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REVIEW

How To Prepare for the Unexpected: a Public Health Laboratory Response

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SUMMARY Public health laboratories (PHLs) continue to face internal and external challenges to their abilities to provide successful, timely responses to public health crises and emerging threats. These laboratories are mandated to maintain the health of their communities by identifying, diagnosing, and warning constituents of potential and real health emergencies. Due to the changing characteristics of public health threats and their cross-jurisdictional nature, laboratories are facing increased pressure to ensure that they respond in a consistent and coordinated manner. Here, the Association of Public Health Laboratories (APHL) Emerging Leader Program Cohort 11 members have compiled stories from subject matter experts (SMEs) at PHLs with direct involvement in crises to determine the characteristics of a successful response. Experts examined a diverse selection of emerging threats from across PHLs, including infectious diseases, opioids, natural disasters, and government shutdowns. While no public health crisis will be identical to another, overarching themes were consistent across subjects. Experiences from SMEs that could improve future responses to emerging threats are highlighted.

KEYWORDS COVID-19, emerging issues, public health laboratories

INTRODUCTION

Providing a consistent and coordinated response to an emerging threat or public health disaster is a priority for public health laboratories (PHLs). However, PHLs and governmental laboratories conducting tests of public health significance are facing an increasing number of threats that negatively affect their ability to provide uninterrupted services. These threats are growing in complexity and often span multiple jurisdictions. To maintain a high standard for public health and safety, it is imperative that PHLs and governmental laboratories have the capability and capacity to prepare for and respond to these threats.

Historically, when responding to an emerging threat, PHLs are often considered separately from other areas of public health despite a shared mission. The creation of silos (both internally and externally) makes the response to emerging events less effective. Though an after-action report may be generated, lessons learned are rarely shared broadly within the organization, and almost never publicly. The Association for Public Health Laboratories (APHL) Emerging Leader Program (ELP) Cohort 11 members identified an unmet need in the capacity of PHLs to respond to public health threats and provide emergency response in a coordinated and consistent manner. Here, we examined a series of unrelated public health crises and demonstrated common challenges experienced by PHLs despite differences in the type of threat or size of the responding PHL.

The background of the public health issue, challenges associated, and recommendations for future planning were collected from subject matter experts (SMEs) working in PHLs at the time of an emerging threat or crisis. The SMEs were chosen based on their level of expertise and their direct involvement in a previous public health crisis. Cohort 11 members conducted interviews with at least two SMEs per subject topic using standardized interview questions. Where possible, SMEs were chosen from disparate geographical areas to provide a broader representation of public health crises across the United States and internationally. While the examined public health crises spanned different public health areas (including infectious disease, opioids, natural disasters, environmental contamination, and government shutdowns), we were able to identify commonalities in PHL practices that successfully improved coordination, consistency, and the chance of a successful response to an emerging crisis (Table 1).

RESPONSE TO OUTBREAKS

Coronavirus Disease (COVID-19) Pandemic

In December 2019, health authorities reported multiple clusters of patients with pneumonia of unknown cause that were epidemiologically linked to a seafood

TABLE 1 Recommendations for PHLs and action items based on lessons learned

Emerging issue	Role of PHLs	Recommended action items	Also applicable to:
SARS-CoV-2	Improve testing capacity Research and development International collaboration	Become active members of national/international organizations to pool knowledge and resources Support R&D of new diagnostic tests to rapidly respond to emerging issues Work with international groups to improve research and public health responses	Ebola, measles, PFAS, opioids
Measles	Consistent messaging ICS activation Funding Electronic solutions	Establish early, efficient, and structured communication between epidemiological, laboratory, and public groups Outline specific roles and responsibilities of individuals and overall expectations Establish consistent funding strategies to maintain cross-trained staff and expertise Decrease required manual entry by implementing integrated LIMs	Ebola, SARS-CoV-2, PFAS
Ebola	Training and retainment of staff Global surveillance Establish agreements	Identify an emergency response team and establish long-term funding to support Participate in international surveillance initiatives to facilitate detection and response to emerging threats Prearrange agreements between stakeholders (national and international) for reagents, testing, and personnel or reciprocal testing between PHLs	Measles, SARS-CoV-2, PFAS, opioids
PFAS	Direct public messaging After-action assessment Education	Develop scripts for FAQs and develop methods for information dissemination (telephone hotlines, websites, etc.) Review events to improve the next response and share lessons learned with stakeholder departments and jurisdictions Clearly communicate the need for resources to leadership and staff to facilitate long-term funding	SARS-CoV-2, measles, Ebola, opioids
Opioids	Opioid surveillance Surveillance for opioid-related diseases	Data can be shared with policy makers for use in evidence-based decision making Monitor secondary health concerns such as bloodborne pathogen rates due to shared needle use	SARS-CoV-2, measles, Ebola, PFAS, government shutdown
Natural disasters	COOP Essential services list Communication plan	Establish COOP which considers geographic location and outlines all possible natural disasters Create essential services lists for each type of disaster Identify alternate communication plans with staff and stakeholders, should services be interrupted	SARS-CoV-2, measles, Ebola, PFAS, government shutdown
Government shutdown	Stockpile reagents	Maintain critical testing reagents	SARS-CoV-2, measles, Ebola, PFAS
Technology transfer	Protocol standardization Share verifications and SOPs	Establish nationwide SOPs to ensure data are accurate and comparable Share resources to facilitate problem solving and implementation of new technology	SARS-CoV-2, measles, Ebola, PFAS, opioids, natural disasters

and animal market in Wuhan, China (1). Isolation and sequencing identified a novel coronavirus (severe acute respiratory syndrome coronavirus 2 [SARS-CoV-2]) as the causative agent (2, 3). The disease spread to nearly every country in the world quickly. By 1 February 2020, the WHO reported 11,953 confirmed global cases (4), by 1 March 2020, 87,137 global cases (5), and to date, as of 26 January 2021, there were 98.9 million confirmed cases and 2.1 million deaths associated with SARS-CoV-2 globally (6).

The ability to quickly diagnose disease and employ contact tracing strategies is paramount to mitigating the spread of infectious diseases. PHLs and acute diagnostic laboratories globally have rapidly developed, and implemented, diagnostic tests to identify SARS-CoV-2 infection. In Canada, multiple laboratory-developed tests were created individually by provincial PHLs and the National Microbiology Laboratory in response to the pandemic. This strategy was highly successful and allowed each province to quickly operationalize diagnostic testing. Rapid volume increases for testing centers quickly followed, which facilitated screening of a large number of patients. By March, the province of Alberta ranked fourth in per capita testing, with 4,183 tests performed per million people (behind the United Arab Emirates, South Korea, and Australia). High testing rates allow appropriate and timely tracing of all positive cases and facilitate contact tracing and appropriate quarantine requirements to prevent spread within the community. The ability of public health institutions to slow the spread of infection is the key to ensure that hospitals, and intensive care units particularly, are not overwhelmed by the number of people needing care.

Other countries, such as South Korea, increased their diagnostic testing capacity at an unprecedented rate. Over the course of few days, South Korea became a leader in diagnostic testing per capita (second only to the United Arab Emirates), and by 19 March 2020 had screened over 316,000 patients, with a per capita testing rate of 6,148 per one million people (7). By 2 July 2020, a total of 1,307,761 tests had been performed country-wide (8). The testing done in South Korea successfully reduced the number of cases in the country from greater than 800 new cases per day at the peak, to under 100 new cases per day as of 25 March 2020. Comparatively, the United States screened just over 100,000 people as of 19 March 2020, with a per capita testing rate of 314 per one million people. This gross undertesting in the United States greatly impeded the public health response as undiagnosed cases facilitated spread of the virus throughout the country. Even with the low level of testing nationwide, the United States surpassed both Italy and Spain in late March to become the leader in the number of confirmed-positive COVID-19 cases.

From the end of March to the beginning of July, the United States experienced a significant increase in the number of SARS-CoV-2 PCR tests performed. New York was the leader in testing in the beginning of April, with 15,694 new tests performed on 1 April 2020. In comparison, California performed only 673 new tests on 1 April 2020. However, by 31 May, both states had significantly increased their numbers to 58,444 and 56,253 new tests performed, respectively (9). Likewise, in many other states, the number of tests significantly increased during May and June, for a country total of over 33,460,000 tests performed since the start of the pandemic (as of 1 July 2020) (7).

Lessons learned. In this crisis, the role of the PHLs is to improve testing capability and capacity and then to facilitate dissemination of this testing to acute care laboratories before the volumes become unmanageable for single PHL testing centers. Countries where PHLs were able to develop and implement in-house laboratory-developed tests for clinical testing early in the pandemic detected cases sooner and implemented appropriate contact tracing and infection prevention strategies earlier. The flexibility to create these assays was key to have numerous viable assays available for clinical use.

Information dissemination was key to learning about the virus and tracking its progress. Many tools have emerged to assess the spread, understand the genetic variation, and improve diagnostic testing of the virus. For example, Nextstrain is an open-source project that is founded on the open sharing of genetic information to improve research and public health responses to emerging diseases (https://nextstrain.org/ncov). Since the first sequence of SARS-CoV-2 was made public, the scientific community has been providing up-to-date analyses of publicly available sequences to identify possible transmission routes and to show the genomic diversity of each location in the genome. The interface can be configured in 10 languages to facilitate knowledge translation of the sequencing analyses. These data are invaluable to assay development which promotes primer design in highly conserved regions and facilitates rapid and accurate assay implementation.

Many organizations have been tracking the number of confirmed infections globally and have made the information available on their websites, which has significantly improved the ability to predict trends and facilitate contingency planning. Two examples are the WHO daily situational reports (4) (now weekly operational reports), where all countries report the number of confirmed cases daily, and the Johns Hopkins's Coronavirus COVID-19 global tracker (10). Both systems emerged early in the outbreak and continue to give near real-time updates of confirmed positives, deaths, and recoveries by country and region.

In a pandemic, it is important that messaging is consistent, clear, and accurate. PHLs can facilitate consistent messaging through engagement with epidemiologists and other partners within the health department. PHLs can help draft language for infection prevention, viral detection, and available treatments and advocate for scientifically based testing algorithms. PHLs can provide result interpretation, describe assay limitations, and recommend strategies for test implementation to external stakeholders. Accurate, timely, and clear information is essential to minimize the effects of misinformation released from political sources or social media.

Appropriate messaging to the public further helps decrease infection rates. Social distancing and isolation of infected individuals are effective in reducing transmission of the SARS-CoV-2 virus. However, public interpretation of social distancing varies. Messaging therefore should be very clear and provide specific examples—stay at home, work remotely, and access essential services (groceries/pharmacy) once a week. Many PHLs have developed relationships with community groups within their jurisdictions to facilitate dissemination of information. Trust in the PHLs through these preexisting relationships could help decrease exposure and infection rates in the community.

In addition, PHLs can reduce the likelihood of their own employees spreading the virus by enforcing public health mandates for personal protective equipment and social distancing in the workplace and ensuring that employees only come in for work that cannot be done remotely. Some of the popular platforms that are available to PHLs and have been adopted to facilitate offsite work include Skype, Zoom, Office365/Teams, GoToMyPC, SharePoint, and PHL-specific sites/programs.

From establishment of novel diagnostic testing assays to promotion of consistent messaging between laboratory partners and the public, PHLs play an essential role in the outbreak response. Organizations such as APHL give active member PHLs a platform where they can pool their knowledge and resources, help set national priorities, and set standards for consistency and coordination both nationally and internationally.

Measles Outbreaks

Measles is a resurging global concern. Indigenous measles transmission was eliminated in the United States in 2000 and in Canada in 1998; however, in 2019, the United States was challenged with the greatest number of measles cases reported since 1992 (11, 12). The virus continues to circulate widely in many regions of the world, including Africa, Europe, and parts of Asia, and has repeatedly been reintroduced into areas of nonendemicity by international travelers (13, 14). Between 1 January and 13 June 2019, 1,044 confirmed cases of measles were reported to the CDC from 28 states. High vaccination rates within communities are necessary to prevent the spread of measles; however, vaccine compliance is negatively affected by misinformation and false science regarding the safety and efficacy of vaccines. The 2019 measles outbreak was the most recent of three significant outbreaks in the United States to demonstrate the importance of addressing low vaccination coverage to ensure that vulnerable subpopulations are adequately protected from a potentially serious vaccine-preventable disease (15).

On 5 January 2015, the California Department of Public Health (CDPH) identified a case of measles in an unvaccinated child. Contact tracers discovered recent travel to Disneyland. In total, 147 people in the United States contracted the virus with epidemiological links to Disneyland or Disney California Adventure Park, with additional cases linked internationally to Mexico and Canada (16). Sequencing detected genotype B3 from 30 different specimen isolates. While officials did not identify an index case, genotype B3 was detected concurrently in at least 14 other countries, including a large outbreak in the Philippines (16).

Another significant measles outbreak occurred in the United States in 2017. Between 11 and 13 April 2017, the Minnesota Department of Health Laboratory (MDH) confirmed three measles cases (11). All cases attended the same day care center, and all were infected with a genotype B3 virus. As in the California outbreak, officials were unable to identify the source of the original infection. Of the 65 laboratory-confirmed cases, the majority were children (under 21 months) residing in Hennepin County. Concurrently, the Somali-American community experienced a significant decline in measles vaccination rates between 2007 and 2017 due to external antivaccination efforts and represented the majority of cases in this outbreak (17). The low vaccine coverage rates in the community, the age of those infected, and the extensive movement of children between different day care centers facilitated a rapid spread of measles in the community.

Some of the biggest challenges for PHLs involved in these outbreaks included the scope of the outbreak investigations, the number of patients requiring testing, and the mobility of the patients. In the Minnesota outbreak, an estimated 8,250 individuals were potentially exposed to measles, while in California, over 44,000 individuals a day accessed Disneyland during the exposure period. During the California outbreak, 14 of the county health laboratories had the capability to perform measles testing at their location. The overwhelming volume of primary specimens, the insufficient epidemiological resources to triage cases, the lack of trained staff to fill in for surge capacity (despite previous cross-training efforts), and the increased number of requests contributed to a significant backlog in testing. The courier service used for transportation further contributed to testing delays, particularly for samples arriving from Los Angeles County or San Diego County, often adding 24 to 48 h to the turnaround time. Although CDPH had an updated outbreak response plan in place, the measles outbreak simply exceeded the testing capacity of laboratory.

Likewise, in Minnesota, receiving specimens from around the state for testing at the local PHL, especially from remote areas, was challenging. The time needed to transport a specimen was not considered by submitters, which caused confusion about expected turnaround times and increased time for individuals to be quarantined inside their homes.

Lessons learned. In response to the overwhelming number of specimens submitted during the outbreaks, both the California and the Minnesota PHLs implemented several strategies to help with specimen flow and communication to other groups. Both PHLs created a "Frequently Asked Questions" sheet to explain specimen collection and testing procedures for submitters and held regular update teleconference meetings with key stakeholders, which saved valuable time spent answering individual phone calls. CDPH determined that activation of an incident command structure (ICS) early during the outbreak likely would have helped identify and communicate specific assignments and responsibilities to stakeholders and partners and result in a more efficient outbreak response. The event also taught both PHLs that structured and predictable communication can help alleviate laboratory staff burnout as test requests climb.

To combat the significant challenge with communication protocols between the laboratory and external health care professionals, the PHLs worked with internal and external stakeholders to streamline communications. CDPH first created an internal

Medical and Epidemiology Liaison Section. This section was used to help appropriately route patient specimens and report results. Members were trained to take calls from submitters, to obtain missing information (including date of symptom onset or vaccination date), and to send out final reports. Ultimately, the Medical and Epidemiology Liaison Section streamlined specimen flow and improved patient reporting. The CDPH also worked with the CDC, who sent trained personnel to assist in harmonizing communication protocols between epidemiology, immunization, and laboratory groups. The online electronic collaborative platform SharePoint was used to share data in real time between the laboratory staff and the epidemiology group. This platform allowed quick and efficient tracking of specimens en route and in the laboratory, which supplanted the need for email or phone communication for locating individual samples. Both initiatives during the outbreak improved communication between stakeholders and reduced staff time required to troubleshoot specimens.

A few very simple solutions were implemented by both PHLs to further streamline laboratory testing. At the CDPH, a specimen arrival cutoff time was established; specimens arriving after that time were scheduled to run the following day. As stakeholders were able to track arrival time via the SharePoint file, they knew when to expect results from specimens, which eliminated a call for estimated turnaround times. Likewise, standardized and consistent laboratory-to-epidemiology reporting (twice a day) allowed both groups to anticipate result arrival and workload. In MDH, email communication between laboratory and epidemiology groups was improved with a simple, but highly effective "positive" in the subject line of emails. This strategy alerted epidemiologists that a positive sample was on the run, helping prioritize specimens and streamline the epidemiological workflow. It also promoted a sense of collaboration and camaraderie between the two groups, which facilitated later downstream troubleshooting. Finally, to service remote regions effectively, and to make transport times more transparent, MDH employed a UPS tracking system to help submitters track the location of samples and ease submitter misconceptions over perceived increases in turnaround time due to shipping delays.

Managing the concurrent outbreaks of measles, mumps, and varicella in MN was particularly challenging. The same laboratory testing and epidemiology follow-up personnel were needed for all three outbreaks, putting a significant strain on staffing. Strong communication and coordination among the various branches of the health system were therefore essential in managing the concurrent outbreaks. MDH instituted outbreak investigation and response activities in collaboration with local health departments, health care facilities, childcare facilities, and schools in affected settings. Scheduled daily meetings included staff representatives from the laboratory and epidemiology (including the Communicable Disease Director, the Patient Coordinator, and members of the following units: Vaccine Preventable Diseases [VPD]; Infectious Disease Laboratory; Epidemiology; MMR; Global Health; Immunizations; and Hospital Acquired Infections). These meetings were essential to maintaining testing, prioritizing issues, and working through problems. MDH worked with Hennepin County Human Services and their local public health department to issue health alerts with recommendations to health care providers for measles laboratory testing (including specimen and epidemiological requirements) and strategies to minimize transmission in health care settings. Updated guidance regarding vaccination recommendations, including an accelerated MMR vaccination schedule was communicated through health alerts in multiple languages (18).

Misinformation regarding vaccines has been linked to a reduction in vaccination rates, the reemergence of previously eradicated infectious diseases, and multiple outbreaks (19, 20). Working with the community, especially where cultural differences are pronounced, helps alleviate the learned mistrust of vaccines and government. During the outbreak, previously established, culturally appropriate community outreach approaches, including working with community and spiritual leaders, interpreters, health care providers, and community members, were intensified. Child care centers and schools were provided talking points and informational sheets on measles and the MMR vaccine, and posters with key messages were distributed in mosques and shopping malls popular with the Somali-American community. Community outreach focused on oral communication, including radio, television messaging, and telephone call-in lines. These community outreach efforts during the California and the Minnesota outbreaks helped increase local vaccination rates.

Recommendations. Whenever possible, implement electronic options to decrease manual entry. These solutions remain useful following the outbreak and can streamline other testing areas. For example, CDPH upgraded from manually transcribing clinical information into the laboratory information management system (LIMS) from handwritten submitter forms and manually faxing laboratory reports to using an electronic submitter form which could be directly received by the CDPH LIMS. Specimens were barcoded to improve tracking in the LIMS, and a formal plan for prioritizing specimens was established in the after-action report for better preparedness in the next outbreak.

While preparations and increased surge capacity may not always be adequate during an outbreak, the improved awareness of the role and importance of the PHL can facilitate improved responses. For example, both CDPH and MDH developed improved surge capacities following the measles outbreaks by increasing the number of cross-trained laboratorians and personnel. Although CDPH conducted cross-training during the outbreak, and staff were borrowed from other sections, many staff worked 7 days a week, leading to burn-out. Though MDH had relatively more cross-trained staff available during the outbreak, more were needed to meet all testing needs.

An outbreak often forces increased communication between groups, where previously, low or no regular communication occurred. Maintenance of this enhanced communication will benefit future outbreaks as familiarity and trust are established between groups. For example, during the California outbreak, the use of SharePoint was increased, allowing the laboratory and the epidemiological group to follow the life span of specimens. Continuing this practice has strengthened communication between the two groups and has embedded the system into routine practice. In Minnesota, joint presentations by the laboratory and epidemiology group at a statewide annual collaborative meeting were introduced to discuss measles and other emerging diseases with general clinical laboratorians and other health care stakeholders. This proactive approach will help facilitate communication between the groups in future outbreaks. Finally, in response to the Minnesota outbreak, MDH increased the number of Somali-American outreach workers. These individuals are active members in the Somali-American community, can serve as translators, and have the capacity to better serve the community for numerous public health issues.

The unexpected nature of an outbreak makes it difficult to prepare for and to ensure that required reagents and staff are on hand when needed. PHLs have limited budgets, often with little room to absorb the unexpected cost of increased testing volumes. During the California outbreak, CDPH used a fee-for-service fund to rapidly purchase reagents. At the conclusion of the outbreak, 977 measles tests had been performed (75 positives), and over 6,000 case contacts had been investigated.

The MDH laboratory director worked with epidemiological leadership to gain support from state legislatures and gather additional funding support during the outbreak. Thanks in part to their advocacy, legislators created a $5 million fund exclusively to combat major infectious disease outbreaks during the 2017 legislative session. The Minnesota public health response account assisted with funding for public health response activities and helped cover the cost of reagents and personnel.

Planned, exercised, early, efficient, and structured communication between epidemiological, laboratory, and other stakeholder groups helps PHLs prepare to handle an outbreak and break down silos. ICS activation needs to be correctly implemented to be successful. Specific roles, responsibilities of individuals, and overall expectations need to be established and clearly communicated when the ICS is activated. Setting reasonable expectations for laboratories, including transparency in turnaround times and shipping estimates, can help decrease submitters' frustration. Finally, maintenance of funding to adequately cross-train staff, provide them support, and acknowledge their efforts during high testing periods can reduce burnout.

Ebola Virus Disease Outbreak in West Africa, 2013 to 2016

Although Ebola had previously caused smaller outbreaks in central and eastern Africa, the large-scale outbreak which emerged in West Africa in 2013 presented an extraordinary challenge to the health care systems of the affected countries and the international public health community (21). Many lessons were learned during these previous outbreaks which strengthened the response efforts in the 2019 response to Ebola in the Democratic Republic of Congo (22).

In the 2014 Ebola outbreak, the inadequacy of laboratory resources to effectively diagnose disease limited the response considerably. Traditionally underfunded laboratories in Ebola-affected areas contained outdated and degraded facilities. Furthermore, many existing laboratories in West Africa did not have the biosafety infrastructure or trained laboratory workers to handle specimens potentially infected with agents of high pathogenicity. PHLs had no algorithms in place for rapid rule-out of Ebola or established methods to deactivate specimens referred for other testing (23), which led to an inability to diagnose other important illnesses such as malaria and typhoid fever in patients who presented with signs of Ebola.

Laboratory staff lacked standardized and coordinated training for the outbreak. Each laboratory established different testing algorithms and trainings, leaving critical gaps in specimen referral and result reporting. Medical staff did not know where to refer specimens or how to safely handle and deliver specimens to the laboratory. Sample submission requirements included unique patient identifiers and forms with completed patient demographic information. While this process is standard practice, a massive influx of samples from existing and new sources made it difficult to ensure that two separate identifiers were included on every test requisition. Inaccurately filled request forms, poor Geographical Information System location information in remote sites, and poor specimen-patient tracking among multiple testing laboratories complicated the tracing of new cases.

The absence of community trust and involvement further complicated the outbreak response in many parts of West Africa where officials failed to engage local and regional community leaders (24). Government attempts to control Ebola transmission through implementing strict curfews and a cessation of commerce were seen as government interference and met with high levels of resistance by the community. Officials struggled to balance transmission prevention messaging and the need for people to live and work in their communities (24). The quality and rapidity of testing can have both positive and negative impacts on trust and community involvement in the response.

Hospitals and treatment centers did not always communicate with families about patients, which led to hesitance in seeking medical care. Although partly stemming from an existing gap in understanding, families were often left uncertain about the status of their loved ones who entered treatment facilities. Furthermore, communication around infection control practices in the community and burial practices was not initially conducted effectively, resulting in preventable infections among family members. The lack of messaging to combat stigmas and fear toward Ebola survivors made their reintegration back into the community difficult.

Lessons learned. Laboratory staff urgently needed training and support during the 2014 Ebola outbreak. International organizations stepped in to provide temporary staff and training. Despite uncoordinated and unstandardized initial training for laboratorians, Sierra Leone successfully trained and retained local personnel as part of the national Ebola rapid response team. The rapid response teams were mobilized to improve contact with and identification of new cases. Sierra Leone took advantage of the workforce initially trained on Ebola testing methods during the outbreak and trained staff in other laboratory testing techniques to improve overall diagnostic testing in affected areas. Importantly, the Ministry of Health and other local laboratory partners absorbed the cost of the Ebola rapid response team members to make them a permanent part of the health care system.

The multinational aspect of the outbreak created challenges with shipment and implementation of laboratory equipment. One of the successes of the Ebola outbreak was the deployment of mobile biosafety level 3 (BSL-3) laboratories, which provided an efficient way to deliver the high-containment facilities needed for Ebola testing (25, 26). These laboratories reduced the need to build or retrofit existing facilities to handle highly pathogenic agents and improved the safety and consistency of testing.

To support the outbreak response, appropriate surveillance and reporting networks were needed in near real time. This initiative required strong coordination between the clinicians, the laboratory, and local and national health care officials. The first step was timely diagnosis of newly infected patients to allow local contact tracing to begin. Community involvement and establishment of emergency telephone numbers further increased communication regarding probable cases and Ebola-related deaths. As the outbreak continued, newly established and broadened national and international surveillance networks facilitated cross-country contact tracing and eventually led to the conclusion of the outbreak.

At the time of the outbreak in West Africa, U.S. PHLs did not have Ebola testing capabilities. The U.S. Department of Defense (DoD) secured U.S. Food and Drug Administration (FDA) emergency use authorization (EUA) for their Ebola Zaire assay (EZ1 real-time RT-PCR assay) (27). As a national member of the Laboratory Response Network for Biological Threats Preparedness (LRN-B), the DoD collaborated with the CDC to deploy the EUA assay to PHLs. APHL assisted the CDC with prioritization of PHLs to ensure optimal nationwide coverage and advocated for widespread distribution of testing. APHL additionally developed a risk assessment template to help laboratories safely implement testing and collaborated with the CDC to provide technical assistance. As a result, the Texas Department of State Health Services, Laboratory Services Section, safely identified the first case of Ebola in the United States (28). However, as additional U.S.-based cases were identified, other public health challenges emerged, including inadequate biosafety practices in clinical laboratories, lack of or inappropriate use of personal protective equipment (PPE), and lack of training and certification for shipping infectious substances. In response, congressional funding to the CDC created dedicated biosafety officer (BSO) positions at PHLs to perform outreach to private clinical laboratories, assist with risk assessments, and strengthen other biosafety practices.

Recommendations. Strengthening communication, coordination, and collaboration between international organizations was a key factor in the conclusion of the West Africa Ebola outbreak. Organizations such the World Health Organization (WHO), CDC, APHL, the American Society for Microbiology (ASM), and nongovernmental partners focused efforts on building and strengthening laboratory systems internationally. These organizations provided foundational support to develop national strategic plans and policies that strengthened national laboratory systems; however, strong laboratory quality management systems through staff training and support for LIMS are still needed in many countries.

National laboratory systems with testing methods, algorithms, and trained personnel ensure a stronger, more prepared workforce. Current testing strategies for Ebola require highly skilled laboratorians and specialized laboratory facilities. In order to successfully prepare for outbreaks, PHLs need to develop testing expertise and, importantly, find strategies to retain trained laboratory staff. Continued research into new generations of field-capable rapid diagnostic testing could allow countries to respond more quickly to new threats. Research universities offer an opportunity for affected countries to conduct research to understand the ecological and biological questions surrounding Ebola; investing in these opportunities can help increase the capacity of these countries to respond to future threats. Importantly, these universities can assist in the creation of biological repositories to assist in the development and evaluation of new technologies.

A One Health approach is particularly helpful in the case of Ebola, where the ecology and evolution of the virus in the environment are not fully understood. In response to the West Africa Ebola outbreak, the Global Health Security Agenda (GHSA) was established. The GHSA represents coordination and partnership of 64 nations, international organizations, and nongovernment agencies (as of April 2019) (https://www.ghsagenda.org) whose goal is to "prevent, detect, and respond to human and animal infectious disease threats." These multisector international initiatives are critical to better prepare the global community for detecting and responding to emerging threats.

The establishment of emergency operations centers in affected countries was critical for bringing together key stakeholders during the Ebola response. However, the cyclical need for response teams can lead to a lack of long-term investment in resources and people for continued disease surveillance systems. It is important to emphasize the role of a systematic and integrated surveillance system to detect future outbreaks. One successful example is the Field Epidemiology Training Program run through the CDC, whose goal is to expand the global public health workforce by training epidemiologists in over 70 countries. These trained individuals are given the expertise to track outbreaks locally and to globally share the information to help decrease disease transmission. Additionally, national and regional strategic planning for public health responses and exercises can help reinforce communication and coordination among stakeholders to ensure appropriate mobilization of response in future outbreaks.

In the United States, a more integrated public-private laboratory system is needed to ensure the early identification of emerging or reemerging threats and coordination of the responses. While the LRN has successfully developed its network of private clinical and governmental PHLs, the network needs to further invest in timely evaluation of new technologies, biosafety, and increased outreach to private clinical laboratories and, importantly, secure increased funding for PHLs.

Key points. Prearranged agreements between stakeholders (national and international) for reagents, testing, and personnel are needed to quickly respond to an emergency. Reciprocal agreements between PHLs have previously been used successfully. SMEs recommend establishing a system for supply procurement to (1) ensure accessibility and (2) facilitate rapid distribution of surge supplies in an emergency response. Biological repositories can also be created to facilitate new diagnostic development. Finally, establishment of adequate infrastructure, trained staff, and robust communication channels, which are tested through tabletop exercises prior to events, can improve the response to emerging outbreaks.

RESPONSE TO CHEMICAL HEALTH EVENTS

Emerging Contaminants: PFAS

Per- and polyfluoroalkylated substances (PFAS), a group of thousands of man-made chemicals, have been manufactured since the 1940s (29). PFAS have many applications, including production of stain and water repellants, food packaging, nonstick cookware, electronics, and firefighting foam (29). PFAS are highly stable chemicals, resistant to environmental and metabolic breakdown, and are found in the environment, humans, crops, and wildlife (30–32). According to the U.S. Environmental Protection Agency (EPA), between 1999 and 2012, perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) were found in the blood serum of up to 99% of the U.S. general population (33). While CDC data show that PFOS and PFOA levels are steadily declining in humans (as their use in manufacturing has declined) (34), high levels of PFAS can lead to severe adverse health effects (35). Exposure routes include contact with items manufactured using PFAS and contact with contaminated water, food, and ambient air (36, 37).

In late 2014, the EPA found high levels of PFAS at a converted New Hampshire Air Force base caused by the use of PFAS-based firefighting foam. Multiple businesses on the former base, including a day care center, regularly used the contaminated drinking water. The New Hampshire Department of Health and Human Services (NHDHHS) worked with the Department of Environmental Services (DES) and the incident management team to release this information to the public. Following the release, members of the public requested to be tested. The New Hampshire governor agreed with the need for testing, and in the interest of public well-being, few limitations were placed on who was eligible.

At the time of the event, the NHDHHS laboratory did not have the capability to perform PFAS testing. The department had to pack and ship all submitted samples to reference laboratories for testing, including the CDC National Center for Environmental Health (NCEH) and the New York State Department of Health's Wadsworth Center, for testing. To accommodate the test numbers and time frame needed to address public concerns, the NHDHHS established a permanent emergency contract with the Wadsworth Center. The NHDHHS relied on local health care providers for specimen collection and provided kits to former residents who had since moved out of state. The department shared information with the affected community through phone hotlines, community meetings, and the DHHS website.

As a result of the growing national concern raised by the contamination in New Hampshire and other states, the EPA released drinking water health advisories in 2016 for PFOS (36) and PFOA (37), with recommended limits for these compounds in drinking water. The detection of high levels of PFAS in a common source water allowed state and local public health departments to mount response efforts and protect the public from this emerging health risk. The governor of Michigan took proactive measures and established the Michigan PFAS Action Response Team (MPART) in 2017. This leadership team comprises seven state departments and includes toxicologists and epidemiologists. Importantly, the state allocated funding to develop testing and support PFAS response efforts.

These measures paid off in July of 2018 during a Michigan-wide initiative to test all public water systems for PFAS. During this project, the city of Parchment public water supply tested above the EPA limit for PFOS/PFOA. The Kalamazoo Health and Community Services Department of Kalamazoo County facilitated the ground response, while the Michigan DHHS Community Health Emergency Coordination Center (CHECC) and the State Emergency Operations Center (EOC), coordinated public messaging. All residents within a 1.5-mile radius were notified of a do-not-drink order until the Parchment water supply could be switched to the Kalamazoo city water supply and affected pipes could be flushed and retested. During this time, officials distributed bottled water and faucet filters to all public and private residences.

Lessons learned. Two different approaches were used to handle the New Hampshire and the Michigan responses. New Hampshire did not have established systems in place for PFAS, while Michigan had established protocols and infrastructure prior to detection of the contamination. However, common themes were identified from each event. For example, clear and concise information to the public was essential to complete testing.

Telephone hotlines were established and publicized early in New Hampshire and Michigan to help answer the public's questions. NHDHHS provided just-in-time training and resources through overtime pay to staff to answer the phones. Staff were also provided with scripted answers to frequently asked questions to ensure that the public received a correct and consistent message. New Hampshire routinely updated the website and included Poison Control in the messaging process. In Michigan, press conferences were held jointly by all local and state agencies to reinforce consistency of messaging. Public messaging was challenging during both the New Hampshire and Michigan events, as the health effects of PFAS exposure were not well understood at the time. Messaging was carefully crafted to decrease public panic while still effectively communicating known facts about PFAS. Advertisement of action items, including switching water sources and providing the public with bottled water and/or filters helped reinforce the states' commitment to public safety and emphasized their role in short- and long-term public health planning.

Consistent internal communication was also found to be essential in both the New Hampshire and Michigan events.

In each case, incident commands were activated for greater than 1 year, which strengthened rapport between departments and encouraged relationships past the initial contamination events. The Michigan DHHS used MPART and other infrastructure, such as the CHECC and state EOC, as tools, while NHDHHS used exercises and team-building activities to help partners get to know each other. Michigan's incident command center streamlined communication and specifically identified roles and responsibilities for the Parchment response. Established lines of communication were fostered through daily coordination calls by the unified command and weekly calls with stakeholders. Relationships were previously established between state and departmental agencies, which facilitated dissemination of governor-supplied PFAS testing resources. New Hampshire relied on external partners for testing services; however, direct entry of results into LIMS in the field allowed for efficient transmission of sample data and results between organizations. Additionally, NHDHHS worked jointly with DES to oversee the response and rapidly disseminate information.

When the contaminated water sources were discovered, neither state laboratory had the capability or capacity to do mass testing of PFAS in humans. Each state relied on testing support from the CDC, other states, and/or private laboratories. The states each overcame early challenges to consistency (e.g., the number of PFAS tested in each laboratories' panel) by using a single reference laboratory. Though New Hampshire established contracts for testing during the response, they addressed the need to have these in place before an event in the after-action activities to increase efficiency in the future. New Hampshire used its strong relationship with New Hampshire hospitals to partner with the local hospital for sample collection. Michigan also established an agreement with a contractual testing laboratory as part of the response and already had vendor agreements in place with funding available to cover the multitude of costs associated with their response.

One of the reasons Michigan was so well prepared was because it had established multiple systems based on lessons learned from previous environmental health threats and had funding and infrastructure in place to address PFAS. New Hampshire participated in impartial, professionally facilitated after-action activities and provided a publicly available report with action items on its website. Monitoring activities continue within the state. Notably, the preparedness efforts allowed the Michigan DHHS to successfully address the PFAS contamination event concurrently with a state hepatitis A outbreak. Importantly, the infrastructure, established communication channels, strong partnerships, and resources were essential for timely and coordinated responses to both crises.

Recommendations. Resource management is a large part of any response effort; therefore, preestablished emergency contracts, memorandums of understanding (MOUs), and sharing agreements can facilitate a quick response to emerging threats. Likewise, preidentification of required resources, such as bottled water, faucet filters, and a distribution plan, can ensure that resources are in place during a crisis. The timely procurement and delivery of resource stockpiles requires appropriate funding for both PHLs and other public health departments. Evacuations may be necessary in cases of dangerously toxic chemical exposure. Displaced individuals require basic needs, including shelter, food, and clean drinking water. Preparedness efforts should also include plans to secure the resources necessary to coordinate evacuations and associated cleanup efforts.

While PHLs have built a solid foundation of surveillance and response procedures related to food and infectious disease outbreaks, chemical contamination events (such as PFAS) have highlighted the importance of developing a similarly strong foundation of response for environmental events. Staff members with environmental epidemiology expertise and the authority to respond during crisis events are essential to identify upcoming threats and activate response teams. Forming leadership groups with cross-representation from associated government agencies, including PHLs, fosters open communication and builds a foundation for environmental issues. Proper stakeholder involvement is particularly important in the case of PFAS, which can be found in soil, groundwater, and shared air and waterways. The development of regional consortia and governing bodies over common resources dedicated to discussing and addressing environmental contaminants can open channels of communication across borders and foster improved working relationships.

The importance of a well-functioning ICS during an event cannot be understated. An ICS allows for a structured method of communication, coordination, and collaboration between government departments, private companies, and the public. To effectively use an ICS during an event, public health leaders and staff must understand and be trained on incident command structure and function. Departments should provide ICS training for all public health entities and their partners, including refresher courses and routine exercises that focus on public health (38). When an ICS is activated, command must include representation from all affected government areas to improve access to information, to coordinate the use of resources, and to prevent redundancy of effort, thereby saving time and money. ICS leadership tends to overlook representatives from finance and legal departments; however, their early involvement in the emerging threat can help increase efficiency and identify pitfalls.

To minimize panic and ensure that safe practices are known and understood during an event (e.g., do-not-drink advisories), information must be distributed to the public in a clear, concise, and uniform manner. The process for the creation, approval, and distribution of information must be streamlined to ensure that accurate information is available quickly and distributed from a centralized source. New Hampshire successfully used regularly updated public information websites to provide on-demand, current information. PHLs may find that they need to train the public to go to their site and promote its existence. Additionally, New Hampshire and Michigan communicated with members of the public through door-to-door campaigns, call centers, and community meetings. Care must be taken to ensure that the message is complete and remains consistent across all distribution methods to avoid confusion and distrust.

After an event, it is important that all parties discuss best practices and improvements for the future. Discussions are best facilitated by impartial, experienced outside professionals and should foster frank and transparent dialogue. Effective after-action focuses on identifying what worked well or could be improved but does not look to assign blame. These discussions, and any resulting plans, should be documented, openly shared, use SMART objectives (specific, measurable, actionable, realistic, and timely), and include relevant stakeholders, a timeline for objective completion, and a plan for future evaluation and follow-up.

While many public health departments have plans and protocols in place to handle short-term events, long-term strategies should also be established for events with long-lasting effects (such as PFAS). For example, human biomonitoring systems and environmental monitoring to establish a baseline level of exposure are essential to understanding changes in PFAS levels over time. Continued long-term monitoring of the general population and comparison against individuals with known exposure can help define risk and health outcomes and be correlated with safety levels of environmental contaminants.

Key points. Educating leadership and staff on emerging environmental threats helps guide decision making; state public health teams need an environmental health expert. States should identify internal resources, prepare distribution strategies, and preestablish contracts and/or agreements for emergency procurement and services. Biomonitoring programs should be established and used to provide state-specific baselines for environmental contaminants and response capability for human specimen screening during a chemical exposure event. After-action discussions should be transparent, documented, and contain SMART objectives.

Opioid Crisis

Whereas PHLs' response to PFAS health threats tend to be for site-specific contaminations, the opioid epidemic requires a significantly more widespread approach. Opioids are a group of chemically similar drugs that includes heroin and prescription painkillers such as oxycodone (OxyContin) and hydrocodone (Vicodin) (39, 40). The misuse of opioids has been increasing in recent years, with 11.5 million people abusing prescription painkillers and 948,000 using heroin in 2016 (39, 40). Additionally, researchers observed a significant increase in the number of people aged 18 to 25 misusing opioids, with 7.3% of the age group reporting use (39, 40).

Unlike infectious disease outbreaks, where diagnosis of disease produces a rapid response from PHLs, clinicians, and the public to mitigate the spread of the pathogen, the onset of the opioid crisis was more insidious. In Kentucky, a switch in workplace fatalities from primarily an agricultural focus prior to 2005 to a focus on motor vehicle fatalities after 2005 indicated early on that the use of opioids was increasing. Many of the motor vehicle fatalities involved commercial drivers who upon autopsy had prescription opioids, benzodiazepine, or muscle relaxants in their system. This observation preceded an increase in opioid-related drug overdoses from hospital inpatient data sources (41).

In response to the increasing number of opioid-related traffic fatalities identified in 2005, and the identification of those who were misusing opioids, the Kentucky Injury Prevention and Research Center (KIPRC) applied for government grants in collaboration with the University of Kentucky and the Kentucky State Department for Public Health. The Core Violence and Injury Program received funding to facilitate ongoing surveillance of opioid overdose and foster statewide collaborations. Researchers compiled results from these studies and presented them to state representatives to assist in policy making. Routine analysis of data sources is critical to identify new and emerging issues, risk factors, and patterns at both the national and state levels. Monitoring trends not only allows public health professionals to better prepare for upcoming issues but allows the time to assess best strategies to address the problem, including stakeholder involvement. Kentucky's first opioid-related report in 2012 (42) played a role in the enactment of House Bill 1, demonstrating the successful translation of public health data into public policy. The house bill included (i) a requirement for pain clinics to be 50% owned by a physician, (ii) a mandatory prescription monitoring program for Drug Enforcement Administration (DEA)-licensed physicians, and (iii) interconnected prescription drug monitoring programs with surrounding states (43). These initiatives prevented pain clinics from opening without a licensed practitioner, with the intent to decrease the overprescribing of opioids for the public. The improved data flow across state borders helped deal with the crisis in multiple ways, including preventing a commercial vehicle driver who tests positive for drugs without a valid prescription from being hired as a driver by another company.

Generally, the PHL is tasked with the diagnosis of disease; however, the unique situation of the opioid crisis required public health to fill an unmet need in the system. In Kentucky, finding an opening for a patient in need of substance use disorder treatment was difficult. Often, nurses could spend up to 6 hours calling facilities to inquire about openings and matching facilities with the patients' insurance provider. A joint initiative between the KIPRC, the Kentucky Office of Drug Control Policy, the Kentucky Department for Public Health, and the University of Kentucky created the website FindHelpNowKY.org. Staff update the website every 24 hours with bed openings, and each facility lists the type of insurance they accept. With a few quick keystrokes, a patient can find an open facility that will also accept their insurance. Users spend an average of 7 minutes on the website. Additionally, the website helps identify where the need is and where patients want to go for treatment. By tracking user inputs (while maintaining user anonymity), the type of facility, location, and service requested can be used by facilitators to determine what facilities/services are required. These results can be presented to policy makers to facilitate directed funding where it is most needed.

Testing for the presence of opioids is relatively new for PHLs, as prior to the opioid epidemic, no PHL routinely tested for these compounds. As with any new test implementation, there are challenges when standard operating procedures (SOP) are not available, and few laboratories have experience with opioid testing. To facilitate coordination of procedures and testing strategies, laboratories with experience in testing openly published their SOPs on the Internet, and organizations such as APHL held Fusion Center meetings to strengthen the community testing ability and bring testers together to solve problems and work on solutions. Simultaneously, PHLs learned from experienced chemists how to improve testing performance characteristics. This strategy was largely successful, as many PHLs across the country have since incorporated routine testing for opioids and other drugs. As with Ebola, where an established test was not readily available, a coordinated response that includes method development saves time, redundancy, and resources.

The District of Columbia PHL (DCPHL) observed an increase in opioid-related deaths in 2015. The laboratory found new chemical compounds to be responsible for the increase, specifically synthetic opioids driven by the presence of fentanyl. The DCPHL implemented new laboratory assays to identify these compounds and became one of the sentinel sites for fentanyl detection in the country. Since then, the DCPHL became a full-time Drug Enforcement Administration (DEA)-licensed drug laboratory and works closely with the Office of the Chief Medical Examiner, law enforcement, and the DEA on opioid-related cases. PHLs have the responsibility to know what other requirements may be needed in addition to a DEA license.

Recommendations. Opioid use is a newly emerging public health threat that is worsening through the SARS-CoV-2 pandemic (44). Like any other illness, opioid addiction requires medical treatment as a disease. PHLs can help by actively monitoring for opioid use to educate policymakers and legislators about the issues in their jurisdictions. Increased patient engagement can help decision makers identify the specific locations and types of treatment facility most needed by communities. Additionally, access to mental health and social services should be easily accessible for users, affordable or free, and tailored to address the challenges presented by the pandemic. PHLs can help by providing and monitoring services, including access to medicinal marijuana, needle exchange programs, safe sites, and naloxone. Secondary health concerns, such as shared needles increasing the prevalence of bloodborne pathogens, may also warrant monitoring by PHLs to better gauge the impact of increased opioid use. As with any emerging threat, data on the efficacy of each tool can be shared with governmental leaders to help shape public policy and ensure that limited resources are used in the most efficient way.

Key points. PHLs need to routinely monitor data sources for emerging trends. Engagement with the community allows those affected to have a voice in what should be done to help. Public health needs to leverage limited funding and ensure that policy makers and all stakeholders know of the issues and needs to ensure that programs are optimally funded.

Natural Disasters

Planning is essential to provide a coordinated and consistent response to natural disasters, especially when those natural disasters threaten the operations of a PHL. Examples include minor short-term shutdowns such as the half-day shutdown in Missouri due to a tornado, and well-publicized long-term shutdowns such as the entire public health system in Puerto Rico after Hurricane Maria. PHLs that have successfully continued operations in the event of a natural disaster emphasized the importance of an up-to-date natural disaster plan.

Lessons learned. Effective continuity of operation plans (COOP) may consider the geographic location of the PHL and anticipate all possible natural disasters that could occur (e.g., hurricanes, storms, wildfires, and earthquakes). Successful laboratory leaders often outline essential services and the maximum time that nonessential services can be offline before backup testing strategies need to be implemented. Making key decisions prior to an event helps ensure a rapid response to the incident. For example, if a wildfire strikes, leadership may decide that rabies testing services should be prioritized due to increased encounters with wildlife and the rapid turnaround time needed for rabies testing, while testing services for ova and parasites may be delayed for a few days. Complete COOP documents may include personnel information (i.e., who is trained and on what assay), requirements for building infrastructure, and available support systems. Having this essential information compiled prior to an emergency event streamlines information gathering and facilitates information-based decision-making. Of note, some natural disasters provide significantly more warning than others (wildfires and hurricanes versus earthquakes and tornados). An adaptable plan allows for flexibility in the lead-up to foreseeable disasters.

Success in maintaining critical laboratory services often relies on direct and frequent communication between laboratory leadership, executive state leadership, and emergency managers at the EOC. Preestablished relationships and the ability to contact leadership quickly can significantly improve response efforts. Some PHLs have created a cell phone list of all staff, including senior leaders in their organizations, to facilitate rapid assistance for issues that cannot wait to flow through normal channels. Communication to laboratory staff via mass communication systems which call or send text messages to staff are effective to rapidly contact staff and let staff to know if the laboratory is open and if it is safe to come to work. Additionally, some web-based systems allow the user to monitor whether staff have responded to the messages. PHLs should be aware that staff may not answer calls from unknown callers and that cellular service can be intermittent during a natural disaster. Prior to an event, PHLs may choose to coach staff regarding the need to answer their cell phones regardless of caller ID during an emergency response. Some laboratories have created a phone message which staff can call into to get timely updates 24/7.

Creation of a laboratory liaison position can fill a pivotal role in coordinating and interpreting needs between the laboratory and the EOC. The liaison listens to the needs of the laboratory, takes those needs to the EOC, coordinates the planning and logistics of meeting those needs, and communicates the priorities of the EOC back to the laboratory. By removing the burden of logistical discussions from the laboratory staff, laboratory personnel can focus on testing and reporting during a crisis. With the liaison, laboratories have been able to find assistance with transport of specimens when courier services were down by coordinating with their state EOCs and to expedite the purchase of fuel for laboratory generators. It is essential that the person chosen as the liaison has detailed knowledge of the laboratory and is able to translate the needs of the laboratory effectively to the EOC.

Clear communication with external stakeholders is also essential during an emergency response, particularly in the event of a laboratory closure. Laboratories can post notices on their websites, send mass emails and faxes, and in some cases, call submitters to notify them. During disaster planning, laboratories should list all stakeholders (i.e., epidemiologists, public health programs, local and regional health departments, and private clinics) and ensure that they have up-to-date email addresses and phone, and fax numbers. Laboratories should also consider that in some emergencies, communication systems, including Internet and phone lines, might be inoperable or have intermittent service. Many laboratories have contingency plans for alternative ways to communicate with customers and can provide a list of private laboratories or regional PHLs who may be able to fill temporary testing voids.

Recommendations. Hurricanes can cause flooding, covering roads and intersections, while heat from wildfires can become so intense that blacktop roads melt. Road closures lead to specimen transportation delays, as couriers can have difficulty picking up and delivering samples to the laboratory. Since the window for treatment of certain metabolic diseases in newborns is very short, newborn screening relies on rapid transport to the laboratory and reporting of results back to physicians. Specimen transport delays and complications in delivering results can significantly impact the health of an infant. Additionally, the transport and testing of public water sources during an emergency is paramount for the health of the population. PHLs that have experienced fires and floods observed a marked spike in the number of water samples sent in for testing, and experienced laboratories can anticipate and plan for an increased specimen load in their COOPs. This preparation may include extending testing hours to meet increased testing volumes (special consideration is needed for jurisdictions where staff are unionized), identifying if permissions are required for laboratory staff to work in the event state offices are closed, identifying emergency-essential staff and securing the appropriate documentation on a yearly basis, creating alternative purchasing and procurement processes to respond to increases in volumes, planning for how to rapidly train additional staff, and working with couriers and delivery teams to detail communication plans during emergencies or disasters prior to an event. These communication plans may be tested regularly to assess their efficacy and to reinforce the process should an emergency event occur.

Finally, laboratory staff are invaluable in a disaster response. PHLs should plan for and diligently provide staff the resources to prepare for the natural disaster at home. When staff are confident their families and homes are adequately prepared for a natural disaster, they are more willing to come into work when called upon during a disaster response.

Key points. Ensuring that laboratory staff are adequately trained at work, and prepared for natural disasters at home, will facilitate the PHL's ability to provide services during an event. Having an up-to-date COOP, testing it on a routine basis, and planning for as many contingencies as possible will help a PHL prepare for many different types of natural disasters. Establishing a laboratory liaison position to communicate laboratory needs to EOC members can relieve the burden from laboratorians, improve efficiency, and facilitate communication of needs. Outlining communication plans and alternative back-up plans with internal and external stakeholders and testing these on a regular basis will help ensure that PHL staff and their partners are prepared for a real-world emergency.

RESPONSE TO GAPS IN FUNDING

Government Shutdowns

All entities rely on funding to provide products or services. For PHLs, these funds can come through fee-for-service revenue streams or can be allocated through government budgets. While fee-for-service makes sense for private laboratories, PHLs offer services including preparedness, emergency response, and surveillance, which do not fit the fee-for-service model. PHLs are therefore susceptible to temporary and long-term loss of funding, such as government shutdowns. Government shutdowns occur when agreement cannot be reached on budget allocations prior to the beginning of a new budget cycle. Generally, lack of a consensus can come from legislators disagreeing on the contents of a bill or the executive branch vetoing the proposed spending bill. Until a compromise can be made, government actions that depend on the unapproved spending bills must cease.

Since the modern-day budget process was implemented in 1976, 22 lapses in government funding have occurred (45). In January 2019, the United States ended the longest government shutdown in the nation's history, which lasted 35 days, surpassing the 21-day shutdown of 1995 to 1996. In the 1995 to 1996 shutdown, 380,000 federal workers were furloughed, and an additional 420,000 workers were required to work without pay (46). The shutdown of December 2018 to January 2019 centered around a disagreement about border security and immigration (46, 47). Overall, the shutdown cost the U.S. government approximately $5 billion, including $3 billion in back pay for furloughed workers, and the U.S. economy $11 billion as a whole (48). Many federal agencies, including the CDC, continued to operate through the December 2018 to January 2019 shutdown; however, other agencies had to identify critical operations and furlough all nonessential personnel.

In 2011, the Minnesota state government shut down for 20 days when the legislature and governor were unable to come to a resolution to balance a budget shortfall. The shutdown started at midnight on 1 July (the beginning of the fiscal year) and ended when a budget bill was passed and signed on 20 July 2011 (5). Like federal government shutdowns, all nonessential services were required to cease during the shutdown, and all agencies were required to determine which functions were deemed "priority one and two critical services" (6), as these were the only services that would continue operating.

In addition to any revenue they may generate, PHLs depend on state and federal funding for their regular activities, as well as indirect support from government agencies such as the FDA and the CDC to support national testing networks, confirmatory testing, training, and communication. State funding sources for PHLs include line items in the state budget, agreements with other state agencies, and in certain cases, state-based grants. Delays in spending allocations can significantly affect the ability of a PHL to provide the public health services required by their constituents.

The CDC uses cooperative agreements to help states with their capabilities and capacity to meet two of the high-priority public health objectives it has identified. The federally funded Public Health Emergency Preparedness Cooperative Agreement (PHEP) has supported preparedness and response efforts in state, local, tribal, and territorial public health departments since 2002. This funding covers over 800 laboratory scientist positions throughout the 50 states, the District of Columbia, and Puerto Rico PHLs, and allows PHLs to maintain the capacity and capability to effectively respond to hazards and threats, including infectious disease, natural disasters, biological, chemical, nuclear, and radiological emergencies. The CDC established the Epidemiology and Laboratory Capacity for Prevention and Control of Emerging Infectious Diseases (ELC) cooperative agreement in 1995 with $2 million serving eight grantees. In 2010, the program significantly expanded, receiving a $40 million annual infusion from the Prevention and Public Health Fund, making it the first and only mandatory public health funding program in the United States. This increase broadened the ELC's scope and expanded the number of PHLs able to receive funding for capacity building aimed at reducing illness and deaths from infectious diseases (49). Currently, all 50 state health departments, 6 of the nation's largest local health departments (Chicago, the District of Columbia, Houston, Los Angeles County, New York City, and Philadelphia), and 8 territories or U.S. affiliates, including the U.S. Virgin Islands, Puerto Rico, and Guam, receive ELC funding.

Biggest challenges. As indicated in "Natural Disasters," part of continuity of operations planning consists of federal and state agencies categorizing their employees as essential or nonessential under various conditions (ranging from weather emergencies to furloughs due to shutdowns). Staffing contracts are not always funded during shutdowns, and contractors need to use vacation time or leave without pay. Determining which employees are essential, and can therefore continue to work with pay, is at the discretion of each organization and has a significant impact on how the agency responds to a shutdown.

In the Minnesota shutdown, essential personnel were defined as those who could perform the testing identified as essential. Testing requirements dictated the skillset and the number of staff needed to perform all essential functions. The MDH initially reduced staffing during the shutdown in 2011 to approximately 40%. Because Minnesota is a union state, agencies were required to consider seniority when determining who could perform the essential testing. Leadership held several planning meetings in advance of the shutdown to identify essential functions and key personnel. To avoid undue stress to staff, management opted to not widely share select discussions while waiting to see whether the shutdown would happen. The MDH coordinated staffing for the infectious disease laboratory with epidemiology partners, as they would be needed to follow up on outbreak investigations. Leadership deemed staffing for newborn screening bloodspot testing and follow-up essential, as well as staffing for receiving environmental samples and testing for water quality. Once the shutdown began, the MDH reduced staffing to minimum levels with bench-level staff being prioritized over managerial/supervisor staff.

To maintain operations of a PHL involved in a government shutdown, just-in-time cross-training is often needed for staff involved in essential testing operations. In the case of the Minnesota shutdown, the laboratory could not start cross-training staff on additional assays ahead of the shutdown, as it was not clear initially which testing areas would be deemed essential. As a direct result of previous cross-training efforts, however, the minimal laboratory staff still adequately covered multiple areas.

Many government organizations offer training to PHL staff from refresher courses for conventional methods to training on new technology. Federal agencies typically prohibit all travel by affected federal or state employees in the event of a government shutdown. In the case of a federal shutdown, some training programs may still be able to operate in the absence of affected federal employees, such as the LRN conventional methods courses. However, if a training program was hosted by an affected federal/state agency, all training is cancelled or postponed until funding is appropriated.

Lessons learned. Much of the funding for the infectious disease laboratory in the Minnesota PHL comes from federal grants. These grants were awarded preshutdown, and therefore funds were accessible even during the state shutdown (8). Overall, the shutdown did not significantly affect the supply of reagents and laboratory materials because of the time of year the shutdown occurred. Every year, the Minnesota PHL experiences a purchasing freeze at the end of the fiscal year. As a result, the laboratory had already prepurchased and received a large supply of testing reagents to last them until the new fiscal year. Purchasing new reagents during the shutdown would have been challenging due to the lack of staffing in the operations and financial areas during the shutdown.

In the event of a federal shutdown, laboratories in the LRN performing biological testing are particularly affected, as they depend on standard reagents developed by the CDC and other governmental organizations. During a shutdown, these organizations have difficulty providing and delivering reagents for testing to laboratories. In preparation for shutdowns, networks will issue communications for laboratories to anticipate reagent delays and prepare to stockpile reagents.

Communication played an important role in all aspects of the Minnesota shutdown, and often, limits to communication were realized for both internal and external partners. Internally, staff were aware of contingency planning activities; however, the final decisions for staffing could not be announced until the proposed list of critical services was court approved, causing anxiety among the staff who were not aware of plan details. For external partners, 10 days prior to the end of fiscal year, MDH sent letters regarding the potential shutdown, with directions about when and how additional information would be shared. On 1 July, MDH shared additional information on essential services via email and communicated through their website. Once the shutdown occurred, Minnesota activated an ICS and held daily meetings to update all on current activities. The ICS requested staffing increases based on testing requests, calls to the health department, and monitoring reports in the news media.

In anticipation of a shutdown, many federally managed networks proactively issue communications to members informing them of what services and staff will be available and what services are not considered essential. Often, coordination from multiple governmental organizations is required to provide consistent messaging.

One of the strategies used by governments to avoid shutdowns and address budget shortfalls is instituting a hiring freeze. A ban on hiring new personnel may be politically convenient; however, it places a great burden on PHLs. When a long-time employee retires, they are either not replaced (placing additional workload on current staff), or there can be significant delays in hiring their replacements. If the workload is shifted to current staff, they become at risk for burnout. If training overlap between the retiring worker and the newly hired worker is not available, institutional knowledge is lost.

PHLs increasingly rely on the use of contract employees as a temporary fix to hiring freezes. These contract positions offer lower pay and often do not provide benefits, increasing the likelihood of staff turnover. Time and resources are lost by permanent staff responsible for training contract workers and by management having to repeatedly fill the position. Higher-level positions are often difficult to fill, as more experienced applicants tend to not accept temporary positions without benefits and are not likely to stay if they do join. Furthermore, not filling a vacant position (or filling it with a contract employee) blocks the career advancement of current employees.

Ensuring that PHL leadership has a seat at the table and can communicate laboratory needs to the legislature and executive offices can help guide hiring policies. Efforts to address staffing that are clearly prioritized and transparent are needed. Permanent, long-term solutions to the increasing number of unfilled vacancies in PHLs are more likely to occur through resolute and honest communication between PHL leadership and policy makers.

Recommendations. Communication is essential and arguably the most important aspect of a coordinated response during government shutdowns. PHLs cannot prevent government shutdowns but can anticipate and prepare for lapses in funding. Laboratories can ensure that essential staff are identified, reagents are stockpiled, and staff are trained and ready to continue testing. If laboratories are prepared, they can minimize the impact of a shutdown and ensure the highest-quality support for public health and safety, domestically and internationally.

Key points. Laboratories should prepare for shutdowns by identifying essential testing in a funded continuity of operations plan, preemptively stockpiling reagents for critical tests, and cross-training staff whenever possible to allow flexibility in essential personnel. PHLs should communicate with internal and external stakeholders to minimize the anxiety of PHL staff and avoid surprises in testing availability. Standing agreements should be established with other PHLs to enable transfer of critical laboratory testing in the event that testing capacity is lost. PHL requirements should be communicated to policy makers, including priorities and cost-saving opportunities to avoid undesirable cost-cutting. These lessons can be put into action as PHLs face tightened budgets, furloughs, and hiring freezes due to lost revenue from suspended services or state funding being cut due to reduced tax revenues during the SARS-CoV-2 pandemic.

Technology Transfer

As global mobility continues to grow, public health threats such as infectious diseases, foodborne outbreaks, and contaminations of shared water and air commonly cross jurisdictional boundaries. To ensure consistency in methodology across PHLs and harmonization of public health data, regulators and funding agencies often need to set deadlines for all laboratories to switch to the newest technology or to adopt new methodologies. This consistency is necessary to ensure that results are comparable across laboratories and facilitates reliable epidemiological tracking of public health concerns. Coordination of large-scale roll-out plans is often challenging; however, strategies have been successfully employed to mitigate their impact.

The CDC established PulseNet in 1996 as a tool to track outbreaks and link cases caused by foodborne pathogens using a standardized protocol. The network has been highly successful at tracking foodborne illness and facilitated source identification in many large-scale outbreaks, including the *Escherichia coli* O157:H7 outbreak related to consumption of raw spinach in 2006 and the *Salmonella enterica* serovar Typhimurium outbreak related to consumption of peanut butter in 2009 (50, 51). In 2014, the CDC launched the Transforming Public Health Microbiology—PulseNet and Beyond program as a first step to move from the current pulsed-field gel electrophoresis (PFEG) method to whole-genome sequencing (WGS). WGS is more precise than PFGE in identifying pathogens, allowing for more robust and detailed data and an increased capacity to link cases of foodborne illness (52, 53). Since that time, PHLs have been working to develop capacity to switch to WGS, but with various states of readiness across North America. To facilitate a complete switch to WGS for all network members, PulseNet adopted WGS as the primary surveillance and outbreak detection method and set a deadline of 15 July 2019 for members to comply.

As technology progresses, the cost of sequencing continues to decrease, making it easier to generate large amounts of information. A challenge that has arisen is where to store and how to compile and analyze the data in a fast, accurate, secure, and easily digestible manner. Upon implementation of WGS in their laboratories, many PHLs experienced slowing of their LIMS due to the volume of data transfer from sequencing systems, while some PHLs did not have the required additional space to incorporate WGS data into their LIMS. PHLs are familiar with this issue, as it previously occurred with the PulseNet transition, requiring extended lag times to upload information into BioNumerics. To avoid delays for other routine testing, some PHLs opted to access secure cloud-based storage. For example, Colorado and Wyoming PHLs used preexisting government contracts with Google to handle data storage for WGS.

Accurate analysis of sequencing data traditionally requires specialized training in bioinformatics. APHL bioinformatics fellows are highly effective in facilitating the transition to WGS, and many SMEs suggest employing a bioinformatician with at least a master's-level degree in bioinformatics. To further address this challenge, the increasing availability of commercial software allows individuals without computer science backgrounds to perform advanced analyses. PHLs without a bioinformatician can still run these analyses, provided they have a laptop and an Internet connection. States relied successfully on leveraging other creative avenues, such as the Virginia Governor Terry McAuliffe's Commonwealth Data Internship Program to bring in expertise in bioinformatics. Through this initiative, an intern worked to connect state agencies with universities and alleviate state government issues with data and information technology usage through partnerships. The intern built a next-generation sequencing (NGS) single nucleotide polymorphism (SNP) pipeline and developed bioinformatics workflows. Since the internship program began, graduate students from academia (outside the internship program) also worked in the laboratory on their projects and helped with data transfer.

The use of highly trained molecular staff is essential to creating usable sequencing data; however, many PHL technologists did not have experience with sequencing at the onset of the transition to WGS. To develop this highly specialized workforce, PHLs often trained technologists with specialization in molecular diagnostics to perform WGS experiments. Using individuals who already had a background in molecular biology decreased the amount of teaching needed to train laboratory staff.

Lessons learned. Protocol standardization is essential for PulseNet members to accurately compare data and to assess linkages between clinical isolates. To ensure a standardized approach to sequencing data, member states used a single software program (BioNumerics) and created a protocol as standard operating procedure for analysis to ensure consistency in data analysis. This approach allowed members to quickly and accurately analyze sequencing data and to report it in a standardized fashion, even in the absence of bioinformatics staff expertise. Additionally, the CDC Office of Advanced Molecular Detection, through ELC, implemented Bioinformatic Regional Resources and Bioinformatic Training Leads for each PulseNet region to provide a centralized regional resource for capacity, troubleshooting, and workforce training.

Though the cost of WGS is decreasing overall, the savings are highest when laboratories perform the sequencing runs at or near full capacity. For large PHLs that have a great demand for testing, these savings can be significant; however, for PHLs that have limited capacity, the analytical costs can still be prohibitive. States such as Wyoming have addressed this issue by using a smaller flow cell as a cost-saving measure.

PulseNet additionally created a SharePoint site for data and document sharing between members. The SharePoint site allowed easy access to all SOPs, protocols, and tip sheets and facilitated quick access to any updates or solutions to frequently encountered problems.

Recommendations. Use of a centralized repository, where all PHLs could go to for resources and SOPs and to ask questions (such as the SharePoint site for PulseNet members) can facilitate communication and shared information. If a laboratory finds a successful solution to a common problem, a collaborative network facilitates the dissemination of the solution to other laboratories who are likely experiencing similar difficulties. Efforts from specialized groups such as the State Public Health Bioinformatics Group (StaPH-B) have started to fill this gap. STaPH-B is a group of public health scientists who develop high-quality answers to problems PHLs frequently encounter in bioinformatics (including training staff, building infrastructure, and developing applications). All resources are available free of charge on their websites (https://www.staphb.org and https://github.com/StaPH-B), which include links to other web-based tools, such as open-source bioinformatics pipeline software (54).

As requirements for quality control and verification studies are currently very high level, PHLs are encouraged to share validation plans and audit experiences. The College of American Pathologists (CAP) created an NGS checklist for cancer genomics testing; however, detailed WGS checklists for pathogen identification are currently unavailable. The Clinical and Laboratory Standards Institute is actively working with partners to develop individualized quality control plans (IQCP) and consensus recommendations for quality assurance and quality control management while focusing on how laboratories should proceed with validation and quality assurance/quality control setups.

Key points. Harmonization of technology and methodology is important for improved consistency of public health data and coordination of responses to public health threats. Having a funded mandate through a collaborative network can significantly expedite acquisition of methodology, instrumentation, and personnel training while incentivizing PHLs who may otherwise not make the transition due to lack of resources or interest. Having a platform where PHLs can share resources to facilitate problem solving and implementation of technology transfers reduces the time and effort that individual PHLs would lose by trying to solve problems on their own. Leveraging of resources (instrumentation or workforce development/fellowships) can increase the uptake of novel technologies while decreasing the barrier to entry for PHLs.

DISCUSSION

Overall, the authors interviewed dozens of subject matter experts and stakeholders on and off the record about their laboratories' response to new crises, the rise of emerging threats, and change management. Interviewers chose SMEs based on their lived experiences, their roles in the emergencies, and the unique challenges they faced during the response. We collected and chronicled their challenges and successes here to help PHLs and governmental laboratories better prepare for the next emerging issue (Table 1). Regardless of the crisis or emerging issue, all SMEs experienced similar themes, challenges, and opportunities for improvement (Table 2). As PHLs continue to face new and more complex challenges, learning from those who have experienced an emerging threat and in turn using those lessons to strengthen current disaster and emergency plans could significantly improve response rates and outcomes.

Resoundingly, SMEs considered communication the single most important criterion to improving responses to all emergency situations, from infectious disease to chemical and environmental contamination to dealing with government shutdowns. Open communication and discussion reduce redundancy and foster relationship building between individuals through face-to-face meetings, exercise events, training, or the encouragement of interdepartmental activities outside work. Fostering long-term

TABLE 2 Opportunities to improve consistency and coordination during a public health crisis

Common themes identified	Advantages	Implementation plan
Communication	Open communication and discussion reduce redundancy and foster relationship building between all stakeholders	Face-to-face meetings Exercise events Training Encouragement of interdepartmental activities outside work Foster long-term community relationships Acknowledge and celebrate wins Break-down silos Use culturally appropriate messaging Establish a single point of contact for external stakeholders Develop strategies to harmonize public messaging at every level
Preplanning	Established relationships and expectations can facilitate continual reagent supply and testing needs	Surge capacity agreements Vendor agreements (guarantee supply) Review MOUs and agreements with external stakeholders yearly Establish accountability and roles during a crisis Establish ICS and triggers for deployment
Stockpiles	Once established, routine laboratory operations can use stockpiles to maintain up-to-date reagents	Model and identify the size and content of stockpiles needed Ensure that supply can be used before expiry Ensure that stockpiles are easily accessible Keep inventories accurate
Surveillance	Improved surveillance systems for emerging events can help identify the scope and effect of the emerging threat	Become member of laboratory surveillance networks Provide local data to national and international surveillance networks Proactively study and try to identify emerging issues Monitor efficiency of responses Conduct after-action evaluations

relationships with communities (as with the Somali-American community in the measles outbreak), as well as external laboratory stakeholders, can facilitate the dissemination of critical, scientifically accurate, and timely information in the event of an emerging threat and help counter intentional or accidental misinformation.

In public health departments, silos tend to increase over time instead of breaking down. It takes active, deliberate efforts to establish and foster relationships between partners. Regular meetings between groups can aid in relationship building and improve communication when an outbreak or an emerging issue occurs. Some laboratory and epidemiological groups use creative ways to grow their relationships beyond planned formal exercises, ranging from informal softball games and leagues to joint volunteering efforts. As these personal relationships form, leaders find that the agencies also work better together and that the silo mentality decreases.

Often, open communication between the laboratory and their stakeholders required a paradigm shift. For example, MDH needed culturally appropriate messaging regarding vaccination in the measles outbreak to reach communities with lower vaccination rates, which would not have been possible without the preestablished working relationship between the laboratory and members of the community. SMEs stressed that trust is earned over time and cannot be hurried (especially in the event of an emerging threat), and relationships that are forced to move too quickly can often create the opposite of the intended effect.

SMEs indicated the need for contacting internal laboratory stakeholders (executive, senior leaders, and local administrators) through an easily accessible electronic resource. Often, a rapid decision is needed to ensure a timely response; however, laboratory workers often do not have the authority to approve a course of action. It is in these situations where direct communication channels with senior leadership are necessary. Such systems should be up to date, allow access through mobile devices, and provide redundancies if the primary contact is unavailable. Multiple PHLs used SharePoint successfully during a crisis to have a secure, easily accessible platform that can be accessed from any site with Internet service.

The ability to contact laboratory workers during an emergency can be challenging. Many PHLs have implemented mass text systems to easily and quickly contact staff to give updates on the emergency and let them know if it is safe to come to work. One major drawback to this method of communication was identified by an SME during an emergency; staff do not answer calls on their phones from unidentified or unknown numbers. Ongoing education and drills for staff to ensure that phones are answered, regardless of that source, improve information sharing during an emergency.

Although the laboratory may comprise many departments and be split into separate buildings (and sometimes separate cities), external stakeholders often see the laboratory as one entity. Therefore, a communication strategy that requires external stakeholders to contact multiple departments within the laboratory can be both frustrating and impractical. A single laboratory point of contact for external stakeholders streamlines communication from the laboratory to external stakeholders and vice versa. The point person needs to be someone who can understand the needs of the laboratory and who can communicate and prioritize these needs appropriately. PHLs successfully used this strategy to ensure appropriate fuel levels for emergency generators, prioritize testing supplies, and ensure that families of laboratory workers were safe during an emergency.

Subject matter experts stressed the importance of preplanning for emergencies. These plans should have agreements that can be arranged prior to an emergency event and include surge capacity agreements with other PHLs, agreements with large private laboratories (to off-load routine testing volumes), and agreements with vendors to ensure appropriate procurement of reagents during a disaster. SMEs recommended that all MOUs and contracts with external stakeholders be reviewed on an annual basis. Response efforts often require the coordination of many organizations; success is dependent on the parties openly communicating with each other and recognizing common goals. It is important that all the parties understand each other's organizational functions and transparently communicate abilities and limitations. Established working relationships facilitate cooperative thinking and problem solving. Learning from one another, adapting to new situations, and learning from past events (for example, after an action review) can significantly improve the response to a current challenge.

The use of stockpiles was also suggested, where minor equipment and supplies can be held, moved into current usage prior to expiration, and replenished as needed. Modeling and planning initiatives can identify the size and content of stockpiles needed to ensure continual functioning of the laboratory for determined time frames. It is important that stockpiles are easily accessible and inventories are accurate to ensure that required material is available when needed. Although one-time funding is needed to establish a stockpile, routine operations should be able to use reagents prior to expiration dates and replace the stock from general laboratory funding sources, thus ensuring a continual but up-to-date stockpile.

Implementation of well-thought out and actionable preparedness plans can facilitate improved emergency responses. In particular, strong communication strategies both within the laboratory and external to the laboratory can ensure that information is spread in the most effective and efficient manner. PHLs should ensure that they continue to work with other PHLs, government agencies, reference laboratories, and the public to align processes and provide a coordinated and consistent approach in response to emerging and public health threats.

A strong link between PHLs and other laboratories is often required to manage testing volume surges during an emergency response. In order to quickly and efficiently engage other laboratories to assist in meeting routine testing needs as part of the Ebola response, the CDC signed a memorandum of understanding (MOU) with APHL, the Council of State and Territorial Epidemiologists, and the American Clinical Laboratory Association to assist in defining roles for all partners during emergency situations. Finally, a tri-agency task force was created in the United States, which formally brought together the CDC, FDA, and Centers for Medicare and Medicaid Services to work together on emergency diagnostic use and more rapid development and deployment of assays for public health testing in emergencies.

Subject matter experts repeatedly highlighted the need to activate the ICS and similar structures early in an emergency. Delays in activation can hinder the release of resources needed to adequately assess and respond to a crisis. PHL staff and leadership need to be familiar with the ICS operation and their roles within it. Plans need to be exercised routinely with partners and complex enough to simulate real-world experiences. SMEs shared multiple examples of concurrent crises such as PFAS paired with hepatitis A or SARS-CoV-2 with government shutdowns and budget restrictions. Externally led after-action activities confirm SME experiences that activation of the ICS often happens too late during a crisis.

Finally, surveillance and monitoring activities are important for the early detection of a crisis, especially with emerging threats. Some disasters are easy to monitor and prepare for, such as an incoming hurricane; however, others are far more complex. Infectious diseases require highly integrated, harmonized testing and tracking networks to identify outbreaks early. Likewise, routine and nontargeted environmental testing and biomonitoring can help identify chemical exposure trends in the population. Monitoring must be done during the crisis to gauge the effectiveness of the response and afterward to ensure that the constituency has returned to normalcy. After-action is a critical part of the response process that allows PHLs and their partners to evaluate successes and challenges to improve the consistency and coordination of future responses.

Looking Forward

It is difficult to predict the future; however, we asked the SMEs to weigh in on what they felt the next emerging threat to public health could be. On the biological side, SMEs felt the emergence of a new communicable disease and the migration of an existing agent from its indigenous region to a new one were both strong possibilities. The SARS-CoV-2 pandemic that originated in Wuhan, China, is such a threat. Additionally, concerns were raised that the antivaccination movement could lead to the reintroduction of previously eradicated diseases, as was seen with the measles outbreaks.

On the chemical side, the development and use of next-generation chemicals to replace the retired PFAS was offered by multiple SMEs. Little is known about these chemicals, as they are often proprietary, and less is known about their effects on the body or on the environment. Others raised concerns about legacy chemicals that may currently be under the radar, such as mercury and hexavalent chromium, but are gaining interest the way lead has in the last few years.

Climate change is leading to more extreme weather, stronger storms, and more intense disasters such as the wildfires in Australia. This change can affect PHLs by interrupting service and changing the scope of work. Natural vector and disease ranges are expanding as summer and winter temperatures change. Increased flooding can lead to more overflow from water treatment plants and increased demand for testing from PHLs.

Political climates are also changing, resulting in increased threats to PHL budgets and continuity of operations. PHLs will have to remain nimble and adaptable as technologies continue to be developed. Fortunately, the insight provided by the SMEs can help PHLs and other governmental laboratories prepare for these possible future events, and for the unpredictable ones, too.

Lastly, misinformation and attempts to discredit science will make crises and emerging threats more complex and hamper the response efforts of PHLs. Though technology provides PHLs with many tools to improve efficiency, harmful movements also take advantage of these resources to falsely discredit the safety of vaccines, the existence of a disease, the efficacy of masks, or the science of climate change. The consequences include the increased likelihood and severity of new disease outbreaks, natural disasters, and other crises over the long term. PHLs will have to work with scientific communities to harmonize messaging on national and international scales to rebuild the trust that others have attacked.

Whether the public health threat is occurring in China, West Africa, or the United States, these events demonstrate that the following priorities are important. (i) Investment in the GHSA is critical for all nations. This collaborative effort to prevent, detect, respond to, and recover from infectious disease threats should be expanded to encompass broader health threats. (ii) EOC and ICS are needed for consistent and coordinated responses to threats. PHLs must be at the EOC table, trained in ICS, and ready to use this approach for an efficient response. (iii) Laboratory networks offer immense value for the timely detection of threats. These networks must balance the roles of private and public laboratories, leveraging the expertise of both systems to produce high-quality and high-volume tests. (iv) A quality management system is pivotal to accurately understanding the scope of disease. The SARS-CoV-2 pandemic illustrates the important role of good-quality and timely diagnostics to reduce the spread of disease. (v) Timely, accurate, harmonized, and credible communications through public alerts or laboratory reports are vital for an effective response and to maintain public trust and support. Finally, appropriate and consistent funding to PHLs and resource-sharing initiatives between PHLs could facilitate implementation of these initiatives nationwide.

PHLs are the forefront of detecting and responding to emerging threats and rely on many partners, including private clinical laboratories, epidemiologists, policy makers, health officials, physicians, nurses, and many others, to ensure that the system works as intended. The lessons shared here illustrate the collaborative nature of all responses and provide a path forward.

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