

Managing Groundwater Nitrate Contamination from Livestock Farms: Implication for Nitrate Management Guidelines

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Abstract Significant nitrate contamination of groundwater has been observed in various parts of the world; intensive livestock farming is one of the major causes. This paper reviews various guidelines/regulations, which have been developed in advanced countries such as USA, Canada, Australia, and Europe to combat this problem by designing effective monitoring and management programs. Monitoring programs deal mainly with selection of sites, number of monitoring wells, specific parameters, and sampling frequency, which are helpful for identifying the source and extend of the contamination. Management programs deal with selection of suitable location, site characterization, proximity of livestock facilities and drinking wells, and proper storage, maintenance of the facilities, and limits of manures application in order to minimize nitrate leaching into groundwater. The main aim of this paper is to help states/countries, which do not have any guideline, and consulting engineers/consultants/owners of livestock operation in the design of effective strategies for point source nitrate management.

Keywords Nitrate contamination · Livestock · Groundwater · Management guidelines

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Introduction

Nitrate (NO_3^-) contamination of groundwater is a serious environmental issue of global concern because of its direct adverse effect on human health via drinking water [1–4]. Ingestion of excess nitrate in drinking water causes harmful biological effects such as methemoglobinemia, hypertension, infant mortality, goiter, stomach cancer, thyroid disorder, cytogenetic defects, and birth defects [5]. Nitrate exists in groundwater through natural processes; however, the concentration can be greatly increased from various anthropogenic sources. One of the major anthropogenic sources of nitrate contamination comes from intensive agriculture activities [6, 7]. Other anthropogenic sources are associated with industrial wastes related to food processing, waste water treatment plants, septic tanks, and livestock facilities [8–11]. Intensive livestock farming (in which large numbers of pigs, chickens, or cows are housed together in a relatively small area) is a potential source of nitrate contamination to the surrounding surface and groundwater in many countries [12–16] and is growing as livestock production has been increased rapidly to meet increased demand for food and other products [17–19]. Most of the growth comes from industrial farms clustered around major urban cities. A joint IFPRI/FAO/ILRI study, *Livestock to 2020: The Next Food Revolution* [17], noted that global meat production has risen from 233 Mt in 2000 and is expected to reach 300 Mt by 2020 and milk production will increase from 568 to 700 Mt over the same 20-year period. To meet this demand, livestock population will need to increase dramatically, along with the waste they produce.

Livestock waste contains nitrogen both in inorganic and organic compounds. The inorganic fraction is equivalent to the N emitted in urine and usually greater than organic one. Microbial action decomposes wastes containing organic

nitrogen into ammonia, which is then converted into nitrite and nitrate. Nitrite is easily oxidized to nitrate, so nitrate is predominant in decomposed wastes [20]. Nitrate-containing compounds in soil are generally soluble and can readily migrate through soil layers [21]. Thus, improper management of livestock waste can pose serious threats to groundwater via several pathways, such as surface runoff from farm building, improper discharge, leaking from storage facility, and excessive land application of wastes [22, 23]. Understanding of nitrate policies to control nitrate dynamics is important for managing potential groundwater pollution.

Based on the toxicity, the maximum contamination level (MCL) for drinking water has been set at 50 mg/L nitrate ion (NO_3) (equivalent to 11.3 mg/L nitrate-nitrogen, $\text{NO}_3\text{-N}$) by the World Health Organization (WHO), and 10 mg/L $\text{NO}_3\text{-N}$ by the US Environmental Protection Agency (EPA) [24, 25]. The MCL for drinking water is set at 10 mg/L for nitrate plus nitrite-nitrogen ($\text{NO}_2\text{-N}$) in Japan [1] and at 45 mg/L NO_3 in India [20]. Several countries and/or states from the USA, Canada, Australia, and Europe have developed monitoring and management guidelines or legislation to regulate nitrate contamination in groundwater or as point sources.

In this paper, we have reviewed the guidelines and regulations that have been developed in advanced countries (e.g., USA, Canada, Australia, and Europe) focusing on livestock facilities. The goal of this review is to compare these guidelines and regulations to explore suitable or best methods for reducing nitrate contamination at livestock facilities based on monitoring and management programs. Monitoring programs are used to identify potential or vulnerable zones where groundwater might be significantly degraded and/or to determine the extent of nitrate pollution plumes that threaten groundwater quality in the vicinity of a facility. Management programs aim at decreasing pollution at the origin such as livestock yard and waste storage area by implementing preventive guidelines. As such, this review is distinct, and it will be helpful to states/countries, which do not currently have guideline, and/or consulting engineers/consultants/owners of livestock operations to design appropriate guidelines/strategies for nitrate management.

Groundwater Monitoring Program

A well-designed monitoring serves to provide a sufficient early warning that allows for corrective action if warranted. Several factors must be considered in establishing a serviceable monitoring program. These include selecting appropriate sites and sampling locations, number of samples to be monitored at each site, and frequency of sampling, among other parameters.

Site Selection

Groundwater monitoring site selection and criteria are significantly different for different parts of the world. Table 1 gives a brief outline of criteria for some of the countries such as USA, Canada, Australia, and Ireland. As this information shows, criteria are based on the size of the livestock herd, proximity to public water sources, geology, soils, well configuration, bedrock, aquifer type and position relative to soils and bedrock, total hydrogeology, and type of waste. There is no agreement nor a way to standardize these criteria into a simple way of classification. That is, the selection process must be taken on a site-to-site basis.

Selection of Monitoring Well

The required number of monitoring wells and samples for each site largely depends on the site-specific conditions, including environmental risk posed by the site and the relative complexity of the geological and hydrological conditions. In general, each facility (Table 2) is required to have a minimum of three monitoring points, one up-gradient and two down-gradient (Fig. 1). However, larger operations with multiple livestock waste control facilities and sites located in sensitive groundwater area as well as areas with public health concerns may require more wells. Up-gradient wells provide the background conditions of the groundwater and so must be located far enough away from the facility. Down-gradient wells should be located very close to the facility to allow early detection of any possible contamination before it migrates far from the well site.

Selection of Monitoring Parameters and Sampling Frequency

Nitrogenous compounds are the main polluting components in livestock wastes with nitrate as the most serious concern. Nitrogen occurs in groundwater mainly in three forms as nitrates, nitrites, and ammonium ion. Nitrite and ammonium ions are intermediate and unstable forms of nitrogen and are quickly oxidized to the more stable nitrate [26]. Thus, nitrate is considered as an indicator parameter to assess the extent of pollution at the vicinity of a facility. Other parameters that indicate pollution are given in Table 3 and include ammonia, nitrite, pH, TDS, P, SO_4^{2-} , and alkalinity. In addition, the selection of suitable monitoring frequency is essential in order to characterize the variability of the groundwater quality with time. In general, frequency of monitoring is based on the hydrogeological properties of

Table 1 Groundwater monitoring criteria and parameters recommended by various governmental regulatory entities

Country/place	Criteria
Nebraska ^a	The decision on whether or not to recommend groundwater monitoring at a point source is based on the following: <ul style="list-style-type: none"> • Depth to groundwater is shallow: <50 ft • Type of unsaturated sediments: sandy sediments • If livestock facility is located in a public water supply's wellhead protection area • If groundwater flows directly to a coldwater class A stream
North Dakota ^b	For open-lot cattle facilities <ul style="list-style-type: none"> • If animals' number: ≥2000 • If production area: ≥20 acres For new or expanding concentrated animal feeding operation, if <ul style="list-style-type: none"> • Soils: sandy loam, loamy sand, sand/ gravel • Water supply well at a depth within 30 ft of the ground surface • The production area is within ¼ mile of a neighboring private water supply well • Within ½ mile of a non-community public water supply well or within 1 mile of a community public water supply well
New Mexico ^c	Monitoring required for each potential source of groundwater contamination. However, the exact criteria for site selection is not mentioned.
Illinois ^d	Groundwater monitoring in accordance with following conditions: If the uppermost aquifer material is located above or within 20 ft of the lowest point of the planned lagoon bottom
Minnesota ^e	Groundwater monitoring based on soil type and depth to water table; considered if the soil is sandy and depth of water table is 5 ft or more
Wyoming ^f	Monitoring requirement if: facility <1 mile from the drinking water intake or well; facility <2 miles but >1 mile from a drinking water intake or well
USEPA ^g	Monitoring site considered: if the existing units and lateral expansions <1 mile from a drinking water intake; existing units and lateral expansions >1 mile but <2 miles from a drinking water intake
Wisconsin ^h	Groundwater monitoring depending upon the type and strength of liquid waste, the volume of discharge, the type of land treatment system, the rate of discharge to the land treatment system, and the site characteristics of the land treatment system
Manitoba ⁱ	Monitoring wells are required where increased risk of groundwater contamination in areas where the subsoil underlying the storage consists of sand, sand and gravel or shallow bedrock forming the aquifers, or sufficient clay or clay-till does not exist under the storage.
Alberta ^j	Groundwater monitoring is based on hydrogeological assessment; however, the exact criteria are not known
South Australia ^{k,l}	Groundwater monitoring is based on site geology, site hydrology, groundwater vulnerability and feedlot descriptions, and feedlot which has potential to cause environmental pollution; however, the exact criteria are not known.
British Columbia ^m	Depend on site-specific geology, soil, and groundwater regime. However, the exact criteria are not known.
UK, Ireland ⁿ	The selection of monitoring locations will depend on the development of a conceptual model/understanding of the objectives for the body of groundwater at risk. However, the exact criteria are not known.
Queensland ^o	Groundwater monitoring is recommended if: <ul style="list-style-type: none"> • Highly permeable strata down to aquifer (K >10⁻⁶ m/s) • Depth to groundwater <5 m • <200 m from a water supply bore • Over unconfined water supply aquifer

^a Ground Water Monitoring at Livestock Waste Control Facilities in Nebraska

^b Livestock Program North Dakota Department of Health

^c Dairy Specific Regulations New Mexico

^d Illinois Livestock waste regulation

^e Minnesota Landfill guidance, MPCA

^f Wyoming Sanitary regulation, DEQ

^g US EPA Groundwater Monitoring and Corrective Action

^h Wisconsin Legislative, document NR 214.21

ⁱ Farm Practices Guidelines for Pig Producers in Manitoba, 2007

^j Farm Practices Guidelines for Pig Producers in Alberta, Farm Practices Guidelines for Pig Producers in Manitoba, 2007

^k Guidelines for Establishment and Operation of Cattle Feedlots in South Australia, 2nd Edition

^l FSA Consulting, Feedlot Groundwater Investigation

^m Guidelines for Environmental Monitoring at Municipal Solid Waste Landfills, British Columbia

ⁿ EU Water Framework Directive

^o Waste disposal (ERA 60) Monitoring system, Department of Environmental and Resources Management, Queensland Government

aquifer and its susceptibility to pollution pressure. Table 3 notes that most guidelines require that the wells are monitored twice a year (usually, spring and fall). The

frequency of groundwater monitoring should be reviewed regularly in response to the overall environmental performance of the site. In some cases, the

Table 2 Selection of number of groundwater samples from monitoring sites recommended by various governmental regulatory entities

Country/sites	No. of wells from up-gradient (U)	No. of wells from down-gradient (D)
Nebraska ^a	1 (at least 300–500 ft away from LWCF)	2 (very close to the LWCF)
North Dakota ^b	1	2 (add. may be required)
Illinois ^c	1	2 (around 20 ft)
Minnesota ^d	1	2 (not farther than 200 ft of the waste fill area)
Wyoming ^e	Minimum 3 wells from each facility	
Wisconsin ^f	1 (far away from sites)	2 (at least around 10 ft), the department may required more number of wells
Canada ^g	1	3
South Australia ^h	Low risk: 1 U, 2 D Moderate to high risk: 1 U, 2 D (groundwater between landfill and site boundary), at least 1 for each receptor (groundwater between site and receptors at risk)	
British Columbia ⁱ	1	3

^a Livestock Waste Control Facilities (LWCF) in Nebraska
^b Livestock Program North Dakota Department of Health
^c Illinois Groundwater Monitoring regulation, Section 506.206
^d Landfill Site, Minnesota Pollution Control Agency
^e Solid Waste Guideline, Wyoming Department of Environmental Quality, Solid and Hazardous Waste Division
^f Wisconsin Legislative document NR. 214.21
^g Solid Waste, Govt. of Newfoundland and Labrador
^h Landfill site, EPA Guideline
ⁱ Guidelines for Environmental Monitoring at Municipal Solid Waste Landfills

agency may increase the frequency of sampling in response to identified poor environmental performance or within high risk zones.

the subsurface and causes nitrate contamination of groundwater. Individual country or agency bodies handle this problem by formulating various management guidelines, which are discussed below.

Management Guidelines

The main sources of nitrate pollution in livestock areas include livestock yard (that includes barnyards, holding areas, and feedlots), manure storage lagoons, and cropland receiving manure [27] areas which are the main sources of animal wastes within livestock facilities. Improper management of these compartments results in manure loss, which then leaches into

Livestock Yard

Proper management of livestock yards includes selecting suitable sites and implementing effective maintenance that can reduce nitrate loss. Detailed requirements of this strategy, as based on the various regulations/guidelines (Table 4), are discussed below.

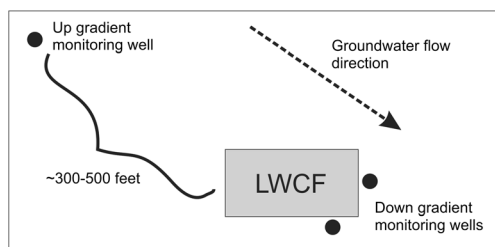


Fig. 1 Generic layout of a typical groundwater monitoring well at livestock waste control facility (LWCF) (Source: Livestock Waste Control Facilities (LWCF) in Nebraska)

Distance from Wells

Table 4 shows that all livestock operations should be located at least 100–200 ft away from any wells to reduce the risk of water pollution. In the case of good farmstead planning, the livestock facility should be placed 300 to 400 ft away from houses, because wells are often located near the house. In addition, livestock operations and/or exercise yards should be placed downslope from the well, so that the chance of runoff entering the well is reduced.

Table 3 Selection of water parameters and sample frequency for groundwater monitoring recommended by various governmental regulatory entities

Country/sites	Parameters	Frequency
Nebraska ^a	Nitrate + nitrite, ammonia, total N, Cl, SO ₄ ²⁻	Minimum two times per year
North Dakota ^b	Nitrate, Cl ⁻ , ammonia, N isotope	At least twice a year, usually in the spring and fall (irrigation is not active)
Illinois ^c	Nitrate-N, phosphate-P, Cl ⁻ , SO ₄ ²⁻ , ammonia N, <i>Escherichia coli</i> or <i>Fecal coliform</i>	Quarterly
Minnesota ^d	Alkalinity, ammonia N, nitrate + nitrite, SO ₄ ²⁻ , heavy metals, EC, temperature, pH	Routine sampling, limited to spring, summer and fall events
South Australia ^e	pH, EC, TDS, nitrite + nitrate, ammonia, heavy metals, Ca, Mg, Na, K, Cl ⁻ , HCO ₃ ⁻ , SO ₄ ²⁻	Biannual
Canada ^f	pH, EC, TDS, ammonia, nitrate, nitrite, P, SO ₄ ²⁻	Biannual (spring and fall)

^a Ground Water Monitoring at Livestock Waste Control Facilities

^b Livestock Program North Dakota Department of Health

^c Illinois Administrative rule, groundwater monitoring regulations around lagoons

^d Landfill Site, Minnesota Pollution Control Agency

^e Landfill Site EPA Guideline

^f Solid waste, Govt. of Newfoundland and Labrador

Site Characterization

Site topography, geology, and soil characteristics are factors in nitrate contamination of groundwater; surface/subsurface soil texture, soil depth, permeability, and water table are very important. According to Utah State University [28], the best sites are located on deep clay soils, although sites with well-drained silt loam/clay loam soil with low permeability are also appropriate. Sites characterized by shallow soil, or a high water

table, or a sandy/gravelly soil with excessive drainage and high permeability are poor or unsuitable [29]. Soil type should be considered as one of the most important criteria for site selection.

Clean Water Diversion and Runoff Control

Reducing the amount of fresh water entering the livestock facility can reduce water pollution (Table 4). Diversion

Table 4 Guideline for livestock yards recommended by various US State governmental regulatory agencies

Site/country	Minimum distance to well water	Location from well	Site assessment before development	Clean water diversion/runoff control system	Vegetative filter strip system	Yard cleaning	Type of yard
North Dakota ^a	100 ft (private) 500 ft (public)	Downslope	Yes	Yes			Concrete
Virginia ^b	150 ft	Downslope	Yes	Yes	Yes	Once per week	Concrete
Indiana ^c	50 ft (new well)	Downslope	Yes	Yes	Yes	Once per week	
Utah ^d	200 ft		Yes	Yes		Once per week	
Tennessee ^e	100 ft	Downslope	Yes	Yes	Yes	Regularly	Concrete
New Mexico ^f	100 ft(private well) 200 (public well)		Yes	Yes	Yes		
New Jersey ^g	50 ft (new well); 200 ft	Downslope	Yes	Yes			Concrete
Nova Scotia ^h	100 m		Yes	Yes	Yes		Concrete

^a Livestock Program North Dakota Department of Health

^b Department of Environmental Quality, Virginia

^c Indiana State Board of Health, Livestock Yards Management

^d Utah State University Extension, Farmstead Assessment for Ground Water and Surface Water Protection, Fact Sheet 8, Revised March 2012

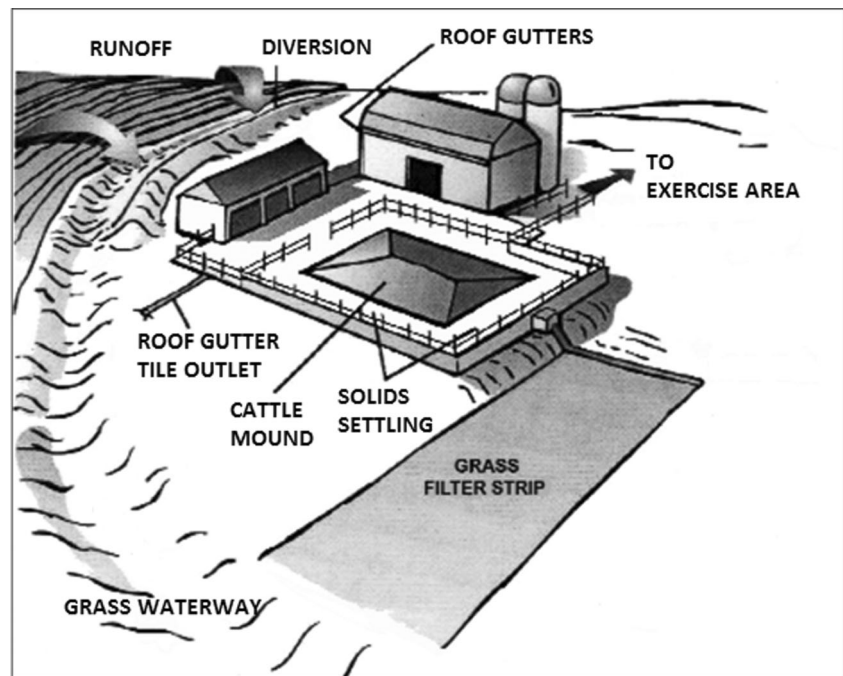
^e The University of Tennessee Agricultural Extension Service, US, Assessing Your Livestock Yard Management, Farm-A-Syst, SP484K

^f New Mexico FARM-A-SYST, Fact Sheet 8, Reducing the Risk of Groundwater Contamination by Improving Livestock Yards Management

^g New Jersey FARM-A-SYST, Fact Sheet 8, Reducing the Risk of Groundwater Contamination by Improving Livestock Yards Management, NJFAS-8F

^h Sitting and Management of Hog Farms in Nova Scotia, Canada, N.S Dept. of Agriculture

Fig. 2 Livestock yard management by diverting surface runoff and using vegetated filter strip (adopted from Utah Farmstead Assessment for Groundwater and Surface Water Protection, Utah State University Extension, Fact Sheet 8, Revised March 2012)



methods (Fig. 2) include small terraces and roof gutters to direct water away from livestock yards and constructing an earthen ridge or terrace across the slope upgrade from the livestock lot to prevent runoff from entering the yard. Vegetation filter strips (Fig. 2) are also effective to control pollutants within the runoff. It has been shown that the application of buffer strips also helps to minimize the pollutant inputs into water bodies around the livestock area [30]. Guidelines for these methods for some areas are given in Table 4.

Yard Surface and Cleaning

The risk of nitrate contamination in surface and groundwater can be somewhat controlled by the type of surface material. Generally, concrete is better than bare earth. In addition, if the bedrock is close to the surface, paving the surface with concrete will be helpful to reduce water contamination. Cleaning the livestock area on a regular basis can reduce the amount of manure in yard runoff. Based on the guidelines given in Table 4, cleaning and scraping at least once a week is preferable. Concrete surfaces are easier to clean than earthen surfaces, which can only be properly cleaned when dry, resulting in less frequent cleaning and increased potential for runoff.

Abandoned Livestock Yard

Abandoned yards can be a significant risk for nitrate contamination of groundwater. In abandoned yards, the manure pack breaks up easily due to lack of use, so that rain water can leach pass through the cracks, resulting in nitrate leaching to

groundwater. To manage this problem, all the manure and soil mixture should be collected from the abandoned feedlot and then spread onto fields as fertilizer; the former feedlot surface can then be filled with other soil material. Afterward, the area should be planted with crops that require lots of nitrogen to make use of the nitrogen released from the manure decomposes.

Manure Storage

Proper storage of manure is crucial for every livestock operation to protect groundwater resources. The detailed requirements for manure storage in some areas are given below (Table 5).

Distance from Wells

Potential groundwater contamination by manure leachate can be more critical if the manure storage is located close to sources of drinking water or public wells. In order to minimize this risk, all manure storages must be located at the minimum setback distances as determined by different agencies with respect to any well. As shown in Table 5, the minimum separation distance should be between 30 and 90 m with 100 m a preferred distance to reduce risk. In addition, manure storage must be positioned downslope from wells so that runoff cannot drain into wells. The type of storage facility also dictates the preferred storage method. At Newfoundland, Canada [31], the minimum separation distance between manure storage and wells is 100 m for earthen storage but only 50 m for synthetic

Table 5 Guidelines for management of manure storage facilities recommended by various governmental regulatory agencies

Site/country	Minimum distance to well water	Location from well	Site assessment before development	Distance from waste structure bottom to groundwater	Surface water diversion	Liner material used	Limits on land application
Nebraska ^a	>100 ft (domestic), >1000 ft (public)	Downslope	Yes	>4 ft	Yes	Soil(1×10^{-7} cm/s) synthetic liner	
Illinois ^b	>150 ft (potable water well)		Yes		Yes	Concrete, earthen, and synthetic liner for shallow aquifer	
Missouri ^c	300 ft		Yes		Yes		
Washington ^d	100 ft	Downslope					
Texas ^e	250 ft (temporary)	Downslope	Yes		Yes	Clay liner with permeability 1×10^{-7} cm/s, concrete	
California ^f	150 ft		Yes		Yes	Must contain at least 10 % clay and no more than 10 % gravel or materials of equivalent impermeability	Yes
Arizona ^g	100 ft		Yes	Varies	Yes	Varies depending on soil types, exposure, and NRCS technical assistance and standards	Yes
Ontario ^h	30 m		Yes		Yes	Soil (hydraulic conductivity of 1×10^{-8} m/s, a geosynthetic clay liner)	Yes
England ⁱ	100	Downslope	Yes		Yes	Plastic liner, organic materials such as leaves or woodships, or concrete	Yes
Prince Edward Island ^j	90 m		Yes	3.3 ft		Concrete, synthetic liner	Yes

^aNebraska Administrative Code

^bIllinois Administrative Code, Section 900, Livestock Management Facility Regulations

^cMissouri Well Construction Code Rule 10 CSR 23-3.010, 1996

^dClean Water for Washington: Managing Livestock Manure to Protect Groundwater, EB1717

^eTexas Agricultural Extension Service, Reducing the Risk of Groundwater Contamination by Improving Livestock Manure Storage and Treatment Facilities Report-B-6030

^fState Water Resources Control Board (statewide), CA Dept. of Food and Agriculture (CDFA), Regional Water Quality Control Boards (9 regions), Local Government

^gArizona Department of Environmental Quality (ADEQ)

^hOntario Regulation 267/03 under Nutrient Management Act, 2002, Siting Regulations for Manure Storage Facilities, Order No. 09-061, 2009

ⁱGuideline for Livestock Yard and Manure Storage Management

^jGuideline for Manure Management for Prince Edward Island, Canada, Department of Agriculture and Forestry

or concrete storage. The groundwater contamination by manure leachate can be more critical if the manure storage is closely located to a drinking water/public well. Therefore, in order to minimize such risk, all manure storages must maintain the minimum setback distance with respect to any well.

Site Characterization

The location of manure storage facilities should consider geologic structure, soil texture, water table depth, and depth to bed rock. Livestock waste can easily contaminate groundwater if a storage facility is located in areas with thin soil, coarse-textured permeable soils, over sand or gravel aquifers, when the water table is at or near the surface, or if fractured bedrock/

karst terrain is within a few feet of the surface. Thus, hydrogeological characteristics of a site must be evaluated to ensure the site is suitable for storage; this is followed by many guidelines/regulations (Table 5).

Use of Liners

Liners are commonly used at storage pits or lagoons to control leachate; the choice of liner depends on multiple factors. According to Illinois Administration Code 506 [32], if groundwater is located near (within 1.5 m) the bottom of the proposed waste storage facility, it must be constructed from concrete to prevent seepage. If the facility is constructed from earthen material, it should also have an earthen or synthetic

Table 6 List of countries/states followed action plan for the management of water pollution

Country/place	Management action
North Dakota ^a	<ul style="list-style-type: none"> • If one sample result of a groundwater monitoring well exceeds the monitoring action limit, an additional sample from that well shall be taken within 30 days. • If the maximum level action limit is reached, the department may require the facility to remove all manure from the area, which has been determined to be the source of contamination, and upgrade the facility and mitigate the source of contamination.
Illinois ^b	<p>For violations of the setback distance requirements, the Department may issue one of the following to the owner or operator of the livestock management facility or livestock waste handling facility:</p> <ul style="list-style-type: none"> • If during construction, a cease and desist order which prohibits further construction of the livestock management facility or livestock waste handling facility prohibits entry of livestock into the livestock management facility and prohibits use of the livestock waste handling facility; or an operational cease and desist order. <p>Waste management plan: Any person who is required to prepare a waste management plan and who fails to do so shall be subject to the following:</p> <ul style="list-style-type: none"> • Warning letter by the Department for the first violation and shall be given 30 working days to do that. • For failure to maintain and implement within 30 working days, the person shall be fined an administrative penalty of up to \$1000 by the Department and given to do another 30 days. • For failure to maintain after the second 30-day period, the Department may issue an operational cease and desist order until compliance is attained.
Ohio ^c	Livestock operations found to be discharging pollutants to the state's water without a valid permit might be liable for civil penalties up to \$10,000 for each day of violation.
Ohio ^d	<p>Anyone found to be discharging pollutants such as manure, including process wastewater, to the state's waters can be found in violation of the Stream Litter Act, which carries penalties of a third-degree misdemeanor for a first offense. Violators can be fined up to \$500, or sentenced to 60 days in jail, or both, for a first offense.</p> <p>Corporations can be fined up to \$3000 for a first offense and \$5000 for subsequent offenses.</p>
Hawaii ^e	<p>Each CAFO (concentrated animal feeding operation) is required to have a National Pollution Discharge Elimination System (NPDES) permit, if it falls under any of three criteria:</p> <ul style="list-style-type: none"> • Any animal feeding operation having over 1000 animal units. • Any animal feeding operation having over 300 animal units, and which discharges process waste pollutants directly into state waters through a manmade device, or otherwise come into direct contact with the animals confined in the operation. <p>If the CAFO does not have an NPDES permit, any discharge occurring from the operation is a violation of the Federal Clean Water Act. The operation is thereby subject to enforcement action under the pollution reduction program by the Director of Health Official. It is accompanied with an order to cease and desist from any further violation and may specify corrective measures and the time schedule for their implementation. A formal action also usually contains an order for the payment of a civil penalty.</p>
Nebraska ^f	<p>Any person owning or operating an animal feeding operation which does not hold an NPDES, Nebraska Department of Environmental Quality, required inspection request with the appropriate fee as follows:</p> <ul style="list-style-type: none"> • \$100 for each small animal feeding operation; • \$200 for each medium animal feeding operation; or • \$500 for each large animal feeding operation.
North Carolina ^g	A livestock farm operator may be fined up to \$5000 immediately for a wilful or deliberate discharge of pollutants to surface waters of the state
South Australia ^h	If liquid waste is placed into, or allowed to enter or form, a pond or lagoon in (whether natural or artificial) where it would be subject to evaporation or percolation into the earth, the licensee is guilty of an offence, penalty \$2000
Hong Kong Waste ⁱ	Any person who failed containers for storage of livestock waste that spillage, leachage of any livestock waste contained therein, and who discharge solid or liquid waste into any channel, ditch, communal sewer, spring, watercourse, well for potable or public shall be liable a fine of \$50,000

^a Livestock Program, North Dakota Department of Health^b Illinois Administrative Code 900: Livestock Management Facility Regulations^c Ohio Administrative Code 901^d Ohio Department of Natural Resources, Division of Wildlife^e Hawaii State Department of Health Wastewater, Guidelines Livestock Waste Management^f Administrative Code—Nebraska Department of Environment Quality^g North Carolina, Water Quality and Waste Management Rules for Livestock Farms^h South Australia, Waste Management Regulations, 1988ⁱ Hong Kong Waste Disposal (Livestock Waste) Regulations, Cap 35A

liner. The earthen liner should be in situ soil to which additives such as clay or clay/bentonite mixtures are added, with a minimum thickness of 0.66 m. Several guidelines/regulations are

given in Table 5. In addition, manure storage facility should include a compacted soil cover to seal the site. This will reduce oxygen contact and lessen aerobic decomposition, which

promotes microbial conversion of nitrate to nitrogen gas, which escapes to the atmosphere and reduces nitrate leaching to groundwater. In the case of karst topography, the facility should be constructed utilizing a rigid material such as concrete or steel to prevent seepage of the stored material into groundwater [32].

Limit of Manure Application

Livestock manure is a valuable fertilizer. However, the amount of manure produced on livestock farms is often more than agronomic requirements of the farm, which can lead to repeat application of manures in excess of crop requirements and a surplus N [33]. A study of 177 Dutch dairy farms showed an average N surplus of 486 kg N ha⁻¹ [34]. Similarly, excess N surpluses at dairy, pig, and poultry farms have been reported from other European countries [35]. This excess N is a potential major source of nitrate in groundwater. [36] reported high nitrate contamination in groundwater in Delaware where cropland received excessive application of livestock manure. To cope with this problem, guidelines/regulations restrict the application of manures on crops. The European Commission Nitrates Directive [37] has set 170 kg of nitrogen per hectare per year for regions that are prone to N leaching.

In addition, manure application is restricted with respect to public water well locations and water table depth. According to Hawaii Guidelines for Livestock Waste Management [38], livestock waste should not be applied to land within 50 ft of drinking water wells. In many countries, manure application is avoided at certain times of the year, mostly immediately before, during, and after high rainfall and during flooding condition. Also, proper concerns must be given to soil types before applying manure, for example, soil with coarse textured soils, fractured bedrock, and low water holding capacity [39]. These sites have high potential for leaching, thus they can cause serious nitrate pollution in groundwater [40]. According Nova Scotia guideline [41], manure should not be applied within 60 m on a sand or gravel soil. Also, manure application should be avoided to frozen or snow-covered soil.

Action Plan

Action plans for responding to N pollution, prevention, and penalties for non-compliance have been determined by numerous countries/states (Table 6). In most cases, the plans deal with the following:

- Monitoring nitrate and reporting the results
- Comply with the regulation and determine contaminant levels
- Action required if nitrate exceeds permissible limits
- Warning in the case of first-time violation

- Action (fine or penalty) when warning is ignored
- Informing the public about water quality and public health risks

Conclusions

Intensive livestock production is a major environment concern of nitrate contamination in groundwater. There are several monitoring and management guidelines/legislations developed in many advanced countries/states to combat this contamination, but there is no single model that can be universally applied because each state has its own, and sometimes complex, guidelines. However, existing guidelines can be adopted or used as a model, where none currently exists. Effective monitoring includes site selection criteria along with selection of sampling points and parameters which can identify the source and extent of the contamination. In most of the US states, the site is selected based on groundwater depth, well location in relation to livestock manure storage areas and surface and subsurface soil texture, and number of livestock. In other countries, it is based more on conceptual modeling. Management programs deal with selection of suitable location (based on the surface/subsurface geological conditions, minimum setback distance, downslope location from wells), proper structure (use of liners and diversion of surface runoff from facility), maintenance of the facility, and limits of manure application, in order to reduce nitrate leaching. In addition, an action plan should be implemented in state level to regulate contamination levels. Awareness and training programs on best livestock management practices should be given to the public, including farming communities, to reduce nitrogenous inputs to groundwater resources.

Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Human and Animal Rights and Informed Consent No human or animal studies are performed by the authors. This article does not contain any studies with human or animal subjects performed by any of the authors.

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