CRISIS AT THE SALTON SEA
The Vital Role of Science

A special report prepared for policymakers and stakeholders by the

UNIVERSITY OF CALIFORNIA RIVERSIDE
SALTON SEA TASK FORCE

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Obsolete dock at Desert Shores. Caroline Hung

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Snow geese in flight above the Sonny Bono Salton Sea National Wildlife Refuge. Jonathan Nye

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EXECUTIVE SUMMARY

The Vital Role of Science in a Successful Salton Sea Policy

The Salton Sea—a hypersaline, terminal lake in southern California—is in crisis. A combination of mismanagement and competition among federal, state and local agencies has hindered efforts to address declining lake levels and unstable water chemistry. This delay has heightened the public health threat to regional communities as retreating shorelines expose dry lakebed—a source of potentially toxic dust—while aquatic ecosystems face collapse due to rising salinity and oxygen loss. Although state agencies are making efforts to mitigate the problems, the scientific assumptions informing current management practices are outdated or lacking entirely, making outcomes unpredictable at best.

THE ABSENCE OF AN ADAPTIVE, SCIENCE-BASED approach to addressing the environmental and human health challenges at the Salton Sea prompted UC Riverside's Environmental Dynamics and GeoEcology (EDGE) Institute and Science to Policy Center to launch an independent Salton Sea Task Force to identify critical scientific research necessary to guide policymakers in making decisions about the region's future. As an interdisciplinary group of scientists, engineers, medical experts, and economists, we considered three potential, realistic scenarios facing the Salton Sea over the coming decade: (1) ongoing decline, where lake levels continue to decrease without intervention, (2) stabilization, where enough water is directed to the Sea to slow the decline and potentially stabilize the lake at a level lower than it is today, and (3) recovery, where enough water is brought in from the ocean or local freshwater sources to stabilize, and possibly increase, lake levels.

Based on our expertise and first-hand research at the Salton Sea, we identified substantial challenges and opportunities in seven interconnected areas: water policy, watershed hydrology, water quality, air quality,

AIR QUALITY MONITORING EQUIPMENT: dust sticks to the marbles and can be analyzed later in the lab. Emma Aronson

ecology, human health, and geothermal resources. This report devotes a chapter to each of these areas of concern and provides specific suggestions for research tasks that would provide the necessary clarity to evaluate outcomes of current Salton Sea management policies and help make necessary adjustments moving forward.

Urgency

PRAGMATIC URGENCY drives the research outlined in this report. We are keenly aware of the limited funding currently allocated for mitigation efforts at the Salton Sea, and we duly focused our scientific curiosity about this dynamic region through the lens of the two primary goals the state of California identifies in its current Salton Sea management plan: (1) improve air quality for the communities surrounding the Salton Sea and (2) provide critical environmental habitat for birds along the Pacific Flyway. Furthermore, we evaluated these goals using four criteria used commonly to determine the success or failure of a policy: *effectiveness*, *efficiency*, *equity*, and *sustainability*.

Effectiveness

FIRST CONSIDER EFFECTIVENESS, which measures how successfully a plan achieves its desired results. We can set a lower bound for the effectiveness of current Salton Sea policies by asking two questions: Will air quality improve? Will there be critical habitat for birds and fish?

The Salton Sea Management Program, led by a consortium of state agencies, aims to achieve its desired outcomes by constructing 30,000 acres of bird habitat and dust suppression projects by 2028. Progress has been slow, however, with only 755 acres completed by the end of 2020 (SSMP, 2021). Potential outcomes of these efforts are highly uncertain. Plans to limit air pollution rely largely on limiting acreage of exposed lakebed, or playa. Yet the acreage of exposed playa will depend on the Sea's volume, which in turn depends on regional water policy (Chapter 1) and complex interactions between surface water and groundwater, a factor that has been overlooked until recently (Chapter 2). Air quality, too, is a function not only of water availability but also of the chemistry and biology of the lake itself, which is changing rapidly as water volume diminishes (Chapters 3, 4, 5).

The degree to which restoration efforts will produce viable bird habitats is similarly uncertain (Chapter 5). The characteristics of restored wetland habitat will depend on the intersection of water quantity, water quality, and other inputs, such as food sources for birds. Yet, as this report demonstrates, we are proceeding with a lack of understanding of the Sea's water quantity (Chapters 1 and 2) and water quality (Chapter 3) dynamics. In short, whether planned wetland projects will provide the minimum range of ecosystem functions required to support specific bird species depends on variety of factors that require further scientific research (Chapter 5).

Efficiency

CURRENT STATE POLICIES are even more concerning from an efficiency perspective. Within the economic lexicon, efficiency is an outcome for which net benefits—total benefits less total costs—are maximized. The lack of understanding of the outcomes associated with current mitigation efforts to reduce air pollution or restore critical habitat coupled with uncertainty surrounding the drivers of pulmonary illness associated with changing Salton Sea characteristics (Chapter 6) make any quantifiable measure of the benefits indeterminate. Reasonable discussions about efficiency are premature until we garner a better understanding of the science. Indeed, expecting efficiency from Salton Sea management policies may be unrealistic. A less demanding criterion would be to seek a solution that is merely cost-effective, defined as the minimum cost to achieving a particular outcome.

Even a less demanding, cost-effective criterion will be difficult to achieve without an understanding of the science and issues identified in this report. Because of the uncertainty surrounding the drivers of pulmonary illness associated with changing Salton Sea characteristics (Chapter 6) and the likely outcomes associated with current mitigation efforts to restore critical habitat or reduce air pollution (Chapters 3, 4, 5), any quantifiable measure of benefits is indeterminate. Without a firmer grasp on probable outcomes for proposed mitigation strategies, assessments of the cost-effectiveness of current policies are also premature.

Put another way, the rate of return on current investments in mitigation as measured by current management targets are highly uncertain and not guaranteed to be positive over time, due largely to the issues identified in this report. Furthermore, as economics is about tradeoffs, the consequences of a receding Sea on the state's intended outcomes of reducing air pollution and improving critical habitat should be considered alongside economic opportunities—namely, what can be gained from further development and investment in the Sea's geothermal and lithium resources (Chapter 7).

Equity

RECENTLY CALIFORNIA has increased its efforts to incorporate local community concerns and insight into its Salton Sea management plan. Considering input from local stakeholders is a commendable pivot relative to the state's earlier efforts, which were focused more on trying to identify cost-effective solutions than on how different communities would bear those distributions of costs and benefits. Despite this progress, equity issues are still largely unresolved because of the uncertain outcomes associated with air pollution (Chapter 4), how that pollution impacts local communities surrounding the Salton Sea (Chapter 6), and what rents associated with geothermal and lithium development can be funneled back into the local communities in terms of employment and income opportunities (Chapter 7).

It is critical to note that significant health disparities in this region are likely to amplify the impacts of expected environmental hazards (Chapter 6). The communities surrounding the Salton Sea are characterized relative to state averages by low income, poor health, and low access to health care. As such, knowing how the benefits and costs of different management plans will affect these communities is paramount to understanding the degree to which such plans are equitable; because of the uncertainty surrounding the effectiveness of the management plans—and until an understanding of the issues raised in this report is achieved—the degree to which such plans are equitable is unclear.

Sustainability

FINALLY, THIS REPORT clarifies the need for more scientific research to understand how the Salton Sea system will evolve over time. Getting a better handle on the Sea's future volume, chemistry and probable generation and transport of dust and other air pollutants is critical to

LAUNCHING WATERCRAFT for field work is difficult. Shorelines have receded far from existing boat ramps. Charlie Diamond

the restoration and sustainability of critical habitat for birds and clean air for local communities. Both a better understanding of the science and continual monitoring and assessment of the consequences of mitigation will be required to gauge the effectiveness and return on the state's efforts. The same kinds of science are crucial for recognizing when ongoing investments in a particular strategy need to be reimagined and reconfigured.

Action

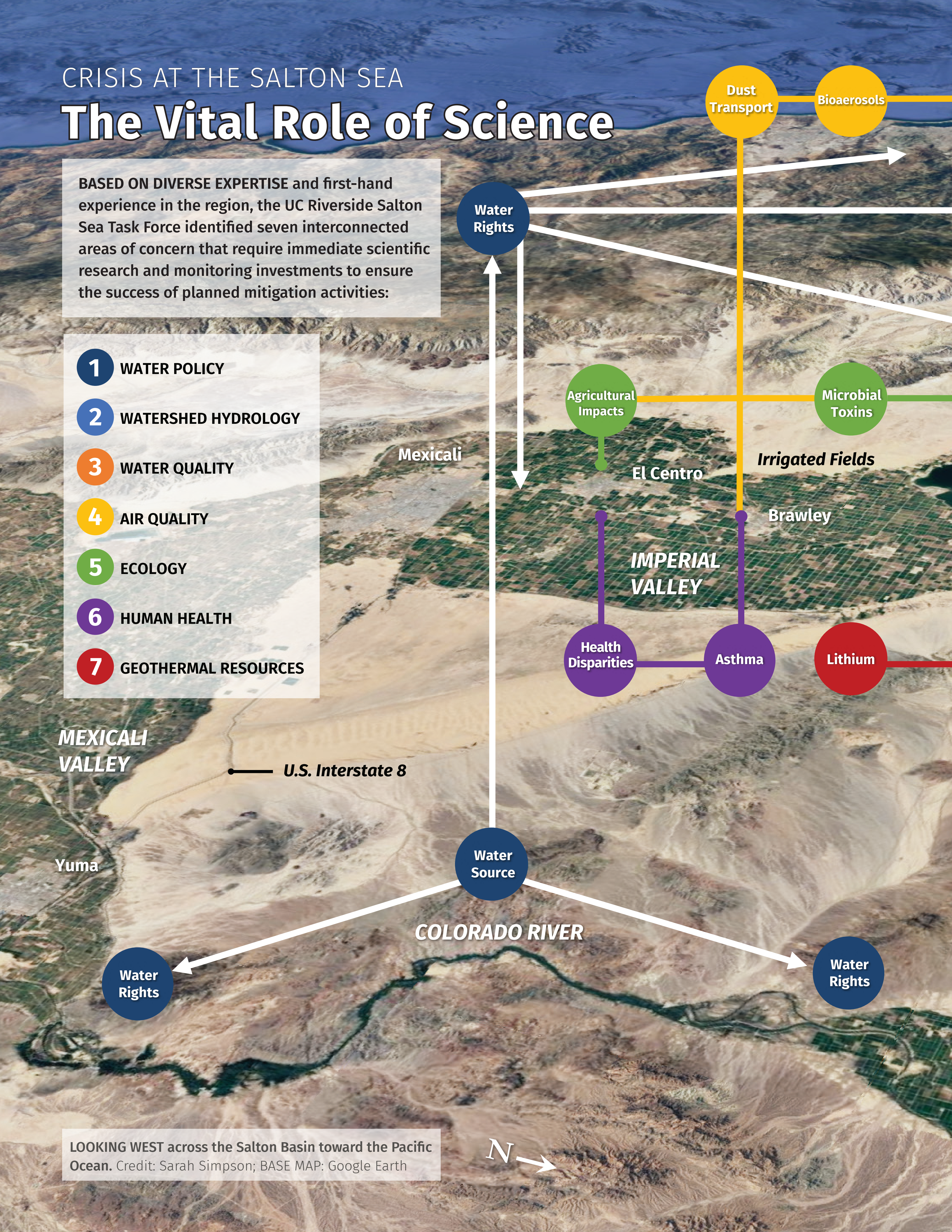
A COMMON REFRAIN in discussions about how to manage the Salton Sea crisis is 'enough science has been done—what we need now is action.' This report makes clear that we need both science and action. Without significant consideration of the issues presented in this report, the ability of the Salton Sea Management Program to achieve the desired outcomes of its mitigation efforts will be difficult, if not impossible. We therefore recommend that the Salton Sea Management Program set aside a portion of the funding allocated to mitigation efforts for a competitive research program open to researchers from universities, non-profits, and other state agencies so that action may be informed by ongoing and complementary scientific monitoring and inquiry. Moreover, we recommend that the federal government, which owns roughly 40% of lands at the Salton Sea, partner with California to invest in economic and mitigation efforts in the region, also setting aside a portion of funding for the necessary scientific research to make effective investments.

CRISIS AT THE SALTON SEA

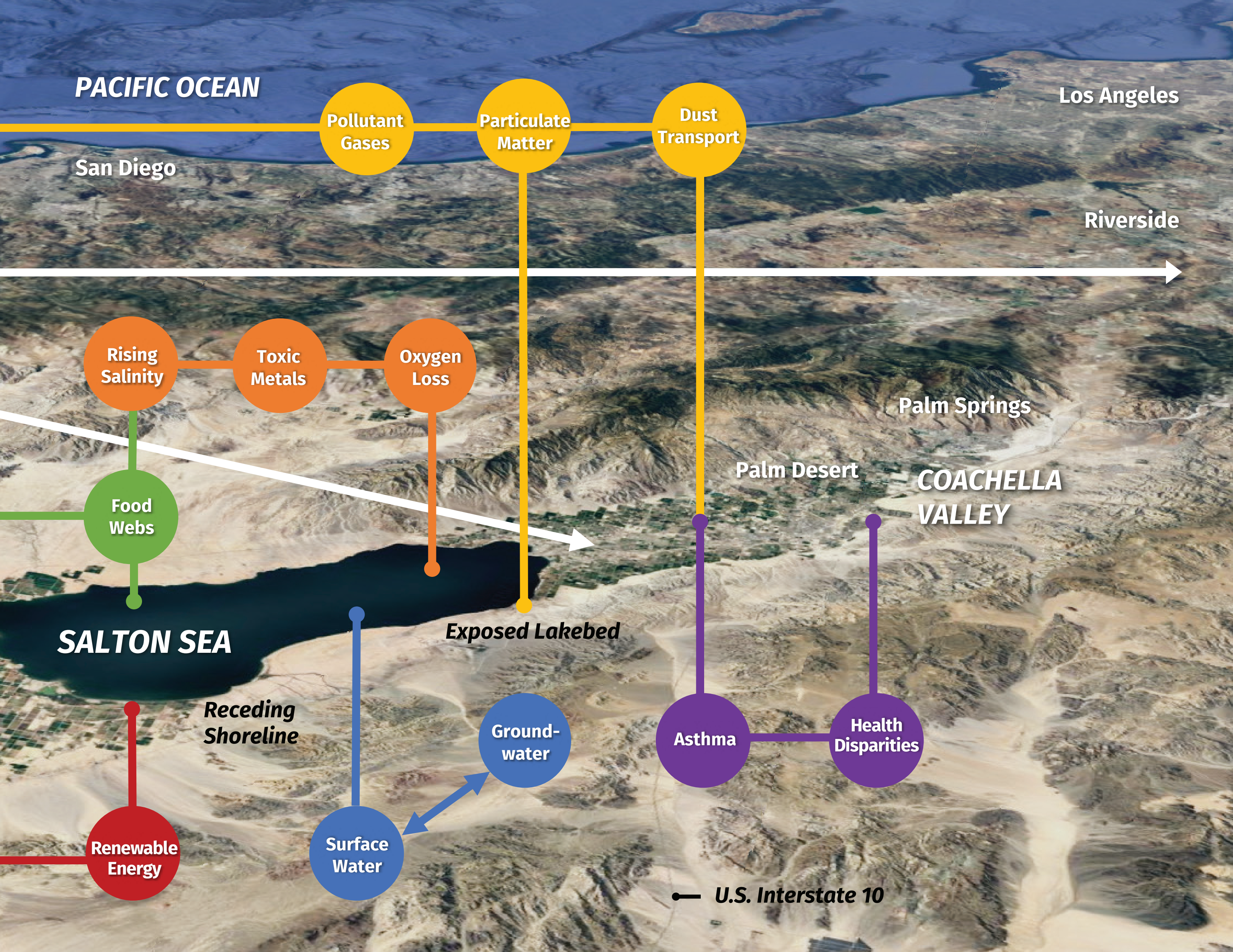
The Vital Role of Science

BASED ON DIVERSE EXPERTISE and first-hand experience in the region, the UC Riverside Salton Sea Task Force identified seven interconnected areas of concern that require immediate scientific research and monitoring investments to ensure the success of planned mitigation activities:

1. WATER POLICY
2. WATERSHED HYDROLOGY
3. WATER QUALITY
4. AIR QUALITY
5. ECOLOGY
6. HUMAN HEALTH
7. GEOTHERMAL RESOURCES



LOOKING WEST across the Salton Basin toward the Pacific Ocean. Credit: Sarah Simpson; BASE MAP: Google Earth



Salton Sea Task Force UC RIVERSIDE

Water Policy 1

A key science need is to determine the optimal lake water level to reduce lakebed dust, maintain wildlife habitat, and improve livelihoods in the region.

The problems facing the Salton Sea are multi-faceted and complex, spanning from ecological and medical concerns to health disparities and economic opportunities. Continued shrinking of the sea exposes dry lakebed that exacerbates windblown dust as aquatic ecosystems crash or disappear. Managing lake levels is challenging in large part because urban water districts in San Diego and Los Angeles compete with agricultural irrigation and natural ecosystems for the same inflows from the Colorado River, which are projected to decline. As the construction of wetland restoration and dust mitigation projects ramps up on the northern and southern shores of the lake in the coming years, it will become increasingly imperative that scientific research and monitoring guides these activities.

2 Watershed Hydrology

A comprehensive assessment of lake-groundwater interactions is needed to explain the underlying causes of significant reductions in Salton Sea volume since 1995.

The Salton Sea watershed is one of the most productive agricultural regions in the United States. With an area of 8,417.4 square miles, this watershed's hydrology is coupled tightly to water imported from the Colorado River, which provided about 1.1 million acre feet per year of water to the lake via irrigated agricultural runoff and subsurface drainage from 1980 to 2018. Despite no substantial decrease in agricultural inflows, lake levels declined significantly from -227.06 feet in 1995 to -236.4 feet in 2018. One possible explanation for this unexpected drop is poorly understood connections among the lake, local groundwater aquifers and subsurface water flows, which have never been evaluated adequately.

The water volume of the Salton Sea is a straightforward difference between inflows and outflows. The Sea's only surface outflow is via well-understood rates of evaporation; inflow is estimated from measured flow rates near the mouths of various rivers. The unknown factor is the dynamics of subsurface water. The model that the Salton Sea Management Program has used to predict lake levels for current management plans assumes constant net groundwater flows into the lake, but it does not consider the possibility that the lake may discharge to groundwater. Accurate predictions of future lake levels require new research to properly quantify all lake-groundwater interactions.

AGRICULTURAL DRAINS (left) entering the Alamo River near its terminus at the Salton Sea. Jonathan Nye

Water Quality 3

Shrinking of the Salton Sea will exacerbate water quality issues as dead zone episodes last longer and the receding shoreline exposes mud that is more highly concentrated in toxic metals and pesticides.

GREEN TIDE from precipitation of gypsum in the warm waters of the Salton Sea in August 2020. Caroline Hung

Changing water chemistry at the Salton Sea is already causing serious perturbations to fish stocks and waterfowl feeding habits. It also makes windblown dust from the dry lakebed increasingly toxic as the Sea recedes. Each summer the deeper waters lose oxygen and accumulate hydrogen sulfide through the activities of algae and bacteria. These dead zone waters mix with the surface layers on windy days, resulting in fish kills and airborne accumulation of foul-smelling hydrogen sulfide. It is likely that these conditions will become longer-lived and more frequent as lake volume decreases. Concentrated in the central portions of the basin, these waters also tend to enrich the underlying sediment in metals far beyond concentrations observed on the lake margin. Molybdenum and selenium, for example, are beneficial at low levels but become health hazards when elevated. Along with pesticides, these metals will likely remobilize to surface waters as the sea recedes and be transported into ambient air as dust from the dried lakebed. It is imperative to monitor the dynamic biogeochemistry of the lake water for patterns of oxygen loss and toxic metal remobilization under different water management strategies.

4 Air Quality

Airborne dust fluxes at sites close to the Salton Sea are already in the high range of values observed at Owens Lake, California, before mitigation began; dust control there has already cost more than $2 billion.

Despite uncertainties in quantifying the impact of the shrinking Salton Sea on local air pollution, measurement and modeling studies suggest that ongoing declines in lake volume will contribute to lower air quality for residents throughout the basin and beyond. A large fraction of the coarse particulate matter captured at sites closest to the shore of the Salton Sea is associated with emissions from the lakebed and sea spray. Pungent and reactive gases are regularly produced in the Sea and emitted to the atmosphere, contributing to noxious odors and formation of fine particulate matter. As the shoreline recedes, harmful algal blooms will likely become more frequent, producing microbial toxins that may become airborne, and newly exposed fumaroles will emit greenhouse gases and ammonia directly to the atmosphere. Worsening air quality will further burden local residents already dealing with disproportionately high levels of ambient particulate matter and related respiratory issues. More research is necessary to fully understand the transport, composition, and health impacts of air pollutants originating from the Salton Sea and its exposed lakebed, and to inform and guide mitigation efforts aimed at improving the health and well-being of local communities.

GYPSUM-LADEN SALT CRUST on the exposed lakebed near Desert Shores. Caroline Hung

Ecology 5

Without significant freshwater introduction to the Salton Sea, the lake ecosystem faces collapse due to excessive nutrients, rising salinity, and declining water levels.

WETLANDS in Unit 2 of the Sonny Bono Salton Sea National Wildlife Refuge. Jonathan Nye

The dynamic and unstable Salton Sea region historically has supported abundant wildlife, ranging from a diverse array of microorganisms to endangered species of fish and birds. Terrestrial desert ecosystems give way to agricultural fields, riparian zones, natural and managed wetlands, and the aquatic ecosystems of the lake itself, which are supported by water and nutrients derived largely from agricultural run-off. Excessive nutrient flows into the Sea result in harmful algal blooms and dead zones, threatening wildlife and humans. Declining lake levels disrupt migration patterns for fish-eating birds and isolate populations of endangered desert pupfish inhabiting the Sea's margins, putting them at increased risk of extinction. The salinity of the Sea—already at 74 parts per thousand, more than double that of the Pacific Ocean—will continue to rise as the Sea shrinks, leading to a catastrophic collapse of the aquatic food web if the current trend is not halted. Planned construction of wetland habitats may benefit certain species of non-fish-eating birds; however, there are currently no official plans to maintain or restore a fully functioning lake ecosystem.

6 Human Health

Respiratory illness and other consequences of the environmental hazards in and around the Salton Sea will likely amplify the region's significant social and economic disparities.

The ongoing crisis at the Salton Sea presents multiple consequences for the region's human residents. In communities already subject to disparities in social and economic status, the environmental hazards of life in the region—particularly increases in windblown dust that are expected as the shrinking sea exposes more dry lakebed—are evident from the epidemiology of diseases, especially pulmonary diseases such as asthma. Co-morbid factors including the high incidence of obesity, poverty, poor access to health care, and chemical exposures from agriculture work further degrade the quality of life, driving additional impacts on mental health in the community. Continued environmental degradation at the Salton Sea accompanied by increased production of dust and other air pollutants has already impaired the economic and social fabric of the region. Health disparities and costs to the community will likely increase unless steps are taken to address the issues raised here.

NORTH SHORE YACHT CLUB, originally built along the shoreline, is now high and dry. Jonathan Nye

Geothermal Resources 7

Economic opportunities for developing non-traditional mineral and energy resources at the Salton Sea could help offset expected environmental and human health costs.

GEOTHERMAL POWER PLANT on the southeastern shore operating in the early morning. Jonathan Nye

The existing renewable electrical generation industry at the Salton Sea Geothermal Field has tremendous potential to become a world-class producer of lithium and other critical metals, which can be extracted from geothermal brines. The industry could also generate nontraditional geothermal energy via production of electricity from pumped storage and by producing hydrogen via electrolysis, thereby boosting California's ability to meet legal mandates to produce more renewable energy while lowering greenhouse gas emissions.

Development of these nontraditional resources together could make expanded geothermal power production at the Salton Sea more competitive with solar and wind power. These efforts would lead to substantial local job creation and increased tax revenues. Multiple benefits would be maximized by coordinating the expansion of geothermal resources with reclamation plans for the Sea, as the receding shoreline opens up new land suitable for construction of both artificial wetlands and new geothermal infrastructure.

SALTON SEA TASK FORCE — ASK THE EXPERTS

WATER POLICY

Water Rights | Water Policy

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Dr. Schwabe's research focuses on economic issues associated with water use, agricultural production, urban water conservation, ecosystem services, and environmental regulation. His papers have appeared in wide range of peer-reviewed publications, including *Nature Sustainability*, *Proceedings of the National Academy of Sciences*, *Journal of Risk and Uncertainty*, *Land Economics*, and the *American Journal of Agricultural Economics*. He is co-editor of two recent books on water: *Drought in Arid and Semi-Arid Regions: A Multi-Disciplinary and Cross-Country Perspective* and *The Handbook of Water Economics*. Dr. Schwabe received a BA in Mathematics and Economics at Macalester College, an MS in Economics at Duke University, and a PhD in Economics at North Carolina State University. Dr. Schwabe also holds appointments as Adjunct Policy Fellow at the Public Policy Institute of California's Water Policy Center and Adjunct Professor in the Center for Global Food and Resources at the University of Adelaide, Australia.

WATERSHED HYDROLOGY

Surface Water | Ground-water

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Dr. Ajami's expertise is in surface water-groundwater interactions, climate change impact assessment, hydrologic modeling, spatial analysis, and remote sensing. She received her PhD in Hydrology from University of Arizona and her BSc and MSc in Natural Resources Engineering (Environmental Sciences) from Isfahan University of Technology and Tehran University, respectively. Prior to joining the faculty at UC Riverside, she was a postdoctoral fellow with the National Centre for Groundwater Research and Training in Australia and a Senior Research Associate in the School of Civil & Environmental Engineering at University of New South Wales, Australia. She received the National Science Foundation CAREER award in Hydrologic Sciences.

WATER QUALITY

Toxic Metals | Oxygen Loss

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Dr. Lyons' primary research interests include geobiology, biogeochemistry, trace metal and isotope cycles and ecological relationships, and co-evolving environments and life. He also currently leads the 'Alternative Earths' team of the NASA Astrobiology Institute and founded the Alternative Earths Astrobiology Center at UC Riverside. Dr. Lyons is a fellow of the Geological Society of America, the American Association for the Advancement of Science, the Geochemical Society, the European Association of Geochemistry, and the American Geophysical Union. He has been honored with visiting professorships throughout the world and is Honorary Professor at the University of St. Andrews. The UC Riverside Academic Senate named him the 2018 Faculty Research Lecturer. Many of his 50 graduate students and postdocs have gone on to professorships around the world. His professional service includes a dozen editorial positions and numerous panels and advisory boards. He holds a BS from the Colorado School of Mines, MS from the University of Arizona, and MPhil and PhD from Yale University.

Toxic Metals | Oxygen Loss

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Ms. Hung specializes in trace elements redox chemistry and cycling in water columns and bottom sediments. She is leading field and laboratory efforts on the Salton Sea to produce data and interpretations for her doctoral thesis, advised by Professor Timothy Lyons. She received her BA in Geosciences and Biology from Williams College in 2019.

AIR QUALITY

Particulate Matter · Pollutant Gases

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Dr. Bahreini specializes in airborne, ground-based, and laboratory measurements of aerosol composition and microphysical properties to understand aerosol sources and formation, influence on air quality, and direct and indirect effects on climate. Dr. Bahreini received her BS in Chemical Engineering from University of Maryland, College Park, and MS and PhD in Environmental Science and Engineering from California Institute of Technology. Before joining the faculty at UC Riverside in 2012, she was a CIRES Visiting Postdoctoral Fellow at University of Colorado-Boulder, a Research Scientist at CIRES and NOAA-ESRL and University of Denver. She is a National Science Foundation CAREER award winner, and in 2014 she received the Thomson Reuters Highly Cited Researchers and The World's Most Influential Scientific Minds awards. In 2019–2020 she served on the Owens Lake Scientific Advisory Panel of the National Academies of Sciences, Engineering, and Medicine.

EXPOSED PLAYA along the Salton Sea shoreline. Jonathan Nye

Dust Transport

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Dr. Porter uses numerical and statistical modeling tools to investigate the causes and consequences of air pollution, with a focus on the impacts of policy and chemistry/climate feedbacks. Dr. Porter received his PhD in Physics at Portland State University before working as a Postdoctoral Associate in the Department of Civil and Environmental Engineering at MIT. As a member of UC Riverside's BREATHE Center, Dr. Porter helps to elucidate the sources, transport patterns, and human health impacts of dust around the shrinking Salton Sea with to equip policymakers and stakeholders with the data and forecasts necessary to make informed decisions and protect local communities.

Bioaerosols · Microbial Toxins

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Dr. Aronson's expertise is the role of soil microbes in ecosystem functions, the dispersal of microorganisms via wind and dust, and the impact of dust microorganisms on human health. She has published more than 30 research papers and is a member of both the Center for Conservation Biology and the BREATHE Center (Bridging Regional Ecology, Aerosolized Toxins, and Health Effects) at UC Riverside. She received her PhD in Biology with a concentration in Ecology and Evolution from the University of Pennsylvania, supported by a Predoctoral Fellowship from NASA, and her BSc in Environmental Sciences from McGill University. Prior to joining the faculty at UC Riverside, she was a NOAA Climate and Global Change Postdoctoral Fellow at UC Irvine. She currently leads a Thematic Cluster as part of the new National Science Foundation Critical Zone Cluster Network.

ECOLOGY

Rising Salinity | Food Webs

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Dr. Fogel uses a wide range of expertise—including biology, chemistry, geology and astrobiology—to study distinctive isotopes of carbon, oxygen, hydrogen, and nitrogen to trace various phenomena tied to fossilized and modern ecosystems. She joined the UC Riverside faculty in 2016 and was Director of the Environmental Dynamics and GeoEcology (EDGE) Institute until her retirement in June 2020. She received her BS in Biology from Pennsylvania State University and a PhD in Botany and Marine Science from the University of Texas at Austin and worked at the Carnegie Institution of Washington's Geophysical Laboratory as a Senior Scientist and Staff Member for more than 35 years. Dr. Fogel is a Fulbright Scholar and a Fellow of the Geochemical Society, the American Association for the Advancement of Science, and the American Geophysical Union. She served as Program Director in Geobiology and Low Temperature Geochemistry with the National Science Foundation. In 2014 Dr. Fogel received the Alfred Treibs Medal in Organic Geochemistry for lifetime achievement in the field. She was elected to the U.S. National Academy of Sciences in 2019.

Rising Salinity | Food Webs

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Dr. Nye's research focuses on ecology and biogeochemistry of ancient and modern food webs. He uses stable isotope systematics to identify dietary changes, nutrient cycling, and energy flow in marine/aquatic organisms and ecosystems. He earned his BS in Earth Sciences and BA in Anthropology at the University of California, Santa Cruz, and his PhD in Geological Sciences at the University of California, Riverside, before studying the Salton Sea as a Postdoctoral Scholar.

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Dr. Jenerette's research focuses on regional ecosystem and biogeochemical dynamics occurring throughout the terrestrial-aquatic continuum in the southwestern United States, and he directs the Center for Conservation Biology at UC Riverside. He uses complementary methods of remote sensing, field experimentation, and in-situ environmental sensing to explore dynamics associated with land use changes, including transitions among wildland, agriculture, and urbanization. Dr. Jenerette is an Associate Editor for several journals, including *Landscape Ecology*, *Science of the Total Environment*, and *Frontiers in Ecology and Evolution*, and he has published more than 100 peer-reviewed articles. He earned a BS in Biology from Virginia Polytechnic and State University and a PhD in Plant Biology from Arizona State University.

HUMAN HEALTH

Asthma | Health Disparities

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Dr. Lo has more than 35 years of experience in molecular and cellular immunology with 162 research publications and several years executive leadership in biotechnology. Holding both a PhD and an MD from the University of Pennsylvania, he was an awardee of the first round of Grand Challenges in Global Health from the Bill and Melinda Gates Foundation and is a Fellow of the American Association for the Advancement of Science. At UC Riverside, Dr. Lo is Founding Director of the BREATHE Center (Bridging Regional Ecology, Aerosolized Toxins, and Health Effects), which focuses on air quality and health, and Co-Director of the Center for Health Disparities Research, a National Institute of Health–funded center supporting training and research on health disparities and community engagement.

GEOTHERMAL RESOURCES

Lithium

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Dr. McKibben is a geochemist and economic geologist who studies natural processes responsible for metal and sulfur transport in modern and ancient hydrothermal and volcanic systems. He first visited the Salton Sea geothermal field as a high school freshman in the late 1960s and has since published extensively on geologic and geochemical aspects of that geothermal area. He received his BSc and MSc degrees from UC Riverside in 1976 and 1979 and his PhD from Pennsylvania State University in 1984. He received the Waldemar Lindgren award for excellence in research from the Society of Economic Geologists in 1989 and has served on their Executive Council and on the Editorial Board of their journal *Economic Geology*. He has also served on the Editorial Board of the Geochemical Society's journal *Geochimica et Cosmochimica Acta*. From 2009–2018 he was Divisional Dean of Student Academic Affairs for the science college at UC Riverside, overseeing 6,000 students in 13 majors.

SNOW GEESE in flight at the Salton Sea. Jonathan Nye

Renewable Energy

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Dr. Elders specializes in the investigation of geothermal resources. He has carried out research on this topic in California, Mexico, Iceland, New Zealand, and Japan, focusing on improving the economics of geothermal energy by producing deeper and hotter resources. From 1983–1988 he was the Chief Scientist of the Salton Sea Scientific Drilling Project, which drilled a 3.1-kilometer-deep borehole that reached temperatures of 365oC. Until his retirement in 2000, he directed the Geothermal Resources Program at UC Riverside and supervised numerous graduate students. He was educated at King's College, University of Durham, England, and the University of Oslo, Norway, and taught at the University of Chicago before joining the faculty at UC Riverside in 1969. In 2016 Dr. Elders received the Pioneer Award of the Geothermal Resources Council, and in 2017 he received a Special Achievement Award from the Geothermal Association of Mexico.

Renewable Energy

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SHOREBIRDS FORAGING near North Shore Yacht Club. Jonathan Nye