California Rice

ENVIRONMENTAL SUSTAINABILITY REPORT

OCTOBER **2016**

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California Rice Commission

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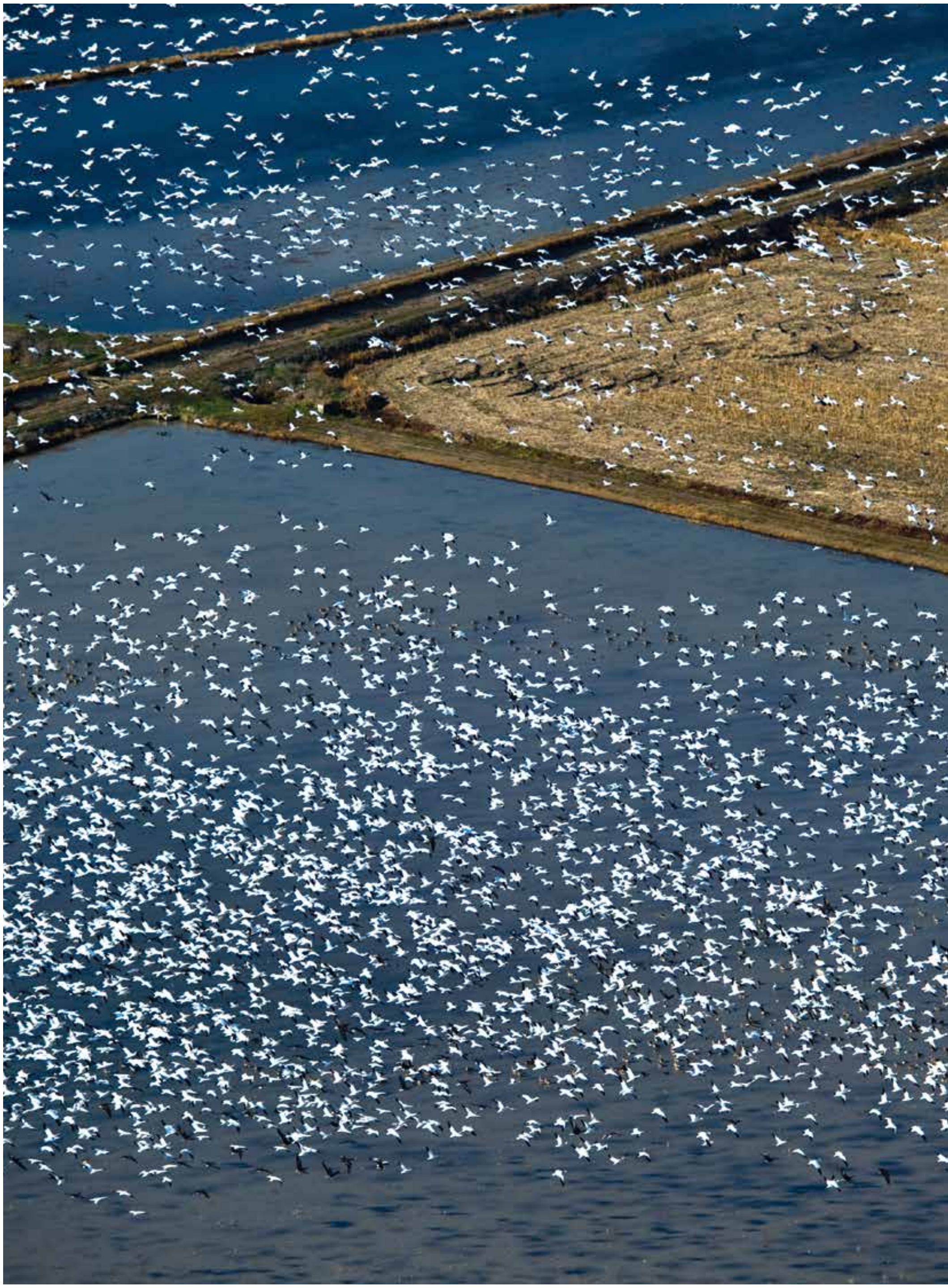


Introduction

OVERVIEW

Agriculture in the 21st century faces the challenge of increasing food production in order to maintain adequate supplies for a growing world population while trying to improve overall environmental and social outcomes. A sustainable agriculture meets current and future societal needs by enhancing farm productivity while minimizing environmental impact, benefiting human health by supplying safe, affordable, nutritious food and fostering the economic viability of rural communities. The California rice industry's sustainability goal is to make the most efficient use of resources, to ensure long-term productivity from the land, and utilize management practices to continue to enhance the environmental and societal benefits of rice production.

A CLOSER LOOK

In order to look more closely at historical performance of the California rice industry towards this goal, some indicator metrics need to be developed. A range of performance metrics related to agricultural sustainability is being discussed at the national level and they relate to environmental, social, economic, and safety outcomes from the agricultural enterprise. This report looks at environmental indicator metrics important to agricultural production including land use, soil loss, water use, water quality, air quality, energy use, climate impact, and biodiversity. Each metric represents an important component of maintaining the overall environmental sustainability of the agricultural enterprise and there are often conflicts and trade-offs between these outcomes. A simple example is a grower using an additional fertilizer pass to increase land use productivity will likely increase energy use and air quality emissions.

MEASUREMENT

The land use metric is primarily related to the amount of land dedicated to the farming enterprise and the productivity of that land. The soil loss metric quantifies erosion and depletion of topsoil which has critically impaired certain agricultural regions of the world. Water use relates to the amount of water required per unit of food produced with the goal of minimizing this often-scarce input. Water Quality indicators attempt to quantify the water pollution impact of the agricultural activity. The air quality metric is an assessment of the regional air pollution impact of the agricultural activity. Energy use is an estimate of the total energy required per unit of food produced, often from fossil fuel resources. Climate Impact is the amount of greenhouse gasses emitted by the agricultural activity. The biodiversity metric is an assessment of the ability of the agricultural land to also provide habitat for native wildlife species.

OUR PROGRESS

The California rice industry has been significantly focused on improving its environmental performance for the last three decades. Much of this has been self-generated from the grower community to increase productivity, reduce inputs, and improve waterfowl and shorebird habitat while some has been related to implementation of stringent local regulatory requirements. The following sections look at each environmental metric category in more detail as related to the California rice industry and presents analysis of how the performance has changed over the last thirty years, from 1985 to 2015, in each critical area.

Land Use

22%

California experienced a 22 percent increase in rice yields between 1985 and 2015.

IDEAL SOIL

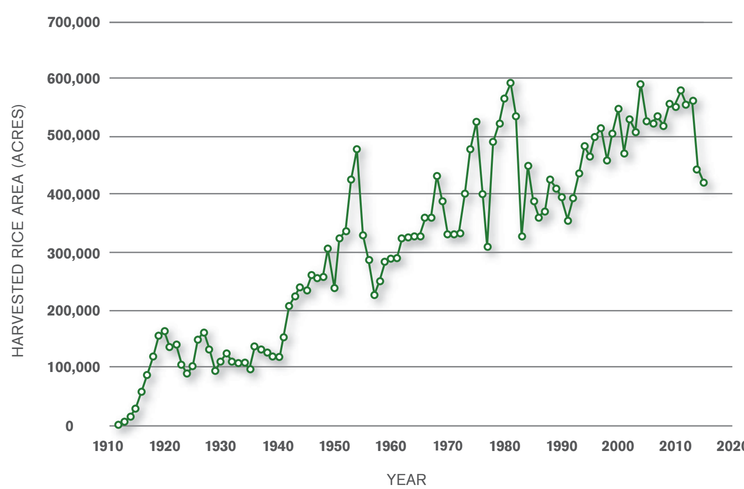
Most of the land currently dedicated to rice production in the Sacramento Valley is unsuitable for other crops because of poor drainage and the tendency for the soils to become saline when not flooded. In contrast, this land is ideal for rice production, producing the world's highest rice crop yields. Rice farming is therefore a productive land use. Further, the compatibility of rice fields with other environmental roles that this land must play, including the provision of high-quality wildlife habitat, makes rice production an attractive land use relative to other options.

COMMERCIAL RICE

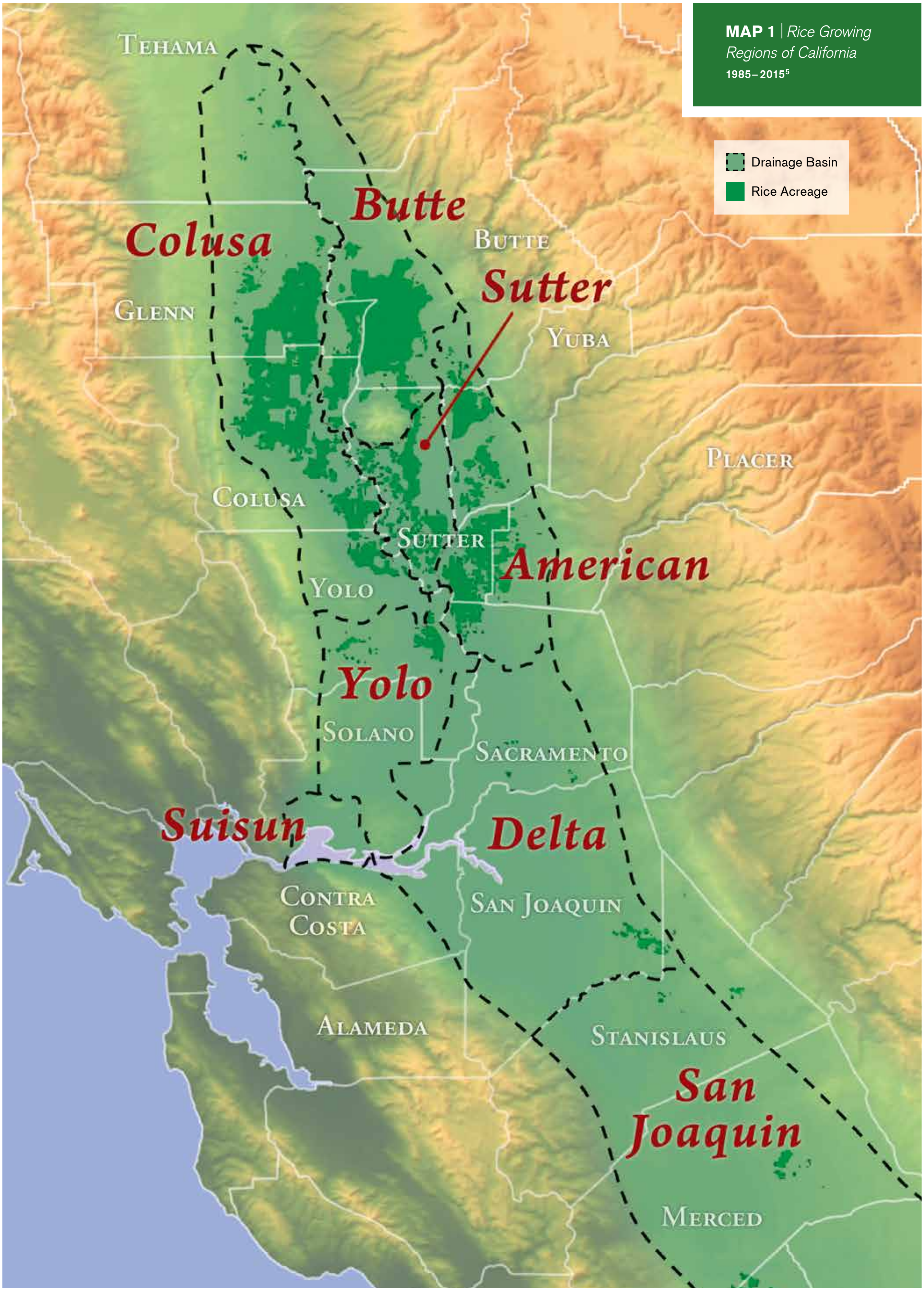
In California, commercial rice was planted on about 100,000 to 150,000 acres from 1920 to 1940.[1] With the onset of World War II, rice production acreage increased and eventually expanded to a peak of about 608,000 acres in 1981.[2] With substantial drops in the mid 1980s and early 1990s (because of changing market conditions), the acreage has stabilized today to between 400,000 to 600,000 acres. Most of this land is in the Sacramento Valley, as illustrated in Map 1 with the historical acreage shown in Figure 1. California's Mediterranean climate of warm and dry with clear days and a long growing season is ideal for rice production.

The expanding need to conserve water has driven California's rice production to acreage with poor drainage that is generally unsuitable for other crops. California rice is grown on heavy clay soils of river valley floors and on eroded terrace soils on the Valley's rim.[3] These soils restrict deep percolation, which greatly reduces the amount of water that must be applied to produce a rice crop.

FIGURE 1 | *Planted Rice Acreage in California* **1910–2015**[4]



MAP 1 | *Rice Growing Regions of California* 1985–2015[5]



LAND USE *(Continued)*

RICE YIELDS

Rice yields have changed significantly since it was first grown in California.[6] From 1910 to 1955, average rice yields were between 2,500 and 3,500 pounds per acre. Between 1955 and 1980, there was a relatively steady rate of increase, approximately 150 pounds per acre each year. This was due to several technological and cultural improvements including improved mechanization, fertilization, weed control, and semi-dwarf rice variety development. Yields are currently averaging about 8,900 pounds per acre, up from about 7,300 pounds per acre in 1985 as shown in Figure 2. This makes California the most productive rice-growing region in the world. California rice producers continue to lead the world and the United States in land productivity as illustrated in Figure 3. On average, the world experienced a 40 percent increase in rice yields between 1985 and 2015 while California experienced a 22 percent increase over the same time period. However the net increase in California of nearly 1,600 pounds per acre exceeded the world increase of 1,200 pounds per acre.

FIGURE 2 | *Average Rice Yield Per Planted Acre* **1912–2015**[7]

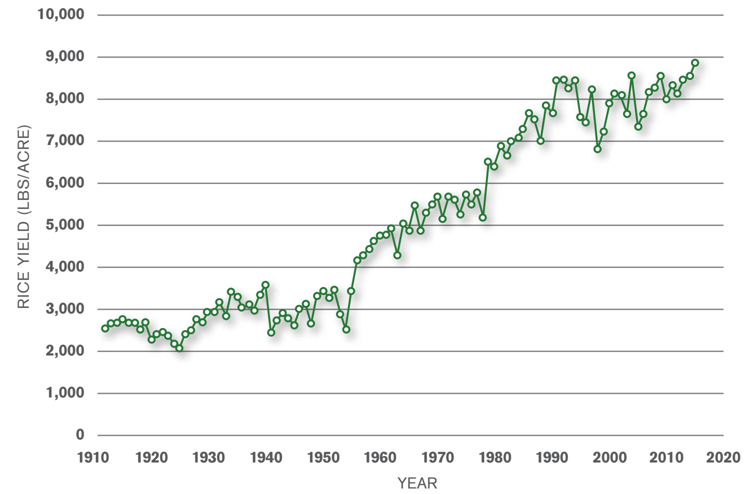
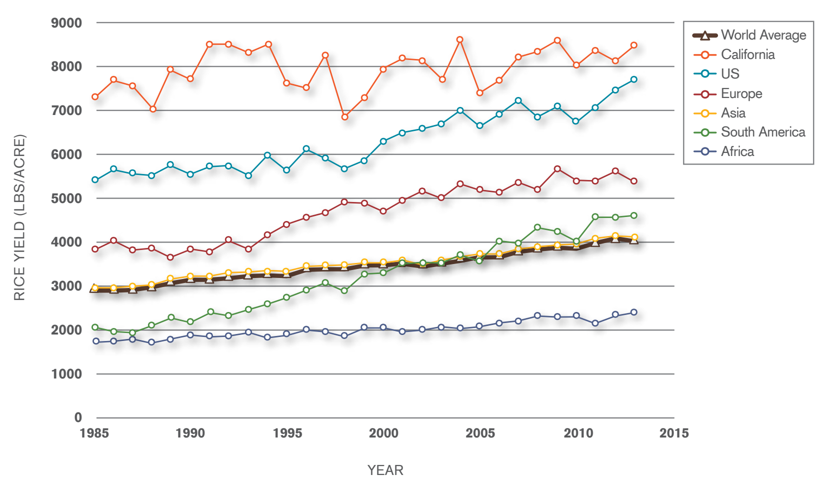


FIGURE 3 | *California Rice Yield Compared to US and World* **1985–2013**[8]



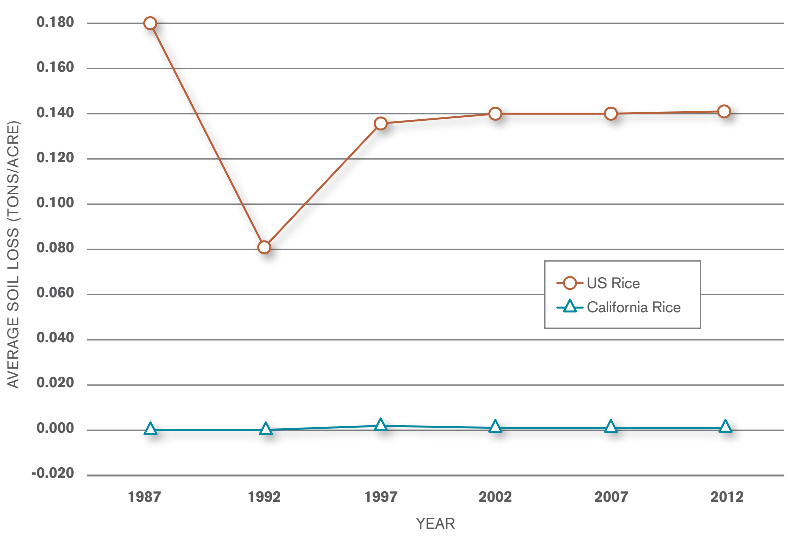
Soil loss is not a critical concern in California rice production because of the heavy soils and irrigation and cultural practices.

Soil Loss

SOIL LOSS

Soil loss is not a critical concern in California rice production because of the heavy soils and irrigation and cultural practices. The dense stand of rice stems and associated root structure hold the soil and the very slow flow of flood irrigation water do not tend to suspend sediment. Sediment in the tailwater from rice fields has not been a concern. Wind erosion is not typically an issue either for the same reasons. However, a discussion on agricultural sustainability would not be complete without an assessment of soil loss because it is an important worldwide concern. The National Resource Conservation Service performs a National Resource Inventory that estimates soil loss from all agricultural land. Figure 5 shows the reported values for soil loss for California rice lands between 1985 and 2015. As can be seen, the soil loss levels for California are very small compared with the average soil loss in US rice production. Soil loss is not significant in the rice cropping practices used in California.

FIGURE 4 | *Soil Loss for California and US Rice Production* **1987–2012**[9]



Opposite page, left: High-yielding rice variety developed through plant breeding programs funded by growers.

Opposite page, right: A typical view of flooded rice fields from an airplane in the Sacramento Valley.

Above, top: A cage roller dragged through a flooded rice field to promote rice straw decomposition and waterbird habitat while reducing dependence on open-field burning.

Above, bottom: A laser-guided leveling operation that gently moves soil to level the fields and save on water use.

Water Use

20%

Compared to 30 years ago, rice farmers are using 20 percent less water to grow almost 25 percent more rice.

IRRIGATION OF RICE

Irrigation of rice is necessary in California because of the dry conditions during the growing season. Because rice is an aquatic plant, continuous flooding is the most productive method of irrigation. This technique also effectively enhances weed control and minimizes the need for herbicides and additional fertilizers. Based on the estimated rice acreage of 500,000 acres and an average applied rate of 4.5 acre-feet per acre, approximately 2.25 million acre-feet of water is used to irrigate California's rice crop annually.[10] Based on rice crop coefficients developed by the UC Davis Cooperative Extension and using satellite imagery, rice evapotranspiration is about 2.8 acre-feet per acre per year,[11] which leaves about 1.7 acre-feet that either is returned to water resource system or percolates to groundwater. Most of the unused water that flows out of rice fields (tailwater) is used by other downstream users and the environment.[12] The water not used by other croplands generally flows back into the rivers and wetlands. In fact, 57 percent of the managed wetlands in the Sacramento Valley use tailwater from the Valley's rice fields.[13] In either case, this supply is used by downstream water users or the environment and therefore is beneficially used. Additionally, rice growers have steadily improved water use efficiency with practices including land leveling, recirculation systems, the use of early maturing varieties, and the development of water-conserving irrigation systems.

INCREASE IN PRODUCTIVITY

During the same period in which productivity has increased, water use per acre has declined significantly.[14] Data from district-wide deliveries to rice fields in the Glenn-Colusa Irrigation District shows water application averaged about 6.5 acre-feet per acre during the 1960s. The district wide average for the next two decades was about 6.0 acre-feet per acre. In the 1990s, the average has been estimated to be about 5.2 acre-feet per acre.[15] On a statewide basis, the level has continued to drop to about 4.5 acre-feet per acre according to the USDA's Farm and Ranch Irrigation Survey. Figure 5 shows water use per acre of California rice over the last 30 years and Figure 6 shows the amount used per ton of rice produced. As compared to 30 years ago, rice farmers are using 20 percent less water to grow almost 25 percent more rice. This 35 percent increase in water use efficiency is comparable with the increases for all US rice production.

FIGURE 5 | *Water Use per Acre of California Rice* **1985–2013**[16]

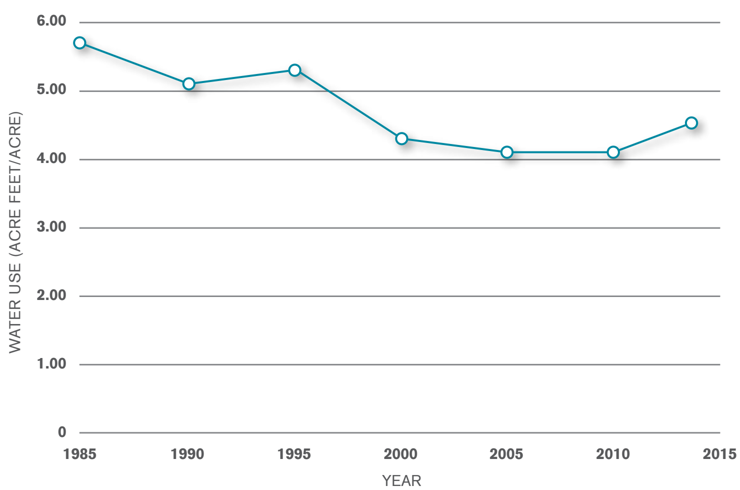
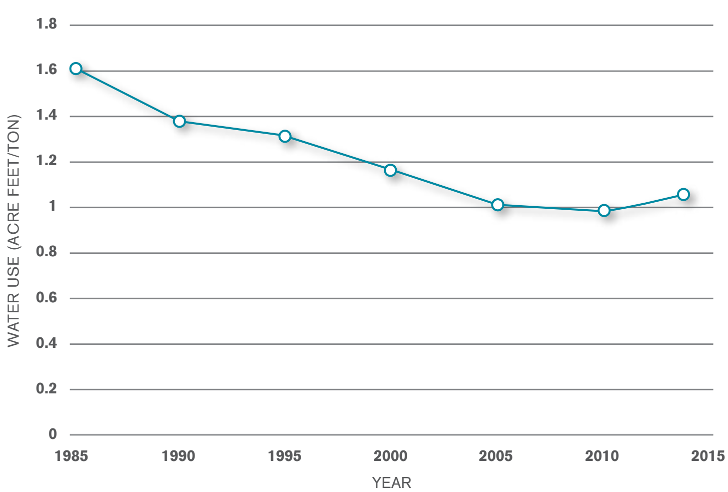


FIGURE 6 | *Water Use per Unit of California Rice Production* **1985—2013**[17]



Below: A screw gate used by farmers to control water movement through water supply/drainage ditches.

Bottom: Iconic view of a Tundra Swan, one of nearly 230 wildlife species known to use California rice fields.

WATER QUALITY

Above: Typical view of water flowing from rice fields to other downstream uses, including wetlands. Not all water is "consumed" by the rice cultivation processes.

Top of page: A converted tractor, with steel wheels, allows growers to apply herbicide by ground that are otherwise prohibited from use. This technique allows growers to use an effective product to maximize rice yields, while protecting the environment and complying with regulatory requirements.

25%

The use of "Reduced Risk" formulations in California rice is on the rise, constituting about 25 percent of total pesticide applications today.

UNIQUE IRRIGATION PROCESSES

Because rice is farmed in fields flooded with shallow water, the importance of good farming practices to water quality is evident. However, water quality problems associated with other crops and locales, such as soil erosion and sediment transport, saline drainage waters, and high concentrations of trace elements in subsurface drainage, are typically not a problem with rice farming because of the slow continuous rate of flow through rice fields and the controlled rate of water release. Trace elements and salts are typically low in the soils and the water released from rice fields.

COLLABORATION

In the late-1970s, the rice industry identified negative impacts of two rice herbicides reaching high detection levels in the drains. Studies began to identify the environmental impact of these herbicides and the flow of rice field drainage. Through the collaboration of regulatory agencies, the University of California, the rice industry and its growers, water holding requirements went into effect to degrade all pesticides to acceptable levels before discharge from a field, thus mitigating any negative impacts.

REDUCED PESTICIDE IMPACT

The major potential water quality challenge for rice farmers is the need to achieve acceptably low pesticide and herbicide concentrations in return flow, which is a problem shared with other sectors of agriculture. Pest management by rice farmers has had to include management practices such as water holding requirements to increase pesticide efficacy, allowing pesticide degradation to an acceptable level before release from the fields, and achieving applicable water quality performance goals for select products as set by the State of California's regional water quality regulators. The Rice Pesticides Program, a collaborative effort of the rice growers, registrants, applicators, and regulators,[18] has resulted in large reductions in the concentrations of pesticides within major agricultural drains and the Sacramento River of the rice production area. Figures 7 and 8 shows the reductions in the maximum concentrations of the two historical compounds from the Rice Pesticides Program (thiobencarb and molinate) during the period of 1986–2015 in the Colusa Drain and Butte Slough.[19] Concentrations of these compounds in the Sacramento River have fallen to non-detectable levels over the same time period. From 2009 through the present time, thiobencarb is the

remaining pesticide covered by the Rice Pesticides Program.

IRRIGATED LANDS REGULATORY PROGRAM

Agriculture in the Central Valley Region of the Regional Water Quality Control Board was regulated for surface water quality through a conditional monitoring and reporting program, the Irrigated Lands Regulatory Program (ILRP). Permanent regulation is in place with the Long-term ILRP implemented as Waste Discharge Requirements (WDR) Order. Rice is the only commodity group to so manage the comprehensive water quality program. Lessons learned from the Rice Pesticides Program have built the foundation for commodity specific WDR, which resulted in continual outstanding performance of this program.

REDUCED RISK PRODUCTS

Another encouraging development in the Water Quality area is that the use of U.S. Environmental Protection Agency (U.S. EPA) designated "Reduced Risk" formulations in California rice is on the rise, constituting about 25 percent of total pesticide applications today (Figure 9). These products have gone through a rigorous risk assessment to demonstrate a low impact to the humans and the environment.[20] This trend is expected to continue as these products are shown to be effective and as more products are subjected to the U.S. EPA criteria for this designation.

FIGURE 7 | *Maximum annual detected concentrations of Thiobencarb in Butte Slough (BS1) and Colusa Basin Drain (CBD5) monitoring sites* **1986—2015**[21]

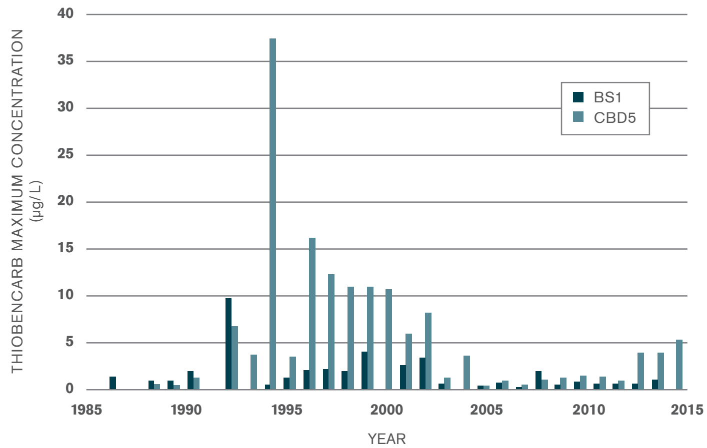


FIGURE 8 | *Maximum annual detected concentrations of Molinate in Butte Slough (BS1) and Colusa Basin Drain (CBD5) monitoring sites* **1986—2015**[22]

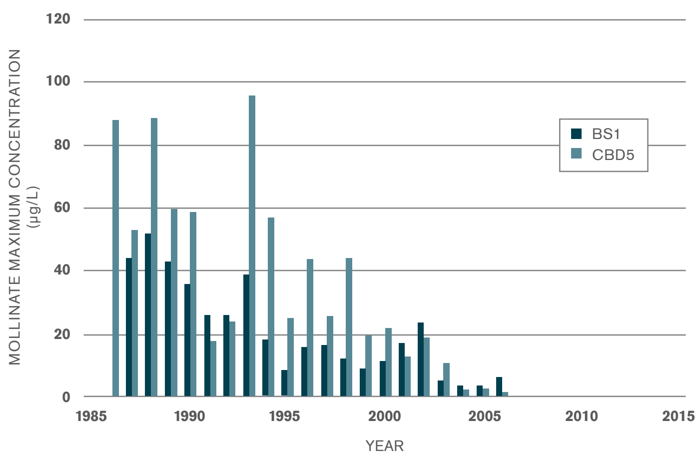
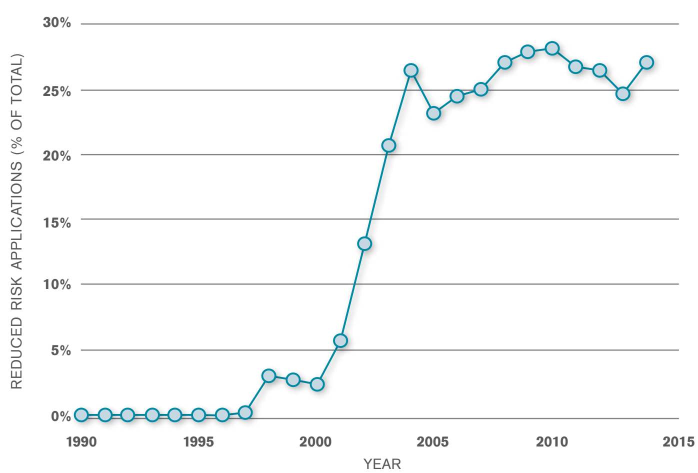


FIGURE 9 | *Application of U.S. EPA designated Reduced Risk Pesticides on California Rice* **1990—2015**[23]



Air Quality

85%

The major air pollutants of regulatory concern have all been reduced by 80–90 percent over the past 30 years.

RICE STRAW MANAGEMENT

Traditionally, rice fields were burned after harvest to dispose of the left over straw and to control disease and pest problems that can carry over between crops. Crop burning can be an effective tool that is used for a number of orchard and field crops. Unfortunately, the burning also produces many pollutants, impacting the air quality of the Central Valley region during burn season. The rice industry worked with the State Legislature on the passage of a program to significantly reduce the practice of rice burning between 1990 and 2000 to address air quality concerns. This left rice growers to find alternative ways to manage the rice straw that remains after harvest.

Three primary ways of managing rice straw in the post-burn era are: (1) incorporation of the straw into the soil coupled with active winter flooding, (2) straw incorporation without active winter flooding, or (3) harvesting the rice straw for use in other industries. Figure 10 shows the percentage reduction in burned acres and increase in the use of other practices that occurred between 1990 and 2000, primarily driven by the phase-down legislation.

POLLUTANT REDUCTION

The emission of regional air pollutants from rice has been significantly reduced from 1985 to 2015. An estimate of air pollution impact from rice production includes the emissions from open

FIGURE 10 | *Straw Management Practices in California Rice* **1985—2015**[24]

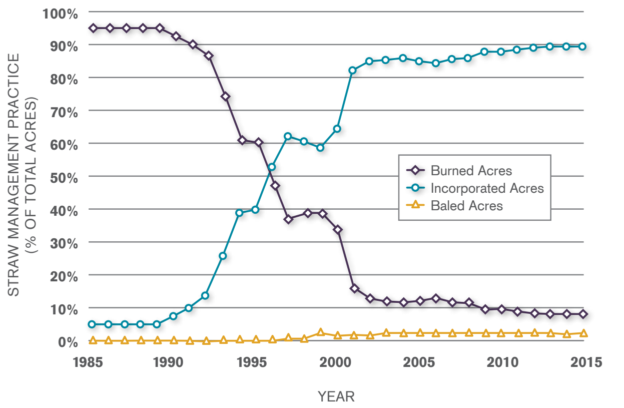
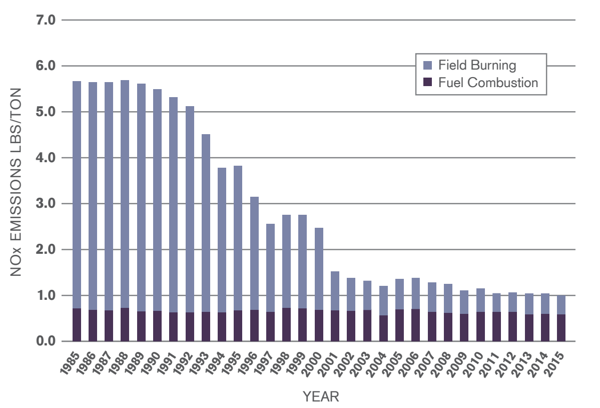


FIGURE 11 | *NOx Emissions from California Rice Production* **1985—2015**[25]



burning of rice as well as emissions from fuel combustion in equipment used to grow, transport, and process the rice. The emissions from uncontrolled burning dominate these other sources of emissions. Figures 11–13 show the overall reduction levels for criteria pollutants including NOx (oxides of nitrogen, ozone and particulate precursor), VOC (volatile organic compounds, ozone precursor), and PM (particulate matter, direct pollutant) per unit of rice production over the 30-year time period. These pollutants have all been reduced by 80-90 percent in the last 30 years.

MINIMIZING SMOKE IMPACT

The rice industry also partners with state and local air officials to manage the very limited amount of disease-control rice straw burning (8-10 percent, year over year). One of the underpinnings of this nationally-recognized effort, called the Sacramento Valley Smoke Management Program, is a network of approximately 13 weather monitoring stations that are owned and operated by the California rice industry. Data from this system, shared with both state and local air officials, is critically important in determining the temporal and spatial distribution of all Sacramento Valley agricultural burning that is required in order to minimize smoke impacts on neighboring urban areas. The California rice industry has provided the funding to build this system and pays for the annual costs to operate and maintain the network.

Top, left: A rice straw baling operation. This straw will be utilized off-field for beneficial uses such as erosion control or cattle feed.

Above: A typical view of rice straw being decomposed in the winter season with the help of winter-flooding.

FIGURE 12 | *VOC Emissions from California Rice Production* **1985—2015**[26]

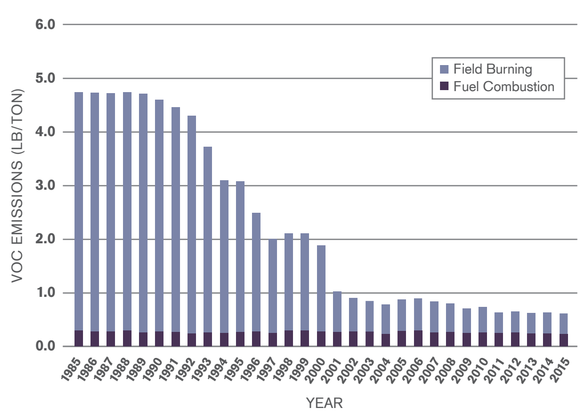
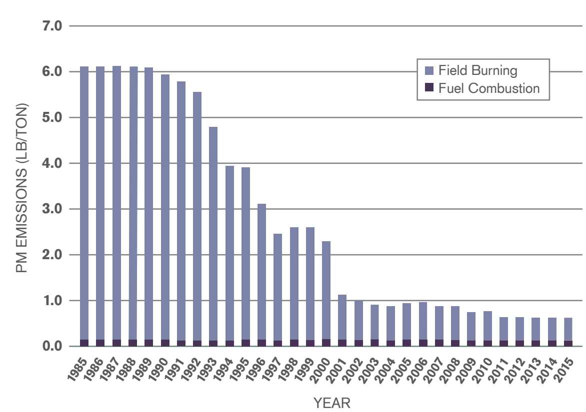


FIGURE 13 | *PM Emissions from California Rice Production* **1985—2015**[27]



Energy Use

20%

The amount of energy used to produce rice has been reduced by 20 percent over the past 30 years.

LOWER ENERGY INPUTS

Energy use per acre of rice production has also been reduced over the last 30 years. In 1981, a study of California agriculture performed a detailed analysis of the amount of energy required to produce California rice and determined that it requires about 15 million BTU of energy to grow and process an acre of rice which included the diesel fuel, gasoline, aviation fuel, natural gas, electricity, and the energy embodied in the fertilizer and other chemicals.[28] This represents a primary energy ratio of 29% for an acre of rice produced in 1980. In other words, it took 29 units of primary energy (fuel and electricity) to produce 100 units of food energy in the form of rice or an energy gain of 71 units.

IMPROVING EFFICIENCY

Over the last 30 years, efficiency improvements in equipment and changes in other rice specific practices have had an impact on the amount of energy required for rice production. Some of the major energy impacts include the following:[29]

- Improved diesel engine and equipment efficiency in farm equipment and trucking has reduced diesel fuel consumption
- The number of aircraft passes for product applications has been reduced
- Use of fewer, larger airplanes has reduced aviation fuel consumption
- Use of stripper headers on some rice acres has increased harvest speed and reduced fuel consumption
- Use of equipment for incorporating rice has increased the number of field passes and diesel fuel consumption over open-burning
- Reduced grain moisture at harvest from early maturing varieties has reduced the amount of energy required for drying
- The location of mills is now closer to where rice is grown which reduces the trucking of rough rice

USAGE PROJECTIONS

Taking into account these changes, Figure 14 shows the change in the estimated primary energy used for rice production from 1985 to 2015. It can be seen that the primary energy ratio for rice has been reduced from 26 percent to 21 percent over the last 30 years, a 20 percent reduction. Diesel fuel, fertilizer, pesticides and electricity are the largest primary energy components in rice production and each has been reduced by about 20 percent over the last 30 years. Aviation fuel and natural gas usage have achieved greater reductions on the order of 60 percent and 30 percent, respectively, over the last 30 years, but they do not account for a very large portion of the overall energy input.

MAJOR BIOMASS FACILITY

Another energy sustainability development that occurred in the time period from 1985 to 2015 was the development of the Wadham Energy biomass facility in Williams, California that uses rice hulls as a renewable fuel to produce electricity. The plant was constructed in 1989 and is rated at 26.5 Megawatts producing over 200 million kilowatt-hours per year from 200,000 tons per year of rice hulls.[30] This plant uses about 50 percent of the rice hulls produced by the rice industry to produce an equivalent amount of electricity to that required for all of rice production operations. This form of biomass power is an example of how agriculture can improve its energy footprint, by using byproducts for energy production.

In the future, there is the potential that additional rice hulls or rice straw can also be used for energy production in California.

SOLAR PROJECTS

There has been a recent increasing trend for rice drying and milling operations in California to install solar energy projects to generate energy on-site. This trend has resulted in 16 projects installed on nearly 100 acres of land adjacent to rice facilities. By 2015, the total installed capacity of these projects was about 11 Megawatts capable of generating about 22 million kilowatt-hours of solar power annually.[31] This is equivalent to about 30 percent of the electricity used for drying and milling of California rice.[32] This is a trend that will likely continue to increase over the next decade.

Above: Increasingly common scenes of solar panels put in place to harvest more solar power at rice processing facilities.

Below: Wadham Energy Plant, near Williams, which creates renewable energy from about half of the rice hulls produced in California.

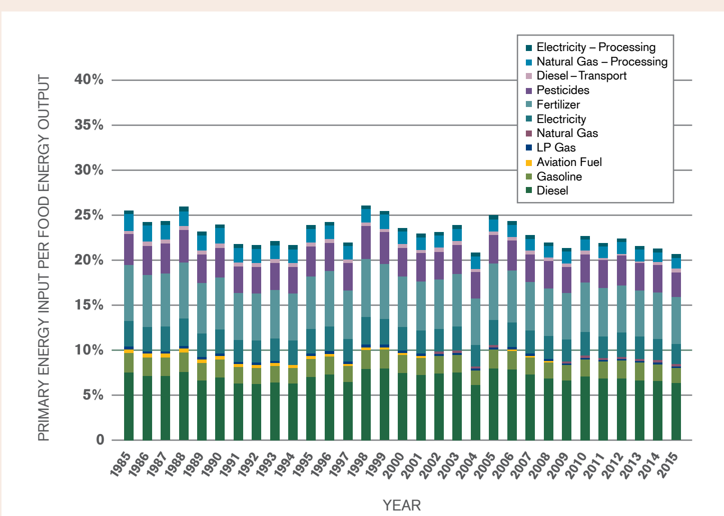


FIGURE 14 | *Primary Energy Required for Rice Production in California*
1985—2015

Climate Impact

0.2%

The amount of greenhouse gas emissions from rice cultivation in California is only two-tenths of one percent (0.2%) of statewide greenhouse gas emissions.

CARBON BENEFITS SOIL

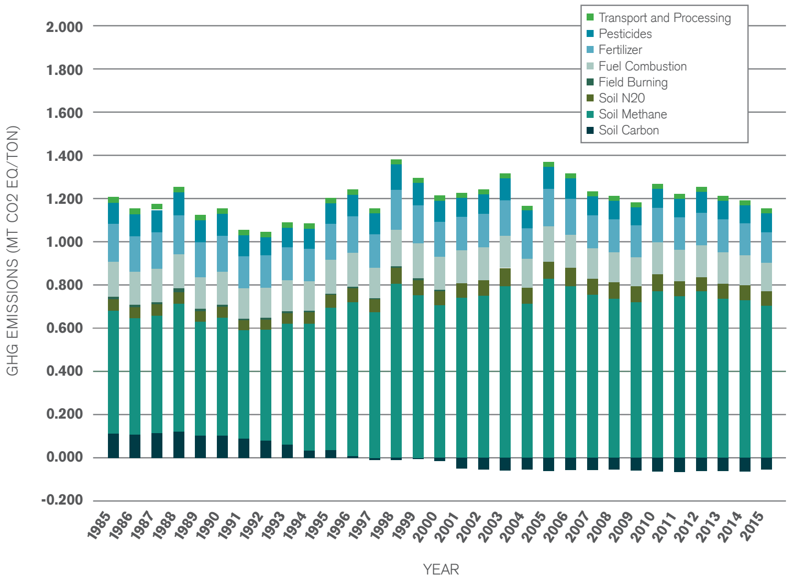
The production of rice in California generates greenhouse gasses in the form of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Carbon dioxide comes from the combustion of fossil fuels in the equipment that is used for producing, transporting, and drying the rice crop. Methane and nitrous oxide come from the soil activity and methane in particular is the largest contributor to greenhouse gas emissions from rice production. Management practices (along with soil type, climate and other factors) have an impact on the amount of emissions of methane. Unfortunately, the incorporation of rice straw that has delivered benefits to regional air quality and waterfowl habitat has resulted in an increase in methane emissions from rice fields. The additional straw provides carbon in the soil that is converted in anaerobically to methane during the growing season when fields are flooded. A benefit of the additional carbon from the straw being incorporated is that a portion of it is stored in the rice soils reversing a long-term trend of carbon depletion.

Above, left and right: Two scenes from a recent project to study possible ways to reduce the small amount of greenhouse gas emissions from California rice fields.

LOW AMOUNT OF TOTAL EMISSIONS

Figure 15 shows the changes in greenhouse gas emissions from rice production in California between 1985 and 2015. It can be seen that there is no net decrease in greenhouse gas impact per unit of rice production in spite of improved yields over the time period. This can be largely attributed to the increased practice of incorporating rice straw, the only viable practice for rice straw disposal on about 75 to 85 percent of rice acres. This alternative practice has increased soil methane emissions from an acre of rice by about half a metric ton of CO2 equivalents per year out of a total of about three metric tons.[33] This is the direct result of a legislatively mandated reduction in rice straw burning causing a sharp increase in the amount of rice straw decomposed in rice fields. This is one of the finest examples of solving one environmental objective only to realize a negative impact on another. However, even with this increase in emissions from moving to non-burning rice straw management alternatives, the amount of greenhouse gas emissions from rice cultivation in California is only two-tenths of one percent (0.2%) of statewide greenhouse gas emissions.[34]

FIGURE 15 | *Climate Impact from California Rice Production* **1985—2015**[35]



BIODIVERSITY

60%

California rice fields provide nearly 60 percent of the food resources consumed by wintering waterfowl in the Sacramento Valley.

SURROGATE WETLANDS

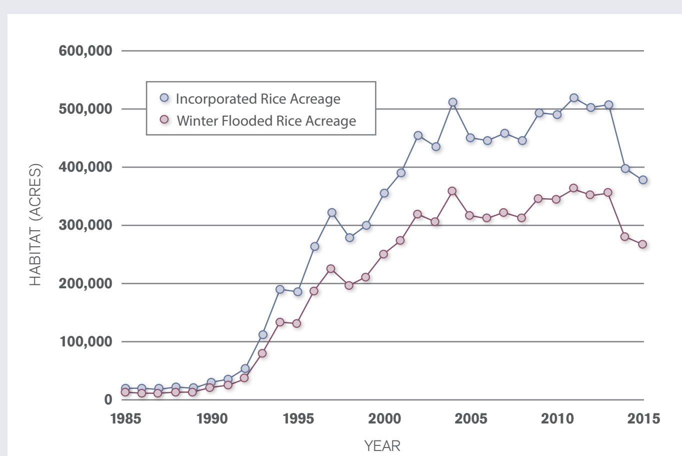
Traditional wetlands have decreased over the years in California due to agricultural and urban development. Historically in the Central Valley, four million acres were available as wetland habitat for various species of waterfowl and shorebirds.[36] Today only 205,000 acres of Central Valley wetlands remain.[37] Because air quality concerns have pushed rice growing practices towards winter flooding, this helped to create new fall and winter wetland habitat for native species. Studies have been done to show that flooded rice fields serve as surrogate wetlands, providing similar habitat benefits[38] and supplying about two-thirds of the food value provided by managed wetlands.[39] The increase in functional wetlands provided by California rice production can be quantified by looking at the increase in winter-flooded fields in rice (Figure 16). The amount of habitat provided by California rice production is on the order of half a million acres. With the majority of these acres flooded in the winter, they provide nearly 60 percent of the food resources consumed by wintering waterfowl in the Sacramento Valley.[40]

HABITAT VALUE

Here are a few more points that help to illustrate the significance of the habitat value provided by California rice fields:

- Sixty percent of all the food consumed by wintering waterfowl in the Sacramento Valley comes directly from rice fields—providing sustenance for approximately 2.5 million of the 5 million ducks using the Pacific Flyway, a critical migration route.

Figure 16 | *Increase in Waterfowl Habitat on California Rice Fields* **1985–2015**



- If winter-flooded rice acres were lost, an estimated 235,000 acres of new wetland habitat would need to be acquired and restored to support same populations of wintering waterfowl in California's Sacramento Valley—at an initial capital cost of approximately $1.5 billion, plus $30 million per year in wetland maintenance costs.[41]
- Approximately 40,000 acres of Sacramento Valley wetlands rely upon rice drain water to maintain their valuable wetland habitat. The increased cost to deliver water to these critical wetlands, if available, could cost as much as $5 million per year or even more if groundwater pumping were not a viable alternative.[42]
- Rice fields in the Sacramento Valley are specially-designated as Shorebird Habitat of International Significance[43] — one of the largest special ecological sites of its kind in North America — supporting upwards of seven million waterfowl (60 percent of all waterfowl in the Pacific Flyway), 300,000 shorebirds, and nearly 230 species of wildlife overall.
- The 500,000 acres of California rice fields have been demonstrated to provide habitat for 14 species of raptors (birds of prey such as hawks, eagles and owls) at a level equivalent to approximately 300,000 acres of wetlands.[44]

While the significance of this habitat value is widely known, the California rice industry continues open dialogue and studies with our many conservation partners to evaluate and encourage the use of new practices that may further enhance the overall wildlife values of California ricelands.

Above: Sandhill Cranes making use of rice fields with drying and storage facility in the background.

Below: A sign placed on a farm by a rice landowner wanting to preserve high-quality wildlife habitat.

Summary & Conclusions

35%

Water use efficiency has improved by 35 percent as indicated by the amount of water used to produce a unit of rice.

RECAP OF FINDINGS

A review of the environmental indicator metrics for sustainability shows both improvements and environmental trade-offs for California rice. For the majority of the indicator metric categories, California's rice industry has made significant improvements over the last 30 years. Land use efficiency has improved as indicated by rice yield data showing a 22 percent increase over this time period. Soil loss has been insignificant and continues to be of little concern in California rice production. Water use efficiency has improved by 35 percent as indicated by the amount of water to produce a unit of rice. In terms of water quality, California rice industry has been able to develop comprehensive programs to address compounds of concern for water quality and reduce these as indicated by monitoring data over the last 30 years. In addition, there has been a steady increase in the use of reduced risk formulations over this time period.

Air quality performance has also been improved substantially as indicated by reductions in overall emissions of over 80 percent for the three major criteria pollutants, NOx, VOC, and PM. Most of this decrease is due to state regulations requiring the reductions in the practice of open-burning of rice straw. While improving emissions, the implementation of new practices like straw incorporation and winter flooding had negative impacts on the amount of energy and greenhouse gas emissions from rice production. However, energy use was still reduced by 22 percent as indicated by the energy requirements to produce a unit of rice. This reduction would have been larger without additional field passes needed to incorporate straw. Due to a negative environmental trade-off, an overall reduction in greenhouse gas emissions was not realized over the 30-year time period as indicated by the net greenhouse gas emissions per unit of rice production. However, even with this trade-off, it can be seen that improved rice yield and energy use efficiency kept greenhouse emissions flat (no increase) during this period. Biodiversity is one area that has improved due to the increase in winter flooding, as winter waterfowl and shorebird habitat in rice has increased ten-fold due to the changes in practice.

CROSS-CATEGORY IMPACTS

Improving environmental performance in one category can have consequences for sustainability in other categories.

Changing agricultural practices like open burning of rice straw has had clear cross-category impacts on environmental sustainability. Future efforts in the environmental arena that focus on improving the environmental performance in one area would benefit from analysis of the potential effect on the other sustainability metrics.

INNOVATIVE SOLUTIONS

Clearly much progress has been made in the last 30 years with striking results. However, it is likely that further progress will be harder fought with solutions that are more complex. We believe that stronger alliances will be needed between the rice industry and other governmental and non-governmental organizations in the future. The percentage of off-field use of rice straw, for example, has struggled to exceed five percent mostly due to limited market demand even though more uses appear technically viable. The only current economically viable uses tend to be erosion control products and cattle feed. However, we believe that stronger initiatives to promote and fund more uses of agricultural byproducts could spur higher resource management outcomes. Cellusic ethanol, as an example, could be a reality for greater reuse potential of agricultural byproducts and reduced dependence on fossil fuels if the right mix of research and incentives were embraced. Thoughtful state and federal policies should be considered to help spur the next generation of progress.

FUTURE STEWARDSHIP GOALS

While significant progress has been realized, the California rice industry remains committed to its stewardship of the land and resources its very future relies upon. We also recognize the societal challenge before all of us as we prepare to meet the nutritional needs of an estimated world population of 9 billion by 2050. We intend to be here, continuing to responsibly grow high quality and nutritional rice, as part of this global effort to feed the world. This will require more progress and innovation in cultural practices in a continuing effort to use resources as efficiently as possible. With these objectives in mind, the California rice industry will strive to improve its current levels of stewardship of the resource use and emissions categories identified in this report by 10 percent, cumulatively, by 2030.

Top: Method of spreading rice straw at construction sites to minimize soil erosion.

Above: Iconic ricelands wading bird, called the Great Blue Heron, munching on a crawfish caught in a winter-flooded rice field.

Below: Rice straw-based products called "wattles" commonly used at construction sites and along highways to minimize soil erosion.

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