Groundwater Monitoring of Liquid Manure Storage Structures in Iowa

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ABSTRACT

Concerns about the impacts of manure storage on groundwater quality were raised in the mid 1990's resulting in the initiation of new research efforts and the incorporation of monitoring requirements into state-issued permits for earthen manure storage (EMS) structures. In 2004, additional monitoring requirements went into effect for below-building pits associated with new construction of confinement animal feeding operations in karst areas. Required monitoring of wells (generally within 15 meters of the EMS structures) and perimeter tiles revealed chloride concentrations generally below 300 mg/L, nitrate-nitrogen (or nitrate-N plus nitrite-N) concentrations up to 140 mg/L, and ammonia-nitrogen concentrations below 3 mg/L with two exceptions at 11 and 160 mg/L. Required monitoring of perimeter tiles around confinements located in karst areas revealed some elevated ammonia-N concentrations (up to 11 mg/L with one exception at 88 mg/L), however, concentrations were highly variable and no clear trends were apparent. To assess the impacts of permitted earthen structures where only 2-3 years of quarterly data are available, these data were compared to data distributions and trends seen in the long-term records obtained from groundwater monitoring of two earthen manure storage (EMS) structures. Groundwater monitoring around three EMS structures located in western, north-central and eastern Iowa began in 1994. Monitoring at the western Iowa basin was discontinued in 1998 when no effects were seen on downgradient wells. The other two EMS site were monitored until 2005. These basins were constructed primarily in glacial till and designed to meet the maximum permitted seepage limit of 0.16 cm/day (1/16th inch per day). The results of long-term monitoring show that water resources located less than 45 meters (150 ft) downgradient of EMS structures are at risk for high nitrate concentrations (up to 150 mg/L) which can affect the health of humans, livestock, and aquatic organisms. The potential for greater transport in more permeable settings, and the potential for transport of other contaminants, such as viruses, cannot be evaluated from available data. The long-term records indicate that wide ranges of nitrate concentrations and/or median nitrate-N concentrations above 20 mg/L are indicative of more severe contamination, while narrow distributions with medians below 20 mg/L nitrate-N are typical of monitoring during the first five years after basin construction or for basins with little impact on surrounding groundwater. The results of short-term monitoring data must be interpreted cautiously, and may be complicated by upgradient feedlots, nearby manure application, or other activities.

Long-Term Studies (1993-2005)

IGWS staff began monitoring three long-term EMS sites in 1993. The three sites are located in north-central, eastern, and western Iowa, in areas characterized by different surficial geology and soils (**Figure 1**). Quade and others (1996; 1998) provide detailed geologic characterization of the sites.

Figure 1. Locations of long-term monitoring sites

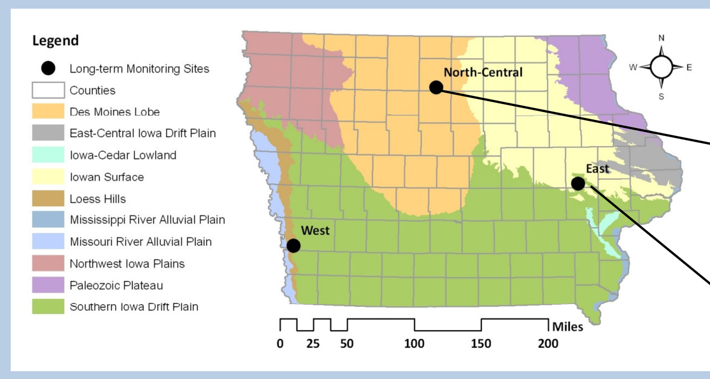


Figure 2. Map of North-Central Iowa Site

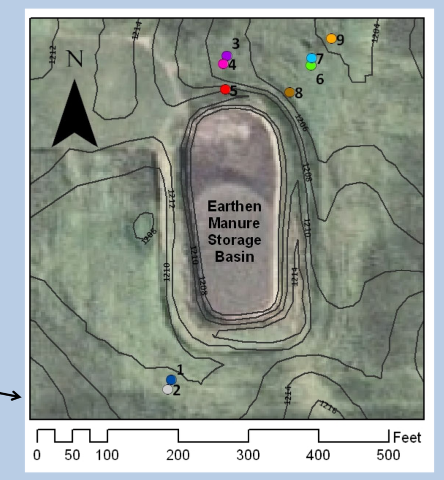
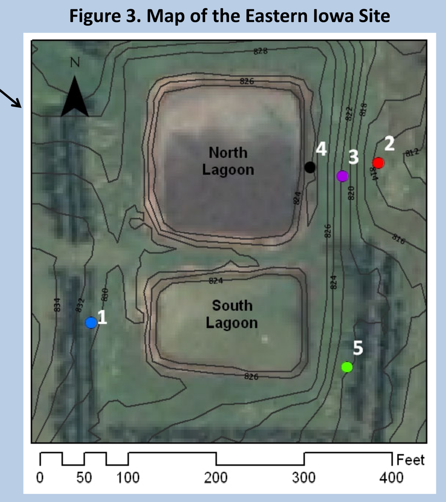


Figure 3. Map of the Eastern Iowa Site



At the north-central site, the earthen basin is constructed within glacial deposits typical of the Des Moines Lobe, which include a 12-15 foot layer consisting of supraglacial till with low bulk density values and highly variable textures, which vary from loam, to sandy loam, to sand, overlaying a uniform, dense, loam-textured subglacial till layer. Seven monitoring wells were installed around the basin which is used to store wastes from a 4,500-head finishing swine operation (**Figure 2**).

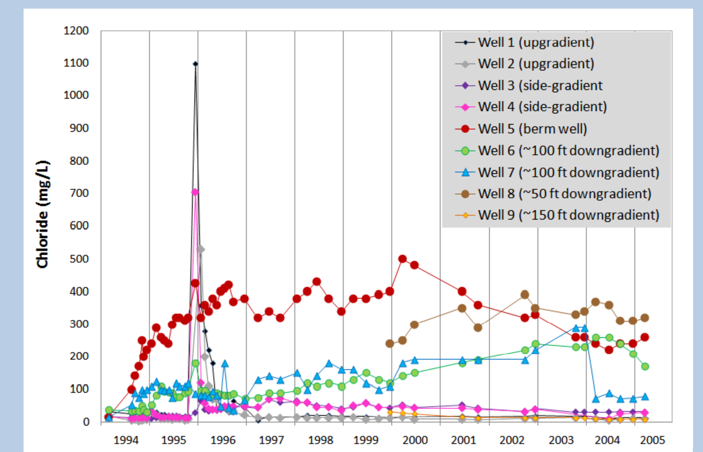
The geology of the eastern Iowa site is characterized by fractured Pre-Illinois glacial till, mantled by colluvium (slopewash materials) and a thin deposit of windblown silt (loess). Wastes from a 130-sow farrowing and 680-hog finishing operation are stored in a two-cell lagoon, constructed primarily in uniform loam-textured, fractured till. Five monitoring wells were installed at this site (**Figure 3**).

The western Iowa site is located in relatively thick loess and loess-derived alluvium. The basin received wastes from a 1,800-head swine finishing operation. A perimeter tile was installed to lower groundwater beneath the basin and seepage into this tile was redirected back into the basin. Three monitoring wells were sampled in addition to the tile. Monitoring at the western Iowa site was discontinued in 1998 when no effects were seen in the perimeter tile or in downgradient wells.

Chloride Results in Groundwater

Figure 4 shows a steady increase in chloride concentrations in wells up to 100 feet downgradient of the lagoon at the north-central Iowa site, while no increase was observed at 150 feet downgradient. Variability in chloride concentrations may result from changes in composition of the stored effluent. It has also been hypothesized that sealing occurs over time as manure solids reduce the permeability of the basin's earthen liner. This sealing effect could be reversed when the basin contents are agitated or when lower liquid levels allow the liner to dry and crack. The spike in chloride concentrations in late 1995 and early 1996 was caused by use of bleach to ensure that bacterial contamination was not introduced into the wells from the surface.

Figure 4. Chloride concentrations in north-central Iowa site wells



Manure Constituents

Table 1 (right) lists results of manure analyses from the north-central Iowa site obtained in 1996. The following volatile organic compounds (VOC's) were not detected above the quantitation limit of 50 µg/L:

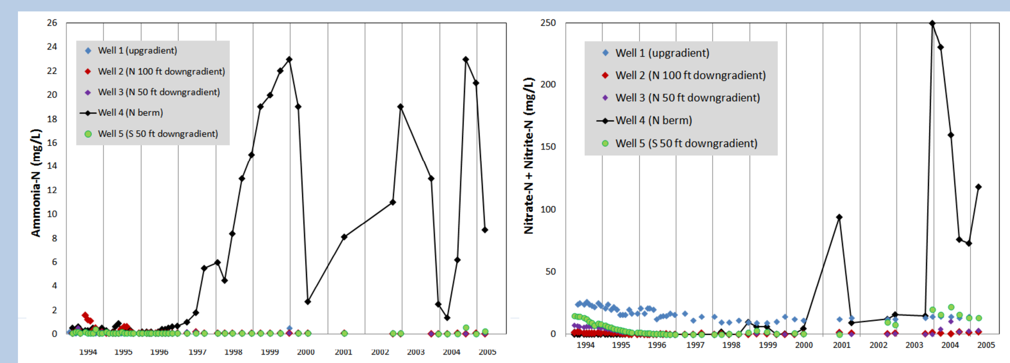
- Benzene
- Bromodichloromethane
- Bromoform
- Bromomethane
- Carbon disulfide
- Carbon tetrachloride
- Chlorobenzene
- Chloroethane
- Chloroform
- Chloromethane
- cis-1,3-Dichloropropene
- trans-1,3-Dichloropropene
- Dibromochloromethane
- Ethylbenzene
- Methylene chloride
- Styrene
- Tetrachloroethene
- Trichloroethene
- Vinyl chloride
- Xylene (total)

Table 1. Manure analyses from the north-central Iowa site.

	Analyte	Result Range or Value	Quantitation Limit	Units	Method Name(s)
Bacteria	Fecal Coliform	170000 - 500000		MPN/100mL	SM21 9221E
	Membrane Fecal Coliform	560 - 570000	10	cfu/100mL	SM21 9222D
Nutrients	Ammonia Nitrogen as N	690 - 5400	0.05	mg/L	TIM 780-86T, LAC10-107-06-1J, SM 4500-NH3 C
	Nitrate + Nitrite Nitrogen as N	<0.05 - 1.7	0.05	mg/L	EPA 353.2
	Nitrate Nitrogen as N	<0.5 - 54		mg/L	EPA 300.0
	Nitrite Nitrogen as N	<0.5 - 20		mg/L	EPA 300.0
	Organic Nitrogen as N	61 - 4200		mg/L	TIM 786-86T, SM 18 4500-P E, LAC10-107-06-2E
	Filterable Ortho Phosphate as P	400		mg/L	TIM 781-86T
	Ortho Phosphate as P	48 - 190	0.02	mg/L	LAC10-115-01-1A, SM 18 4500-P E
	Phosphate	66 - 350		mg/L	EPA 300.0
	Total Phosphate as P	240		mg/L	TIM 787-86T
Basic Chemistry	Bromide	<0.5 - 26		mg/L	EPA 300.0
	Chloride	85 - 1900		mg/L	EPA 325.3, EPA 300.0
	Dissolved Calcium	35 - 160	1	mg/L	EPA 200.7
	Dissolved Iron	0.73 - 6.2	0.02	mg/L	EPA 200.7, SM 3111B
	Dissolved Magnesium	2.5 - 58	0.1	mg/L	EPA 200.7
	Dissolved Manganese	0.06 - 0.3	0.02	mg/L	SM 3111B
	Dissolved Potassium	1100 - 3400	1	mg/L	EPA 200.7
	Dissolved Sodium	260 - 820	0.5	mg/L	EPA 200.7
	Fluoride	<0.5 - 460		mg/L	EPA 300.0
	Laboratory pH	7.1 - 8		pH Units	SM 4500-H+ B, EPA 150.1
	Sulfate	<2 - 570		mg/L	EPA 300.0
	Total Alkalinity as $CaCO_3$	4200 - 19000	1	mg/L	SM 2320B
	Total Organic Carbon	710 - 22000		mg/L	EPA 415.1, SM 5310 B
VOC's	2-Butanone	110	100	ug/L	EPA 8260
	Acetone	140	100	ug/L	EPA 8260
	Toluene	130	50	ug/L	EPA 8260

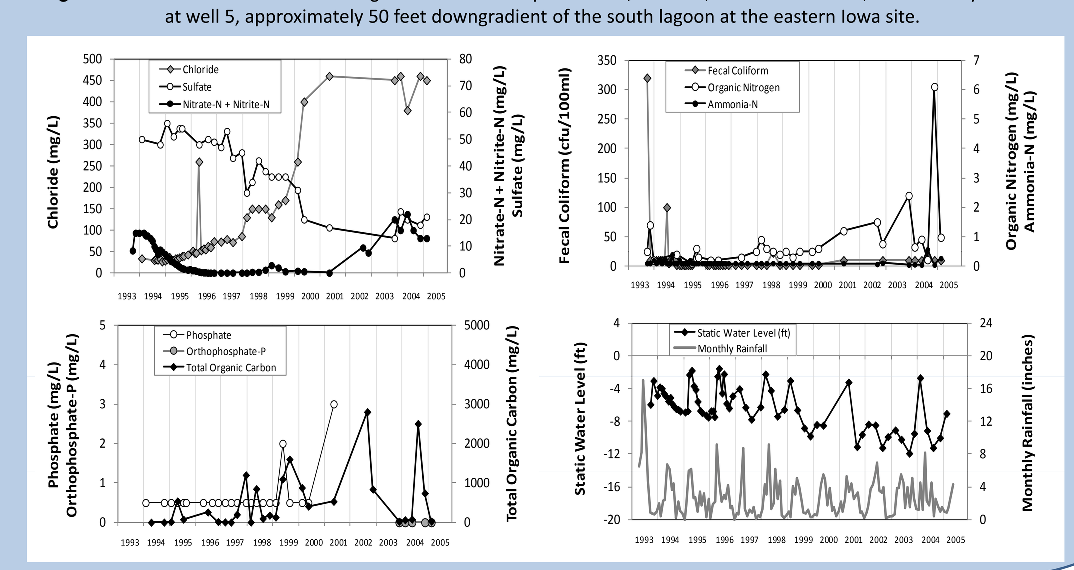
Nitrogen Results in Groundwater

Figure 5 illustrates the relationships between different forms of nitrogen in the monitoring wells at the eastern Iowa site.



Ammonia-nitrogen began to rise in the berm well immediately downgradient of the north basin (well 4) four years after the basin was constructed. After seven years, nitrate-N + nitrite-N concentrations rose in well 4, and after ten years, nitrate-N + nitrite-N levels began to rise above original background levels in well 5, the monitoring well approximately 50 feet downgradient of the south basin. Nitrate-N + nitrite-N concentrations started out much lower (1.9 mg/L) at well 2, the well approximately 100 feet downgradient, and rose only slightly to 2.2 mg/L during the last year of monitoring.

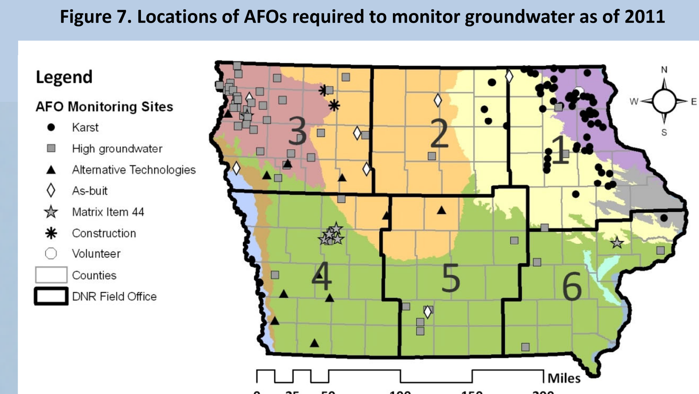
Figure 6 shows the results of monitoring for nine chemical parameters, bacteria, static water levels, and monthly rainfall at well 5, approximately 50 feet downgradient of the south lagoon at the eastern Iowa site.



Required Monitoring at Animal Feeding Operations Sites

As of January 2011, IDNR had records of 159 animal feeding operations that were required to do water monitoring. Reasons for required monitoring include location of new confinements in vulnerable karst areas, construction of earthen manure storage structures less than 2 feet above seasonal high water tables or above coarse-grained alluvial deposits, and use of alternative technologies (such as vegetative treatment areas) for waste treatment.

Figure 7. Locations of AFOs required to monitor groundwater as of 2011



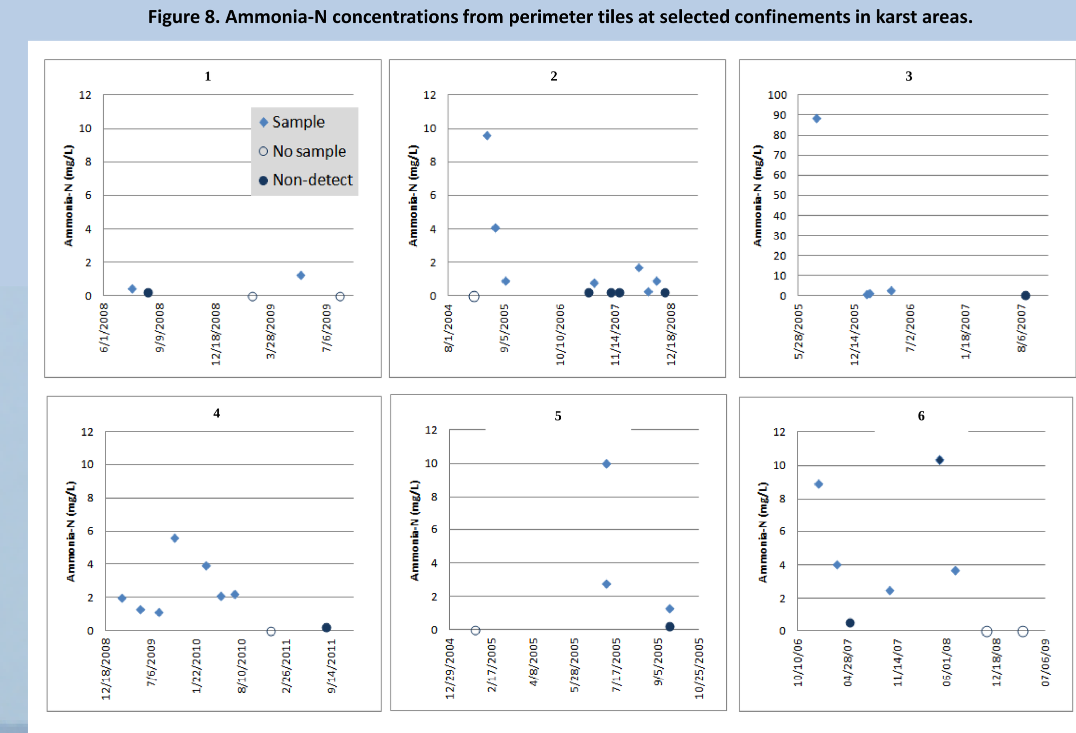
For new confinements constructed after 2004 in karst areas, quarterly monitoring of perimeter tiles installed around the footings of these typically 8-foot deep concrete structures was required. When water was available, results of ammonia-N analyses were submitted. EMS structures that do not meet groundwater separation requirements are allowed to install perimeter tiles to artificially lower groundwater levels. In these cases, quarterly monitoring from the tile outlet has been required for nitrate-N, ammonia-N, and chloride for a minimum of 2 years. In other cases, EMS structures located above alluvial deposits were required to install upgradient and downgradient wells.

Ammonia-Nitrogen Results at Karst Sites

Over 400 sampling attempts were reported. Approximately 80% of the quarterly reports submitted indicated that perimeter tiles were dry or frozen at the time of sampling. When water was available, ammonia-N concentrations were below 11 mg/L, with the exception of one sample at 88 mg/L (**Figure 8**). No clear trends in the ammonia-N concentrations are discernible. Higher ammonia-N concentrations appear to occur during wet periods, perhaps when water table levels rise close to the bottom of the pits.

Ammonia-N in deep-pit swine manure has been reported between 2000-5000 mg/L. Ammonia-N levels in rainfall are generally below 1 mg/L, however, monitoring of ammonia in melted snow shows that ammonia-N in snow can reach as high as 2.5 mg/L in Iowa and surrounding states (Jones and Duff, 2011). Ammonia-N in groundwater may also come from application of commercial fertilizer or manure on nearby cropland, therefore, further study would be required to confirm the source of high ammonia levels (>2 mg/L). Where ammonia is detected above 2 mg/L, it would be instructive to develop monitoring wells to determine if contamination of the karst aquifer is occurring.

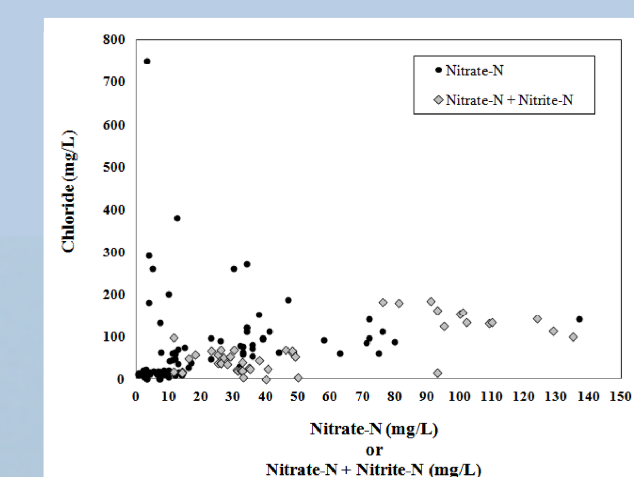
Figure 8. Ammonia-N concentrations from perimeter tiles at selected confinements in karst areas.



Groundwater-lowering Tile Nitrogen and Chloride Results

A total of 228 sample results from required monitoring of groundwater-lowering tiles around permitted EMS structures were compiled. **Figure 9** shows sample results from 21 tiles representing 18 sites. The majority of tile-water samples had nitrate-N (or nitrate-N + nitrite-N) concentrations between 10-50 mg/L, but five tiles had concentrations ranging from 50 to 150 mg/L. These values represent groundwater quality beneath earthen basins holding cattle, swine, and dairy manure from both confinements and open feedlots.

Ammonia-N was detected in only a handful of samples. Ammonia-N concentrations were all below 3 mg/L, except for two samples with 13 and 160 mg/L ammonia-N. The majority of the samples had chloride concentrations between 0–200 mg/L, but a few samples ranged from 200–400 mg/L and one sample was reported at 750 mg/L chloride. There appears to be no significant correlation between nitrate-N concentrations and chloride for the entire data set, but the high nitrate-N samples did have chloride levels over 100 mg/L.



Comparing Data Distributions From Long-Term Sites to Required Monitoring Sites

A few individual AFOs required to submit monitoring showed increasing nitrate-N concentrations over time, but others trended downward. A comparison with the long-term monitoring studies shows that the downward trends are likely in the first few years after construction, while upward trends are likely as the basin ages.

Further analysis comparing the data distributions at individual sites with the results of monitoring at one of the long-term study sites was done to help assess the impacts of each basin on shallow groundwater quality. **Figures 10 and 11** depict these distributions in the form of boxplots, where the median is represented by the line in the middle, the boxes represent the data between the 25th and 75th percentile, and the whiskers and outliers represent the rest of the data.

If monitoring data are tightly distributed around a median below 20 mg/L nitrate-N, significant seepage has not occurred. If monitoring data are broadly distributed and/or the median nitrate-N concentration is greater than 20 mg/L, significant seepage is probably occurring. Nitrate-N concentrations above 30 mg/L are not likely to be observed within the first five years of a basin's life, as seen in **Figure 10**. Monitoring sites 1 and 2 displayed in **Figure 11** are open feedlots where high nitrate-N levels may be originating, in part, from the upgradient open feedlots. Without independent monitoring wells, this contribution cannot be distinguished from that of the basin.

Figure 10. Distributions of Nitrate-N concentrations at the north-central Iowa site over increasing time spans

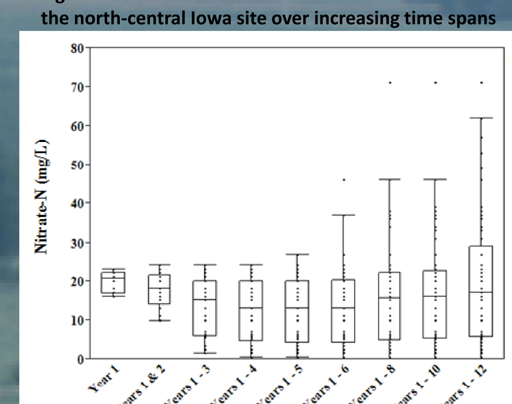
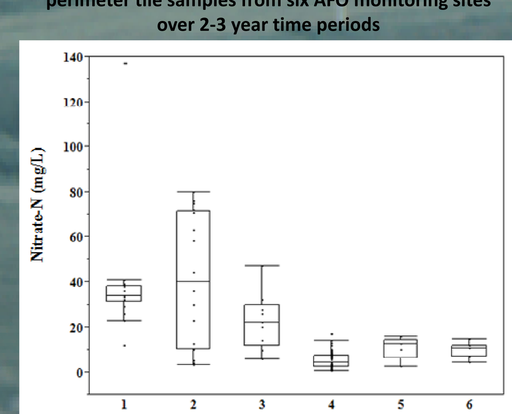


Figure 11. Distributions of Nitrate-N concentrations in perimeter tile samples from six AFO monitoring sites over 2-3 year time periods



Conclusions and Recommendations

•**Liquid manure storage in earthen and concrete structures** has the potential to impact localized groundwater resources. The extent of nutrient contamination is likely to be less than 500 feet for earthen basins constructed according to permit requirements in clay-rich soils. Contamination may travel further in more permeable materials, such as sands and gravels, however, monitoring data in these settings is limited in Iowa and complicated by contributions from open feedlots, spills, and fertilizer and manure application on adjacent cropland.

•**For concrete structures constructed above seasonal high water tables**, it appears that the water quality impacts are minimal. Elevated ammonia-nitrogen concentrations were observed in perimeter tiles at a few sites, however, concentrations were not found to remain elevated. Variable ammonia-nitrogen concentrations may be related to changes in precipitation patterns and associated water table elevations below manure storage structures. More frequent monitoring and installation of monitoring wells would be necessary to verify this relationship.

•**The accumulation of ammonia below manure storage structures** poses a concern for water quality impacts after closure. Removal of carbon-rich materials and addition of oxygen to the soils beneath these structures could lead to transformation of soil-bound ammonia-N to nitrate-N, which moves easily in groundwater. If basins will no longer be used for manure storage, the materials beneath the basin may need to be excavated and land-applied in order to avoid long-term groundwater contamination, especially where there is a possibility that future drinking water wells could be located in the vicinity or where the structures are in close proximity to surface waters.

•**Ammonia-N levels ranged as high as 88 mg/L in perimeter tiles** encircling below-ground concrete manure storage structures at confinement sites in karst areas, but follow-up sampling indicated that concentrations did not remain high. Sufficient water for sampling was rare due to the deep water-tables at the majority of karst monitoring sites. Monitoring at karst sites was done at newly constructed facilities. Groundwater contamination is more likely to occur as the concrete structures degrade or leakage is accumulated in soils below these facilities. Additional investigations would be necessary to determine if contamination of karst aquifers from individual storage structures is occurring.

•**Drinking-water obtained from shallow, poorly constructed, or vulnerable wells** could be directly affected by manure. Producers using EMS or in locations where manure or fertilizer is stored or spread, should have their private well-water tested annually to protect the health of their families and their livestock from elevated levels of nitrate and pathogens. Even if nitrate or bacteria concentrations are below levels of concern, their presence indicate that other contaminants (such as viruses) could be present.

•Current monitoring data indicates that **manure storage structures are not likely to be significant sources of nutrients in surface waters relative to other contributions in Iowa**. Groundwater monitored near earthen manure storage basins can range as high as 250 mg/L nitrate-N, but most measurements were between 10-50 mg/L. Leaking manure storage structures could impact surface waters in small upland waterways where groundwater-lowering tiles or contaminated groundwater discharge to small streams. The volume of water impacted by these structures is small in comparison to that which is contributed to surface waters from below fertilized crop-land which often contains between 15-30 mg/L nitrate-N.

•**Future Monitoring:** At this time, there is little additional understanding to be gained from the quarterly monitoring currently required of 159 permitted and unpermitted AFOs in Iowa. Continued or expanded monitoring of key sites in certain high-risk settings, however, would be necessary to answer questions raised in this review, such as the effects of earthen basins located above alluvial aquifers and the effects of aging concrete manure storage structures in karst areas with relatively high seasonal water tables. Renewed testing of the long-term north-central and eastern Iowa sites could reveal information about groundwater quality since 2005, and additional testing for antibiotic resistance, viruses, and specific pathogens could be used to better characterize localized risks to private wells from EMS structures.

Acknowledgements

References