Columbia World Projects:
Disaster Preparedness, Resilience, and Response
Forum Report

August 15, 2019

Foreword

Dear Reader,

On behalf of Columbia World Projects (CWP), we are pleased to present the following report on our Forum on Disaster Preparedness, Resilience, and Response, one of an ongoing series of meetings dedicated to bringing together academia with partners from government, non-governmental and intergovernmental organizations, the media, and the private sector to identify projects designed to tackle fundamental challenges facing humanity.

Natural disasters and public health emergencies impact tens of millions of people each year. At the individual level, the impact is often felt physically, mentally, and emotionally, and can destroy homes and businesses, wipe out financial resources, uproot families, and cause lasting injuries and even deaths. At the community and regional level, the impact can be equally devastating, inflicting enormous environmental and structural damage; stalling or even reversing a society's economic growth and development; and producing and exacerbating poverty and instability. While natural disasters and public health emergencies have been a consistent feature of human existence, the frequency and intensity of such incidents have increased over the last few decades, in significant part as a result of climate change and growing mobility. All of this has made managing disasters more urgent, more expensive, and more complex.

On June 10, 2019, CWP invited approximately 35 experts from a range of fields and disciplines to take part in a Forum with the aim not only of deepening our understanding of natural disasters and public health emergencies, but also of proposing concrete ways to improve the lives of people affected by these events. The attached report describes the work that took place at that Forum and identifies five promising project ideas that emerged, which will be shared with our Advisory Committee for possible further development by CWP.

We chose to focus on natural disasters and public health emergencies not only because it is a challenge with profound global consequences, but also because it is a field in which we believe universities, and in particular CWP, can have significant impact. As is reflected in the attached report, strategic approaches that combine a range of substantive expertise and institutional views, and inspire new ideas using the latest advances in research and technology, have the potential to be transformative in disaster preparedness, resilience, and response.

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I. Defining the Challenge

Natural disasters and public health emergencies often result in profound harm to the physical, ecological, biological, and social environments, immediately impacting people's lives, while also exacting long-term harm on communities' health, well-being, and survival.[1] Such disasters, which include earthquakes, hurricanes, floods, wildfires, droughts, and pandemics,[2] are often dynamically interconnected and intensifying growing in important ways, in no small part as a result of human behavior. Yet at the same time, human behavior can play a critical role in reducing the impact and likelihood of such events. Effectively preparing for and responding to such disasters necessitates a systems approach that integrates economic, social, and environmental measures. As many participants in the CWP Forum noted, simply managing such events is insufficient. We must find ways to mitigate the drivers of disasters, such as climate change; we must do more to understand and take into account the increasingly dynamic relationship between individual hazards; and we must recognize and address the degree to which the preparation for and response to catastrophic events can often exacerbate structural inequities in our societies that are unrelated to the causes of such disasters.

In light of these serious challenges, participants agreed that significant and simultaneous efforts must improve on all aspects of dealing with natural disasters and public health emergencies. In particular, these include three overlapping areas: (1) *preparedness*: forecasting, planning, and training for disasters before they occur, such as developing and testing predictive modeling, early warning systems and delineating lines of responsibility in advance of an event; (2) *resilience*: taking steps to improve the capacity of people, institutions, physical structures, ecological systems, and other building blocks of our societies to absorb, recover from, and adapt to the shocks and stresses caused by disasters, thereby diminishing the harm they cause; and (3) *response*: addressing the immediate and direct consequences of such events, such as providing for people's essential needs and ensuring emergency assistance for those who need it, in addition to the long-term consequences.[3] At the same time, participants reflected on the significant organizational, behavioral, and public policy obstacles that make it especially challenging to engage in successful and sustainable disaster preparedness, resilience, and response. For example, not only do societies typically underinvest in such efforts, but it has also

[1] For the purpose of this Forum, CWP decided to focus primarily on natural disasters and public health emergencies, and not on other types of disasters such as conflicts and forced displacement. While these other types of disasters have a significant impact on countless people worldwide and would certainly benefit from bringing academic research to bear, CWP determined that focusing on a wider range of disasters would constitute too broad of a topic for this Forum.

[2] A disaster is "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts." United Nations Office for Disaster Risk Reduction, "Terminology on Disaster Risk Reduction," accessed July 2, 2019, https://www.unisdr.org/we/inform/terminology.

[3] The definitions for response, preparedness, and resilience are drawn from conversations with a range of experts and a review of relevant literature. See Malcolm E. Baird, "The 'Phases' of Emergency Management: Background Paper," University of Memphis, 2010, http://www.memphis.edu/ifti/pdfs/cait_phases_of_emergency_mngt.pdf; "Our Resilience Approach," Mercy Corps, accessed July 16, 2019, https://www.mercycorps.org/sites/default/files/Mercy%20Corps%20Resilience%20Approach_April%202015.pdf; and Anne Tiernan, Lex Drennan, Johanna Nalau, Esther Onyango, Lochlan Morrissey and Brendan Mackey, "A review of themes in disaster resilience literature and international practice since 2012," *Policy Design and Practice*, 2:1, 53-74 (2018), https://www.tandfonline.com/doi/full/10.1080/25741292.2018.1507240.

proven extremely difficult to promote a culture of disaster preparedness and resilience before disaster strikes,[4] and bringing together the different stakeholders during a crisis to promote an effective response is a constant challenge.

The problem is big and getting worse.

Estimates of just how big vary. According to the Center for Research on the Epidemiology of Disasters (CRED), in 2018 alone approximately 68.5 million people were affected by natural disasters, nearly 12,000 of whom were killed.[5] Meanwhile, the World Health Organization (WHO) estimates that such disasters on average affect 160 million people annually and take some 90,000 lives.[6] However, what most experts agree on is, first, that the number of deaths directly caused by such disasters has been falling in recent years,[7] which may demonstrate improved disaster management; and second, that the strength, pace, and intensity of many disasters are on the rise, fueled largely by increased mobility and climate change, and that their widespread impact is increasing.

In the case of public health emergencies, historical examples demonstrate the immense impact that such events can have. Before it was eradicated, smallpox caused more deaths than any individual war,[8] and the 1918 influenza pandemic is estimated to have killed approximately 5 percent of the world's population at the time.[9] In recent decades, greater mobility has allowed new and reemerging pathogens to spread more rapidly, resulting in epidemics that can swiftly overwhelm health systems, roll back years of economic development, and bring to a standstill the movement of people and goods within and across borders. A virulent pandemic was one of eight "black swans" warned against by the U.S. intelligence community in a global trends report looking forward to 2030.[10] An easily transmissible novel respiratory pathogen that kills

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[4] Despite the fact that millions of lives are affected yearly without warning by disasters, most people do not concern themselves with preparing until disaster strikes, making it necessary to engage in broad-based efforts of behavioral change. Washburn, C and, Saunders K, "Extension Disaster Education Network: Preparing Families for Disaster." *Journal of Family and Consumer Sciences*, 102(2): 61-3 (2010).

[5] Center for Research on the Epidemiology of Disasters, "CRED Crunch 54 - Disasters 2018: Year in Review," April 2019, https://www.cred.be/publications.

[6] "Natural events," World Health Organization, accessed June 1, 2019, https://www.who.int/environmental_health_emergencies/natural_events/en/.

[7] The number of fatalities in 2017 (9,697) and 2018 (11,804), for example, were quite low compared to the annual average of the prior decade (2006-2016) of 68,273. In a CRED report on natural disasters from 2017, it was noted that this is likely due to three events with very high mortality in the preceding decade – the 2010 earthquake in Haiti (222,500 deaths); the 2008 Cyclone Nargis in Myanmar (138,000 deaths); and the 2008 Sichuan earthquake (87,000 deaths). Center for Research on the Epidemiology of Disasters, "Cred Crunch 50 - Natural disasters in 2017: Lower mortality, higher cost," March 2018, http://cred.be/sites/default/files/CredCrunch50.pdf.

[8] Michael Specter, "The Doomsday Strain: Can Nathan Wolfe thwart the next AIDS before it spreads?" *The New Yorker*, December 12, 2010, https://www.newyorker.com/magazine/2010/12/20/the-doomsday-strain

[9] Richard Gunderman, "Ten Myths About the 1918 Flu Pandemic" *Smithsonian*, January 12, 2018, https://www.smithsonianmag.com/history/ten-myths-about-1918-flu-pandemic-180967810/.

[10] National Intelligence Council, *Global Trends 2030: Alternative Worlds*, December 2012, https://www.dni.gov/files/documents/GlobalTrends_2030.pdf; see also, Peter Sands, Anas El-Turabi, Phil Saynisch and Ryan Morhard, *Outbreak Readiness and Business Impact: Protecting Lives and Livelihoods across the Global Economy*, World Economic Forum, January 2019, http://www3.weforum.org/docs/WEF%20HGHI_Outbreak_Readiness_Business_Impact.pdf. The latter report

or incapacitates more than 1 percent of its victims is among the most disruptive events possible, as it could result in millions of people dying across the world within six months.[11] In regions with fragile health systems, such disasters can have a particularly devastating impact, as was seen in the way the 2014-2015 Ebola outbreak decimated the health sector in Guinea, Liberia, and Sierra Leone.

When it comes to natural disasters, it is storms that often receive the most public attention. That is in part because while the number of hurricanes may not have changed, their wind speed and the speed with which they are intensifying in strength is increasing, which can significantly complicate disaster preparedness.[12] When a storm transforms from a Category 1 to a Category 5 hurricane in less than 24 hours, as happened with Hurricane Maria in the Caribbean in September 2017, there is insufficient time to prepare the people in its path for the impending disaster.[13] Rapid intensification is part of the reason why the damage caused by Maria was estimated at a colossal $90 billion. Hurricanes are also producing more rain, and the sea level, which is expected to rise by between one and four feet globally over the next century, is already amplifying the impact of storm surges. Combined with increasing development along coastlines, these climate change-driven impacts on storm characteristics have important implications for future storm damage.[14] According to some experts, rising ocean temperatures are projected to increase the frequency of Category 4 and 5 hurricanes in the Atlantic Ocean by between 45 and 87 percent.[15] One participant described the extraordinary challenge for island nations that dealt with 17 named storms in 2017, six of which were major hurricanes and two of which were Category 5 storms. One of those Category 5 hurricanes, Hurricane Irma, had maximum sustained wind speeds of 185 miles per hour and was the strongest hurricane ever recorded in the Atlantic.

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notes that, "with increasing trade, travel, population density, human displacement, migration and deforestation, as well as climate change, a new era of the risk of epidemics has begun. The number and diversity of epidemic events has been increasing over the past 30 years, a trend that is only expected to intensify."

[11] *Ibid.*

[12] Meteorologists use the term "rapid intensification" or RI to describe a storm that increases its maximum sustained winds by at least 35 miles per hour within a 24-hour time period. In 2017, there were 40 separate cases of RI, the most in at least 35 years. Daniel Levitt and Niko Kommenda, "Is climate change making hurricanes worse?" *The Guardian*, October 10, 2018, https://www.theguardian.com/weather/ng-interactive/2018/sep/11/atlantic-hurricanes-are-storms-getting-worse.

[13] According to a study conducted at the government of Puerto Rico's request by George Washington University's Milken Institute School of Public Health, Hurricane Maria was estimated to have caused 2,975 deaths. Another study, conducted by Harvard's T.H. Chan School of Public Health, estimated the hurricane caused 4,645 deaths.

[14] National Science Foundation, "Hurricanes: Stronger, slower, wetter in the future?," May 21, 2018, https://www.nsf.gov/news/news_summ.jsp?cntn_id=245396.

[15] Thomas R. Knutson, Joseph J. Sirutis, Gabriel A. Vecchi, Stephen Garner, Ming Zhao, Hyeong-Seog Kim, Morris Bender, Robert E. Tuleya, Isaac M. Held, and Gabriele Villarini, "Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios," *Journal of Climate*, 26, (2013): 6591–6617, https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-12-00539.1.

Similarly dramatic trends hold for wildfires and landslides.[16] The 2018 Attica wildfires in Greece killed more than 100 people, making it the deadliest set of wildfires recorded in Europe since people began to keep records of such events in 1900. Of the ten most destructive fires in California's history, six took place in the 18 months from November 2017 to May 2019; the most recent one was the deadliest and costliest on record.[17]

Furthermore, the economic cost of natural disasters is substantial, and also appears to be increasing. CRED reports that, in 2018, the global economic damage caused by disasters totaled roughly $131.7 billion, while according to the reinsurance firm Munich Re, the total was closer to $160 billion, with the greatest costs generated by California wildfires and tropical storms in the United States and Asia.[18] Although there is no consensus on the total cost of damage or even how to measure it, there is no question that the scale is massive. Overall, insurance companies paid out $80 billion in claims for damage from natural disasters last year, down from 2017's $140 billion, but double the 30-year average. In the United States, the Federal Emergency Management Agency (FEMA) public assistance program – which helps states and localities remove debris, provide life-saving emergency measures, and rebuild public infrastructure – had eight of its most expensive years on record during the decade between 2007 and 2016.[19] This impact is felt at the small-scale level as well: in the United States, nearly 40 percent of small businesses never reopen their doors after a disaster.[20]

Natural disasters can additionally have wide-ranging and long-term environmental consequences that are not often captured in initial damage estimates, generating or releasing pollution, disrupting and at times permanently altering delicate ecosystems, destroying infrastructure, and in some instances demolishing entire habitats. For example, in March 2011, a tsunami following the 9.0 magnitude Tohoku earthquake in Japan caused the Fukushima Daiichi nuclear disaster, releasing radioactive material. The largest nuclear disaster since Chernobyl, the event caused a cascade of serious problems in the ecosystem and surrounding waters, spreading radioactive material far beyond Japan through ocean currents.

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[16] Regina Below and Pascaline Wallemacq, *Natural Disasters 2017*, Center for Research on the Epidemiology of Disasters, February 7, 2018, https://www.cred.be/publications (noting that in 2017, the world saw 25 landslides, compared to an annual average of 17 landslides during the prior decade, from 2007 to 2016).

[17] Mark Chediak and Brian Eckhouse, "California May Go Dark This Summer, and Most Aren't Ready," *Bloomberg*, May 12, 2019, https://www.bloomberg.com/news/articles/2019-05-12/california-may-go-dark-this-summer-and-most-aren-t-ready.

[18] It is worth noting that in 2017, the United States experienced a historic year of weather and climate disasters, the cumulative damage of which was assessed at over $300 billion. Adam B. Smith, "2017 U.S. billion-dollar weather and climate disasters," NOAA Climate.gov, January 8, 2018, https://www.climate.gov/news-features/blogs/beyond-data/2017-us-billion-dollar-weather-and-climate-disasters-historic-year.

[19] Susan K. Urahn and Kerri-Ann Jones, *What We Don't Know About State Spending on Natural Disasters Could Cost Us*, Pew Charitable Trusts, June 2018, https://www.pewtrusts.org/-/media/assets/2018/06/statespendingnaturaldisasters_v4.pdf.

[20] Federal Emergency Management Agency, "Protecting Your Business" last modified September 20, 2018, https://www.fema.gov/protecting-your-businesses. See also reporting indicated that FEMA was, among other things, understaffed and underresourced going into the hurricane season in 2017, which ultimately led to inadequate support and unacceptable delays in distributing relief to hurricane victims in Puerto Rico and other areas. Laura Sullivan and Emma Schwartz, "FEMA Report Acknowledges Failures in Puerto Rico Disaster Response" NPR, July 13, 2018, https://www.npr.org/2018/07/13/628861808/fema-report-acknowledges-failures-in-puerto-rico-disaster-response.

In short, the ramifications of natural disasters and public health emergencies are so complex and wide-ranging that part of the problem is understanding and assessing their impact in a way that can enable better preparedness, resilience, and response. What is clear is that the increasing scope, pace, and intensity of these catastrophic events are inflicting a significant toll, not only causing deaths and injuries, but also displacing people, destroying livelihoods and property, and undermining years of progress toward various internationally promoted development goals. Evidence suggests such events may even foster conditions where violence and conflicts are more likely to occur, as in the Lake Chad basin, where sustained droughts and desertification have intensified disputes between farmers and herders over dwindling natural resources. As such, even understanding the challenge presented by disasters requires a range of substantive expertise and institutional perspectives that are not often found outside of university settings, making it a critical – if underutilized – partner in this effort.

Modeling, data, and the dynamic interplay among disasters and trends.

Forum participants took note of the tremendous opportunities offered by today's technological developments, sophisticated use of data, and advances in methodologies for measuring the risk of catastrophic events occurring and their projected impact, noting the potential for such advances to transform the field of disaster preparedness, resilience, and response. Nevertheless, participants explained that many of the models that exist to predict the likelihood of disasters and assign levels of risk – from mapping floodplains to forecasting hurricanes – have proven to have a range of critical shortcomings and obstacles.

For a start, conducting effective modelling requires the ability to access critical data, understand its provenance, and have trust in its quality. For example, one participant discussed the challenges that exist in many jurisdictions when it comes to obtaining integrated, relevant data for disaster preparedness, resilience, and response in light of the fact that individual institutions (e.g., government agencies, humanitarian organizations) tend to develop and maintain their own data sets and categories, and thus, even when they are willing to share data, it can be challenging to do so effectively.

Participants also highlighted issues with the accuracy, transparency, and accessibility of existing models. For example, many models focus on specific catastrophic events, without taking into account the potential interplay between such events. Participants discussed how the interplay between disasters can increase the complexity of understanding, predicting, and assessing the consequences of such events. A participant noted that one manifestation of this increasing complexity can be found in the capacity of storms to spark or aggravate public health crises. This was the case in Mozambique, where, for example, Cyclone Idai's landfall in March 2019 helped spur a massive cholera outbreak that resulted in more than 6,700 cases of cholera in less than two months.[21] In the wake of natural disasters such as hurricanes, cyclones, or typhoons, facilities for water and sewage are often damaged and rendered inoperable; standing water can provide a breeding ground for pathogenic bacteria and disease vectors like mosquitoes; and damaged transportation systems can make it difficult to reach people with

[21] United States Agency for International Development (USAID), "Southern Africa – Tropical Cyclones: Fact Sheet #13, Financial Year 2019," May 31, 2019, https://www.usaid.gov/sites/default/files/documents/1866/southern_africa_cy_fs13_05-31-2019.pdf.

chronic health issues and deliver vital medicine such as vaccines and insulin. Another participant noted the dynamic relationship that exists between landslide risks that can be triggered by earthquakes, floods, or severe storms. The fact that individual hazard research communities often remain in silos, using different approaches for measuring and modeling risks, makes it especially challenging to take into account the increasingly dynamic relationships that exist between hazards.

Another shortcoming is that many models rely exclusively or disproportionately on historical events to predict the magnitude and frequency of future events without sufficiently taking into account trends like climate change, which is rendering past events a less and less reliable indicator for what will happen in the future.[22] Indeed, as the 2018 United States National Climate Assessment points out: "The assumption that current and future climate threats and impacts will resemble those of the past is no longer reliably true. Human-caused carbon pollution in the atmosphere has already pushed many climate-influenced effects – such as the frequency, intensity, or duration of some types of storms and extreme heat, drought, and sea level rise – outside the range of recorded recent natural variability." Other trends such as demographic shifts and settlement pattern adjustments are also critical to reliably assessing the likely impact of disasters, but are not consistently or effectively factored into disaster risk estimates. For example, as one participant noted, in Indonesia, the impact of tidal and flash floods caused by a rise in the sea level is significantly exacerbated by urban development, land subsidence, and ground water extraction.

When modeling does exist, it is furthermore problematic that the cost of such models may mean that some of the governments and communities that face the greatest risks cannot afford them, depriving them of learning from and acting on predictions derived from the models. Moreover, the proprietary nature of several models means they are not transparent, making it hard to evaluate their efficacy and the way they are applied, which is a matter of public concern. Several participants noted that the transparent nature of most academic research is well suited for developing models that are accessible and subject to critical review and improvement. This is particularly important given the need for academic expertise focused on distinct, potentially linked hazards, as well as from a range of disciplines, in order to effectively design, contribute to, and evaluate such models.

Finally, there were two additional issues raised by participants, which are often overlooked in the context of data interventions, but critical to their effectiveness. First, even when models and data are accurate in forecasting disasters or detecting the onset of public health emergencies, that information is not often presented in a way that allows decision-makers or communities to act on it swiftly. As one participant pointed out, the best science, data, and models are a key part of the equation, but they rarely offer the full solution. As such, multiple participants spoke to the need to find ways of conveying information in a way that is timely, directed toward those with the authority to take action, and reflective of the kinds of decisions they can make. Second, engaging the affected community is crucial to obtaining information

[22] This is true for financial models' underestimation of risk of climate-related disasters as well. See for example, Ashley Schulten, Andre Bertolotti, Peter Hayes, and Amit Madaan, *Getting Physical: Scenario Analysis for Assessing Climate-Related Risks*, BlackRock Investment Institute, April 2019, https://www.blackrock.com/us/individual/literature/whitepaper/bii-physical-climate-risks-april-2019.pdf.

and context for modeling – particularly modeling to predict the likely damage of catastrophic events and options for improving resilience. As such, modeling intended to address these questions should build into its design and implementation ways to tap into communities and their knowledge. This observation led participants into a discussion of the importance of community engagement generally in this field, and the need to take into account existing structural inequities that may be exacerbated in the context of resilience building and disaster response.

The importance of engaging communities and avoiding the exacerbation of structural inequities.

Multiple participants underscored that while communities possess unique knowledge, experience, and capacities, they are too often left out of preparedness, resilience, and response efforts. Instead, they are routinely treated as passive recipients, rather than as active participants, in the conception and implementation of such efforts, as well as in the decision-making processes that decide on which of these approaches to pursue. One participant pointed to the way reconstruction contracts are often awarded to outside firms, missing an opportunity to generate work in communities where disasters have shuttered businesses and cost people their jobs. Engaging the community is also important for designing approaches that people are likely to trust and accept, as in efforts to stop the spread of infectious diseases, where it has been crucial to understanding local fears, channels of information, customs, and sources of authority.

Furthermore – and the focus of one of the Forum's working groups on this issue demonstrates the importance of this point – there was a consensus among the participants that the impact of disasters is not experienced equally by all regions, communities, and individuals. Race, socioeconomic status, age, and geography are among the factors that can make people more vulnerable to the effects of natural disasters and when preparedness, resilience, and response efforts fail to take these factors into account, they can put individuals at heightened risk in the immediate term, while simultaneously deepening inequities and cleavages in our societies in the long term. On the other hand, the resources brought to bear on disasters can also be viewed as an opportunity to promote greater equity, engage more vulnerable and disenfranchised members of our communities, and build trust in institutions and across communities. Doing this effectively, several participants noted, requires recognizing the dignity and knowledge of the individuals and communities affected – such as existing organizational structures that can be mobilized in an emergency – and understanding the factors that have produced such inequities in the first place, which, as a participant noted, include institutional racism through practices like redlining in the United States. In sum, allocating adequate resources is not enough. Those resources must be directed to the right places, to the people who need them the most, when they need them the most.

Organizational, behavioral, and public policy challenges.

Forum participants working across the full spectrum of disasters and representing a range of different institutions all spoke to chronic underinvestment in preparedness and resilience, and the way such underinvestment augments the damage caused by natural disasters and health emergencies. This is in large part due to human behavior. We tend to underestimate risks we have not experienced. Even when we have experienced a disaster, the more time has elapsed since it took place, the more we tend to underestimate the likelihood of it happening again,

regardless of how great risks are in the present. For example, a study found that most homeowners in flood-prone areas will not purchase insurance until after they experience flood damage, and they will give up that insurance if they do not experience floods in the next few years.[23]

Several participants pointed to the lack of adequately trained health workers as a prime example of this occurring in the international sphere. Investing in training and equipping frontline doctors, nurses, community health workers, and epidemiologists, participants pointed out, can make the difference between a small number of people contracting an infectious disease and the emergence of a global pandemic. Yet there is a persistent worldwide shortfall in health workers, which was estimated at approximately 17.4 million in 2013 and is projected to number roughly 14 million by 2030. While this would constitute some progress toward reducing the shortfall, it is insufficient to meet health care needs of populations even in normal circumstances, much less in the heightened urgency of public health emergency or in the aftermath of a disaster.[24] Not surprisingly, the most significant deficits – both in coverage and in training – tend to be in areas where infectious disease outbreaks are most likely to occur.[25] When outbreaks occur in these countries, health workers are often the ones at greatest risk and can inadvertently act as "super-spreaders" if they are not given adequate training and equipment, a participant noted. In fact, it is estimated that investing approximately $4.5 billion annually in pandemic preparedness – which amounts roughly to between $0.50 and $1.50 per person per year – could help prevent a global expected loss of $570 billion per year over the coming decades.[26] Yet that funding gap is consistently unfilled, in part because of the failure of developed countries to invest in the preparedness of developing countries, in spite of the fact that the health security of these countries is inextricably linked.

In the United States – where studies have consistently demonstrated that investing in preparedness and resilience not only saves lives, but also is cost-effective – the same

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[23] Howard Kunreuther, "The Role of Insurance in Reducing Losses from Extreme Events: The Need for Public–Private Partnerships," *The Geneva Papers*, 40 (2015): 741-762, http://opim.wharton.upenn.edu/risk/library/J2015GPP40_The-Role-of-Insurance-in-Reducing-Losses-from-Extreme-Events_Kunreuther.pdf.

[24] Buchan J., Dhillon I.S., Campbell J., editors, *Health Employment and Economic Growth: An Evidence Base*, World Health Organization, 2017, https://www.who.int/hrh/resources/WHO-HLC-Report_web.pdf?ua=1.

[25] For example, according to *The Lancet's* 2017 Global Burden of Disease Study, "only half of all countries had the health-care workers required to deliver quality health care (estimated at 30 physicians, 100 nurses or midwives, and five pharmacists per 10,000 people). Although many European countries have highly resourced health workforces, countries across sub-Saharan Africa, southeast Asia, south Asia, and some countries in Oceania were estimated to have the greatest shortfalls." See "GBD 2017: a fragile world," editorial, *The Lancet*, Volume 392, Issue 10159 (Nov. 10, 2018), https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)32858-7/fulltext#articleInformation.

[26] Kelly Ayotte, Ami Bera, Susan Brooks, Beth Cameron, Steve Davis, Mark Dybul, Tom Frieden, Julie Louise Gerberding, Amanda Glassman, Jonathan Greenert, Jim Greenwood, General Carter Ham, Margaret Hamburg, Karl Hofmann, Tom Inglesby, Rebecca Katz, Jimmy Kolker, J. Stephen Morrison, Carolyn Reynolds, Christine Wormuth, Todd Young, and Juan Zarate. "Harnessing Multilateral Financing for Health Security Preparedness." CSIS Commission on Strengthening America's Health Security, Center for Strategic and International Studies, April 03, 2019, https://healthsecurity.csis.org/articles/harnessing-multilateral-financing-for-health-security-preparedness/.

phenomenon of chronic underinvestment is replicated, albeit on a smaller scale.[27] For example, every $1 FEMA spends on mitigation efforts in the United States is estimated to save $6 in response and recovery spending.[28] But a study found that between 1985 and 2004, the U.S. government on average spent 15 times as much on disaster relief as it did on disaster preparedness.[29] Governments rarely offer incentives to encourage public institutions, businesses, and individuals to take mitigation measures, even if it would be in their interest to do so. In fact, in some cases, a government's decision to provide relief may even provide perverse incentives for people and localities *not* to prepare for disasters, as it generates expectations that the government will come to the rescue of those affected, regardless of whether people or institutions have made responsible decisions to hedge against foreseeable risks. At times, this has been the case in the United States with flood insurance and the maintenance of aging infrastructure.

This pattern is inextricably linked to a broader observation made by several Forum participants: in designing disaster preparedness, resilience, and response efforts, we often fail to take into account the countervailing pressures on, and incentives for, key decision makers, which can lead them to make seemingly shortsighted or counterproductive decisions. Participants gave multiple examples of this phenomenon, such as a program that trained countries to detect and report infectious disease outbreaks but did not anticipate that those monitoring cases would feel pressure from their superiors not to report outbreaks and to conceal vulnerabilities. Likewise, particularly in resource-strapped countries, government officials may feel it is unwise to spend any of their own funds on resilience measures, because those are more likely to be funded by the international community, and because their constituents may view investments in resilience as a lower priority than spending on programs such as health and education.

Participants noted that even when decision makers and institutions *do* invest in preparation and building resilience to disasters, they are rarely rewarded by constituents for their actions, even if a disaster occurs and their efforts ultimately save lives and reduce other forms of harm. This is in part because there is rarely a counterfactual showing how much worse a disaster would have been in the absence of such actions. As one participant who works in preventing the spread of epidemics put it, "If we are successful, no one will die." And for that matter, no one will know how many people around the world could have been infected if they had not taken steps to prevent outbreaks from spreading.

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[27] *See, e.g.*, "Outbreak Readiness and Business Impact," *supra* note 8: "Investments needed to improve pandemic preparedness are not large relative to the risk of being unprepared. After all, responding to outbreaks once they have occurred is far more expensive, in lives and money."

[28] A report from the National Institute of Building Sciences looked at the results of 23 years of federally funded mitigation grants provided by the Federal Emergency Management Agency, U.S. Economic Development Administration, and the U.S. Department of Housing and Urban Development and found mitigation funding can save the nation $6 in future disaster costs, for every $1 spent on hazard mitigation. National Institute of Building Sciences, *Natural Hazard Mitigation Saves: 2017 Interim Report*, January 2018, https://www.nibs.org/page/mitigationsaves.

[29] Andrew Healy and Niel Malhorta, "Myopic Voters and Natural Disaster Policy," *American Political Science Review*, 103, no. 3 (2009), 387-406, https://digitalcommons.lmu.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1007&context=econ_fac.

Complicating the organizational requirements associated with an effective response is the fact that 21st century disasters demand that a range of institutions – across and within government, nongovernmental and intergovernmental organizations, companies, and communities – work together in highly-pressurized circumstances. This can come in the form of coordination between federal, state, and local governmental entities, between public and private institutions, or even horizontally between government agencies that tend to be walled off from each other, such as the Ministry of Defense and the Ministry of Health. The institutions, however, whose collaboration is crucial to such efforts, have perennially proven ill-prepared and slow to act, and have done a poor job coordinating their efforts, often leading to unacceptable delays, duplication of efforts, and the waste of limited resources.

Participants suggested that it would be wise for projects that emerge from this Forum to take into account these organizational, behavioral, and public policy challenges, and consider ways of better communicating to policymakers, communities, and individuals the profound risks associated with disasters and why it makes sense to invest more in preparedness and resilience – drawing not only on statistics and lessons learned from prior efforts to try to persuade people, but also offering incentives that make farsighted decisions easier to choose. They also underscored how crucial it is that projects engage the affected community throughout the process, whose buy-in and input are essential.

II. Working Group Discussions

The participants separated into five working groups, the topics for which were selected in the run up to the Forum based on discussions with participants and other experts on areas of disaster preparedness, resilience, and response that require focused attention and innovative approaches: (1) public health emergencies; (2) inequities and vulnerable communities in disaster response; (3) ecosystems of resilience; (4) adaptation and mitigation strategies; and (5) data and disasters.

Each working group consisted of approximately eight experts, who were asked to evaluate three or four project proposals that had been developed in advance of the Forum by participants in collaboration with CWP staff. Participants had been pre-assigned to working groups in an effort to bring together complementary fields of expertise, while simultaneously representing different schools of thought in areas where splits exist in the expert community, with the idea of promoting a maximally effective interrogation of each project idea.

For each project proposal, the lead drafter presented a succinct summary of the idea, after which the working group's moderator facilitated a discussion aimed at providing critical feedback. Participants were asked to focus their discussion around the following questions:

- Strengths and weaknesses. In particular, are there key weaknesses, omissions, or risks in the framing of the problem or the proposed solution? How can the project be strengthened?
- Implementation challenges. What are the greatest obstacles to effectively implementing this project, and can they be overcome?
- Likely impact. If successful, what magnitude of impact will the project likely have on disaster preparedness, resilience, and response? Is the project scalable?

- Role of the university. Do research and scholarship play a significant role in the project?

Before breaking into the working groups, the CWP Forum organizers pointed out that the groups' themes were naturally overlapping. In fact, several of the projects dealt with more than one of the themes and thus could easily have been assigned to another working group. As such, participants were asked not to limit their evaluation of assigned projects to the theme of their working group. Rather, participants were encouraged to consider how the individual projects they were evaluating were impacted by – and might help address – the themes being taken up by other working groups.

After discussing all of the individual projects, the working groups were asked to consider the strength of the project ideas reviewed relative to one another, from the perspective of which projects CWP should pursue, and summarize the main points and any recommendations they wished to make regarding each project to the plenary of Forum participants. What follows is a discussion of each of the five working groups, followed by a summary of each project discussed and the feedback it received.

1. Public Health Emergencies

Public health emergencies have the capacity to inflict catastrophic consequences, taking countless lives, ravaging economies, and undermining national security. The combination of growing mobility, globalization, and urbanization – together with the emergence of new pathogens and increasing antibiotic resistance – have made outbreaks of infectious disease both more likely to occur and to spread rapidly. It is widely accepted that to protect against such outbreaks and limit their consequences, it is necessary to invest in vaccines and other treatments and to develop systems that are capable of detecting, reporting, and responding to such outbreaks. Nevertheless, the efforts on both of these fronts have been inadequate.[30] Similarly, while there is global recognition of the need to develop an international public health system capable of marshaling a rapid, robust, and coordinated response to prevent outbreaks from turning into pandemics – and to invest in weak links across the system, particularly in countries with a weak and under-resourced public health infrastructure – time and again outbreaks have laid bare the failure of governments and international institutions to do this, with the 2014-2015 Ebola epidemic in West Africa being a recent example. The failure to address these shortcomings could be catastrophic. The 1918 flu is estimated to have killed between 50 and 100 million people worldwide; the Ebola epidemic wiped out years of development in the countries it impacted; and modeling suggests that pandemics could cause an average annual economic loss of 0.7 percent of global GDP in coming decades.[31]

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[30] *See, e.g.*, "Outbreak Readiness and Business Impact," *supra* note 8 (noting that "[a]lthough significant progress has been made since the response to Ebola in West Africa between 2104 and 2016, experts generally agree that the world remains ill-prepared to detect and respond to outbreaks and is not prepared to respond to a significant pandemic threat."). With respect to vaccines, new ones are emerging far more slowly than we would wish, and are often reactive as opposed to proactive. Research is often hindered by a lack of understanding of the immune responses required specifically for protection, intellectual property rules, and a lack of funding. Joel N. Maslow, "The cost and challenge of vaccine development for emerging and emergent infectious diseases," *The Lancet*, October 17, 2018, https://www.thelancet.com/journals/langlo/article/PIIS2214-109X(18)30418-2/fulltext.

[31] Victoria Fan, Dean Jamison, and Lawrence Summers, "The Inclusive Cost of Pandemic Influenza Risk," National Bureau of Economic Research Working Paper No. 22137, March 2016, https://www.nber.org/papers/w22137.

Forecasting Influenza at Hospital Scale to Inform Decisions and Improve Outcomes: The first project discussed by the working group would use real-time, probabilistic forecasts of the spread of influenza to inform operational decision-making in healthcare facilities in New York City. The forecasts would be generated by researchers at Columbia using combined mathematical and statistical approaches in conjunction with observations of influenza incidence, as well as social media, online activity, or other proxies of measured influenza incidence, and would be delivered as weekly reports and notifications, with detailed predictions at fine geographic scale, for New York City Health + Hospitals (NYCH+H). Forecasts would include predictions of the total epidemic curve, as well as key outbreak characteristics, including timing of the outbreak peak, magnitude of the peak, duration of the outbreak, and total number of cases. These predictions would provide insight into where and when an influenza outbreak is expected to peak next and the number of patients that should be expected at each of NYCH+H's care sites. As the forecasting system is developed, validated and implemented operationally, NYCH+H and partners at Columbia would develop, test, and adapt (based on results) a framework for making optimal decisions in the context of both the predicted influenza burdens and logistical and financial constraints. Drawing on utility theory, the framework would optimally account for forecast uncertainty and changing hospital conditions, and inform decisions around vaccine distribution, hospital and clinic staffing, public awareness efforts, and supply chain and retail pharmacy inventory management. The overarching purpose would be to use the information generated by the forecasting model to inform better real-time decisions around how resources are allocated in tackling influenza outbreaks. If effective, the systems developed through this project could be adapted and established in cities across the United States and the world, and the forecasting model could be broadened to include the prediction of other infectious diseases (e.g., Ebola, West Nile virus), allowing clinicians, hospitals, businesses, and governments to better prepare for and mitigate the economic and health costs of infectious disease.

Participants in the working group discussed whether the forecasting should be used not only to better manage influenza outbreaks, but also to help shift the curve through public health efforts, particularly vaccination efforts. However, participants noted that even massive vaccination campaigns have only led to a 5 percent increase in vaccinations, and therefore it would be better to direct limited influenza resources into staffing. To that end, multiple participants suggested working with the individuals in each hospital who are in charge of staffing, such as head nurses, and figuring out how the model could be integrated into their existing systems. One participant pointed out that while the accuracy of such forecasting models has improved, it has been challenging to get decision-makers to use the models to inform their decisions. As such, it was recommended that the project study why key decision-makers have not used such models in the past and seek to address those reasons in its design. Relatedly, participants suggested fleshing out how the decision support framework would work, mapping out the specific decisions that the model would seek to influence and which people in the system make those decisions, so as to more clearly identify the project's vectors of change. Lastly, a participant pointed out that it would be extremely difficult to adapt this model for contexts where hospitals lack electronic medical records, have poor data quality, or lack technical expertise, which is the reality in many developing countries, though the participant said that this limitation would not mean the project would not be valuable.

Training on the Front Line of Care: The second project considered by the working group would develop, deploy, and evaluate a curriculum for health care providers on the front lines in order to enhance their ability to recognize suspected cases of epidemic-prone diseases, thereby improving the chances of preventing local outbreaks from becoming widespread pandemics. The curriculum would target physicians, nurses, community health workers, and field epidemiologists, whose capacity to quickly identify patients with notifiable diseases,[32] administer effective treatments, prevent amplification within the health facility by enforcing appropriate infection prevention and control (IPC) protocols, and report cases through the proper mechanisms is critical to preventing epidemics. The curriculum would educate or reinforce existing knowledge of the clinical signs and symptoms, differential diagnosis, diagnostic tests, management, appropriate infection control measures, and standard case definitions of epidemic-prone diseases and other priority pathogens. Developed using test-enhanced learning strategies and delivered via WhatsApp, a short message service (SMS) format, or a native application, the curriculum would be accessible to frontline providers over time in order to assess and refresh their knowledge and keep them in a state of readiness. The ongoing nature of the training would be a critical component given the lack of continuing education for frontline providers and the poor retention of knowledge and skills imparted in prior trainings, which has been documented by numerous studies. The curriculum would be piloted in Ethiopia and Zambia, in partnership with the Africa Center for Disease Control (Africa CDC) and key public health institutions in each country.

Participants in the working group suggested thinking through ways to incentivize frontline care workers to take part (such as gamifying the online applications, allowing participants to compete with their peers, or providing cell phone credits or even modest pay for taking part), and eliminating obstacles that might prevent participation (such as cost, by persuading cell phone companies to allow users to take surveys without using cell phone minutes or data). One participant noted that while WhatsApp may be the preferred mode of communication, it might not be the ideal format for imparting online training, and recommended first doing some research to investigate the pros and cons of various potential platforms. Another participant noted that certain critical skills, such as how to properly put on personal protective equipment (PPE), have proven difficult to teach online, and asked whether it might be worth integrating a virtual reality or alternate reality dimension to teach such skills. Multiple participants saw as a strength the project's ability to draw on a range of expertise within Columbia, as well as partnerships the project leads had already explored with governments, NGOs, and multilateral bodies. The scalability of this approach – such as the potential to provide training and continuing education to health care workers across an entire nation, which has otherwise proven too expensive or labor intensive – was seen as another key strength, particularly given the global shortage of adequately trained frontline health workers.

Travel Screening Tool to Aide Clinicians and Healthcare Facilities in Identifying Diseases and Pathogens*:* In the third project, NYC Health + Hospitals proposes to work with Columbia University researchers and public health entities (such as the CDC) to develop, test, and adapt based on clinical feedback a travel screening platform to help clinicians identify and isolate patients with travel-associated infectious diseases; report the cases to the appropriate authorities, and inform optimal decisions for the facilities and relevant officials. The platform

[32] Notifiable diseases are those that, if recognized, must be reported to the relevant local authority, consistent with the World Health Organization's International Health Regulations (IHR).

could be a stand-alone application for clinicians and healthcare facilities, and/or integrated into a health system's electronic medical records system. When a clinician sees a patient who has a domestic or international travel history and has hallmark signs of an infectious disease, they would be able to access a platform that would: (a) inform the provider of the outbreaks happening in the places where the patient has recently traveled; (b) give access to a "case definition" for each potential infectious disease identified, which would indicate to the provider what the clinical manifestation of that disease might be and symptoms to aid in identification; (c) inform the clinician what infection control and prevention steps need to be taken (e.g., isolation of patient, wearing PPE); and (d) identify the internal and external public health authorities who should be notified and, through the platform itself, allow the provider to begin appropriate notifications. Presently, no one tool brings together these components. This places a significant burden on providers to do the research themselves, which can delay the ability to rapidly identify suspected infectious disease patients and notify the right authorities, and in some instances leads to illnesses being missed altogether, to the detriment of the patient, clinicians, and perhaps many others.

Participants questioned what the role of university research and scholarship would be in the project and who the university partners would be. While one participant suggested that designing such a tool for a well-resourced city like New York would focus disproportionate resources on identifying just a few infected individuals among millions of people, another participant argued that maintaining vigilance for a high-risk, low-probability event is an appropriate priority for developed country environments, and would be useful not only across the United States but also in other well-resourced countries. Participants debated whether using the platform should be a required procedural step that is recorded in electronic medical records (EMRs) or a resource that practitioners can use when they choose. A few participants raised the concern that clinicians are so overwhelmed that adding another requirement could be counterproductive. If the platform were to be integrated with EMRs, participants pointed out, a major challenge would be ensuring compatibility with different systems, which would necessitate designing different applications for each system.

2. Inequities and Vulnerable Communities in Disaster Response

Disasters have the capacity to exacerbate existing inequities in societies, whether as a consequence of race, gender, education, economic status, citizenship, or other factors. Individuals and communities who lack access to basic resources such as health care; are isolated by geography, language, or some other factor; or who, as a result of a history of discrimination, have less access to and trust in public institutions and their services, suffer greater loss in the aftermath of disasters. And such populations tend to have fewer resources to absorb the catastrophic shocks that disasters inflict. Moreover, the marginalization of these populations is frequently rooted in systemic discrimination that is perpetuated by both public and private institutions. For example, recovery and resilience programs are often designed in ways that curtail the ability of impoverished populations to access their resources, further disadvantaging them. The failure to account for such risks in disaster mitigation efforts, in the immediate response to catastrophic events, and in long-term recovery efforts can deepen disparities and cleavages in communities. For instance, a study found that aid from the U.S. Federal Emergency Management Agency (FEMA) significantly increased wealth inequality in post-disaster settings. Another study of the agency's home buyout strategies and cost-benefit analysis methods after Hurricane Harvey revealed channels of financial relief favored white,

highly-educated residents over those from other demographic groups, particularly African-Americans.

In addition, there are some groups, such as children, people with disabilities, and older and chronically-ill adults, whose status makes them more vulnerable during disasters and who, consequently, require a tailored response that takes into account their unique needs. In the United States, people with disabilities are two to four times more likely to die or sustain a critical injury during a disaster than people without disabilities. While the inequities and vulnerabilities that exist in our societies cannot be addressed by disaster mitigation, response, and recovery alone, disaster-related efforts should not have the perverse consequence of exacerbating these challenges, and may have the positive effect of reducing unacceptable inequalities in access and services that persist in our societies. This working group examined three projects that aim to reduce the unique harms and risks faced by certain individuals and communities, and thereby ameliorate some inequities and vulnerabilities in the context of disaster preparedness, resilience, and response.

Addressing Inequities in Disaster Mitigation and Recovery Programs: The first project, which would be piloted in Virginia and subsequently expanded to other states, would work with state emergency management agencies, local communities, and academics to identify biases in existing recovery and mitigation programs and then develop best practices to address the biases in these programs and reduce inequities. Virginia is a microcosm of the national phenomenon in the United States, where coastal and inland communities have suffered from increasingly frequent and destructive weather, after which communities of color and lower income residents have experienced greater loss. The project would build on efforts by the Virginia Department of Emergency Management (VDEM) to determine the equitability of disaster mitigation and resilience efforts by analyzing the distribution and effect of these programs on low-income communities and communities of color. Quantitative data would be complemented by interviews and focus groups in affected communities to better understand barriers they have faced in trying to access federal programs. Based on this analysis, the project would identify laws, policies, and best practices that could promote greater equity in resilience efforts. Finally, new programs would be tested and evaluated for their ability to mitigate inequality, leading to recommendations for policy changes at federal, state, and local emergency management agencies.

In discussing the proposal, several participants underscored the importance of elevating the issue of equity in disaster science and management. They described how "economic" priorities tend to define the allocation of resources for disaster mitigation and recovery, and the impact on poor or marginalized communities gets lost in conversations around "business efficiency." Several participants noted that response and mitigation efforts have too often prioritized preventing people from "abusing" the system, even if that has made it harder for the people in greatest need to access those resources and further disadvantaged marginalized populations. Participants noted that marginalized communities have historically lived in or been relegated to areas prone to natural disasters. One participant pointed out that trust in government is especially low among communities of color as a result of long-standing institutional racism and inequity, and, consequently, that enhancing preparedness and resilience in such communities is both more challenging and potentially transformative. A participant suggested that a promising line of inquiry could center on messaging and delivery systems of preparedness strategies, suggesting that certain nongovernmental entities such as faith-based organizations

could have greater credibility among community members and therefore be useful partners. Another participant noted that a primary challenge for the project will be measuring the impact of any individual intervention on reducing inequity, given that the project will implement multiple measures simultaneously.

Preparing to Meet the Unique Needs of Children in Disasters: A Community-Based Approach: The second project discussed would refine and scale an existing model for building child-focused community resilience to additional sites in the United States and internationally, with the ultimate goal of promoting widespread adoption of best practices, tools, and methods, and reducing the adverse effects of disasters on children. The proposed project would build on research carried out by the National Center for Disaster Preparedness (NCDP) at Columbia University through its Resilient Children/Resilient Communities (RCRC) Initiative, which works with community leaders to prepare the institutions that serve children to respond to children's unique needs during and after disasters. The primary measure of success of this Initiative has been the implementation of a baseline and end-of-project Community Preparedness Index (CPI), as well as the identification of critical policy levers to promote systemic change. In addition to applying the Initiative's model in new sites domestically and internationally, the project would conduct comparative studies regarding the impact of disasters on children and the nature of support services internationally, in order to develop an international version of the CPI and further refine the RCRC model.

Participants in the working group raised a number of key issues with the project, including: (i) the need for further clarification regarding strategies for scaling up (i.e., Does the project seek to evaluate previous lessons learned in the new communities to which it would be expanding, test new intervention designs under different conditions, or pool information about best practices and communicate to a broader audience?); (ii) whether there is a bias for selecting sites that have a greater likelihood of success, rather than working with communities that may be less resilient or have fewer community-based organizations; (iii) the importance of building equity into the RCRC's model, by recognizing that community organizations with a mission to serve underrepresented groups do not necessarily integrate those communities into their ranks or represent them in their work; and (iv) whether the CPI is a sufficient and inclusive measure of effectiveness.

Using Verified Virtual Inspections to Accelerate Assistance to Vulnerable Populations in Post-Disaster Scenarios: The final project considered would aim to streamline and accelerate the distribution of disaster assistance to the people who need it most using a verified and virtual inspections platform, Truepic Vision, in coordination with an administrator of post-disaster assistance (government, private, or nongovernmental) and a community-based partner. Truepic's image verification technology establishes that digital photos and videos have not been manipulated and that the time, date, and location are accurate. In the proposed project, an administrator of post-disaster aid (e.g., a government agency or insurer) that was trying to inspect damage from a catastrophic event would send a smartlink through to a phone number or email address to an affected individual. In near-real time, that individual would receive a one-touch link on their mobile phone, download a secure camera, and then follow a checklist of what to document via video footage or photograph in order to record damage. Upon completion of the virtual inspection, all images and videos would be automatically uploaded to the administrator's portal with time, date, location, verification, and immutability checks. The use of this technology would allow vulnerable populations to more quickly file for assistance,

while simultaneously freeing up time and resources of the administrators of post-disaster aid, who might otherwise need to rely on in-person inspections, while simultaneously helping to identify cases of fraud. The involvement of a local organization with the trust of the affected community – and in particular of socioeconomically disadvantaged groups – will be critical to engaging the affected population.

Participants in the working group noted that the technological and connectivity requirements of the project could pose a barrier to implementation, given that people may not have mobile service in the aftermath of a disaster and that people in socioeconomically disadvantaged communities may not own smartphones or may lack the data or service that is required to document the damage (as a result of the costs of such services).[33] One participant suggested partnering with an organization such as the Red Cross that already engages in documentation after disasters, while another participant recommended reframing the project to encourage documentation of potentially relevant property before a disaster, instead of waiting for a disaster to strike. The project leader noted that early-stage discussions with the CEO of a metropolitan economic development corporation suggested there may already be an interest in deploying technology to record the status of property at risk in some urban environments. In response to a question about the comparative value of partnering with academia, several participants noted that the open-source nature of academic research and the explicit focus on socioeconomically marginalized populations would help ensure that the project aids populations with greater needs who are otherwise underserved and disadvantaged during typical recovery efforts. Finally, several participants questioned whether fraud in disaster assistance is a core reason for delays or inequity in aid distribution, as the project proposal suggests; rather, they noted that because of its relatively limited incidence, fraud reduction should be seen as secondary to the project's main goal of streamlining aid distribution from the government to individuals. There was agreement among several participants that a more effective point of entry for the project would be to leverage the technology to improve the communication and data exchange between federal, state, and local agencies, thereby improving the efficiency of aid distribution to communities.

3. Ecosystems of Resilience

While the term "natural disasters" refers to naturally occurring events rather than manmade ones, such disasters are often intensified by – and in some instances may even be largely caused by – human behavior.[34] For example, the pace at which a city grows and paves over landscapes that were once wetlands or forests, and the places where people choose to build new homes, businesses, and schools, can increase the frequency or magnitude of flooding and the number of people placed at risk. The chronic degradation of coral reefs caused by runoff from farming and unprocessed human waste may place coastal communities at greater risk in a hurricane or

[33] Because the proposed technology would require that individuals be online at the affected site (e.g., their home or business) when documenting the damage caused by a disaster, individuals who lack a data or service plan would be unable to use the program. It was noted that individuals from socioeconomically marginalized communities often rely on locations offering free wifi to use their devices with the Internet when attempting to success relief in the context of a disaster.

[34] See for example, Anthony Oliver-Smith, "Anthropology and the Political Economy of Disasters," in *The Political Economy of Hazards and Disasters*, eds. Eric C. Jones and Arthur D. Murphy (New York: AltaMira Press, 2009), 11-28. Oliver-Smith notes: "In any environment with existing hazards, a disaster becomes inevitable in the context of a historically produced pattern of vulnerability, evidenced in the location, infrastructure, sociopolitical organization, production and distribution systems, and ideology of a society."

tsunami. The Ecosystems of Resilience working group considered four proposals, each of which sought to take a holistic approach to building disaster resilience. These projects proposed bringing together measures to increase resilience to catastrophic events in the short term with measures to promote behaviors and forms of development that over the long term will make disasters less likely to occur, particularly with respect to urbanization and climate change.

The Barbados Roofs to Reefs Program: Resilience Begins at Home: The first project discussed by the working group would aim to strengthen the resilience of homes in Barbados during extreme weather events, while simultaneously reducing the carbon footprint and the runoff and wastewater produced by such homes and dispersed into coastal waters, which is having a negative impact on their environmental surroundings. Household-focused interventions would include equipping residential building envelopes with roof fortifications, solar panels, rainwater harvesting systems, potable water storage systems, and wastewater treatment systems. Collectively, these interventions would make Barbados' residential stock more resistant to hurricanes and other extreme wind events, which are growing in intensity as a result of climate change, and which could render the island economically unproductive or even uninhabitable for long stretches of time. Additionally, nitrogen-rich runoff from residential wastewater and agriculture has already stressed the island's coastal ecosystem, harming coral reefs that act as natural protective barriers for coastal communities and local beaches, which are essential drivers of tourism. The project aims to pilot its building envelope interventions for 100-200 homes, partnering with Columbia University researchers, the University of the West Indies, the Government of Barbados, and various regional institutions to assess the pilot's impact, and eventually seek the support of multilateral institutions to expand the project to the island's entire building stock, as well as potentially to other Small Island Developing States.

In the discussion, multiple participants noted as strengths the project's multifaceted approach to increasing resilience and its potential scalability. There was consensus that choosing the right scale and unit of intervention for the pilot program was critically important, with participants putting forward several prospective approaches. One participant suggested that existing forms of social infrastructure, such as neighborhood or religious associations, could be leveraged as units for pilot implementation, while another suggested exploring how regulatory jurisdictions might form practical boundaries for a pilot. The project team suggested that a government-owned housing development might be administratively straightforward to target – an idea that multiple participants supported – and underscored the value of focusing on areas of dense residential development. Several participants queried whether the household should be the sole focus of the project, or whether critical infrastructure such as schools, health care facilities, and emergency shelters should also be considered. The group then discussed whether individual homeowners, neighborhoods, or cities would eventually be required to fund the project's interventions, and whether they would be achieved through incentives, requirements, penalties, or some combination thereof. One member recommended that the approach seek to mimic how nature would handle these challenges, rather than trying to redirect or alter natural systems, which can often have negative unintended consequences. Finally, a participant noted that the project team should think carefully about the potential for technologies installed on individual homes to eventually tie in to wider energy grids and utility systems.

Enhancing Protection for Disaster Displaced Persons: A Scalable & Solutions-Based Approach from the Caribbean: The second project discussed by the working group would build on regional economic mobility agreements between Caribbean countries to address the outsized

impact of disaster-driven displacement on small island developing states, which are disproportionately affected by natural hazards and have the highest per capita levels of disaster displacement in the world.[35] Cross-border displaced persons, already reeling from losses at home, enjoy no international legal status and struggle to access employment, financial and legal services, and key identification documents while outside of their home countries. The project would seek to implement three protection enhancement measures for disaster displaced persons: expedited processing of work permits, relaxed travel document requirements, and temporary suspension of return to disaster-affected countries. The project would address these challenges by leveraging two key economic mobility agreements – Caribbean Community (CARICOM) and the Organisation of Eastern Caribbean States (OECS) – to offer disaster displaced persons legal options to enter, stay, and work in nearby host territories. The project proposes partnering with academics, government officials, and nongovernmental organizations in one to two Caribbean countries to implement these key measures. Following a phase of research and on-the-ground planning, the team would work with partners to formally launch legal protections, track their use and effectiveness, and work to widely disseminate the results.

In the discussion, one participant questioned potential perverse consequences of the project, such as people taking advantage of the protection enhancement measures to seek out greater economic opportunity in another country rather than due to a disaster-driven hardship, or a government cynically using the measures to displace its own people or to avoid providing disaster assistance. With respect to the former concern, the project's drafters noted that the existing mobility agreements that the proposal would build upon are intended to facilitate the movement of people to find work and fill labor gaps, so it is merely their use in the disaster context that would represent an innovation. Others spoke to the potential political challenges of implementing such a project, as some governments might resist accepting disaster-displaced persons, particularly as the numbers increase. Participants suggested the project consider additional measures to more fully integrate migrants in destination countries, such as cultural and social integration, and to ensure disaster-displaced people are not segregated in specific neighborhoods, for which it would be important to include sociologists, anthropologists, and urbanists in the project. Another question raised was what process would be used to determine whether individuals would qualify as persons eligible for these special disaster displacement protection measures. While participants felt the mobility agreements in the Caribbean were a strength of the project, they also questioned whether this feature made the Caribbean the sole region in which the project could achieve success. Another participant questioned whether this set of protections would be framed around disaster-displaced persons or climate refugees, to which a project lead responded that, while the issues are interrelated, climate refugees currently do not have a legal framework, which is why the project focused on them.

Building Climate Resilient Landscapes through Ecosystems Management and Research: This project proposes addressing the challenges of flood risk and water resource management faced by vulnerable communities in Pekalongan, Indonesia by applying Mercy Corps' proven urban resilience model in conjunction with academic experts in areas such as agriculture, ecology, water management, engineering, anthropology, and disaster preparedness. Pekalongan, home to over 1,176,000 inhabitants, currently lacks a cohesive community resiliency plan to address

[35] IDMC, 2015, *Global Estimates 2015: People Displaced by Disasters, available at*: http://www.internal-displacement.org/publications/global-estimates-2015-people-displaced-by-disasters.

its severe risk of widespread water inundation, frequent floods, and land subsidence, which are already having cascading negative effects on the population. Piecemeal interventions such as grey water infrastructure have recently been implemented in the area, but these strategies failed to address the root causes of the area's vulnerability. This project would pursue the following three objectives to produce greater resilience: 1) strengthen transboundary coordination for water resource management through multi-stakeholder dialogues; 2) use modeling resources to assess the social and economic drivers of landscape change, identify potential solutions, and work with community groups to produce action plans to mitigate these drivers and improve early warning and response; and 3) design, implement, and evaluate ecosystem-based solutions and climate smart livelihood opportunities that can be taken forward by government, communities, and the private sector. The project would leverage Mercy Corps' longstanding regional presence and several strong local partnerships to achieve its goals, with the ultimate intention of transferring learning to other geographies with similar challenges.

Several participants noted the strength of the project's holistic, multi-faceted approach, which brings together social, ecological, and economic measures. One participant questioned whether Columbia's researchers were needed, given that the tools and processes had already been applied by Mercy Corps and ESG, while another questioned whether the project design relied too heavily on experts and external partners, at the risk of failing to build local capacity for future climate-related problem solving. Multiple participants agreed that involving local universities in the development and implementation of the project would be an ideal way to ensure institutional knowledge is transferred to local entities. One participant noted that land use decisions related to sustainability are often the responsibility of local governments, and suggested the project team work to ensure that all local entities within the project boundaries are bought-in and consulted before proceeding.

An Experience-Based Toolkit to Advance Integrated Disaster Planning and Build Resilient Cities in Chile: This project proposes studying recent disaster relief efforts in Chile to refine a resilience planning toolkit, which would then be used to help three districts in Chile's capital city, Santiago, develop their own tailored plans for disaster resiliency and preparedness. Historically, Chile's land use decisions – including those related to disaster preparedness, resilience, and response – have been made unilaterally by the federal government, resulting in a system that has failed to incorporate local knowledge, has overlooked local context, and has prioritized promoting economic growth over promoting greater resilience and equity. This project would provide an adaptable set of tools that diverse municipalities, regions, and neighborhoods could use to reduce the risk of extreme events and increase equity, while also increasing preparedness for the growing impact of climate change. Each time the toolkit is implemented, results would be tracked closely, allowing for further refinements that would benefit future users. The project team would leverage strong existing partnerships with national government agencies, local and regional governing bodies, Chilean research institutes, and Columbia University researchers to improve, implement, and, based on results, refine the toolkit, as well as disseminate the model so that it can be applied across Chile and beyond.

In the discussion, participants questioned how successful the toolkit had been in past applications. One participant suggested tracking the increases in spending that have occurred in places where the toolkit has been piloted. This led to discussion about how the toolkit could educate local stakeholders about ways to better access resources available for resiliency interventions at the regional and national levels. One participant commented that the existence

of pilot sites is a strength of the project because it offers both performance data and a sense of feasibility. Another participant noted that toolkits are challenging to adopt holistically and questioned whether CWP's support would be used to analyze and strengthen the toolkit itself or to assist with its implementation; the group agreed that both activities would be important to the project's success.

4. Adaptation and Mitigation Strategies

The Earth's climate is changing faster today than at any point in human history, creating myriad risks for diverse natural ecosystems and threatening human health, water and food sources, infrastructure, built environments, and economies. The Intergovernmental Panel on Climate Change (IPCC) forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century, and climate-related threats, including those manifested in the form of disasters, will continue to grow as the Earth warms.[36] Rising ocean temperatures are projected to increase the frequency of Category 4 and 5 hurricanes in the Atlantic, while sea level is expected to rise by between one and four feet globally over the next century, devastating both natural and built environments.[37] These and other climate-driven disasters are predicted to impose immense economic tolls in the form of increased mortality, health care costs, resource depletion, and infrastructure failure, among others. The Adaptation and Mitigation Strategies working group considered three proposals to adapt to or mitigate the impact of increasingly catastrophic events.

Renewable Energy Delivery Infrastructure in the Dominican Republic: The first project would install microgrid technology using renewable energy options (solar panels, battery systems, or biomass) in select underserved and at-risk communities in Santo Domingo and Santiago – the Dominican Republic's largest cities – to provide an energy safety net in the event of a natural disaster and frequent blackouts. A hotspot for natural disasters, the Dominican Republic also has the third lowest quality electricity supply in the Western Hemisphere. The capacity of catastrophic events in the Caribbean to disrupt the electricity supply was brought into stark relief in 2017, when the damage caused by Hurricanes Irma and Maria resulted in widespread, prolonged disruptions to the electricity grid, leaving millions of people without power for months, and disproportionately affecting vulnerable communities. Yet while microgrids could prove an effective way to address both of these challenges, investments in this technology in the Caribbean have been extremely limited. The proposed project would bring together local authorities, researchers, philanthropic organizations, government officials, utilities, and local communities to design and implement two test beds for integrating a microgrid system into an urban setting. Its ultimate aim would be to demonstrate the viability, resiliency, and efficacy of such technology for potential nationwide deployment on the island and perhaps other parts of the Caribbean.

Some participants questioned whether five years was long enough to design, implement, and measure the results of the project. Participants also probed which parts of the project would be

[36] NASA, "Effects of Climate Change," accessed May 23, 2019, https://climate.nasa.gov/effects/.
[37] Thomas R. Knutson, Joseph J. Sirutis, Gabriel A. Vecchi, Stephen Garner, Ming Zhao, Hyeong-Seog Kim, Morris Bender, Robert E. Tuleya, Isaac M. Held, and Gabriele Villarini, "Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios." *Journal of Climate*, 26, (2013): 6591–6617, https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-12-00539.1.

scalable to countries in other regions (such as sub-Saharan Africa) and contexts (such as rural areas), versus what measures would be context-specific to cities in the Dominican Republic. In response to one participant's question as to why, if it is generally accepted that microgrids provide an energy safety net in the face of blackouts and a potential disaster, more have not been set up, another participant indicated that a sustainable business model for investing in microgrids has yet to be established, and that significant work remains to be done regarding ideal ways for structuring such grids alongside the main grid in urban settings. Understanding these obstacles, it was noted, would be critical to knowing not only where Columbia's research and scholarship capacities could be most useful, but also how to design the pilots. Participants underscored that finding a sustainable business model was critical, for even if financing could be lined up for a pilot, it is not clear how that pilot could be scaled given the high up-front costs. One participant suggested insurance reduction from resilience building could be one way to offset costs, though the participant also noted that insurance penetration in the Dominican Republic is low. Another noted that a more reliable provision of energy would foster economic growth, which could be measured against the microgrids' cost, but that such development would need to be credibly evaluated and measured. Another participant questioned how to protect the microgrids themselves from damage in major weather events, noting that, for example, hurricane winds or debris could severely damage solar panels.

Open-Source Catastrophe Models for Disaster Risk Reduction and Climate Adaptation: The second project would develop, test, and implement an open-source catastrophe model for tropical cyclone risk, which could eventually be broadened to incorporate other types of catastrophic events, and would aim to both assess the risk of such events and the damage they would likely cause. Working with partners such as the World Bank, the World Food Programme, reinsurance companies, non-governmental organizations, and/or individual nations, the model could be integrated into their decision-making and thereby impact efforts intended to enhance disaster preparedness, resilience, and response. Catastrophe models, which are built mostly by the insurance industry, extrapolate from the historical record to generate large synthetic "event sets" that estimate the probability of these hazards and their likely damage. Current models, however, are limited by their use of past data, which does not take into account climate change; the fact that they are not transparent and thus cannot be critically evaluated or used; and their focus on risks in which the insurance industry has a stake, which frequently means leaving out risks to the developing world and to socioeconomically marginalized communities. The project would build off of a recently developed statistical-dynamical model for tropical cyclone hazard that generates large numbers of synthetic tropical cyclone tracks and intensities, but does not yet model precipitation, storm surge, or the flooding that would result from either of those data sets. That is a significant blind spot, as these hazards are often the worst consequences of tropical cyclone disasters, so one part of the project would encompass the development of these components. The project would also develop a model to predict the vulnerability and exposure of on-the-ground assets if a hazard reaches a given level, and inter-comparisons with existing tropical cyclone catastrophe models. The overarching goal of the proposed project, which would involve collaboration with large multilateral organizations, open-source storm modeling nonprofits, academic research partners, and private-sector modeling firms, is the development of more transparent, consistent, collaborative, and ultimately fair and just methodologies for the measurement of disaster risk in a changing climate, expanding beyond tropical cyclones to a full set of potential hazards.

In the discussion, participants noted the important contributions the project could make, not only by offering a model that is open source and thus accessible, but also one that is more accurate and efficient than those insurance companies use by, in particular, taking into account climate change. Participants questioned how the model would impact the decision-making of multilateral institutions like the World Bank and the World Food Programme, to which the project leads said that such institutions make decisions on where to invest based in part on vulnerability to, and ability to mitigate against, the consequences of natural disasters and climate change. As such, the model could help such institutions in their cost-benefit analysis, such as being able to project the losses that certain investments would likely avert. Also noted was the potential value of the project for governments that are grappling with decisions regarding where to prioritize their allocation of limited resources for promoting resilience. The project team suggested that the following project, "Optimization of Coastal Protections," was perhaps more suited to this goal, but that the two projects could work in tandem. The discussion then shifted toward concerns about the availability and accuracy of data, which would be essential to the functioning of the model. It was noted that getting access to data on the damage caused by disasters, which is not publicly available information and which the project leads have not yet obtained, will be a key challenge. One participant suggested partnering with IOs and NGOs to collect data in various countries, while another said governments would be incentivized to share high-quality data, as doing so would improve the quality of forecasts and thereby mitigate their own risks. In either circumstance, it was understood that the model's fidelity would depend on getting reliable, comprehensive data.

Optimization of Coastal Protections: The third project would use multiple computer models that incorporate local stakeholder input into assessing the probability of certain flooding events and their likely damage, and apply it in partnership with one or two coastal communities to: (1) predict certain flooding events; (2) estimate the likely damage to critical infrastructure in the community in association with such events; (3) identify specific preventive measures to be taken in order to promote resilience in the face of such events; and (4) implement the recommended measures and assess the improved resilience of the community as a consequence. While areas throughout the world have long faced the risk of coastal flooding, with storms being one of the most ubiquitous and devastating causes, these disastrous events will become more common and more intense due to the impacts of climate change. The project would establish a replicable process for hardening coastal communities to flooding events, establishing scientifically-based strategies that incorporate multiple and diverse protection mechanisms, critical feedback from stakeholders, and a community's unique needs, such as access to the coast for fishing or other commercial and recreational activities, while seeking to make optimal decisions with constrained budgets.

In the discussion, participants questioned whether the proposed project would require a level of granularity in data that has been accessible in initial research in New York City but that would be difficult to acquire in other places. A member of the project team clarified that the approach could be applied with different levels of data, though the accuracy of predictions improves with more granular data; the participant also distinguished between data on "above ground" and "below ground" infrastructure, with the former being accessible using satellite data, while the latter often depends on a partner entity (i.e., government or private sector). The discussion focused at length on the question of how the information generated from the model would be used, and who would use it. Another participant raised the question of how one would ensure that the empowered officials would use the optimal model of preventive measures that the

model recommends. In response, a participant explained that, as in many scenarios, it would be necessary to partner with an authority that is interested in using the model to help in its decision-making. One participant questioned whether there would be the political will to actually pursue the right decisions, even if it is optimal in terms of cost and effectiveness. Another participant posited that making such information available publicly could mobilize the communities that stand to be most affected as advocates of investments in resilience, as they will have a personal stake in seeing the measures implemented. One participant suggested that it might be useful to partner with motivated private-sector stakeholders, such as energy companies, hotels, or insurers, who might also see the value of investing in such measures; alternatively, another suggested partnering with public institutions, such as the MTA or the Army Corps of Engineers, which are routinely making decisions regarding investments in resilience. Still another participant raised a key question as to how to weigh an "optimal" decision, noting that different options might be optimal for different populations, and that such a determination might depend on defining certain priorities, which could vary from community to community. Several participants agreed that a motivated, technologically sophisticated, and proactive municipal partner would be best positioned to take advantage of the model.

5. Data and Disasters

Advances in technology and in data science have made it possible to more accurately predict disasters and their impact, and respond to them more effectively, though this remains a rapidly evolving field. The potential applications are myriad: from allowing first responders and citizens to swiftly identify the people and places most severely impacted and in need of attention; to systems that can more effectively match needs on the ground with capacities of providers and lead to a more efficient allocation of limited resources; to tools that can help health surveillance teams predict areas of risk for the spread of outbreaks based on identified cases. Yet this capacity is often underutilized due to a range of challenges, including the sheer quantity of data of varying quality that systems collect, which are difficult to clean, analyze, and visualize in a timely manner. Additionally, the lack of inclusivity of available data, with lacunae around some of the most vulnerable areas and communities, and the failure of different data systems to communicate effectively – whether across governments, multilateral institutions, and nongovernmental organizations, and more often than not, *within* these individual entities themselves – can produce misleading information and inaccurate projections. These, in turn, can make the problems caused by disasters even worse by, for example, leading to the misallocation of resources, stoking unfounded fear, or suggesting that a response is working when it is not. This working group considered three projects where improved data planning, management, processing, analysis, and use can improve preparation for and response to disasters.

Tracking for Effective First Response to Emergencies: The first project discussed by the working group seeks to design a tracking system that would allow first responders to better track people and essential objects during times of emergency. Large emergency responses require rapid mobilization and organization across a diverse range of actors, including first responder agencies and ordinary citizens who may require assistance, as well as a range of resources to support these operations. With so many people and critical objects involved in emergency response efforts, tracking such information is a highly complex and dynamic task. Police officers, emergency medical personnel, people in need of evacuation, ambulances, and hospital beds are just a handful of the individuals and object that must be tracked in an

emergency. Yet often those with the knowledge of where these individuals or items are, do not effectively share this information with others who need it, causing significant inefficiencies in response and recovery efforts, leading to duplication of effort, and missed opportunities to help people in need. The proposed project would involve the development of software for a publish-subscribe (pub-sub) system that would match status and location updates to all varieties of queries from first responders and other approved actors – both structured in the sense that it might require specific formatting, such as a pull-down menu, and unstructured in the sense that the system would have some ability to interpret specifics about the query, as is true for a Google search. The system would be accessible in various ways, including via a smartphone app, the web, and even simple SMS-based interfaces, and would be "self-maintaining," attempting to provide best estimates of items whose information is possibly outdated or inaccurate. The project could enhance the efficiency with which emergency processes are performed and completed by reducing the time required for various information searches that bottleneck rescue and recovery efforts.

Several participants asked how the proposed tracking system could complement or add value to existing systems in the public and private sectors, noting that most groups of first responders have tracking systems, and that many also draw upon data mining apps for information, even if their use is not officially sanctioned. Multiple participants queried whether the system would be integrated with the inventories of large companies, such as Walmart and Home Depot, which could be used to meet needs in an emergency. The point was made that a key challenge would be to ensure interoperability across various types of data systems, which would require labeling information in a consistent way. Data would also need to be updated consistently, whether manually or automatically, to remain useful. Given that the system would rely on a range of individuals and entities to input information, and that a range of users could conceivably access the system, participants raised a number of questions about data access and security, noting that agencies often, and not unreasonably, want assurances about privacy and the appropriate use of data. Participants also inquired about functionality and infrastructure needs, given that power and cellular service may be disabled or unreliable in the event of an emergency. Finally, participants discussed the challenge of how data would be disseminated and the implications this could have for how the public responds to information in emergencies. A participant suggested the system might offer two tiers of information: a more detailed set of information for first responders and agencies, and a less detailed set for the general public.

Multi-Hazard Assessment of Disaster Risks in a Rapidly Changing World: The second project would develop a new multi-hazard risk assessment framework that incorporates the likely interactions between hazards (e.g., floods, droughts, hurricanes) and pilot it with a small set of organizations for the purpose of informing better decisions. The more robust analytic framework would better accommodate likely interactions between hazards on different spatial and temporal scales, as well as knock-on effects mediated through both environmental and socioeconomic systems; develop better risk metrics across hazards and impacts, including mortality, morbidity, affected populations, displacement, direct and indirect economic losses, and sector-specific impacts (e.g., those associated with food, water, or energy security); and incorporate measures of the resilience of critical infrastructure, especially when dealing with multiple system stresses or failures (e.g., in communications, transportation, supply chains). Ideally, the framework would be linked with ongoing data collection, monitoring, early warning, and prediction efforts in the pilot organizations, which would use it to inform decisions related to disaster preparedness, resilience, and response. The framework would help

policymakers understand where proposed interventions may have unexpected consequences for other linked hazards or downstream impacts on future risks, and provide more reliable information on risk levels across hazards in order to help prioritize risk mitigation efforts.

During the discussion, multiple participants questioned whether investors would take into account multi-hazard assessments – even if accurate – when making decisions about where to invest. Participants also questioned the ability to gather the necessary buy-in and data from diverse stakeholders and queried whether it would be better to partner with a single institution that has a global reach or limit the pilot to a specific geography. One participant suggested a large multilateral organization, such as the World Food Programme, would benefit from knowing how to respond to potential disruptions in its supply chain. Several participants saw opportunities to combine the multi-hazard assessment project with either of the other two projects discussed in the working group, as it provides a "strategic" tool to complement the more "tactical" approaches of the other projects.

Strengthening In-Country Geographic Preparedness: The third project would design, implement, and evaluate a program to improve the collection, quality, and accessibility of geospatial data across governmental and non-governmental organizations in the Philippines to improve the efficacy of disaster response efforts. Master lists – uniquely coded lists that include critical information, such as the location of administrative areas like municipalities and regions; and critical infrastructure, such as health facilities, ports, and evacuation centers – typically play a critical role in informing disaster response. In the absence of shared master lists and a common geographic data set at the time of a disaster, however, individual stakeholders tend to develop and maintain their own master lists that may differ. This results in duplication of effort, less effective allocation of limited resources, and poor monitoring, undermining the ability to meet the urgent needs of the affected population. This project would analyze the existing approach, study responses to previous disasters in the Philippines, and interview experts from various sectors – with the aim of learning how the absence of a master list system has undermined past efforts and what obstacles have stood in the way of building such a system. The ultimate goal would be to use this analysis to create a new model that would allow government agencies, humanitarian groups, and nongovernment organizations to coordinate in building and maintaining open, accurate master lists and associated geographies for emergency response efforts. Doing so, it is hoped, would increase the political will for investing the resources needed to improve the fidelity of such data over time.

Key issues and concerns raised by participants included: (i) whether the project would build on existing geospatial technologies and data, and not be duplicative; (ii) how to translate the collection of higher quality data into impact on disaster preparedness and response; (iii) whether there is a unique role and value-add for academic research and scholarship; and (iv) how to obtain data from actors who are reluctant to share it. Participants suggested several ways the project might have a more significant impact, such as providing a deeper understanding of the relationship between disasters, population movements, and climate change; developing richer metrics that could be tracked dynamically and compared; and working with complex data at a national scale.

III. Conclusions and Project Selection

When participants reconvened in the Forum's closing plenary session, the five moderators reported out on the ideas discussed in their respective working groups and the feedback each project had received from the group's experts. Next, each participant was asked to identify the one or two projects that she or he thought most merited further development by CWP for potential implementation. Most participants noted how challenging it was, given the high quality of project ideas discussed, to prioritize among them, and a few participants chose not to identify individual projects, instead offering general conclusions. Nevertheless, there was overwhelming support for three consolidated projects, with some adjustments, as well as significant support for two additional projects. As a result, we intend to bring five projects to the CWP Advisory Committee for consideration.

The first was "The Barbados Roofs to Reefs Program," which would bring together a series of interventions at the household level – roof fortifications, solar panels, rainwater harvesting systems, potable water storage systems, and wastewater treatment systems – to make homes more resilient in the face of both extreme wind events and the sustained impacts of climate change. At the same time, the project would seek to reduce the harmful ecological impacts of individual households, which are destroying the island's delicate coral reef and contributing to global warming. The project would draw upon Columbia's research and scholarship expertise to design, implement, and measure the comprehensive set of interventions and, based on demonstrated results, improve these interventions, with the eventual aim of seeking multilateral support to scale the project across the island and more broadly across the region, given that the challenges Barbados faces are not unique. With this in mind, the idea of a second pilot was raised, which would produce a similar but distinct model for promoting resilience in an urban community in the Dominican Republic, making it possible to design two approaches that could be scaled in different environments. Finally, given the geographic overlap and the regional focus, a number of participants suggested combining this effort with another proposed project, "Enhancing Protection for Disaster Displaced Persons," which would build on economic mobility agreements in the Caribbean to implement additional protection measures for disaster-displaced people in employment and in financial and legal services, and facilitate their travel without standard identification documents following catastrophic events.

The second project that received considerable support was "Addressing Inequities in Disaster Mitigation and Recovery Programs," which would work with state emergency management agencies, local communities, and academics in the United States to identify biases in current disaster recovery and mitigation programs, and develop programs and practices to seek to address them. The project would then work with partners to implement these programs and practices and measure their impact, with the aim of informing recommendations for emergency management agencies across the country at the federal, state, and local level. The project would begin by piloting this approach in Virginia in partnership with the state's emergency management agency, with a proposed expansion to at least one additional state over the course of the project.

The third was "Open-Source Catastrophe Models for Disaster Risk Reduction and Climate Adaptation," which would develop, test, and implement an open-source catastrophe model to predict the risk of tropical cyclones and forecast the damage they would cause, with the idea that the model could eventually be expanded to include other types of hazards (such as tornadoes, earthquakes, and wildfires). This project would aim to address a number of problems with the current field of catastrophe modeling, which is dominated by the insurance industry:

the lack of transparency around how the models work and how they are applied by governments; the models' failure to take into account climate change; their omission of risks that are seen as not having value for insurance purposes, failing to take into account assets of value to socioeconomically marginalized communities; and the fact that many of the governments and communities that would benefit from access to such models cannot afford them. More than one participant suggested folding into this model another project proposal titled "Optimization of Coastal Protections," which would use computer models to assess the probability of certain flooding events and the likely damage they would inflict, and then identify what measures might promote optimal resilience in the face of such events. Together these two proposals, in partnership with a coastal community, could assist in identifying and testing interventions to improve the community's resilience in the face of predicted flooding events.

The two additional projects that received significant support for further development by CWP, though not as much as the three other projects, came out of the Public Health Emergencies working group. The first, "Forecasting Influenza at Hospital Scale to Inform Decisions and Improve Outcomes," would use real-time, probabilistic forecasts of the spread of influenza to inform operational decision-making in public healthcare facilities in New York City. While the second, "Training on the Front Line of Care," would develop, deploy, and evaluate a curriculum for frontline health care providers in countries most vulnerable to infectious disease outbreaks in order to enhance their ability to recognize suspected cases of epidemic-prone diseases, which is critical to preventing pandemics. These additional projects will be presented to the CWP Advisory Committee alongside the other three projects in July, soliciting members' views on whether CWP should develop the proposals further.

While the experts cited a number of reasons for selecting the projects they did, a few were especially resonant. Almost all participants highlighted the importance of promoting sustainable resilience in communities, which ultimately would have a transformative impact on both the challenge and the communities' long-term health. Participants highlighted the value of promoting resilience in ways that reduce, rather than contribute to, the underlying drivers of the growing impact of such catastrophic events, particularly climate change. Participants additionally noted the importance of seeking to ameliorate the disproportionate impact that disasters have had on certain communities, particularly those that have a harder time accessing urgently needed resources, and for whom inadequate efforts have been made to integrate them into disaster preparedness, resilience, and response efforts. By prioritizing such groups and focusing on where the need is the greatest, participants said, long-standing inequities could be reduced and new forms of resilience built.

With both the "Roofs to Reefs" and "Addressing Inequities" projects, multiple participants noted as a strength the fact that the proposals had buy-in from government actors who would have the capacity to take meaningful actions to address the problems identified, as well as a commitment to build those interventions through early and sustained engagement with the affected communities. Both elements, participants noted, are critical to designing and implementing effective efforts in this sphere. Indeed, the view that communities need more of a voice in shaping disaster preparedness, resilience, and response programs was one that a plurality of participants expressed.

Multiple participants also pointed to unique facets of the selected projects as critical reasons for investing in their development. In the case of the "Addressing Inequities" project proposal,

multiple experts acknowledged having long recognized that disaster mitigation and response efforts often have the perverse consequence of deepening inequities, yet the problem was insufficiently understood, received little attention, and largely went unaddressed. Meanwhile, a number of participants noted that the combination of Columbia's deep expertise in the areas of tropic cyclone forecasting and climate change, alongside academia's approach of making its research open, transparent, and subject to peer review, would not only make for accurate modeling, but also more accessible modeling – breaking the monopoly of the insurance and re-insurance firms on such information.

IV. Next Steps: Project Development, Assessment, and Implementation

In July 2019, the five project proposals will be presented to the CWP Advisory Committee, whose role is to advise on whether project ideas coming out of the Forum meet CWP's criteria and merit further development as potential CWP projects.

Projects that are determined to merit further development will receive an initial tranche of funding to undergo a rigorous project design phase of approximately three to four months, during which the project leads will work with CWP staff to define major deliverables, a precise timeline for implementation, a funding plan, a set of performance indicators for monitoring and evaluation, and the key implementing partners – all of which will be synthesized in a project design report. CWP staff will then prepare an evaluation of this plan, which will be combined with the project design plan and shared with Columbia President Lee C. Bollinger and the CWP President's Council for final consideration.

V. Acknowledgements

A number of people helped conceive of, organize, and shape the CWP Forum on Disaster Preparedness, Resilience, and Response, to whom we are profoundly grateful.

First, we thank the many individuals who gave generously of their time in advance of the Forum, informing our understanding of the challenge, helping develop ideas for specific projects, and suggesting potential partners for implementation. They include (unless otherwise noted, the institution with which individuals are affiliated is Columbia University): Anshu Banerjee, World Health Organization; David Bibo, Deputy Associate Administrator for Response and Recovery, FEMA; Elizabeth Cameron, Vice President, Global Biological Policy and Programs, Nuclear Threat Initiative; Mukesh Chawla, Chief Adviser, Health Security, The World Bank; Mari Denby, Humanitarian Research Specialist, Office of Emergency Programmes, UNICEF; Chang Chiu, Senior Policy Advisor, County Judge Lina Hidalgo, Harris County, Texas; Frances Colón, Leadership in Government Fellow at Open Society Foundations; David Collado, Mayor of Santo Domingo, Dominican Republic; Arzu Culhaci, Urban Resilience Advisor, Mercy Corps; Ruth Defries, Denning Family University Professor of Sustainable Development, Department of Ecology, Evolution, and Environmental Biology; Glenn Denning, Professor of Professional Practice in International and Public Affairs and Director of Master of Public Administration in Development Practice, School of International and Public Affairs; Steeve Ebener, Head of the Management Office, Health GeoLab Collaborative; Christopher Fabian, Co-Founder, UNICEF Innovation; Magdalena Gil,

Universidad Católica of Chile; Stéphane Hallegatte, Senior Economist, Climate Change Group, World Bank; Alex Halliday, Director, Earth Institute; Victoria Hamilton, Executive Director, Research Initiatives, Office of the Executive Vice President for Research; Sarah Henly-Shepard, Senior Advisor in Technical Support Unit, Mercy Corps; Radley Horton, Lamont Associate Research Professor, Earth Institute; Rajeev Issar, Policy Specialist, Disaster & Climate Risk Governance, United Nations Development Programme (UNDP); Jeremy Konyndyk, Senior Policy Fellow, Center for Global Development; Upmanu Lall, Alan & Carol Silberstein Professor of Engineering, Chair of Department of Earth and Environmental Engineering, Director of Columbia Water Center, and Senior Research Scientist at International Research Institute for Climate and Society; Eliot Levine, Director of Environment, Energy and Climate, Technical Support Unit, Mercy Corps; Nicole Lurie, Former Assistant Secretary for Preparedness and Response, United States Department of Health and Human Services; Kyle Mandli, Applied Physics and Applied Mathematics; Samantha Medlock, Head of North America Capital, Science & Policy, Willis Towers Watson; Dame Billie Miller, Former Deputy Prime Minister, Barbados; Stephen Morse, Professor of Epidemiology at the Columbia University Medical Center and Director, Infectious Disease Epidemiology Certificate Program; Shailagh Murray, Executive Vice President for Public Affairs; Thaddeus Pawlowski, Director of Center for Resilient Cities and Landscapes, Research Scholar, Adjunct Associate Professor, GSAPP; Justin Pearlman, Chief of Staff to the Provost; Omar Pimentel, Office of Congressman Adriano Espaillat; Jackie Ratner, Senior Project Manager, National Center for Disaster Preparedness; Irwin Redlener, Clinical Professor, Health Policy and Management and Pediatrics, Earth Institute and Director, National Center for Disaster Preparedness; Bessie Schwarz, CEO, Cloud to Street; Sharon Sputz, Executive Director of Strategic Programs, Data Science Institute; Jonathan Sury, Project Director, National Center for Disaster Preparedness; Bina Venkataraman, Director of Global Policy Initiatives, Broad Institute of Harvard and MIT; Park Williams, Lamont Associate Research Professor in the Lamont-Doherty Earth Observatory; and Valeriya Zaytseva, Project Manager, Innovation Accelerator, UN World Food Programme.

Second, we are deeply indebted to the moderators of the Forum's working groups, who went above and beyond to facilitate discussions of proposed projects and improve our work in all respects: Dylan George (Public Health Emergencies); Rebecca Hersher (Inequities and Vulnerable Communities), Tim Manning (Ecosystems of Resilience), Dickie Whitaker (Adaptation and Mitigation Strategies), and Matt Keller (Data and Disasters).

Third, we thank the experts who enriched the conception of specific projects and their discussion in the Forum's working groups: Suzana Camargo, Lamont Research Professor, Lamont-Doherty Earth Observatory and Executive Director, Initiative on Extreme Weather and Climate; Pauline Claramunt Torche, M.S. Urban Planning, GSAPP; Ama Francis, Climate Law Fellow, Sabin Center for Climate Change Law; Vice Consul Eduardo Hernandez, Consulate of the Dominican Republic, New York City; John C. Mutter, Professor of International and Public Affairs and Professor of Earth and Environmental Sciences; Joseph Newman, Office of Congressman Adriano Espaillat; Bruce Shaw, Lamont Research Professor; Melissa Stockwell, Associate Professor, Population and Family Health and Pediatrics; and Aubrie Swan Sein, Director, Center for Education Research and Evaluation, Assistant Professor of Educational Assessment.

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Finally, our greatest thanks go to the Forum participants, many of whom went above and beyond the call in helping us to design the work of the Forum and who are listed in the annex that follows.

VI. Annex: Biographies of Forum Participants

Lee C. Bollinger
President, Columbia University
Lee C. Bollinger became Columbia University's nineteenth president in 2002. Under his leadership, Columbia stands again at the very top rank of great research universities, distinguished by comprehensive academic excellence, historic institutional development, an innovative and sustainable approach to global engagement, and unprecedented levels of alumni involvement and financial stability. President Bollinger is Columbia's first Seth Low Professor of the University, a member of the Columbia Law School faculty, and one of the country's foremost First Amendment scholars. As president of the University of Michigan, Bollinger led the school's historic litigation in *Grutter v. Bollinger* and *Gratz v. Bollinger*. These Supreme Court decisions that upheld and clarified the importance of diversity as a compelling justification for affirmative action in higher education were reaffirmed in the Court's 2016 ruling in *Fisher v. University of Texas*. As Columbia's president, Bollinger conceived and led the University's most ambitious expansion in over a century with the creation of the Manhattanville campus in West Harlem. An historic community benefits agreement emerging from the city and state review process for the new campus provides Columbia's local neighborhoods with decades of investment in the community's health, education, and economic growth.

Curtis Brown
Chief Deputy State Coordinator, Virginia Department of Emergency Management
Curtis Brown serves as the Chief Deputy State Coordinator at the Virginia Department of Emergency Management. He has homeland security and emergency management experience at the federal, state, and local levels. Previously, Brown served as Deputy Secretary of Public Safety and Homeland Security, Regional Emergency Management Administrator for the Hampton Roads Planning District Commission, professional staff on the U.S. House of Representatives Committee on Homeland Security, and Senior Special Assistant to the Governor in the Office of Commonwealth Preparedness. Brown received a Bachelor of Science in Political Science from Radford University, Master of Public Administration from Virginia Tech, and Master of Arts in Homeland Security and Emergency Preparedness from Virginia Commonwealth University. He is a graduate of the Virginia Executive Institute, Commonwealth Management Institute, and FEMA's Emergency Management Executive Academy. He is recognized as a Certified Emergency Manager by the International Association of Emergency Managers.

Michael Burger
Executive Director, Sabin Center for Climate Change Law; Senior Research Scholar, Columbia Law School
Michael Burger is the Executive Director of the Sabin Center for Climate Change Law, and a Senior Research Scholar at Columbia Law School. His research and advocacy focus on legal strategies to reduce greenhouse gas emissions and promote climate change adaptation through pollution control, resource management, land use planning and green finance. Burger frequently collaborates with researchers across Columbia's Earth Institute, and with local and national environmental groups, government representatives, and international organizations. He is a widely published scholar, a frequent speaker at conferences and symposiums, and a regular source for media outlets, including the *New York Times*, *Washington Post*, *Newsweek*, *Time*, *Forbes*, the *Guardian*, *Bloomberg*, and *Vox.com*. He has been featured on *Science Friday* and *Living on Earth*. Prior to joining the Sabin Center in 2015, Burger was an associate professor at Roger Williams University School of Law, an assistant professor in the Lawyering Program at New York University School of Law, and an environmental attorney for New York City's Office of the Corporation Counsel. He is a graduate of Columbia Law School and of Brown University and holds a Master of Fine Arts degree from the Creative Writing program at NYU.

Robert Chen
Director, (CIESIN) Center for International Earth Science Information Network
Robert Chen is director of CIESIN, the Center for International Earth Science Information Network, a research unit of the Earth Institute at Columbia. He has managed the NASA Socioeconomic Data and Applications Center (SEDAC) for more than two decades and co-leads the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center. He is a co-chair of the Thematic Research Network on Data and Statistics (TReNDS) of the United Nations Sustainable Development Solutions Network, a Councilor of the American Geographical Society, and co-leader of the Group on Earth Observations (GEO) Data Sharing Working Group and Human Planet Initiative. Chen currently manages multiple sponsored projects, including support from NASA, NOAA, the U.S. Army Corps of Engineers, the Bill & Melinda Gates Foundation, Schmidt Futures, and Facebook. He is a member of the Earth Institute's Practice Committee and affiliated with Columbia's Data Science Institute. He received his Ph.D. in geography from the University of North Carolina at Chapel Hill and holds B.S. and M.S. degrees from the Massachusetts Institute of Technology.

George Deodatis
Santiago and Robertina Calatrava Family Professor of Civil Engineering; Chair, Department of Civil Engineering and Engineering Mechanics, Columbia University
Professor George Deodatis received his Diploma in Civil Engineering from the National Technical University of Athens in Greece in 1982. He holds M.S. and Ph.D. degrees in Civil Engineering from Columbia University (received in 1984 and 1987 respectively). He started his academic career at Princeton University where he served as Assistant Professor and Associate Professor (with tenure). He moved to Columbia University in 2002 where he served as Associate Professor and Professor. He currently holds the Santiago and Robertina Calatrava Family Endowed Chair at the Department of Civil Engineering and

Engineering Mechanics at Columbia University. He is also currently serving as Department Chair. His research interests are in the area of probabilistic methods in civil engineering and engineering mechanics, with emphasis on risk analysis and risk management of the civil infrastructure subjected to natural and man-made hazards (including climate change). He has received the National Science Foundation Young Investigator Award, the International Association for Structural Safety and Reliability Junior Research Prize, and the American Society of Civil Engineers Walter Huber Research Prize. He is a Fellow of the Engineering Mechanics Institute of the American Society of Civil Engineers. In 2009, he was elected President of the International Association for Structural Safety and Reliability for a four-year term. In 2017, he was elected President of the Engineering Mechanics Institute of the American Society of Civil Engineers for a two-year term. While on the faculty at Princeton University, he was awarded the President's Award for Distinguished Teaching, Princeton's highest teaching honor. At Columbia University, he has received the Presidential Award for Outstanding Teaching and the Great Teacher Award from the Society of Columbia Graduates, Columbia's highest teaching honors.

Congressman Adriano Espaillat
New York's Thirteenth Congressional District
Representative Adriano Espaillat proudly represents New York's Thirteenth Congressional District. He was sworn into office on January 3, 2017, during the 115th Congress. He serves as a member of the U.S. House Foreign Affairs Committee, the House Committee on Transportation and Infrastructure, and the House Small Business Committee. He serves as Senior Whip in the House Democratic Caucus, Whip of the Congressional Hispanic Caucus, (CHC) and Deputy Whip of the Congressional Progressive Caucus (CPC). Prior to his election to Congress, Rep. Espaillat served in the New York State Senate (2011-2016) and New York State Assembly (1997-2010). Rep. Espaillat is a graduate of Queens College.

Dylan George
Vice President, Technical Staff in BNext, In-Q-Tel
Dylan George, Ph.D., is a Vice President, Technical Staff in BNext at In-Q-Tel (IQT). George provides strategic science and technical vision to strengthen capacity within the United States to counter biological threats, specifically those from infectious disease epidemics whether natural, accidental, or intentional. Prior to joining IQT, George served Dr. John Holdren, Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy (OSTP), as a Senior Advisor for Biological Threat Defense. Among other responsibilities at OSTP, George provided technical expertise and interagency coordination supporting the response to the Ebola outbreak in West Africa. From 2013-2014, George worked in the Department of Health and Human Services within the Biomedical Advanced Research and Development Authority where he led a team that developed analytical approaches to assess risks from emerging infectious diseases and other mass casualty events. From 2009-2013, he worked within the Department of Defense on anticipating and assessing infectious disease risks that would impact mission readiness and force health protection. George worked at the National Science Foundation within the Divisions of Biological Infrastructure and Environmental Biology. While at NSF he supported, among other activities, the National Ecological Observatory Network (NEON) and the Ecology of Infectious Diseases program. George received his Ph.D. from Colorado State University and focused on quantitative

analytical approaches for considering how clinically severe pathogens (e.g., Yersinia pestis, rabies) persist within wildlife populations.

Christopher "Bong" Grajo
Founder and President, Emergency Response Integration Center
Christopher "Bong" Grajo is the founder and current President of the Emergency Response Integration Center (ERIC), a non-governmental, non-profit organization that specializes in data management and alternative communication before, during, and after emergencies using emerging and disruptive technologies. Since 2009, ERIC has served in various mobilizations in the Philippines, connecting and providing life-saving information between and among affected communities and emergency responders, government agencies, humanitarian organizations, and private donors. During blue skies, ERIC trains communities at risk in establishing baseline data and preparing emergency communications. During emergencies, ERIC works with the National Disaster Risk Reduction and Management Council of the Philippine Government, the UNHCR, UNICEF, UNOCHA, faith-based groups, and other humanitarian organizations.

Avril Haines
Senior Research Scholar, Columbia University; Deputy Director, Columbia World Projects
Avril Haines is a Deputy Director of Columbia World Projects, a Lecturer in Law at Columbia Law School, and a Senior Fellow at the Johns Hopkins University Applied Physics Laboratory. She was appointed by President Obama to serve as a Member of the National Commission on Military, National, and Public Service, co-chairs the U.S. Holocaust Memorial Museum's Simon Skjodt Center for the Prevention of Genocide's Advisory Group, and serves on a number of boards and advisory groups, including the Nuclear Threat Initiative's Bio Advisory Group, the Board of Trustees for the Vodafone Foundation, and the Refugees International Policy Advisory Council. Prior to joining Columbia University, Haines served as Assistant to the President and Principal Deputy National Security Advisor to President Obama. Before that, she served as the Deputy Director of the Central Intelligence Agency. She also held a number of senior legal positions in the government, including Legal Adviser to the National Security Council. Haines is a graduate of the University of Chicago and the Georgetown University Law Center.

Kevin Halsey
Analyst, ESG; representative, Mercy Corp
Kevin Halsey is currently an ecosystem service analyst at ESG and has been working in the ecosystem services field since 2004. Prior to working in the ecosystem service world Halsey worked as an environmental attorney and was involved in litigation involving the Clean Water Act, Endangered Species Act, and National Environmental Policy Act. Halsey also worked as an adjunct professor at Lewis and Clark Northwestern School of Law from 2008 to 2014, and for the University of Oregon's Sustainability Leadership Program from 2009 to 2013.

Rebecca Hersher
Reporter Science Desk, NPR
Rebecca Hersher is a science reporter at National Public Radio, where she covers climate science, climate policy and toxics. She has reported widely on disaster risk and resilience in the U.S., and on the social implications of climate policy. She previously covered global epidemics, conflict and health.

Junia Howell
Assistant Professor, University of Pittsburgh
Junia Howell is an Assistant Professor of Sociology at the University of Pittsburgh and a Kinder Scholar at Rice University's Kinder Institute for Urban Research. Her research investigates how local and national policies perpetuate racial and socioeconomic inequality. Specifically, she investigates how disaster relief, housing appraisals, and other public policies effect inequality. Her recent publications have appeared in *Social Forces*, *Social Problems*, *Urban Studies*, *The Sociological Quarterly*, and *Population and Environment*, and has been featured in various news outlets including *NPR*, *The Atlantic*, and *The New York Times*.

Wilmot James
Visiting Professor of Pediatrics, School of International and Public Affairs, Columbia University
Wilmot James is a visiting professor of (non-clinical) pediatrics and international affairs at Columbia University in New York City. An academic by background with a Ph.D. from the University of Wisconsin at Madison, James was previously a Member of Parliament (South Africa). James serves on the expert panel of the Global Health Security Index (Nuclear Threat Initiative [NTI], Johns Hopkins University and The Economist Intelligence Unit) and works with the Nuclear Threat Initiative and Africa Center for Disease Control on biosecurity issues.

The Hon. Jeh Johnson
Partner, Paul, Weiss, Rifkind, Wharton & Garrison LLP; Former Secretary of the U.S. Department of Homeland Security
Jeh Johnson is a partner with the law firm Paul, Weiss, Rifkind, Wharton & Garrison LLP and the former U.S. Secretary of Homeland Security (2013-2017). Prior to that, Johnson was General Counsel of the Department of Defense (2009-2012), General Counsel of the Department of the Air Force (1998-2001), and an Assistant United States Attorney for the Southern District of New York (1989-1991). Johnson is a Fellow in the American College of Trial Lawyers and a member of the Council on Foreign Relations. He is a graduate of Morehouse College (1979) and Columbia Law School (1982), and the recipient of nine honorary degrees. Johnson frequently lectures at Harvard, Yale and other law schools, and is a non-resident Senior Fellow at the Harvard Kennedy School.

Ira Katznelson
Ruggles Professor of Political Science and History, Columbia University; Deputy Director, Columbia World Projects
Ira Katznelson is Ruggles Professor of Political Science and History at Columbia University. His 2013 *Fear Itself: The New Deal and the Origins of Our Time* has been awarded the Bancroft Prize in History and the Woodrow Wilson Foundation Award in Political Science. Other books include the just-published *Southern Nation: Congress and White Supremacy After Reconstruction* (co-authored with David Bateman and John Lapinski). Katznelson is a former president both of the American Political Science Association and the Social Science Research Council. He earned his BA at Columbia College and his PhD in History at the University of Cambridge, where he served in 2017-18 as Pitt Professor of American History and Institutions.

Matthew Keller
Partnership Lead for North America, UN World Food Programme
Matt Keller is the partnership lead for North America for the UN World Food Programme's Innovation Accelerator. Prior to re-joining WFP, Keller was Executive Director of the $15 million Global Learning XPRIZE sponsored by Elon Musk which he led for six years. Previously, as Vice-President of One Laptop per Child (OLPC), Keller led OLPC's ground-breaking literacy project in remote Ethiopia testing the theory that children from non-literate communities could teach themselves to read using tablets filled with off-the-shelf applications. He has worked as a senior program officer with the United Nations World Food Programme serving in Rome, Italy, where he worked both as a lawyer and as a key advocate in raising global awareness around the issue of child hunger, working with governments, the private sector and citizens from dozens of countries around the world.

Nicholas Lemann
Director, Columbia World Projects; Director, Columbia Global Reports; Joseph Pulitzer II and Edith Pulitzer Moore Professor of Journalism; Dean Emeritus of the Faculty of Journalism
Nicholas Lemann directs Columbia World Projects. He also directs Columbia Global Reports, a book publishing venture that presents reporting around the globe on a wide range of political, financial, scientific, and cultural topics. Lemann is Dean Emeritus and Pulitzer Moore Professor of Journalism at Columbia. During his deanship, the Journalism School completed its first capital fundraising campaign, started its first new professional degree program since the 1930s, and launched significant initiatives in investigative reporting, digital journalism, and executive leadership for news organizations. Board memberships include Columbia's Knight First Amendment Institute and the Russell Sage Foundation. Lemann is a member of the New York Institute for the Humanities and the American Academy of Arts and Sciences, and a staff writer for *The New Yorker*.

Anne Liu
Lecturer, School of International and Public Affairs, Columbia University
Anne Liu is an innovations expert focused on digital solutions for disease surveillance and health systems strengthening. She currently serves as Technical Adviser at the Clinton Health Access Initiative, focusing on developing, implementing, and monitoring a suite of digital solutions to enhance surveillance capability in malaria elimination settings across Southern Africa, Southeast Asia, Mesoamerica and Hispaniola. Previously, Liu led the Community Health Worker and Mobile Health programs in 10 countries with the Millennium Villages Project from 2010-2015 and oversaw the deployment of mobile tools for Ebola surveillance in Guinea during the West Africa Ebola Outbreak in 2014. She currently co-teaches Introduction to Global Health at Columbia University School of International and Public Affairs, with a focus on health systems strengthening, community health worker systems, and health technology.

Syra Madad
Senior Director, System-wide Special Pathogens Program, NYC Health + Hospitals
Syra Madad, D.H.Sc., M.Sc., MCP is nationally recognized leader in public health and special pathogen preparedness and response. She is Senior Director, System-wide Special Pathogens Program at New York City Health + Hospitals, the nation's largest municipal healthcare delivery system overseeing special pathogen preparedness and response efforts across 11 acute care hospitals in addition to post-acute/long-term care facilities and ambulatory care sites. She is Co-Principal Investigator and founding member of NYC Health + Hospitals Center for Global Healthcare Preparedness to Special Pathogens. She is also an Assistant Professor in the Graduate Biotechnology/BioDefense Program at the University of Maryland and Core Faculty/Team Lead in the National Ebola Training and Education Center's (NETEC) Special Pathogens Exercise Resource Team. In addition, Madad is a Fellow in the Emerging Leaders in Biosecurity at the Johns Hopkins Bloomberg School of Public Health, Center for Health Security. Previously, Senior Research Fellow in the Behavioral Informatics & Technological Enterprise Studies at the Federal Bureau of Investigation. Madad has a number of peer-reviewed articles and has been a guest speaker at numerous scientific and medical conferences/workshops/webinars around the world. She was recently quoted in the *Wall Street Journal* on pandemic preparedness along with other national public health figures. She serves on over five editorial boards and advising committees and councils, nationally and internationally.

Michael Mahar
Lead for GHSA and IHR Collaborating Center, US Centers for Disease Control and Prevention
Michael Mahar, PhD, is the Lead for the Global Health Security Agenda (GHSA) and WHO International Health Regulations collaborating center in the Division of Global Health Protection (DGHP), within the U.S. Centers for Disease Control and Prevention. In this role, Mahar oversees work on DGHP's implementation of the GHSA and directs the collaboration with the WHO on the International Health Regulations, including the Joint External Evaluation, National Action Plans for Health Security, and other components of the IHR Monitoring and Evaluation Framework. Prior to joining the CDC, Mahar worked at the U.S. Department of Defense (DoD) where he provided

program management and oversight to the Cooperative Biological Engagement Program and helped develop the DoD's objectives for the Global Health Security Agenda. Mahar has also worked at the National Academies and the American Society for Microbiology where he collaborated with experts to develop recommendation reports covering topics ranging from the microbial ecology of water distribution systems to the microbiology of brewing beer.

Tim Manning
President and CEO, Berglind-Manning l.c.
Tim Manning has worked on both the front lines and the senior most levels of homeland security, emergency management, and resilience for more than twenty-five years; Manning is a former Deputy Administrator at the Federal Emergency Management Agency, governor's homeland security advisor, firefighter, rescue mountaineer, and geologist. He served through the entirety of the Barack Obama administration as the Deputy Administrator of the Federal Emergency Management Agency for Protection and National Preparedness, having been confirmed by the U.S. Senate in the spring of 2009. He was responsible for the establishment and design of numerous national programs and Presidential directives, overseeing more than twenty billion dollars in grants and assistance and the education and training of millions of America's first responders and homeland security professionals. He helped coordinate the response to countless emergencies and disasters throughout the United States and worked with partners around the globe. Manning earned a Master of Letters with distinction in Terrorism and Political Violence from the University of St. Andrews, a Bachelor of Science in Geology from Eastern Illinois University, and is a graduate of the Center for Homeland Defense and Security Executive Leaders Program at the Naval Postgraduate School. He is currently a Senior Advisor to the Pacific Disaster Center, on the faculty of the Disaster and Emergency Management program at Georgetown University, a Senior Fellow at the Atlantic Council, and President and CEO of Berglind-Manning l.c., an international resilience, security, and strategic policy consulting firm.

Amanda McClelland
Senior Vice President, Prevent Epidemics, Resolve to Save Lives
Amanda McClelland is the Senior Vice President of the Prevent Epidemics team at Resolve to Save Lives, an initiative of Vital Strategies. McClelland has more than 14 years' experience in global health, working in response to natural disasters, conflict and public health emergencies including the West Africa Ebola crises. With a focus on local prevention and response, she has spent much of the last decade working with frontline health workers and communities on prevention, early detection and response to health crises. Now, as part of the Resolve to Save Lives mission, she focuses on building technical, political and financial support for preparedness efforts, including effective IHR that improve a country's ability to find, stop and prevent epidemics.

Roberto Moris
Director of Planning and Urban Projects, Pontificia Universidad Católica de Chile
Roberto Moris is an architect and urban planner. Moris is the Director of the Planning and Urban Projects Program at Pontificia Universidad Católica in Chile. He is an expert on integrated planning, carrying capacity models, climate change adaptation, risk management, and resilience. He has worked with the United Nations Development Program, the World Bank and the Inter-American Development Bank, with professional and academic activities in five continents. In the Chilean public sector, Moris was Technical Secretary of the Committee of Ministers of the City and Territory, and Director of the Directorate of Urban Projects (DPU). He is a professor at the School of Architecture and the Institute of Urban and Territorial Studies (IEUT UC). He previously served as Assistant Director of IEUT PUC and is currently the Director of the UC Cities Observatory. He also serves as Principal Investigator of the National Research Center for the Integrated Management of Natural Disasters (CIGIDEN).

Kate Orff
Associate Professor, Director, Urban Design Program, Columbia University
Kate Orff is a landscape architect focused on nature-based infrastructure and urban resilience. She is an Associate Professor at Columbia GSAPP and Director of the Urban Design Program. She is also the Faculty Director of the Center for Resilient Cities and Landscapes at Columbia and a 2017 MacArthur Fellow.

Roger Parrino
Senior Advisor Security and Emergency Management, The Port Authority of New York & New Jersey
Roger L. Parrino Sr. currently serves as a senior advisor for security and emergency management at the Port Authority of New York and New Jersey, having previously served as the Commissioner of the New York State Division of Homeland Security and Emergency Services. As Commissioner, he provided overall direction and leadership for New York's efforts to prevent, protect against, prepare for, respond to, and recover from man-made and natural disasters. Prior to his appointment as the Commissioner, he served as Senior Counselor to U.S. Department of Homeland Security Secretary Jeh Johnson, where he provided operational crisis management to all levels of leadership in a Cabinet-level agency of 232,000 persons responsible for border security, counterterrorism, immigration, aviation security, cybersecurity, infrastructure protection, and emergency management. Parrino has over 35 years of public service, starting in 1980 when he enlisted in the Marine Corps Reserve and reported to Paris Island. He served in the New York Police Department for over 21 years, where he was promoted to Lieutenant Commander of Detectives and was a member of the Hostage Negotiation Team for over ten years.

Andrew Phelps
Director, Oregon Office of Emergency Management
Andrew Phelps has served as the Director of the Oregon Office of Emergency Management since 2015. In addition to managing the state's 9-1-1 program and multi-million-dollar state and federal preparedness, recovery and mitigation grant programs, Phelps' office maintains comprehensive planning, training, exercise, and community engagement programs to ensure Oregon can mitigate against, prepare for, respond to, and recover from any emergency or disaster, regardless of cause. Phelps also serves as the Governor's Authorized Representative for federal disaster declarations. He has also held leadership positions with state, local and non-profit emergency management and response agencies and organizations in New York and New Mexico. He received his undergraduate degree from the City University of New York and his graduate degree from the Naval Postgraduate School in Monterey, California.

Richard Plunz
Professor of Architecture, Director, Earth Institute Urban Design Lab, Columbia University
Richard Plunz is Professor of Architecture at Columbia University and founder of the Earth Institute Urban Design Lab. In the past he served as Chair of the Division of Architecture and until 2015 he directed the post-professional Urban Design Program. Plunz is known for a wide range of innovative urban research, development and design projects both nationally and internationally, with a particular expertise in urban infrastructure and fabric. He has been the recipient of many awards including the Andrew J. Thomas Pioneer in Housing Award from the American Institute of Architects for his contributions to housing research. A revised edition of his book, A History of Housing in New York City (Columbia 1992) was published in the Fall 2016. His latest book on sustainable urban development is City Riffs: Urbanism, Ecology, Place (Lars Muller Publisher 2017).

The Hon. Julissa Reynoso
Partner, Winstron & Strawn; Former U.S. Ambassador to Uruguay
Julissa Reynoso is a partner at the law firm of Winston & Strawn. Her extensive experience includes analyzing and advising on complex cross-border litigations, investigations and disputes before U.S. Courts and Agencies. Reynoso has conducted arbitrations under the major international rules, including ICC and UNCITRAL, and managed bilateral investment treaty disputes under the Dominican Republic-Central America Free Trade Agreement (DR-CAFTA) and the North American Free Trade Agreement (NAFTA). She is the former United States Ambassador to Uruguay and served as Deputy Assistant Secretary of State for Central American, Caribbean and Cuban Affairs in the US Department of State. In the role, she was charged with developing comprehensive security and rule of law strategies for Central America and the Caribbean. Reynoso is the recipient of the highest diplomatic honors bestowed by several Latin American governments. She serves on the boards of several nonprofit and advocacy organizations and was on the faculty of Columbia Law School and Columbia's School of International and Public Affairs. She serves as trustee for New York-Presbyterian Hospital and for Columbia University. Reynoso was appointed to co-chair New York Attorney General Letitia James' transition committee. She holds degrees from Harvard University, the University of Cambridge, and Columbia Law School.

Dan Rubenstein
Associate Professor of Computer Science, Columbia University
Dan Rubenstein is an Associate Professor in the Department of Computer Science at Columbia University. He received a B.S. degree in mathematics from M.I.T., an M.A. in math from UCLA, and a PhD in computer science from University of Massachusetts, Amherst. His research interests are in network technologies, applications, and performance analysis. He was an editor for IEEE/ACM Transactions on Networking, was general chair of IFIP Performance 2017, program chair of IFIP Networking 2010 and ACM Sigmetrics 2011, and has received an NSF CAREER Award, IBM Faculty Award, the Best Student Paper award from the ACM SIGMETRICS 2000 conference, and Paper awards from the IEEE ICNP 2003 Conference, ACM CoNext 2008 Conference, and IEEE Communications 2011. He spent 2011 at Google, and in 2012 was the original Chief Scientist at Infinio, a company founded on his research at Columbia. Rubenstein is a Fellow of the IEEE.

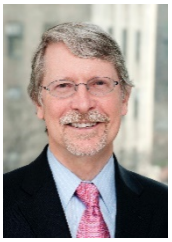
Jeff Schlegelmilch
Deputy Director, National Center for Disaster Preparedness
Jeff Schlegelmilch is the Deputy Director for the National Center for Disaster Preparedness. His areas of expertise include public health preparedness, community resilience, and the integration of private and public-sector capabilities. Some topics of past work include developing inter-organizational processes for operational epidemiological modeling, evacuation and sheltering planning for people with medical dependencies, and adapting business intelligence systems for disaster response and recovery operations. He has advised local, state, and federal leaders on preparedness programs and policies and has briefed congressional staff on key preparedness legislation and funding areas. He frequently serves as a subject matter expert source for the media and is an expert Contributor for *The Hill*. He holds a Master's degree in Public Health from UMASS Amherst in Health Policy and Management, and a Master's in Business Administration from Quinnipiac University.

Hugh Sealy
Special Envoy, Government of Barbados; Lecturer, University of West Indies
Hugh Sealy is a chemical engineer and environmental scientist. He is a Special Envoy of the Prime Minister of Barbados and advises the Government of Barbados on matters relating to climate change, energy, water resources and waste management. Sealy is a negotiator for the Alliance of Small Island States (AOSIS) and a Lecturer in the Centre for Resource Management and Environmental Studies (CERMES) at the University of the West Indies (UWI).

Jeffrey Shaman
Professor, Department of Environmental Health Sciences; Director, Climate and Health Program, Columbia University
Jeffrey Shaman is a Professor in the Department of Environmental Health Sciences and Director of the Climate and Health Program at the Columbia University Mailman School of Public Health. He studies the survival, transmission and ecology of infectious agents, including the effects of

meteorological and hydrological conditions on these processes. Work-to-date has primarily focused on mosquito-borne and respiratory pathogens. He uses mathematical and statistical models to describe, understand, and forecast the transmission dynamics of these disease systems, and to investigate the broader effects of climate and weather on human health.

Adam Sobel
Professor of Applied Physics and Applied Mathematics, Earth & Environmental Sciences, Columbia University
Adam Sobel studies weather and climate, with a focus on extreme weather events and a particular interest in the tropics. Phenomena include tropical cyclones, intraseasonal variability, precipitation, severe convection, and climate change. Sobel's research spans basic and applied prediction and risk assessment, and uses observations, theory, and numerical simulations with models spanning a hierarchy in complexity. He is particularly interested in the interactions between turbulent deep convection and large-scale atmospheric dynamics, as these are key to the qualitative and quantitative understanding and prediction of many modes of atmospheric behavior, including extreme precipitation events. He has developed novel methods for diagnosing these interactions, connecting high-resolution explicit simulations of cloud systems to simple theoretical representations of large-scale dynamics in order to extract essential mechanisms and understand the connections between weather and climate. In another line of work, with colleagues in both academia and the insurance industry, Sobel has been developing hybrid statistical-dynamical models, combining mechanistic understanding with inference from observational data, to assess the risk of rare but extremely damaging extreme weather events, particularly tropical cyclones, tornadoes, and hail.



Lawrence Stanberry
Associate Dean, International Programs; Director of the Programs in Global Health, Columbia University
Lawrence Stanberry is the Associate Dean for International Programs, the Director of the Programs in Global Health and, formerly, the Chairman of the Department of Pediatrics at Columbia University's Vagelos College of Physicians and Surgeons. Trained in pediatrics and infectious diseases, he is an authority on vaccines and viral infections. He has served on numerous advisory boards and review panels including serving as the chair of the Vaccine Study Section and the Pediatrics Review Panel at the National Institutes of Health. He has received research funding from the National Institutes of Health, the Centers for Disease Control and Prevention, numerous vaccine, pharmaceutical and biotech companies, and the Bill and Melinda Gates Foundation. Stanberry has authored over 200 scientific articles and chapters and authored or edited seven books including, "Vaccines for Biodefense and Emerging and Neglected Diseases, London, Elsevier (2009). "Understanding Modern Vaccines" Elsevier (2011), and "Viral Infections of Humans: Epidemiology and Control," (5th edition 2014, 6th edition in preparation). His current work focuses on the preparedness of children's hospitals globally to prevent, detect, and respond to infections of pandemic potential.

Nik Steinberg
Forum Director, Columbia World Projects
Nik Steinberg is the Forum Director at Columbia World Projects. He previously served as the Counselor and Chief Speechwriter for Amb. Samantha Power, U.S. Ambassador to the United Nations. Prior to that, Steinberg was Senior Researcher in the Americas Division of Human Rights Watch, where his work focused primarily on Mexico and Cuba. He is a graduate of Dartmouth College and the Harvard Kennedy School of Government.

Jeff Stern
State Coordinator of Emergency Management, Virginia Department of Emergency Management
Jeff Stern leads the Virginia Department of Emergency Management, the Commonwealth's disaster preparedness and response agency. Appointed in 2014, Stern has led VDEM through a modernization program that decentralized staffing, doubled rural staff, trained all personnel to support disaster operations, and streamlined finances, planning, response, training and exercise programs. He has led VDEM through nearly 40 gubernatorial-declared states of emergency and four presidential disaster declarations. During 2017 and 2018, he deployed Virginia responders to California, Texas, Florida, North Carolina, South Carolina, Maryland, Massachusetts, Hawaii, Alaska, Puerto Rico, and the U.S. Virgin Islands. His career spans three decades of operational and policymaking roles in local, state, and federal government, and in the private sector, including presidential appointments as a White House Fellow at the US Department of the Interior and the White House, and as Executive Director of the Homeland Security Advisory Council at the Department of Homeland Security. He started his career in government as a firefighter/paramedic, serving in Maryland, Virginia, and Colorado, and has led response teams to many disasters, including Hurricane Katrina and the 2010 Haitian earthquake. Stern earned his PhD in Public Administration/Public Affairs from Virginia Tech's Center for Public Administration and Policy, an MPA from the American University School of Public Affairs, and a BA in government from the College of William & Mary. He chairs FEMA's National Advisory Council Response & Recovery Committee, and is a member of the Department of Commerce FirstNet Public Safety Advisory Committee, the National Capital Region Homeland Security Executive Committee, the DHS Science and Technology First Responders Resource Group, and previously served as chair of the National Emergency Management Association's Legislative Committee during the passage of the landmark 2018 Disaster Recovery Reform Act. As State Coordinator of Emergency Management, he chairs Virginia's 911 Board and serves as the state administrative agent for all homeland security and emergency management programs. Stern is an adjunct professor at Georgetown University's Emergency and Disaster Management program.

Tara Vassefi

Washington Director of Strategic Initiatives, Truepic

Tara Vassefi is the Washington Director of Strategic Initiatives for Truepic, a technology company specializing in image authentication. She is currently a visiting scholar with UC Berkeley Law School's Human Rights Center, where she is exploring how the latest technologies are weighed in justice and accountability systems. Prior to this, she worked as a human rights lawyer, developing expertise on how to optimize the use of digital evidence and user-generated content for a range of human rights and humanitarian cases with a several organizations and clinics including WITNESS, the War Crimes Research Office, and the Berkeley's Open Source Investigations Lab. Before and during law school, she worked on National Security issues with the U.S. Department of Defense. Vassefi received her BA in International Relations at the University of St Andrews and a JD from American University Washington College of Law.

Dickie Whitaker

Chief Executive, Oasis Loss Modelling Framework

Dickie Whitaker has 30 years' experience in the (Re)Insurance business and for the last 20 years has specialized in risk and innovation, linking academia, government and finance. He co-founded The Lighthill Risk Network, Oasis Palm Tree Ltd, The Oasis Hub and is chief executive of Oasis Loss Modelling Framework Ltd. He provides advisory roles to: UK's Satellite Applications Advisory Board, Expert Group for the Global Risk Assessment Framework (GRAF), UNISDRR The Centre for Risk Studies, Cambridge University and Cabot Institute advisory board.