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Special Report:

Our Fate in the Stars: How a Universe Rich with Alien Worlds Can Help Us Save Our Own

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Editor's Note

Anthropogenic climate change has become a matter of intense debate in the public sphere, not only regarding how human civilization can respond to this threat, but even whether or not it is happening at all. University of Rochester astrophysicist Dr. Adam Frank describes a new, astrobiological framework for thinking about climate change that broadens our perspective on humanity's place on Earth. By considering current environmental dilemmas in a wider context — how life on Earth impacts physical planetary processes, and how civilizations throughout the universe might naturally induce climate change on their planets — Frank argues that we are better positioned to solve the compelling, existential problem of climate change.

This report is adapted from a lecture of the same name that Frank presented at Dartmouth College in May 2017. His book Light of the Stars*, published July 2018, provides further reading on astrobiology and climate change.*

What is the Problem?

The premise of Frank's argument is: **You can't solve a problem until you can understand it, and you can't understand it until you can tell its story**. What, then, is the real story behind climate change?

There is broad scientific consensus that humans are driving changes in the Earth's current climate state by burning fossil fuels. Problems associated with climate change, such as ocean acidification, shifting weather patterns and melting ice caps, are further compounded by general resource depletion across the world's biomes. While the science surrounding the topic is well established, political debate has lagged behind, and many people do not think climate change is happening or do not believe it is a threat to civilization.

This was not always the case, however. High-level political rhetoric surrounding climate change goes at least as far back as 1964, with an address by President Lyndon Johnson to Congress:

"This generation has altered the composition of the atmosphere on a global scale through radioactive materials and a steady increase in carbon dioxide from the burning of fossil fuels."

Over fifty years after LBJ's address, debate in the public sphere has become extremely polarized, and political gridlock has limited the options of how to tackle the climate change problem. A new framework for thinking about climate change could move the conversation in a more productive direction.

Think Like a Planet

Much of the social misconceptions about climate change could be attributed to a problem in perspective. Fundamentally, climate change is thought of as a one-time phenomenon — that it has never happened before — and many people unfamiliar with climate science concepts simply don't believe that that human beings are capable of drastically altering the planet's atmosphere. In order to tackle these misunderstandings, Frank argued the perspective on climate change needs to move beyond just human beings in this moment in history.

To do this he suggested "thinking like a planet." Scientific understanding of planets has seen rapid advancements in recent decades. Frank noted that the idea of planets as a general, universal, cosmic phenomenon is very new, as are ideas suggesting that planets, their biospheres, and even their civilizations are broadly governed by knowable rules. Studying these rules and thinking about how planets and civilizations occur as a natural phenomenon can help us "think like a planet."

Many Earths

Earth at one time had a magma ocean. Earth was also a continent-less water world. There was a later time when the Earth was seven degrees warmer than it is now — a jungle world. Later, the Earth was completely glaciated. In the distant future, as the sun heats up, Earth will be a desert world. There have been many different versions of Earth throughout the planet's long history, and there will continue to be many more in the future.

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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Geologists have demarcated epochs in the Earth's history that represent the planet's wildly different conditions. Currently, we are in the Holocene, a period of warm, moist, conditions that has only started since the last Ice Age about 10,000 years ago. Generally speaking, sophisticated human civilizations began and flourished in the Holocene.

Because civilization has thrived within the Holocene, it is unclear what would happen to human civilization outside of the Holocene. Frank stated that this point is particularly important to understand, because when we say we are worried about the climate, what we *really* mean is that we are worried about the Holocene. The word "sustainability" is often used to describe solutions to climate change. But what, exactly, do we want to sustain? We want to sustain is Earth as it currently is — comfortable for human civilization. Specifically, a civilization that maximizes human well-being, is technological and energy intensive, and has a high enough population to support a functioning, complex, technologically advanced society. To do this, we need to keep the Holocene. But by sustaining the Holocene in perpetuity, we are altering the planet's evolution. A perspective encompassing a long history of Earth shows that humans are far from the first species to do this.

Biosphere Affecting the Planet/Co-Evolution

Life and Earth have been evolving together for billions of years. Physical processes on the planet affect life, and biological processes of life affect the physical processes on the planet. Frank noted that if a human landed on Earth three billion years ago, they would die, because there would be no oxygen for them to breathe. Earth's oxygen-rich atmosphere was created through the activity of life. Specifically, the large-scale success of one kind of life—blue-green algae, the oxidic photosynthesizers. Four billion years ago, the Earth's atmosphere was mostly carbon dioxide and nitrogen, with about a million times less oxygen than the air we breathe today. The blue-green algae created the oxygen atmosphere wholesale about 2.5 billion years ago through what is known as the Great Oxidation Event. Increased oxygen in the atmosphere created the possibility of more complex life and fundamentally changed the course of the planet's history.

The Great Oxidation Event demonstrates 'co-evolution' – an important component in the way we can "think like a planet." The Earth and life are closely connected, or "coupled." (Frank emphasized that by "Earth" he means the Earth's surface, from the lithosphere to the atmosphere.) Through coupled systems, the biosphere and physical processes on Earth impact each other in incredibly complex ways. While some argue that the amount of CO_2 that humans put into the atmosphere cannot possibly have an effect on global climate, the Great Oxidation Event proves that life can alter the atmosphere, and by extension other systems on Earth, a great deal.

The Heroes of the Gaia Hypothesis

Several scientists have been instrumental in bringing about the idea of coupled systems and the co-evolution of life and Earth, which had been known as the Gaia Hypothesis. The Gaia Hypothesis states that life as a whole is regulating the conditions of the planet to keep those conditions favorable to life. Frank compared the connection between life and Earth to what humans would experience if they were in a desert—they would start to sweat because evaporation cools the body and helps keep internal temperatures at 96 degrees Fahrenheit. Likewise, life has feedbacks to physical changes that keep the planet stable and suitable to life, similar to a thermostat.

The idea of the planet as a thermostat was conceptualized by James Lovelock while he was working for NASA in 1961. When he was asked to look for single-celled life on Mars Lovelock realized he had no way of knowing what microbes would look like on other planets – they probably would not look like Earth microbes. But, he hypothesized, by studying a planet's atmosphere, scientists might be able to tell whether or not the planet had single-celled life. After all, the presence of life could be identified on Earth from great distances by the presence of oxygen in the atmosphere, which was created by the single-celled blue-green algae. While Lovelock was comparing Mars' oxygen-deprived atmosphere to Earth's, it occurred to him that Earth's life might be altering the planet's atmospheric composition to be more favorable to the dominant lifeforms. Carl Sagan, Lovelock's former colleague, later introduced Lovelock to Lynn Margulis, a biologist studying how microbes can change atmospherice content. Together, Lovelock and Margulis developed the Gaia Hypothesis.

The Gaia Controversy

The Gaia Hypothesis, while important to our current understanding of life on Earth, was initially a controversial concept. This was in part due to how some members of the public interpreted and embraced the Gaia Hypothesis; Frank highlighted people like Oberon and Morning Glory Zell-Ravenheart, self-proclaimed Gaian priests and priestesses, who promoted ideas like the "Earth Mother." Scientists pushed back on the teleological implications behind these ideas — that the Earth had some kind of consciousness, knew how to regulate itself, and intentionally "wanted" to be comfortable for life.

Since then the Gaia Hypothesis has been more broadly absorbed into what is now called 'Earth Systems science,' which eschews the teleological components of Gaia ideas and still recognizes the biosphere as a primary player in the planet's physical history, intertwined with other planetary phenomena in 'coupled systems.' Coupled systems – the cryosphere, lithosphere, atmosphere, hydrosphere, and biosphere – cannot be separated or pulled apart. All are connected and affect each other in different and surprising ways. All together they drive planetary evolution.

The Anthropocene

Within the context of the Gaia Hypothesis and Earth Systems science emerged the idea of the Anthropocene. The Anthropocene posits that the Earth is entering a human-dominated geological epoch, and humans are leaving enough deposits to be detectable in geological layers distinct from the Holocene. While there are on-going arguments over whether the Anthropocene has officially started and if human presence can already be detected on the planet's geological layers, there is general consensus that human activity is a driving force on the planet.

The Anthropocene suggests that the planet is going to change, with a different climate and different atmospheric circulation patterns. Entry into the Anthropocene raises new questions about the nature of human activity within Earth's coupled systems, how life impacts Earth's physical processes, and how we can build a sustainable civilization. Problems for sustaining civilization in the Anthropocene are further compounded by the increasing complexity of human networks. Right now, Frank commented, civilization's social networks are sitting on top of economic networks, that sit on top of energy distribution networks, which are connected to transportation networks. All of these networks interact with each other in complicated ways, and each individual network has its own separate vulnerabilities. As networks become more interconnected and more complex, they are more easily affected by each other's vulnerabilities. One problem that would normally affect only one network could propagate through an entire system of tightly interconnected networks.

Frank contended that a serious worry is that it would not take much to damage our civilization – not necessarily to the point of extinction, but just to the point of serious degradation. The Anthropocene is a threat to not only the planet's tightly coupled physical and biological systems, but to tightly coupled social and economic networks as well. How humans can become a sustainable driving force on Earth is a high-stakes challenge, and this is where the astrobiological perspective can be helpful.

Astrobiology

The astrobiological perspective can both shift the conversation surrounding sustainability and ask compelling questions about life in the universe.

While people have been thinking about other planets for millennia, the field of astrobiology has only gained prominence in the last 30 or 40 years, in particular because of three scientific revolutions:

1) The discovery of exo-planets
2) The *in situ* exploration of cosmic bodies
3) The exploration of Earth's own past

1) The Discovery of Exo-Planets

Three thousand years ago, Greek thinkers had debated the existence of other planets around other stars. That question, what they call the plurality of worlds, has been with humanity as long as humanity has existed.

Now scientists know that every star in the sky has planets orbiting around it. Scientists also know that about one in five stars has a planet located at a distance from their star where liquid water could exist on its surface. With liquid water a planet could have rain, oceans, rivers, and lakes, and possibly life. Discovering the vast number of exo-planets in the universe completely changed how people think about the possibility of life on other planets.

2) Exploration *In Situ*

The second revolution is within solar system studies and recent developments in the *in situ* monitoring of other planets and objects within the solar system.

In 1961 scientist Jack James was tasked with designing a probe that could visit Venus. His project was highly successful and became a point of national pride and a testament to human achievement. Ever since then Americans, Russians, Europeans, and other scientists from around the world have been sending probes into the solar system to study and observe various galactic objects. Humans have sent probes to every kind of object in the solar system — asteroids, comets, dwarf planets, moons, and every planet. Some exploratory missions include only satellite observations, but others have sent devices that could land on the object's surface.

In situ observations of other planets have revealed much about climate change as a generic planetary feature and informed models of climate on other planets that work very well. These models have been used over decades with multiple planets and moons to study climates and climate change. Scientists discovered the greenhouse effect by observing Venus, and studies of Martian dust storms ignited the debates on nuclear winter in the 1980s. Studies on Mars also show that Mars, now dry and barren, had torrents of water on its surface 3.5 billion years ago. Martian climate models are an example of thinking like a planet — scientists know the rules of climate deeply, for all planets, and the understanding of general climate principles is applicable to any planet that has an atmosphere.

These observations are further proof that habitability — the possibility for a planet to be habitable — and sustainability, is a moving target. Sustainability is a subset of planetary habitability. We want Earth to be sustainable, and habitable, for a particular kind of life — ours — and a particular kind of civilization — ours — so we have learned from studying other plants a broad way of thinking about our own existence.

3) Understand Earth's Past

The third revolution is an expanded understanding of Earth's history, going back 4.5 billion years — Earth's multiple physical states over its long existence.

All three of these revolutions, Frank explained, have changed our understanding of planets, and they have allowed scientists to begin thinking about the Anthropocene in a broader context.

What does Astrobiology Change?

Is sustainability even possible? Has civilization anywhere in the universe across the 13.7 billion years of cosmic history ever achieved sustainability? After all, if sustainability has never occurred in any civilization at any place and time, humanity is doomed. Astrobiology can help us frame and understand the options, and odds, for achieving a planet that is sustainable for human civilization.

Frank framed the concept of other-worldly intelligent life, what he calls "exo-civilizations," as a generic planetary phenomenon that sees a species becoming intelligent, learning how to harvest energy, and building an information resource processing system called a civilization. Putting aside sociological musings and focusing on physics and chemistry, scientists can begin to consider the likelihood of the existence of exo-civilizations and the additional likelihood that those exo-civilizations learned to live sustainably on their respective planets.

Optimists Versus Pessimists

If it is the case that no other planet in the history of the universe has ever hosted a civilization, the case for astrobiological thinking falls apart. However, Frank and others have developed mathematical formulas that argue that humans are not the first and only civilization.

The history in thinking about exo-civilizations has been a battle between optimists, who believe there have been many other instances of civilization in the universe, and pessimists, who believe humanity is completely unique. Scientists conceptualize this problem through the Drake Equation, developed in 1961 by Dr. Frank Drake. The Drake Equation is a probabilistic argument that posits that the number of civilizations in our galaxy right now that can be interacted with is equal to the product of several different factors (Table 1):

- Rate of star formation
- The fraction of planets that exist around each star
- The number of planets in the right place for life to form
- The fraction of those planets where life actually does form
- The fraction of those planets where intelligence is created
- The fraction of those intelligences that go on to create technology
- The average lifetime of those species.

$$N = R^{*} \cdot f_{p} \cdot n_{e} \cdot f_{\ell} \cdot f_{i} \cdot f_{c} \cdot L$$

N: Number of communicating civilizations in our galaxy	**R*: The rate of star formation suitable for the development of intelligent life**	**f_p: The fraction of those stars with planetary systems**	**n_e: The number of planets, per solar system, with an environment suitable for life**
f_l: The fraction of suitable planets on which life actually appears	**f_i: The fraction of life bearing planets on which intelligent life emerges**	**f_c: The fraction of civilizations that develop a technology that releases detectable signs on their existence into space**	**L: The length of time such civilizations release detectable signals into space**

Table 1: The Drake Equation and factor definitions

The Pessimism Line

Frank and colleague Woody Sullivan recently published a paper inspired by the Drake Equation, estimating the likelihood that humans are the first and only civilization in the universe's history. They developed what they called the "pessimism line." The previously mentioned revolutions in astrobiology created an enormous amount of data that was used as inputs for the pessimism line.

Through the pessimism line equation, Frank argued that the odds that humans are the first and only civilization are 10^{-22}, or one in ten billion trillion. In other words, the probability for a given planet in the right place relative to its star to cultivate civilized life would have to be worse than one in ten billion trillion in order for other civilizations never to have existed at any time. As long as nature's processes can beat those odds, Frank contended, then there have been other civilizations in cosmic history. This is not to say those civilizations currently exist, because it is unknown how long those civilizations might have lasted.

Compared to famous historical pessimists, Frank and Sullivan's equation shows remarkably good odds. Evolutionary biologist Ernst Mayr argued that the pessimism line would be at 10^{-15}, while theoretical physicist Brandon Carter said it would be 10^{-20}, and is quoted as saying "[this value] is more than sufficient to ensure that our stage of development is unique in the visible universe." However, Frank noted, if Carter were correct, according to the Frank and Sullivan pessimism line there would still have been 100 other civilizations in history. Frank further added that because the pessimism line is so low, there would have to be a strong bias against civilization formation for it not to have happened thousands, millions, or even trillions of times.

All Civilizations Have Driven Their Own Anthropocenes

Accepting that there have been many instances of civilization throughout cosmic history leads to questions about what happened to those civilizations. Frank's argument is that all civilizations have driven their own Anthropocenes.

The Anthropocene, Frank contended, is impossible to escape as civilizations use their planet's resources and alter the planet's physical state. The question should therefore not be, "are we driving climate change?" but rather "of course we're driving climate change! What would you expect?" Civilizations by definition harvest energy from the planet to build, organize, and move things from one place to another. The second law of thermodynamics says that energy cannot be used without creating waste. What this means on a planetary scale is that there is always pushback to any energy extracting endeavor. In fact, a recent study came out showing that two degrees of climate warming would occur even if the entire Earth were powered by wind energy.

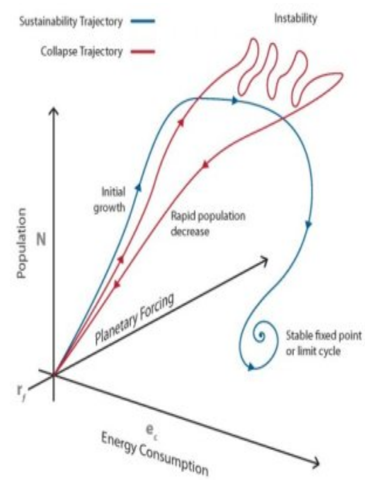

Figure 1. *Model of civilization sustainable and collapse trajectories. Frank, Adam, and Woodruff Sullivan. "Sustainability and the astrobiological perspective: framing human futures in a planetary context." Anthropocene 5 (2014): 32-41.*

These observations can guide us to the conclusion that Anthropocenes have happened before. Because scientists know generally how planets respond to waste, models can be created of the feedback between any civilization and its planet. Frank presented a model of what such a civilization could look like (Figure 1).

Figure 1 essentially shows that there are different kinds of trajectories for any kind of civilization. Some trajectories will lead to collapse, where a civilization grows, gets technology, has higher birth rates, and then pushes the planet too hard, until the planet cannot support the civilization anymore. The sustainability trajectory, on the other hand, similarly shows population numbers growing along with a general pushback on the planet, however this civilization would recognize the adverse consequences of its overexploitation, and shift over to a new energy modality. The sustainability trajectory would ultimately lead to a stable population, a stable amount of available energy, and an overall sustainable form of civilization.

By taking this broader perspective, Frank argued, we can begin to understand that the current Anthropocene is a generic event of the universe. The next questions, then, are which trajectory is humanity on? Which trajectory is average across all cosmic civilizations? Right now, human population is increasing considerably, along with energy use per capita – where does it go from here?

While there is no data on any exo-civilization, planetary physics and chemistry are well understood, and the astrobiological perspective allows scientists to theoretically model the average lifetime of a civilization like Earth's. While scientists have yet to make this estimate, we can observe that an average civilization lifetime of 200 years would not bode well for humanity, as humans would have to start making immediate changes to become more sustainable and avoid collapse. If the average civilization lifetime is two million years, however, there would be a lot of room to make mistakes and still recover.

Conclusion

And how does this perspective give us a new way of telling the story of the human race?

Frank proposed that the story of climate change and the Anthropocene should be told as a story of humans as an energy harvesting species. Just as planets have given rise to dinosaurs and blue-green algae, planets have also fostered energy harvesting civilizations, and from that perspective, humans are not that unique. Civilizations are just one of many different experiments a planet can run on its surface, and there have likely been many civilizations throughout the universe, as the pessimism line shows. Frank argued that humans are a part of the biosphere, not above the biosphere. New York City, then, is as much a part of nature as a bird's nest. Can humans learn to cooperate with the planet and sustain their civilization, or will the Anthropocene see the Earth moving on to a different experiment?

The crux of Frank's argument is that Anthropocenes have happened before and are a natural part of the formation of civilizations. Climate change is not humanity's fault — it is simply what any civilization would naturally do. Frank cautioned that this does not mean humans are not causing climate change, but rather civilizations did not set about harvesting energy and burning coal and oil with the intention of changing the climate. The Anthropocene is not a story of human greed, human unworthiness, or humans as a plague upon the planet. It is simply a story about the natural course of events under civilizations. It is a story about a planet and its experiments.

Climate change is inevitable — any civilization will cause climate change, but whether or not we can build a sustainable civilization is an open question. A planetary view of the Anthropocene problem allows for hope and optimism in staving off a collapse of Earth's civilization. The Anthropocene, Frank contended, is not a story with villains, it's just a story about winners and losers. We want to make sure that we are on the winning side, and can join the community of cosmic civilizations that have also managed to create a sustainable world. After all, Frank concluded, if another civilization has made it, why can't we?

Plastic Is a Global Health Crisis Hiding in Plain Sight

David Azoulay, Priscilla Villa, Yvette Arellano, Miriam Gordon, Doun Moon, Kathryn Miller, and Kirsten Thompson

Despite being one of the most pervasive materials on the planet, plastic and its impact on human health is poorly understood. Yet exposure to plastic is expanding into new areas of the environment and food chain as existing plastic products fragment into smaller particles and concentrate toxic chemicals. As plastic production increases, this exposure will only grow.

To date, research into the human health impacts of plastic has focused narrowly on specific moments in the plastic lifecycle, from wellhead to refinery, from store shelves to human bodies, and from disposal to ongoing impacts as air pollutants and ocean plastic. Individually, each stage of the plastic lifecycle poses significant risks to human health.

Together, the lifecycle impacts of plastic paint an unequivocally toxic picture: plastic threatens human health on a global scale.

This report provides a detailed overview of the health impacts associated with plastic at every stage of its supply chain and lifecycle, and it reveals the numerous exposure routes through which human health is impacted at each stage. The report details the physical impacts of ingesting, inhaling, and touching plastic, as well as the toxic chemicals associated with those plastic particles, whether chemical additives, processing agents, or byproducts of plastic. This report also reveals that systemic and troubling gaps in our knowledge may exacerbate exposure and risks for workers, consumers, frontline communities, and even communities far removed from the sources of plastic. Despite those gaps, the evidence collected in this report is conclusive that there is an urgent need to adopt a precautionary approach to protect human health from the plastic pollution crisis.

Key Findings

Plastic requires a lifecycle approach. The narrow approaches to assessing and addressing plastic impacts to date are inadequate and inappropriate. Understanding and responding to plastic risks, and making informed decisions in the face of those risks, demands a full lifecycle approach to assessing the full scope of the impacts of plastic on human health. This includes to ensure that we are not creating yet more and increasingly complex environmental problems in attempts to address this one.

At every stage of its lifecycle, plastic poses distinct risks to human health, arising from both exposure to plastic particles themselves and associated chemicals. The majority of people worldwide are exposed at multiple stages of this lifecycle.

- **Extraction and Transport of Fossil Feedstocks for Plastic**

  The extraction of oil and gas, particularly the use of hydraulic fracturing for natural gas, releases an array of toxic substances into the air and water, often in significant volumes. Over 170 fracking chemicals that are used to produce the main feedstocks for plastic have known human health impacts, including cancer, neurotoxicity, reproductive and developmental toxicity,

This is adapted from the executive summary from Plastic & Health: The Hidden Costs of a Plastic Planet.

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impairment of the immune system, and more. These toxins have direct and documented impacts on skin, eyes, and other sensory organs, the respiratory, nervous, and gastrointestinal systems, liver, and brain.

- **Refining and Production of Plastic Resins and Additives**

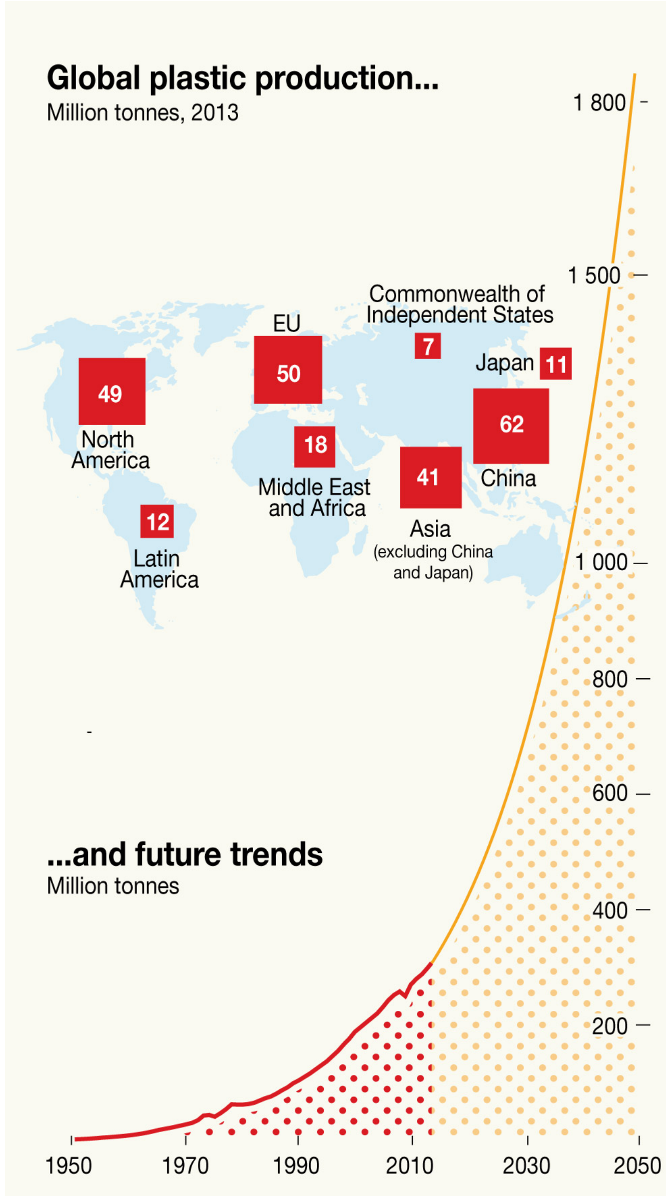
  Transforming fossil fuel into plastic resins and additives releases carcinogenic and other highly toxic substances into the air. Documented effects of exposure to these substances include impairment of the nervous system, reproductive and developmental problems, cancer, leukemia, and genetic impacts like low birth weight. Industry workers and communities neighboring refining facilities are at greatest risk and face both chronic exposures and acute exposures due to uncontrolled releases during emergencies.

- **Consumer Products and Packaging**

  Use of plastic products leads to ingestion and/or inhalation of large amounts of both microplastic particles and hundreds of toxic substances with carcinogenic, developmental, or endocrine disrupting impacts.

- **Toxic Releases from Plastic Waste Management**

  All plastic waste management technologies (including incineration, co-incineration, gasification, and pyrolysis) result in the release of toxic metals such as lead and mercury, organic substances (dioxins and furans), acid gases, and other toxic substances to the air, water, and soils. All such technologies lead to direct and indirect exposure to toxic substances for workers and nearby communities, including through inhalation of contaminated air, direct contact with contaminated soil or water, and ingestion of foods that were grown in an environment polluted with these substances. Toxins from emissions, fly ash, and slag in a burn pile can travel long distances and deposit in soil and water, eventually entering human bodies after being accumulated in the tissues of plants and animals.



Source: Ryan, A Brief History of Marine Litter Research, in M. Bergmann, L. Gutow, M. Klages (Eds.), Marine Anthropogenic Litter, Berlin Springer, 2015; Plastics Europe

- **Fragmenting and Microplastics**

  Microplastics entering the human body via direct exposures through contact, ingestion, or inhalation can lead to an array of health impacts, including inflammation, genotoxicity, oxidative stress, apoptosis, and necrosis, which are linked to an array of negative health outcomes including cancer, cardiovascular diseases, inflammatory bowel disease, diabetes, rheumatoid arthritis, chronic inflammation, autoimmune conditions, neurodegenerative diseases, and stroke.

- **Cascading Exposure as Plastic Degrades**

  Most plastic additives are not bound to the polymer matrix and easily leach into the surrounding environment, including air, water, food, or body tissues. As plastic particles continue to degrade, new surface areas are exposed, allowing continued leaching of additives from the core to the surface of the particle in the environment and the human body.

- **Ongoing Environmental Exposures**

  Once plastic reaches the environment in the form of macro- or microplastics, it contaminates and accumulates in food chains through agricultural soils, terrestrial and aquatic food chains, and the water supply. This environmental plastic can leach toxic additives or concentrate toxins already in the environment, making them bioavailable again for direct or indirect human exposure.

Uncertainties and knowledge gaps undermine the full evaluation of health impacts, limit the ability of consumers, communities, and regulators to make informed choices, and heighten both acute and long-term health risks at all stages of the plastic lifecycle.

- **Hidden Risks**

  Extreme lack of transparency of the chemicals in most plastic and its production processes prevents a full assessment of its impacts. Broad protection of confidential business information and inadequate disclosure requirements play a key role in creating these uncertainties, and they reduce the ability of regulators to develop adequate safeguards; consumers to make informed choices; and frontline and fenceline communities to limit exposure to plastic-related health hazards.

- **Intersecting Exposures and Synergistic Effects Remain Poorly Understood**

  Risk assessment processes fail to evaluate the health effects of cumulative exposure to the mixtures of thousands of chemicals used in consumer goods like food packaging and found in the environment.

- **Plastic in the Food Chain**

  Despite their pervasive presence and potentially significant impacts across an array of pathways, research into the impacts and movement of plastic and microplastics through terrestrial environments, marine ecosystems, and food chains is limited. The potential transfer of microplastics and associated toxic chemicals to crops and animals demands urgent and sustained investigation.

- **Plastic in People**

  Microfibers and other plastic microparticles are increasingly being documented in human tissues. Until these impacts are better understood, we should adopt a precautionary approach to limit the production and use of these persistent contaminants.

Reducing toxic exposure to plastic will require a variety of solutions and options because plastic has a complex lifecycle with a diverse universe of actors.

- **Putting Human Rights and Human Health at the Center of Solutions**

  At every stage of the plastic lifecycle and across those stages, solutions should be guided by the respect for the human rights to health and to a healthy environment. Despite remaining uncertainties, existing information about the severe health impacts of the plastic lifecycle justifies the application of a strong precautionary approach to the lifecycle of plastic and the overall reduction of plastic production and uses.

- **Recognizing the Suite of Interacting Exposures**

  Health impact assessments that focus solely on the plastic components of products while ignoring the thousands of additives and their behavior at every stage of the plastic lifecycle are necessarily incomplete.

- **Making the Invisible Visible**

  Addressing plastic pollution will require adapting and adopting legal frameworks to ensure access to information regarding the petrochemical substances in products and processes, as well as increased independent research to fill existing and future knowledge gaps.

- **Building Solutions on Transparency, Participation, and the Right to Remedy**

  In identifying, designing, and implementing possible solutions to the plastic pollution crisis, transparency is key to success. Transparency is required to identify the nature and breadth of exposure to toxic material, as well to assess possible health and environmental impacts of technologies touted as "solutions" to the plastic pollution problem, such as incineration and plastic-to-fuel technologies. Solutions must integrate not only access to information, but also the right to meaningful participation in decision-making about plastic-related risks, and access to justice when harms arise.

- **Think Globally, Acting Everywhere**

  The production, use, and disposal of plastic is interwoven in supply chains that cross and recross borders, continents, and oceans. To date, efforts to address the human health impacts of plastic have largely ignored the global dimensions of the plastic lifecycle and the plastic crisis. As a result, measures that succeed at a local level or with respect to a single product stream are often undermined or offset by the emergence of new plastic, new additives, and new exposure pathways. Until efforts at all levels of government confront the impacts of the full plastic lifecycle, the current piecemeal approach to addressing the plastic pollution crisis will fail.

Thus far, efforts to address the plastic crisis have had limited success. This results from an array of factors: the scale and complexity of impacts, the limitations of risk assessment systems (in particular the combined effects of chemical substances and the limited exposure data), long and complex supply chains, formidable financial stakes in maintaining the status quo, and an industry in denial of the health impacts. Yet while the economic interests of the plastic industry are indeed enormous, the financial costs to society are even more so. The findings of this report are clear. Even with the limited data available, the health impacts of plastic throughout its lifecycle are overwhelming. Many actions and solutions are needed to confront this threat to human life and human rights. To be effective, they must ultimately reduce the production, use, and disposal of plastic and its associated toxic chemicals.

The full report can be accessed here: https://www.ciel.org/reports/plastic-health-the-hidden-costs-of-a-plastic-planet-february-2019/

Crisis on the High Plains: The Loss of America's Largest Aquifer – The Ogallala

Jeremy Frankel

The grain-growing region of the High Plains of America—known as America's breadbasket—relies entirely on the Ogallala Aquifer. But long term unsustainable use of the aquifer is forcing states in the region to face the prospect of a regional economic disaster. As the High Plains states reach the verge of a major crisis, the states have taken different approaches to conservation with varying results.

The Ogallala Aquifer supports an astounding one-sixth of the world's grain produce, and it has long been an essential component of American agriculture. The High Plains region—where the aquifer lies—relies on the aquifer for residential and industrial uses, but the aquifer's water is used primarily for agricultural irrigation. The agricultural demands for Ogallala water in the region are immense, with the aquifer ultimately being responsible for thirty percent of all irrigation in the United States. The Ogallala Aquifer has long been unable to keep up with these agricultural demands, as the aquifer recharges far slower than water is withdrawn.

Aside from the obvious agricultural ramifications from the Ogallala's depletion, recent studies have shown that groundwater depletion also has a severe effect on freshwater ecosystems in the region. Each state has had to confront the issue in their own way, but the depletion of the aquifer has become severe enough to warrant the attention of the federal government as well. At the state level, the focus has been on maintaining an orderly depletion of the aquifer rather than developing a plan for sustainable use. However, some states have achieved some level of success in slowing down the aquifer's depletion. Kansas, for example, has recently achieved mild success by adopting a program that put conservation in the hands of the State's farmers. On the other hand, Nebraska has seen more success than Kansas by being tougher on farmers and exercising its enforcement powers. The federal government has

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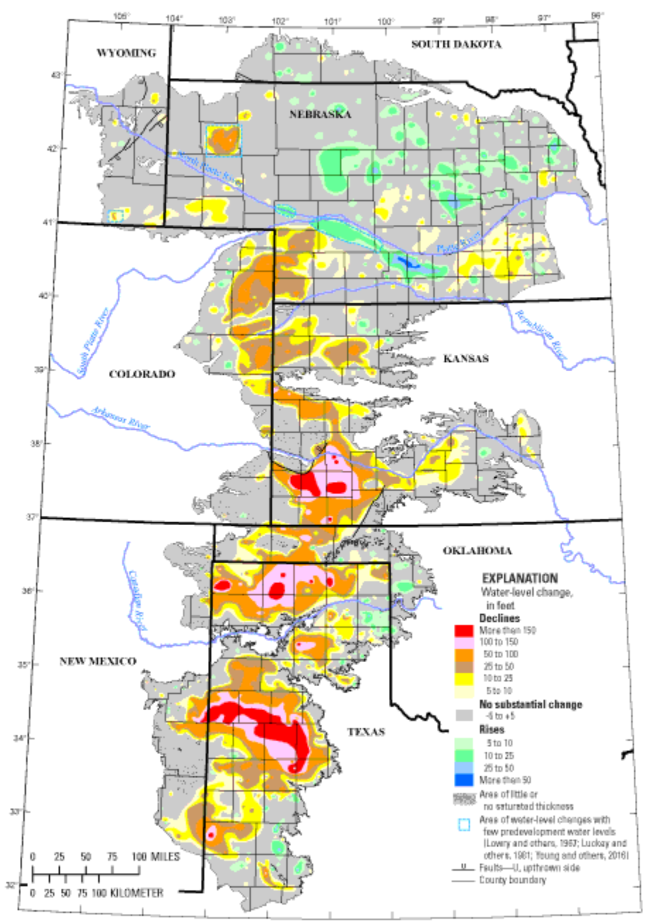

(Image: Map of the Ogallala Aquifer identifying areas of depletion. United States Geological Survey.)

also set up financial and technical assistance for farmers who commit to conservation and is funding large-scale pipeline projects to bring in water to the more desperate areas of the High Plains.

Background

The Ogallala Aquifer, also known as the High Plains Aquifer, underlies eight different states, stretching across America's High Plains from South Dakota down to Northern Texas. It is an unconfined aquifer that is recharged almost exclusively by rainwater and snowmelt, but given the semiarid climate of the High Plains, recharge is minimal. In some areas, the water table is dropping as much as two feet a year, but recharge in the aquifer only averages around three inches annually.

The aquifer provides nearly all of the water for residential, industrial, and agricultural uses in the High Plains region. Irrigated agriculture is particularly straining on the aquifer as the region is responsible for one-fifth of the wheat, corn, cotton, and cattle produced in the United States. The High Plains actually leads the entire Western Hemisphere in irrigation with fourteen million acres irrigated annually, primarily in Nebraska, Kansas, and Texas. Accordingly, farming accounts for an astounding ninety-four percent of groundwater use in the region.

The resulting strain on the aquifer has been apparent for decades as recharge in the semiarid region has been unable to keep up with such a high demand. Because of the continuous decline in the aquifer, some areas that traditionally relied on the aquifer for irrigation are now unable to do so. "We are basically drying out the Great Plains," according to Kurt Fausch, a professor at Colorado State University who studies the Ogallala. In Western Kansas, for example, water levels have declined by up to sixty percent in some areas as the gap between what is withdrawn for irrigation and what is recharged continues to expand. In northwest Texas, so much water has been pumped and so little recharged that irrigation has largely depleted the aquifer in the area.

Effects of Depletion

Without Ogallala water, significant portions of the High Plain's agriculture and related businesses are entirely unsustainable, which could threaten the existence of entire towns whose economies are dependent on water drawn from the aquifer. There are global implications as well, as the region produces one-sixth of the world's grain produce. A study from Kansas State University predicted that the aquifer would be seventy percent depleted by 2060 if irrigation practices do not change. However, the study further predicted that the aquifer could potentially last up to one hundred more years if all farmers in the region cut their use by twenty percent.

Aside from the devastating effects on agriculture, a study recently published by a team of stream ecologists concluded that depletions to the Ogallala Aquifer are also leading to fish extinctions in the region. Streams and rivers that depend on the aquifer are drying out after decades of over-pumping. The study found pumping to be associated with collapses of large-stream fish and the simultaneous expansion of small-stream fish. This creates a catalyst for biotic homogenization, which in turn leads to less resilient aquatic communities and loss of ecosystem functions. The study predicts an additional loss of 286 kilometers of stream by 2060, as well as the continued replacement of large-stream fish by fish suited for smaller streams.

Addressing Depletion at the State Level

The High Plains states are accustomed to periods of water shortages, and, accordingly, these states have all established the statutory or regulatory power to strictly control groundwater use. However, while the High Plains states all have the legislative authority to regulate use of the Ogallala aquifer to ensure sustainable use, some states have been more or less hesitant to exercise those powers. Those states that do not strictly regulate groundwater have instead chosen to leave conservation in part to the water users themselves. Two states in particular have highly diverged in their approach to regulating groundwater—Kansas and Nebraska.Each state has legislation in place allowing the government to force farmers to reduce water use, but while Nebraska has actively used that power, Kansas has been much more hesitant.

In Kansas, the state's chief engineer has the statutory power to designate an Intensive Groundwater Use Control Area to preserve the aquifer when required by the conditions. In exercising that power, the chief engineer can dramatically cut water applications for farmers and close applications for new water rights. The chief engineer has exercised that power several times in the last few decades, but Kansas state officials are often reluctant to do so. The director of the Kansas Water Office, Tracy Streeter, said, "We think it's a harsh method. We would like to see groups of irrigators come together and work out a solution."

Accordingly, the Kansas State Legislature amended the state's water laws to allow groups of farmers and irrigators to voluntarily create Local Enhanced Management Areas ("LEMA(s)") where they can implement their own groundwater conservation plans. These plans are then subject to approval by the state. Once approved, the plan becomes legally binding. One group of farmers has set up a ninety-nine square mile conservation zone where they agreed to a twenty percent reduction in irrigation for five years. After four years, they have steadily achieved their twenty percent reduction rate while, significantly, not seeing a reduction in profits. Some of their success has also been due in part to the implementation of drip irrigation and more sophisticated irrigation water management.

While that is a step in the right direction, this group of farmers is still the only group that has submitted a plan in Kansas. This arrangement has proven its potential for success, but the question remains on whether it is scalable for the rest of the state. The fact that only one group has formed is likely due to how difficult it is to create one—here, talks lasted three years before boundaries were agreed upon, and members of the group said they had to change their whole mindset and culture to come to an agreement.

Nebraska has taken a tougher stance than Kansas, and consequently has had more success in combating aquifer depletion. The Nebraska Ground Water Management and Protection Act allows the state government to limit irrigators' water allocations as well as implement programs such as rotating water permits. Nebraska has also compromised with farmers, adopting a system like Kansas that empowers farmers and gives them control—so long as they come up with a plan to reduce use of the aquifer. The approach the state has taken has allowed Nebraska to sustain water levels—or at least slow depletion—in the Ogallala Aquifer better than most other High Plains states. Despite their success, however, the aquifer in Nebraska is still continuously depleting, and annual allocations to farmers have been steadily decreasing.

Addressing Depletion at the Federal Level

Interstate compacts—created and enforced through federal law—have played a critical role in driving state efforts to curtail groundwater use. For example, part of the reason Nebraska has taken such a tough stance on groundwater pumping is because of their obligations to Kansas under the Republic River Compact. The Compact apportions Colorado, Nebraska, and Kansas each a supply of "virgin water" that is undepleted by human activity from the Republican River Basin, which is primarily drained by the Republican River and its tributaries. Much of the water from the Basin passes through Nebraska before entering Kansas via the Republican River, and Nebraska must limit water consumption to comply with the state's obligations to Kansas under the Compact. As the Ogallala aquifer feeds into the Republican River, Nebraska has had to limit its use of the aquifer to comply with the Compact, which has resulted in a more sustainable use of the aquifer but also lowers crop yields for farmers.

The federal government itself has addressed the issue of the depleting Ogallala by instituting the Ogallala Aquifer Initiative. The Initiative works by providing technical and financial assistance to farmers and ranchers to implement conservation practices that use less water, improve water quality, and keep croplands productive. The Initiative benefits agricultural producers by cutting costs for water, cutting costs for energy to power irrigation systems, and increasing crop yields. Extending the life of the aquifer also benefits the public at large, as the public directly benefits from irrigation with Ogallala water.

In New Mexico, circumstances are more critical, prompting the federal government to take a more drastic approach. In eastern New Mexico specifically, the Ogallala aquifer has depleted to the point of crisis. To make matters worse, alternative sources of water in the area are primarily located along the border with Texas, where oil and gas development dominates water use. For its part, New Mexico has started reviewing hydrological information before renewing or approving new access to drill wells that involve using Ogallala water. The federal government has also stepped in, investing in a pipeline project called the Ute pipeline, which has recently required an additional investment of five million dollars. The project is designed to eventually bring billions of gallons of drinking water to eastern New Mexico from nearby Ute Lake.

Conclusion

The Governor of Kansas, after seeing the success of the one and only LEMA group in the state, has recently declared that Kansas has been producing real results towards water conservation and that Kansas's status as a breadbasket for the nation has been secured. However, it is important to remember to contextualize this success; it is only one group in an area less than one hundred square miles, meaning that the Ogallala is far from saved. And while there is value in allowing farmers to voluntarily take the reins in conserving the Ogallala, it is clear that they are not jumping at the opportunity to do so. The farmers themselves have commented that it is going to take a whole change of culture in the region to see the results that the Kansas legislature envisioned from the LEMA program—an uphill battle that certainly will not happen overnight. Nebraska is at least seeing some more substantial results from their hardline policies, which may be the direction the High Plains states need to take to avoid a major crisis. While the Ogallala may not be able to be completely saved at this point, it is certainly worth preserving for as long as possible, and states should not hold back in using their enforcement powers to do so.

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Announcements

American Geophysical Union

AGU-SEG Airborne Geophysics Workshop

June 11-13, 2019. Davie, FL

https://connect.agu.org/2019aguseg/home

The AGU-SEG Airborne Geophysics Workshop is being held to share advancements and applications of airborne geophysics for ground water, mineral, petroleum, geotechnical and hazards investigations.

The development and application of airborne geophysics is rapidly accelerating. Airborne methods are increasingly used for groundwater assessment, natural resource exploration and large-scale geotechnical investigations. The workshop will provide a venue for participants to learn about new instrumentation, interpretation software, and applications of Airborne methods to solve diverse real- world problems.

Chapman Conference: Winter Limnology in a Changing World

October 14-18, 2019. Polson, MT

https://connect.agu.org/aguchapmanconference/upcoming-chapmans/winter-limnology

Recent high-profile syntheses of lake water temperatures and ecology under lake ice are galvanizing a scientific community, and new data streams are being amassed by in situ sensors deployed during seasonal ice cover. We are now positioned us to catalyze progress in our understanding of winter limnology inclusive to polar, alpine, and temperate systems. Continued acceleration of winter research by a geographically diverse group of investigators will generate irreplaceable information about lake dynamics and enable future research on lake-climate interactions as we enter an increasingly ice-free world.

To accelerate progress in winter limnology, AGU's Chapman Conference on winter limnology will address hypotheses associated with 5 topics: climate and ice dynamics; winter and cross-seasonal biogeochemistry; biological connections across seasons; temperature dependency of biotic processes and habitat; and trophic interactions under ice.

Fall Meeting

December 9-13, 2019. San Francisco, CA

https://meetings.agu.org/fall-meeting-2019/

AGU's Fall Meeting will prepare attendees for what's ahead: rapid developments in our science, new approaches to observing our Earth and beyond, the introduction of new data streams, growing demand for accessible science, the expansion of convergent science, and more.

American Meteorological Society

15th Conference on Polar Meteorology and Oceanography

May 19-23, 2019. Boulder, CO

https://www.ametsoc.org/index.cfm/ams/meetings-events/ams-meetings/15th-conference-on-polar-meteorology-and-oceanography1/

The Conference on Polar Meteorology and Oceanography explores the topics of observational and modeling studies of polar clouds, aerosols, and precipitation, sea ice variability and change in the Arctic and/or Antarctic, the state of the cryosphere, as measured by field campaigns and satellites, observational needs for the cryosphere, and much more.

Annual Meeting

January 12-16, 2020. Boston, MA

https://annual.ametsoc.org/index.cfm/2019/

The AMS Annual Meeting is the world's largest yearly gathering for the weather, water, and climate community. It brings together great minds from a diverse set of scientific disciplines – helping attendees make career-long professional contact and life-long friends while learning from the very top people in the atmospheric sciences.

American Society of Civil Engineers

World Environmental & Water Resources Congress

May 19-23, 2019. Pittsburgh, PA

https://www.ewricongress.org/

Created in 1999, the Environmental & Water Resources Institute (EWRI) is the recognized leader within ASCE for the integration of technical expertise and public policy in the planning, design, construction, and operation of environmentally sound and sustainable infrastructure impacting air, land and water resources.

This Congress will allow attendees to earn Professional Development Hours, network with industry leaders, learn about the latest trends and techniques being applied in the industry, participate in policy dialogue on water resource and environmental issues affecting the profession, among others.

ASCE 2019 Convention

October 10-13, 2019. Miami, FL

https://www.asceconvention.org/about

The ASCE Convention is the Society flagship membership event. It is the single annual opportunity that the entire Society is represented together and therefore needs to reflect the diversity that ASCE encompasses. The program for the Convention will be of an integrated, cross-cultural, technical, and educational nature.

American Society of Landscape Architects

Conference on Landscape Architecture

https://www.asla.org/conference.aspx

November 15-18, 2019. San Diego, CA

The meeting will feature a diverse spectrum of industry experts speaking on a wide range of subjects, from sustainable design and best practices to new materials and technologies.

More than 130 education sessions and field sessions will be presented during the meeting, providing attendees with the opportunity to earn up to 21 professional development hours under the Landscape Architecture Continuing Education System™ (LA CES™).

Many of the sessions will also qualify for continuing education credit with the Green Building Certification Institute (toward LEED AP credential maintenance), the American Institute of Architects, the American Institute of Certified Planners, and other allied professional organizations and state registration boards.

American Water Resources Association

2019 Spring Conference: Setting Conditions for Success of Integrated Water Resources Management

March 25-27, 2019. Omaha, NE

https://members.awra.org/Members/Events_and_Networking/Events/Spring_2019_Specialty_Conference.aspx

Following in the steps of the 2011 and 2014 AWRA Integrated Water Resources Management (IWRM) conferences, the 2019 AWRA Spring Specialty Conference will support dialog, sharing and learning about the tactics, strategies and policies that are helping IWRM succeed across North America and the world. Researchers, practitioners and academics will assemble in Nebraska - a state that has implementing IWRM for over a decade - to consider how IWRM can become the normative model of water management, or simply, "how we do things."

2019 Summer Conference: Improving Water Infrastructure through Resilient Adaptation

June 16-19, 2019. Sparks, NV

https://members.awra.org/Members/Events_and_Networking/Events/Summer_2019_Specialty_Conference.aspx

This conference will allow attendees to confer about what engineering solutions and policy conditions are needed for improving water resources resilience of our nation, discuss what has or hasn't worked as we have tried to adapt to water related risks, and review what innovative data and tools are being developed and used to support efforts to improve resilience and adapt to new water realities.

Annual Conference

November 3-7, 2019. Salt Lake City, UT

https://www.awra.org/Members/Events_and_Networking/Events/ANNUAL_WATER_RESOURCES_CONFERENCE.aspx

Praised by attendees year-after-year, AWRA's Annual Conference is an immersive experience, providing attendees with innovative, practical, and applied water resource management solutions, management techniques, and current research. Attendees will 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 issue.

Geological Society of America

2019 Annual Meeting

September 22-25, 2019. Phoenix, AZ

http://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/2019info.aspx

Attendees can look forward to a modern, exciting metropolitan area with great activities and events. There will also be many field trips throughout the state to study Arizona's extensive geological features. GSA expects to have a strong education program during the meeting because of the emphasis on geoscience literacy promoted by the many natural parks in the state.

Society of Environmental Chemistry and Toxicology

SETAC Africa Biennial Conference

May 6-8, 2019. Cape Town, South Africa

https://saf2019.setac.org/

SETAC places emphasis on basic applied sciences such as environmental chemistry, toxicology and ecology. The primary goal of this joint conference with the Society of Risk Analyses (SRA) is to illustrate how these sciences relate to using health and environmental risk analyses within Africa. The long-term goal is supporting the eventual use of risk analyses and related sciences in policy making and regulatory development.

The conference will include daily plenary panels, joint SRA and SETAC sessions, platform and poster sessions and special symposia.

The program will blend health, environmental and risk sciences from SRA and SETAC as well as abstracts from members from the American Society of Civil Engineers (ASCE), who plan to be a conference sponsor.

SETAC North America Annual Meeting

November 3-7, 2019. Toronto, Canada

https://toronto.setac.org/

The meeting will emphasize the need for environmental scientists and managers from all sectors (e.g., academia, business, government, non-profit, non-governmental and intergovernmental organizations) to work together at a global scale to address shared environmental challenges. Under such a paradigm, discrete technical advances would be leveraged to create harmonized approaches towards mutual solutions. The meeting offers opportunities to focus on transboundary issues within a holistic system approach.

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