Potential Major Greenhouse Gas Emissions From Proposed Salton Sea Long-Range Plans

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Executive Summary

- Exposure of Salton Sea lakebed to the atmosphere and collapse of the lake's ecosystem will likely cause major quantities of greenhouse gases to be emitted to the atmosphere continuously for the foreseeable future unless an appropriate long-range mitigation and restoration plan is implemented.
- Very large amounts of greenhouse gases, including both carbon dioxide and methane, are likely to be emitted on an ongoing basis from various components of some proposed long-range plans for dust mitigation and ecosystem restoration at the Salton Sea.
- Conversely, significant and permanent carbon sequestration would likely be achieved by restoration of an enormous saltwater lake comparable in size, as well as in biological, ecological, and biogeochemical functions, to the late 20th-century Salton Sea. Data from previous studies indicate that such a lake could continuously capture and permanently store huge amounts of carbon.
- It is essential that the Salton Sea Long-Range Planning Committee and other representatives of the State of California assess the potential net carbon emissions associated with each proposed long-range plan for mitigation and restoration, and select a plan that will either be carbon-neutral or, preferably, carbon-negative.
- If a long-range plan for the Salton Sea is chosen and implemented without analyzing the net carbon emissions associated with each plan, and without a selection process committed to choosing a carbon-neutral or carbon-negative plan, there is a major risk that the State of California's actions and omissions will cause the release of very large quantities of greenhouse gases on an ongoing basis for the foreseeable future, prevent California from attaining carbon neutrality, and worsen climate change.

Introduction

No previous evaluation of possible mitigation and restoration activities at the Salton Sea has considered the fact that exposure of Salton Sea lakebed to the atmosphere and collapse of the lake's ecosystem will likely result in major quantities of greenhouse gases (GHGs) being emitted to the atmosphere on an ongoing basis. Moreover, so far there has been no analysis of the potentially significant GHG emissions that will result from implementation of various proposed long-range plans for ecosystem restoration and dust mitigation at the Salton Sea. Such GHG emissions—primarily carbon emissions in the form of carbon dioxide (CO_2) and methane (CH_4)[1]—will come from numerous sources, including: exposed Salton Sea lakebed, areas of exposed lakebed that are periodically rewetted due to natural or man-made causes, dry lakebed sediments that are significantly disturbed and aerated, areas of impounded fresh or low-salinity water on the exposed lakebed, a brine sink on the lakebed, and other components of some proposed long-range plans. Although no scientific quantification has yet been done of the carbon emissions from those specific sources in the Salton Basin, data from recent studies conducted elsewhere indicate such emissions are likely to be very large, and will continue into the indefinite future.

On the other hand, previous studies done in other locations also suggest a refilled Salton Sea that is restored with a highly productive and robustly functioning saltwater ecosystem would be either carbon-neutral or potentially a substantial net carbon sink[2] rather than a net source of significant carbon emissions. Indeed, carefully executed restoration of such a huge saline lake may enable it to provide the immensely valuable ecosystem service of carbon sequestration on a large scale—as the Salton Sea likely did until the recent deterioration of its ecosystem and the increasing exposure and desiccation of its carbon-rich lakebed.

It is well known that shrinkage of the Salton Sea because of freshwater deprivation poses clear and dire threats to the well-being of both people and wildlife. Exposure of a large and increasing area of the Salton Sea's lakebed to the region's strong winds will cause (and is already causing) worsening particulate pollution, danger to public health, and economic harm. In addition, ecological deterioration of the lake toward complete ecosystem collapse (a process that is already well underway) may have devastating effects for numerous wildlife species, including ones that are already endangered or threatened with the possibility of extinction. The serious risks to public health, wildlife, and the regional economy have rightly drawn much attention from the public and policymakers, as have associated issues of environmental injustice. Those consequences of the Salton Sea crisis have been well-elucidated elsewhere (e.g., Cohen, 2014), and I will therefore not discuss them further in detail here—except to point out that if the issues I do discuss are properly addressed through implementation of an appropriate long-range restoration plan, that action would also fully ameliorate the threats to public health, wildlife, and the regional economy that are related to particulate pollution and ecosystem breakdown.

In a recent scientific paper, J. Rockström and colleagues emphasize that "[m]aintaining and enhancing carbon sinks in the biosphere is a prerequisite to hold global warming well below 2°C." (Rockström et al., 2021.) They explain:

> *"For the first time in human history, we face a planetary emergency. Not only have human pressures on Earth reached dangerously high levels, but we see signs that humanity may no longer be able to count on the capacity of the biosphere to continue dampening greenhouse gas emissions and hold onto its carbon stocks.* ***The question therefore is how can we safeguard and***

[1] Nitrous oxide (N_2O), an extremely powerful GHG with a warming potential of approximately 300 times that of carbon dioxide (IPCC, 2021), may also be released and is an additional concern in the Salton Basin. However, because of the paucity of studies on N_2O emissions from lakes and exposed lakebed sediments, and the high complexity and uncertainty of the issues involved, such emissions will not be discussed here.

[2] A carbon sink is a natural or man-made system or device that removes more carbon from the atmosphere than it emits, and that stores the absorbed carbon indefinitely (i.e., sequesters it).

> ***enhance the ecological functions in the living biosphere that regulate its carbon sinks to have a chance of maintaining a stable and manageable planet that can equitably support humanity?"***

At the Salton Sea, the answer to the above question has three components: The State of California must take effective actions to: (1) prevent emissions to the atmosphere of the huge quantities of carbon that were previously sequestered in the Salton Sea's submerged lakebed but are now being released as carbon dioxide and methane[3] from increasingly large areas of exposed lakebed as the Salton Sea shrinks; (2) avoid utilizing Salton Sea mitigation and restoration measures that themselves entail significant, ongoing releases of GHGs; and (3) select and implement a long-range restoration plan for the Salton Sea that is either carbon-neutral or carbon-negative, and includes enhanced carbon sequestration by a restored Salton Sea ecosystem.

Context: The Urgent Need to Reduce Greenhouse Gas Emissions

As a consequence of human-caused emissions of greenhouse gases, the recent global average temperature has increased to approximately 1.2 degrees C above pre-industrial temperatures[4], and widespread harmful repercussions of the resulting global climate change are already adversely affecting ecosystems and the well-being of people around the world. Despite a brief dip in global GHG emissions early in the coronavirus pandemic, and notwithstanding the nascent global effort to utilize renewable energy sources rather than continuing to burn fossil fuels, there has been little progress in slowing the accumulation of GHGs in the atmosphere. Based on current policies, plus countries' announced pledges for emissions reductions through 2030 (which may or may not actually be achieved), the world is still potentially heading for a dangerous temperature rise this century of nearly 3°C. (See, e.g., Climate Action Tracker, 2021; United Nations Environment Programme, 2021.)

If there is to be any hope of limiting the global average temperature increase to "well below 2°C" in order to avert the most hazardous impacts of climate change—as the countries of the world have pledged to do (Paris Agreement, 2015)—new sources of carbon emissions must be avoided, existing carbon sinks must be preserved and enhanced, and carbon neutrality (so-called "net-zero" emissions) must be achieved very rapidly. Moreover, because overshoot of the 2°C goal is becoming increasingly likely despite efforts to curtail emissions, and because even 2°C warming will cause extremely harmful impacts for people and ecosystems, humanity must also strive to develop and implement additional carbon-negative mechanisms—nature-based systems and technological devices—for removing carbon directly from the atmosphere and sequestering it in order to minimize the dangerous effects of climate change.

With the passage of Senate Bill SB-32 in 2016, California committed to reducing the state's greenhouse gas emissions to 40 percent below 1990 levels by 2030[5]. That goal, and the hoped-for attainment of

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[3] Methane is a more powerful GHG than carbon dioxide. The average residence time of CH_4 in the atmosphere is lower than that of CO_2; however, the Global Warming Potential (GWP) of methane is much higher than that of CO_2. The 2021 report of the Intergovernmental Panel on Climate Change (IPCC) states the GWP for CH_4 is approximately 80 times greater than that of CO_2 over a 20-year time-frame, and about 30 times greater when considering its impact over a 100-year time-frame. (IPCC, 2021.)

[4] The 5-year global average temperature increase for 2016-2020 in relation to pre-industrial temperatures was 1.2°C, according to NASA and Copernicus data. https://data.giss.nasa.gov/gistemp/tabledata_v4/GLB.Ts+dSST.txt and https://climate.copernicus.eu/climate-indicators/temperature.

[5] California Senate Bill SB-32 (2016), The California Global Warming Solutions Act of 2006, as amended in 2016. This statute added Section 38566 et seq. to the California Health and Safety Code, relating to greenhouse gases.

carbon neutrality statewide by 2045 and net-negative emissions thereafter[6], cannot be achieved if existing carbon sinks in California are lost or if there are significant new sources of GHGs in the state. But collapse of the Salton Sea ecosystem likely represents the loss of an important carbon sink, and the exposure to the atmosphere of increasingly large expanses of the Salton Sea's carbon-rich lakebed likely constitutes the addition of a major new source of carbon emissions in California.

Based on relevant studies conducted elsewhere, it is reasonable to suspect that the GHG emissions resulting from the collapse of the Salton Sea ecosystem and major shrinkage of the lake will be so large that California's attainment of the state's emissions-reduction goals could be thwarted. At a minimum, if those emissions are not prevented through implementation of an appropriate long-range restoration plan that is either carbon-neutral or carbon-negative, it should be anticipated that they will be large enough to warrant accounting and require offset into the indefinite future in order for California to attain and maintain carbon neutrality. But the major offset mechanisms necessary for genuinely counteracting such large carbon emissions on an ongoing basis may not actually be available[7], in which case California would be left with huge amounts of unmitigated GHGs being emitted continuously for the foreseeable future. That is precisely the type of situation that California and the world must avoid if there is to be any real possibility of solving the climate crisis.

Carbon Processing and Sequestration in the Late 20th-Century Salton Sea

The late 20th-century Salton Sea was an extraordinarily productive saltwater ecosystem that sustained a gargantuan biomass of algae, invertebrates, and fish. Because of ongoing input of nutrients via agricultural drainwater, the eutrophic nature of the vast lake enabled huge quantities of algae to grow. The algae continuously absorbed immense amounts of carbon dioxide from the atmosphere, and transformed it into carbon-based plant matter. In turn, countless invertebrates and hundreds of millions of fish (including algae-eating tilapia that were uniquely adapted to thrive in the Salton Sea[8]) constantly consumed enormous quantities of algae, and the carbon held within those plants became incorporated into the bodies of the fish and invertebrates. Then the carbon was transferred to the bottom of the lake in the animals' waste products and in their bodies when they died. The carbon-rich organic material that reached the bottom of the Salton Sea was broken down by microorganisms in the submerged sediments, and the carbon became buried in the lakebed. In this way, the Salton Sea ecosystem functioned as a natural carbon-capture-and-storage system: On an ongoing basis, a huge amount of carbon was removed from the atmosphere, conveyed through the food web to the Salton Sea's sediments, and sequestered in the submerged lakebed. Although there also may have been some carbon emissions from the lake, data from

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[6] California Executive Order B-55-18 to Achieve Carbon Neutrality (10 September 2018).

[7] In order to attain carbon neutrality, major emitters—including government entities—anticipate having enormous carbon removal and sequestration capacities available for their use in offsetting future emissions. However, research indicates expectations for the availability of many extremely large, permanent carbon sinks are likely to prove grossly unrealistic. For example, Oxfam has calculated that the total amount of land required for planned carbon removal could potentially be five times the size of India, or the equivalent of all the farmland on the planet. (Oxfam, 2021; see also Stabinsky and Dooley, 2021.) Moreover, the actual climate benefit of some credited carbon offsets may be significantly exaggerated. For example, a comprehensive evaluation of California's forest carbon offsets program found it "creates incentives to generate offset credits that do not reflect real climate benefits." (Badgley et al., 2021.)

[8] The Salton Sea's fish population also includes the desert pupfish, an endangered omnivore that eats algae and a variety of other foods, such as invertebrates and detritus.

studies conducted elsewhere indicate that overall the Salton Sea ecosystem was either carbon-neutral or, more likely, a significant net carbon sink because of its specific characteristics.[9]

Research Findings on Carbon Emissions from Lakes and Dry Lakebeds

Inland waters—including lentic types (still waters such as lakes, ponds, marshes, and man-made reservoirs) and lotic ones (actively moving waters such as rivers and streams)—are an important part of the global carbon cycle, serving both to emit and to sequester carbon. Quantification of net carbon emissions from inland waters is a relatively new scientific endeavor with important implications for regional and global carbon budgets, and for attempts to mitigate anthropogenic climate change by limiting emissions of greenhouse gases. (Clow et al., 2015; Raymond et al., 2013.)

In the 21st century, many inland waters are becoming partially or completely desiccated, intermittently or permanently, as a consequence of anthropogenic climate change, diversion and consumptive use of freshwater resources, and other human-caused modifications of waterbodies and the hydrological cycle. The areas of shrinking lakes, ponds, marshes, reservoirs, rivers, and streams where previously submerged sediments are exposed to the atmosphere are referred to in the scientific literature as "dry inland waters."[10] (Keller et al., 2020; Marcé et al., 2019.) When the sediments of inland waters become partially or completely desiccated, the carbon stores held in those sediments may be released to the atmosphere as greenhouse gas emissions. (See, e.g., Paranaíba et al., 2022; Keller et al., 2020; Marcé et al., 2019; Kosten et al., 2018; Obrador et al., 2018; Jin et al., 2016; Fromin et al., 2010.) Recently it has become apparent that dry inland waters may be significant sources of GHGs that have not been adequately considered in regional or global accounting of current and future carbon emissions. (Keller et al., 2020.) Although studies of the carbon emissions from temporarily and permanently desiccated sediments of a variety of inland waters have been conducted during the past two decades, detailed information on the gaseous carbon fluxes from various types of dry lentic systems in particular remains limited.

The importance of carbon fluxes in terrestrial and aquatic ecosystems has been the focus of increased attention by policymakers in recent years. In 2007 the U.S. Congress recognized the need for further research on carbon cycling by passing legislation that included a requirement for both terrestrial and aquatic ecosystems in the U.S. to be assessed for GHG emissions and carbon storage.[11] The Energy Independence and Security Act of 2007 required the Secretary of the Interior to: "(1) determine the processes that control the flux of covered greenhouse gases[12] in and out of each ecosystem; (2) estimate the potential for increasing carbon sequestration in natural and managed ecosystems through management

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[9] For example, preliminary data from a pending study at the Great Salt Lake—which may be a less productive and less complex ecosystem than the late 20th-century Salton Sea—indicate that the Utah waterbody has net CO_2 emissions near zero, or possibly net-negative emissions. (S. Brothers, personal communication, October 2021.) The published findings of other relevant studies are discussed below.

[10] "Dry inland waters" have been defined scientifically as "the areas of lotic and lentic aquatic ecosystems on the Earth's land masses where surface water is absent, and sediments are exposed to the atmosphere." (Keller et al., 2020; Marcé et al., 2019.)

[11] Although the term "ecosystem" was defined in the statute to include "freshwater aquatic" systems and "estuaries" as well as other types of ecosystems, brackish or saline lakes were not explicitly included in the definition. This appears to have been an inadvertent omission rather than an intentional exclusion of such waterbodies.

[12] The greenhouse gases covered by the statute are carbon dioxide, methane, and nitrous oxide.

activities or restoration activities in each ecosystem; (3) develop near-term and long-range adaptation strategies or mitigation strategies that can be employed— (A) to enhance the sequestration of carbon in each ecosystem; (B) to reduce emissions of covered greenhouse gases from ecosystems; and (C) to adapt to climate change; and (4) estimate the annual carbon sequestration capacity of ecosystems under a range of policies in support of management activities to optimize sequestration." (EISA 2007, Section 712(c).)

At the Salton Sea, there has been no quantification of net GHG emissions from any mitigation or restoration measures in use or proposed to be used, or from the lack of implementation of such measures. However, data from previous studies are highly relevant to understanding potential net carbon emissions at the Salton Sea. Of particular pertinence are data concerning the emissive tendencies of different types of lentic waterbodies, the characteristics of dry inland waters that are most likely to result in high GHG emissions, and the potential for carbon sequestration in lentic systems. The following findings from prior studies are especially important for evaluating potential GHG emissions, as well as possible carbon sequestration, resulting from the implementation of various proposed long-range plans at the Salton Sea, and from failure to implement an appropriate plan:

- **Elevated GHG emissions are an intrinsic characteristic of exposed lake sediments.** (Paranaíba et al., 2022; Keller et al., 2020; Marcé et al., 2019.) Multiple studies have measured **high CO_2 emission rates from drying and desiccated sediments of various types of shrinking lentic inland waters**, **including exposed sediments of lakes, ponds, and reservoirs.** (See, e.g., Kosten et al., 2018; Obrador et al., 2018; Jin et al., 2016; Catalan et al., 2014; Fromin et al., 2010; Koschorreck, 2000.) A new study has also found that **all types of dry inland waters—including dry sediments of lakes, ponds, and reservoirs** in all climate zones—**have high CH_4 emission rates**. (Paranaíba et al., 2022.)

- A study that evaluated 196 dry inland waters globally across diverse ecosystem types and climate zones (Keller et al., 2020) concluded that **CO_2 emissions from exposed lakebeds were significantly higher than from the lakes themselves**: "All studied lentic ecosystem types (i.e. reservoirs, lakes and ponds) showed higher CO_2 emissions from dry sediments than globally estimated for their inundated stages." Specifically, the study found that **"[m]easured CO_2 emissions from dry inland waters to the atmosphere were an order of magnitude higher than average water surface emissions** (water-to-atmosphere) previously reported for lentic waters…"

- "**CO_2 emissions from dry inland waters share fundamental drivers across diverse ecosystem types and climate zones**…" (Keller et al., 2020.) This comprehensive study found **the strongest individual predictors of very high CO_2 fluxes from dry inland waters** were: (1) high organic matter content, (2) presence of some moisture, and (3) elevated temperatures. Moreover, the researchers determined that the combination of high organic matter content and the presence of some moisture constituted the strongest predictor of very large CO_2 fluxes from dry inland waters, which they attributed to greater microbial activity in the presence of those factors.

- **Portions of inland waters that have become dry and then are rewetted** as the result of a variety of natural and human-caused processes **have been documented to be major emitters of GHGs** to the atmosphere during both rewetting and drying periods, because of changes in microbial processes. (Paranaiba et al., 2020; Marcé et al., 2019; Kosten et al., 2018; Camacho et al., 2017; Jin et al., 2016; Catalán et al., 2014; Fenner and Freeman, 2011; Fromin et al., 2010.)

- **Significant disturbance of exposed dry lakebed increases GHG emissions** by increasing the sediment-atmosphere interface and oxygenating the sediments. Oxygenation of carbon-rich sediments through recurrent disturbance tends to cause renewed microbial activity and significant associated pulses of elevated gaseous carbon fluxes. (See, e.g., Fenner and Freeman, 2011.)

- **Smaller and shallower lakes, ponds, and impoundments** are considered potential hotspots of carbon cycling, and have been documented to **emit GHGs to the atmosphere at a much higher rate than large lakes**. (See, e.g., Obrador et al., 2018; Holgerson and Raymond, 2016; Downing, 2010.) "Small ponds tend to have higher concentrations of both CO_2 and CH_4 than larger lakes… Very small ponds can have exceptionally high CO_2 and CH_4 concentrations." (Holgerson and Raymond, 2016, and references cited therein.) Larger lakes tend to have much lower CH_4 emissions than smaller lakes (Bastviken et al., 2004), and "**the smallest lakes are responsible for the highest emission**" (Rosentreter et al., 2021). High carbon emissions from small lentic systems "probably result from shallow waters, high sediment and edge-to-water volume ratios, and frequent mixing. These attributes increase CO_2 and CH_4 supersaturation in the water and limit efficient methane oxidation." (Holgerson and Raymond, 2016.) Ebullition (bubbling) is a primary pathway by which CH_4 is released directly to the atmosphere from shallow ponds and lakes, and as the result of either natural or man-made drawdown in the volume of initially larger waterbodies, in part because of low hydrostatic pressure on shallow sediments. (Beaulieu et al., 2018; Bastviken et al., 2008; Bastviken et al., 2004.) In addition, CH_4 produced in shallow sediments largely avoids oxidation by methanotrophic bacteria and escapes to the atmosphere. (Bastviken et al., 2008.) **In bigger and deeper lakes**, particularly ones that tend to be persistently stratified[13], **gaseous carbon is more likely to be broken down** by biological and biogeochemical processes in the water column and sediments **before it can reach the lake surface and be emitted to the atmosphere**. (Zimmerman et al., 2021; Holgerson and Raymond, 2016; Bastviken et al., 2004; Joye et al., 1999; Segers, 1998.)

- **Production and emission of GHGs tend to be lower in lakes that are more saline**.[14] For example, in comparison to freshwater lakes and lentic waterbodies of low-to-medium salinity, hypersaline lakes (ones that are saltier than the ocean) release methane at significantly lower rates. (Camacho et al., 2017; Segers, 1998.) **Hypersaline lakes have been determined to have methane emission rates that were an order of magnitude less than the average CH_4 emission rates from freshwater and low-salinity lakes.** (Camacho et al., 2017.) However, a limit for emission reduction is eventually reached at some point after a lake becomes hypersaline, so that additional increases in salinity do not result in further decreases in GHG emissions. (Camacho et al., 2017.)

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[13] The Salton Sea tends to be stratified for a large portion of the year. (See, e.g., Watts et al., 2001.)

[14] Although one early study of CO_2 emissions from saline lakes found they play a major role in global carbon cycling and have a higher gas exchange rate than freshwater lakes (Duarte et al., 2008), that study has been criticized because few measurements were made of actual CO_2 emissions from any of the lakes involved. (S. Brothers, personal communication, October 2021.) The study's conclusions were drawn based on indirect calculations of emissions using other types of published data. Moreover, the study did not differentiate among different types of saline lakes based on their specific characteristics, or evaluate the extent to which particular characteristics either enhanced or limited emissions for individual lakes.

- **Extreme hypersalinity in brine sinks and industrial salt-production ponds is associated with high methane emissions.** In extraordinarily hypersaline waterbodies such as brine sinks and industrial salt-production ponds, the activities of halophilic methanogenic (i.e., CH_4-producing) archaea and other salt-loving microbes, and the occurrence of various biogeochemical processes that result in methanogenesis, are associated with significantly heightened methane production and high rates of CH_4 emission to the atmosphere. (Zhou et al., 2022; Obrador et al., 2018.)

- **Highly productive eutrophic lakes**[15] **have been documented to have elevated carbon sequestration rates** that are nearly an order of magnitude greater than oligotrophic lakes (waterbodies that have relatively low productivity because of low nutrient content and low biological activity). (Downing, 2010; see also Anderson et al., 2014; Anderson et al., 2013; Heathcote and Downing, 2012; Einsele et al., 2001.) **High carbon burial rates are strongly correlated with extensive agricultural land cover in the lake's catchment area**, indicating that high nutrient input is associated with elevated carbon sequestration in lakebed sediments. (Anderson et al., 2013.) Primary production by algae and carbon storage in both biota and sediments are especially great in nutrient-enriched eutrophic lakes. In such lakes the water tends to be depleted in CO_2, atmospheric carbon therefore diffuses readily into surface waters, and **biological and biogeochemical processes in the water and sediments enable such waterbodies to function as net carbon sinks**. (See, e.g., Heathcote and Downing, 2012; Schindler et al., 1997.) Nutrient-rich saline lakes tend to be extremely productive (Hammer, 1981); and **hypersaline, highly productive, endorheic lakes**[16] may be particularly effective at accumulating carbon in their sediments. (See, e.g., Jellison et al., 1996.) **Higher temperatures and drier climate** are also factors associated with greater carbon burial rates in lakes and reservoirs. (Mendonça et al., 2017; Clow et al., 2015.)

Potential Major GHG Emissions from Proposed Salton Sea Long-Range Plans

Application of the above research findings to the components of possible long-range mitigation and restoration measures at the Salton Sea yields significant reasons for concern about potentially large, ongoing net GHG emissions from implementation of many proposals. With the exception of plans involving water importation to refill the Salton Sea[17] and restore a productive, robustly functioning saltwater ecosystem, all other proposed plans include key components that will likely be major net sources of CO_2 and CH_4 emissions to the atmosphere for the foreseeable future. For example[18]:

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[15] The Salton Sea is a highly productive eutrophic lake. It has major input of nutrients, largely from agricultural drainwater. Consequently, prior to the recent decline of the lake's ecosystem, the Salton Sea had an extraordinarily large population of algae-eating tilapia because of very high algal biomass. (See, e.g., Holdren and Montaño, 2002.)

[16] The Salton Sea is a highly productive, hypersaline endorheic lake. (See, e.g., Holdren and Montaño, 2002.)

[17] The phrase "refill the Salton Sea" as used herein refers to the use of imported water (typically ocean water, pursuant to most proposals) to supplement the lake's volume and increase its surface elevation to approximately -226 feet below sea level, where it was relatively stable from the late 20th century to the beginning of the 21st century prior to subsequent out-of-basin water transfers that affected the lake's water supply.

[18] This itemization is not intended to be an exhaustive analysis of the potential carbon emissions associated with all aspects of all proposed long-term mitigation and restoration measures.

- **Very large areas of exposed lakebed:** All proposals for long-range mitigation and restoration other than water importation plans that will refill the Salton Sea will involve permanent exposure of very large areas of Salton Sea lakebed. Yet studies indicate that these vast expanses of drying, desiccated, and periodically rewetted lakebed sediments will likely be sources of extremely high GHG emissions. All of the factors that prior studies have found to be the strongest predictors of the highest CO_2 and CH_4 emissions from dry inland waters are characteristics of the Salton Sea's exposed lakebed. The eutrophic lake's sediments are loaded with immense quantities of organic material as a result of the Salton Sea's extraordinary productivity, large areas of the exposed lakebed are frequently dampened by moisture from various sources, and the entire region is subjected to high temperatures annually for lengthy periods. Therefore, pursuant to all long-range mitigation and restoration proposals other than water importation plans that will refill the Salton Sea, it appears likely that very large areas of the Salton Sea's exposed lakebed will emit massive amounts of CO_2, and potentially also CH_4, on an ongoing basis for the foreseeable future.

- **Frequent, significant disturbance of lakebed sediments:** The important role that greater oxygenation of disturbed dry sediments plays in spurring increased CO_2 production rates and emissions indicates that any significant disturbance of the Salton Sea's dry lakebed that causes more exposure of sediments to the atmosphere—such as excavation and movement of sediments, creation and ongoing maintenance of deep furrows on the exposed lakebed for dust control, surface roughening for dust control, and the construction and ongoing maintenance of impoundment berms, levees, and dirt roads on the exposed lakebed—will increase sediment exposure and oxygenation, and thereby exacerbate CO_2 emissions.

- **Periodic rewetting of large areas of exposed lakebed:** Based on research findings that rewetted dry inland waters are major emitters of GHGs, as well as the conclusion that the combination of high organic matter content plus the presence of moisture is the strongest predictor of very large gaseous carbon fluxes, it is likely that periodically rewetted areas of the exposed Salton Sea lakebed will have extremely high GHG emissions, regardless of the causes of rewetting. For example, natural dampening of exposed lakebed by rain or by shallow groundwater that is raised to or near the surface via capillary action, blowing of Salton Sea water onto portions of the exposed sediments during wind events, and variable movements of irrigation drainwater and tributary water across the exposed lakebed would all serve to create conditions likely to yield very high CO_2 emissions, and potentially CH_4 emissions, from increased microbial activity in the moistened, organic-rich sediments. Similarly, dust mitigation measures such as periodic intentional dampening of exposed lakebed sediments or the addition of water into dust-control furrows are also likely to result in rapid, significant, repeated pulses of GHG production and emissions due to stimulation of microbial activity in the sediments.

- **Small areas of shallow ponded water on portions of the exposed lakebed:** Some restoration plans call for the construction and maintenance of relatively small, shallow impoundments on portions of the Salton Sea lakebed to be used as habitat for wildlife. Based on findings in multiple studies that smaller and shallower lakes, ponds, and impoundments emit GHGs to the atmosphere at significantly higher rates than large lakes, it appears likely that such proposed impoundments will be strong emitters of large quantities of GHGs—both carbon dioxide and methane.

- **Large areas of ponded water on portions of the exposed lakebed:** Some restoration plans call for the construction and maintenance of large areas of ponded water on portions of the exposed lakebed that would capture flow from tributary rivers and discharge water to a brine sink. The proposed impoundments would either hold fresh water or water of low salinity. Studies have found that freshwater and low-salinity lentic systems typically have significantly higher carbon emissions than ones that are mesosaline or hypersaline, so these impoundments could be major sources of GHG emissions. In addition, because of the structure, characteristics, and anticipated recreational use of these impoundments, they may be unlikely to host highly productive, fully-functioning ecosystems with multiple trophic levels that are capable of capturing and sequestering large quantities of carbon. Therefore it appears unlikely such impoundments will be carbon-neutral or achieve net carbon sequestration; instead they are likely to be net emitters of greenhouse gases.

- **Extremely hypersaline brine sink(s):** The exceedingly hypersaline brine sink(s) that will be part of some proposed long-range plans will support halophilic microbes, but will be too salty to sustain an ecosystem with multiple trophic levels capable of capturing and sequestering large amounts of carbon. In addition, the elevated temperatures in these shallow waterbodies, the activities of methanogenic archaea and other microorganisms, and the occurrence of various biogeochemical processes that result in net methanogenesis would collectively be likely to yield a very high rate of methane production and major CH_4 emissions to the atmosphere on an ongoing basis.

On the other hand, based on available research data from previous studies, water importation proposals that entail refilling the Salton Sea and restoring its ecosystem would be unlikely to result in net GHG emissions; rather, the lake created by such projects would likely be either carbon-neutral or carbon-negative. If properly implemented, a plan of this type could restore a highly productive and robustly functioning saline lake ecosystem that would serve to draw down immense quantities of CO_2 from the atmosphere on an ongoing basis, incorporate that carbon into biota and sediments, and permanently sequester it in the lakebed. In fact, a refilled and restored Salton Sea could be specifically designed to function ecologically as a major carbon-capture-and-storage system, providing the enormously valuable ecosystem service of significant, ongoing, long-range carbon sequestration—while simultaneously providing crucial wildlife habitat, comprehensive and permanent suppression of lakebed dust, and excellent recreational and economic opportunities.

Quantification of Net Carbon Emissions from Proposed Long-Range Plans

As part of the cost-benefit analysis to be conducted for the purpose of selecting a long-range plan to address the Salton Sea crisis, the Long-Range Planning Committee and other representatives of the State of California should evaluate the potential net GHG emissions associated with all mitigation and restoration components of each proposed long-range plan. Carbon emissions from existing relevant sources should be measured; carbon emissions from potential future sources should be estimated based on the characteristics of those sources and GHG emissivity described in scientific studies of analogous sources at other locations.[19]

[19] In addition, in some cases focused experiments might enable the development of quantitative data on carbon emissions from and/or carbon sequestration by some components of proposed long-term plans.

The components of proposed long-range plans evaluated for their net GHG emissivity should include, but not be limited to, the following:

- **Permanently or intermittently exposed areas of Salton Sea lakebed.**
- **Periodically rewetted areas of exposed Salton Sea lakebed.**
- **Exposed sediments of the lakebed that are significantly disturbed**.
- **Small areas of shallow ponded water of varying salinity on portions of the exposed lakebed.** This category includes, but is not limited to: (a) freshwater or low-salinity impoundments and wetlands constructed on the Salton Sea lakebed to function as shallow habitat for wildlife; (b) dust-mitigation furrows and other low areas on the exposed lakebed where water naturally ponds or wets the sediments because of an elevated water table, or as the result of rain, or because of flooding from adjacent streams or wetlands; and (c) dust-mitigation furrows into which water is added for enhanced dust control.
- **Large areas of ponded freshwater or low-salinity water on portions of the exposed lakebed.** This category includes, but is not limited to, the proposed "Perimeter Lake" and "North Lake."
- **Any extremely hypersaline brine sink(s).**
- **A refilled Salton Sea that is biologically and ecologically restored.** This waterbody, proposed to be created by some water importation proposals, would be a highly productive saltwater lake comparable in size, as well as in biological, ecological, and biogeochemical functions, to the lake that existed in the late 20^{th}-century. The net GHG emissions of such a refilled Salton Sea would include carbon emissions to the atmosphere from the lake, if any, as well as negative emissions resulting from capture of atmospheric carbon by biota and in lake water, and carbon sequestration in the submerged lakebed.

Conclusion

If a long-range plan for ecosystem restoration and dust mitigation at the Salton Sea is selected and implemented without an analysis of the net carbon emissions associated with its components, there is a significant risk that the State of California's actions and omissions will release large quantities of greenhouse gases on an ongoing basis, prevent California from attaining carbon neutrality, and worsen climate change. Therefore, in evaluating proposed long-range options for mitigation and restoration, it is essential that the Long-Range Planning Committee and other representatives of the State of California assess the potential carbon emissions associated with each suggested approach to addressing the problems at the Salton Sea.

In particular, it is crucial for GHG emissions to be taken into account when comparing the costs and benefits of proposed plans to refill the Salton Sea and reestablish its robust ecosystem with the costs and benefits of other possible restoration options that will entail permanent exposure of very large areas of dry and intermittently rewetted lakebed, involve the construction and maintenance of water impoundments on portions of the lakebed, require significant and ongoing disturbance of exposed lakebed sediments, and include the permanent presence of one or more extremely hypersaline brine sinks on or adjacent to the lakebed.

Based on available scientific data, it appears that refilling the Salton Sea to its late 20^{th}-century level and reestablishing a productive ecosystem that stores carbon permanently in the submerged lakebed may be the only long-range approach that will not only enhance public health, protect wildlife, support recreation, and contribute to a vigorous regional economy, but—crucially—will also avoid major, ongoing releases of greenhouse gases to the atmosphere. In fact, if carefully implemented, such a restoration plan could achieve carbon sequestration on a very large scale and enable California to make a significant contribution toward solving the climate crisis.

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