The Potential Impact of Flooding on Confined Animal Feeding Operations in Eastern North Carolina

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Thousands of confined animal feeding operations (CAFOs) have been constructed in eastern North Carolina. The fecal waste pit and spray field waste management systems used by these operations are susceptible to flooding in this low-lying region. To investigate the potential that flood events can lead to environmental dispersion of animal wastes containing numerous biologic and chemical hazards, we compared the geographic coordinates of 2,287 CAFOs permitted by the North Carolina Division of Water Quality (DWQ) with estimates of flooding derived from digital satellite images of eastern North Carolina taken approximately 1 week after Hurricane Floyd dropped as much as 15–20 inches of rain in September 1999. Three cattle, one poultry, and 237 swine operations had geographic coordinates within the satellite-based flooded area. DWQ confirmed 46 operations with breached or flooded fecal waste pits in the same area. Only 20 of these 46 CAFOs were within the satellite-based estimate of the inundated area. CAFOs within the satellite-based flood area were located in 132 census block groups with a population of 171,498 persons in the 2000 census. African Americans were more likely than whites to live in areas with flooded CAFOs according to satellite estimates, but not according to DWQ reports. These areas have high poverty rates and dependence on wells for drinking water. Our analysis suggests that flood events have a significant potential to degrade environmental health because of dispersion of wastes from industrial animal operations in areas with vulnerable populations. *Key words*: agriculture, disasters, environmental justice, GIS, livestock, water pollution. *Environ Health Perspect* 110:387–391 (2002). [Online 7 March 2002]
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Confined animal feeding operations (CAFOs) produce concentrated wastes that include numerous pathogens, antibiotic and hormone residues, and nutrients (*1–4*). Many CAFOs in the United States use liquid waste management systems that flush fecal waste into open pits, euphemistically called "lagoons," and spray the liquid component on fields. Excessive nitrogen and phosphorus can lead to eutrophication of rivers and estuaries, where they can promote harmful algal blooms; pathogens and chemical wastes can threaten human health directly through contamination of ground and surface water (*5*).

Although seepage from waste pits and spray areas may contaminate ground water over long periods of time (*2*), most CAFOs are classified and permitted as nondischarge facilities under the assumption that all waste is contained onsite. Heavy rain events that occur periodically in the southeastern United States, a region affected by large tropical storms as well as localized thunderstorms, may prevent retention of all wastes onsite. In 1996, 22 fecal waste pits were reported to have been ruptured or inundated following flooding from Hurricane Fran, and one major spill was reported following Hurricane Bonnie in 1998 (*5*). However, the logic of the nondischarge classification was questioned on a large scale in 1999 when Hurricane Floyd dumped as much as 15–20 inches of rain in eastern North Carolina, an area where thousands of CAFOs have been issued nondischarge permits to operate. The impact of subsequent flooding on confinement buildings, waste pits, and spray fields was documented in numerous still photographs and video footage made by journalists, environmental groups, and private citizens (*6–9*).

Besides the effects of inundation and damage to fecal waste pits, pollutant discharge occurs because of practices necessary to protect waste pit structures from collapse. Permits require maintenance of adequate free board in waste pits to prevent weakening and collapse of their earthen walls. In theory, during the growing season and under nonflood conditions, free board can be maintained by spraying waste at agronomic rates as required by regulations. However, when free board is reduced during extended periods of heavy rainfall, operators may face a choice between loss of free board and spraying on already saturated fields, leading to pooling and runoff of waste and discharge offsite. This situation is compounded during winter months because crop uptake is minimal. In these conditions flooding can accelerate movement of wastes offsite.

Over 2000 CAFOs in eastern North Carolina are permitted to use liquid waste management systems, and flood events can be expected to pose environmental health threats in the future. In this article we evaluate the potential for such events to produce offsite discharge from CAFOs based on the experience of Hurricane Floyd. The DWQ did not inspect all CAFOs during the flood following Floyd, and for those CAFOs that were inspected, the DWQ recorded only flooding or breaching of waste pits; inspections were not reported for confinement structures or spray fields. We therefore link information from the DWQ CAFO permits with satellite images made following the flood to estimate the potential number of CAFOs that experienced flooding approximately 1 week after Floyd hit eastern North Carolina. North Carolina swine CAFOs are located disproportionately in low-income and African American communities and in areas heavily dependent on ground water (*10*). Because of their potential vulnerability to environmental contamination due to inadequate housing, poorly protected water supplies, and lack of access to medical services (*11*), we also examine whether African Americans and low-income families were located disproportionately in areas with flooded CAFOs.

Materials and Methods

We used four sources of data to estimate the potential impact of flooding on intensive livestock operations, compare the estimates with the DWQ list of breached or flooded waste pits, and evaluate the demographic characteristics of populations in areas with flooded operations:

- The DWQ provided a list of 3,039 CAFOs registered as of February 1998 (*10*). Our quality control procedures for correcting latitude and longitude coordinates of 2,514

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swine operations have been described previously (*10*). We applied the same correction procedures to cattle and poultry CAFOs in eastern North Carolina, using driving instructions to correct latitude and longitude for CAFOs with geographic coordinates that did not agree with the reported county location. During correction of geographic coordinates, we were blinded to satellite-based information on flooding and to the DWQ's classification of breached or flooded waste pits.

- The DWQ also provided a list of CAFOs with breached or flooded waste pits (Water Quality Section, North Carolina Department of Environment and Natural Resources, Raleigh, NC). "Flooded" was defined as water from the outside entering the waste pits; "breached" was defined as loss of a portion of the earthen wall of the waste pit. Reports of breached or flooded waste pits were made by farmers, integrators, members of environmental organizations, and the general public. DWQ staff inspected by visitation or aerial overflight and confirmed that waste pits on the DWQ list had been breached or flooded. One CAFO reported to have had a breached or flooded waste pit was out of business and therefore was not present in the database of CAFOs registered with the DWQ. Our study concerns only operations considered to have been in business as of February 1998; therefore we excluded this operation from analyses. Most CAFOs in this region are swine operations, and a moratorium on construction of new operations was in place during 1998 and 1999. Therefore, the list of CAFOs transferred in February 1998 should match fairly well the operations in place in September 1999.
- The North Carolina Division of Emergency Management (Department of Crime Control and Public Safety, Raleigh, NC) provided us with estimates of inundated areas derived from digital synthetic aperture radar satellite imagery taken on 23 and 25 September 1999. The imagery has a resolution of 50 m. These preliminary estimates of inundation were used as an early assessment of flooding.
- We obtained information on population size, ethnicity, and race from the 2000 census (*12*). Race and ethnicity are of interest because the historically low incomes, lack of access to services, and institutional discrimination experienced by African Americans and Hispanics in this region (*13*) make these populations more susceptible to environmental hazards (*11*). The 2000 census permitted respondents to list more than one race. More than 95% of persons in the study area reported their race as white only or African American (black) with or without another race. We counted persons as African American if they reported their race as African American alone or in addition to another race. Other population characteristics for the 2000 census were not available at the time of our analysis. We therefore obtained data on poverty and household water source from the 1990 census (*14*).

The geographic region included in this study was determined by the area covered in satellite imagery of the flooding. Some flooded areas on the western extent of the study area were excluded from our analyses because they were not included in the satellite imagery. All land area east of the western boundary of census block groups completely included within the satellite coverage was included in our analyses.

Operations were considered to be within the satellite-based flooded area if their geographic coordinates were within wet areas according to the satellite imagery. Note that

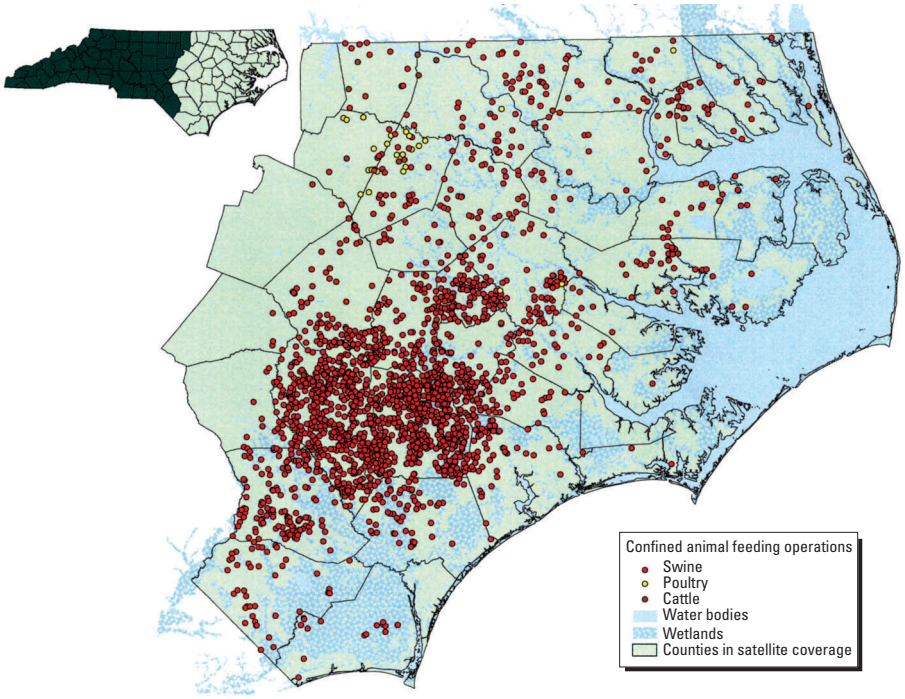

Figure 1. Confined animal feeding operations, eastern North Carolina, Feburary 1998.

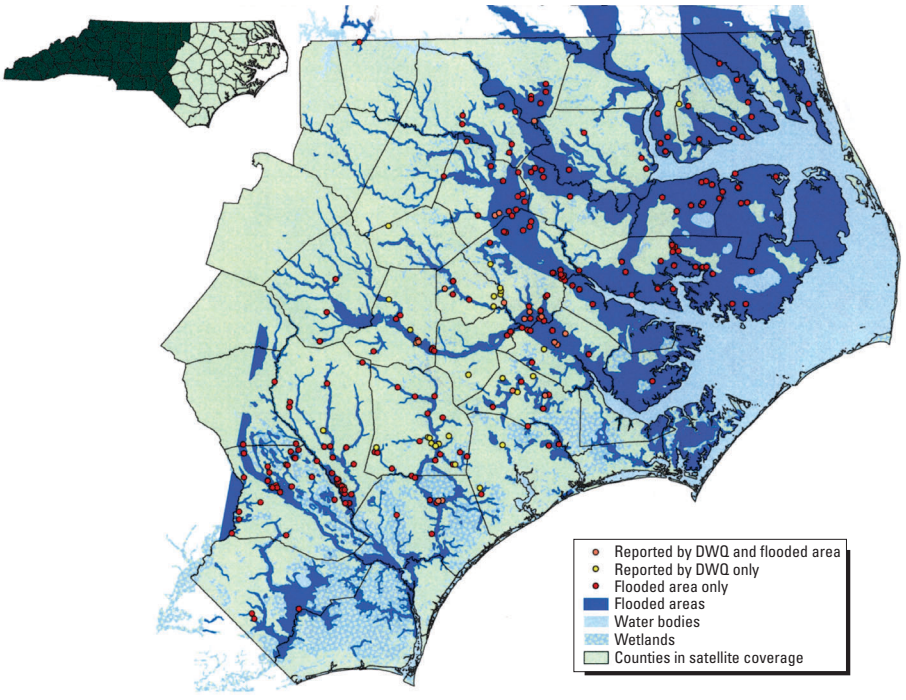

Figure 2. Flooded confined animal feeding operations, eastern North Carolina, September 1999.

this methodology is subject to errors in the geographic coordinates of the CAFOs and in estimates of inundation, as is the use of point data as locations for CAFOs that cover specific areas. Geographic data for CAFOs, flooding, and block group boundaries were combined using ArcView 3.1 software (ESRI, Redlands, CA). Racial differences in potential exposure to contaminants from flooded operations were evaluated using race data for blacks and whites, because less than 5% of the population were of other races. Ratios of the proportion of blacks to the proportion of whites living in areas with flooded CAFOs were calculated according to satellite and DWQ definitions of flooded operations. These estimates are based on 100% sample data, so statistical tests for sample data are not necessary. However, Mantel Haenszel 95% confidence limits were calculated for purposes of evaluating the precision of the ratios (*15*).

Results

Figure 1 displays counties in eastern North Carolina with at least one block group lying completely within the area covered by the satellite image of the flood. Locations of 2,286 CAFOs are indicated by symbols distinguishing swine, poultry, and cattle operations. The densest concentration of facilities occurs in Duplin and Sampson Counties, whose borders are largely hidden by symbols for swine CAFOs.

Figure 2 shows the satellite-based estimates of inundation and locations of those CAFOs classified by the DWQ, by satellite, or by both as breached or flooded. Flooding occurred in all major river basins, and CAFO coordinates intersected the inundation estimates across the region. Most operations with waste pits that were confirmed by the DWQ as breached or flooded occur in the middle part of the flooded area in the Neuse and Northeast Cape Fear River basins.

Table 1 shows the total number of CAFOs, the number with breached or flooded waste pits reported to the DWQ, and the numbers flooded according to the satellite-based estimates. Most CAFOs in the region are swine operations, and most flooded CAFOs are swine operations by either definition. The DWQ reported breached or flooded fecal waste pits at 46 (2.1%) of the 2,286 CAFOs in the area, including one poultry and 45 swine operations. In contrast, 241 operations (10.5%) had geographic coordinates within the satellite-based flooded area, including three cattle, one poultry, and 237 swine operations. The 237 swine operations were permitted for 736,058 head with a steady-state live weight of 143.5 million pounds.

Table 2 presents agreement between classification of flooding of CAFOs based on DWQ reports and satellite imagery. Among the 46 operations with breached or flooded fecal waste pits according to DWQ inspections, 26 (56.5%) had geographic coordinates that were not within the satellite-based flooded area. Among the 241 operations that had coordinates within the flooded area, 221 (91.7%) were not on the DWQ list of operations with breached or flooded fecal waste pits.

Table 3 presents information about the resident population of block groups in the study area with CAFOs. According to 2000 census counts, 171,498 people lived in block groups with CAFOs lying within the satellite-defined flood area. Of these, 60,546 lived in 48 block groups where two or more CAFOs were within the satellite flood coverage. These block groups contained 157 flooded CAFOs; 110,952 people lived in the 84 block groups that contained only one flooded operation. A total of 46,800 people lived in block groups with breached or flooded fecal waste pits according to DWQ estimates, of which 16,346 lived in 10 block groups where two or more CAFOs flooded. There were 3.64 times as many persons living in block groups with one flooded CAFO according to satellite than according to DWQ definition, and 3.70 times as many living in block groups with two or more flooded CAFOs.

Table 4 gives information comparing the proportion of blacks to whites who lived in areas with flooded CAFOs according to satellite and DWQ definitions. According to satellite estimates, 11.3% of blacks, compared with 9.3% of whites, lived in block groups with two or more flooded operations. The black:white ratio is 1.22 [95% confidence interval (CI), 1.20, 1.24]. According to satellite estimates, 19.4% of blacks and 17.2% of whites lived in areas with one flooded operation, a black:white ratio of 1.13 (95% CI, 1.11, 1.24). In contrast, 2.8% of blacks and 2.6% of whites lived in areas with two or more flooded CAFOs according to the DWQ, whereas 4.3% of blacks and 5.1% of whites lived in areas with one flooded CAFO. Black:white ratios were 1.05 (95% CI, 1.02,1.09) in

Table 1. Animal types and flood status of eastern North Carolina CAFOs.

		Source of estimate			
Type	Total	DWQ (*n*)	Percent	Satellite (*n*)	Percent
Cattle	15	0	0.0	3	20.0
Poultry	26	1	3.9	1	3.9
Swine	2,245	45	2.0	237	10.6
Total	2,286	46	2.1	241	10.5

Table 2. Concordance of DWQ and satellite classification of CAFO flood status.

	DWQ		
Satellite	Flooded	Not flooded	Total (%)
Flooded	20	221	241 (10.5)
Not flooded	26	2019	2,045 (89.5)
Total	46 (2.1%)	2,240 (97.9%)	2,286 (100%)

Table 3. Numbers of census block groups and population size (Census 2000) according to presence of flooded CAFOs (Satellite and DWQ).

	Two or more flooded operations		One flooded operation	
Flooded CAFO estimate	BGs[a]	Persons (%)	BGs[a]	Persons (%)
Satellite	48	60,546 (9.8)	84	110,952 (17.9)
DWQ	10	16,346 (2.6)	20	30,454 (4.9)
Ratio satellite: DWQ	4.80	3.70	4.20	3.64

[a]Number of Census 2000 block groups.

Table 4. Numbers of blacks and whites (Census 2000) and black:white relative risk.[a]

Flooded CAFO estimate	Two or more flooded operations (%)	One flooded operation (%)
Satellite		
Blacks	21,667 (11.3)	37,055 (19.4)
Whites	37,050 (9.3)	68,502 (17.2)
Black:white ratio	1.22	1.13
95% CI	1.20, 1.24	1.11, 1.14
DWQ		
Blacks	5,252 (2.8)	8,261 (4.3)
Whites	10,141 (2.6)	20,138 (5.1)
Black:white ratio	1.05	0.89
95% CI	1.02, 1.09	0.87, 0.91

[a]According to presence of flooded CAFOs (satellite and DWQ).

areas with two or more flooded operations and 0.89 (95% CI, 0.87,0.91) in areas with one flooded operation. Hispanics comprised only 4.3% of the study area. The proportion of Hispanics living in flooded block groups defined by satellite was about 10% less and the proportion of Hispanics living in flooded block groups defined by DWQ was about 8% greater than the proportion of non-Hispanics.

We analyzed data from the 1990 census for income and water source. According to satellite estimates, 25% more persons in poor households lived in areas with two or more flooded operations, and 10% more lived in areas with one flooded operation, compared with persons living in nonpoor households (ratios of 1.25 and 1.10). According to DWQ estimates, smaller proportions of persons in poor households lived in areas with flooded CAFOs (ratios of 0.92 and 0.86 in areas with two or more and one flooded operation, respectively). According to satellite estimates, 59.1% of households in areas with two or more flooded operations used well water, and 57.5% of persons in areas with one flooded operation used well water. Estimates according to DWQ-defined flooding were 54.8 and 46.9%, respectively.

Discussion

Our analysis shows that 241 (10.5%) of the 2,286 active CAFOs registered with the North Carolina DWQ had geographic coordinates within the area of inundation estimated from satellite images taken 1 week after Hurricane Floyd hit eastern North Carolina. These areas were inhabited by 171,498 people, of whom more than one-third were African American according to the 2000 census, 20.7% lived in poor households, and 58.1% lived in households that used well water (according to the 1990 census, the most recent for which those data were available). In contrast, the DWQ inspected 46 operations with breached or flooded fecal waste pits. Populations of those areas were substantially smaller and had somewhat lower percentages of African Americans, persons in poverty, and households using well water compared with block groups with flooded operations identified by satellite.

The geographic pattern of flooded CAFOs according to satellite estimates reflects the intersection of geographic coordinates of the operations and the inundation estimated from satellite images. CAFOs flooded according to this estimation method are dispersed across eastern North Carolina. In contrast, most CAFOs reported by the DWQ occur in the Neuse and Northeast Cape Fear River basins. These watersheds were subject to active aerial surveillance during and after the flooding by the Neuse River Foundation, an environmental group that reported its observations to state officials (*9*).

Errors in satellite-based estimates of CAFO flooding occur in the location information for CAFOs as well as in satellite data on flooding. Although CAFOs are represented as points in our analysis, they are actually areas of many acres, including confinement structures, fecal waste pits, and spray fields. Although information on waste pits and spray fields in the permit database suffer from missing values and are not verified, an estimate of the average size of the operations can be made from the 2,085 CAFOs in the study area that reported information on the area available for spraying, which had a mean of 65.1 acres. Better estimates of the impact of flooding on environmental dispersion of waste contaminants from CAFOs could be produced if information were available on the sizes and shapes of CAFOs, including fecal waste pits and confinement structures, as flooding may have affected only some portions of an operation. The locations of the points representing CAFOs are another source of error. Although some were determined by DWQ inspectors using global positioning systems, many were reported by operators (using undocumented methods) and others were determined from maps according to driving instructions used by inspectors.

Inundation estimates are another source of error. The synthetic aperture radar images used to estimate inundation were taken approximately 1 week after Floyd passed over the state. CAFOs flooded in upstream areas where waters had receded would be misclassified in our analysis. Conversely, some downstream areas with standing water or saturated soil would have been classified as flooded even though they were not covered by flowing water. Environmental impacts of standing water are a concern despite the lack of flushing action of flowing flood waters that can transport large quantities of wastes downstream over longer distances in a short period of time. Standing water would have occurred in particular in the very flat Northeastern Tidewater region in those counties west of the Outer Banks. Saturation of soil and standing water could facilitate movement of wastes from spray fields into ground water and wetlands, especially for operations with subsurface drains located in their spray field or waste pit areas. Subsurface drains have been commonly used to introduce agriculture into chronically wet areas. Although data are incomplete, 316 of the 2,286 CAFOs in the study area, of which 15 were within the inundation area, reported on their DWQ permits that there were subsurface drains in their spray field or waste pit areas.

Another important consideration in comparing satellite-based evaluation of CAFO flooding and DWQ reports is the specificity of the latter definition compared with the former. The DWQ reported only breached or flooded fecal waste pits. CAFOs that experienced flooding of confinement structures or spray fields without waste pit inundation or rupture would not fall within the reporting system of the DWQ. However, all DWQ reports were confirmed by inspection and therefore constitute one standard for evaluating the sensitivity of use of the satellite-based identification of flooded CAFOs.

These sources of error suggest our analyses are useful for some purposes but not others. Because information is lacking on the boundaries of animal operations and errors in geographic coordinates, our satellite-based estimates should not be used to evaluate whether particular CAFOs were flooded. Our inability to detect as flooded over half of the operations with breached or flooded waste pits confirmed by the DWQ may be an indication of the magnitude of errors in our estimates. However, because of the nonsystematic reporting of breached or flooded fecal waste pits, the lack of adequate DWQ staff to evaluate all operations, and the disruption of most normal government functions in the aftermath of the flooding, we consider it likely that some operations with breached or flooded fecal waste pits were not identified by the DWQ. Furthermore, the environmental health impact of flooding on confinement structures and spray fields is also of concern.

We suggest the most appropriate interpretation of our estimate of flooded CAFOs is that we have evidence that a substantial proportion of CAFOs in North Carolina are at risk of experiencing offsite discharge of waste from flooding. Although Hurricane Floyd was an extreme event, other tropical storms have led to discharges in recent years (*5*), and future regional flooding should be expected from large storms. Localized flooding from thunderstorms may also be expected to impact this area. Although some operations, particularly in the northeast, may have experienced only increased ground water transport of waste offsite, our estimate of the impact of flooding on CAFOs following Hurricane Floyd may be low becasue of *a*) incomplete satellite imagery for the western part of the flood zone; *b*) lack of flood estimates from satellite imagery taken nearer to the time of rainfall; *c*) lack of perimeter boundaries for CAFOs; and *d*) lack of consideration of closed or abandoned CAFOs. Our estimate of flooding of approximately 10% of the region's CAFOs missed more than half of the breached or flooded fecal waste pits reported by the DWQ. Operations found by

the DWQ to have been breached could have spilled their wastes through water pressure inside their earthen walls in the absence of inundation, and would not have been classified as flooded by satellite estimation.

The demographic characteristics of areas with flooded operations are relevant for evaluation of potential for offsite waste discharge to impact human health and environmental justice. Satellite-based estimates indicate that 60,546 people inhabited block groups with two or more flooded operations, and 110,952 people inhabited block groups with one flooded operation. The 2000 census was conducted 6 months after Hurricane Floyd left 17,000 homes uninhabitable, 56,000 damaged, and 47,000 people in temporary shelters in eastern North Carolina (*16*). Population counts for some flooded block groups would have been underestimated because residents were living elsewhere in temporary housing. This was particularly true for African Americans, because of the historical location of some black towns in flood plains (*17*). Estimates of the size of African-American populations in block groups with flooded CAFOs may be low due to disproportionate flooding of black communities and longer residence of African Americans in temporary housing. Although our data do not permit us to conclude that anyone was exposed to waterborne contamination from CAFOs, they do show that substantial numbers of persons live in close proximity to CAFOs at risk of flooding. Our estimates do not include areas downstream that may have been affected by flooded upstream operations. Surveillance of human health following flood events is compromised in these areas by high levels of poverty and lack of access to medical care.

Eastern North Carolina is a poor region and home to most rural African Americans in the state. Previous studies showed that swine CAFOs are more common in poorer communities and communities of color (*10,18*). According to satellite estimates, African Americans were disproportionately located in areas with flooded CAFOs compared with whites (Table 4). In contrast, areas with breached or flooded fecal waste pits confirmed by the DWQ were less poor and African American and depended less on well water than block groups with flooded CAFOs according to satellite estimates. Differences between the demographic characteristics of areas with flooded CAFOs according to satellite and DWQ estimates could reflect differences in the definition of flooded CAFOs, differences in reporting to the DWQ, or differences in inspections. The Neuse and Northeast Cape Fear areas where most flooded fecal waste pits identified by DWQ reports were located have proportionately more white residents than some other regions of eastern North Carolina (*10*).

Ground water is a common household water supply in rural eastern North Carolina, and swine CAFOs are located primarily in areas where a large proportion of households depend on ground water for drinking (*10*). Areas with flooded CAFOs have a large proportion of households using well water, nearly 60% according to satellite definitions, and approximately 50% according to DWQ definitions. Contamination of ground water from CAFOs is a public health concern due to the presence of nitrates, pathogens, and antibiotic residues in animal wastes (*1*). Although we are unable to evaluate the flooding of wells downstream from CAFOs in our analysis, the presence of large numbers of households in areas with flooded CAFOs raises concerns about contamination of water supplies during flood events.

The southeastern United States periodically experiences flooding, in particular due to tropical storms and hurricanes. Flood waters may expose humans to contaminants from a variety of sources including municipal solid waste facilities, sewage treatment facilities, hazardous waste facilities, and underground storage tanks containing petroleum products. In eastern North Carolina, the recent construction of thousands of CAFOs that use liquid waste management systems, which are susceptible to flooding and discharge of wastes offsite, raises new concerns about flood-related dispersion of hazardous wastes. Our analyses suggest that a substantial proportion of CAFOs in eastern North Carolina experienced offsite dispersion of waste following flooding in September 1999. Better estimates of environmental impacts of flooding on CAFOs in this area depend on improved data on CAFO locations, including boundaries of confinement structures, fecal waste pits, and spray fields, as well as improved estimates of flooding that can follow the temporal patterns of inundation through watersheds.

Our analyses are relevant to conditions in some other states and nations where flood events occur and where CAFOs are locating or considering expansion. In some of these areas, including Mississippi (*19*), environmental contamination may also occur in African-American and low-income communities where surveillance of environmental health is compromised by poverty and lack of access to medical care. Evidence from eastern North Carolina raises questions about the regulatory classification of CAFOs as nondischarge facilities.

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