At the Expense of the Environment: *Economic and Regulatory Factors Impacting the Location and Management of Concentrated Animal Feeding Operations (CAFOs) in North Carolina*

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ABSTRACT North Carolina is the second largest pork producer in the United States where 10 million hogs are raised annually resulting in 10 billion gallons of waste. Environmental risks, including the contamination of ground and surface water contamination, exist when the amount of nutrients in animal waste exceeds the assimilative capacity of available farmlands. This case study introduces students to the environmental impact of hog production associated with concentrated animal feeding operations and the externalized costs of industrial farms on freshwater and coastal ecosystems. A particular focus is on factors related to the location, governance, and monitoring of these industrial farms. The case engages with the long-standing challenge of how to better align economic development with environmental protection. The case allows students to explore the competing motivations of a diverse group of stakeholders and appreciate the challenges faced when private economic decisions made by business entities move into the public realm due to threats to the health and safety of the public and environment. Students should gain insight into the economic and regulatory factors that contributed to the proliferation of large, industrialized hog farms in North Carolina and how these same factors impact the development and implementation of solutions to mitigate environmental risk. **KEYWORDS** CAFO, swine, water quality, environmental law, waste management, agriculture, hog, pig, pork

INTRODUCTION

Agriculture/agribusiness is the largest industry in North Carolina, where more than 52,000 farms occupy 8.5 million acres of land [1]. North Carolina is currently the second largest producer of hogs in the United States [2]. North Carolina farming led to cash receipts of US$10.687 billion in 2019 with US$2.169 billion attributable to swine production [3]. The structure of farming in North Carolina, and the United States as a whole, has changed dramatically in the last 50 years shifting from small, family-owned farms to large, industrial operations [4]. In the 1960s, there were over 1 million hog producers in the United States, but by 2005, the number of swine producers had dropped to 67,000 with little change in production [5]. Between 1992 and 2004, the market share of operations with 2,000 or more heads increased from less than 30% to over 80% [6]. In 2005, 55% of the total national inventory was produced by 110 operations, each producing more than 5,000 hogs annually [5, 6]. Consolidation and vertical integration of all stages of production and marketing continue today [7].

Large industrial farms where animals are kept and raised in a confined space are defined as animal feeding operations (AFOs) and are regulated by the U.S. Environmental Protection Agency (EPA). In contrast to farms where animals graze or feed in pastures or fields, AFOs congregate all production operations (animals, feed, and waste) in a small land area. Confined animal feeding operations (CAFOs) are large AFOs. For swine farms, a CAFO is defined as 2,500 hogs weighing more than 55 pounds and kept in a confined site for more than 45 days per year [8]. An AFO that discharges manure or

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wastewater into a ditch, stream, or waterway, however, is defined as a CAFO by the EPA regardless of size [8].

The proliferation of swine CAFOs in North Carolina has led to environmental concerns and conflict between multiple stakeholder groups including industry, neighboring communities, environmentalists, and elected officials. When properly located, managed, and monitored, CAFOs can leverage economies of scale and efficiencies in feeding and housing animals to provide a benefit to consumers through low-cost food commodities [9]. Stakeholder groups, however, disagree about the risks to the environment and public health posed by CAFOs, the potential economic benefit of CAFOs to communities, and the regulation and enforcement of these operations. Given a wide variety of stakeholders with differing goals, values, responsibilities, and available resources, solutions to mitigate any potential negative impacts associated with CAFOs are likely to be complex. *This case study examines the contributing factors to the rise and impacts of swine CAFOs in North Carolina with a particular focus on factors related to the location and regulation of these industrial farms*. The case may be used to inform efforts to facilitate changes to reduce the risk of environmental damage from CAFOs in other locations.

CASE EXAMINATION

The Rise of the Factory Farm in North Carolina

The proliferation of CAFOs has been attributed to technological advances that created economies of scale [4]. New technologies that reduce costs and increase the efficiency of meat production, such as the mechanization of swine slaughterhouses, create scale economies where costs are reduced as the size of the operation grows [4, 10]. As a result, larger farms tend to realize higher profits, which provide an incentive for producers to develop larger operations [10]. Large farms with lower costs of production yield lower retail food prices. Lower retail prices, however, add additional pressure on small farms with higher costs causing small farms to be priced out of the market [10].

In North Carolina, Wendell Murphy was one of the first to apply the CAFO model to swine production in the 1970s. A successful swine farmer and businessman, Murphy was also a successful politician [11]. He served five terms in the North Carolina legislature. He sponsored and helped pass legislation that eliminated sales tax on swine farm equipment and prevented local authorities from using zoning authority to address odor issues associated with swine farms [12]. Following the implementation of these bills, collectively known as Murphy's laws, the swine industry in North Carolina grew rapidly [12]. Today, state records indicate that there are 2,148 swine farms in the state, although only 1,477 farms raise enough swine to meet the EPA definition of a CAFO (figure 1) [13–16]. The majority of CAFOs are owned or contracted by large agriculture corporations that integrate farming, processing, finishing, packaging, and distribution. Smithfield Foods is the largest pork producer both in North Carolina and in the United States and was purchased by a Chinese conglomerate in 2013 [17].

Environmental Impact of Swine CAFOs in North Carolina

CAFOs produce large amounts of concentrated wastes that include a variety of pathogens, nutrients, and antibiotic and hormone residues [13]. North Carolina produces 10 million swine each year, which produce more than 10 billion gallons of waste [18]. For context, CAFOs located in Duplin County, North Carolina, raise 2.2 million swine annually, which produce twice as much urine and feces than the entire New York City metro area home to over 20 million people [19]. Annually, swine CAFOs in North Carolina produce 124,000 metric tons of nitrogen and 29,000 metric tons of phosphorus [20]. Notably, most of the feed that supports this production originates from the Midwest indicating that these are additions of nutrients to the natural internal transport and cycling of nitrogen and phosphorus [21].

Most swine CAFOs in North Carolina use liquid waste management systems that flush fecal waste into open pits or "lagoons." Waste is periodically washed from the containment facility into waste lagoons where anaerobic bacteria transform organic material into methane and carbon dioxide and denitrification occurs [20, 22, 23]. As the waste breaks down, farmers apply both solid and liquid waste components onto fields as fertilizer. Despite the efficacy of this system, solid sludge must regularly be removed to preserve the function of the waste lagoons [24]. Furthermore, the liquid waste still retains high concentrations of nitrogen. From March to September, land spraying of liquid waste is allowed to improve the production of Bermuda grass, which is typically used as a cover crop to absorb excess nitrogen [25].

Spraying of liquid waste contributes to the volatilization of ammonia (NH_3). Nearly 80% of ammonia

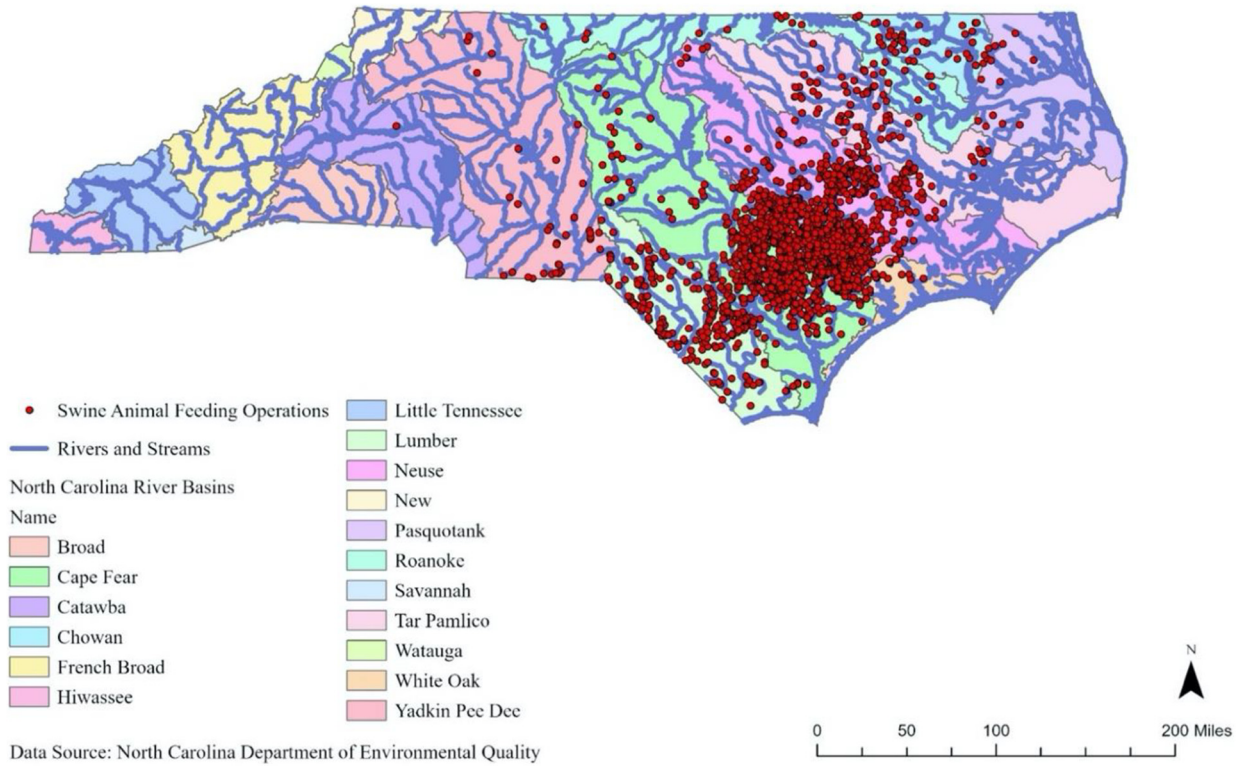

FIGURE 1. Swine concentrated animal feeding operations located in North Carolina organized by major river drainage.

emissions from all swine operations in the United States originate in North Carolina [26]. Nitrogen inputs in the form of ammonia into the atmosphere represent 70–80% of all swine waste–related nitrogen [20] and 40% of novel nitrogen inputs into North Carolina coastal ecosystems [20, 26, 27]. Terrestrial application of the solid sludge is also allowed, but high phosphorus concentrations in the waste contribute to nitrogen runoff [20, 24]. Furthermore, liquid and solid wastes spread heavy metals from swine feed, unmetabolized pharmaceuticals, and more than 100 human pathogens onto the surrounding landscapes [24].

While industry advocates deny significant environmental impacts [28], there are now many studies that indicate swine CAFOs in North Carolina present a significant environmental risk due to both accidental breaches of hog waste lagoons and chronic effects associated with largely unregulated pollution through the atmosphere and groundwater [20, 29–34]. Chronic contamination of ground and surface water results from each stage in the swine waste treatment and disposal [20, 23, 35]. Despite requirements for waste lagoons to be lined with a clay or synthetic liner, evidence suggests groundwater can be contaminated within 3.5–5 years following the introduction of swine waste, and groundwater regularly exceeds EPA safe drinking water limits for nutrients [35]. Surface runoff also carries excess nutrients from the fields into adjacent surface waters [20, 23, 25, 31, 34, 36–39]. Nitrate concentrations in receiving streams regularly exceed 10 mg/L that exceed EPA standards [39, 40].

All uses of receiving rivers and coastal zones have been impacted by CAFO-related pollution. Eutrophication and associated anoxia have had far-ranging effects [37]. Both the Neuse and Cape Fear Rivers have been listed among the top 10 most endangered rivers in the United States by advocacy groups [41]. Excess phosphorus in particular stimulates nitrogen-fixing cyanobacteria contributing to anoxia [37]. These bacterial communities also produce toxins that impact the physiology and locomotor performance of organisms that come into contact with these blooms [42–44].

Further, excessive nutrient loads contribute to the growth of toxic dinoflagellates including *Pfiesteria piscicida* and *Pfiesteria shumwayae* [45]. *Pfiesteria* have bloomed downstream of CAFOs in the Neuse, Pamlico, and White Oak River basins [20], where they contributed to the death of over 1 billion fish in the Neuse River alone in 1997 [45]. Together, low dissolved oxygen, algal blooms,

TABLE 1. Number of Swine Concentrated Animal Feeding Operations (CAFOs) and Fish Kill Events (1996–2016) by River Basin.

North Carolina River Basin	National Basin	Total Acres	Population	Current Number of Swine CAFOs	Number of Impaired Waterways	Number of Fish Kill Events 1996–2016
Neuse†	Atlantic	3,879,756	1,687,462	467	181	236
Cape Fear†	Atlantic	5,864,701	2,072,305	1,152	148	141
Tar-Pamlico†	Atlantic	3,934,445	472,629	82	111	130
Pasquotank	Atlantic	2,154,534	118,913	12	55	44
Lumbar	Atlantic	2,130,799	472,276	193	55	23
Roanoke	Atlantic	2,235,430	289,784	23	18	13
White Oak	Atlantic	884,173	336,210	42	306	23
Yadkin-Pee Dee	Atlantic	4,621,350	1,675,937	37	115	53
Broad	Atlantic	968,893	204,803	0	12	3
Chowan	Atlantic	830,901	61,548	39	2	22
Catawba	Atlantic	2,102,659	1,560,563	1	66	42
Savannah	Atlantic	109,611	5,563	0	0	0
New/Watauga	Interior	613,847	95,765	0	8	5
French Broad	Interior	1,181,436	485,140	0	50	15
Hiwassee	Interior	412,375	38,237	0	9	0
Little Tennessee	Interior	1,150,152	94,566	0	24	1

Note: NSWs are at high risk for eutrophication and frequently experience algal blooms, growth of toxic dinoflagellates, low dissolved oxygen levels, and fish kills. Excessive nitrogen and phosphorus from swine CAFOs have been implicated as one contributing factor to widespread eutrophication and fish kills in North Carolina river basins. Population based on 2010 Census [47]. Number of impaired waterways reported to Environmental Protection Agency in 2019 by NC DEQ [48]. Only official fish kills confirmed by the North Carolina Department of Environmental Quality are reported. Fish kills reported by the public but not verified by the state are not included [49].

†Basins with waterways identified as Nutrient Sensitive Waterways (NSW) by the North Carolina Department of Environmental Quality (NC DEQ).

and blooms of toxic dinoflagellates have led to hundreds of fish kill events in the state (table 1, figure 2) [36, 46]. Compounding chronic concerns associated with non-point source pollution originating with swine CAFOs, catastrophic events that result in the breaching of waste treatment lagoons exacerbate environmental impacts. Although data on spills are difficult to ascertain due to a lack of reporting and enforcement [50, 51], there have been at least four large spills of over 1 million gallons of waste in the past 2 years in the state (table 2) [52–54]. In 1995, a lagoon breach in Onslow County resulted in 25 million gallons of swine waste entering the New River estuary, resulting in fish kills and long-term shifts in algal communities directly impacting the entire food web of the Cape Fear estuary [20, 33]. Furthermore, anoxic conditions and blooms of cyanobacteria following spills can persist for multiple months after the spill inhibiting ecological recovery [37]. These effects have been documented more than 30 km downstream from the source (figure 3) [66].

Besides the strong negative effects of hypoxia on local food webs, advisories against swimming, boating, and fishing cause significant economic losses for local municipalities [67]. Following breaches of swine waste treatment lagoons, cyanobacteria often exceed the World Health Organization's recommendations for safe recreation of 100,000 cells per ml [18, 37]. The economic costs of eutrophication and harmful algal blooms are estimated at US$2.2 billion annually in the United States [67]. Stocks of all key commercial species (e.g., southern flounder, striped bass, sea trout, red drum, croaker, blue crabs) have declined significantly over the past 20 years [68]. With an industry valued at US$97 million in 1997, frequent fish kills have become common in North Carolina waterways, negatively impacting the local economy and unemployment [69, 70].

Impact of CAFOs on Human Health

Swine wastewater contamination in the form of pathogens [71], veterinary antibiotic pharmaceuticals [72], and heavy metals [37] can negatively impact human health.

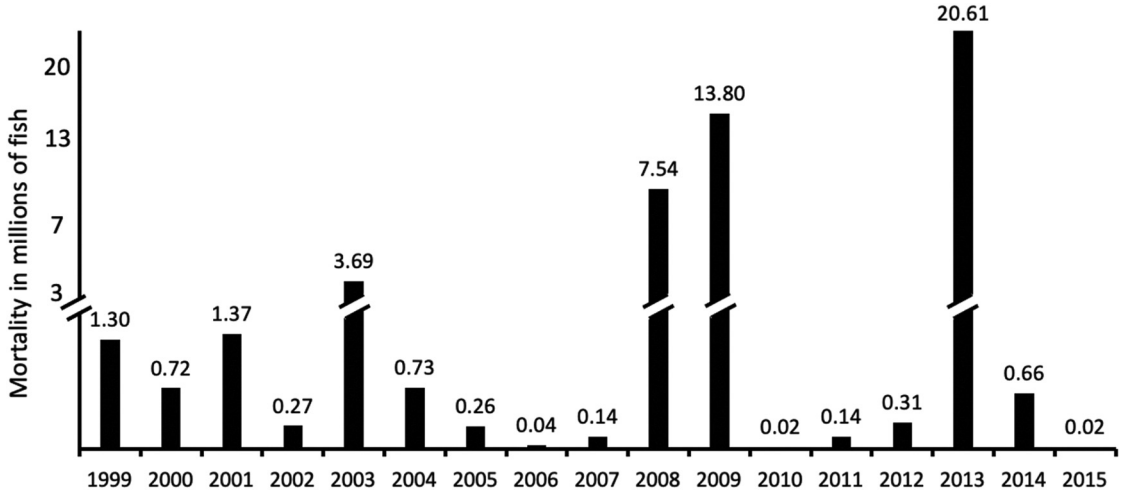

FIGURE 2. Total mortality associated with fish kills recorded in North Carolina, 1999–2015. Note: Only mortality from official fish kills investigated by the North Carolina Department of Environmental Quality is reported. Fish kills reported by the public but not verified by the state are not included. Estimates from 2009 are noted to be extremely conservative and that actual fish counts could have approached 26 million. Data Source: North Carolina Division of Water Resources annual reports 1999–2005.

There are more than 70 peer-reviewed papers indicating negative health effects of swine CAFOs on human health [5]. Individuals working in CAFOs are at increased risk of respiratory diseases including bronchitis, acute respiratory distress syndrome, and other asthma-like syndromes [5]. In addition to negative health effects on workers, CAFOs impact the health of neighboring communities. A recent study examining mortality and health outcomes in North Carolina found that communities located near swine CAFOs have higher all-cause mortality and infant mortality even after adjusting for age, income, education, insurance coverage, availability of primary care providers, and smoking prevalence [73]. Similarly, in a study that controlled for age, gender, race, economic status, and smoking in the household, children attending North Carolina schools within 3 miles of a hog CAFO had increased frequencies of asthma and asthma-related medical visits than students who attend schools further away [74].

Location of CAFOs in North Carolina Exacerbate Human and Environmental Concerns

In 1982, all but one of North Carolina's counties had a commercial hog farm, but by 1997, approximately 95% of swine CAFOs in North Carolina were located in the coastal plain [75]. Given the noxious smell of swine CAFOs, the "not in my backyard" phenomenon has led to most CAFOs being clustered in rural, low-income, minority communities in eastern North Carolina where land is inexpensive, and populations tend to have lower levels of education and political influence [76, 77]. After correcting for rurality, swine CAFOs are 3.30 times more likely to be located in communities with 80% people of color relative to those without a significant proportion of people of color [78]. Because CAFOs also reduce the value of surrounding properties, their presence increases the likelihood that other CAFOs will be located nearby [79].

The location of CAFOs in the coastal plain (figure 1), however, is particularly problematic because of sandy soils and high water tables. These conditions allow for easy movement of pollution from lagoons and spray fields into ground and surface water [77]. North Carolina ranks among the highest in the nation in vulnerability to manure nutrient contamination from CAFOs due to the coastal plain's soil runoff potential, soil percolation, erosion, and land application of treated waste [20].

Further, the absence of rural zoning allowed for hundreds of CAFOs to be established in flood plains. Locating these farms and their associated waste lagoons in flood plains increases the likelihood of environmental disaster when flooding occurs. The clustering of CAFOs in the coastal plain is particularly problematic in North Carolina because of the risk of hurricanes. North Carolina is ranked third in the nation in hurricane exposure, and at least one storm is expected to impact the state each year [18, 80]. In 1999, Hurricane Floyd destroyed six facilities, flooded over 55 lagoons, and led to 120,000,000 gallons of untreated swine waste into

TABLE 2. Major Discharges to Freshwater Systems From Swine Waste Lagoons in North Carolina, 2018–2020.

Event	Date	Amount of Waste Spilled (Gallons)	Impacted River Basin	Impacts/Violations
Breach: DC Mills Farms	December 2020	1,000,000	Tributary of Trent River Neuse River Basin	Fecal coliform bacteria exceed state's surface water maximum [55]. Four violations including failure to prevent the discharge of animal waste to surface waters, failure to notify the public. Investigation is ongoing [56].
Breach: B&L Farms (contract Smithfield)	June 2020	3,000,000	Discharged into Starlins swamp and unnamed tributary Cape Fear River Basin	Fish kill of >1,000 fish, including brim, catfish, bass, and other freshwater species [57]. Extremely high fecal coliform bacteria levels [57]. Multiple violations including failure to prevent discharge of waste to surface waters or wetlands, failure to maintain protective vegetative cover on lagoon embankment, and failure to maintain records and make them readily available. US$87,000 fine [58].
Illegal draining: Lanier Farms	August 2018	1,000,000	Discharged into woodland; drained into Trent River Neuse River Basin	State informs residents to avoid contact with water in Trent River over Labor Day weekend [59]. Groundwater samples indicate extremely high levels of fecal coliform, nitrogen, and phosphorus [60]. 11 Violations and extensive history of noncompliance. US$64,000 fine [61].
Hurricane Florence: six breaches; 23 lagoons inundated by flood water; 31 lagoons overflowed	September 2018	7,300,000	Cape Fear Neuse River Tar/Pamlico	>5,500 hogs drown [62]. Marked increase in *Escherichia coli* and fecal coliform bacteria in drinking water in eastern North Carolina; 14.9% of wells tested positive versus 2% before the storm [63]. State warns against swimming in all coastal waters due to high levels of bacteria [64]. Widespread fish kills—mostly attributed to anoxia [65].

North Carolina waterways [81]. In 2018, there were 926 CAFOs located in areas where the U.S. National Weather Service said flooding was imminent during Hurricane Florence [14]. Although industry advocates applauded findings that 98% of hog farms were undamaged during Hurricane Florence, the 2% that were impacted led to the discharge of 7 million gallons of swine waste into North Carolina waterways [82].

Regulation and Enforcement

The EPA began regulation of AFOs and CAFOs based on the 1972 Clean Water Act, which identified "feed lots" as point source polluters. The National Pollutant Discharge Elimination System (NPDES) was established as a permitting program and set limitation guidelines and standards for CAFOs since the 1970s [9]. These regulations were in effect for over 25 years until the EPA issued new rules in 2003. The new rules established best management practices for waste treatment and required CAFOs to implement waste management plans and submit annual performance reports [83]. The 2003 rules were challenged in court by farm industry groups, which led to a revision of the rules in 2008 that eliminated the requirement for CAFOs to apply for an NPDES permit. The lawsuit also eliminated a provision that held CAFOs to a zero-discharge limit where direct hydrologic connections to surface water exist [84].

FIGURE 3. Satellite imagery of North Carolina waterways following hurricane-related flooding. Natural-color imagery and combined visible and infrared satellite data showing colored dissolved organic matter impacting water quality after Hurricane Florence (September 20, 2018). Credits: NASA Earth Observatory images by Joshua Stevens using Landsat data from the U.S. Geological Survey.

In North Carolina, permitting has been controlled by the North Carolina Department of Environmental Quality since 1992 and General Statute 143–215.10B that defined "animal operations" as feedlots involving more than 250 swine and a liquid waste management system (e.g., lagoons) [85]. Currently, North Carolina CAFOs are required to have a certified animal waste management plan that defines the fields to which waste is applied and the cover crops to which it will be applied [85]. Notably, the establishment of new swine CAFOs that employ anaerobic waste lagoons as the primary waste treatment has been banned in the state since 2007 [85]. North Carolina claims it has the strongest

TABLE 3. Externalities of Confined Animal Feeding Operations.

Type	Costs
Subsidies	
Subsidized grain yields low swine feed costs.	Indirect grain subsidies equated to US$35 billion between 1997 and 2005 [93].
USDA Environmental Quality Incentives Program provides assistance to small and medium farms to reduce environmental impacts. CAFOs became eligible in 2002.	In 2007, CAFOs received US$125 million. Swine CAFOs receive 37% of EQIP funding [55].
Water pollution	
Swine CAFO waste is treated in treatment lagoons with high nutrient concentration and a high risk of accidental discharge into nearby waterways.	All stocks of commercially harvested fish have declined in the past 20 years. The industry is valued at US$97 million [71, 72]. 2.4 Million residents rely on groundwater for drinking water that is contaminated by seepage from waste lagoons [56].
Air pollution	
70% of swine manure nitrogen is volatilized and is a respiratory irritant.	USDA estimates total costs for control of air and water pollution would be US$1.6 billion annually but would only reduce CAFO emissions by 40%.
Contaminated soil	
No guidelines exist for the remediation of swine manure and lagoon contaminated soils.	Soil remediation of CAFOs is estimated to cost more than US$4.1 billion [57].
Antibiotic resistance	
More antibiotics are produced for CAFOs than for humans. Widespread use for nontherapeutic purposes contributes to resistance.	Antibiotic resistance increases health care costs by US$4 billion annually [93]. Total costs of antibiotic resistance are estimated to be US$30 billion annually [58]. Eliminating nontherapeutic use of antibiotics would cost consumers US$5–10 per person or US$1.5–3 billion annually [59].
Property value loss	
Noxious smells from CAFOs have reduced property values within a 3-mile radius.	Affected property values decline by 5–40% valued at a loss of US$26.5 billion.

Note: CAFOs = confined animal feeding operations; USDA = U.S. Department of Agriculture.

permit program for CAFOs in the country and is one of the only states that require annual inspection of every facility. These claims are undermined, however, by the fact that North Carolina has one of the lowest levels of Clean Water Act compliance in the nation [86]. North Carolina's Right to Farm Act has also protected CAFOs by significantly limiting the right for citizens to bring public nuisance suits against agricultural farms [87].

CAFO-related contamination is poorly regulated by both federal and state regulations. Atmospheric pollution from CAFOs is currently not regulated at all despite being a major source of nitrogen [20, 26, 27]. At the federal level, the Trump administration has weakened the National Environmental Policy Act (NEPA), which required that any large-scale project including CAFOs that receive federal funding or loans to undergo an

environmental review to assess the project's impact on water and air quality [88]. In July 2020, the Trump administration exempted CAFOs from environmental review and limited public information requirements [88]. More generally, federal inspection and enforcement of CAFO waste regulations have declined significantly in the past 10 years. In 2012, there were 19,835 farm inspections nationally by the EPA, but by 2016, there was only 13,500—a decline of 32% [89]. The lack of investment in regulatory enforcement is a significant barrier to ensuring that CAFOs are properly monitored and managed.

In North Carolina, compliance of CAFOs with minimal environmental requirements is limited by a lack of enforcement resources in the North Carolina Department of Environmental Quality (NC DEQ). Between 2008 and 2018, NC DEQ eliminated 376 jobs dedicated to providing enforcement of environmental regulations and has experienced a 34% inflation-adjusted decrease in funding during this period (the fourth largest decrease in the United States) [90]. As a result, NC DEQ only filed 33 public complaints against livestock operations in North Carolina between January 2008 and April 2018, where other hog-producing states have registered thousands [51]. In 2018, the top state official overseeing annual inspections of North Carolina's 2,200 swine CAFOs admitted in court testimony that "It's possible that the facility could be in violation and it's possible that we might not find out," noting that annual inspections could allow a facility to be in violation 364 out of 365 days of the year [91].

Unfortunately, legislation enacted to more closely regulate swine CAFOs in North Carolina has had little impact on improving existing farms to date. The North Carolina's 2007 Swine Farm Environmental Performance Standards Act banned new lagoons and mandated the use of environmentally superior technologies (ESTs) to reduce emissions and prevent waste discharges into surface and ground waters for new operations. To reduce the impact on existing CAFOs, this law also provided funds to offset some of the costs for operators to upgrade their lagoons and implement ESTs. Five years after the law had been enacted, however, only eight of all the swine CAFOs in North Carolina had participated suggesting that the legislation was largely ineffective [12]. Thus, little improvement has been made to reduce the risk of aquatic contamination from swine waste.

Possible Strategies to Reduce Environmental Impact of CAFOs

Developing solutions to reduce the impact of CAFOs on water quality across North Carolina is challenging. The swine industry is highly competitive, and few financial incentives exist to minimize environmental impact. The industry continues to have strong political power in North Carolina that has made requiring stricter enforcement of environmental regulations difficult. Despite these challenges, strategies to reduce the environmental impact include litigation aimed at forcing CAFOs to take responsibility for externalized costs associated with environmental pollution and public policies that provide increased funding to support enforcement and regulation of CAFOs, support relocation of farms, and the development of new pollution mitigation strategies.

Litigation

The primary motive for CAFOs is to maximize profits. By externalizing many costs to surrounding areas and society, CAFOs earn higher profits. CAFOs have been successful in externalizing the cost of water and atmospheric pollution onto the public (table 3) [92]. Recently embraced by environmental groups, litigation is a strategy to attempt to enforce CAFOs to incur some of the externalized costs and to enforce compliance with environmental regulations. In 2014, 25 cases were filed in North Carolina against Murphy-Brown, a subsidiary of Smithfield foods [15]. Plaintiffs argued that they were owed punitive damages due to Murphy-Brown's wrongful actions that prohibited them from enjoying the use of their homes due to odors, flies, and waste spraying [15]. Trials began in 2018, and plaintiffs won the first five trials and were awarded multimillion-dollar verdicts from separate juries. Although state-imposed limits and appeals reduced the awards, these verdicts have provided members of rural communities hope that court action could force CAFOs to reduce air and water pollution [15]. To date, litigation has not resulted in industry-wide change.

Increased Regulation and Enforcement

To reduce the environmental impact of swine CAFOs, public policies are needed that strengthen environmental regulations, improve efforts to monitor and enforce regulations, and increase incentives/penalties for compliance/noncompliance. First and foremost, enacting monitoring and regulations surrounding atmospheric emissions of nitrogen is essential [20]. Current monitoring of CAFOs

in North Carolina is inadequate. Novel and stricter regulation will require additional funding and coordination among regulatory agencies including the EPA, U.S. Department of Agriculture (USDA), and the NC DEQ. The primary obstacles to increased regulation and monitoring are financial and political. Industry is likely to object to any increased regulation and enforcement efforts and have well-funded political action committees that actively lobby against increased regulation [15].

Risk Mitigation: The North Carolina Swine Buyout Program

One of the most effective strategies to prevent CAFO lagoons from flooding during hurricanes is to relocate farms out of the 100-year flood plain. North Carolina implemented a buyout program to encourage farms to relocate. Since 1999, the program has received four state grants and support from the USDA. Farms with a history of flooding, proximity to a municipal water supply, waste lagoons without technological upgrades, and low elevation of the swine barn and lagoons are eligible for the program [14]. Qualifying farms must also agree to implement best practices in waste management including the construction of a 100-foot forested riparian buffer and a conservation easement [94].

As of 2018, over 100 farms have applied for the buyout program, and 43 farms have been relocated out of the 100-year flood plain. The program has successfully eliminated 106 waste lagoons in the floodplain and prevented the release of hundreds of thousands of swine waste. Over 30 former locations of participating farms have subsequently flooded during recent hurricanes [93]. Unfortunately, limited funding has prohibited wider application of this program. As of 2018, the buyout solution has cost taxpayers US$18.7 million [95]. In comparison, the total costs associated with damage during Hurricane Florence were estimated at US$24 billion [96]. In 2019, the North Carolina General Assembly provided another US$5 million to restart the swine buyout program as part of a US$280 million disaster relief program following Hurricane Matthew [97, 98].

Other Risk Mitigation Strategies

To reduce the environmental impact of CAFOs described above, new cost-effective technologies to treat swine waste are needed. In 2000, North Carolina reached an agreement with industry leaders Smithfield Foods and its subsidiaries to fund a US$17.3 million research project to create new technology that could replace the traditional waste lagoon model [99]. The goals were described in North Carolina 15A NCAC 02T.1307 and included to "(1) eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff; (2) substantially eliminate atmospheric emissions of ammonia; (3) substantially eliminates the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located; (4) substantially eliminates the release of disease transmission vectors and airborne pathogens; and (5) substantially eliminates nutrient and heavy metal contamination of soil and groundwater" [99, 100]. At least five candidate technologies were developed, but at the conclusion of the project, both industry leaders and the North Carolina Attorney General concluded that a superior environmental technology could not be adopted in an economically viable manner. Academic and environmental groups disagreed, however, noting that the economic evaluation conducted by the State did not account for the costs associated with pollution [12]. None of the new waste management technologies have been widely implemented [99].

Another risk mitigation strategy is the creation of constructed wetland systems. Constructed wetland systems use plant life to remove nutrients from swine wastewater [101]. Evidence has suggested that constructed wetlands can be highly effective though costly to implement [101, 102]. North Carolina has established voluntary programs to reduce nonpoint source pollution, which provide grants and in-lieu fee mitigation programs designed to assist private and public entities comply with state and federal compensatory mitigation for streams, wetlands, riparian buffers, and nutrients [103, 104]. Programs can provide 75% cost-share assistance to an applicant to install best management practices that benefit all citizens by improving water resources in North Carolina [105]. These programs have not been widely used by swine farmers but could be better leveraged to mitigate risks associated with CAFO pollution from swine lagoons. Increased outreach and publicity of these programs could help increase voluntary participation.

CONCLUSION

Both economies of scale and legislation that was favorable to agriculture interests contributed to the rapid proliferation of large swine CAFOs throughout North Carolina [12]. Although industry interests often allege that CAFOs

are not an environmental risk [82], data clearly indicate that CAFOs and associated manure nutrient contamination negatively impact freshwater and coastal ecosystems and the local communities that rely on them for recreation and tourism [20, 33, 36, 38]. Eutrophication of waterways contributes to low dissolved oxygen levels, algal blooms, growth of toxic dinoflagellates, and large fish kill events. Lax regulation and enforcement continue to allow CAFO owners and operators to externalize costs associated with swine waste-related pollution.

The concentration of CAFOs in rural Eastern North Carolina was driven by financial factors; however, clustering of these industrial farms in predominately minority communities raises concerns of environmental justice [12]. The location of CAFOs in the coastal plain is especially problematic due to increased risk of flooding and conditions that facilitate the leaching of nutrients into ground and surface water [77]. Widespread acute pollution from flooding due to hurricanes has been a recurrent problem in the state and is inevitable as long as CAFOs continue to be located in flood plains.

The agriculture industry continues to have significant political influence leading to laws that shield CAFOs from expensive lawsuits aimed at encouraging CAFOs to protect the environment and in limiting information sharing with the public [15]. Public policies that tighten enforcement and regulations on CAFOs, provide incentives for CAFOs to move out of flood plains, and facilitate a shift in demand for more environmentally and economically sustainable livestock production are needed to protect public health and freshwater ecosystems from swine CAFO pollution.

CASE STUDY QUESTIONS

1. What are the environmental impacts of CAFOs on freshwater and coastal ecosystems?
2. What are the socioeconomic factors that contribute to the placement of CAFOs in environmentally sensitive or risky areas?
3. What changes would reduce the risk of environmental damage from CAFOs?
4. What changes in state and federal policies could facilitate changes in CAFO waste management?
5. How could policy makers encourage better CAFO waste management without negatively impacting the CAFO operations?

AUTHOR CONTRIBUTIONS

WRC conceived, designed, interpreted, and wrote the case; KKC provided comments and revisions at each step in the process.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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