Nation's Drinking-Water System

The drinking water consumed by Americans comes from a variety of sources, mainly surface water and groundwater, of varying degrees of initial purity, and it is delivered by means ranging from direct withdrawal from individual private wells to long-distance transport from distant reservoirs, followed by various forms of filtering and disinfection in treatment plants and distribution through networks of underground piping to reach individual residential, commercial, and public buildings. In nearly all cases, the water also passes through "premise plumbing" to reach the tap.

The drinking-water systems that manage the flows from source to premise vary enormously in size, type of treatment, and ownership. As of 2016, there are over 150,000 public drinking-water systems in the United States—systems that have 15 or more connections or serve more than 25 people. ("Public" here refers to the people served, not to ownership.) Of these 150,000 systems, 50,000 are community water systems that supply water to the same population year-round; these serve over 300 million Americans. The community water systems that rely on surface water as their source serve about 200 million people, those that rely on ground water about 100 million. Just 3 percent of the community water systems—those that serve over 10,000 people each—provide the drinking water for 79 percent of the U.S. population.

The 100,000 non-community public water systems are transient and non-transient systems that supply such entities as campgrounds, in the first instance, and office buildings, schools, and hospitals that have their own water systems, in the second. About 45 million people, or approximately 15 percent of the U.S. population, get all or part of their water from private wells.

The approach to ensuring the safety of drinking water in U.S. public water systems is to place multiple barriers to contamination along the entire water system from the source, to multiple decontamination and disinfection processes in treatment plants, to maintenance of water-distribution systems, to (in some cases) filters at the tap. The locations within the water system where water quality can be monitored and problems addressed are called "critical control points" and historically have been principally at the source, at various points within the treatment plant, and at certain points within the distribution system. Operationally, water utilities may have sensors and critical control points within water-treatment plants to assess performance of individual processes. Relatively little monitoring has been done, however, at the final critical control point—the consumer's tap. This omission is due in part to the lack of jurisdiction of the water utility over what happens in the premise plumbing—that is, the pipes, valves, and fixtures on the consumer's property—and in part due to lack of consumer motivation and knowledge.

Drinking-Water Contamination at the Source

Ground water and surface water are each susceptible to contamination by multiple phenomena. These include discharge of sewage (which may be further contaminated by household chemicals) and of industrial, mining, and agricultural wastes; unintended spills, discharges, leakage, and seepage of all of these and of fossil fuels in extraction, processing, transport, and storage; wet and dry fallout from atmospheric pollution; and dissolution of naturally occurring, potentially toxic elements (such as arsenic) from soil and rock. The presence of nitrates and phosphates from domestic and agricultural sources, moreover, can nourish blooms of algae that are directly toxic or conducive to bacterial population explosions.

Across the Nation over half of all surface water intakes for drinking-water treatment facilities serving more than 10,000 people are impacted by at least one upstream wastewater discharge, and many have more than 10 upstream wastewater sources. Smaller rivers and drinking-water facilities are even more influenced by the potential microbial and chemical loads from these upstream wastewater plants, and even modest seasonal changes in streamflow can result in rivers containing in excess of 50 percent water of wastewater origin at the point of intake for downstream drinking-water facilities.

Problems with the quantity of drinking-water sources can magnify problems of quality. For example, reduced volume of surface and groundwater resulting from seasonal low flows, drought, or overuse means less dilution of contaminants; shortfalls in water availability from the cleanest sources may force resort to lower-quality supplies; heavy downpours and flooding can increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, and other materials into water supplies; and floods may swamp sewage-treatment plants, leading to discharge of untreated wastes, or overflow storage ponds for agricultural and mining wastes.

The quantity/quality problems with drinking-water sources are being exacerbated by impacts of global climate change on the United States, as elaborated in the Third National Climate Assessment released in 2014 and the Fourth Assessment's 2016 special report on climate change and human health. For example:

- Increases in water temperatures are altering the seasonal windows of growth and the geographic range of suitable habitat for freshwater toxin-producing harmful algae and certain naturally occurring *Vibrio* bacteria, one species of which causes cholera.
- Decreased snowpack and earlier, faster spring snowmelt are decreasing summer and fall river flows.
- Sea level rise puts freshwater resources along the coasts at risk from saltwater intrusion.

- Droughts are becoming longer and more intense in some regions, even as torrential downpours and associated flooding become more prevalent in others.
- And a lengthening wildfire season, exacerbated by drought and massive tree die-offs caused by insect infestations, is increasing the area that is burned and that, as a result, is susceptible to accentuated erosion in subsequent storms, transporting sediment and contaminants into water-supply reservoirs where they can impact drinking water quality for periods ranging from days to years.

All of these climate-related impacts on source-water quantity and quality can be expected to grow for some decades to come as climate continues to change.

Contamination Issues at Drinking-Water Treatment Plants

Which water-treatment technologies are most appropriate, in what combinations, depends on the type and extent of contamination in the source water. This varies geographically and between surface and groundwater sources, where the differences range across the categories of inorganic (including trace metals) and organic chemical contaminants of both natural and human origin, radionuclides (mostly natural, but not always), and microbes of a wide variety of types. Treatment plants must be designed for both average levels of contaminants for the water sources they draw upon but also for the temporal variations in those levels. Spikes in the concentrations of one set of contaminants or another, whether resulting from leaks and spills associated with human activity or from natural phenomena, may exceed the capability of a given treatment plant to cope.

Contamination in the water leaving a treatment plant, then, can be the result of input concentrations exceeding the capability of a given treatment plant, as well as from operational breakdowns or lack of adequate back-up when equipment is down for maintenance. But it can also be the result of chemical substances deliberately added at the treatment plant for purposes of disinfection or the by-products of reactions of these disinfectants with contaminants in the source water. Common disinfectants include free chlorine gas as well as chloramines; disinfection byproducts commonly encountered include bromate, chlorite, trihalomethanes, and haloacetic acids.

Contamination Issues in Distribution Systems

Much distribution piping in the United States, up to the premise itself, is old and metallic (65.5 percent) or cementitious (18.5 percent) in nature; and much of the premise plumbing in older buildings is also metallic. These materials are subject to both internal and external corrosion, depending respectively on the chemistry of the water passing through the pipes and the chemistry of the water in the piping's external environment. Internal corrosion in lead and copper piping yields contamination by these metals in the drinking water; and iron oxides are a very effective concentrator of trace inorganics (arsenic and other metals) that can be released in bursts. In addition, the corrosion products in the pipe can harbor microbes and interfere with disinfection. Piping that corrodes through, moreover, is subject to intrusion of pathogens and other contaminants from the soil environment.

Premise plumbing brings with it all the problems of distribution-system plumbing, but magnified. Drinking water can have long residence times in premises, more stagnation, decreased flow, higher surface area exposure to pipe materials, decreased chlorine residual, and is maintained at higher temperatures more conducive to bacterial growth than water in the mains. Households may also have patchwork plumbing fixes that can lead to cross-connections and back-siphoning (inadvertent connections to non-potable water sources), elevating the risks of bacterial and chemical contamination. Premise plumbing may also include lead fixtures or solders in houses built before 1986.

In addition to leaching of metals, bacterial overgrowth, and cross-connections in premise plumbing, the warm water environment is also conducive to the growth of *Legionella pneumophila* within residences and public buildings. This bacterium can cause Legionnaires' disease, named after a 1976 outbreak during which some people attending a Philadelphia convention of the American Legion suffered from a new type of pneumonia. In the last 2 years, outbreaks have occurred in several U.S. cities, including Flint, Michigan; Milwaukee, Wisconsin; Hopkins, Minnesota; and New York City.

Recently, various forms of plastic have begun to be used in outside-of-premise distribution systems and premise plumbing. While not subject to corrosion like metal or cement, plastics have their own challenges including brittleness (especially in cold temperatures), potential permeation of organic solvents into the water, special requirements for bedding/installation, and limitations in pipe size. The most commonly used plastics in piping materials are polyvinyl chloride (PVC), polyethylene (PE), cross-linked polyethylene (PEX), and glass reinforced plastics (GRP).

Regulatory Oversight of Drinking-Water Safety

In the United States, the Safe Drinking Water Act (SDWA), passed by Congress in 1974 and amended in 1986 and 1996, creates the basic national framework for regulating public water supplies and suppliers to ensure that water at the tap is safe for human consumption. Under SDWA, the Environmental Protection Agency (EPA) sets standards for a number of naturally occurring or manmade contaminants that may be present in water and requires public water utilities to test and treat to ensure their water meets those standards. The 1996 amendments to SDWA added requirements to, *inter alia*: provide regular information to the public about the quality of their drinking water and regularly update the list of contaminants for potential regulation. The EPA's approach to its responsibilities under the SDWA is one of "multiple barriers," relying on both managerial and technical capability and including source water protection, water treatment and testing, training and certification of water-system operators, and providing public information.

The SDWA establishes two types of standards. Primary drinking-water standards, which are enforceable by EPA and the states, are set to protect public health with a margin of safety. Secondary drinking-water standards are guidelines that address aesthetics of drinking water (taste and odor), and are not enforceable. The SDWA process for establishing maximum contaminant levels and ultimately primary drinking water standards requires EPA to:

(1) Identify potential contaminants (naturally occurring or man-made) that may be present in in drinking water frequently enough and at levels that may pose a threat to public health.
(2) Establish a maximum contaminant level goal (MCLG) below which there would be no expected risk to public health.
(3) Develop a maximum contaminant level (MCL) as close to the MCLG as is feasible. Feasibility includes consideration of treatment cost and the availability of treatment technology or techniques.

To date, EPA has established primary standards for 88 harmful substances or indicators of such, comprising 53 organic chemicals, 16 inorganic chemicals, 8 classes of micro-organisms or indicators of micro-organism presence, 4 disinfection byproducts, 3 disinfectants, and 4 classes of radionuclides.

The regulations germane to the primary standards may specify allowable concentrations (MCLs), percentage reductions from contamination levels in the source water, or treatment technologies that public water systems must use. The regulations also require sampling and testing. The complexity of many public water systems—e.g., reliance on a number of water sources, large and complex distribution networks—make it challenging to provide sampling and testing adequate to ensure that standards are being met and to isolate the source of the problem when they are not.

Responsibility for ensuring that SDWA's requirements are met is, in most cases, shared by EPA and the states; EPA determines whether a state can have "primacy" in implementing and enforcing SDWA provisions. Individual states may impose and enforce drinking-water standards stricter than the primary standards set by EPA. The SDWA regulations apply only to public water systems. Smaller systems or private wells may be overseen by State or local authorities; in most cases, the responsibility for ensuring the safety of water from private wells is left to well owners.

Other Federal, State, and local agencies, laws, and regulations, may affect drinking-water quality and safety. For example, the Federal Clean Water Act (CWA) contains a number of provisions, policies, programs and regulation to protect the Nation's waters, including sources of drinking water. Toxic-chemical cleanup and stewardship statutes, such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, 1980) and the Resource Conservation and Recovery Act (RCRA, 1976), also serve to protect public health and the environment by reducing discharges to surface and groundwater, thereby reducing contamination of drinking-water sources. Local building and plumbing codes may require techniques to protect drinking-water quality within a building or residence.

The Special Case of Lead

For millennia, lead has been used in water system to convey or contain water, due to its malleable nature and resistance to corrosion. In fact, the English word "plumbing" comes from the Latin word for lead. Major sources for lead in drinking water have traditionally been: service-line pipes (connecting water mains in the street to individual premises; lead-tin solders used to join copper tubing in homes; and brass plumbing fixtures that contain lead. But lead is a neurotoxin to which fetuses, infants, and young children are particularly susceptible. Even at very low concentrations, it can lead to reduced development of mental capacity.

In some environmental circumstances, drinking water may not be the principal source of lead intake for the most vulnerable. For many years, for example, lead additives in gasoline were a major sources, and, even after such additives were phased out between 1973 and 1988, the lead that fell out of the atmosphere after emission from automotive exhaust remained an important source of lead intake for young children who ingest dirt. Lead-containing house paint has likewise been a significant source of lead intake for children who live in houses with such paint and ingest chips or dust from it; lead paint was not banned in all residential construction in the United States until 1978. Still another major source was food from lead-soldered cans; lead solder in food cans was banned only in 1995, 15 years after scientists showed that lead solder in tuna cans increased the lead concentration in the contained tuna to 1,400 parts per billion (ppb, or 1 microgram per kilogram) compared to 7 ppb in tuna in unsoldered cans.

As for lead in drinking water, the 1986 Amendments to the SDWA required EPA to establish regulations for lead in public water systems. The Amendments also defined "lead-free pipes" quantitatively and requires their use in plumbing for drinking water installed subsequently. The MCL for lead was set at 20 ppb. In the subsequent "Lead and Copper Rule" (1991), EPA determined that there is no safe level of exposure to lead, dropping the previous MCL and setting the MCLG at zero. EPA defined a "lead action level" (requiring ameliorative steps) for drinking water systems with greater than 15 ppb in more than 10 percent of taps sampled every 6 months in a given location. (The FDA's standard for lead in bottled water is 5 ppb.) The EPA protocol leaves open the possibility that Americans are unknowingly exposed to high lead levels, as the 10 percent threshold accepts that higher lead levels are present in a small subset of homes. The EPA is currently revising the Lead and Copper Rule, with the proposed revisions expected to be released in early 2017.

Risk Comparisons

In theory, being able to compare the magnitudes of different environmental risks with each other, as well as against some absolute yardstick, is important to making sensible decisions about risk management and regulation. Specifically, one would like to focus the most remedial effort on the biggest risks, and one would like to have a basis for determining which risks are small enough to require no remedial effort at all. The kinds of risk comparisons that are germane include:

- health risks from contaminated drinking water versus other risks to the health of the same population (e.g., air pollution, contamination of food, epidemic disease);
- health risks from different pathways of exposure to the same contaminant (e.g., lead from drinking water versus lead from food, ingestion of dust and dirt, or breathing contaminated air);
- health risks from different classes of drinking-water contaminants—chemical, microbial, and radiological; and
- health risks from a given contaminant or class of contaminants entering the water supply at different points in the drinking-water chain (e.g., water source, treatment plant, municipal distribution system, premise plumbing).

In practice, however, while the categories of relevant health-risk comparisons are easy enough to describe, carrying out the comparisons in any comprehensive way is extremely challenging. That is so because:

- there is an immense variety of potential drinking-water contaminants of potential health concern in both the chemical and microbial categories, with new ones being identified regularly;
- there are different types of health impacts ("endpoints" in the specialized literature) of the various contaminants (acute and chronic illnesses, mild to life threatening, transitory effects to lifelong disabilities), so there is no universal, quantitative measure of harm;
- there are often large variations within communities and from community to community and region to region in drinking-water sources and the range of distribution-system characteristics (including premise plumbing) that influence what contaminants are present and in what concentrations;
- deriving risk estimates from exposure data requires knowing the relations between exposure (how many people live in households with what concentrations of what contaminants in their drinking water) and dose (which depends on how much they drink), and between dose and probability and severity of harm ("dose-response relations"); and
- while exposure-dose relations can be estimated within some reasonable uncertainty bounds, quantitative dose-response relations are known for only a modest fraction of the syndromes known to result from the large variety of drinking-water contaminants of potential concern.

Despite these challenges, careful efforts to rank drinking-water health hazards by the magnitude of the risks they pose can be instructive—particularly across contaminants within a given class (chemical, microbial, radiological) and with common health end-points (e.g., reduced life expectancy)—as long as it is recognized that such rankings are necessarily partial, preliminary, and variable across locations.

The simplest approach that, at the current state of knowledge, can yield useful insights about comparative risks from different contaminants in the Nation's drinking water is based on looking, for those contaminants for which EPA has established Maximum Concentration Levels (MCLs), at how frequently and by what margins the measured concentrations across the country's public water systems exceed the MCLs. One attraction of this approach is that the process by which EPA constructs the MCLs accounts for whatever is known about the exposure-dose and dose-response relations for the individual contaminants.

The main liabilities of the approach are: (a) that the "end points"—the health damages the MCLs are intended to avoid or minimize—are not always comparable across contaminants; (b) for many contaminants of potential concern, the MCLs have not yet been published; and (c) the most recently published nationwide data based on sampling public-water systems—provided by EPA as the second 6-year review under the Safe Drinking Water Act—are both out of date (covering 1999-2005) and incomplete (including neither lead, nor microbial contaminants, nor major disinfection products). Data from the third 6-year review, which are expected to be released soon, still will not include data for lead.

In the main report, PCAST offers an example, based on a limited number of chemical contaminants, of how a quantitative risk comparison based on frequency and magnitude of MCL exceedances can be done and what the (partial) results look like.

Monitoring Issues

Monitoring drinking water for a wide variety of microbial, chemical, and physical contaminants is critical to ensuring the safety of the Nation's drinking water. Monitoring data are essential for evaluating the performance of the drinking-water system; surveillance of microbial, chemical, and physical risk factors; and informing the public on the quality of their water. These data are needed in all four components of the drinking-water system: source water quality, treatment-plant performance, distribution-system integrity, and the premise plumbing that delivers water to the tap.

Testing drinking water for various types of contamination is delegated by EPA, under SDWA, to the states—"state primacy"—in connection with their regulation of private and municipal water utilities, usually through departments of health or environmental protection. In addition to setting standards for nearly 90 drinking-water contaminants, as noted above, the EPA regulates the frequency of water-testing schedules and methods that water utilities or State regulatory agencies must use. For homes that are not connected to public water systems and are not part of any water utility (approximately 15 percent of households), however, there are no monitoring requirements set by the EPA. But the U.S. Department of Agriculture has a variety of programs aimed at improving water quality in rural America, including private wells and wastewater systems.

Under EPA rules, monitoring requirements vary for different contaminants. For example, under the Lead and Copper rule, water utilities must sample water from customers' taps every 6 months from a specified number of homes, depending on the size of the water utility (i.e., how many people are served). Under the Revised Total Coliform Rule (RTCR), which addresses a variety of microbial health risks, total coliform bacterial load is used as an indicator of other problems including integrity of distribution systems and effectiveness of water treatment. Total coliform monitoring plans are regulated by states, but a specified number of samples per month are required by the EPA, depending on the size of the water utility.

There are many technologies that can detect a range of contaminants at very low levels in drinking water. One important shortfall, however, is that monitoring technologies in distribution systems are currently extremely expensive and, in order to be effective, must be spread around the distribution system at multiple nodes or control points. While these sensors can detect many contaminants at very low levels, it is difficult to discern small, real, changes from background variability, due to statistical "noise" in background water-quality data.

U.S. Drinking-Water Safety in Practice

Most existing water-treatment plants meet current Federal regulations most of the time, although some—often older facilities that serve smaller or declining-population communities—have significant treatment challenges that lead to consistent shortfalls in meeting standards. Of the Nation's roughly 150,000 public water systems, the number found with any violation of EPA's primary drinking-water standards fell from 60,000 in fiscal year (FY) 2011 to under 50,000 in FY 2015, and the number found with a serious violation fell from 7,700 in FY 2011 to about 4,500 in FY 2015. Among the 429 very large public water systems—those serving more than 100,000 customers—the number with a serious violation in FY 2015 was 16, under 4 percent. By far the largest proportion of the violations related to coliform bacteria and other microbes; disinfection byproducts were a distant second with about a fifth as many violations; and arsenic, lead, and copper combined were third with about a sixth as many.

The much-publicized drinking-water-system closures in Toledo, Ohio and Charleston, West Virginia, in 2014, were the result of source-water contamination—harmful algal-bloom growth and microcystin toxin in Lake Erie, and an industrial spill of 4-methylcyclohexanemethanol (MCHM) from the Freedom Industries facility in Charleston into the Elk River, respectively. The Flint, Michigan crisis the next year, which resulted from a source-water change that interacted destructively with distribution-system plumbing, highlights the interconnectedness of the entire drinking-water system: the change of source water from Lake Huron to the Flint River greatly increased the corrosiveness of the water, and, absent adequate corrosion control at the Flint drinking-water treatment plant, the water leached lead from the aged distribution-system pipes, leading to elevated lead levels in the drinking water provided to much of the community.

Lead pipes are not just a problem in Flint, but nationally, especially in older cities and the Midwest. The American Water Works Association estimated in 2016 that approximately 6.1 million lead service lines remain in U.S. communities, and that approximately 7 percent of U.S. homes connect to community water systems that have a lead service line, or 15-22 million citizens. These lead service lines are partially owned by the drinking-water utility, and partially by the property owner. Partial removal of only the utility section of a lead service line can cause more release of lead into household water through disruption of the pipe and its lining, and is not recommended. This dual ownership of the lead service pipes highlights the need to find means to encourage and support removal of the property owner's portion of the lead service pipe, at the same time as utility actions. Note, too, that lead pipe fixtures and solder remain in many homes constructed prior to the mandates to remove lead from faucets and solder, which started in the 1980s and only recently (January 2014) required that all faucets contain no more than 0.25 percent lead.

The localized issues that have come to light regarding lead—together with the suspicion that other instances are likely going undetected because of weaknesses in the monitoring system—underscore the need to propagate best practices using currently available treatment and monitoring technologies and to develop and deploy better such technologies over time.

Best current and emerging treatment technologies

Historically, standard water-treatment practice has included, in sequence, flocculation, settling, and filtration, with disinfection using chlorine or its compounds either preceding or following filtration. Disinfection before filtration maximizes filter run times and helps control turbidity in "finished" (fully treated) water, but it can lead to production of carcinogenic disinfection byproducts (DBPs).

For the past decade, water utilities have been changing their use of chemical disinfectants, mostly to comply with increasingly stringent DBP regulations enacted in amendments to the SDWA. This trend has coincided with integration of new processes into their treatment plants, such as use of granular activated carbon and engineered biological films on the surface of filter media.

Biological filtration processes can act on both organics and inorganics to remove many contaminants of concern, including algal metabolites that cause unpleasant tastes and odors, iron, manganese, nitrate, and other specific organic molecules. Today, perhaps a quarter of water utilities are intentionally or unintentionally practicing some form of biological filtration.

Over the past decade or so, other significant technology changes have included:

- <u>A shift from free-chlorine to chloramines to comply with disinfection-byproducts rules.</u> Currently, more than 50 percent of the U.S. population is served by chloraminated water, yet comprehensive epidemiological studies are needed to confirm a reduced health risk compared to the previous free-chlorine disinfection process. Innovations in monitoring disinfection byproduct precursors (e.g., ultraviolet- or fluorescent-based instruments) or on-line measurements of disinfection byproducts have been made, but few utilities employ them because they are not required by regulation.

- Micro- or ultrafiltration membranes have gained increasing use over the past 2 decades. These membranes provide smaller reactor footprints than granular media filters, but cost 10 percent to 50 percent more than granular media filters. The membranes typically have greater automation and higher effluent water quality than granular media filters, but innovation is needed to reduce their costs.
- Ultraviolet-based, in-plant, disinfection use with low-pressure mercury-based lamps has increased dramatically over the past decade. But innovations are needed to reduce energy consumption (by, e.g., transitioning to non-mercury based lighting technologies such as LEDs), reduce scale formation on lamps, and improve on-line monitoring capabilities to ensure continuous disinfection.

Other aspects where improvement is needed include the following:

- Nitrate removal is most commonly achieved using ion exchange. This type of treatment generates large volumes of highly saline brines that are most commonly disposed to the sewer system which impacts wastewater-treatment practices. Innovation is needed to devise new treatment processes that do not generate brine waste and improve ion-exchange treatment efficiency for nitrate (and other pollutants including fluoride, perchlorate, arsenic, hexavalent chromium, and perfluorinated compounds) in the presence of elevated levels of sulfate, bicarbonate, and other anions.
- Arsenic removal from drinking water is most commonly achieved by sorption, coagulation/ filtration, or ion exchange in packed-bed columns. Increasing treatment performance and minimizing waste volumes and hazards from these existing technologies is needed. Simplification of arsenic-treatment processes is also needed to make the technologies more accessible and operable by the small water systems that represent the greatest number of systems currently not complying with the arsenic drinking-water standard.
- Many home and industrial point-of-use devices employ low pressure reverse osmosis. These have less than 30 percent efficiency when operated off of water-distribution-system pressures, leading to large flows of wasted water. Innovation is needed to reduce membrane fouling, improve membrane cleaning, and improve reverse-osmosis polymer material to decrease sensitivity to oxidants.

Best current and emerging monitoring technologies

It is currently impractical to rely on “high-tech” sensor systems that can identify specific contaminants. Instead, a “lower tech” approach is used, employing general water-quality monitors that can give utility operators a general sense of the state the water. Most current water systems rely on “grab” sampling under the Revised Total Coliform Rule to understand chlorine levels in the distribution system; relatively few use on-line sensors; and even fewer have the distribution system blanketed with enough to fully understand spatial and temporal variability. Most water utilities likewise use monthly or less frequent “grab” samples from the distribution system for disinfection byproduct monitoring, complemented by daily or weekly samples at the water-treatment plant.

New sensors are continually becoming available, allowing for new streams of data to be collected by water systems. There are now several commercially available on-line sensors that are capable of measuring multiple parameters simultaneously, including various combinations of turbidity, pH, pressure, conductivity, oxidation-reduction potential, and disinfectant residuals. The combination of these basic parameters can be used to assess the integrity of the distribution system and determine when deviations from baseline conditions occur. These sensor systems can be spread throughout the distribution system and require little power and other utilities to operate; and data can be uploaded to cloud-based systems or hard-wired into utilities’ control systems.

The size of the sensors has greatly diminished over the last decade and can now be easily deployed instead of having to be placed in pump stations or locations with a lot of available room. At costs below $5,000 for the most basic systems and up to $10,000 for systems that can also measure disinfectant residuals, and coverage of 50-100 service connections, this comes to between $50 and $100 per connection. Combined with low operating costs, these sensors are a substantial upgrade over the existing grab-sampling requirements and can give water utilities a more comprehensive view of real time (or near real time) conditions in their distribution systems.

The National Oceanic and Atmospheric Administration (NOAA) recently deployed the first-ever freshwater environmental sample processor (ESP). The ESP, an autonomous robotic instrument is collecting and analyzing water samples for algal toxins in near real-time and will be able to provide treatment plants with information in advance to potentially mitigate effects from harmful algal blooms. With time (hours to a day), utilities have options including: shifting water production to alternative sources; reducing flows through water treatment plants; or optimization of chemical treatments.

Leak detection plays a major role in maintaining distribution-system integrity. Often, leaks are discovered only when they surface or when they grow to the point of a major main break. Leaks are not only sources of lost water but are also potential entryways for contamination. In an effort to reduce leaks, utilities traditionally have conducted periodic leak surveys, which entail trained consultants or utility staff canvassing the distribution system making physical contact between acoustic equipment and available water system components (e.g., hydrants, valve nuts, curb stops, customer faucets, meters) and monitor for leak sound. Over a number of years, leak survey equipment has become increasingly sophisticated. Today's electronic monitoring equipment can amplify, filter, and display noise far better than the limited and subjective ear of the operator of yesterday's leak survey.

More recently, continuous acoustic monitoring (CAM) equipment has become available that can be placed directly on pipes. These sensors become active at night (during periods of reduced background noise) and listen for telltale sonic fingerprints associated with leaks. When connected with Advanced Meter Infrastructure (AMI) systems, the data from several sensors can be correlated to determine the location of a leak. Because the sensors operate continuously, leaks can be identified from the time they start, and a prioritization can be made as to which leaks need immediate repair and which can wait until they grow to become large enough to warrant repair. Several companies are working on aircraft- and satellite-based sensor systems to detect leaks remotely.

Ongoing National Activities on S&T for Safe Drinking Water

Research on the science of safe drinking water and R&D on safe-drinking-water technologies are and have been conducted, supported, and assessed by a variety of Federal agencies, interagency and intersectoral consortia, and nongovernmental organizations, many of which maintain databases, data portals, and dashboards of drinking-water-safety information. Some examples follow. The work of these entities has informed PCAST's studies and provides the foundation for much of what we recommend.

<u>Federal Agencies</u>

The **Environmental Protection Agency** through its Office of Research and Development conducts research on the evaluation of microbial and chemical contaminants in resource-water-treatment streams, safe and sustainable management of waste residuals, and advancing innovative technologies for water and resource recovery. The EPA's Safe Drinking Water Information System (SDWIS) contains information about public water systems and their violations of EPA's drinking water regulations, as reported to EPA by the states.

The **U.S. Geological Survey** (USGS) has several monitoring and modeling activities that support efforts to ensure safe drinking water including: monitoring source-water quality in the Nation's streams, rivers, lakes, reservoirs, and aquifers and how it is changing over time; conducting research to understand the natural and human factors that affect sources and drinking water quality; and developing water-quality models and related decision-support tools that: (1) predict source water-quality in unmonitored areas, (2) forecast short- and long-term changes in water quality, and (3) evaluate contaminant loading to receiving waters used for drinking water supply.

The **National Oceanic and Atmospheric Administration** (NOAA) plays a significant role in Harmful Algal Bloom prediction, forecasting, and research, especially in the Great Lakes region where HABs can directly impact local drinking water supplies for millions of Americans (and Canadians). NOAA has also constructed a National Water Model (NWM) that is a hydrologic simulation of observed and forecast streamflow over the entire continental United States. NOAA, USGS, and the U.S. Army Corps of Engineers are collaborating under the Integrated Water Resources Science and Services (IWRSS) partnership, with the first national water-resource facility at the National Water Center in Tuscaloosa, AL.

The **Centers for Disease Control and Prevention** (CDC) conducts work on drinking water focused on preventing diseases caused by chemical or microbial contamination. Key activities include surveillance, technological, and emergency or outbreak assistance, building laboratory and environmental health expertise and capacity, monitoring and evaluation of prevention interventions, and health promotion to keep domestic drinking water, swimming pools, lakes, and other water sources healthy and safe. CDC also provides national leadership on children's health by working with other Federal agencies and states through programs and policies to prevent childhood lead poisoning, including monitoring and evaluating children's blood-lead surveillance data and setting and revising the national blood lead reference level of 5 micrograms per deciliter (µg/dL) for U.S. children ages 1-5.

The **National Science Foundation** (NSF) supports basic scientific research across a variety of domains through a rigorous merit review process. Drinking water-related activities are funded under several Directorates, covering such topics as materials science and nanosystems engineering research to improve water-treatment systems, new sensor technologies, urban water-systems innovation networks, and the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) to develop shared infrastructure for improving and promoting access to data, information, and models on water system research.

<u>Interagency and Intersectoral Consortia</u>

The **Subcommittee on Water Availability and Quality** of the National Science and Technology Council (NSTC—a Cabinet-level council that coordinates cross-agency R&D efforts) is a Federal interagency group focused on research needs related to the availability and quality of water resources of the United States. Its current priority is to deliver the action items assigned to SWAQ in the March 2016 Presidential Memorandum on Drought Resilience and associated Federal Action Plan. SWAQ is in the process of expanding its current membership base to include expertise in drinking water monitoring, technologies, and infrastructure, with the objective of developing a Federal Strategy on research needs to improve drinking-water quality, scheduled for 2017.

The **Water-Energy-Food Nexus Taskforce** under the NSTC is currently exploring Federal activities and potential gaps in research areas affecting two or more vertices of the nexus (i.e., water-energy, energy-food, food-water, or all three). There are several nexus elements that relate to drinking water, including agricultural runoff and water quality, energy use for water treatment, and energy production from dual-use water resources. A working paper in preparation will include discussion on the interaction of the nexus and drinking water.

The **Water Treatment Interagency Working Group** (WaTr) is a recently re-established working group of the Bureau of Reclamation and the U.S. Army Tank Automotive Research, Development, and Engineering Center to provide an opportunity for Federal entities that work in the area of water treatment to come together and leverage resources and collaborate on topics such as: water quality, innovative technologies, water reuse for indirect/direct and agricultural uses, energy efficiency, cost reduction, environmental impacts, modeling, and smart water systems.

The **Water Quality Portal** is a cooperative service sponsored by USGS, EPA, and the intersectoral National Water Quality Monitoring Council. It serves as a portal for water quality data collected by more than 400 Federal, State, tribal, and local agencies, including many citizen-science organizations.

The EPA Drinking-Water Action Plan

In response to concerns about the growing array of challenges to the drinking-water system, the EPA evaluated its regulatory authorities over the course of 2016 and issued, on November 30, 2016, a new Drinking-Water Action Plan (Plan) that is complementary to the PCAST study of S&T for safe drinking water summarized here. The Plan aims to re-energize the safe-drinking-water enterprise through engagement across the Federal Government, water utilities, and other key stakeholders. It builds on advances in drinking-water and information technologies and public-private partnerships, coupled with EPA's experience in implementing its authorities under the Safe Drinking Water Act. It is organized around six priorities: (1) promotion of equity and building of capacity for water-infrastructure financing and management in disadvantaged, small, and environmental-justice communities; (2) advancing a next generation of oversight approaches for the Safe Drinking Water Act; (3) strengthening source-water protection and resilience of drinking-water supplies; (4) taking action to address unregulated contaminants; (5) improving transparency, public education, and risk communication on drinking water safety; and (6) reducing lead risks through a revised Lead and Copper Rule.

The EPA has identified challenges and goals for each priority and has proposed a diverse group of actions that, in order to be successful, must be addressed in an integrated and strategic way. PCAST was accorded the opportunity to review the proposed actions under each of EPA's priorities areas, and has focused on how S&T advances can support the important steps that EPA has outlined to transform the Nation's drinking-water system into a safer and more modern enterprise. Several of the proposed actions in the EPA Plan align with specific PCAST's S&T recommendations, including the development of low-cost and innovative technologies to remove a broad spectrum of contaminants, promoting the use of advanced monitoring technology and citizen science, development of a national e-reporting rule, and implementation of a data portal to report monitoring compliance.

PCAST's Recommendations

PCAST is making the following near- and long-term recommendations, which we believe will help to further improve the safety of the Nation's drinking-water system. The near-term recommendations are targeted with a focus on activities that the Administration can undertake in the areas of: monitoring for chemical and microbial contaminants including a focus on monitoring exposure in particularly vulnerable populations; development of strategies for improved data sharing and accessibility; expansion of citizen-science projects on drinking water; and growth and training of the water-system workforce. PCAST has categorized these recommendations as "near-term" because there currently exist either personnel, funding, or programs that can help jump start the implementation of these recommendations within the current Administration.

PCAST is also making long-term recommendations to enable coordination and execution of a Federal strategy for the research and application of science and technology to understand and address the challenges associated with providing safe drinking water. Additional long-term recommendations that will help ensure the safety of the Nation's drinking water include: improved quantitative assessments of comparative risk across contaminants; development and deployment of innovative, next-generation water technologies; and launching of city-based demonstration pilots to assess innovative technologies in realistic conditions. PCAST considers these "long-term" strategic recommendations visionary, requiring dedicated resources. These recommendations together will enable the development of a technologically advanced drinking-water system based on scientific research and innovation.

Near-Term Targeted Recommendations

RECOMMENDATION 1: INCREASED MONITORING OF DRINKING-WATER CONTAMINANTS, ESPECIALLY FOR VULNERABLE POPULATIONS

FINDING: The use of existing drinking-water-monitoring technologies can be expanded through innovative implementation and funding mechanisms to obtain and disseminate additional public health-relevant information to affected systems and communities. Technologies have also advanced and can be adapted to provide affordable, real-time sensors and data tailored to the needs of system managers, researchers, and customers. These monitoring advances are relevant to both public water systems and to non-regulated, small systems and well sources. PCAST believes that there are particular monitoring opportunities that can reduce the exposure of pregnant women, infants, and young children to chronic, water-borne pollution, such as lead, arsenic, and nitrate, through targeted monitoring of those most at risk and remediation when appropriate. PCAST finds that there is an opportunity to monitor drinking-water contaminants for the most vulnerable populations, identifying situations like what happened in Flint, Michigan, and allowing for immediate intervention.

RECOMMENDATION 1A: PCAST recommends that all women who enroll in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) be referred to the appropriate agency for tap-water testing for lead. That agency should also provide point-of-use treatment, when appropriate. Testing for additional contaminants that have similar risk profiles to lead such as arsenic and nitrate, particularly in rural areas that rely on private wells, should also be provided. This effort would require some new funding (approximately $100 million per year) that can either come from reallocation of existing lead-mitigation funds or from new appropriations. PCAST recommends that the President ask the Secretary of Agriculture, the Secretary of Housing and Urban Development, and the Administrator of the Environmental Protection Agency to explore ways to cooperate in establishing this program; developing testing protocols, training, and data management; identifying possible sources of funding; and assigning primary responsibility for its administration.

RECOMMENDATION 1B: PCAST recommends that the EPA consider modifying the Lead and Copper Rule, as well as additional contaminant rules, to require follow-up testing when contaminant levels exceed a threshold level, even if the frequency of these samples is below the number that would trigger remedial actions under current rules. This will help to identify clusters of high-contaminant-level occurrences that remain invisible under existing rules.

RECOMMENDATION 2: BIG-DATA ANALYTICS FOR DRINKING-WATER SYSTEMS

FINDING: Data accessibility, utilization, and interoperability across time and space are severely limited in public and private drinking-water systems, and across Federal agencies. At least three important data trends are emerging in the water industry that make the present an ideal time to improve coordination. First, tens to hundreds of millions of dollars are spent annually on data collection by multiple Federal agencies related to water quantity (e.g., lake levels, precipitation patterns, snowfall depths) and quality (e.g., temperature, salinity, trace organics, pesticides) and by cities or other local agencies within water treatment plants, distribution systems, and to a lesser extent premises. Some data are near real-time or continuously monitored, while the frequency of other samples for chemical analysis tends to rely upon sporadic grab samples with highly variable time periods. Data describing potential contaminants of concern in watersheds (such as chemicals stored in tanks) are also managed and maintained by states, yet most of these data are inaccessible to the water community for purposes of protecting—proactively or reactively—against source-water contamination events. Second, there is no common data-analytics platform to access this data across agencies or across states and local communities. The limited data are difficult to link across city, State, or watershed boundaries, or to link to specific water-treatment plants or distribution systems. Third, private industry is beginning to market a series of sensors, data analytics, control systems, and interfaces for utility operators but the industry lacks standardization, security, and interoperability capabilities in this emerging internet of things related to drinking-water systems.

RECOMMENDATION: The Executive Office of the President—with leadership from the Office of Science and Technology Policy (OSTP), the Council of Environmental Quality (CEQ), the Domestic Policy Council (DPC), and the Office of Management and Budget (OMB)—should support the development of a Drinking Water Data Platform for collection, analysis, storage, and sharing of geospatially linked drinking-water-system contamination data. This platform should be accessible to agencies, water utilities, researchers, and the public and include information related to water quality and contamination levels. The Drinking Water Data Platform should be informed by and could build off of the EPA's Safe Drinking Water Information System (SDWIS) and the Water Quality Portal managed by EPA, USGS, and the National Water Quality Monitoring Council.

RECOMMENDATION 3: INCREASE DATA COLLECTION AND SHARING THROUGH CITIZEN SCIENCE EFFORTS

FINDING: Under current EPA rules, monitoring requirements and sampling rates vary by state, water-system size, and contaminant. Private wells are not covered and some utilities are granted waivers to sample less frequently when monitoring results collected in accordance with drinking-water regulations have consistently been found to be below levels of concern. The Lead and Copper Rule is the only national primary drinking-water regulation in which compliance samples are collected in customer's homes. The limited frequency and distribution of sampling of water for lead, and no sampling for other contaminants, in premises suggests that geographic and temporal gaps might exist in data about drinking-water contamination. PCAST found that there is a near-term opportunity to increase data collection of a broader range of drinking-water contaminants through leveraging of citizen-science activities, while increasing public understanding of drinking-water safety.

RECOMMENDATION: The Environmental Protection Agency (EPA), the National Science Foundation (NSF), the Centers for Disease Control and Prevention (CDC), the National Institute of Environmental Health Sciences (NIEHS), and the Department of Housing and Urban Development (HUD) should develop and support research to enable efforts to expand measurement and monitoring of drinking-water supplies in the United States by actively funding citizen-science activities such as home water testing, with an emphasis on including activities focused on drinking-water sources, small systems, and private wells. As soon as practical, Citizen-Science Coordinators from these agencies should begin the process of bringing together relevant agencies, State and local government, and water utilities in a roundtable discussion to identify a series of near-term activities focused on collection of water-contamination data. The relevant agency Citizen-Science Coordinators should also begin to identify long-term activities for developing safe drinking water-related citizen-science programs within states. These programs should leverage new developments in low-cost instrumentation, including sensors, and consider the following citizen-science components:

(1) recruitment, education, and training of citizen scientists;
(2) development of study protocols designed to engage a broad range of participants;
(3) data forms and collection procedures that balance ease to use while maximizing the accuracy of data;
(4) mechanisms for sharing citizen-science data with other citizens and to inform utilities, states, and the Federal Government; and
(5) establishment of an ideation challenge for citizen-science programs.

RECOMMENDATION 4: DEVELOPING THE DRINKING-WATER TREATMENT AND DISTRIBUTION-SYSTEM WORKFORCE

FINDING: Water operators are critical to the delivery of safe drinking water. To maintain a strong workforce, to attract new talent and younger entrants as the existing workforce reaches retirement, the Nation needs to create new excitement around a technologically advanced drinking-water workforce. NSF's Advanced Technological Education (ATE) program can be leveraged in the near-term to attract individuals to the field, while additional projects could be started for the long-term enhancement of the water system workforce.

RECOMMENDATION: The Federal Government should increase investment in programs aimed in helping American workers get the skills and credentials needed to support the operation, maintenance, and improvement of drinking-water systems throughout the Nation. Both OSTP and CEQ should guide the following near- and long-term opportunities to support this recommendation including identifying mechanisms for engaging with existing organizations involved in workforce development and training.

Near-term Opportunity:

The National Science Foundation should increase funding of meritorious drinking-water-related projects through the Advanced Technological Education (ATE) program. Currently, the ATE program supports water-quality education programs at community colleges developed in partnership with industry representatives. NSF should actively encourage applications from community colleges that are interested in innovative approaches for educating a highly-skilled drinking-water and water-management workforce.

Long-term Opportunity:

The Environmental Protection Agency (EPA), in coordination with NSF, ED, and DOL, should initiate a stakeholder process to develop a blueprint for the overall professional development of water treatment operators. The blueprint should include identification of:

(1) descriptions of key positions needed to ensure delivery of safe drinking water;
(2) funding mechanisms for training;
(3) critical components of new training programs and professional development;
(4) workforce development priorities and timeline; and
(5) new knowledge needs including advanced IT and big data.

The blueprint should consider the different training needs of small water-system operators in identifying components of new training programs.

Long-Term Strategic Recommendations

RECOMMENDATION 5: FEDERAL COORDINATION OF RESEARCH AND DEVELOPMENT FOCUSED ON SAFE DRINKING WATER

FINDING: Responsibilities for R&D on topics related to the safety of drinking water are spread across a number of Federal agencies. No single Federal entity has responsibility for ensuring coordination across these efforts. Although, as noted above, there are three interagency groups with mandates relating, in part, to the challenge of providing safe drinking water, none has comprehensive visibility into or explicit responsibility for coordinating the broad array of R&D needs germane to drinking-water safety from source to tap. Neither does any of these bodies—or any of the individual Federal departments and agencies with responsibilities related to drinking water—have the resources or the mechanisms to promote the application of the best available science and technology in the approximately 150,000 public water systems across the Nation, nor the many small private systems and wells. PCAST finds that there is a need for a more coordinated and Federal strategy for science and technology research, development, and demonstration to remedy these shortfalls.

RECOMMENDATION: The Executive Office of the President—with leadership from the Office of Science and Technology Policy (OSTP), the Council of Environmental Quality (CEQ), the Domestic Policy Council (DPC), and the Office of Management and Budget (OMB)—should oversee the development, and coordinate the execution, of a Federal Strategy for the research, development, and deployment of adequate and affordable drinking-water monitoring, treatment, and distribution technologies across the Nation's drinking-water system, from source to tap. The formal mechanism for this EOP-led effort could be a new National Science and Technology Council (NSTC) subcommittee that absorbs the relevant parts of the existing interagency groups with responsibilities related to drinking water, or it could be a free-standing interagency council chaired by OSTP, CEQ, DPC, and OMB, much in the format of the Council on Climate Change Preparedness and Resilience (which is chaired by CEQ, OSTP, NSC, and OMB). Whatever the format, the new entity should be supported by dedicated staff in both OSTP and CEQ, e.g., an OSTP Assistant Director for Safe Drinking Water. The creation of a new entity along with dedicated support staff will ensure that the development and execution of the Federal Strategy will be effective and efficient. The new entity's initial steps toward fashioning the above-described strategy should include:

(1) cataloging current drinking-water related Federal R&D programs and budgets, Federal monitoring programs of water quality, human exposure to contaminants, the cost of waterborne disease, and data-collection and sharing efforts;
(2) similarly surveying public and private non-Federal actors in the drinking-water space to understand their activities relating to research, development, and deployment of clean-drinking-water technologies and their views about needs, gaps, opportunities, and the appropriate roles for the Federal Government and other external stakeholders;
(3) identifying—based on (1), (2), and the use of the best available metrics for characterizing potential leverage—the most important unmet research, development, and deployment needs where additional Federal and other efforts would have promise of moving the needle;
(4) reaching agreement on which agencies or combinations of agencies could most expeditiously and effectively address those needs;
(5) working with the same agencies identified in (4) and the EOP budget process to secure funding for the indicated efforts; and
(6) identifying avenues for Federal interaction with, and education of, the broader stakeholder community, including State and local agencies, the private sector, and citizens.

Building from these activities, the entity should aim to complete a comprehensive strategy, with a 10-year outlook, for Federal research, development, and deployment efforts on clean-drinking-water technologies within 2 years, to be updated at 2-year intervals thereafter.

RECOMMENDATION 6: DEVELOPING THE NEXT GENERATION OF TECHNOLOGIES TO IMPROVE SAFETY OF DRINKING WATER

FINDING: The Nation's R&D ecosystem for development and deployment of innovative technologies to improve the safety of drinking water is inadequate. Across the government, various funding and management mechanisms exist for the development of innovative technologies (e.g., prizes, grand challenges, research hubs, focused research centers). PCAST recognizes the value of these mechanisms and encourages agencies with drinking water-related programs to consider establishing such activities. Similarly, PCAST encourages learning from programs that have led to the historical successes in rapidly developing and deploying new technologies at the Defense Advanced Research Projects Agency (DARPA) and the Advanced Research Projects Agency – Energy (ARPA-E).

RECOMMENDATION: The Federal Government should create a new, focused research entity to develop transformational technologies aimed at improving the safety of drinking water. This research

organization should build on the focus, speed and flexibility attributes inherent in existing Advanced Research Projects Agencies. It could logically be located in EPA, the Department of Interior, DOE, or other agencies, with each having advantages and disadvantages that should be weighed by the next Administration. The EOP-led interagency entity described in Recommendation 5 should, among its other duties, assist the new research organization with priority-setting and interactions with key stakeholders, including the private sector. The President should request initial funding in the FY 2018 Energy and Water Appropriations budget for $300 million to support the launch. Among the topics for early attention by the new research program are:

(1) inexpensive multi-contaminant sensing, testing, and treatment technologies;
(2) new techniques for pipe and lead service line identification, mapping, and replacement;
(3) microbiome of water systems from source to tap;
(4) brine disposal technologies;
(5) early warning water-main and service-line leak detection;
(6) lower-cost technologies to enable direct potable reuse;
(7) water purification for oxidized pollutants;
(8) ex-situ sensing of groundwater quality and availability;
(9) low-cost and ubiquitous water-quality sensors;
(10) beyond chlorine-based disinfectant; and
(11) instruments capable of decreasing the costs of water-contamination analysis by tenfold.

RECOMMENDATION 7: DEVELOPING COMPARATIVE RISK ASSESSMENT METHODOLOGIES AND CAPACITY

FINDING: Comparison of different risks with each other is generally an important part of developing an overall strategy for risk reduction, most notably in helping to decide where to focus attention and resources. Methodologies for conducting quantitative risk comparisons across different drinking-water contaminants and different sources of exposure constitute an underdeveloped field of study. The health endpoints of concern differ between the various drinking-water contaminants, as do the methods for calculating "safe" concentrations, making it challenging to select a common endpoint—toxicity, days of life impacted by illness, proportion of systems exceeding a regulatory standard—for risk comparison based on measured levels of each contaminant in different drinking-water systems. Microbial pathogens pose a particular opportunity to advance quantitative microbial risk-assessment methods, supported by the necessary monitoring and epidemiological surveillance data, in order to facilitate comparison with the quantitative risk methods already in use for chemical and radiological contaminants.

RECOMMENDATION: The Centers for Disease Control and Prevention (CDC), the Environmental Protection Agency (EPA), the National Institute of Environmental Health Sciences (NIEHS), and the U.S. Department of Agriculture (USDA) should initiate a coordinated research effort, in conjunction with State and other drinking-water experts, to improve the methodologies and develop the data needed to support more comprehensive comparative-risk assessments of contaminants across the spectrum of chemical mixtures, sources, and treatment systems that provide drinking water to the Nation. This activity should supplement information collection and assessment activities already undertaken under Safe Drinking Water Act authorities, including collaborations to enable collection and assessment of data pertinent to drinking-water systems not under regulatory oversight, such as private wells and premise plumbing.

RECOMMENDATION 8: SAFE DRINKING WATER DEMONSTRATION PROJECTS

FINDING: American cities are facing significant effects from water shortages, crumbling drinking water infrastructure, and shortages of trained water-system operators. PCAST learned that some cities are beginning to take on these challenges through innovative approaches along with developing partnerships across water utilities, universities, and public companies. PCAST finds there is an opportunity and a need to pilot innovative ideas related to safe drinking water.

RECOMMENDATION: The Environmental Protection Agency (EPA), in conjunction with the Department of Housing and Urban Development (HUD), U.S. Department of Agriculture (USDA), the Centers for Disease Control and Prevention (CDC), Department of Energy (DOE), and Department of Commerce (DOC), should consider deploying city-based safe drinking-water demonstration projects. The demonstration projects should be deployed in: (1) an in-land arid city; (2) a groundwater dependent city; and (3) an industrial mid-western (or northeastern) city. The interagency initiative should coordinate and finance projects that engage local and State governments, public and private water utilities, non-governmental organizations, and the general public with goals to:

(1) test the deployment and efficacy of current and new technologies for monitoring, detection, and treatment of water contaminants throughout the distribution system and in premises, including technologies that are developed through the Federal research entity described under Recommendation 6;
(2) test current and new technologies, including green infrastructure, for the replacement or repair of water systems;
(3) understand financial challenges and opportunities for supporting the use of current and new technologies for water systems to ensure safe drinking water, including means to facilitate mutual validation and adoption of improved technologies across drinking-water utility systems and states;
(4) implement and test the impact of water-safety plans in improving system water quality including the monitoring and evaluation of health outcomes;
(5) work with local universities and community colleges to develop timely curricula for drinking water-system operators;
(6) include social science and communication components enabled through social media; and
(7) create a publically-accessible database of results and communicate best practices and lessons learned.

The interagency initiative should start three demonstration projects with new funding for each in the range of $20-30 million a year for 5 years. The President should request monies for this activity in the FY 2018 budget request. These monies should be matched through public-private partnerships to spur development and commercialization of new technologies, and are not intended to exclusively fund infrastructure-development projects within the cities.