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CONTENTS

Global Trends 2040: A More Contested World

U.S. National Intelligence Council

***Editor's Note:** This article is adapted from the U.S. National Intelligence Council's March 2021 report, "Global Trends 2040: A More Contested World." It includes the report's Executive Summary, which puts climate considerations into the context of the strategic environment for the U.S. in the next two decades. It also includes an excerpt from the report's "Structural Forces: Environment" chapter, which identifies a series of environmental trends that the Council anticipates will be highly impactful in the coming decades.*

Structural Forces Setting the Parameters

Trends in demographics and human development, environment, economics, and technology are laying the foundation and constructing the bounds of our future world. In some areas, these trends are becoming more intense, such as changes in our climate, the concentration of people in urban areas, and the emergence of new technologies. Trends in other areas are more uncertain—gains in human development and economic growth are likely to slow and may even reverse in some areas, although a mix of factors could change this trajectory. The convergence of these trends will offer opportunities for innovation but also will leave some communities and states struggling to cope and adapt. Even apparent progress, such as new and advanced technologies, will be disruptive to many people's lives and livelihoods, leaving them feeling insecure and forcing adaptation.

The most certain trends during the next 20 years will be major **demographic** shifts as global population growth slows and the world rapidly ages. Some developed and emerging economies, including in Europe and East Asia, will grow older faster and face contracting populations, weighing on economic growth. In contrast, some developing countries in Latin America, South Asia, and the Middle East and North Africa benefit from larger working-age populations, offering opportunities for a demographic dividend if coupled with improvements in infrastructure and skills. **Human development,** including health, education, and household prosperity, has made historic improvements in every region during the past few decades. Many countries will struggle to build on and even sustain these successes. Past improvements focused on the basics of health, education, and poverty reduction, but the next levels of development are more difficult and face headwinds from the COVID-19 pandemic, potentially slower global economic growth, aging populations, and the effects of conflict and climate. These factors will challenge governments seeking to provide the education and infrastructure needed to improve the productivity of their growing urban middle classes in a 21st century economy. As some countries rise to these challenges and others fall short, shifting global demographic trends almost certainly will aggravate disparities in economic opportunity within and between countries during the next two decades as well as create more pressure for and disputes over migration.

In the **environment**, the physical effects of climate change are likely to intensify during the next two decades, especially in the 2030s. More extreme storms, droughts, and floods; melting glaciers and ice caps; and rising sea levels will accompany rising temperatures. The impact will disproportionately fall on the developing world and poorer regions and intersect with environmental degradation to create new vulnerabilities and exacerbate existing risks to economic prosperity, food, water, health, and energy security. Governments, societies, and the private sector are likely to expand adaptation and resilience measures to manage existing threats, but these measures are unlikely to be evenly distributed, leaving some populations behind. Debates will grow over how and how quickly to reach net zero greenhouse gas emissions.

During the next two decades, several global **economic trends,** including rising national debt, a more complex and fragmented trading environment, a shift in trade, and new employment disruptions are likely to shape conditions within and between states. Many governments may find they have reduced flexibility as they navigate greater debt burdens, diverse trading rules, and a broader array of powerful state and corporate actors exerting influence. Large platform corporations—which provide online markets for large numbers of buyers and sellers—could drive continued trade globalization and help smaller firms grow and gain access to international markets. These powerful firms are likely to try to exert influence in political and social arenas, efforts that may lead governments to impose new restrictions. Asian economies appear poised to continue decades of growth through at least 2030, although potentially slower. They are unlikely to reach the per capita gross domestic product (GDP) or economic influence of existing advanced economies, including the United States and Europe. Productivity growth remains a key variable; an increase in the rate of growth could alleviate many economic, human development, and other challenges.

Renewable Natural Resources Foundation

The Renewable Natural Resources Foundation (RNRF) is a nonprofit, public policy research organization. Its mission is to advance the application of science, engineering and design in decision-making, promote interdisciplinary collaboration, and educate policymakers and the public on managing and conserving renewable natural resources. Member organizations are:

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Technology will offer the potential to mitigate problems, such as climate change and disease, and to create new challenges, such as job displacement. Technologies are being invented, used, spread, and then discarded at ever increasing speeds around the world, and new centers of innovation are emerging. During the next two decades, the pace and reach of technological developments are likely to increase ever faster, transforming a range of human experiences and capabilities while also creating new tensions and disruptions within and between societies, industries, and states. State and nonstate rivals will vie for leadership and dominance in science and technology with potentially cascading risks and implications for economic, military, and societal security.

Emerging Dynamics

These structural forces, along with other factors, will intersect and interact at the levels of societies, states, and the international system, creating opportunities as well as challenges for communities, institutions, corporations, and governments. These interactions are also likely to produce greater contestation at all levels than has been seen since the end of the Cold War, reflecting differing ideologies as well as contrasting views on the most effective way to organize society and tackle emerging challenges.

Within societies, there is increasing fragmentation and contestation over economic, cultural, and political issues. Decades of steady gains in prosperity and other aspects of human development have improved lives in every region and raised peoples' expectations for a better future. As these trends plateau and combine with rapid social and technological changes, large segments of the global population are becoming wary of institutions and governments that they see as unwilling or unable to address their needs. People are gravitating to familiar and like-minded groups for community and security, including ethnic, religious, and cultural identities as well as groupings around interests and causes, such as environmentalism. The combination of newly prominent and diverse identity allegiances and a more siloed information environment is exposing and aggravating fault lines within states, undermining civic nationalism, and increasing volatility.

At the **state level,** the relationships between societies and their governments in every region are likely to face persistent strains and tensions because of a growing mismatch between what publics need and expect and what governments can and will deliver. Populations in every region are increasingly equipped with the tools, capacity, and incentive to agitate for their preferred social and political goals and to place more demands on their governments to find solutions. At the same time that populations are increasingly empowered and demanding more, governments are coming under greater pressure from new challenges and more limited resources. This widening gap portends more political volatility, erosion of democracy, and expanding roles for alternative providers of governance. Over time, these dynamics might open the door to more significant shifts in how people govern.

In the **international system,** no single state is likely to be positioned to dominate across all regions or domains, and a broader range of actors will compete to shape the international system and achieve narrower goals. Accelerating shifts in military power, demographics, economic growth, environmental conditions, and technology, as well as hardening divisions over governance models, are likely to further ratchet up competition between China and a Western coalition led by the United States. Rival powers will jockey to shape global norms, rules, and institutions, while regional powers and nonstate actors may exert more influence and lead on issues left unattended by the major powers. These highly varied interactions are likely to produce a more conflict-prone and volatile geopolitical environment, undermine global multilateralism, and broaden the mismatch between transnational challenges and institutional arrangements to tackle them.

Alternative Scenarios for 2040

Human responses to these core drivers and emerging dynamics will determine how the world evolves during the next two decades. Of the many uncertainties about the future, we explored three key questions around conditions within specific regions and countries and the policy choices of populations and leaders that will shape the global environment. From these questions, we constructed five scenarios for alternative worlds in the year 2040.

- How severe are the looming global challenges?
- How do states and nonstate actors engage in the world, including focus and type of engagement?
- Finally, what do states prioritize for the future?

In **Renaissance of Democracies,** the world is in the midst of a resurgence of open democracies led by the United States and its allies. Rapid technological advancements fostered by public-private partnerships in the United States and other democratic societies are transforming the global economy, raising incomes, and improving the quality of life for millions around the globe. The rising tide of economic growth and technological achievement enables responses to global challenges, eases societal divisions, and renews public trust in democratic institutions. In contrast, years of increasing societal controls and monitoring in China and Russia have stifled innovation as leading scientists and entrepreneurs have sought asylum in the United States and Europe.

In **A World Adrift,** the international system is directionless, chaotic, and volatile as international rules and institutions are largely ignored by major powers like China, regional players, and nonstate actors. Organization for Economic Cooperation and Development (OECD) countries are plagued by slower economic growth, widening societal divisions, and political paralysis. China is taking advantage of the West's troubles to expand its international influence, especially in Asia, but Beijing lacks the will and military might to take on global leadership, leaving many global challenges, such as climate change and instability in developing countries, largely unaddressed.

In **Competitive Coexistence,** the United States and China have prioritized economic growth and restored a robust trading relationship, but this economic interdependence exists alongside competition over political influence, governance models, technological dominance, and strategic advantage. The risk of major war is low, and international cooperation and technological innovation make global problems manageable over the near term for advanced economies, but longer-term climate challenges remain.

In **Separate Silos,** the world is fragmented into several economic and security blocs of varying size and strength, centered on the United States, China, the European Union (EU), Russia, and a couple of regional powers; these blocs are focused on self-sufficiency, resiliency, and defense. Information flows within separate cyber-sovereign enclaves, supply chains are reoriented, and international trade is disrupted. Vulnerable developing countries are caught in the middle with some on the verge of becoming failed states. Global problems, notably climate change, are spottily addressed, if at all.

In **Tragedy and Mobilization,** a global coalition, led by the EU and China working with nongovernmental organizations and revitalized multilateral institutions, is implementing far-reaching changes designed to address climate change, resource depletion, and poverty following a global food catastrophe caused by climate events and environmental degradation. Richer countries shift to help poorer ones manage the crisis and then transition to low carbon economies through broad aid programs and transfers of advanced energy technologies, recognizing how rapidly these global challenges spread across borders.

Structural Forces: Environment

The most recent decade was the hottest on record, and every decade since the 1960s has been hotter than the previous one.

Eroding Human Security

The physical impacts of a warmer world, combined with environmental degradation, are likely to lead to an array of human security challenges, primarily but not exclusively in developing countries in the near term. According to a 2018 study, 36 percent of cities globally face acute environmental stress from droughts, floods, and cyclones; climate change will add to these. These challenges will compound one another in coming years; as extreme events become more intense and more frequent, societies may struggle to recover from one event before the next one hits.

Exacerbating Food and Water Insecurity. Changing precipitation patterns, rising temperatures, increased extreme weather events, and saltwater intrusion into soil and water systems from rising seas and storm surges are likely to exacerbate food and water insecurity in some countries during the next two decades. Regions that remain dependent on rain-fed agriculture will be particularly vulnerable, such as Sub-Saharan Africa, Central America, some areas of Argentina and Brazil, parts of the Andean region, South Asia, and Australia. By contrast, some higher latitude regions such as Canada, northern Europe, and Russia may benefit from global warming by lengthened growing seasons.

Fisheries are also under threat from severe overfishing that climate change will further stress through oxygen depletion, rapid warming, and ocean acidification. Fishermen have to go further to catch fewer and smaller fish, potentially venturing into the territorial waters of other countries. In addition, warming ocean temperatures threaten to kill many more coral reefs—already they have declined by 30 to 50 percent, and at 1.5°C warming, they could decline by 70 to 90 percent—further threatening fishing and tourism industries.

Threats to Human Health. Decreased water, air, and food quality, along with changes in disease vectors and water-borne pathogens, all threaten human life. Death rates from pollution vary significantly across the world—typically highest in middle-income countries in East and South Asia. In addition, extreme weather and disasters often kill people and disrupt health infrastructure and prevent access to care. Climate change is expected to change the geographic range and in some cases frequency of disease outbreaks affecting humans, animals, and plants, including those that are vector-borne (West Nile, malaria, Dengue), waterborne (cholera), airborne (influenza, hantavirus), and food-borne (salmonella).

Loss of Biodiversity. The variability among all living organisms—known as biodiversity—is declining faster than at any point in human history, risking food and health security and undermining global resilience. Warming temperatures are likely to lead to the extinction of plants and animals that can no longer survive in their traditional habitats or shift quickly to new locations as well as encourage the spread of invasive species that choke out native organisms.

Increased Migration. Extreme weather events increase the risk of more environmentally-induced migration, which usually occurs within states as affected populations move to nearby communities, often temporarily. Climate change probably will exacerbate this as sea level rise or extreme heat makes certain locales permanently uninhabitable, although mainly after 2040, possibly causing permanent migration and movement to other states.

Growth of Resilience and Adaptation

In addition to efforts to reach net zero emissions, many countries and local communities will expand investment in adaptive infrastructure and resilience measures. Some measures are as inexpensive and simple as restoring mangrove forests or increasing rainwater storage; others are as complex as building massive sea walls and planning for the relocation of large populations. A key challenge for these efforts will be funding for vulnerable communities—particularly as governments face competing fiscal and political challenges and have to choose which communities to support.

Public-private partnerships are innovating new insurance approaches aimed at building resilience to climate risks, such as insuring natural assets like the Mesoamerican reef off Mexico or index-based weather insurance for local farmers in Kenya. These approaches rely on new data and machine learning technologies—suggesting that as these technologies advance during the next 20 years, resilience mechanisms may become more sophisticated.

Calls for Geoengineering. As warming gets closer to exceeding the Paris Agreement goals, it is increasingly likely that states and nonstate actors will more aggressively research, test, and possibly deploy geoengineering measures—deliberate large-scale interventions in the earth's natural systems—to try to counteract climate change. Current research is largely focused on solar radiation management (SRM), an effort to cool the planet by reflecting the suns energy back into space. Stratospheric aerosol injection (SAI), a form of SRM that sprays particles in the stratosphere to cause global dimming, has attracted funding by those who fear the worst of climate change. Proponents argue that the needed energy transformation will happen too slowly and that SAI can buy the planet time because it is technologically feasible and less expensive than mitigation.

Current research is almost entirely in computer models with academia, nongovernmental organizations, and private companies playing a leading role. However, there will be increased calls for countries to begin engaging in the dialogue and possibly take leadership to develop international agreements that could help set research standards, ensure transparency in live tests, determine the legal framework around if, how, and when to deploy SRM technologies, and monitor the effects. The possibly catastrophic unintended side effects are not well understood, and some scientists fear that SRM, while keeping temperatures down, would create unexpected and devastating changes in weather systems and rainfall patterns. Countries and nonstate actors deploying it alone will increase the risk of conflict and blowback, especially when others blame them for a disaster they believe was caused by geoengineering.

Broader Implications and Disruptions

In addition to direct physical effects of climate change, states and societies are likely to be strained by hard choices and tradeoffs given the difficulty and costs of drastic emissions cuts and adaptive measures. The burden of these steps will not be evenly distributed within or between states, and the long-term payoff of mitigation policies runs counter to political incentives, making it difficult to sustain controversial commitments. The second- and third-order implications of climate change will affect human and national security in several ways.

Drive Societal Cleavages and Political Movements. Concerns about climate change have grown across the globe with hundreds of thousands of protesters—mostly young people—marching in the streets advocating for faster change. Policy responses to mitigate or adapt to climate change also contribute to political volatility—particularly when they are linked to broader socio-political interests—such as the French protests against fuel price hikes in 2018. In Europe, nationalist and populist parties have capitalized on public concerns about the economic hardships associated with climate mitigation policies, and they have framed their opposition in terms of equality and social justice for working class populations.

Increased Pressure for Global Action. As warming continues to rise, there will be more debate and tension among countries over transparency, cuts, and responsibility. Developing countries that want the room to grow their economies and increase emissions will more forcefully demand that developed countries provide them with advanced energy technologies to leapfrog their energy systems to a low carbon model. In addition, developing countries will increasingly demand that developed countries meet their commitments to provide financing to help vulnerable populations adapt. Greater demands will be made on international financing vehicles such as the Green Climate Fund, which has approved $4 billion worth of adaptation projects.

Heighten Competition. Climate change and environmental degradation will contribute to and reflect a more contested geopolitical environment. Countries and other actors are likely to compete over food, mineral, water, and energy sources made more accessible, more valuable, or scarcer. Receding Arctic sea ice is opening new sea routes and opportunities to access valuable resources there, including natural gas and oil deposits, rare earth metals, and fish stocks. Russia is building more icebreakers to patrol its northern coastline and project power as an Arctic leader, and even non-coastal states like China and India are seeking to take advantage of shorter trade routes and resources. In addition, China is trying to boost its international image by claiming to be a leader on climate diplomacy despite its growing emissions—already the highest in the world.

Contribute to Instability and Conflict Risk. Rarely is climate change the sole or even primary driver of instability and conflict; however, certain socio-political and economic contexts are more vulnerable to climate sparks that ignite conflict. Countries of particular concern are those with ethnic or religious polarization; livelihoods highly dependent on natural resources or agriculture; weak or illegitimate conflict resolution mechanisms; a history of violence; and low adaptive capacity. For example, an increase in drought or extreme weather may reduce the opportunity cost of joining armed groups for struggling farmers and herders, while sectarian elites may advance their polarizing political goals by exploiting local grievances exacerbated by climate change.

Strain Military Readiness. While militaries will continue to adapt and fight in the changing world, climate effects will strain readiness and compound fiscal pressures on many militaries. Storm surges and sea level rise will force changes to the design and protection of naval bases and aircraft runways, prolonged extreme heat will limit training days, and major storms and floods will force militaries to divert more resources to disaster relief at home and abroad.

Increase Pressure on Strained International Systems. Current international law and cooperative bodies are increasingly mismatched to global climate challenges. For example, international refugee law does not account for people displaced by climate change effects. Many existing organizations designed to help manage shared resources, such as the Arctic Council or the Nile Basin Initiative, may be overwhelmed or sidelined, given their voluntary nature and lack of enforcement mechanisms. Also, efforts to develop international standards or regulations for high-risk activities like SRM lag behind the technology, increasing the possibility that countries or individuals will pursue unilateral action that risk blowback.

*This article is an adaptation of a report by the U.S. National Intelligence Council; the full report can be found **here**.*

Pathways and Pitfalls in Extreme Event Attribution

Geert Jan van Oldenborgh, Karin van der Wiel, Sarah Kew, et al.

***Editor's Note:** This article is a summary of a report by the World Weather Attribution (WWA) collaboration. WWA was founded by climate scientists at the University of Oxford in the UK, KNMI in the Netherlands, IPSL/LSCE in France, and Princeton University and NCAR in the US, ETH Zurich in Switzerland, IIT Delhi in India and climate impact specialists at the Red Cross/Red Crescent Climate Centre (RCCC) around the world. The collaboration provides robust assessments of the role of climate change quickly in the aftermath of natural disasters, providing scientific evidence to answer questions about disaster response, rebuilding, and relocating.*

Experiences from the World Weather Attribution collaboration: We attempt to answer the question whether and to what extent the likelihood and intensity of an observed event changed due to the anthropogenic modification of the Earth's climate using a method called extreme event attribution.

Although this is a relatively new branch of science that developed over the last 15 years, there are many groups that compute these connections. Our approach in the World Weather Attribution (WWA) collaboration is different in two ways: we attempt to have our results ready as soon as possible after the event, and we try to respond as much as possible to questions posed by the outside world. Both approaches aim to make the attribution studies more useful. Commissions to investigate a disaster typically operate within a few months and appreciate if the event being attributed is as close as possible to the aspects that caused the disaster, media interest that reaches a large audience wanes on the order of weeks to months after large events.

*"Pathways and pitfalls in extreme event attribution" was written by **Geert Jan van Oldenborgh, Karin van der Wiel, Sarah Kew,** and **Sjoukje Philip** of KNMI; **Friederike Otto** of the University of Oxford; **Robert Vautard** of IPSL/LSCE; and **Julie Arrighi, Roop Singh,** and **Maarten van Aalst** of the Red Cross Red Crescent Climate Centre.*

We started doing event attributions on our first physical meeting during a heat wave in Paris in the summer of 2015 and learned a lot of lessons from the over two dozen studies we performed since then. These are summarised in a scientific paper that was published in April 2021, "Pathways and pitfalls in extreme event attribution." This article is a summary of the scientific paper. An even more detailed description of the methodology that resulted from all these lessons learned has been published as "A protocol for probabilistic extreme event attribution analyses." The main lesson was that the actual attribution step, on which most attention was focused in 2015, was only one step out of eight. We needed ways to deal with:

1. the trigger: which studies to perform,
2. the event definition: which aspect of the extreme event were most relevant,
3. observational trend analysis: how rare was it and how has that changed,
4. climate model evaluation: which models can represent the extreme,
5. climate model analysis: what part of the change is due to climate change,
6. hazard synthesis: combine the observational and model information,
7. analysis of trends in vulnerability and exposure, and
8. communication of the results.

We discuss each step in turn.

1. Analysis trigger

The Earth is large and extreme weather occurs somewhere almost every day. Which of these events merit an attribution study? In WWA we try to prioritise events that have a large impact on society, or that provoked a strong discussion in society, so that the answers will be useful for a large audience. These are often events for which the Red Cross issues international appeals. Sometimes smaller events closer to home or even meteorological records that did not affect many people also seem to generate enough interest to spend the effort to obtain a scientifically valid answer to the attribution question. We explicitly do not include the expected influence of climate change on the event on the trigger criteria: the result that an event was not affected by climate change, or even became less likely, is just as useful as one that the probability increased.

2. Event definition

Defining the event turned out to be both much harder and more important than we thought when we started attribution science. As an example: the first published extreme event attribution study analysed the extremely hot summer of 2003 in Europe (Stott et al, 2004). It took as event definition a European-wide seasonally averaged temperature, whereas the impacts had been tens of thousands of deaths in the 10-day hottest period in cities. A large-scale event definition like a continental and seasonal average has the advantage that climate models can represent it better and the signal-to-noise ratio is usually better than a local, short time scale definition. However, it is not the event that caused the damage and in WWA we try to relate our attribution question to the impacts, so we usually choose a definition of the event that corresponds as closely as possible to the impacts.

However, we stick to meteorological or hydrological quantities, like temperature, wet bulb temperature, rainfall, river discharge and do not consider real impacts like number of deaths or economic damage. The reason is that the translation from extreme weather into impacts usually is a complex and uncertain function of the weather. It also changes over time: the introduction of heat plans in Europe after the disastrous heat waves of 2003 and 2006 has reduced the number of deaths per degree of heat by a factor of two or three. Similarly, more houses in natural areas have increased the risk of wildfire damage, or more houses on the coast are now exposed to storm damage. We do not have the expertise to also take these changes into account and therefore restrict ourselves to indicators of heat, fire weather risk and wind in these examples.

A final consideration of the choice of event definition is that the quantity chosen has to have long and reliable observations and be represented by climate models.

In practice we use the following definitions. For heat waves, the local highest daily maximum temperature of the year is a standard measure that captures the health risk to outdoor labourers in e.g. India. For Europe and North America, the maximum of 3-day mean temperature appears to be more relevant as the most vulnerable population is indoors. If humidity plays a role the wet bulb temperature can be used instead. For cold waves we just use temperature as the wind chill is hard to measure. Local daily maximum precipitation is usually relevant for flash floods, for larger floods we either average over a river basin or use hydrological models to compute river discharge. Drought has many definitions, from lack of rain to water shortage and great care has to be taken to choose the most relevant one. For wind the highest 10-minute or hourly wind speed is chosen as these are closest to the impacts.

It should be noted that in practice, finding out what really happened is not easy as different estimates of the variable can be very different. An example is given in Fig. 1, which shows the very different estimates of the highest 3-day averaged precipitation around Houston due to Hurricane Harvey from different observing systems. We used the GHCN-D station data.

3. Observational trend analysis

In WWA, we consider an analysis of the observations an essential part of an extreme event attribution. The observational dataset should go back at least to the 1950s but preferably to the 19th century and be as homogeneous as possible. To choose the most representative observation we usually collaborate with local experts, who know which time series are most reliable and least influenced by other factors than climate change, e.g., station changes, irrigation or urban heat.

The observational analysis gives two pieces of information: how rare the event is in the current climate and how

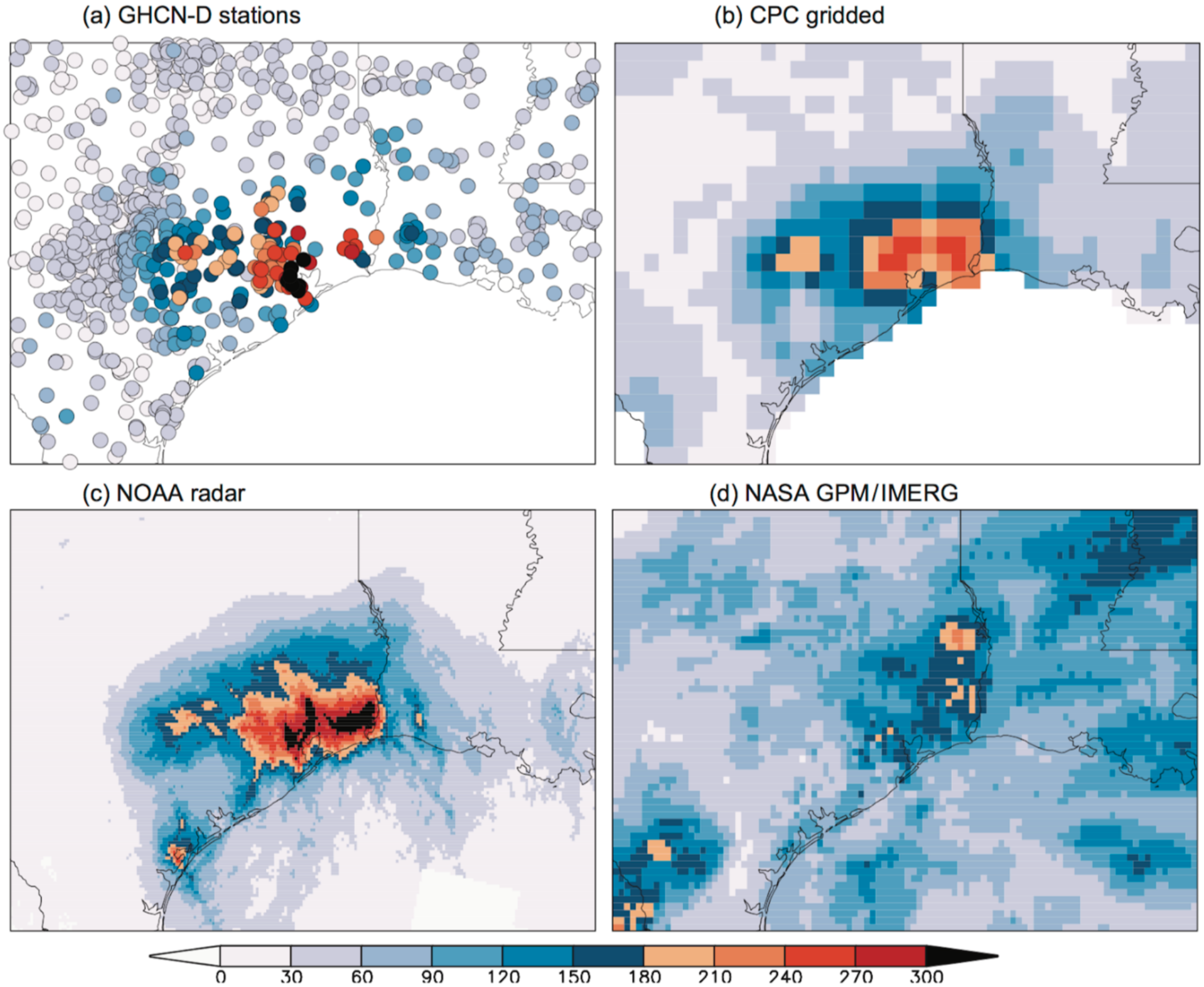

Figure 1: *Observed maximum three-day averaged rainfall over coastal Texas January-September 2017 (mm/dy). a) GHCN-D v2 rain gauges, b) CPC 25 km analysis, c) NOAA calibrated radar (maximum in August 25–30), d) NASA GPM/IMERG satellite analysis. From Van Oldenborgh et al. (2017).*

much this has changed over the period with observations.

The probability in the current climate is very important to inform policy makers whether this is the kind of event that you should be able to handle or not. As an example, the floods that paralysed Jakarta in January 2014 turned out to be caused by a precipitation event with a return times of only 4 to 13 years, pointing to a very high vulnerability to flooding (which is well-known). Conversely, the floods in Chennai in December 2015 were caused by rainfall with an estimated return period of 600 to 2500 years, which implies that the event was too rare to make it worth it to defend against.

Climate change is by now so strong that many observed time series of extreme events show clear trends. An efficient way to quantify the changes is to fit the data to an extreme value distribution, which theoretically describes either block maxima like the hottest day of the year, or exceedances over a threshold like the 20% driest years. We describe the effects of climate change by either shifting or scaling the distribution with the 4-yr smoothed global mean surface temperature (GMST). This quantity is proportional to the anthropogenic forcing and estimates are available in real time. The smoothing serves to remove influences of El Niño and other weather that are unrelated to the long-term trends. The assumptions in these fits—constant variability for temperature, constant variability over mean for precipitation and other positive-definite quantities—can be checked in the observations themselves to some extent and more fully in the climate model output.

In practice we find that there are very clear trends in heat waves, although these are also influenced strongly by non-climatic factors such as land use changes, irrigation and air pollution. Cold waves also show significant trends by now, although due to the greater variability of winter weather the signal-to-noise ratio is not as good as for heat waves. Daily or sub-daily precipitation extremes also often show clear trends, longer-duration ones are more mixed. Drought trends are very difficult to see in observations, because droughts are long-term phenomena so there are not many independent samples. Drought is also usually only a problem when the anomaly is large relative to the mean, which usually implies that it is also large relative to the trend, so the signal-to-noise ratio is poor. In all our drought studies only one showed a borderline significant trend in precipitation.

Fig. 2 shows the trend in a heat extreme (the highest daily mean temperature at De Bilt, the Netherlands), which shows a clear trend by eye already, and 3-day precipitation extremes along the US Gulf Coast, for which the GEV fit shows a significant trend under the assumption that all intensities increase by the same percentage.

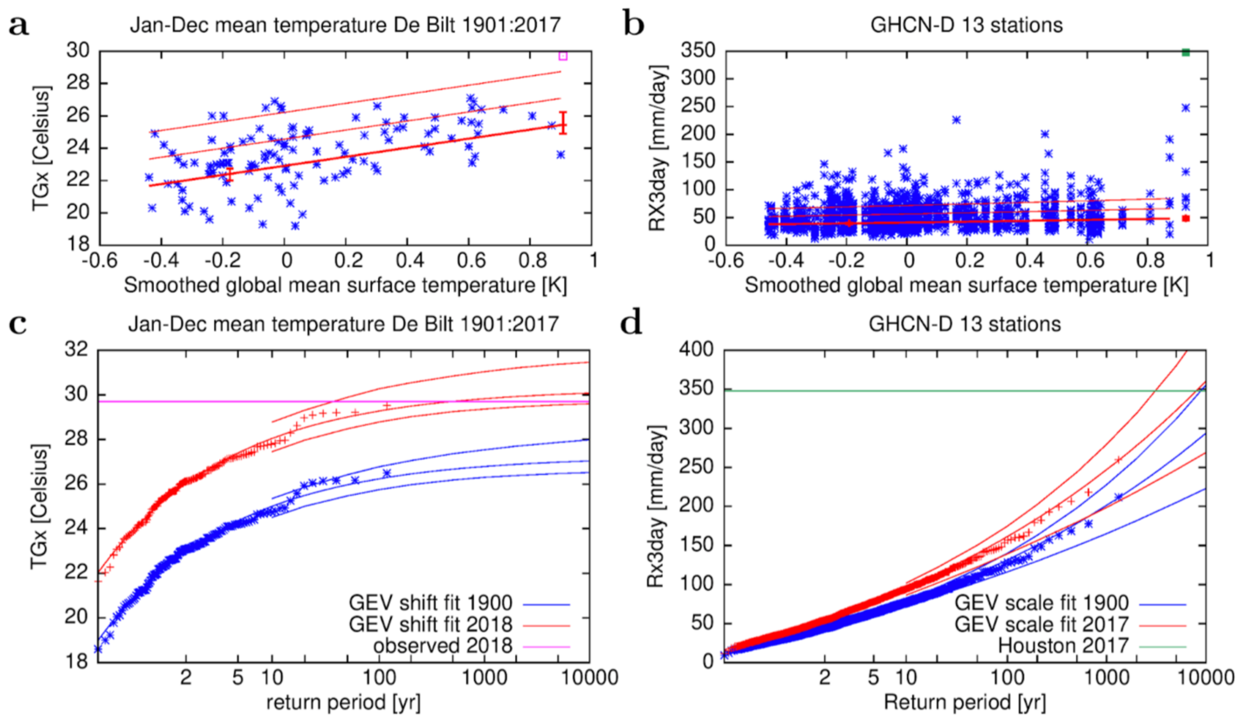

Figure 2: *a,c) Highest daily mean temperature of the year at De Bilt, the Netherlands (ho- mogenised) for the period 1901-2018, fitted to a GEV that shifts with the 4-yr smoothed GMST. a) as a function of GMST and c) in the climates of 1900 and 2018. b,d) The same for the highest 3-day averaged precipitation along the US Gulf Coast for 13 stations with at least 80 years of data and 2º apart, fitted to a GEV that scales with 4-yr smoothed GMST. From climexp.knmi.nl, (b,d) also from Van Oldenborgh et al. (2017).*

4. Climate model evaluation

Observations alone cannot show what caused the trend. In order to attribute the observed trend to global warming (or not), we have to use climate models. These are similar to the weather models that we use to forecast the weather of the next days to weeks, but instead of predicting the specific weather the next few days, they predict the statistics of it: how often extreme events occur in the computed weather in the climate model. However, we can only use the climate model output if these extremes are realistically simulated. In practice we use the following three criteria to select an ensemble of climate models.

- Can the model represent the extreme in principle?

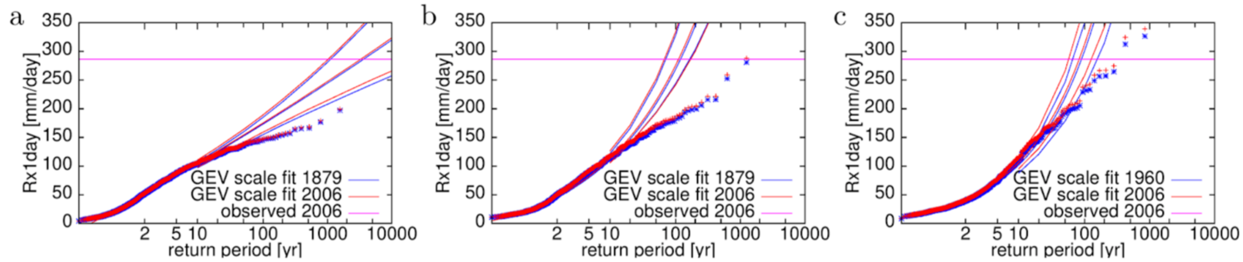

Figure 3: *Return time plots of extreme rainfall in Chennai, India, in two CMIP5 climate models with ten ensemble members (CSIRO-Mk3.6.0 and CNRM-CM5) and an attribution model (HadGEM3-A N216) showing an unphysical cut-off in precipitation extremes. The horizontal line represents the city-wide average in Chennai on 1 December 2015 (van Oldenborgh et al., 2016)*

- Is the statistical distribution of extreme events on the climate model compatible with the observed one, allowing for a bias correction?
- Is the meteorology leading to these extremes in the model similar to the observations?

The first criterion usually concerns the resolution and included mechanisms. A relatively coarse resolution model with a 200 km grid may well be able to represent a heat wave, but for somewhat realistic tropical cyclones we need a resolution better than 50 km. If we study heat in an area where irrigation is important we would like the model to include that cooling influence on extreme temperatures.

For the second criterion we just fit the tail of the distribution to the same extreme value function as the observations and check whether the variability and shape of the tail are compatible. To verify that the agreement is not for the wrong reasons we try to check the meteorology behind the extremes. This includes in any case the seasonal cycle and spatial patterns, but if relevant also may concern El Niño teleconnections or the source of precipitation. We even found that many climate models have an unphysical limit on high precipitation amounts (Fig. 3), these cannot be used for attributing (or projecting) these kind of events.

As climate models are imperfect representations of reality we demand at least two and preferably more models to be good enough for the attribution analysis. The spread of these models gives an indication of the model uncertainty.

5. Climate model analysis

The next step is the original attribution step. For each model we compute how much more likely or intense the extreme event has become due to anthropogenic emissions of greenhouse gases and aerosols. This can be done in one of two ways. The original proposal was to simulate the world twice: once for the current climate and once for a counterfactual climate that is the same as the current one but without anthropogenic modifications of the climate. For each climate we perform many simulations of the weather and count or fit the number of extremes. The difference between the two gives how much more (or less) likely the extremes have become.

The alternative is to take simulations of the historical climate, usually extended with a few years of the climate under one of the climate scenarios up to the current year (these are very close together up to 2040 or so). These transient simulations can then be analysed exactly the same way as the observations. This assumes that the influence of natural forcings—variations in solar radiation and volcanic eruptions—is small compared to the anthropogenic ones, which is usually the case.

As climate models usually have biases, we define the event by its return period and not by its amplitude. So if the observational analysis gives a return period of 100 yr, we also count or fit 100-yr events in the models. This turns out to give a better correspondence to the observations than specifying the amplitude and explicitly performing a bias correction when the extreme value distribution has an upper bound, as usually occurs for heat extremes, or a very thick tail, which we find for precipitation extremes.

For each model the attribution step gives a change in probability for the extreme to occur due to anthropogenic climate change, or equivalently the change in intensity for a given intensity.

6. Hazard synthesis

The next step is to combine the information from the observations and multiple models into a statement how the probability and intensity of the physical extreme event has changed. We use the term 'hazard' for this as the total 'risk' also includes how much exposure there is to the extreme and how vulnerable the people or systems are, which is addressed in the next step.

How to best combine this information is still an area of active research. Our current method is to combine all observational estimates under the assumption that they are highly correlated, as they are based on the same observations of the same sequence of weather. The model estimates are combined under the assumption that they are not correlated, as the weather in each model is different. However, the model spread can be larger than expected on the basis of weather variability alone, in which case we add a model uncertainty term to the average. Finally we combine observations and models. If they agree this can be a weighted average, but if they disagree we either have to increase the uncertainty or even give up on an attribution altogether.

An example of the latter is our study into the winter storms that hit Europe in January 2018, Fig. 4a. The climate models compute a small increase in probability due to the increased temperature, but the observations show a large decrease. We think the latter is caused by the increased roughness of the land surface due to more buildings, trees and even wind turbines. This is not included in the climate models, so they cannot be expected to give a reliable projection of the intensity of future storms.

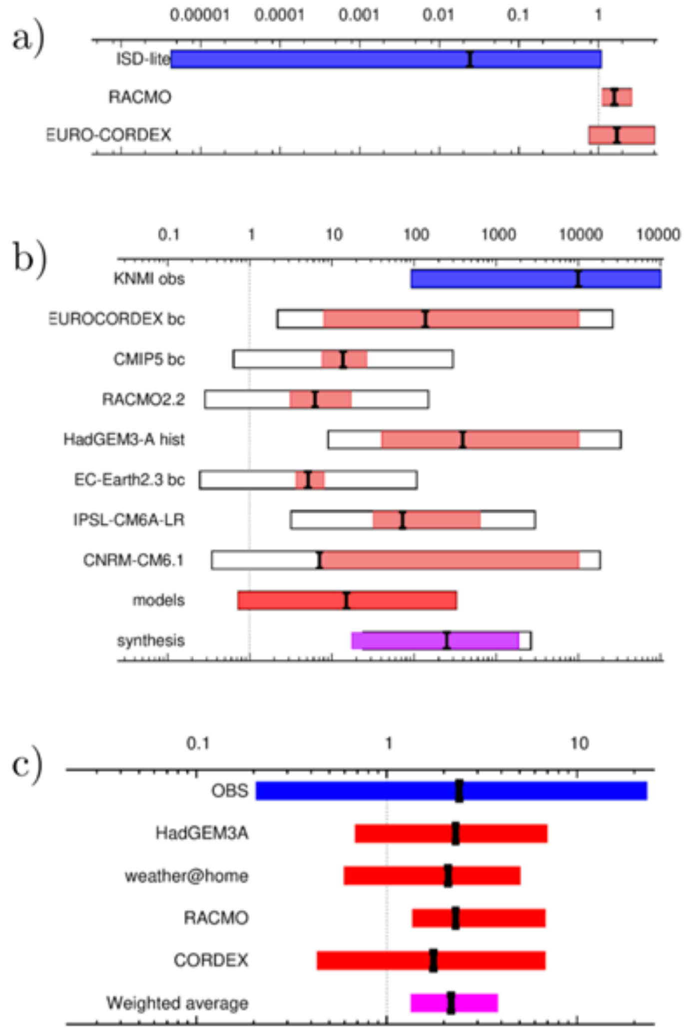

Figure 4: *Synthesis plots of a) the probability ratio (PR) for changes in wind intensity over the region of storm Friederike on 18 January 2018 (Vautard et al., 2019), b) the PR for the highest 3-day averaged daily mean temperature of the year at De Bilt, the Netherlands (Vautard et al, 2020) and c) the PR for extreme 3-day averaged precipitation in April–June averaged over the Seine basin (Philip et al., 2018a). Observations are shown in blue, models in red and the average in purple. An additional model uncertainty term is added as black outline boxes.*

A less severe discrepancy is apparent in heatwaves in northwestern Europe, Fig. 4b. The models simulate a much lower trend than the observations. This means we can only give lower bounds on the changes in probability and intensity due to human induced climate change. The same holds for southeastern Australia.

In other studies observations and models agree well and we can give an accurate attribution statement based on the combination of all information, e.g. for the rainfall in the Seine basin in 2016 (Fig. 4c).

7. Vulnerability and exposure

A disaster happens due to a combination of three factors:

1. the hydrometeorological hazard: process or phenomenon of atmospheric, hydrological or oceanographic

nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage,

2. the exposure: people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses, and
3. the vulnerability: the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

We consider it essential to also discuss the vulnerability and exposure in an attribution study. Not only do these combine with the changes in the physical extremes that we have computed in the previous step to determine the impact of the extreme weather, but they may have significant trends themselves.

As an example: we found that the drought in São Paulo, Brazil in 2014–2015 was not made worse due to climate change. Instead, the analysis showed that the increase of population of the city by roughly 20% in 20 years, and the even faster increase in per capita water usage, had not been addressed by commensurate updates in the storage and supply systems. Hence, in this case, the trends in vulnerability and exposure were the main driver of the significant water shortages in the city.

Even though this section often has to be qualitative due to a lack of standardised data and literature describing trends in these factors, we think it is vitally important to put the extreme weather into the perspective of how it impacts society or other systems. Changing the exposure or vulnerability is also often the way to protect against similar impacts in the near future, as stopping climate change is a long-term project and we expect in general stronger impacts over the next decades. For instance the number of casualties of heat waves has decreased by a factor two or three in Europe after heat plans were developed in response to the 2003 and 2006 heat waves. Similar approaches are now being taken throughout the world. The inclusion of vulnerability and exposure is thus vital to making the analysis relevant for climate adaptation planning.

8. Communication

Finally, the results of the attribution study have to be communicated effectively to a range of audiences. We found that the key audiences that are interested in our attribution results should be stratified according to their level of expertise: scientists, policy-makers and emergency management agencies, media outlets and the general public.

For the scientific community a focus on allowing full reproducibility is key. We always publish a scientific report that documents the attribution study in sufficient detail for another scientist to be able to reproduce or replicate the study's results. If there are novel elements to the analysis the paper should also undergo peer review. We have found that this documentation is also essential to ensure consistency within the team on numbers and conclusions.

We have found it very useful to summarise the main findings and graphs of the attribution study into a two-page scientific summary aimed at science-literate audiences who prefer a snapshot of the results. Such audiences include communication experts associated with the study, science journalists and other scientists seeking a brief summary.

For policy-makers, humanitarian aid workers and other non-scientific professional audiences, we found that the most effective way to communicate attribution findings in written form are briefing notes that summarise the most salient points from the physical science analysis and the specific vulnerability and exposure context. This audience often requires the information to be available relatively quickly after the event.

Finally, if there is a demand from the media, a press release with the main points and quotes from the study leads and local experts is prepared. In addition to the physical science findings, these press releases typically provide a very brief, objective description of the non-physical science factors that contributed to the event. In developing this press piece, study authors need to be as unbiased as possible, for instance not emphasising lower bounds as conservative results because in practice this may lead to interpretations that underestimate the influence of climate change. This is also an effective way to reach other target audiences.

Conclusions

Using the procedure outlined above, based on lessons learned during five years of doing attribution studies, we found that often, we could find a consistent message from the attribution study based on imperfect observations and model simulations. This we used to inform key audiences with a solid scientific result, in many cases quite quickly after the event when the interest is often highest.

However, we also found many cases where the quality of the available observations or models was just not good enough to be able to make a statement on the influence of climate change on the event under study. This also points to scientific questions on the reliability of projections for these events and the need for model improvements.

Over these years, we found that when we can give answers, these are useful for informing risk reduction for future extremes after an event, and in the case of strong results also to raise awareness about the rising risks in a changing climate and thus the relevance of reducing greenhouse gas emissions. Most importantly, the results are relevant simply because the question is often asked — and if it is not answered scientifically, it will be answered unscientifically.

This summary was republished from the ***World Weather Attribution website****. The full report upon which it is based can be found* ***here****.*

Glaciers of the Himalayas: Climate Change, Black Carbon, and Regional Resilience

Muthukumara Mani

Glaciers around the world are rapidly melting. Human activities are at the root of this phenomenon. Specifically, since the Industrial Revolution, carbon dioxide and other greenhouse gas emissions have raised temperatures, even higher in the poles, and as a result, glaciers are rapidly melting, calving off into the sea and retreating on land. The disappearance of glaciers also means less water for consumption by the population, a lower hydroelectric energy generation capacity, and less water available for irrigation.

The glaciers in the Himalaya, Karakoram, and Hindu Kush (HKHK) mountain ranges are melting faster than the global average ice mass. The HKHK glaciers are retreating at a rate of 0.3 meters per year in the west to 1.0 meter per year in the east. Field, satellite, and weather records confirm that 9 percent of the ice area present in the early 1970s had disappeared by the early 2000s. Scenario studies—for example, Shea et al. (2015)—project that the glacier mass within the Everest region today will decrease 39–52 percent by 2050. The almost 55,000 glaciers in the HKHK mountains store more freshwater than any other region outside of the North and South Poles. They contain estimated ice reserves of 163 cubic kilometers, of which almost 80 percent feeds into three major rivers in South Asia: the Indus, Ganges, and Brahmaputra. The basins of these three rivers are home to 750 million people.

The changes in water supply caused by melting glaciers affect agriculture and human consumption of water as well as the potential for hydropower development and tourism. In the short term, glacier melt contributes to disasters such as flash floods, landslides, soil erosion, and glacial lake outburst floods, with mountain communities especially vulnerable to such disasters. In the short run, the increase in melting water could compensate for the receding groundwater levels downstream. In the long run, however, decreased water flow from glaciers will exacerbate water shortages, endangering the livelihoods of rural communities downstream. The melting and thinning of glaciers may also affect hydropower production, which is a key source of renewable energy for the region. In the short term, increased water flows from melting glaciers could increase the risk of floods that damage hydropower facilities, while in the long term, water flow may become insufficient for operating the facilities. Glacier areas are also important to the national tourism industry. The melting of glaciers threatens both local glacier-related tourism and infrastructure that facilitates tourism in downstream areas. Potential damage to other sectors (infrastructure, hydropower, water supply) will also adversely affect the larger tourist industry.

Climate change is accelerating glacier melt in South Asia by changing the patterns of temperature and precipitation. Apart from glacier melt, global climate change driven by greenhouse gases (GHGs) is also changing the region’s water resources as temperature and precipitation change throughout the region. A recent World Bank report estimates that increasing temperatures and changing patterns of monsoon rainfall due to climate change could lower the living standards of half the regional population by 2050

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(Mani et al. 2018). Therefore, reversing glacier melt and securing access to water in South Asia are not possible without global measures to mitigate climate change. However, climate change is not the only driver of excessive ice melt in the HKHK mountains.

Recent evidence suggests that deposits of anthropogenic black carbon (BC) are responsible for more than 50 percent of the accelerating glacier and snow melt. Black carbon is a product of incomplete combustion from human activities, such as industrial and vehicular emissions, biomass burning, and forest fires. BC produced and circulated within the region decreases the reflectance of glacier surfaces, increasing glaciers' absorption of solar radiation; it also raises air temperatures, increasing glacier melt. The role of BC has important policy implications because, unlike other GHG emissions, it can be eliminated from the atmosphere if emissions stop. This means that local policies to reduce air pollutants can help to reduce the melting of glaciers.

This book investigates the extent to which BC reduction policies undertaken by South Asian countries may affect glacier formation and melt. Through historic analysis, the book assesses the relative impact that each source of black carbon (for example, diesel engines, brick making, cookstoves fueled by biomass, open fires, kerosene wick lanterns, and agricultural practices) has on snow and glacier dynamics. Through the calculation of emission sensitivities, the book also simulates how BC emissions interact with projected climate scenarios, estimates the extent to which these glacial processes affect water resources in downstream areas of the Indus, Ganges, and Brahmaputra river basins, and presents scenarios until 2040 to align with a reasonable policy-making time horizon.

In a business-as-usual scenario, glacier melt will accelerate. Although uncertainty surrounds these scenarios and there are significant variations within the region, it is clear that the very high level of biomass use and increasing energy demands from coal-fired power plants in South Asia are increasing the amount of BC circulating over the HKHK mountain ranges and threatening to accelerate glacier melt. The book derives the following policy conclusions:

- *Full implementation of current BC emissions policies in South Asia can reduce BC deposition in the region by 23 percent.* While countries of the region are taking a number of steps to curb BC emissions through enhancing fuel efficiency standards for vehicles, phasing out diesel vehicles and promoting electric vehicles, accelerating the use of liquefied petroleum gas for cooking and through other clean cookstove programs, and upgrading brick kiln technologies, various cost-effective measures are available and have been put in place to curb future BC emissions. Even then, the water released from glacier melt is projected to increase in absolute volume and as a share of total water production in the 2040s in the upstream areas of the Indus, Ganges, and Brahmaputra basins. BC emissions can be reduced by an additional 50 percent by enacting and implementing new policies that are currently economically and technically feasible, reducing glacier melt to current levels.
- *Improving the efficiency of brick kilns could be key to managing BC.* Industry (primarily brick kilns) and residential burning of solid fuel together account for 45–66 percent of regional anthropogenic BC deposition, followed by on-road diesel fuels (7–18 percent) and open burning (less than 3 percent in all seasons). Several factors influence BC emissions from brick making, including the technology used, the fuel source, and how the brick kiln is operated and maintained. Some modest up-front investments could pay off quickly. A recent World Bank report identifies a few cost-effective technology solutions geared toward cleaner brick kiln operations that could be implemented with government incentives (Eil et al. 2020).
- *Cleaner cookstoves and especially cleaner fuels can help to reduce BC.* Several programs in the region have supported cleaner cookstoves, but they have met with only limited success, in some cases due to behavioral aspects or lack of an affordable supply chain. Switching to a cleaner fuel, which in many cases would mean moving from biomass or coal to kerosene or liquefied petroleum gas in the short run and to solar in the long run, holds more promise. In India, the central government and some state governments have launched programs to implement fuel switching among low-income households in urban and rural areas. These efforts have met with some success and could potentially be replicated in other parts of the region.

- *Managing water resources now is key to mitigating the potential impacts of glacier melt.* The current inefficient allocation and use of water aggravates the impacts of melting glaciers on water supply, both upstream and downstream. Improving institutions for basin-based water management and using price signals to influence water use are key elements of more efficient water management.
- *Countries in South Asia need to manage their hydropower and storage resources carefully.* Hydropower from the HKHK mountain systems is a resource for supplying the region's growing energy needs and enhancing economic prosperity through energy trade and security. Hydropower can provide local, national, and global environmental benefits by reducing the consumption of fuelwood and fossil fuels. Hydropower developers that are still planning and building their projects need to consider the possibility of changing water flows. Increased water flow from glacier melt and more variable precipitation may boost the case for undertaking large water storage projects to stabilize availability over the years.
- *Regional cooperation can be an effective transboundary solution, helping countries in the HKHK region to manage glaciers and related natural assets collaboratively.* The HKHK mountain ranges span 2,400 kilometers across six nations (Afghanistan, Bhutan, China, India, Nepal, and Pakistan). The commonality of BC challenges and uncertainties posed by climate change suggest that adopting joint strategies to counteract predicted changes in snow cover and glaciers can bring many benefits. A first step in regional cooperation is to exchange information about BC emissions, changing water flows, best practices, and forecasting exercises. Improved information sharing can also help countries to manage natural disasters caused by melting glaciers.

This book demonstrates that managing BC emissions in South Asia carries the potential of a "quadruple-win" solution. In addition to reducing BC deposits on glaciers, cleaner cooking and burning can improve local air quality, help to mitigate global climate change (and thus help the region to meet its climate targets), and support the achievement of long-term energy security, especially after countries switch to solar and other clean energy solutions.

Water management policies should not be based on past experience. Current practices lead to a different, more challenging future, so policies must be designed to reverse trends like the melting of glaciers. This book is meant to guide the forward-looking policies needed. Success will require active, agile cooperation between researchers and policy makers so that both groups can continue to learn. To support an open dialogue, the model developed and used in this book is an open-source, state-of-the-art model that is now available for others to use and improve on.

This article is taken from the Overview section of the World Bank report Glaciers of the Himalayas: Climate Change, Black Carbon, and Regional Resilience. *The full report can be found* ***here****.*

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News and Announcements

Renewable Natural Resources Foundation

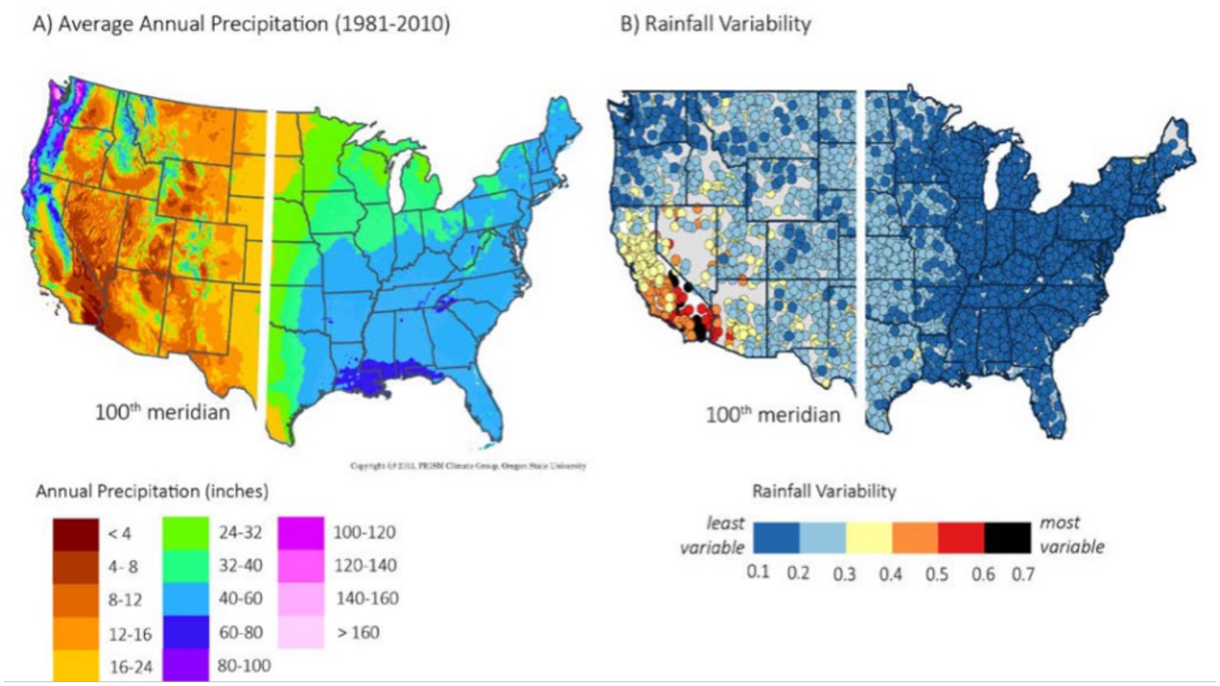
Report of RNRF Round Table: Sustainably Managing California's Groundwater in the Midst of a Prolonged Drought

Ellen Hanak, vice president of the Public Policy Institute of California (PPIC) and director of the PPIC Water Policy Center, spoke at a virtual meeting of the Washington Round Table on Public Policy on June 9, 2021. Her talk was titled, "Sustainably Managing California's Groundwater in the Midst of a Prolonged Drought."

Background

The Western region of the United States, west of the 100th meridian, has a drier and more variable climate than the East, as shown in Figure 1. Both of these characteristics are becoming more pronounced as the climate changes, leading to new challenges in water management. California's climate is extremely variable, and while droughts have always been a recurring feature, climate change is making them more common and more severe compared to historical conditions. Warmer temperatures also make drought management more complex due to increased evaporation, lower soil moisture, and higher water temperatures—which stress many fish species and cause water quality problems (**Mount et al. 2018**).

Figure 1: *Precipitation in the West is Lower and More Variable*



Source: Escriva-Bou et al. (2016) using data from Oregon State (A) & Mike Dettinger (2011) (B)

Water management in most Western states has historically been conducted under the assumption that every summer will bring dry weather. California is no exception. Home to the largest agricultural sector in the nation, it has always needed irrigation to grow its crops during the summer months. Water is stored in both surface and undergroundreservoirs for use during summers, as well as in dry years. Stored surface water tends to be used early in droughts, so groundwater proves very valuable as a reserve in multi-year droughts. Hanak explained that it is fine to rely on groundwater during dry years as long as this is done in a sustainable way. In some parts of the state, this has not been the case – even in non-drought years, some areas have either continued to deplete reservoirs or not replenished them sufficiently to maintain stable storage levels in the long-term. This has led to a chronic, serious overdraft problem in some areas.

The Sustainable Groundwater Management Act

During the last drought, which lasted from 2012 to 2016, this overdraft problem led to the passage of the Sustainable Groundwater Management Act (SGMA) in 2014. Hanak said that this act was "100 years in the making" – California's modern water code for surface water was enacted in 1913 and went into effect in 1914. 100 years later, the state enacted comprehensive groundwater legislation. It was the last Western state to implement a statewide groundwater management system.

While SGMA is a state law, it is primarily implemented by local agencies and jurisdictions. Under the act, local Groundwater Sustainability Agencies are formed to manage groundwater and develop and implement Groundwater Sustainability Plans. To ensure that local jurisdictions do this, state agencies can take control over groundwater management in a basin if the act is not being satisfactorily implemented there. Thus far, this motivating factor has been successful. Implementation has been proceeding and jurisdictions are seeking to comply with the new law.

There are about 85 priority basins that have to develop these sustainability plans. They are mostly in agricultural areas, where there is less pressure to sustainably manage groundwater compared to urban areas. (In many urban areas that rely on groundwater—both in Southern California and Silicon Valley—more intensive local groundwater oversight has been in place for decades.) Deadlines for the development of groundwater sustainability plans are either in 2020 or 2022 depending on how serious the overdraft of groundwater is in the basin. Critically overdrafted basins, which had to submit their plans in 2020, are largely located within the San Joaquin Valley, plus some parts of the Central Coast. After submitting their plan, agencies have 20 years of implementation to achieve groundwater sustainability, but they must also avoid significantly unreasonable, undesirable effects of pumping in the interim. Plans must be updated every five years and include data on the status of their implementation. These are early days in SGMA implementation, but the law is already shifting how water is managed in California.

The San Joaquin Valley

The San Joaquin Valley is the largest agricultural region in California and "ground zero" for the implementation of the SGMA (**Hanak et al. 2019**). Hanak said that if you eat fruits and nuts in the US, and even some brands of wine, they likely came from the San Joaquin Valley. While it is a booming agricultural region, it is very dry and relies heavily on bringing surface water in from the northern part of the state, as well as pumping groundwater. There is a large imbalance between supply and demand for water in this region – on average, there is a groundwater overdraft of about 2 million acre-feet per year, accounting for about 11% of net water use in the region. This is causing chronic depletion of groundwater basins that took millennia to fill.

During the last drought, California experienced the consequences of this depletion: dry wells, sinking lands, and reduced groundwater reserves available for use during future droughts. The wells that have gone dry include those used for agriculture but more commonly they are shallow drinking water wells used by residences, an important consideration from an equity perspective. Sinking land is harmful to urban infrastructure but can also be a problem in rural areas, causing damage to roads, bridges, and major water conveyance infrastructure.

Hanak explained that the issue comes down to a simple math problem: attaining balance and sustainability for groundwater either means increasing water supply from other sources, decreasing water use, or (most likely) a combination of both. There is an important economic component to this problem as well. Some solutions are more costly than others; in particular, some methods of supply augmentation like ocean desalinization are very expensive. Ultimately, agriculture is a business, so supply must be managed in a way that is cost effective.

More than 90% of net water use in the San Joaquin Valley is for crop irrigation. For this reason, agriculture is the sector that will require the most adaptation to achieve sustainability. Inflexible cuts to local water use are not preferable because they tend to cause the largest crop revenue losses, diminished farm-related GDP and job losses, and land fallowing. Water trading (both locally within basins and valley-wide) allows water to move to the most productive lands; this could reduce the costs of adjustment by more than 60%. There is also some scope for augmenting supplies cost-effectively, such as through groundwater recharge, which is a process of actively storing water in the ground. Different parts of this region have varied access to surface water, making cooperation very important.

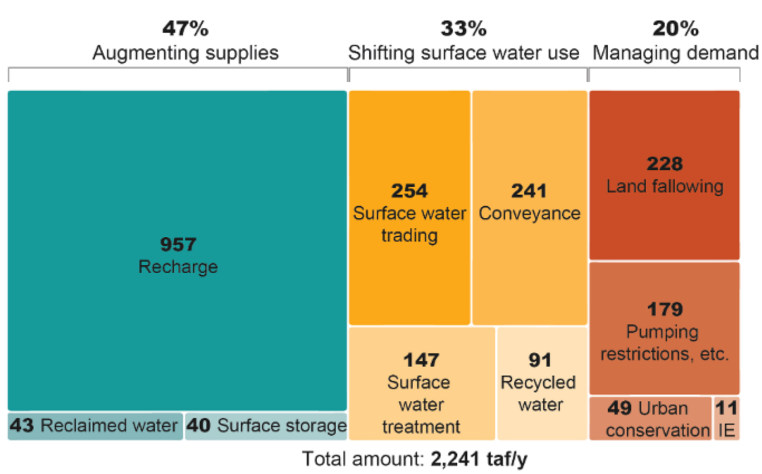
Over-Reliance on Supply Management

Hanak noted that the groundwater sustainability plans that have been submitted so far in the San Joaquin Valley largely do a good job of recognizing the problem of groundwater overdraft in their basin. Agencies had to submit plans for how they will address this problem through supply projects, demand projects, or a combination of both. In these first plans, 47% of the solutions submitted are based on augmenting supply, as shown in Figure 2. This is mainly done by capturing additional flood flows in wet years and recharging groundwater basins. A third of solutions involve shifting water use from one use to another, such as by treating surface water for residential use that was previously used for another purpose. While such solutions can augment the planning area's supplies, they entail reductions in supplies used by other parties within the region—something not accounted for in the overall planning process.

Only 20% of current proposed solutions utilize demand-management solutions. Hanak said that this number needs to be much higher to achieve groundwater sustainability. There is a reason that demand-management plans are lagging behind where they need to be; demand management is a difficult conversation to have. Over the next twenty years, PPIC research estimates that between 500,000 and 750,000 acres of agricultural land will have to come out of production to achieve groundwater sustainability (**Hanak et al. 2019**). This is 10-15% of irrigated acreage in the region.

People are understandably worried about impacts on local communities and economies as water demand is managed. During the Q&A session, Hanak explained that concerns are not limited to job and revenue losses. Depending on how land is managed, fallowed land could cause increased dust in areas that already have air quality issues. Fallowed land can also create pest and weed problems for neighboring farms. Potential solutions include intermittent fallowing (for instance, only fallowing land in dry years), as well as using land for habitat recovery to benefit endangered species. Using former farmland for utility-scale solar power installations is also an option, but ensuring that this creates benefits for local economies is important. Hanak expressed confidence that as implementation of SGMA proceeds, people will devote increasing attention to implementing demand-management solutions.

Figure 2: *Plans Emphasize Recharge, Have Limited Focus on Demand Management*



Source: Hanak et al. A Review of Groundwater Sustainability Plans in the SJ Valley: Public Comments to DWR (PPIC, 2020)

Addressing the Negative Consequences of Groundwater Overdraft

While groundwater sustainability agencies have 20 years to achieve sustainability, they have to do so in a way that will avoid significant undesirable impacts of groundwater depletion. The law is very comprehensive in outlining these undesirable consequences and explicitly dictates that plans need to explain how they will be addressed. The undesirable consequences of groundwater overdraft include:

- Lowering groundwater levels
- Reduction of storage
- Land subsidence
- Seawater intrusion
- Surface water depletion
- Degraded water quality

Options include limiting pumping enough to avoid these problems, or mitigating the effects, for instance by providing alternative water supplies to those whose wells are adversely affected. Mitigation is not always a viable option; some issues can only be addressed by prevention. This could require some basins to attain groundwater sustainability before the end of the 20-year SGMA window.

PPIC reviewed how plans address two of these impacts that are particularly salient in the San Joaquin Valley: the lowering of groundwater levels (which has major implications for shallow drinking water wells) and land subsidence.

Lowering Groundwater Levels

The most immediate impact that arises from lowering groundwater levels is to shallow drinking water wells, which are common in many rural areas. During the last drought, an estimated 2,600 domestic wells went dry, and roughly 150 small community water systems were at risk of shortages. This was one of the major reasons that the SGMA was passed. Some groundwater sustainability plans submitted thus far intend to maintain sufficient water level thresholds to prevent wells from going dry, and some have mitigation plans to drill wells deeper. But plans in some of the areas that experienced the greatest impacts in the last drought have no program to prevent or mitigate dry wells—a considerable planning gap.

Land Subsidence

Many San Joaquin Valley plans also allow for significant land subsidence to continue—in some cases by as much as 10-15 feet over the next 20 years. This is already causing infrastructure damage, including to major water conveyance infrastructure like the California Aqueduct and the Friant-Kern Canal. Subsidence can also cause compaction of the aquifer system that leads to a permanent reduction of groundwater capacity. **This phenomenon was also observed during the previous drought**. Hanak noted that these basins will probably have to reevaluate how they are addressing land subsidence.

Avoiding Impacts to Surface Water and Ecosystems

One important innovation of the SGMA is that it formally connects groundwater and surface water law. This creates more of an implementation challenge for less overdrafted basins (those that are not "critically overdrafted," largely in the northern region of the state) because they are more likely to be in an area where groundwater is still closelyconnected to river flow. This means that these basins have to be more careful not to pump too much groundwater during droughts, since pumping can quickly reduce streamflow. This can have ecosystem impacts, including on endangered salmon and steelhead populations in Northern California.

The Current Drought & Short-Term Priorities

California presently is in the second year of another severe drought, the first since the one that prompted the

California legislature to pass the SGMA in 2014. Water scarcity makes the supply-demand balancing act much more difficult. Drinking water impacts for rural communities are expected to escalate as more farmers turn to groundwater for irrigation.

The transition to sustainable management of groundwater in California is a long process, but to get off to a strong start and take into account the added challenges of ongoing drought, Hanak closed her presentation by identifying some priorities for the short-term:

- Address undesirable impacts of groundwater overdraft (including dry rural wells, ecosystem impacts in places with strong surface water-groundwater connections, and land subsidence).
- Develop strong water accounting frameworks and allocating pumping budgets. This incentivizes careful utilization of the resource, including trading and saving water.
- Assess smart infrastructure investments. This includes identifying where it makes sense to build new conveyance infrastructure to enable more recharge, expand trading, and allow for the use of surface water reservoirs alongside groundwater.
- Launch broad-based planning for both water and land. This includes finding the least harmful and most beneficial ways to take land out of agricultural production.
- Pilot innovative approaches to water trading, groundwater recharge, and land stewardship.

Hanak concluded by noting that efficient, equitable solutions to the multi-faceted challenges of managing groundwater will require increased cooperation among multiple parties, both within and across basins. And while this process is fundamentally one that requires local leadership, the state and federal governments can help with financial and regulatory incentives.

– Stephen Yaeger, RNRF Program Manager

The PowerPoint presentation Hanak used during the round table can be viewed **here**.

In her presentation, Hanak referenced a list of studies and reports for further reading on this topic. They include the following:

"**Droughts in California**" (fact sheet, April 2021)

"**California's Latest Drought in 4 Charts**" (PPIC blog, May 2021)

"A Review of Groundwater Sustainability Plans in the San Joaquin Valley" (**blogseries** and **public comments submitted to DWR** May 2020)

"**Water and the Future of the SJ Valley**" (report, Feb 2019)

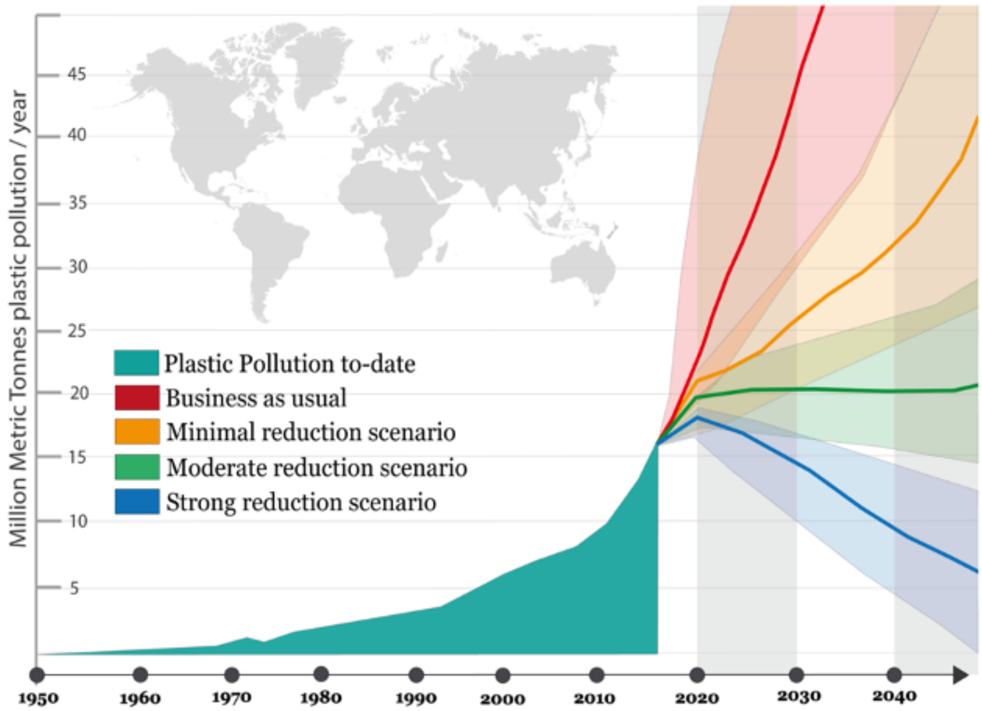
"**Managing Drought in a Changing Climate**" (report, Sept. 2018)

"**Replenishing Groundwater in the SJ Valley**" (report, April 2018)

Report of RNRF Round Table: Meeting the Challenge of Microplastic Management to Protect Human Health and the Environment

Scott Coffin, a research scientist at the California State Water Resources Control Board, spoke at a virtual meeting of the Washington Round Table on Public Policy on June 23, 2021. He discussed the initial steps being taken toward managing microplastics in California, as well as the challenges and barriers to regulating microplastics under traditional regulatory paradigms. He also discussed potential changes in approaches to better regulate complex and persistent contaminant classes like microplastics for the protection of human health and the environment.

__Figure 1:__ Plastic Pollution Increases Exponentially



Source: __Plastic Pollution Emissions Working Group__

History and Background

Coffin began by giving a brief history of plastic, microplastics, and early studies that began to raise alarm over their environmental impact. Single-use plastic started being used substantially in 1955, touted as a "cure" for the inconvenience of many household chores. If a plastic item was dirty, you could just throw it 'away.' This was the beginning of a societal change toward the widespread adoption of single-use, disposable plastics.

Only five years later, in 1960, the first scientific study was published which demonstrated that plastics can cross barriers in the body and be taken up into the cells of the intestines and liver.[i] This began to prompt concern that plastic particles could be harmful to human health.

In 1969, less than twenty years after the widespread use of plastic began, researchers in Hawaii found that 90 of the 91 Laysan Albatross they studied had identifiable pieces of plastic in their gut.[ii] This caused people to begin questioning whether the widespread use of plastic in society could be sustainable.

Since then, plastic pollution has only continued to increase exponentially with time. Under a business-as-usual pathway, the volume of plastic expelled into the environment is expected to double by 2040. However, it is possible to change the trajectory of plastic production and pollution and work toward a more sustainable future. Figure 1 demonstrates some possible pathways.

Scientists have been studying plastics, including their impacts on the environment and human health, for decades. However, there are still no regulations on microplastics anywhere in the world. As a class of contaminants, microplastics are very difficult to regulate. Coffin identified four main factors that make assessing and managing the risks of microplastics very challenging, preventing meaningful regulation over the years. These are: **ubiquity, complexity, secrecy, and persistence.** Throughout his presentation, Coffin gave examples of each barrier and proposed solutions for how we can potentially overcome them.

Plastic in Air, Water, and Food

Plastic can be found everywhere on earth, from the deepest parts of the ocean to the tallest mountain in the world, and everywhere in between. Plastic is constantly being broken down into smaller and smaller pieces, until eventually they are micro and nano-sized particles that can only be viewed through a microscope and can never be recovered from the environment. Microplastic particles are often so small that they can be transported by the wind and the rain – a 2020 study found that plastic exists in the air in U.S. national parks at relatively high concentrations, many miles away from their sources.[iii] Plastics have also been found in the air in Antarctica and the Arctic, suggesting that they are being transported globally.

Plastics are also ubiquitous in water around the world. They can enter surface water through many different pathways: rainfall and settling from the air are common, as well as stormwater, wastewater, and littering. Once plastic has entered a body of water, it typically continues to break down into smaller pieces. Microplastics exist at the surface of bodies of water, as well as suspended and buried in sediment. They can also make their way from the environment into surface drinking water reservoirs.

Wastewater treatment plants are typically very effective at removing microplastics. They can remove up to 99% of microplastics from water, depending on the type of facility.[iv] However, the sludge (treated waste residue removed from the water during the treatment process) that comes from these plants is often converted to biosolids, nutrient-rich materials that are frequently used as fertilizer. A recent study found that the concentration of plastic in biosolids has risen over the past few decades, closely correlating with rates of global plastic production.[v] Another study found that plants can uptake microplastics through their roots, prompting concern that biosolids could be transferring microplastics to the food we eat. Microplastics in soil can also stunt plant growth and decrease fruit production, raising concern over future food security.[vi]

California's Efforts to Manage Microplastics

In 2018, California passed two laws related to the management of microplastic pollution. **California Senate Bill 1263** is focused on microplastic pollution in marine environments. It requires the California State Water Resources Control Board to collaborate with the Ocean Protection Council to initiate a statewide microplastics strategy by the end of 2022. By the end of 2026, they are required to develop a risk assessment framework, develop standardized methods for monitoring microplastics, establish baseline occurrence data to know where microplastics occur in the environment, investigate sources and pathways for microplastic pollution, and recommend source reduction strategies to the California legislature.

Developing a risk assessment framework for microplastics in marine environments is expected to be a serious challenge. Microplastic exposure in the environment is very heterogeneous: exposure can vary significantly based on where you look. Microplastics and other particles in the ocean

Figure 2: *Plastic Fibers in Tap Water, 2017*

Source: ***Orb-media.org***

tend to accumulate in natural circular ocean currents (gyres). There are 5 major ocean gyres, and one is unlikely to encounter significant levels of plastic pollution in the open ocean outside of those gyres. The heterogeneity of environmental exposure makes assessing risk a complex endeavor. Additionally, most models account for only about 1% of ocean plastic because they largely observe the plastic that is floating near the surface. Due to fragmentation and biofouling, plastic in the ocean becomes denser over time and falls beneath the surface, often all the way to the seabed, where it can enter sediment and affect benthic communities. The ubiquity and persistence of microplastics in the environment also makes risk assessment more challenging.

The other law passed in 2018, **California Senate Bill 1422**, requires the California State Water Resources Control Board (State Water Board) to take action on microplastics in drinking water. This is a concerning yet poorly understood issue, especially in the United States – a 2017 study found that 94% of tap water samples in the U.S. contained microplastics, compared to 83% of samples worldwide.[vii]

The law's implementation began with a requirement to define "microplastics" by July 1, 2020. It is rare for environmental contaminant classes not to have a harmonized definition but the complexity of microplastics made defining them a relatively difficult task. They are composed of countless different polymers and have different distributions of size, shape, color, adsorbed contaminants, and other factors that need to be taken into account. California adopted the following definition of "microplastics in drinking water":

"Solid polymeric materials to which chemical additives or other substances may have been added, which are particles which have at least three dimensions that are greater than 1 nanometer and less than 5,000 micrometers. Polymers that are derived in nature that have not been chemically modified (other than by hydrolysis) are excluded." – California State Water Resources Control Board, 2020

This is a very broad definition, covering chemicals from 1 nanometer to about the size of a human thumb. It includes particles of all "traditional" plastics, including any plastic product with the "chasing arrows" symbol often associated with recycling (although they do not necessarily mean that a piece of plastic can be recycled). It also includes "non-traditional" plastics that do not have the chasing arrows symbol, including synthetic rubber (used in automobile tires) as well as the synthetic fibers in clothing, silicones, bio-based and biodegradable polymers, and cellulose acetate (most commonly found in cigarette filters).

The definition of microplastics adopted by the state of California was similar to one recently proposed by the European Chemicals Agency (ECHA) to restrict the types of microplastics that can be intentionally added to products. However, ECHA provides an exclusion for chemicals that are biodegradable, under the presumption that the persistence of chemicals in the environment is what determines their toxicity. California did not exempt biodegradable polymers from its definition. To explain this decision, Coffin cited a 2020 study which asked whether bioplastics are safer than conventional plastics. The study examined a suite of conventional petroleum-based plastics and bioplastics of various product types and looked for endocrine disrupting activity and other concerning impacts. They found that overall, there is no discernable difference in toxicity between conventional plastics and bioplastics.[viii] Many bioplastics, like conventional plastics, contain hazardous chemicals. Just because a product biodegrades does not mean that it is not harmful.

By July 1, 2021, SB 1422 mandates that the California State Water Board adopt a standardized method to monitor microplastics. In the Q&A session Coffin said that this deadline has been delayed due to the pandemic but they are still aiming to complete it by the end of fall 2021. Previously, no such standard existed, so the State Water Board launched a method development and standardization project. It focuses on four matrices for microplastic pollution: drinking water, ocean water, fish tissue, and sediment. Coffin noted that having a standardized method for monitoring a contaminant is a critical first step toward being able to manage it. Over 40 organizations are participating in this process, including government agencies, academia, plastic manufacturers, and others.

Coffin then explained what is involved in identifying plastics in the environment. Typically, to identify a polymer, you must match it to one that has been identified and exists in a library of polymer types. It can be challenging to identify all types of plastics, especially if they contain dyes or other additives. Over 37,000 polymers are used in commerce, but around 20-25 of them are by far the most common. Many of the libraries available to identify polymers are very expensive and proprietary, so the scientific community has begun to invest in open access alternatives. This is a step toward circumventing the secrecy that has been gatekeeping knowledge about plastics in the environment for decades.

Evaluating Health Impacts of Microplastics

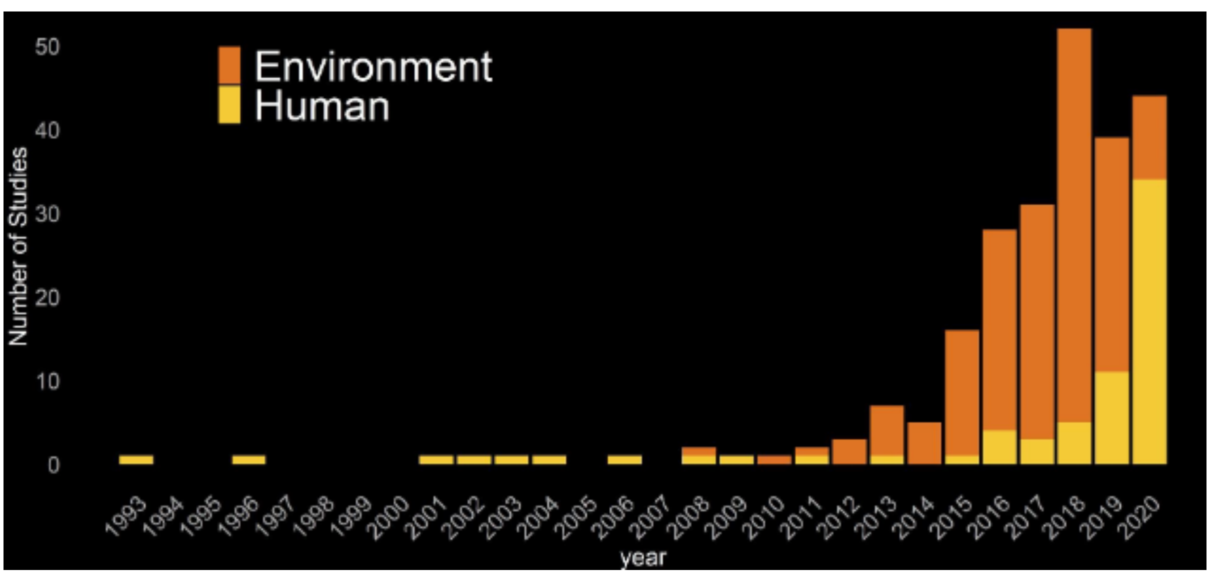
When California starts monitoring microplastics and reporting that data to the public, people will certainly wonder what microplastic exposure means for their health, if they were not already. This is why the California senate recommended the State Water Board consider developing a health-based guidance level for microplastic exposure as a part of SB 1422.

In 2019, the World Health Organization (WHO) released a report about microplastics in drinking water.[ix] At the time, there was very limited information available about microplastics, especially related to their impacts on human health. The report concluded the following: “Humans have ingested microplastics and other particles in the environment for decades with no related indication of adverse health effects… [there is] no evidence to indicate a human health concern.” Coffin explained that this argument is a fallacy – a lack of evidence against something does not necessarily mean that it is true.

In order to move past this fallacy and give better information to the public, the State Water Board is conducting a workshop with experts from around the world about the health impacts of microplastics. They are evaluating impacts of microplastics on both human and ecosystem health. This workshop will help inform the development of thresholds and regulations.

Just in the past few years, the number of toxicity studies about microplastics has risen exponentially. Very few studies about the impacts of microplastics on mammals had been published prior to 2019, so the WHO report mentioned by Coffin has access to limited information. Since then, the number of mammalian toxicity studies published on the topic has more than tripled. Coffin believes that this trend of more microplastics studies being published will continue in the future, and this will allow us in the coming years to learn a lot more about how microplastics impact human and ecosystem health.

Figure 3: *Rapidly Developing Science*



Source: Thornton-Hampton et. al (unpublished)

Before describing our current understanding of the human health impacts of microplastics, Coffin defined the language used to address the topic. Risk, or the probability that something will cause harm, comes about by the combination of two other components: hazard and exposure. Hazard is defined as the potential to cause harm. However, if exposure to the hazard never happens, there is no risk. Simply put: **Hazard x Exposure = Risk.**

Exposure

There has been a wide range of studies examining the various ways that humans are exposed to microplastics. Everyone is exposed to microplastics from water, air, food, etc. at different rates due to a variety of factors. For instance, some people drink a lot of water from plastic bottles, while others do not. A recent study found that microplastic exposure risks were, on average, higher in bottled water than tap water. This is because the plastic packaging of bottled water releases microplastics, both into the water and into the air when the bottle is opened. Therefore, somebody who drinks bottled water is typically more likely to be exposed to microplastics than someone who drinks from the tap.[x]

Alarmingly, a similar observation has been made for polypropylene infant feeding bottles, some of which release enough microplastics to expose some small children to millions of particles daily.[xi] While the hazard component of evaluating this risk is not yet well understood, infants may potentially be exposed to higher amounts of microplastics than people at later life stages, making them a sub-population potentially at high risk.

Inhalation is likely the most significant exposure pathway for microplastics, more so than drinking water. Most of this exposure happens indoors through household dust: between 1.5% and 13% of dust is composed of microplastics. Indoor air typically has about 15 times more microplastics than outdoor air. The majority of this comes from fibers that shed from our clothing, upholstery, carpets, and rugs.[xii]

Another very important factor in evaluating microplastic risk is that they are persistent in human bodies. Our bodies do not break them down, so over our lifetimes, we tend to continuously accumulate more microplastics. This results in between 535 and 9,330,000 microplastic particles in the body of the average person.[xiii] There is also evidence that microplastics can be transferred across generations – identifiable levels have been found in human placentas.[xiv]

Hazard

Coffin then described the hazard component of assessing microplastic risk. Hazard is defined as the potential to cause harm to humans and aquatic organisms. There are two main types of microplastic hazards: particle and chemical hazards. This contributes to the complexity that can make assessing risk difficult.

Chemical Hazards

Plastic often contains hazardous chemicals. There are at least 3,300 known chemical additives to plastics. At least 33 plastic-associated contaminants are known to be hazardous; 7 are persistent, bioaccumulative, and toxic; and 15 are endocrine disrupting. It is especially difficult to assess risk for endocrine disrupting chemicals (EDCs). EDCs are defined as chemicals that mimic a hormone in the body. For instance, the common plastic additive bisphenol A (BPA) is chemically similar to estrogen, and elicits a similar bodily response. In fact, BPA was originally developed as a form of birth control. It was phased out of use when a more potent birth control was developed but years later it was discovered to be a useful plastic additive and made its way into many food-contact materials.

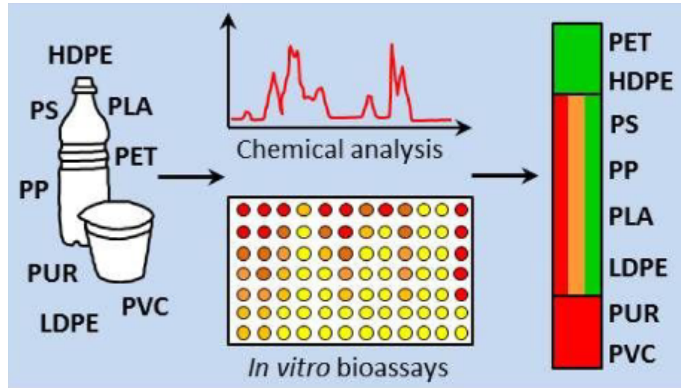
It is especially difficult to evaluate the health impacts of EDCs because they do not function in the body like a typical toxicant. The health impacts of a typical toxicant would become more severe as exposure increases. This is not always the case with EDCs. Often, severe health impacts can happen at very low doses of exposure. This makes assessing risk extremely challenging. In the United States, it causes us to typically underestimate our risk from EDCs.

Underestimating the health risks of EDCs has resulted in significant harm to society already. Between 2001 and 2016, PBDEs (a class of flame retardant that acts as an endocrine disruptor) resulted in between 750,000 and

1,750,000 intellectual disabilities. This is more than pesticides, mercury, and lead combined, and has resulted in an estimated $3.6 trillion loss to the economy based on healthcare costs and other indirect impacts, according to a 2020 study.[xv]

Examining known chemicals in plastics is concerning. However, the vast majority – over 85% – of plastic ingredients are confidential.[xvi] Their identities are not in any public database. A recently published study found that 53% of hazardous chemical additives are unregulated globally, accounting for an estimated 1,327 chemicals that are not regulated and are expected to cause harm for various reasons (due to being persistent, bioaccumulative, toxic, carcinogenic, endocrine disrupting, etc.).[xvii]

Figure 4: *>85% of Plastic Ingredients are Confidential*



Source: Zimmerman et al., Environmental Science & Technology (2019)

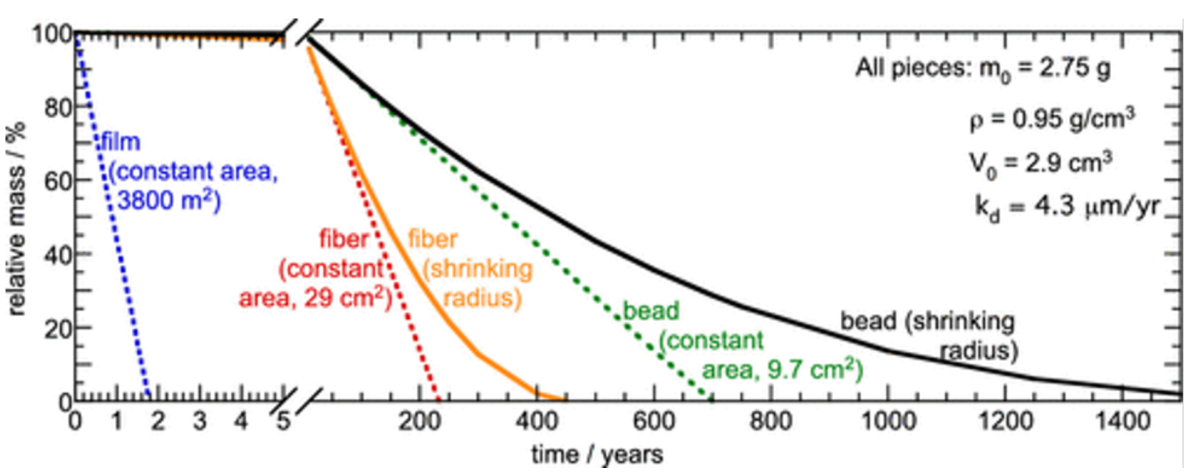
Particle Impacts

Coffin then discussed the particle impacts of microplastics. Microplastics can have different health effects depending on the size and type of organism that is exposed. Impacts can be explained by at least two hypothesized types of effect mechanisms: oxidative stress and food dilution. Oxidative stress is caused by exposure to particles that are so small, they can cause inflammation and cell death. This can lead to mortality, lack of reproduction, impaired development, and other impacts. Food dilution is when there is so much plastic in the gut of an organism that they cannot absorb nutrients from foods. While oxidative stress is likely to occur for humans, food dilution is likely to only be of concern for other organisms.

Studying Risk

Coffin then discussed the difficulties posed by the differences between how microplastics occur in the environment and how they are studied in a laboratory. The mixture of plastic in the environment is "polydisperse," meaning that all shapes and sizes of microplastic exist in a continuous distribution. In a lab, they are "monodisperse" – only one type, or a set of specific types, is typically used. A set of particles studied in a lab is not going to be exactly the same as a set of particles in the environment. This presents a significant complexity that Coffin believes has impeded progress on assessing microplastic risk for a long time.

Figure 5: *Plastic Degrades Very Slowly in the Ocean*



Source: Chamas et al. (2020). ACS Sustainable Chemistry & Engineering

In 2019, a significant advancement was made to address this nonalignment. Scientists found that microplastics have predictable behaviors in the environment. They found that researchers can make probability alignments using distribution functions to compare lab experiments to the real world.[xviii] This was a big step forward in assessing microplastic risk.

Microplastics are persistent in the environment, meaning that risk assessments need to evaluate future environmental occurrence scenarios as well as present conditions. In general, plastic degrades very slowly in the ocean. Its degradation period is estimated to be as long as 1,400 years. Probability and severity of risk rises as more plastic accumulates with time, making modelling scenarios for the future important to protecting future generations.[xix]

Microplastics as a Non-Threshold Contaminant

In Coffin's words, addressing issues related to plastic pollution can sometimes feel like pushing a boulder up a hill. There are countless challenges for assessing and managing risks for microplastics. It can feel like a Sisyphean task for risk assessors. Addressing the issue in a meaningful way will require a paradigm shift in how we approach it.

This paradigm shift may require the adoption of a more precautionary approach to managing microplastics. While it may be a decade or longer before we have a concrete idea of the risks that microplastics pose to human health and the environment, exposure is happening right now and is only expected to increase. In 2019, the European Chemicals Agency recognized this and defined plastic as a "non-threshold contaminant," a precautionary definition that means that no safe level of discharge exists. Effectively, the goal of such a definition is to work toward having zero input of microplastics into the environment.

In the Q&A session of the round table, Coffin noted that universally defining microplastics as a non-threshold contaminant would not necessarily mean that they need to be phased out entirely. He compared plastic to PFAS, which is used for everything from swim trunks to essential medical equipment. Obviously, the necessities of these uses are not equivalent. For plastics, there are use cases where a better, more sustainable alternative exists. Many single-use plastic products have better alternatives, and due to their unnecessary use have played a significant role in bringing us to the unsustainable plastic pollution levels of today.

Conclusion

Microplastics are everywhere, they are extremely complex, they are persistent, and they contain secret chemicals which make assessing and managing risk extremely challenging. We can begin to address this issue through inter-sector collaboration and open data. However, to manage the risks that microplastics pose we may need to rethink our paradigms of risk assessment. Because they do not break down quickly on a molecular level, their environmental concentrations will only increase with time. The earlier action is taken to manage microplastics, the more likely we will be able to avoid their ill effects on the environment and human health.

– Stephen Yaeger, RNRF Program Manager

To access the PowerPoint Coffin used during his presentation, click **here**.

Timelines of California Microplastic Legislation

California Senate Bill 1263 (2018)

2022:

- Initiate Statewide Microplastics Strategy

2026:

- Develop risk assessment framework
- Develop standardized methods
- Establish baseline occurrence data
- Investigate sources and pathways
- Recommend source reduction strategies

California Senate Bill 1422 (2018)

2020:

- Define 'microplastics'

2021:

- Standardize method
- Four years of testing
- Health-based guidance level
- Accredit laboratories

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American Geophysical Union

AGU suggests improvements to federal scientific integrity structure

On 28 July 2021, AGU **submitted comments** to the White House Office of Science and Technology Policy (OSTP)'s Request for Information to Improve Federal Scientific Integrity Policies.

Fostering scientific integrity is a key goal of our new strategic plan and we are actively engaged in supporting scientific integrity broadly, including with federal agencies. AGU urges OSTP to consider two key points:

1. Fostering integrity — and in turn public trust in science and science policy — requires a broad, holistic view of practices that extend beyond the typical focus on transparency and ethics including ensuring deeper public engagement; addressing diversity and inclusivity in science; and supporting the backbone infrastructure that enables all of these.

2. The way science is supported, practiced, conducted and communicated is changing significantly and these changes have important implications for fostering integrity in the 21st century. OSTP and federal policy can be a proactive force in improving the culture and reward system of science to align with these changes.

To read more, click **here**.

AGU community provides recommendations and ideas for implementing climate change solutions to NSF

Several bills moving through Congress are likely to provide significant funding for expanding research and results in climate change solutions (CCS). Tackling the climate crisis is also a priority of the Biden-Harris Administration and emphasized in their proposed budget. If passed, the National Science Foundation (NSF) is expected to distribute and manage much of this funding through its grant processes. This would represent a tremendous opportunity for NSF, working in concert with other federal agencies, to spawn the innovations and applications that will help humanity respond to climate change.

In mid-April, in anticipation of this challenge, NSF contacted AGU and several other societies to rapidly convene our respective communities and provide robust input and innovative ideas on climate change solutions to help inform a potential implementation strategy.

To read more, click **here**.

American Meteorological Society

AMS Community Synthesis on Climate Change Solutions

This AMS Policy Program study provides a summary of input from the AMS community on climate change solutions. It was carried out in an accelerated time frame in response to a request from the National Science Foundation for rapid community input. NSF was particularly interested in ideas from the AMS community on ways to address climate change that might be implemented and show progress relatively quickly (i.e., a 2–3-yr time frame), while having positive impacts that continued for much longer time frames.

For more information, click **here**.

American Society of Civil Engineers

ASCE Joins Coalition for Bipartisan Infrastructure Investment

The American Society of Civil Engineers (ASCE) joins the U.S. Chamber of Commerce, the National Association of Manufacturers, AFL-CIO, the National Retail Federation, the Bipartisan Policy Center, North America's Building

Trades Unions, as well as over 20 business and labor organizations to launch the Coalition for Bipartisan Infrastructure Investment. The Coalition commends the bipartisan group of 22 senators and the Biden administration on reaching agreement on a historic $1.2 trillion infrastructure framework and urges Congress to turn the framework into legislation that will be signed into law this summer.

To read more, click **here**.

American Water Resources Association

AWRA 2021 Annual Water Resources Conference

November 8-10, 2021

Kissimmee, FL (Orlando area)

This conference is one of the most diverse and inclusive conferences in water resources management, AWRA provides you with innovative, practical, and applied water resource management solutions, management techniques, and current research. Attendees can expect to hear:

- lessons learned from the implementation of multidisciplinary projects,
- best practices discovered in the design and application of water resource management,
- implications of water policy decisions, and
- research into current and emerging issues.

For more information, click **here**.

Geological Society of America

Earth to Economy: Accelerating Innovation for Climate Change Solutions

With a grant from the National Science Foundation (NSF), the Geological Society of America (GSA) gathered input from the geoscience community to identify bold and creative ideas for translating scientific research to solutions for climate change that can be implemented within a two- to three-year timeframe.

To learn more, click **here**.

Society of Environmental Toxicology and Chemistry

New Environmental Risk Assessor Certification Program Kicks Off

It's official! Representatives from SETAC signed the incorporation documents for an independent global environmental risk assessor certification program, which will be led by the International Board of Environmental Risk Assessors (IBERA) under the leadership of Karel De Schamphelaere, Ghent University, as president. The board held their formal incorporation meeting on 2 June.

The new association, established by SETAC, aims to promote the conduct of scientifically robust and technically advanced environmental risk assessment of chemical substances through certification of individuals with demonstrated expertise.

To read more, click **here**.

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