United States Environmental Protection Agency

Office of Water
EPA-823-R-22-001
May 2022

The Universe of Lagoons: An analysis of state and tribal lagoon wastewater treatment systems and socioeconomic, environmental justice, and compliance patterns in small, rural communities in the United States

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This report was developed under Assistance Agreement No. 84003501 awarded by the U.S. Environmental Protection Agency to AAAS. This document has been approved for publication by the Standards and Health Protection Division, Office of Science and Technology, United States Environmental Protection Agency. EPA does not endorse any products or commercial services mentioned in this publication. This document does not impose legally binding requirements on EPA, states, authorized tribes, other regulatory authorities, or the regulated community.

EPA Document Number: EPA-823-R-22-001
Date: May 2022

Acknowledgments

The development of this document was made possible through an effort led by Marika Schulhof (AAAS Science & Technology Policy Fellow) and Shari Barash, Chief, National Branch, Standards and Health Protection Division, Office of Science and Technology, Office of Water.

This work would not have been possible without the many individuals those who generously shared their time, data, and knowledge on lagoon systems, explained how to use and interpret EPA data systems, and reviewed drafts of this report. Thank you to the following individuals at EPA: Mike Tate and Paul Shriner for sharing their extensive knowledge on lagoon systems and for sharing data; Tina Laidlaw, Mike Boeglin, and Stephanie DeJong of Region 8 for sharing EPA regional knowledge on lagoons; Kathryn Kazior for sharing data; Rusty Wasem, Carey Johnston, Nick Spalt, Courtney Tuxbury, Daniel Palmer, and Seth Heminway for sharing their knowledge on compliance and ECHO data systems; Morgan Teachey, Ahmed Rachid El-Khattabi, Adam Thiesig for retrieving EJSCREEN data for lagoon facilities using their newly developed EJSCREENbatch R tool; Tim Connor, Josh Klein, Elisabeth Schlaudt and Kara Edquist for their help with retrieval and interpretation of CWNS 2012 data; Matthew Richardson for providing tribal facility data; Gajindar Singh, Joel Owen, Gaida Mahgoub and for early conversations on lagoon systems and data sources; Kelly Gravuer and Gary Russo for providing extensive feedback and assisting with Census data and statistical analyses; and finally, Shari Barash and Menchu Martinez for their mentorship, guidance and feedback on this project. Additionally, thank you to Mike Tate, Paul Shriner, Kelly Gravuer, Gary Russo, Shari Barash, Menchu Martinez, Courtney Tuxbury, Carey Johnston, and Sara Hisel-McCoy for reviewing and providing feedback on this report. Thank you also to Bill O'Connell of the National Rural Water Association and Steve Harris for sharing knowledge of lagoon systems; Andrew Nordbye and Kevin Kundert of the Rural Community Assistance Partnership for sharing data; Sean Rolland and Jake Adler of the Association of Clean Water Administrators for assisting us with information gathering efforts on lagoons and facilitating conversations on lagoons with states; and states for generously sharing data on their lagoon systems (AL, IN, CO, IA, OH, NH, IL, WA, VA, KS, OR, AK).

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Executive summary

Facultative and aerated lagoon wastewater treatment systems are often utilized by small, rural communities because lagoons are cost-effective, low maintenance wastewater treatment options appropriate for areas with low population density. However, lagoons alone are often unable to meet increasingly stringent water quality requirements for pollutants such as ammonia and nutrients, and add-on technologies can be cost-prohibitive for small communities because they lack economies of scale, resulting in higher rates of noncompliance and potentially adverse impacts to human and environmental health.

This report details a research effort that was carried out to understand the 'universe' of lagoon systems utilized by small, rural communities in states and tribes in the United States by:
1) building a dataset of known discharging lagoon systems with NPDES permits that are publicly or semi-publicly owned, in which lagoons serve as the main form of secondary treatment, without more advanced treatment or add-on technologies;
2) analyzing lagoon facility data in conjunction with compliance data (from EPA's ECHO website), socioeconomic data (from U.S. Census American Community Survey) and environmental justice data (from EPA's EJSCREEN tool) to characterize lagoon compliance issues and understand demographic and environmental justice patterns in communities that utilize them. The dataset and analysis provide useful information to help EPA prioritize support to underserved lagoon communities through technical and financial assistance efforts.

In total, 4,657 publicly or semi-publicly owned discharging lagoon systems were identified through this research effort[1]. Of these lagoons, 83% were identified as publicly owned treatment works (POTWs), indicating that lagoons may comprise at least 24% of total POTWs in the United States. Although this dataset likely does not capture every lagoon in the U.S., it represents a compilation of all relevant data sources on this topic known to EPA. These lagoon systems are concentrated in midwestern states (primarily IA, IL, KS, ND, and MO), tend to serve communities with small populations (84% have less than 3,000 people) and have small design flows (94% have less than 1 MGD). The majority of communities with lagoons are economically disadvantaged, lagging behind Census national estimates of economic indicators including median household income (MHI), upper limit of the lowest quintile of household income (LQI), and percentage of the population below twice the federal poverty level. Many lagoon communities have demographic characteristics consistent with rural populations, including high reliance on manufacturing sector jobs, aging population structure, low undergraduate and post-graduate educational attainment and low broadband connectivity. Lagoon communities with more environmental justice (EJ) concerns (more EJ environmental indicators with values above the 80th national percentile) were found to be more prevalent in communities with higher values for demographic indicators of social vulnerability including people of color, low income, and less than high school education. Additionally, lagoon communities with high numbers of total (demographic and environmental) EJ indicators with values above the 80th percentile were

[1] The dataset used to generate this report was reviewed and updated in May 2022 by eight states (CO, WA, IL, OR, IA, AL, KS, IN) that provided revisions to lagoon data from their states, resulting in a revised total of 4565 lagoons. Therefore, the Lagoon Inventory Dataset has been updated with changes that are not reflected in this report. For the most recent data on lagoons, see the Lagoon Inventory Dataset (EPA-820-R-22-001, available at https://www.epa.gov/small-and-rural-wastewater-systems).

concentrated in southeastern states. Lagoon facilities were found to have compliance challenges, as 61% of facilities had effluent exceedances for at least one pollutant between September 2018 and September 2021, 18% of facilities had Significant/Category I Noncompliance (SNC) violation status, 38% had non-SNC violation status, and 33% of lagoons discharged to water bodies with impaired status under Clean Water Act Section 303(d). The most common lagoon effluent exceedances were for biological oxygen demand, total suspended solids, fecal indicator bacteria, pH, and ammonia – all of which can negatively impact human and environmental health.

Introduction

Small, rural communities in the United States face unique wastewater treatment challenges and associated water quality impairments due to financial and staffing constraints for operation and maintenance of wastewater facilities. Wastewater treatment and collection facilities serving small communities (10,000 people or less) comprise approximately 80% of such facilities in the United States (Congressional Research Service, 2016). Many small lagoon systems are constrained by staffing shortages, often with only one full- or part-time operator balancing other duties. Small systems have higher rates of noncompliance with Clean Water Act discharge permits than larger systems and require more funding for infrastructure improvements on a ratepayer basis, because ratepayers in small systems face heavier financial burdens per capita for clean water investments (Congressional Research Service, 2016). Noncompliance – including the inability of facilities to meet water quality requirements for pollutants such as ammonia – can reduce water quality of rivers, streams, lakes, estuaries and coastal waters receiving wastewater discharges, with potentially adverse consequences for environmental and human health.

Rural communities are sparsely populated, as rural areas account for 97% of the total land area in the United States but comprise only 19% of the total population in the United States (roughly 63 million people in 2018; U.S. Census Bureau, 2020a). Rural areas have unique demographic and geographic characteristics that contribute to wastewater treatment challenges: they are less densely populated and have less developed infrastructure (U.S. Census Bureau, 2016), and have lower socioeconomic outcomes in comparison to urban areas. Nonmetropolitan areas have lower personal income, slower employment growth, lower labor force participation, less demand for labor, lower educational attainment, and an older and more disabled population than in metropolitan areas, with the highest rates of population loss and poverty in the most isolated and rural nonmetropolitan counties (USDA, 2019). Rural areas depend more heavily than urban areas on the manufacturing sector as a source of employment (USDA, 2017a), in addition to agriculture, forestry, and mining sectors. Furthermore, rural areas have fewer college-educated adults compared to urban areas, contributing to higher rates of unemployment, poverty and population decline (USDA, 2017b).

Facultative and aerated lagoon wastewater treatment systems are often utilized by small, rural communities (often less than 3,000 people) because these systems offer a cost-effective treatment option that is low in energy and capital expenditures, operations, and maintenance costs (U.S. EPA, 2011). Lagoons treat municipal and industrial wastewater through biological processes carried out by microorganisms. Facultative lagoons are earthen ponds approximately 4-8 feet in depth that often operate by gravity flow and are not mechanically mixed or aerated (U.S. EPA, 2002a). In contrast, aerated lagoons are mechanically aerated, partially or completely mixed and more energy-intensive, but require less land, have shorter detention times, and are appropriate in warm, sunny climates (U.S. EPA, 2002b; U.S. EPA, 2011).

While lagoons offer a viable wastewater treatment option for small communities, lagoons are often unable to meet increasingly stringent water quality requirements for ammonia and nutrients, which have been enacted in response to scientific evidence for the detrimental impacts of these pollutants on human and environmental health. Facultative lagoons can be more effective at removing ammonia from wastewater than aerated lagoons, although ammonia levels in effluent even from facultative lagoons can be variable and difficult to control (U.S. EPA, 2002a,b). Removing ammonia and nutrients from effluent is critical because excess nutrients entering receiving waters can have negative impacts on water quality, aquatic life, recreation and public health via processes such as eutrophication, harmful algal blooms and toxic effects on aquatic life. In order to meet more stringent water quality standards, nutrient removal processes often must be added to lagoon systems (U.S. EPA, 2011). However, these add-on technologies can be cost-prohibitive for small communities because they lack economies of scale.

For small lagoon communities that are in noncompliance with Clean Water Act discharge permits but lack financial resources to upgrade infrastructure to address ammonia and nutrient standards, financial and technical assistance efforts may be necessary to meet water quality requirements. President Biden's Executive Order 13985 (Advancing Racial Equity and Support for Underserved Communities Through the Federal Government) establishes a whole-government responsibility to advance equity, civil rights, racial justice, and equal opportunity for underserved communities. The definition of equity includes "the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities that have been denied such treatment, such as Black, Latino, and Indigenous and Native American persons, Asian Americans and Pacific Islanders and other persons of color; members of religious minorities; lesbian, gay, bisexual, transgender, and queer (LGBTQ+) persons; persons with disabilities; persons who live in rural areas; and persons otherwise adversely affected by persistent poverty or inequality." (Exec. Order No. 13985, 2021). It is imperative to address water quality problems occuring in underserved small, rural lagoon communities because noncompliance in these systems can threaten water quality and public health, creating environmental justice concerns.

Purpose

The purpose of this study is to understand the 'universe' of lagoon systems utilized by small, rural communities in states and tribes in the United States and use this information to guide technical and financial assistance by:
1) building a dataset of known discharging lagoon systems with NPDES permits that are publicly or semi-publicly owned, in which lagoons serve as the main form of secondary treatment, without more advanced treatment or add-on technologies;
2) analyzing lagoon facility data in conjunction with compliance data (from EPA's ECHO website), socioeconomic data (from U.S. Census American Community Survey) and environmental justice data (from EPA's EJSCREEN tool) to characterize lagoon compliance issues and understand demographic and environmental justice patterns in communities that utilize them; and

3) using the results of this analysis to help prioritize support to underserved lagoon communities through technical and financial assistance efforts.

Methods

Lagoon data collection

EPA collected lagoon facility data between October 2020 to May 2021 with the help of state governments, Association of Clean Water Administrators (ACWA), and Rural Community Assistance Partnership (RCAP).

EPA compiled the lagoon dataset from the following eighteen datasets and prioritized in the following order (based on completeness and recentness of data sources) when data from multiple sources were available for a facility:

- A list of POTW lagoons compiled in 2018 from the Integrated Compliance Information System National Pollutant Discharge Elimination System database (ICIS-NPDES) by identifying all POTW facilities covered under general permits for lagoons or based on permit reviews, lagoons identified by satellite imagery, and lagoons identified based on wastewater treatment facility names ("lagoon," "stabilization," or "pond" in the facility name) (EPA)
- Lagoon facility data from twelve states[2] (AL, IN, CO, IA, OH, NH, IL, WA, VA, KS, OR, AK), provided directly by states (via outreach by ACWA), or obtained from state websites
- A 2020 list of tribally owned wastewater treatment facilities with Individual NPDES permits (EPA)
- Results of the 2012 Clean Watersheds Need Survey (EPA)
- Initial results as of 2020 of questionnaires received from POTWs participating in the National Study of Nutrient Removal and Secondary Technologies (EPA)
- Lagoon facility data from RCAP
- Facility search results (from March 2021) of EPA's Enforcement and Compliance History Online (ECHO) Pollutant Loading Tool using state-specific adjusted total suspended solids (TSS) requirements for waste stabilization ponds (based on alternate TSS limitation, 30-day average (EPA, 2010) as search criteria)

EPA sought to collect the following types of data on lagoon facilities, although data on each of these parameters was not always available from all data sources:

- NPDES permit number
- Facility name
- Facility address
- Facility contact person
- Latitude and longitude
- Facility ownership (e.g., private, public)
- Treatment type (e.g., primary, secondary)
- Lagoon type (e.g., facultative, aerated)
- Design flow (millions of gallons per day; MGD)

[2] *Water Quality Standards Regulation (Renewal)* Information Collection Request, EPA ICR Number 0988.13, OMB Control Number 2040-0049.

- Actual flow (MGD)
- Number of lagoon cells
- Name of receiving waters
- Publicly owned treatment works (POTW) status
- Major status (design flow greater than 1 MGD)
- Population size served by facility

After data was collected from various sources, these data were merged, cleaned and filtered using Tidyverse R package (Wickham et al., 2019) to focus on lagoon systems that met the following criteria, when data on these parameters was available: publicly or semi-publicly owned, NPDES-permitted lagoons with discharge to surface waters, in which lagoons provide the main form of secondary treatment without more advanced treatment or add-on technologies. Following selection of the lagoon facilities, demographic data from the U.S. Census American Community Survey (using five-year average data from 2015-2019) was obtained for lagoon facilities based on the town or city in which they were located; environmental justice data was obtained from EPA's EJSCREEN tool for Census block groups within a 3-mile radius of lagoon facilities; and compliance data was obtained from EPA's ECHO website based on each facility's NPDES ID.

Further methodological details of data merging, cleaning, and filtering, and caveats regarding missing data, can be found in Appendix I (Methods).

Results

Lagoon facility characteristics

In total, there were 4,657 unique lagoon facilities, of which 14.6% (680) contained aerated lagoons, 32.3% (1505) had facultative lagoons, and 53.1% (2472) were missing data on lagoon type ('unspecified' type) (Fig. 1B). Lagoons were found in forty-six states, of which the five states with the highest abundance of lagoons were Iowa, Illinois, Kansas, North Dakota and Missouri, and tribes owned 125 facilities in total (Table 1, Fig. 1A). Lagoon ownership types were designated as county government (0.2%), state government (0.4%), tribal government (2.7%), mixed ownership (semi-public, i.e., private/public); 4.5%), public (14.1%), municipal (52.8%), and unspecified (25.3%) (Fig. 2A). Additionally, 83.4% were POTWs, comprising 24% of the total POTWs (15,979) in the United States while 9.4% were non-POTWs and 7.2% did not specify (Fig. 2B). Nearly all lagoon facilities had minor status (1 MGD or less; 86.2%), while others had major status (greater than 1 MGD; 3.48%) or did not specify (10.3%) (Fig. 2C). Design flow data was available for 81% of facilities (3793). For facilities with design flow data, the median value was 0.12 MGD; 93.9% had design flow less than 1 MGD and 85.6% had design flow less than 0.5 MGD (Fig. 3).

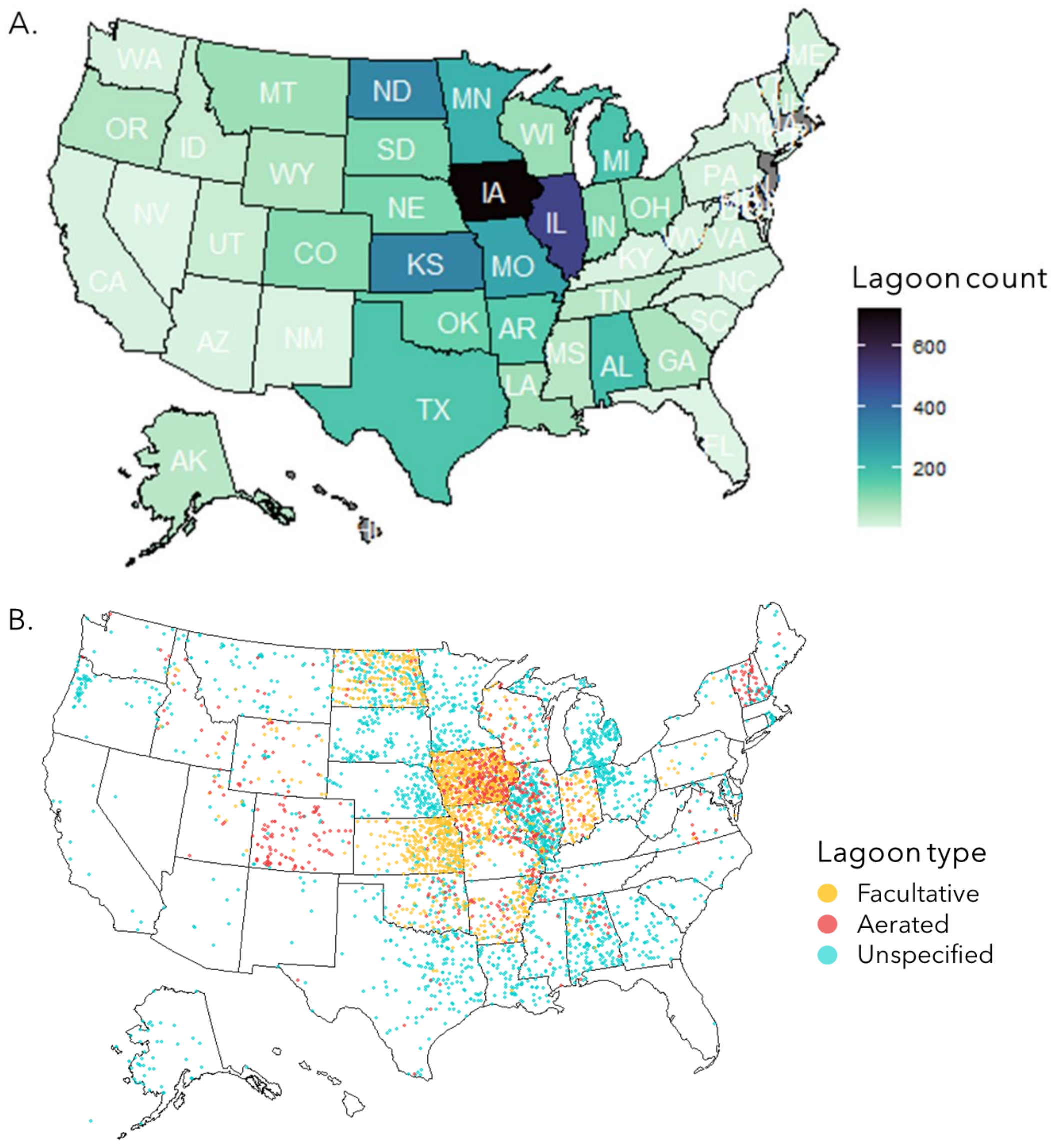

Figure 1: *A. Map shows the total number of lagoon facilities per state, with darker shades indicating higher lagoon abundance. B. Map shows lagoon facility locations as points, with color indicating lagoon type. Yellow indicates facultative lagoons (14.6%), red denotes aerated lagoons (32.3%), and blue signifies unspecified lagoon type (53.1%).*

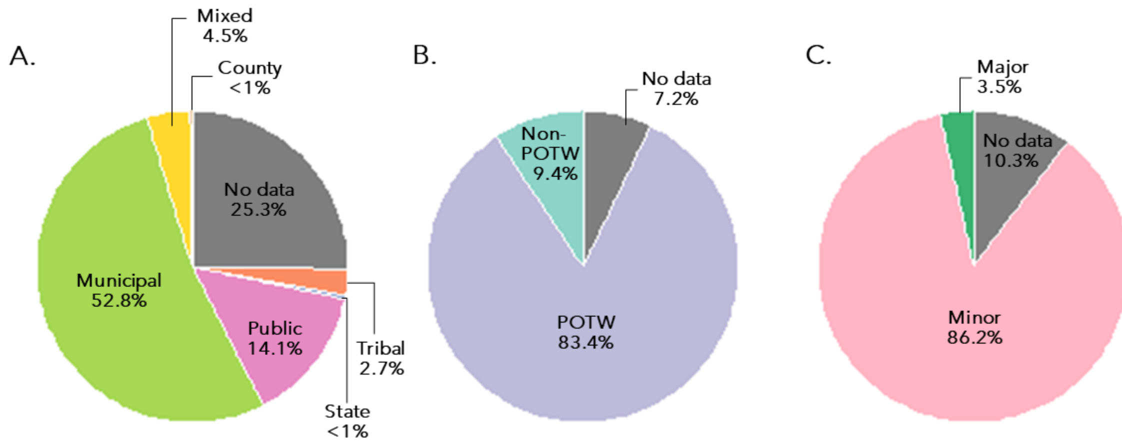

Figure 2: *Pie charts displaying lagoon facility data (n=4657; missing data for variables is designated in gray) delineated by: A. Ownership type (percent public, municipal, mixed (semipublic; public and private), county government, state government, tribal government); B. Facility type (publicly owned treatment works (POTWs) versus non-POTWs); C. Major (greater than 1MGD design flow) or minor (equal to or less than 1MGD design flow) facilities.*

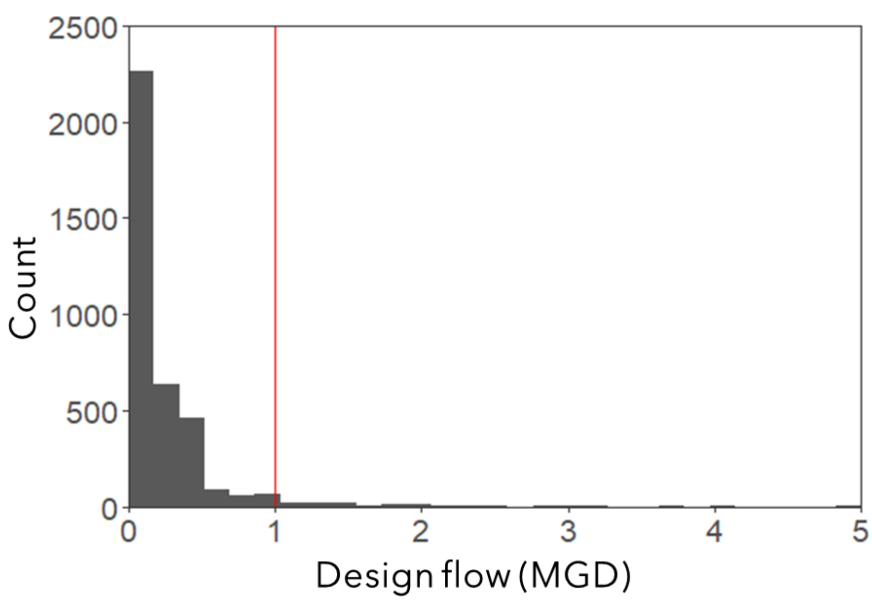

Figure 3: *Histogram showing lagoon facility design flow data (MGD) (n=3793), with x-axis truncated at 5 MGD. The red vertical line indicates 1 MGD for reference; 93.9% of facilities with available flow data have design flow less than 1 MGD.*

Table 1: *Number of lagoon facilities (n=4657) by state, broken down by lagoon type (unspecified, aerated and facultative), ordered from highest to lowest total lagoons per state. The subsets that are tribally owned are listed by the states within which they are located.*

State	Total lagoons	Unspecified lagoon	Aerated lagoon	Facultative lagoon	Tribally owned lagoons (subset of total)
IA	722	17	174	531	1
IL	493	342	93	58	--
KS	337	43	5	289	2
ND	329	149	16	164	25
MO	252	47	63	142	--
MN	222	222	--	--	2
AL	187	161	17	9	--
MI	177	177	--	--	1
TX	170	159	7	4	--
AR	160	36	32	92	--
OK	138	63	22	53	--
NE	120	120	--	--	2
SD	117	117	--	--	56
CO	107	16	89	2	3
IN	105	10	19	76	--
OH	99	99	--	--	--
WI	87	32	26	29	2
MT	84	76	6	2	15
LA	80	79	--	1	--
GA	69	69	--	--	--
WY	62	21	22	19	2
OR	59	58	1	--	--
TN	54	39	12	3	--
MS	53	46	5	2	--
AK	50	50	--	--	--
NH	50	28	22	--	--
ID	35	16	12	7	2
UT	29	13	8	8	7
VA	23	12	8	3	--
VT	20	4	16	--	--
PA	17	8	--	9	--
MD	16	16	--	--	--
ME	16	15	1	--	--
SC	16	16	--	--	--
RI	15	15	--	--	--
NY	14	12	--	2	1
WA	14	10	4	--	--
WV	12	12	--	--	--

CA	10	10	--	--	--
KY	10	10	--	--	--
NC	9	9	--	--	--
AZ	8	8	--	--	4
NM	7	7	--	--	--
CT	1	1	--	--	--
FL	1	1	--	--	--
NV	1	1	--	--	--

Lagoon compliance characteristics

ECHO compliance data was available for 99.8% (4650) of lagoon facilities. Of these facilities, 17.5% (815) of lagoon facilities had SNC violation status, 38.2% (1777) had non-SNC violation status (includes reportable noncompliance; other violations; resolved; resolved-pending; see Appendix I), and 44.3% (2058) had no violations identified (Fig. 4A). Additionally, 61.3% (2851) of lagoons had permit effluent limit exceedances for at least one pollutant in the last three years (Fig. 4B). Of lagoons with effluent exceedances for at least one pollutant in the last 3 years, the five most abundant exceedance categories were biological oxygen demand (BOD; 69.9%), total suspended solids (TSS; 61.1%), fecal indicator bacteria (36.7%), pH (34.5%), and ammonia (20.9%) (Fig. 5). Furthermore, 33.4% (1555) of lagoon facilities discharged to water bodies with impaired status under Clean Water Act Section 303(d) (Fig. 4C). The designated use of the waterbodies receiving lagoon wastewater discharges consisted of 57.2% aquatic life use (2660), 54.7% recreational use (2545), 33.5% fish consumption use (1562), 18.1% drinking water use (840) (Fig. 6) and 42.3% had no designated use listed (1970). Finally, 24.6% (1146) of facilities were identified as having pollutants potentially contributing to impairment of receiving waters (i.e., pollutants that overlap between the facility's permit parameters and the reason for impairment in the receiving water body, but do not necessarily contribute to impairment) – the five most abundant pollutants in this category were fecal indicator bacteria (61.8%), BOD (39.4%), TSS (29.6%), ammonia (26.4%), and phosphorus (19.7%) (Fig. 7).

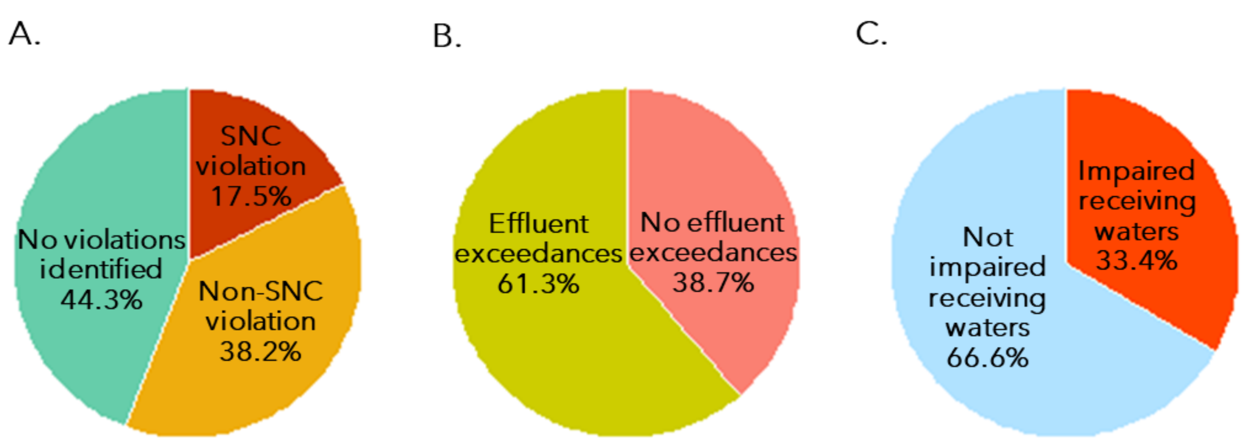

Figure 4: *Pie charts showing compliance data for lagoon facilities (n=4650). A. The percent of lagoons with Significant/Category I Noncompliance (SNC) violation status is shown in red, the percent of lagoons with non-SNC violation status (reportable noncompliance, other violations, resolved, resolved-pending) is shown in yellow, and the percent of lagoons with no violations identified is shown in light green. B. The percent of lagoons with effluent exceedances for at least one pollutant in the last three years is shown in green and the percent without effluent exceedances in the last three years is shown in pink. C. The percent of lagoons discharging to impaired waters (waters not meeting water quality standards and include impairment classes that both require total daily maximum loads (TMDLs; category 5) and those that do not (categories 4a, 4b, 4c)) are shown in orange-red and the percent discharging to waters without impaired status are shown in light blue.*

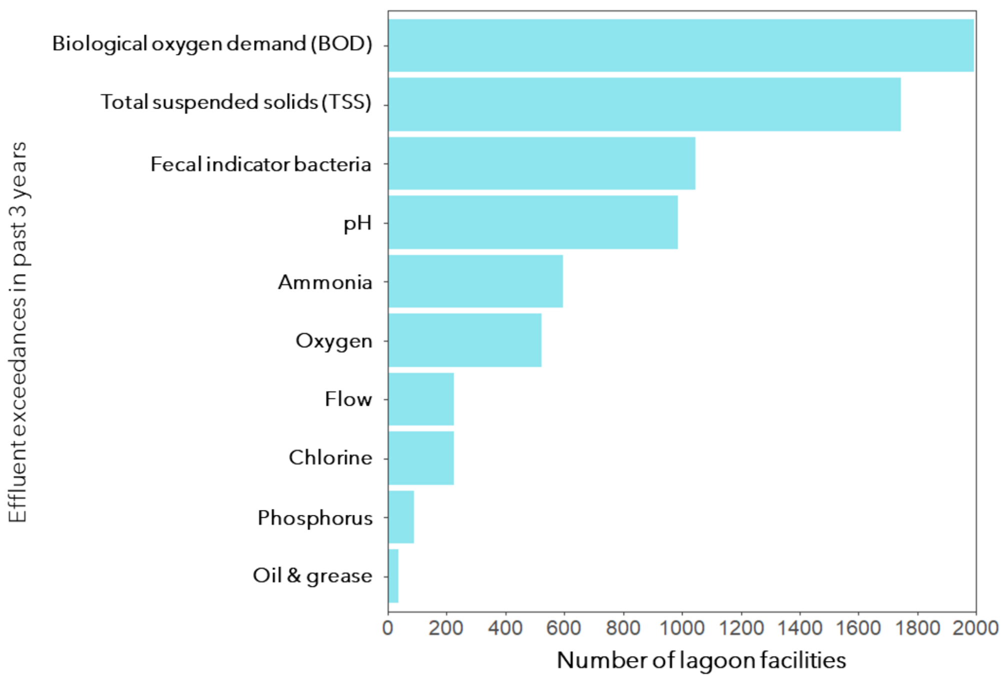

Figure 5: *The number of facilities with effluent exceedances for at least one pollutant in the past three years (n=2851) are shown for the ten most abundant exceedance categories. A single facility may have exceedances for more than one type of pollutant.*

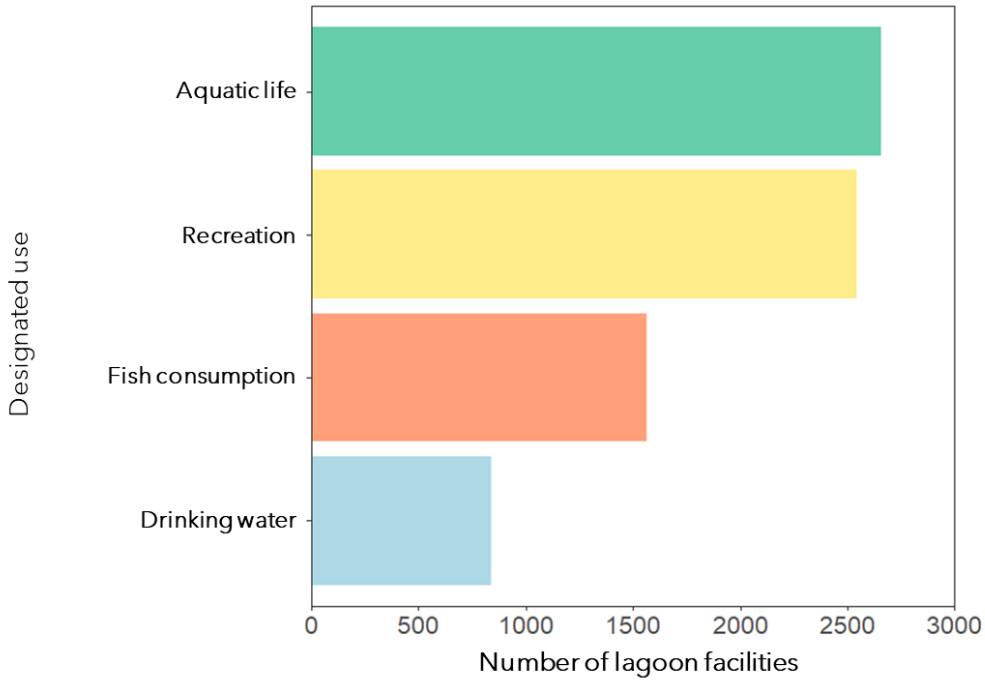

Figure 6: *The number of facilities with designated use categories listed for receiving waters is shown (n= 2680). A single lagoon facility may have more than one type of designated use.*

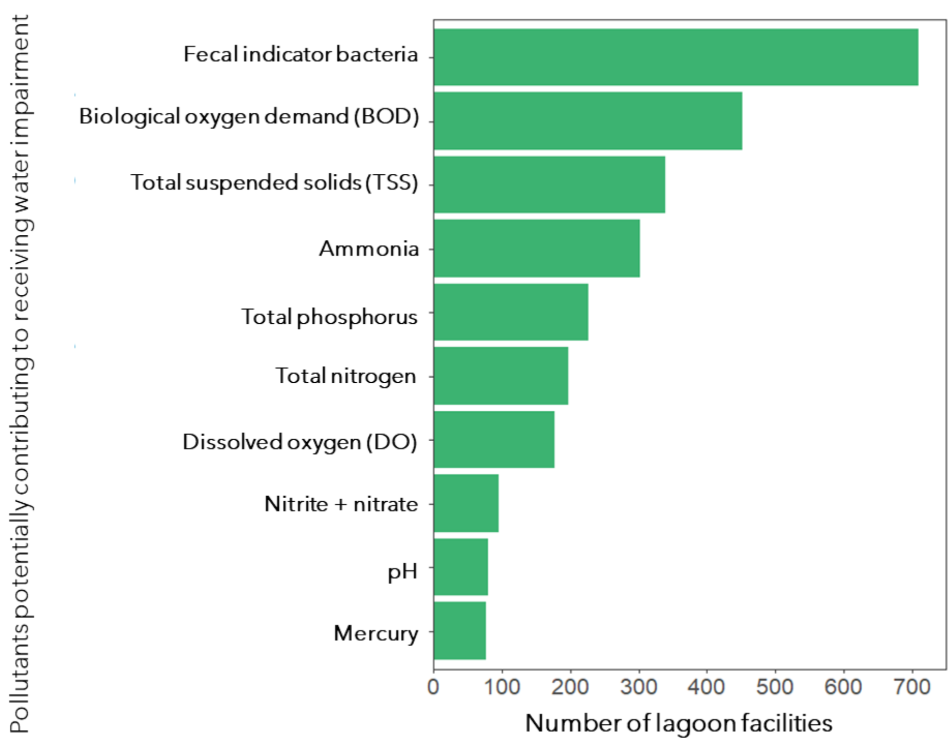

Figure 7: *The number of facilities with pollutants potentially contributing to receiving water impairment (does not necessarily indicate a facility's contribution to the impairment, but indicates pollutants that overlap between the facility's permit limit parameters and the reason for impairment in the receiving water body; n=1146) are shown for the ten most abundant*

pollutants. A single lagoon facility may have more than one type of pollutant potentially contributing to impairment.

Demographic and socioeconomic characteristics

Census ACS place-level data were identified for 94.7% (4408) of lagoon communities. In lagoon communities for which population data was available (4408), the median population size of lagoon communities was 793 (min. = 0, max. = 2.3M) people. The majority of these lagoon communities had less than 1000 people (57.9%), 84.3% of lagoon communities had populations less than 3000 people, and 89.5% had populations less than 5000 people (Fig 8).

Median household income (MHI) data was identified for 93.3% (4344) of lagoon communities. Of these communities, the median MHI value of lagoon communities was $47,023.5 (min. = $2,499, max. = $137,303), and 85.3% of lagoon communities had MHI values lower than the national MHI estimate of $62,843 (Fig. 9A). Furthermore, mean lagoon community MHI values per state (for 37 states that had data on more than ten lagoon communities) were less than state MHI estimates in 94.6% (35) of states, less than national MHI estimates in 91.9% (34) of states, and less than both state and national MHI estimates in 89.2% (33) of states with lagoon community MHI data (significant at 95% confidence interval; Fig. 9B).

Household income lowest quintile upper limit (LQI) data was obtained for 94.5% (4402) of lagoon communities. The median LQI value of lagoon communities was $21,206 (min.= $2,499, max.= $85,407), and 70.0% of lagoon communities had LQI values lower than the national LQI estimate of $25,766 (Fig. 10A). The percentage of individuals with income below the 200% poverty level was obtained for 94.6% of lagoon communities (4405) and 68.3% of lagoon communities had more individuals with income below the 200% poverty level (median=38.0%) than the national estimate (30.9%) (Fig. 10B).

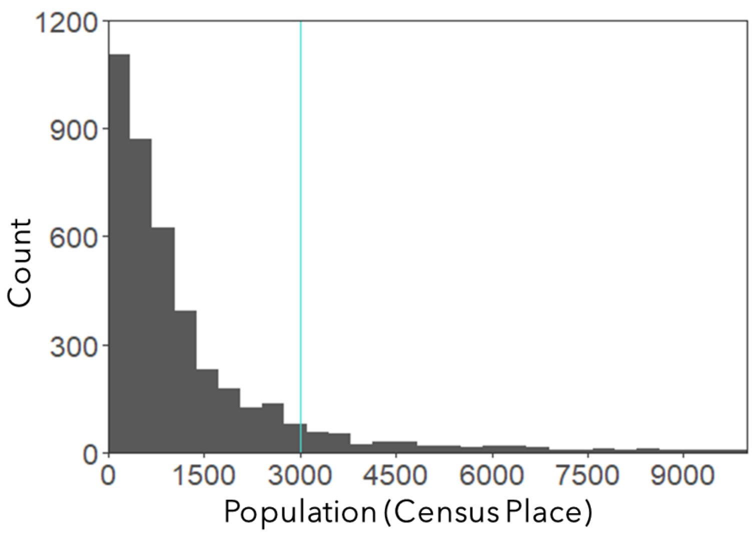

Figure 8: *Histogram showing ACS place-level population data (n=4408) for lagoon facility locations, with x-axis truncated at 10000 people. The turquoise vertical line indicates 3000 people for reference; 84.3 % of communities had populations less than 3000 people.*

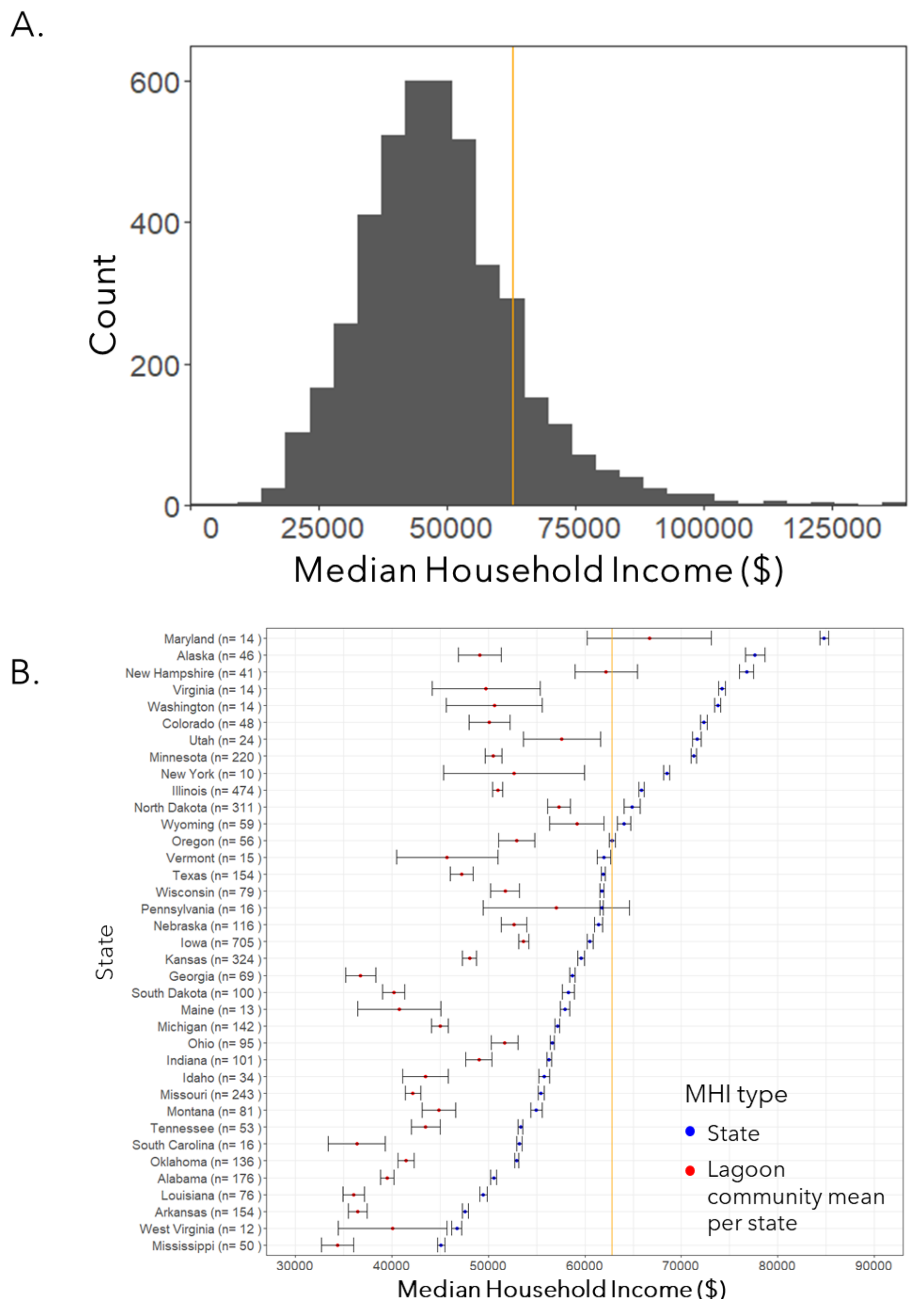

Figure 9: *A. Histogram showing ACS place-level median household income (MHI) data for lagoon facility locations (n=4344). The yellow vertical line indicates the ACS MHI national estimate ($62,843) for reference; 85.3% of lagoon communities had MHI values lower than the national MHI estimate. B. Plot showing ACS MHI national (yellow) and state (blue) estimates and mean lagoon community MHI per state (red) for states with more than ten lagoon community MHI values (n=37). Mean lagoon community MHI values per state were significantly less than both state and national MHI estimates in 89.2% of states. Error bars represent 90% margins of error.*

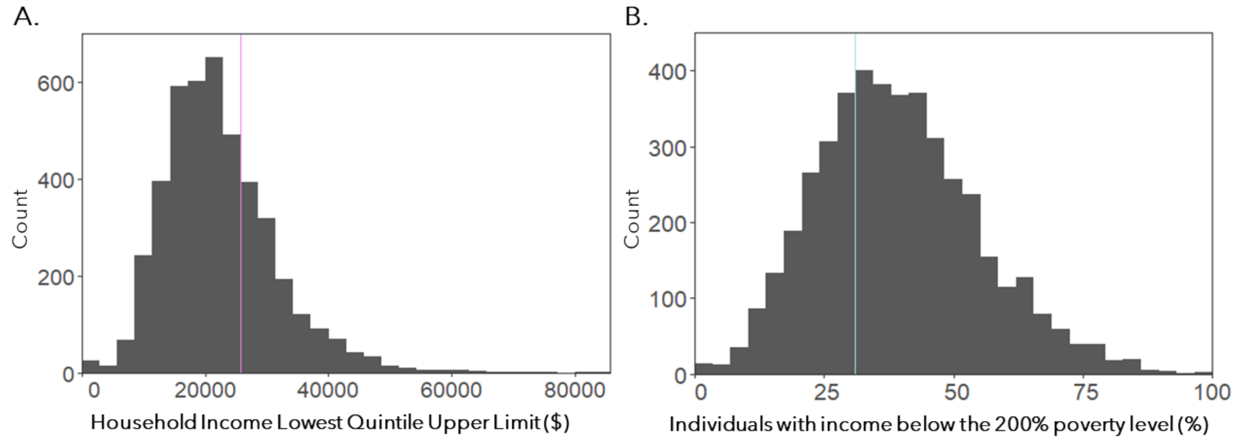

Figure 10: *A. Histogram showing ACS place-level household income lowest quintile upper limit (LQI) data for lagoon facility locations (n=4402). The violet vertical line indicates the ACS LQI national estimate ($25,766) for reference; 70.0% of lagoon communities had LQI values lower than the national LQI estimate. B. Histogram showing ACS place-level data for percentage of individuals with income below the 200% poverty level for lagoon facility locations (n=4405), with the light blue vertical line indicating the ACS national estimate (30.9%) for reference; 68.3% of lagoon communities had more individuals with income below the 200% poverty level than the national estimate (30.9%).*

In addition to economic characteristics of lagoon communities, demographic variables were obtained for 94.6% (4405) of lagoon communities. In 84.4% of lagoon communities, the percent people of color (median=8.8%) was lower than the national estimate (39.3%; Fig. 11). Additionally, socioeconomic variables relevant to rural communities were examined – including educational attainment, employment in manufacturing, age structure and broadband connectivity. In 93.9% of lagoon communities, the percent of the population 25 years and older with a bachelor's degree or higher (median=15.3%) was lower than the national estimate (32.1%; Fig. 12A). Furthermore, in 64.3% of lagoon communities, the percent of the civilian employed population age 16 and over in manufacturing jobs (median=13.5%) was higher than the national estimate (10.1%; Fig. 12B). In 62.9% of lagoon communities, the percent of people age 65 and over (median=17.5%) was greater than the national estimate (15.6%; Fig. 12C). Finally, in 81.4% of lagoon communities, the percent of households with a broadband internet subscription (median=74.4%) was lower than the national estimate (82.7%; Fig. 12D).

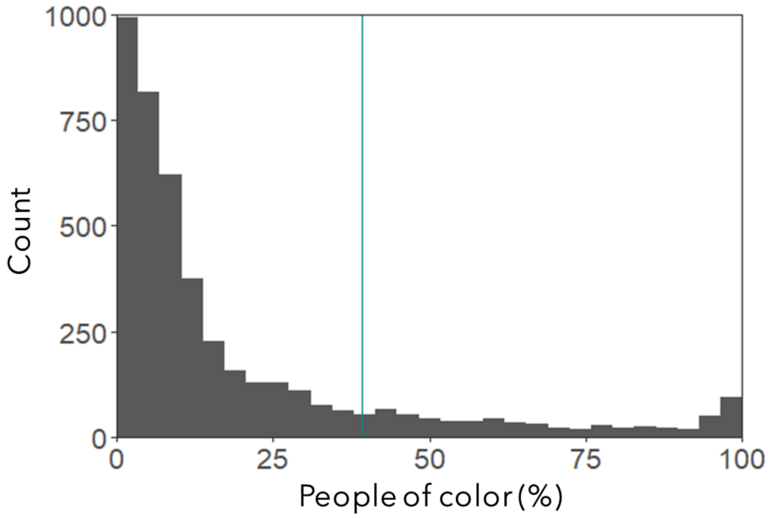

Figure 11: *Histogram showing ACS place-level data for percent people of color for lagoon communities (n=4405), with the teal vertical line showing the ACS national estimate (39.3%) for reference; in 84.4% of lagoon communities, the percent people of color was lower than the national estimate.*

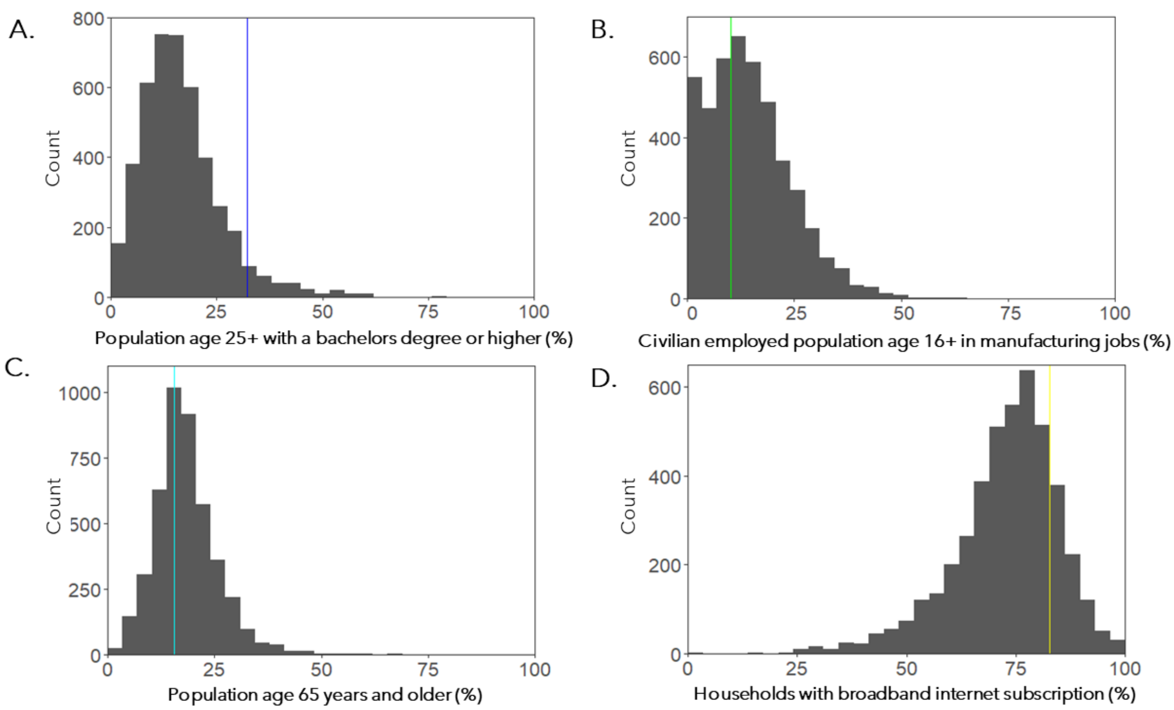

Figure 12: *Histograms showing ACS place-level data for lagoon facility locations (n=4405). A. Percent of population age 25 and older with a bachelor's degree or higher is shown with the ACS national estimate in blue (32.1%); 93.9% of lagoon community values were lower than the national estimate. B. Percent of civilian employed population age 16 and older in manufacturing jobs is shown with ACS national estimate in green (10.1%); 64.3% of lagoon community values*

were higher than the national estimate. C. Percent of population with individuals age 65 and older is shown with ACS national estimate in cyan (15.6%); 62.9% of lagoon community values were greater than the national estimate. D. Percent of households with broadband internet subscription is shown with ACS national estimate in yellow (82.7%); 81.4% of lagoon community values were lower than the national estimate.

Environmental justice characteristics

Environmental justice (EJ) data from EJSCREEN was obtained for 94% (4365) of lagoon communities but data was not available for facilities in Alaska. Lagoon communities with environmental EJ indicator values over the 80th national percentile (i.e., values higher than 80% of the United States) included those with zero (57.5%), one (29.3%), two (10.0%), three (2.6%), four (0.5%), five (0.05%), six (0.07%), and seven (0.05%) indicators, while lagoon communities with demographic EJ indicator values over the 80th percentile had zero (62.9%), one (28.5%), two (4.6%), three (3.0%), four (0.9%) and five (0.09%). Lagoon communities with total (demographic and environmental indicators combined) EJ indicators with values over the 80th national percentile included those with zero (35.5%), one (36.2%), two (17.2%), three (7.0%), four (2.6%), five (1.1%), six (0.3%), seven (0.09%), nine (0.02%), ten (0.02%), and eleven (0.02%) indicators, with geographic variation in the number of total EJ indicators with values above the 80th percentile and notable clustering of communities with three or more EJ indicators above the 80th percentile in the southeastern states (Fig. 13).

Communities with higher numbers of environmental EJ indicators with values above the 80th percentile tended to have higher distributions of values for demographic indicators of social vulnerability. There were no significant differences (using pairwise Wilcoxon rank-sum test; significant at $p<0.05$) in distributions of values between communities with zero or one indicators above the 80th percentile, except for less than high school education, in which communities with one indicator had significantly lower values than communities with zero indicators ($p<0.001$; Figure 14). Compared to communities with zero or one environmental EJ indicators above the 80th percentile, those with two, three, or four environmental EJ indicators above the 80th percentile had significantly higher distributions of values for people of color and less than high school education ($p<0.05$; Figure 14). Additionally, low-income value distributions were significantly higher in communities with two or three environmental EJ indicators above the 80th percentile as compared to those with zero or one ($p<0.001$; Figure 14). This suggests that lagoon communities with lower income, more people of color, and less than high school educational attainment experience higher pollution burdens. Communities with 5, 6, or 7 environmental EJ indicators above the 80th percentile could not be analyzed because sample sizes were too small (n=2 or n=3).

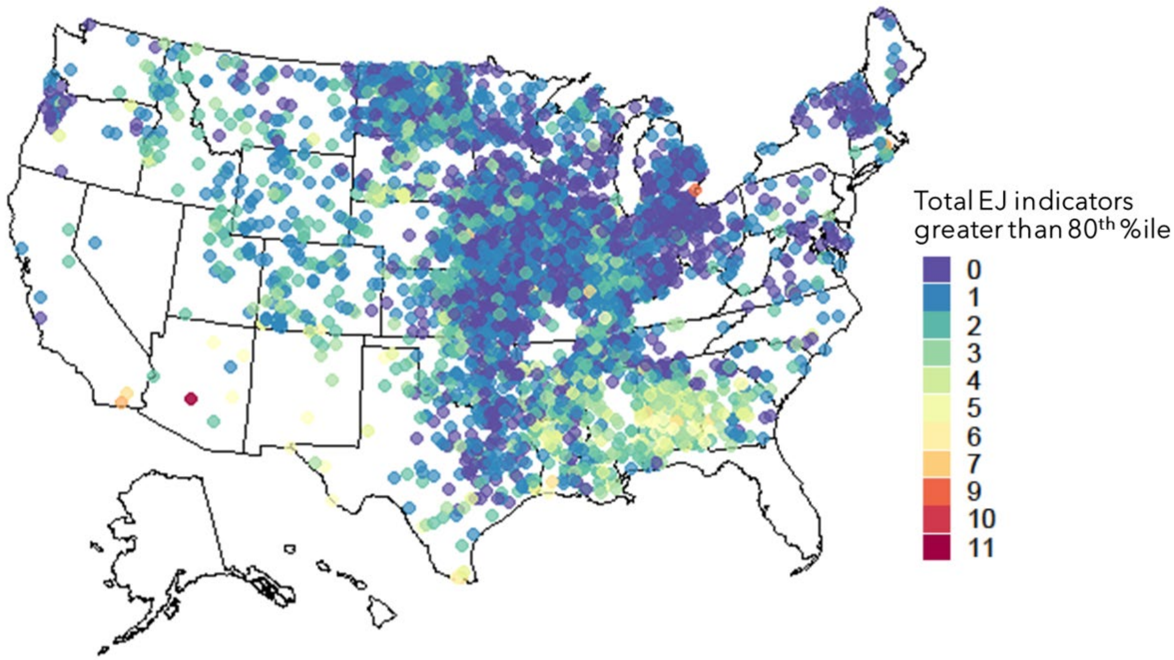

Figure 13: *Map of total EJ indicators greater than 80th national percentile shown for each lagoon facility location, shown as points (n=4365). Colors indicate the number of EJ indicators with values greater than the 80th percentile. Data is not available for AK.*

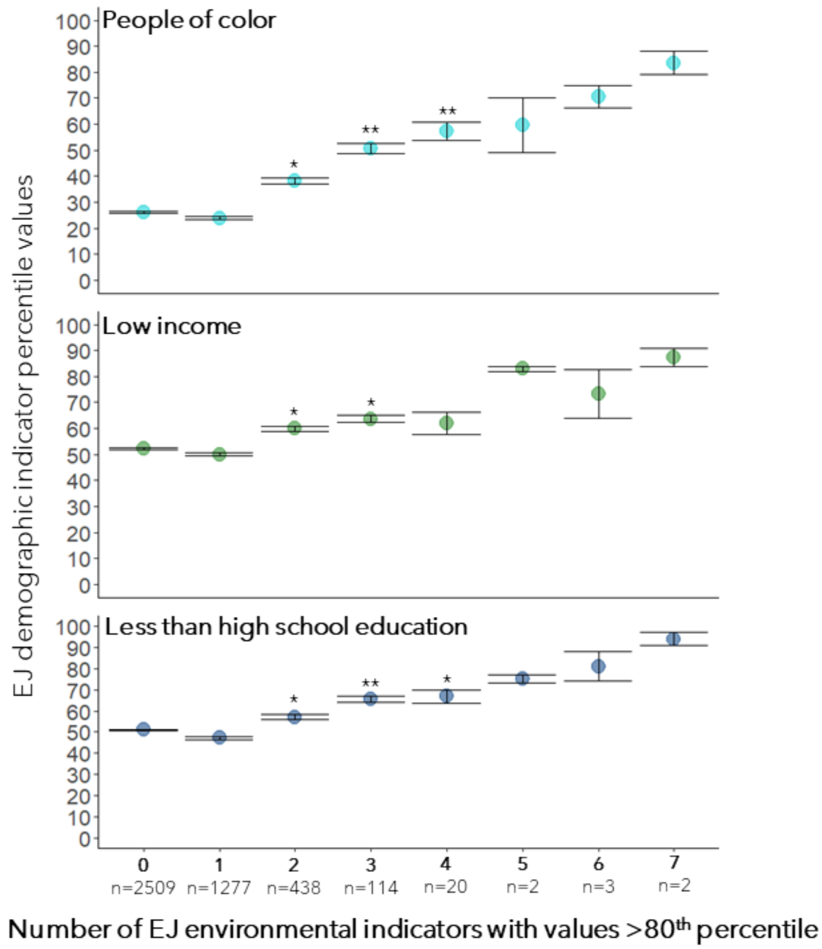

Figure 14: *For lagoon communities with 0-7 environmental EJ indicators exceeding the 80th national percentile, the mean (± standard error) national percentile values are shown for people of color (top), low income (middle) and less than high school education (bottom). The number of communities (n) with a given number of EJ indicators exceeding 80th percentile are shown below the x-axis. Asterisks indicate significantly higher distributions of values (p<0.05) relative to communities with 0 and 1 EJ indicators exceeding 80th percentile (one asterisk) or relative to those with 0,1 and 2 (two asterisks). Communities with 5, 6, or 7 environmental EJ indicators above the 80th percentile could not be analyzed because sample sizes were too small. All data shown here is from EJSCREEN.*

Discussion

Lagoon communities are concentrated in midwestern states (primarily IA, IL, KS, ND, and MO; Fig. 1), characterized by small populations and design flows (Figs. 3, 8) and rank behind Census national estimates of economic indicators including MHI, LQI, and percent of the population below twice the federal poverty level (Figs. 9, 10). Furthermore, mean lagoon community MHI values per state are less than state-level ACS estimates in 95% of states with lagoon communities (Fig. 9B), indicating that lagoon communities are economically disadvantaged relative to both state and national data. The high concentration of lagoons in midwestern states is consistent with findings that small community facilities account for a majority of publicly owned facilities in many states, notably contributing to more than 95% of publicly owned facilities in Iowa, Montana, Nebraska and North Dakota (Congressional Research Service, 2016). However, because small systems have a small base of ratepayers, they face heavy financial burdens and highest percentage increases in fees for clean water investments (Congressional Research Service, 2016); such financial burdens are likely to be unsustainable in small lagoon communities ranking behind state and national indicators of economic health.

In addition to lagging behind national economic indicators, lagoon communities have demographic characteristics consistent with rural populations (Fig. 12), including high reliance on manufacturing sector jobs, aging population structure, low undergraduate and post-graduate educational attainment (USDA, 2019; 2017a, b) and low broadband connectivity. Lagoon communities with more EJ concerns (more EJ indicators exceeding the 80th national percentile) were found to be more prevalent in communities with more people of color, lower income, and less education (Fig. 14) especially in Southeastern states (Fig. 13). This geographic pattern is consistent with findings that outcomes such as educational attainment are generally lower for people of color in rural areas, and that the rural South has the lowest levels of educational attainment and high levels of persistent poverty, especially in regions along the Texas-Mexico border, Mississippi Delta and Appalachian regions (USDA, 2017b). Thus, within already disadvantaged lagoon communities, those with lower income, more people of color, and fewer people with high school education carry higher environmental justice burdens than lagoon communities at large.

Lagoon facilities comprise 24% of total POTWs and were found to have compliance problems: 61% of facilities had effluent exceedances for pollutants in the last three years, 18% had a SNC violation status, 38% had non-SNC violation status, and 33% discharged to water bodies with impaired status under Clean Water Act Section 303(d) (Figs. 4, 5). The five most abundant effluent exceedance categories were BOD, TSS, fecal indicator bacteria, pH, and ammonia – all of which have potential to cause negative impacts to public and environmental health, as lagoon receiving waters are designated for aquatic life use (57%), recreational use (55%), fish consumption use (34%) and drinking water use (18%) (Figs. 5, 6). Furthermore, the five most abundant pollutants potentially contributing to impairment of receiving waters in lagoon facilities include fecal indicator bacteria, BOD, TSS, ammonia and phosphorus (Fig. 7).

Exceedances of TSS and BOD can cause a myriad of harmful impacts to aquatic ecosystems. The concentration of suspended particles in water (TSS) can increase turbidity and reduce water clarity, resulting in aquatic life impacts such as clogging gills of fish or filter feeding systems of other aquatic organisms, reducing visibility in waters, hindering photosynthesis and growth of aquatic plants and phytoplankton, concentrating toxins in sediments, altering larval development, and reducing dissolved oxygen (U.S. EPA, 2021a). Sufficient levels of dissolved oxygen are critical for the growth, reproduction and survival of aquatic life and the overall health of aquatic ecosystems (U.S. EPA, 2021b). BOD is a measure of the quantity of oxygen required by microorganisms to decompose organic matter – when BOD is elevated due to higher organic matter load in wastewater, dissolved oxygen in the water column can be drawn down, with negative impacts on aquatic life.

Alterations in pH, nutrients and ammonia can also have substantial negative impacts on aquatic life. pH determines water acidity and is an important mediator of chemical and biological processes in aquatic ecosystems. Changes in pH can alter the toxicity of metals in water, such as aluminum, lead, mercury, copper and arsenic; a decrease in pH can cause these metals to become more soluble and increase toxicity to aquatic life. Additionally, an increase in pH can increase the toxicity of ammonia (U.S. EPA, 2021c). Furthermore, changes in pH can impact biochemical and metabolic processes in aquatic organisms and cause damage to structures such as gills and exoskeletons – in coastal and marine waters, ocean acidification is having detrimental impacts on the ability of calcifying organisms to form shells or exoskeletal structures, with broader impacts on food webs and ecosystem health (NOAA, 2018). Finally, excess concentrations of nitrogen and phosphorus can cause eutrophication of aquatic ecosystems and stimulate harmful algal blooms, leading potentially to blooms of toxic cyanobacteria, fish kills, drawdown of dissolved oxygen, increased turbidity and lowered pH levels (U.S. EPA, 2021d). In particular, ammonia can have toxic effects on aquatic organisms when present at high levels, such as buildup in tissues and blood of organisms with potentially lethal effects. Ammonia toxicity can be exacerbated by co-occuring environmental conditions such as pH and temperature conditions that are stressful to aquatic life (U.S. EPA, 2013).

In addition to having negative impacts on aquatic life, lagoon effluent exceedances can have harmful effects on human health and recreation. Exceedances of fecal indicator bacteria can cause gastrointestinal illnesses such as diarrhea or vomiting when humans consume pathogen-containing waters via swimming or recreation (U.S. EPA, 2021e). Fecal indicator bacteria can reduce the recreational value and health of waters by reducing water clarity, causing foul odors, and increasing BOD, and high fecal indicator bacteria concentrations often accompany high levels of TSS and turbidity, as well as high levels of nutrients and BOD (U.S. EPA, 2021e). TSS can also have human health impacts by interfering with UV disinfection of wastewater and therefore increasing the likelihood of pathogen discharge to surface waters (U.S. EPA, 1999). Additionally, excess nutrients can have negative impacts on both recreational water and drinking water quality, as nutrients can stimulate harmful blooms of cyanotoxin-producing cyanobacteria. If ingested, cyanotoxins can cause adverse human health effects including gastrointestinal illness, liver and kidney damage (U.S. EPA, 2021f). Aquatic ecosystems degraded by effluent exceedances can also reduce the recreational and economic value of waters for human use by reducing aesthetic value, supporting less aquatic life, or harboring toxin-contaminated fish and shellfish unfit for human consumption.

Conclusions

As scientific findings drive water quality requirements that are more stringent, small, rural communities with lagoon systems may face equity, environmental justice, and environmental and public health concerns. In particular, these communities are socioeconomically disadvantaged, with high rates of lagoon effluent exceedances that may pose risks to community and environmental health. Small, rural communities face compounding challenges, as their small populations and limited financial resources make lagoons an appealing wastewater treatment option, but clean water investments can be rendered unaffordable due to heavier financial burdens for ratepayers. EPA is exploring ways to collaborate with states, tribes, and other federal agencies to work directly with these communities to provide financial and technical assistance programs that will provide timely and equitable access to wastewater infrastructure improvements necessary to achieve cleaner water for public and environmental health. A focus on building technical, managerial, and financial capacity in these small communities and through technical assistance providers is also central to ensure sustainable, lasting, and right fit solutions that address the unique needs and circumstances of the lagoon community.

Appendix I: Methods

Lagoon data merging and cleaning

All data merging, cleaning and statistical analyses were performed using the statistical program R version 4.1.1 (R Core Team, 2021). Before merging datasets, each individual dataset was filtered to focus on lagoon systems with the following facility ownership, treatment technology, and discharge method attributes: publicly or semi-publicly (mixed public and private ownership) owned; NPDES permitted with discharge to surface waters; and systems in which lagoons served as the main form of secondary treatment without more advanced treatment technologies. Facilities that were missing NPDES IDs were searched by name in the ICIS-NPDES database and matched to corresponding NPDES IDs when possible. In cases where facility names did not match exactly, the closest name match was chosen, and when a facility had more than one NPDES ID listed, the NPDES ID with a later permit expiration date was selected. In some cases, additional missing data on facilities (major/minor status, facility type, ownership) were also added to replace missing data.

In order to identify lagoon systems in which lagoons served as the main form of secondary treatment, lagoon facilities containing more advanced or add-on technologies were removed from the dataset. If any of the following treatment technologies were found to be present at a facility, the facility was removed from the dataset:

- activated bio filter
- activated sludge
- advanced integrated pond system
- aerobic digestion
- anaerobic digestion or treatment

- anaerobic lagoon or pond
- attached growth process
- biolac
- biological nutrient removal
- biosolids processes (biosolids aerated storage, biosolids air drying/sand bed, biosolids anaerobic digestion, biosolids lagoon, biosolids disposal, biosolids land application, biosolids mechanical dewatering/filter press, biosolids thickening)
- complete mix aerated lagoon
- dissolved air flotation
- drying beds
- duckweed (lemna)
- extended aeration
- fermentation basin
- finishing pond
- freesurface/wetland (marsh system)
- holding or detention pond
- ion exchange
- land application (slow rate without underdrain)
- land treatment
- leach field
- mechanical clarification and color removal
- moving bed/moving bed biological reactor (MBBR)
- NIT reactor
- nitrification processes (nitrification-denitrification, nitrification tower, biological nitrification with combined and BOD reduction)
- overland flow
- oxidation pond or ditch
- ozone injection
- package plant
- rapid infiltration system without underdrain
- retention pond
- rock filter
- rotating biological contractor
- submerged attached growth reactor (SAGR)
- septic tank
- sequencing batch reactor (SBR)
- settling lagoon or settlement cell
- settling pond or tank
- sewer
- sludge lagoon
- storage lagoon or pond
- tertiary treatment
- terrestrial treatment
- total containment pond

- trickling filter
- wetland or vegetative pond
- wet ponds

Facilities that were labeled as either current or projected mechanical plants (CWNS 2012 data) were also removed from the dataset. After removing these treatment technologies, the remaining lagoon systems were either standalone lagoon systems or accompanied by primary treatment and disinfection processes such as grit removal or screening, solids settling, polishing lagoons, sand filters, and chlorination or UV disinfection.

In order to categorize lagoon types present at facilities, facilities were binned into aerated or facultative lagoon categories depending on the type of lagoon present at the facility, and into an ‘unspecified’ category when data on lagoon type was unavailable. Facultative lagoons were identified by several names including waste stabilization lagoons or ponds, hydrograph controlled release (HCR) lagoons, non-aerated lagoons, and natural lagoons. When facilities had both aerated and facultative lagoons, they were binned into the aerated category.

In the EPA National Study of Nutrient Removal and Secondary Technologies dataset, a ‘minor’ facility type label was added to facilities that were designated as having design flow less than 1 MGD, while a ‘major’ label was added to facilities that were designated as having design flow equal to or greater than 1 MGD.

In order to identify lagoon systems with only public or semi-public ownership, lagoons with the following ownership categories were included in the dataset: public, municipal, mixed (public/private), county government, state government, and tribal government. Data on tribal ownership from an EPA 2020 list of tribally owned NPDES permitted wastewater treatment facilities was prioritized when facility ownership data was available from multiple sources and had conflicting ownership designations (e.g., municipal vs. tribal). Facilities labeled as industrial, private or operation ownership types were removed from the dataset.

Additionally, in order to identify lagoon systems that discharged to surface waters, lagoons systems that utilized the following discharge methods were removed from the dataset, unless they were used in combination with discharge to surface waters: irrigation reuse, spray irrigation, evaporation, CSO discharge, overland flow with no discharge, non-discharging, and discharge to another facility.

Facilities with missing data on technology, ownership, and discharge method parameters were not removed from the dataset, thus facilities with missing data on some or all of these parameters may not meet the criteria for lagoon systems targeted by this study. After filtering and cleaning individual datasets, datasets were merged. For facilities missing NPDES IDs, facility names were used to search corresponding NPDES IDs in the ICIS-NPDES database, but those with no matches were removed. In cases where duplicate NPDES IDs were present from multiple datasets, data from duplicate entries were concatenated into a single column for each variable, and duplicate rows of NPDES IDs were removed such that the merged dataset contained only unique NPDES IDs. When removing rows of duplicate NPDES IDs, lagoon data that was derived from ICIS-NPDES was maintained as the primary entry when available (see list of data sources and order of prioritization in main Methods section). Next, data completeness for each variable was examined, and missing values were replaced to the extent possible by replacing them with the first value of concatenated columns (in cases where there had been multiple entries concatenated into one column for duplicate NPDES IDs). When text entries from multiple data sources were found for a given facility, keywords were searched and binned into categories of interest (e.g. lagoon type, minor vs. major facility types, lagoon ownership type). Text and numeric entries were also cleaned to have consistent spelling and formatting. Furthermore, in cases where latitude and longitude values were missing, data downloaded from ICIS-NPDES database was used to fill missing values for latitude and longitude. Data was also filtered to focus on states and tribes, as there were only two facilities from U.S. territories (Guam and the U.S. Virgin Islands).

Data completeness

While the facilities identified through the compilation of these datasets represent the list of known publicly or semi-publicly owned discharging lagoon systems with NPDES permits in the United States, the total number of lagoon systems in this dataset may be an underestimate due to incomplete or outdated data (such as the CWNS 2012 dataset), and some NPDES permits may be currently expired or terminated. Additionally, as some states directly provided data while others did not, data completeness may vary by state, and the list of tribally owned facilities may be incomplete. Design and actual flow data were provided as MGD by facilities, but in cases where there are outliers with very large values, it is possible that there are inaccuracies (e.g., if facilities entered data using different units such as gallons per day instead of MGD).

In the final dataset, there were 4,657 lagoon facilities: data on wastewater treatment technologies or lagoon types (e.g., facultative or aerated) present at facilities was available for 54% of facilities; data on facility ownership type was available for 75% of facilities; and data on discharge method was available for 27% of facilities.

U.S. Census American Community Survey data

In order to analyze demographic and economic data on lagoon communities, the R package ‘tidycensus’ (Walker and Herman, 2021) was used to obtain data from the U.S. Census Bureau American Community Survey (ACS), using 5-year averages from 2015-2019. ACS data was downloaded using Census place-level geography and matched with names of cities, towns, villages, boroughs or Census Designated Places (CDPs) in which lagoon facilities were located. When city names were missing or were not identifiable as Census places, lagoon facility names (e.g., lagoon facility named Upper Kalskag Lagoon used to identify Census place Upper Kalskag City) or locations (latitude/longitude) were used to search locales that could be matched with census places. For facilities that provided county-level locations or lacked a Census place location match, Census data was not analyzed. Although place-level Census geography may not always precisely match lagoon facility service areas, census place-level data nonetheless provided a reasonable representation of service areas because census place population sizes matched most closely with the service area population sizes for lagoons where service population data was available. In addition to place level data, national and state level data were also obtained for comparison to lagoon community data. Census data was obtained from the following ACS Tables:

- Selected Social Characteristics in the United States (DP02)
- Selected Economic Characteristics (DP03)

- Selected Housing Characteristics (DP04)
- ACS Demographic and Housing Estimates (DP05)
- Household Income Quintile Upper Limits (B19080)
- Poverty Status in the Past 12 Months (S1701)

EJSCREEN data

Additional demographic and environmental justice (EJ) data were collected from EPA's EJSCREEN tool (version 1.0; U.S. EPA, 2020), which provides data at the Census Block Group (CBG) level. EJ data for lagoon facilities in the dataset were obtained using the EJSCREENbatch R package version 1.0 (El-Khattabi et al., 2022). EJSCREENbatch uses an areal apportionment method to weigh each Census Block Group (CBG) to calculate Census Block level population-weighted mean summary values for CBGs within a 3-mile buffer radius of the lagoon facilities, expressed as percentiles relative to national data. Data was unavailable for sites in Alaska due to missing population raster data. For both Census ACS and EJSCREEN data, the uncertainty of data estimates is greater in small geographic areas or areas with small populations due to larger sampling error associated with these sites.

The six demographic indicators from EJSCREEN (data from the U.S. Census American Community Survey, using 5-year averages from 2014-2018) include:

1. Low income (percent of population where household income is less than or equal to twice the federal poverty level)
2. People of color (percent of individuals listing racial status as other than non-Hispanic white individuals)
3. Less than high school education (percent of people age 25 or older who did not attain a high school diploma)
4. Linguistic isolation (percent of people in linguistically isolated households in which individuals age 14 years and older speak a non-English language and lack English proficiency)
5. Individuals under age 5 (percent of people younger than 5)
6. Individuals over age 64 (percent of people older than 64).

The eleven environmental indicators (and years of data sources) from EJSCREEN include:

1. National-Scale Air Toxics Assessment (NATA) air toxics cancer risk (lifetime cancer risk from air toxics inhalation, 2014)
2. NATA respiratory hazard index (ratio of air toxics exposure concentration to health-based reference concentration, 2014)
3. NATA diesel PM (diesel particulate matter in air ($\mu g/m^3$), 2014)
4. Particulate matter ($PM_{2.5}$ annual average ($\mu g/m^3$), 2017)
5. Ozone (summer seasonal average (ppb), 2017)
6. Lead paint indicator (percent of housing units built pre-1960 as proxy for lead paint exposure, 2014-2018)
7. Traffic proximity and volume (vehicle count based on average annual daily traffic, 2017)
8. Proximity to risk management plan (RMP) sites (Count of potential chemical accident management plan facilities within 5 km (or nearest one beyond 5 km), each divided by distance in kilometers, 2020)

9. Proximity to hazardous waste facilities (count of hazardous waste treatment, storage and disposal facilities (TSDF) and large quantity generators ((LQG) within 5km, 2020)
10. Proximity to national priorities list (NPL) sites (superfund sites within 5km, 2020)
11. Wastewater discharge indicator (stream proximity and toxic concentration, 2020).

EPA ECHO data

In order to characterize compliance issues faced by lagoon systems, EPA's ECHO website was searched for compliance data using NPDES permit numbers for all facilities in the lagoon dataset on September 20, 2021. Data was retrieved and analyzed for lagoon facility effluent exceedances, facilities discharging pollutants potentially contributing to receiving water impairment, Clean Water Act compliance status, receiving water impairment status, and receiving water designated uses.

Facilities that had effluent exceedances for at least one pollutant within the last 3 years (from September 2021) were counted (based on E90 violation code; ECHO data column "PollWithViolation"). Multiple pollutants with exceedances were often listed for a given facility, and the total number of facilities with effluent exceedances was calculated for each listed pollutant. Pollutant categories that were equivalent but used different analytical methods, or belonged to the same broader category of pollutants with the same environmental impacts, were summed and grouped together. Pollutants that were grouped and counted together include those related to biological oxygen demand ("BOD, 5-day, 20 deg. C", "BOD, carbonaceous [5 day, 20 C]", "BOD, 5-day, percent removal", "BOD, carb-5 day, 20 deg C, percent removal", "BOD, carbonaceous, percent removal", "BOD, carbonaceous [5 day, 5 C]", "BOD, 5-day, dissolved", "BOD, percent removal[total]"); total suspended solids ("Solids, total suspended", "Solids, suspended percent removal"); fecal indicator bacteria ("E. coli", "Coliform, fecal general", "Enterococci", "Total coliforms"); pH ("pH", "pH range excursions, > 60 minutes", "pH range excursions, monthly total accum", "pH, minimum"); and flow ("Flow, in conduit or thru treatment plant", "Flow", "Flow, total", "Flow rate").

Additionally, facilities discharging pollutants potentially contributing to impairment were calculated by summing the total number of facilities that have pollutants with limits or monitoring requirements in their NPDES permit with the potential to contribute to impairment of local water bodies based on the water body impairment cause (ECHO data column "AttainsPossibleNPDESParams"). This parameter indicates pollutants that overlap between the facility's permit parameters and the cause of impairment in the receiving water body and does not necessarily indicate a facility's contribution to the impairment. Multiple pollutants potentially contributing to impairment were often listed for a given facility, and the total number of facilities with potential contributions to impairment was calculated for each listed pollutant. Pollutant categories that were equivalent but used different analytical methods, or belonged to the same broader category of pollutants with the same environmental impacts, were summed and grouped together. Pollutants that were grouped and counted together include those related to fecal indicator bacteria ("E. coli", "Coliform, fecal general", "E. coli, MTEC-MF", "E. coli, colony forming units (CFU)", "Fecal coliform", "Enterococci", "E. coli, thermotol, MF, MTEC", "Coliform, fecal - % sample exceeds limit", "Coliform, fecal MF, MFC broth, 44.5 C", "Coliform, fecal MPN + membrane ftl 44.5 C", "Coliform, fecal, colony forming units", "Coliform, total general", "Fecal coliform, MPN, EC med, 44.5 C"); biological oxygen demand

(“BOD, 5-day, 20 deg. C”, BOD, carbonaceous, 05 day, 20 C”, “BOD, 5-day, percent removal”, “BOD, carb-5 day, 20 deg C, percent removal”, “BOD, carbonaceous, percent removal”, “BOD, percent removal (total)”); total suspended solids (“Solids, total suspended”, “Solids, suspended percent removal”); total nitrogen (“Nitrogen, Kjeldahl, total (as N)”, “Nitrogen, total (as N)”, “Nitrogen, organic total (as N)”, “Nitrogen, inorganic total”, “Nitrogen, Total As N”, “Nitrogen, total Kjeldahl”); pH (“pH”, “pH, maximum”, “pH, minimum”); and mercury (“Mercury, dry weight”, “Mercury, total recoverable”, “Mercury, total (as Hg)”, “Mercury, dissolved (as Hg)”, “Mercury, tot in bot deposits (dry wgt)”, “Mercury, total low level”).

Compliance status of facilities was identified (using the most recent official quarterly QNCR compliance status (Quarter 12) for the NPDES permit; ECHO column “CWPVioStatus”). Compliance status of facilities were grouped into three broad categories:

1. Significant/Category I Noncompliance (SNC) violations (includes the following five violation categories: 1) enforcement action or permit compliance schedule event violation (more than 90 days late), 2) enforcement action or permit compliance schedule reporting violation (more than 30 days late), 3) effluent violations of monthly average limits or SNC-level single event violation, 4) effluent violations of non-monthly average limits, and 5) reporting violations for non-receipt of a discharge monitoring report (DMR))
2. Non-SNC violations (includes reportable noncompliance; other violations (facility has effluent, compliance schedule, permit schedule, or single-event violations in the current quarter but is not considered to be in RNC or SNC); resolved (the facility has returned to compliance with its permit conditions, either with or without issuance of an enforcement action); resolved-pending (facility is in compliance with an enforcement order and has no new additional violations, but the enforcement order has not yet been closed)
3. No violations identified (the facility did not have a noncompliant status generated for the quarter)

Facilities discharging into waters listed for impairment under section 303(d) of the Clean Water Act were identified (ECHO data column *“*AttainsImpWaterFlg”); these are waters not meeting water quality standards and include impairment classes that both require total daily maximum loads (TMDLs; category 5) and those that do not (categories 4a, 4b, 4c).

The number of facilities with particular designated uses for receiving waters (aquatic life use, recreational use, fish consumption use, drinking water use) were calculated by summing the total number of facilities that listed each designate use (ECHO data columns “AttainsDrinkingWaterUseFlg”, “AttainsRecreationUseFlg”, “AttainsAquaticLifeUseFlg”, “AttainsFishcnsmptnUseFlg”); multiple uses were often listed for a given facility.

Furthermore, in order to calculate the percent of publicly owned treatment works (POTWs) that are lagoon facilities relative to the total number POTWs in the United States, the total number of POTWs was identified in the ECHO wastewater facility search on January 26, 2022, by searching “POTW” in the “Facility type” search field for wastewater facilities. The resulting number of facilities (15,979) was used to calculate the percent of lagoon POTWs relative to the total number of POTWs.

Statistical analyses

Characteristics of lagoon systems such as lagoon type, facility ownership type, design flow, major status (facilities with design flow greater than 1 MGD), and whether lagoons were POTWs were calculated as percentages relative to the total number of lagoon facilities, and the total number of lagoon facilities and types (facultative, aerated, unspecified) per state were calculated. The number of tribally owned facilities were also counted per state within which they are located. Lagoon community service area populations were approximated using Census ACS place level total population estimates (DP05_0001).

ACS demographic and socioeconomic variable estimates for lagoon communities were converted to percentages and compared to the national estimate for each variable by calculating the percentage of communities with values above or below the national estimate. Median values were also calculated. The following percentages were calculated using ACS variables for lagoon communities (based on Census place level geography; ACS variable ID numbers and calculations are indicated in parentheses):

- percent of total population age 65 years and over (DP05_0024E/DP05_0001E)
- percent of civilian employed population 16 years and over employed in manufacturing (DP03_0035E/DP03_0004E)
- percent of the population 25 years and over with a bachelor's degree or higher (DP02_0068E/DP02_0059E)
- percent of total households with broadband internet subscription (DP02_0153E/ DP02_0001E)
- percent people of color (the percent of the total population that includes people of color, calculated by subtracting individuals that are white alone (and not Hispanic or Latino) from the total population (DP05_0001E-DP05_0077E)/ DP05_0001E))
- percent of the population for whom poverty status is determined with income below 200% of the federal poverty level (S1701_C01_042E/S1701_C01_001E)

Additional economic variables that were compared to national estimates include the upper limit of the lowest quintile of household income (LQI; B19080_001E) and median household income (MHI; DP03_0062E). Median values of each Census variable were calculated and mean MHI values of lagoon communities were calculated per state, for states in which MHI data was available for more than ten lagoon communities. Ninety-percent margin of error (MOE) values were calculated for means using the MOE formula for means and ratios (U.S. Census Bureau, 2019):

$$MOE\left(\frac{A}{B}\right) = \frac{1}{B}\sqrt{MOE(A)^2 + \left(\frac{A}{B}\right)^2 \times MOE(B)^2}$$

The MOE for the numerator of the mean was calculated using the MOE formula for sums, where A and B represent ACS estimates for a given variable (U.S. Census Bureau, 2019):

$$MOE(A + B + \cdots) = \sqrt{MOE(A)^2 + MOE(B)^2 + \cdots}$$

Statistically significant differences between mean lagoon community MHI values per state and state MHI ACS estimates were evaluated at the 95% confidence interval using a Z-score test where A and B represent ACS estimates, SE_A and SE_B are the standard error values for each estimate (calculated by dividing MOE values by 1.645), and Z_{CL} is the Z score for the desired confidence level (Z_{CL} = 1.960 for 95% confidence interval; U.S. Census Bureau, 2020b):

$$\left| \frac{A-B}{\sqrt{{SE_A}^2+{SE_B}^2}} \right| > Z_{CL}$$

For EJ data, national percentile values of EJSCREEN data were used to calculate the total number (sum) of demographic and environmental EJ indicators ranking above the 80^{th} percentile in lagoon communities. The 80^{th} percentile threshold was used because EPA's EJSCREEN technical documentation recommends this threshold as an Agency-wide starting point to identify areas that may warrant further consideration, analysis, review or outreach (EPA, 2019).

The percent of communities with each value of environmental, demographic, and total (environmental and demographic) EJ indicators greater than 80^{th} percentile were calculated. In order to assess whether communities with higher numbers of environmental EJ indicators above the 80^{th} percentile had higher social vulnerability, the mean and standard error values for national percentiles of percent people of color, percent low income and percent with less than high school education were calculated for communities with the same number of environmental EJ indicators above the 80^{th} percentile (0-7). Because data were not normally distributed, had unequal variances, and sample sizes differed vastly for the numbers of communities with different numbers of environmental EJ indicators above the 80^{th} percentile, a pairwise Wilcoxon rank-sum test with Bonferroni correction was used to determine whether distributions of values for people of color, low income, and less than high school education differed significantly (significant at $p<0.05$) between communities with different numbers of environmental EJ indicators above the 80^{th} percentile (0-7).

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