ORIGINAL ARTICLE

Suitability of Public Records for Evaluating Health Effects of Treated Sewage Sludge in North Carolina

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BACKGROUND Exposure to potentially harmful agents because of waste disposal practices is receiving increased attention. Treated sewage sludge (TSS), or biosolid material, is the solid waste generated during domestic sewage treatment after it has undergone processes to reduce the number of pathogens and vector attractants. Application of TSS to land, which is the most common method for disposal, is promoted as a soil amendment and fertilizer. Few studies have examined the effects of land application on the health and quality of life of neighboring populations. We describe and summarize publicly available records that could be used to study the public health impact of practices associated with land application in North Carolina.

METHODS We abstracted public records from the North Carolina Department of Natural Resources Division of Water Quality, to determine the following activities associated with land application of TSS in 8 counties in central North Carolina: the process for obtaining permits, reported applications, violations, documented concerns of residents, and penalties assessed.

RESULTS The Division of Water Quality routinely collects records of permits and approvals for land application of TSS, amounts applied, and reported pollutant levels. Documentation was useful in summarizing land application practices, but lack of standardization in reporting was a concern. Research into the public health impacts of the land application program is hindered by inconsistency in documenting inspections and resident concerns.

LIMITATIONS We were not able to validate state records with direct observation of land application of TSS.

CONCLUSIONS Records from the Division of Water Quality would be of limited use in epidemiologic studies of the health effects of land application of biosolids. Information about locations, amounts, and dates of application are relevant to exposure potential, but additional information is needed for health investigations.

Waste disposal practices may impact human health. In North Carolina, municipal, medical, industrial, and agricultural wastes are receiving increased attention because of health and environmental justice concerns [1-5]. While most solid and industrial wastes are disposed of in landfills, animal wastes and solids from municipal sewage (ie, sludge) are typically used as agricultural fertilizers, increasing their potential to affect the quality of air, water, and food. Animal manure and sewage sludge contain pathogens, endotoxins, allergens, and toxicants that have the potential to harm health and cause disease [6]. Studies of 16 eastern North Carolina communities located near industrial hog farms that apply swine waste to the land demonstrated human exposure to airborne pollutants [7] and dose-response relationships between pollutant levels, symptoms of illness, and stress levels in humans [8, 9]. Other research has demonstrated the presence of pathogens and antibiotic-resistant bacteria in surface waters near industrial swine farms [10].

Although municipal wastewater receives more treatment than animal waste, it includes chemicals from homes and industries that are not present in animal waste [11]. These chemicals and other constituents become concentrated in the residuals, or sewage sludge, resulting from wastewater treatment. After sewage sludge is processed to reduce pathogens and vector attractants, the treated sewage sludge (TSS), also referred to as biosolid material [12], is commonly applied to farmland. Neighbors of fields where TSS is applied have reported respiratory, gastrointestinal, and irritation symptoms in response to the application [13-16], and 7 of 19 regulatory and health officials who were interviewed about their opinions on tracking and investigating health problems around sites of land application said they receive reports of illness from people living nearby [17].

The health impacts of swine waste [7-10], the presence of toxicants and pathogens in TSS [6], and national interest in tracking and investigating symptoms of illness in relation to sludge application [17] raise questions about the practice of applying TSS to fields in North Carolina. This article provides an evaluation of North Carolina's residuals management program and a summary of state records on the land application of sewage sludge in 8 North Carolina counties. The findings could help to increase awareness of medical

Electronically published May 20, 2011.

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N C Med J. 2011;72(2):98-104.
0029-2559/2011/72204

and public health officials about the potential environmental health impacts of land-applied sewage sludge and could help state agencies initiate or participate in a program to track and investigate reports of illness.

Materials and Methods

The North Carolina Department of Environment and Natural Resources Division of Water Quality (DWQ) oversees land application of sewage sludge in the state as part of its Residuals Management Program. We reviewed land application permits, annual reports, and electronic records of violations among permit recipients, recorded from 2005 through 2007, for 8 North Carolina counties near Chapel Hill, where this research was conducted.

Permits. To apply sewage sludge to land in North Carolina, appliers must obtain a Residuals Land Application Permit [18]. Permits contain information on the sources and destinations of sewage sludge. Source information lists generators (typically wastewater treatment plants [WWTP]), nutrients, hazardous wastes, and other pollutants measured in the sludge, and describes pathogen and vector attractant reduction procedures [18]. The permits note which fields are approved for application, but not the fields that are actually used. We abstracted information from an electronic database of active permits about the total number, locations, and acreage of associated fields. We abstracted dates and descriptions of permit violations and penalties from an electronic database of wastewater management events and reports of residents' concerns from paper copies of individual permits.

Annual reports. In North Carolina, permit holders are required to monitor levels of pollutants and indicator organisms in sewage sludge at least once per year and up to once per month, and they must submit an annual report to the DWQ that contains monitoring data, evidence of measures used to reduce pathogens and vectors, and other information [19]. We abstracted the dates of each application (ie, day, month, or bimonthly period); the amount applied in dry tons, gallons (for liquid sludge), and/or cubic yards (for cake sludge; data were converted to gallons for comparisons); the crop grown on the sewage sludge amended fields; and the source WWTP(s). We abstracted this information from annual reports for municipalities with permits to apply sewage sludge in 8 counties in North Carolina.

For application amounts, we report the raw number of gallons of liquid sewage sludge applied to each field. We report application concentration in dry tons per acre and biosolid concentration in dry pounds per gallon. The term "dry weight" refers to the mass of the solid and dissolved constituents in the sludge.

Inspection documentation. State inspections of land application sites are required when a municipality is undergoing the permit application or renewal process for a "site," defined as a field or group of fields in close proximity. Before application to land on a proposed site, DWQ officials review the plan for the proposed application and conduct a site visit to confirm that site operators are certified and that each field meets requirements for buffers and topographic characteristics. Inspectors use standardized inspection forms to document compliance or noncompliance with rules. We were unable to examine inspection forms systematically because of missing and/or checked out permits. We requested documentation of federal inspections, which occur biennially and assesses all points of sludge production and application, but no records were held by the DWQ.

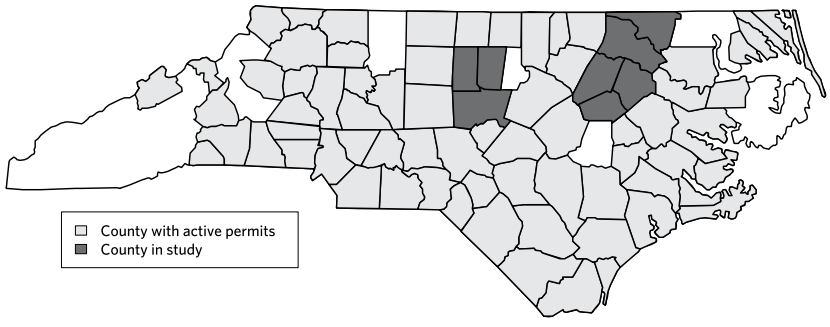
We linked data from permits and annual reports to create summary statistics of sewage sludge application in 8 North Carolina counties from 2005 through 2007. DWQ personnel could not locate one of the annual reports for Orange County. We also assessed the consistency and completeness of records.

Results

Reported Land Application of TSS in North Carolina

As of July 2008, there were 148 active permits for land application of TSS on agricultural fields, with sites in 76 North Carolina counties (Figure 1). Of the 8 counties for which we abstracted annual report data, Alamance County had

FIGURE 1.
North Carolina Counties With Active Permits for Land Application of Treated Sewage Sludge



Note. Permits were obtained in all study counties.

the highest volume of applied sewage sludge (U53 million gallons), followed by Orange County (≥51 million gallons), Chatham County (≥51 million gallons), Edgecombe County (≥27 million gallons), Nash County (≥22 million gallons), Halifax County (≥9 million gallons), Northampton County (≥6 million gallons), and Wilson County (≥2 million gallons) (Figure 1; Table 1). Agents who applied TSS in Wilson County reported the most concentrated sewage sludge (2.2 pounds dry weight per gallon), whereas agents in all other counties reported less than 1 pound per gallon. During 2005-2007, Orange County received sewage sludge from more WWTPs than any other county and had sewage sludge applied on 306 fields, which is nearly twice as many fields as Alamance Country, the next most-active county of those we studied. The counties differed with respect to dry tons of sewage sludge applied per acre, ranging from 1.4 dry tons in Nash County to 7.2 dry tons in Wilson County. The maximum volume applied on any single field over span of the study period was nearly 6.5 million gallons, or 162 dry tons, which was applied to a 72-acre field in Chatham County.

During 2005-2007, the overall volume (in gallons) of sludge applied and the number of fields receiving application increased, while the dry weight or volume per acre did not change greatly within each county. The one exception was Wilson County, in which the dry tons per acre of application decreased from 10.7 dry tons in 2005 to 0.9 dry tons in 2007. Fescue was the most commonly reported crop to which sewage sludge was applied. Other crops were Bermuda and rye grass, corn, cotton, wheat, soybeans, and pine.

From 2005 through 2007, March, June, and November were the months in which the largest volume of sewage sludge was applied, although the pattern varied from year to year (Figure 2). A small proportion (<5%) of the residuals originated from water treatment plants, rather than from sewage treatment facilities (data not shown). Cumulative monthly application across all 8 counties was between 15 and 25 million gallons for all months except December and February.

Completeness and Consistency of DWQ Records

Annual reports. Annual report forms generally included information on application locations and amounts of application for reported application events. There was inconsistency among permit recipients with regard to the reporting of application dates; some recipients listed the month (or bimonthly period) of application, whereas others reported specific dates.

State inspection records. At the state level, inspection forms (Figure 3) are filled out by DWQ employees, including a soil scientist, for routine inspections during the permit application or renewal process, for annual inspections, or after permit violations. Not all inspections occur during active application events. No inspection forms are retained with the permit if the inspection is performed when the process for obtaining the permit is being expedited, which requires an additional fee. We could not locate any record of the frequency of visits or inspections. DWQ personnel also conduct periodic, informal inspections of fields for some land application events, although these inspections are not systematically documented.

Known violations of state laws are recorded in an electronic database of more-general wastewater handling violations, such as sewage overflows. The recording of violation type is subjective. For example, a renewal form submitted after the deadline could be entered as "late renewal" or "permit conditions violation," depending on which DWQ personnel enter the data.

Residents' concerns. Residents are responsible for reporting concerns to appropriate authorities, and no centralized database of these reports exists in North Carolina. For example, if a resident contacts a health department to report concerns about land application, that report will not likely be recorded by state offices, and vice versa. Written concerns that are lodged directly with the DWQ are generally stored with the permit for which the concern has been stated, and e-mail correspondence is printed out and stored as a hard copy with the permit. Of note, one permit contained e-mails from several residents, including a physician, concerned

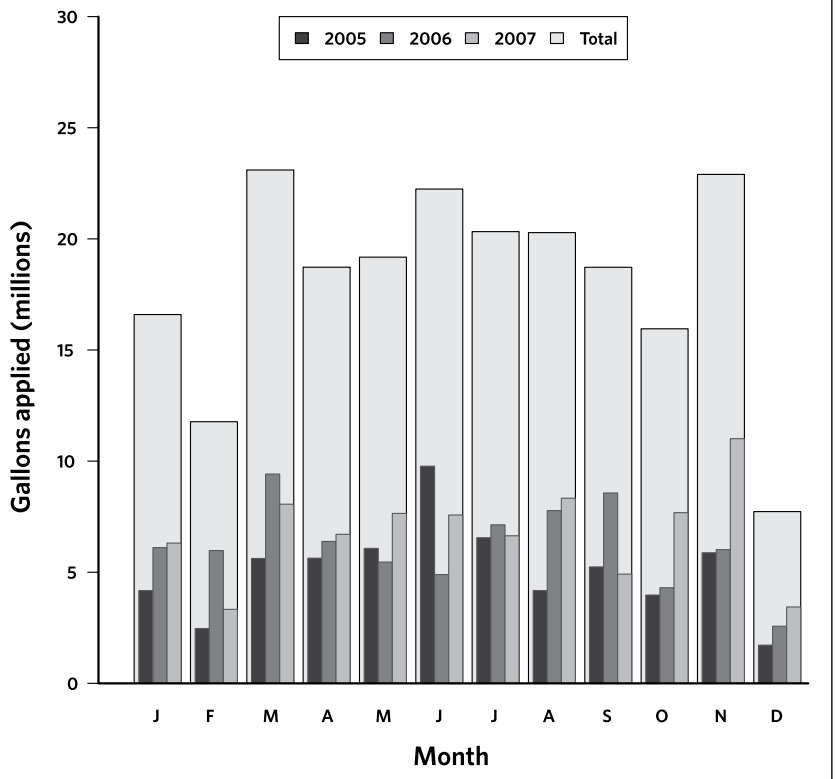
TABLE 1.
Sewage Sludge Application Summary for 8 North Carolina Counties

Characteristic	Alamance	Chatham	Edgecombe	Halifax	Nash	Northampton	Orange[a]	Wilson
Permits, no.	3	8	4	4	2	3	5	1
Source WWTPs, no.	7	11	6	8	8	4	12	2
Fields used, no.	163	152	65	34	65	33	306	23
Volume, x10^6 gallons	53.8	51.0	27.3	9.2	22.4	6.8	51.2	2.4
Dry mass								
Tons/acre	2.6	2.6	2.8	2.9	1.4	2.1	3.5	7.2
Pounds/gallon	0.3	0.3	0.4	0.4	0.2	0.4	0.6	2.2

Note. Data are from self-monitoring reports that must be submitted to the North Carolina Department of Natural Resources Division of Water Quality by appliers on an annual basis. WWTP, wastewater treatment plant.

[a]Records from 1 WWTP were missing for 2005.

FIGURE 2.
Gallons of Treated Sewage Sludge Applied Monthly in 8 North Carolina Counties



about land application practices in Alamance County and physical symptoms exhibited by neighbors. No other reports of symptoms were found in the DWQ documents that we reviewed. The DWQ does not keep a summary of reported concerns or illnesses.

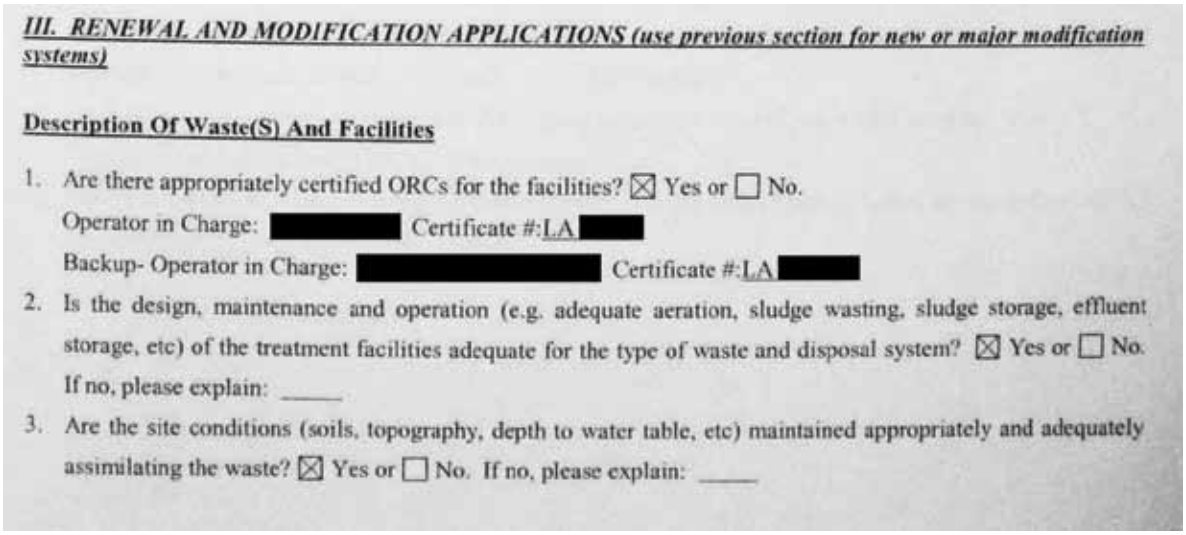
Discussion

Evaluation of the safety of programs for applying TSS to land is generally based on risk assessments. These assessments neglect potential interactions between toxicants and pathogens in sewage sludge, which could make the assessments unreliable for predicting public health impacts [20, 21]. A review by the National Research Council [6] of epidemiologic studies relevant to the health of those living around sewage sludge application determined that only 23 studies addressed the connection between sewage sludge and human health. Only one of the studies evaluated residents living proximal to a site of application [22]. Authors of a survey in Ohio reported an excess prevalence of self-reported symptoms and illnesses within 1 mile of fields for which there were permits [23]. Given the many case reports of illnesses connected to land application of TSS [13-17], the dearth of observational studies is unfortunate; some authors have suggested that conflicts of interest have impeded in-depth investigation [24, 25].

To our knowledge, our research represents the first evaluation of DWQ records as a basis for quantifying amounts of sludge applied to land, as well as associated time trends, seasonal patterns, and geographic variation. We have shown that, despite some weaknesses, the data are suitable for conducting basic surveillance of a practice that has the potential to affect the health of nearby populations. For example, during 2005-2007 more than 50 million gallons of sewage sludge was applied to 306 fields in Orange County. Since all of the TSS was applied via surface spreading, using equipment that broadcasts liquid or solid material, there is potential for drift, which could expose neighboring residents to toxicants, pathogens, and odorant compounds that could cause acute symptoms, reduce health-related quality of life, affect mental health, or contaminate ground or surface waters. To reduce the potential for pollutant drift into populated areas, surface application is illegal in North Carolina within 400 feet of a house; 50 feet of a property line; 100 feet of surface waters, wells, or swimming pools; and 25 feet of ephemeral streams [18]. However, pathogen repopulation in land-applied sewage sludge increases the potential for exposure to harmful constituents following land application [26].

We report both dry weight per acre, which relates to nutrient and pollutant load, and dry pounds per gallon, which relates to the concentration of waste in liquid applications. Since little is known about mechanisms by which sludge could cause symptoms, both are of potential interest for a public health investigation.

FIGURE 3.
Sample Questions on a Form Completed During Inspection of Land Where Treated Sewage Sludge Has Been Applied



III. RENEWAL AND MODIFICATION APPLICATIONS (use previous section for new or major modification systems)

Description Of Waste(S) And Facilities

1. Are there appropriately certified ORCs for the facilities? ☒ Yes or ☐ No.
   Operator in Charge: [redacted] Certificate #:LA [redacted]
   Backup- Operator in Charge: [redacted] Certificate #:LA [redacted]
2. Is the design, maintenance and operation (e.g. adequate aeration, sludge wasting, sludge storage, effluent storage, etc) of the treatment facilities adequate for the type of waste and disposal system? ☒ Yes or ☐ No.
   If no, please explain: _____
3. Are the site conditions (soils, topography, depth to water table, etc) maintained appropriately and adequately assimilating the waste? ☒ Yes or ☐ No. If no, please explain: _____

Note. The form is from the North Carolina Department of Natural Researches Division of Water Quality.

Given our resources and the time and effort required to manually abstract data from paper copies, we were only able to evaluate records for a convenience sample of 8 counties from 2005 through 2007. Since the North Carolina residuals program is "a self-reporting program that requires permit holders to contact DWQ when permit violations occur" [19p15], there is room for improvement in tracking land application events that violate state and federal regulations [18, 27]. DWQ personnel may note violations they witness at inspections (eg, applying sewage sludge on a marked buffer) or violations of permit conditions (eg, submitting renewal forms after the deadline), but the inspection records held in the permits and database of violations are not detailed, systematic, or consistent enough to be research tools. On the day of our request, half of the nearly 15 permits we asked to examine for recorded violations were missing or checked out. One annual report was never located over the course of several months. We could not review documents for all counties in the state. However, if North Carolina's uniform reporting requirements are effective, records that we examined should be representative. Routine computerization of records would facilitate evaluation of time trends, spatial variation, and other surveillance. Since North Carolina follows federal minimum reporting requirements, records from other states should be at least as informative as North Carolina records; therefore, comparisons should be possible if these records can be centralized [27, 28].

One prior study of violations of land application regulations suggested that reporting patterns in other regions are similar to those in our investigation and found numerous examples of resident concerns that were not recorded by local agencies or were reported to the wrong agency [13]. Records may be limited because of the requirement for self-report, and we could not evaluate medical documentation of reports. There is potential that the paucity of illness reports in our study results from nonsystematic recording of concerns by both local and state agencies.

Although DWQ records had limitations, including lack of direct observation of land application events and inconsistent reporting on the timing of applications, we believe these records constitute an important tool for public health investigation and exposure surveillance.

The second basic surveillance activity for evaluating the effects of land application of sludge on the health of North Carolina residents involves tracking reports of symptoms, illness, and diminished quality of life. Such information could be used to evaluate the locations of reports of health problems, secular trends, seasonal variation, associations with waste treatment methods, sources of waste, or sensitivity of neighboring populations (eg, children, elderly individuals, and people with allergies, asthma, or other sensitizing conditions). Health surveillance is a challenge because of a lack of awareness about sludge (including terms such as "biosolids" and "residuals," which may not be familiar to members of the public and health care professionals), variation in levels of concern about symptoms, and barriers to health care access, including lack of insurance coverage. Despite these difficulties, public officials connected with sewage sludge land application programs have an interest in conducting surveillance, which has been recommended by national and North Carolina officials [17, 21]. Federal regulations do not address criteria for keeping records of symptom reports, so the effort must come at state or local levels.

Health care professionals may not consider land-applied sludge as a possible source of illness because of their unfamiliarity with programs for disposal of wastewater residu-

als [13]. Increased awareness about possible health impacts of TSS among clinicians is important both for patient care and for epidemiologic investigation. For example, if sensitive patients present with respiratory symptoms in connection with land application of sewage sludge near their homes, they could be counseled to reduce or avoid exposure to outdoor air during those periods. Furthermore, clinicians could ask rural and semirural patients about possible exposures and could then contribute reports of symptoms to a health surveillance system. The Occupational and Environmental Epidemiology Branch of the North Carolina Department of Health and Human Services has previously recommended development of a surveillance program to track potential adverse health effects of land application of sewage sludge [21], and this scenario was one key component of a surveillance approach developed at the University of North Carolina–Chapel Hill, described in a report produced for the Water Environment Research Foundation [29]. The protocol is currently being tested in Ohio [30].

Impediments to performing basic research on the public health impact of land application of sewage sludge include lack of a health surveillance program and the dependence on groups that generate and apply sludge to report their own practices to a regulatory body that assesses violations and fines, which is an inherent conflict of interest. For example, one of us (A.K.) observed land application during a rain event, which is disallowed under state and federal laws and increases the likelihood of surface water contamination [18, 27]. More than 90% of the violations noted in DWQ records were a result of a paperwork error or a violation detected during inspection, hinting that violations may be unreported if they are not observed directly by the DWQ.

As the population of North Carolina increases, there will be more municipal sewage sludge and increasing pressure to apply TSS to land in rural and semirural areas that are experiencing population growth. Consequently, more residents may be exposed to the complex mixture of wastes and treatment byproducts present in TSS. Existing DWQ records can be useful to identify spatial and temporal variation in the potential exposure of North Carolina residents to land-applied sewage sludge, but an illness surveillance effort and a more systematic effort to report land application events in a consistent and complete manner would benefit future studies. Support from the medical and public health communities could help encourage better records and further the scientific understanding of potential health impacts of this growing program. NCMJ

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Acknowledgments
Financial support. National Institute of Health Sciences (grants T32ES007018 and 5R01ES015469-04).
Potential conflicts of interest. All authors have no relevant conflicts of interest.

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