Generic Environmental Impact Statement on Animal Agriculture:

A Summary of the Literature Related to the Effects of Animal Agriculture on Water Resources (G)

Prepared for the Environmental Quality Board

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MN ENVIRONMENTAL QUALITY BOARD

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To Interested Minnesotans:

The GEIS on Animal Agriculture is a statewide study authorized and funded by the 1998 Minnesota Legislature and ordered by the EQB. The Legislature directs the EQB to "...examine the long-term effects of the livestock industry as it exists and as it is changing on the economy, environment and way of life of Minnesota and its citizens."

The intent of the GEIS is twofold: 1) to provide balanced, objective information on the effects of animal agriculture to future policymakers; and 2) to provide recommendations on future options for animal agriculture in the state. The success of the GEIS on Animal Agriculture will be measured by how well it educates and informs government officials, project proposers, and the public on animal agriculture, and the extent to which the information is reflected in future decisions and policy initiatives, made or enacted by Minnesota state and local governments.

The GEIS consists of three phases during the period summer 1998 through summer 2001: scoping the study; studying and analyzing the 12 scoped topics; and drafting and finalizing the GEIS. The EQB has established a 24-member Advisory Committee to provide advise to EQB during all phases of the GEIS. The scoping phase of the GEIS was completed in December of 1998.

This literature summary is the first step in the second phase aimed at study and analysis of the 12 key topics. This summary is intended to inform the Environmental Quality Board (EQB) members, EQB staff, and the Advisory Committee on the "Feedlot GEIS" scoping questions and research needed for adequate completion of the GEIS. The EQB would like to acknowledge the time and effort of the Advisory Committee members who provided invaluable input in the development of this "tool" for use throughout the GEIS process.

The literature summary is formatted to address the 12 topics of concern and 56 study questions outlined in the Feedlot GEIS Scoping Document (www.mnplan.state.mn.us). Any conclusions or inferences contained in this report are those of the authors and do not necessarily reflect the positions of the EQB or the Feedlot GEIS Advisory Committee.

The EQB would like to make this literature summary available to others interested in the effects of animal agriculture. Copies of this literature summary will be available for use in the Minnesota Planning/EQB Library: 300 Centennial Building, 658 Cedar Street, St. Paul. The Library will also house copies of the key literature review articles and the searchable database compiled as part of this literature review. A limited number of copies of this literature summary will be printed for distribution at cost.

For further information on the GEIS or this literature summary please contact the EQB at 651-296-9535.

Sincerely,

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Chair, Minnesota Environmental Quality Board

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EXECUTIVE SUMMARY

Surface and ground water are precious resources to be protected from various types of pollution arising from animal agriculture. Surface waters can be degraded by excess nutrients (nitrogen and phosphorus), pathogens, and oxygen demanding organic materials. Nutrients and oxygen demanding organic materials in excessive quantities can lead to eutrophication and diminished oxygen levels in water, as measured by dissolved oxygen. Ground waters can also be degraded by excess nutrients and pathogens. The extent of water quality degradation from less well studied substances in animal manure such as heavy metals and hormones is unknown.

Degradation of surface water quality can arise from various types of problems associated with poor management of animal operations. These include surface runoff from feedlots, spills from manure storage lagoons, tile drain effluent from lands receiving excessive manure and fertilizer applications, leaching losses from lands receiving excessive applications of manure and fertilizer, and seepage of manure from waste storage lagoons. Degradation of stream water quality, aquatic habitat, and riparian habitat can occur when grazing operations are poorly managed.

In this report, we were asked to answer ten scoping questions relating to the impacts of animal agriculture on water resources. We reviewed the recent literature published in scientific publications to formulate an answer to these questions, and identify research needs where insufficient knowledge was available to provide an answer. In the summary below, our main conclusions from this study are presented for each of the ten scoping questions.

STUDY TOPIC 1: TO WHAT EXTENT ARE GROUNDWATER AND SURFACE WATER AFFECTED BY OR AT RISK FROM ANIMAL MANURE STORAGE, HANDLING, AND APPLICATION?

Some of our main findings in this report with respect to pollution of surface streams by animal operations include the following:

- Livestock waste can contribute significantly to phosphorus loads in surface waters (7-65% of total load), although another major source is non-agricultural land (especially municipal waste water treatment plants). Livestock waste usually contributes less significantly to nitrogen loads (15-37% of total load). However, the primary source of watershed impairment by nitrogen is from fertilizers.

- Nutrient losses per unit area in runoff can be greater in magnitude from croplands, manured croplands, and grazed pastures than from rotationally grazed lands, forest lands, or natural prairies. Losses from well managed cropland or grazed pastures are usuallysmall and are comparable to the small losses observed on rotationally grazed lands.

■ Critical areas for phosphorus loss to streams and lakes are typically those areas high in soil available phosphorus in close proximity to waterbodies.

■ Feedlot runoff contains extremely large loads of nutrients and oxygen demanding substances, and if not properly collected and prevented from entering surface waters, this runoff can severely degrade surface water quality.

■ Fecal bacteria concentrations in surface waters from manured lands are often not significantly different from pathogen levels in surface waters from unmanured lands if the manure has been stored and aged before land application. Natural wildlife can also be a significant source of fecal bacteria leading to surface water quality degradation.

■ Fecal bacteria in surface waters from lands receiving fresh manure applications can be a significant proportion (over 80%) of the fecal bacteria carried in surface waters. Where illegal discharge of septic tanks to surface waters occurs, human waste can also be a significant source of pathogens in surface waters.

■ The most significant components of pollutant losses in surface runoff from manured lands are for ammonium, particle-bound and soluble phosphorus, and oxygen demanding organic materials. Nitrate-nitrogen is rarely a significant contaminant in surface runoff.

■ Nutrient losses in runoff from manured or fertilized fields are typically much greater than losses from unmanured or unfertilized control plots.

■ Nutrient losses in runoff increase with the rate of manure or fertilizer applied.

■ Losses of nitrogen and phosphorus in runoff from manured versus fertilized fields are not significantly different if the manure and fertilizer are applied at equivalent rates of nitrogen content.

■ Nutrient losses in runoff from manured fields decrease when manure is injected or if manure is stored for several weeks before land application.

■ Nitrogen losses in runoff from manured fields are least when manure is applied in spring (especially late spring), and greatest when manure is applied in fall.

■ Nutrient losses in runoff from manured fields increase when the time between land application and rainfall is brief, especially for intense rainfall events.

■ Nutrient losses in runoff from manured fields are usually excessive when land application to snow or frozen soils occurs.

■ Losses of phosphorus in runoff are generally greater when manure is applied to corn rather than alfalfa or grass, but can be negligible when erosion and runoff are controlled on corn fields using conservation tillage. In comparison, phosphorus losses in runoff from manured corn are generally greater than losses from natural prairie, woodlands, and forest lands.

Surface water impairment from pathogens is a great problem in most rural areas of southern Minnesota, which causes many rivers and lakes to be unsuitable for swimming. Research on fecal bacteria transported in runoff from manured lands shows that:

- There are typically no significant differences in fecal bacteria levels in surface runoff from manured versus unmanured or grazed versus ungrazed lands. This is due to fecal bacteria from natural wildlife, and die-off of bacteria in manure after storage or land application.

- Rate, method, or timing (spring versus fall) of manure application has little effect on fecal bacteria counts in surface runoff.

- Fecal bacteria counts in surface runoff are significantly greater after application of manure to snow or frozen soil than after application at any other time of year.

Large areas of Minnesota are poorly drained and have artificial tile drainage installed to improve soil productivity. The major factors which influence losses of nutrients through tile drains include rate of application, timing of application, form and method of application, tillage, and cropping system. The literature on nutrient losses through tile drains shows that:

- The most significant contaminant in subsurface tile drain effluent is nitrates. Soluble and total phosphorus losses are generally negligible in comparison to their losses in surface runoff. Losses of ammonium and oxygen demanding organic materials are generally lost in much smaller quantities through subsurface tile drain effluent than through surface runoff.

- Nitrate losses in subsurface tile drainage increase with the rate of manure or fertilizer applied, unless very high rates of manure are applied on wet soil, when denitrification reduces the losses of nitrogen. Nitrate losses in tile drains from manured fields are typically less than or equal to losses from fertilized fields receiving equivalent rates of nitrogen.

- Liquid manure applications cause more risk for nitrate leaching to subsurface tile drains than surface applications of solid manure, especially when liquid manure is injected.

- Manure applications to continuous corn will typically cause greater losses of nitrate-N in subsurface tile drainage than manure applications to other crops, all other factors being equal.

- Losses of phosphorus through subsurface tile drainage systems are typically negligible, unless very high rates of manure are applied, or the soil test phosphorus levels have built up to excessive levels.

- No research on the impact of surface tile inlets on nutrient losses from land application of manure through tile drainage systems has been published in peer reviewed journals.

Catastrophic spills from large manure storage facilities can occur primarily through overflow following large storms or by intentional releases. A third mechanism, collapse of a sidewall is less frequent, and has never occurred in Minnesota. A review of scientific literature shows that spills from manure storage basins have the following characteristics:

- The impacts on surface water quality and aquatic life from manure lagoon and storage basin spills, feedlot runoff, and applications of manure to frozen ground can be devastating.

- The number of documented serious water quality pollution problems involving manure lagoon spills and feedlot runoff is generally several tens of events per year in each of the states with high concentrations of feedlots.

- Compared to the several thousands of feedlots in most states, the number of water quality pollution problems causing documented fish kills from lagoon and basin manure spills and feedlot runoff is typically a small fraction of the total number of operations.

Numerous studies have been conducted to determine the impacts of animal agriculture on ground water quality. These studies show that many factors influence contamination of ground water by nitrates or fecal bacteria. These factors include:

- Depth and condition of the well,
- Type of soil and geologic material above the aquifer,
- Location of the well,
- Land use surrounding the well (particularly cropland),
- Density of animals and manure handling and application practices, and
- Type of lining on manure storage systems.

Ground water contamination from animal agriculture is most likely to occur when intensive animal agriculture occurs in regions having coarse textured soils, shallow ground water, and heavy precipitation. Lined manure storage basins and lagoons which are properly constructed, engineered, and managed are generally not a serious threat to ground water quality, unless constructed in coarse textured soils or karst terrain. Unlined earthen manure storage systems generally pose a much greater risk for pollution of ground water by seepage than lined storage facilities.

STUDY TOPIC 2: HOW DO THE EFFECTS OR RISKS (FROM #1) AFFECT THE USE OF WATER BY HUMANS FOR DRINKING, RECREATION, AND OTHER PURPOSES?

Drinking water can be contaminated by pathogens and nitrates arising from animal agriculture. It is estimated that up to 900,000 illnesses and 900 deaths occur each year from waterborne microbial infections, but the source of contamination in these instances is not known. There have been 14 documented incidents of cryptosporidium disease outbreaks in U.S. and Canada since 1984. Four of these events were linked to nonpoint source agricultural pollution, the others were primarily caused by septic tank and human sewage contamination.

It is estimated that roughly 7% of the 450,000 private drinking water wells in Minnesota have nitrate-N levels exceeding the maximum contaminant level (MCL) of 10 mg/L. There are another roughly 1,700 public community water supply wells in Minnesota, of which roughly 1% have nitrate levels greater than the MCL. The percent of these contaminated wells that are affected by animal agriculture is unknown.

Nationally, it is estimated that 36% of rivers and streams, or 39% of lakes are impaired, meaning that they did not support or could not attain the goals and standards set forth in the Clean Water Act and state regulations. The primary cause of impairment in 70% of the rivers and streams classified as being impaired was agriculture. Of these agriculturally impacted rivers and streams, non-irrigated cropland production was the leading cause of impairment (36%), followed by irrigated cropland production (22%). Other causes of impairment were rangeland (12%), pastureland (11%), feedlots (8%), animal operations (7%), and animal holding areas (5%).

In Minnesota, about 60% of the surveyed or monitored rivers and streams, and 17% of the surveyed or monitored lakes were classified as being impaired. Agriculture was identified as the cause of 90% of the impaired river miles, and 64% of the impaired lake acres. It is unknown to what degree various types of agricultural activities (cropland, feedlots, rangeland, etc.) caused the impairment. In the Minnesota River basin, it is estimated that from 50-100% of the assessed tributary river miles in the Minnesota River basin do not adequately support aquatic life. This results in reduced diversity of fish and other aquatic life, and predominance of undesirable fish species. None of the tributaries is fit for swimming, primarily because of high levels of fecal bacteria.

STUDY TOPIC 3: HOW DO THE EFFECTS OR RISKS (FROM #1) AFFECT FISH AND WILDLIFE (SUCH AS FISH KILLS DUE TO POLLUTION)?

There are many reports in the literature which suggest that well-managed livestock grazing is compatible with a healthy riparian ecosystem but the impacts of specific practices depend on site characteristics. The negative impacts of livestock grazing on stream and riparian ecosystems are widespread in the western U.S, but relatively little is known about grazing impacts on stream and riparian ecosystems in the midwestern U.S.

The negative effects of cattle on habitat for fish and wildlife can include:

- An increase in streambank erosion, reducing habitat availability for both terrestrial and aquatic animals.

- A decrease in large woody debris habitat in and near the stream channel in grazed areas.

Macroinvertebrates are a very important component of the food chain in streams and lakes. Macroinvertebrates, primarily insects, are a highly diverse community, they are indicators of ecosystem biodiversity, they serve as fish food, they perform a wide range of ecosystem functions such as energy and nutrient cycling, and they are valuable indicators of ecosystem health. The negative impacts of livestock grazing on macroinvertebrates can include:

- Reduced terrestrial and aquatic invertebrate densities in streams, especially in small streams.

Fish are quite susceptible to the impacts of poor management in animal agriculture. A few serious incidents of feedlot runoff, manure spills, and runoff from manure on frozen ground can lead to the death of thousands of fish. It is widely believed that many fish kills are undocumented, and there is no comprehensive record keeping mechanism for tracking the number or magnitude of fish kills. At least two agencies have responsibility for responding to fish kills but fish kills are not regularly recorded and reported.

The impacts of grazing on fish are largely based on extensive research conducted in the western U.S. These studies show that:

- Grazing negatively impact fish populations, based on very weak or flawed experimental designs.

- In only a very few cases are there data describing impact to the overall fish community, and those data are inconclusive.

The impacts of poorly managed livestock grazing on birds can be mixed. The literature on this topic shows that:

- Livestock grazing often reduces canopy density and therefore habitat for riparian birds. That in turn reduces densities and diversity of some passerine species.

- Some birds excel in the more fragmented riparian habitat that results from grazing and that same pattern is true for many species which rely on grassland habitats.

- Shorebird populations (especially coastal species) appear to be positively impacted by low levels of grazing; it is not clear that the same responses would be shown in Minnesota waterbirds.

- No evidence suggests that waterfowl are negatively impacted by livestock although those waterfowl are dependent on aquatic invertebrates and may be secondarily impacted by changes in food availability.

Grazing can be a useful tool to enhance wildlife habitat. However, grazing must be carefully managed to control the frequency, intensity and timing of livestock access to insure compatible use with wildlife. Improved livestock management will facilitate more streamside vegetation and increase the abundance and diversity of terrestrial habitat.

STUDY TOPIC 4: WHAT ARE THE HEALTH RISKS TO HUMANS FROM CONTAMINATION OF GROUND AND SURFACE WATERS FROM ANIMAL MANURE STORAGE, HANDLING, AND APPLICATION?

There are basically two types of risks in drinking water which are related to animal agriculture, excessive nitrate levels and pathogens. Nitrate is a common contaminant found in many wells in Minnesota. It has been known since the mid-1940s that too much nitrate in drinking water can cause serious health problems for infants. Roughly 7% of drinking water wells in Minnesota exceed the Maximum Contaminant Level set by EPA for nitrates in drinking water. Drinking water contamination can occur from nitrogen in fertilizer, septic tank seepage, and animal manure.

Fresh animal manure contains a variety of microorganisms which may be pathogenic to man and/or animals. The major types of pathogens include bacteria, viruses, parasite eggs, protozoa, and fungi. The potential of disease transmission from land application of animal manure depends upon:

- The number and viability of microbial pathogens in manure, which in turn depends upon the type of treatment it has received.
- The survival of pathogens for a sufficient period of time and in sufficient numbers.
- The entry of these pathogens into waters and their subsequent ingestion through the mouth as a result of drinking or swimming.

It is unknown whether coliform indicators should continue to be considered as the best indicator of surface water contamination by pathogens for the following reasons:

- new pathogens have been recently discovered (viruses, anti-biotic-resistant bacteria, etc.);
- new information shows that some pathogens have very different viability capacities than coliform bacteria; therefore the latter may not be a very good representative any longer.

STUDY TOPIC 5: TO WHAT EXTENT ARE SURFACE WATERS AFFECTED BY OR AT RISK FROM ALLOWING PASTURED ANIMALS (PRIMARILY CATTLE) ACCESS TO SURFACE WATERS?

Unmanaged grazing has many negative impacts on streams and their nearby landscapes. Heavy grazing reduces vegetative cover, compacts the soil, reduces infiltration, increases runoff, erosion and nutrient and sediment yield. In riparian zones, trampling the streambanks decreases erosional resistance of the streambank and contributes to sediment yield, while vegetation removal increases solar insolation and leads to higher stream water temperature. Excrement deposited either in the uplands or directly into waterbodies can lead to elevated levels of pathogens. Fish and aquatic invertebrates are sensitive to sediment input, water temperature and excess algae and plant growth due to nutrient input. In contrast, low or moderate grazing have effects that are much less significant than heavy or unmanaged grazing.

More specifically, unmanaged grazing has the following effects on sediment production:

- Sediment yield increases with increasing grazing pressure, with the lowest levels of erosion occurring in ungrazed or "retired" riparian areas.

- Fine textured soils are more susceptible to trampling effects than coarse textured soils.

- Soil loss increases on steeper slopes.

- Associated with changes in erosion are changes in stream channel morphology. The main effects of unmanaged grazing include:

- Development of unstable channel morphology and the loss of fish and invertebrate habitat.

- Stream channels along heavily vegetated areas are deeper and narrower than along poorly vegetated areas which have been over-grazed.

Unmanaged grazing can also increase the mean stream temperature and the extremes of temperature experienced by aquatic organisms. Relatively small changes in stream temperature can shift aquatic communities from more desirable to less desirable species. An increase of less than 4 degrees Fahrenheit is often sufficient to cause such shifts, and increases in stream temperature of from 4 to 9 degrees F are common when streamside vegetation is removed by grazing.

Finally, unmanaged grazing can cause excess nutrients to enter adjacent streams. In general, nutrient concentrations in runoff increase with increasing grazing intensity.

STUDY TOPIC 6: HOW DO THE VARIOUS IMPACTS IN #1 TO #5 VARY BY SPECIES, OPERATION, SYSTEM TYPE, MANAGEMENT, GEOGRAPHY, GEOLOGY, WATERSHED CHARACTERISTICS, AND CONCENTRATION OF LIVESTOCK FACILITIES?

Minnesota has a wide range of characteristics in soil and geologic sediment properties, hydrogeology and climate, and patterns in runoff and erosion. Each of these factors strongly influences the potential for pollution of surface and ground waters by animal manure and animal operations. State-wide patterns in degradation in river water quality as reflected by monitoring data for oxygen demanding substances, fecal bacteria, dissolved oxygen, and total phosphorus vary dramatically among the major basins in Minnesota. State-wide patterns in degradation of lake water quality as reflected by monitoring data for phosphorus, water clarity, and algae vary significantly among the major ecoregions of Minnesota. State-wide patterns in degradation of ground water quality as reflected by monitoring data for nitrates vary primarily in response to soil and sediment properties.

Geographic distributions of cattle, hog, chicken, and turkey population densities in Minnesota are presented in the report. Animal population densities are compared with European limits on animal density, and with geographic distributions of degradation in river, lake, and ground water quality. The following conclusions can be drawn from these comparisons:

- In some instances, crude visual comparison of geographic patterns in degraded ground water quality appeared to resemble patterns in cattle population densities. This does not prove that animal operations caused the water quality degradation. Areas with large human population densities also coincided with areas having degraded ground water and lake water quality. Further study is warranted of these relationships.

The concentrations of nitrate in ground water vary considerably across the state of Minnesota. Inputs of nitrate from agriculture have clearly impacted areas of the state where high-intensity agriculture has been practiced, particularly in the geologically sensitive areas, including:

- The karst area of southeastern Minnesota,

- The sand plains (glacial outwash areas) of Central Minnesota,

- Areas of alluvial sands (deposited by old meandering streams), especially those in southwestern Minnesota,

- Other areas with enhanced surficial permeability (such as scattered sand and gravel deposits), where rural residents often use shallow sandpoint wells for their drinking water.

- No clear geographic relationship between degradation of rivers or lakes and animal population densities was observed used crude visual comparisons. Further study is warranted of these relationships.

- As size of animal operations increases, the nutrients available for loss to the environment also increase. This is mainly due to a lack of proper land area for spreading manure. The critical density of animals depends upon the type of animal, and the methods used in storing, handling, and applying manure to cropland.

- As the density of animals in a watershed increases, there is an increasing impact on surface water quality. This is primarily due to increased nutrient production in manure, and inadequate crediting of manure in nutrient applications to cropland. The critical threshold density depends upon the type of animal, the region and its characteristics, and waste storage, handling, and application methods.

- Animals located where their waste has a direct pathway for runoff losses to surface waters have a much greater potential to degrade water quality than animals located away from these direct pathways or on pasture land.

- Minnesota animal densities do not appear to be above the critical threshold levels set for animal operations in Europe. Further evaluation of this issue is needed, because county-wide average animal densities may be considerably different than densities for individual animal operations.

- Blue Earth county conducted a comprehensive evaluation of each and every one of the 886 feedlots in the county. The primary pollution hazards were unlined earthen basins (mostly for swine operations) and runoff to surface water (mostly for cattle operations). A total of 49 feedlots (10% of the active feedlots) were identified as pollution hazards, of which 18 had unlined earthen basins, and 30 had runoff hazards. There is a tendency in Blue Earth county for small sized feedlots to be a more frequent pollution hazard than medium or large feedlots. This may occur because medium and larger feedlots tend to be fewer in number, are newer, are better designed, and use improved methods for manure storage, handling, and application than smaller feedlots.

STUDY TOPIC 7: WHAT ARE THE CURRENT AND POTENTIALLY AVAILABLE BEST MANAGEMENT PRACTICES AND MITIGATION TECHNOLOGIES TO PREVENT AGAINST GROUND AND SURFACE WATER POLLUTION FROM MANURE STORAGE, HANDLING, AND APPLICATION, AND TO WHAT EXTENT ARE THEY EFFECTIVE?

Several management practices and mitigation technologies were reviewed for this scoping question. These included manure storage, handling, and application practices.

Recommended manure storage practices include providing adequate storage capacity, proper engineering design and siting of storage facilities, diverting and collecting runoff water away from surface water bodies, repairing leaks and cracks promptly, and stockpiling manure on impermeable surfaces. Recommended manure collection practices for solid manure include low stocking densities on pastures away from surface water bodies, and impermeable surfaces away from surface waterbodies with proper diversion and collection of runoff on open lots. For liquid systems, the deep pit offers good environmental protection. One of the current limitations in proper application of manure is the lack of reliable calibration of application equipment. Three types of application methods are common, namely; liquid tank applicators, liquid tow hose irrigation, and box spreaders. Liquid tank applicators have the least environmental impact if manure is injected during application. Tow hose irrigation can lead to excess ammonia volatilization, or runoff of liquid manure if applied in excess to sloping land. Box spreaders are notoriously difficult to calibrate, and are rarely used with incorporation of manure.

Animal manure has been land-applied for centuries to supply nutrients for improving crop growth and yield. Within the last generation, however, concern that animal manure may be degrading water resources has increased. Reasons for this have been due largely to poor manure application practices, disposal of manure at high application rates, and greater concentrations of animals associated with modern livestock production systems.

Numerous management practices affect the availability of nutrients from land-applied manure, and hence, the potential for nutrient contamination of surface and ground waters. These practices include: (1) rate of application, (2) time of application, (3) incorporation method, (4) nitrification inhibitors, (5) tillage, (6) vegetative filter strips and setback distances, (7) cropping systems, and (8) wetland treatment. Each of these practices is thoroughly reviewed in the report.

Application rate is the single, most important manure management practice affecting the potential for contamination of water resources by nitrogen from manure. Simply said, applying nutrients in excess of crop need, whether from fertilizer or manure, increases the potential for nutrient (N and P) movement to ground and surface water. For phosphorus, while rate of application is important, other factors that influence the potential for contamination of water resources include application method (incorporation is best), and potential for runoff and erosion losses (which can be effectively controlled using conservation tillage). Estimating the proper manure rate is more difficult because: (a) nutrient content among manures varies substantially, (b) application equipment is often not sufficiently precise, and (c) climate and soil properties influence the availability of nutrients from manure.

Application of manure for disposal purposes to soybeans, alfalfa, and grass has been extensively studied in Minnesota. Manure can be applied following corn harvest for soybean at rates totaling about 200 lb available N/acre without incurring environmental risk. Hog manure can be applied prior to planting alfalfa at rates up to 12000 gal/acre with much less environmental risk than applications to established alfalfa. Liquid dairy manure can be broadcast-applied at very high rates to established stands of reed canarygrass without much environmental risk.

Vegetative filter strips are potentially very useful in removing contaminants from runoff on manured lands. Their ability to remove pollutants from manured soils depends upon the type of pollutant, the slope of the field, the amount of runoff and erosion, the presence or absence of concentrated flow (rills), and the length of the filter strip. For slopes less than 9%, with dispersed sheet flow runoff (no concentrated flow), filter strips of from 15 to 20 ft in length are usually able to remove a majority of the sediment, total phosphorus, soluble phosphorus, organic and ammonium nitrogen, and chemical oxygen demand in the incoming runoff from manured plots. Filter strips are not generally able to effectively reduce concentrations of fecal bacteria in runoff from manured plots.

Also of interest is the use of constructed wetlands to treat animal waste from storage lagoons and basins. Wetlands receiving animal waste are generally very effective at reducing the incoming pollutants. They are typically more effective at removing oxygen demanding substances, ammonium, and organic forms of nitrogen than at removing phosphorus.

STUDY TOPIC 8: TO WHAT EXTENT DOES MINNESOTA ANIMAL AGRICULTURE CONTRIBUTE TO THE HYPOXIA PROBLEM IN THE GULF OF MEXICO?

Hypoxia is a zone of low oxygen levels (< 2 mg/L) covering an area as large as 7,000 square miles in the Gulf of Mexico in 1997. Unlike freshwater systems where phosphorus is usually the limiting nutrient for growth of algae, in the saline waters of the Gulf nitrogen is the often the most limiting nutrient for growth of diatoms. Agricultural nitrogen sources, and to a much lesser extent phosphorus, have been indirectly identified as a major cause of hypoxia. The primary pathway for nitrogen sources to enter surface waters is after intense rainstorms via subsurface tile drainage systems on poorly drained soils with high organic matter contents receiving excessive rates of nitrogen from fertilizer and/or manure.

The largest source of nitrogen to the Gulf of Mexico from Minnesota is the Minnesota River basin, which generates roughly 5% of the total nitrogen flux to the Gulf of Mexico (see table below). The Mississippi River upstream of the Twin Cities generates roughly 1% of the nitrogen flux to the Gulf. Wastewater treatment plants in the Twin Cities and upstream of the Twin Cities generate around 1% of the total nitrogen flux to the Gulf. Streams in southeastern Minnesota draining to the Upper Mississippi River probably generate about 1% of the nitrogen flux to the Gulf of Mexico. Our best estimate using limited information is that animal agriculture in Minnesota contributes less than 1% of the nitrogen entering the Gulf of Mexico. Minnesota also contributes roughly 4% of the total phosphorus flux to the Gulf of Mexico (see table below). Wastewater treatment plants are responsible for at least half of this contribution. In comparison, nonpoint sources from the Minnesota and Upper Mississippi River basins are together a smaller source of total phosphorus than wastewater treatment plants.

Table A: Total Nitrogen and Phosphorus Loads from Various Rivers in the Mississippi River Upstream of Joslin, Illinois, and for Wastewater Treatment Plants (WWTP) in the Twin Cities Metropolitan Area and Upstream of the Twin Cities.

Source	Total Nitrogen Flux	Total Phosphorus Flux
	——— U.S. tons/yr———	
Discharge to the Gulf of Mexico	1.8 million	152,320
Mississippi River at Joslin, Illinois	165,154	8,800
Minnesota River at Jordan, Minnesota	59,180	1,488
Mississippi River at Anoka, Minnesota	21,059	1,088
St. Croix River at Prescott, Wisconsin	6,132	241
Chippewa River at Durand, Wisconsin	10,318	811
Wisconsin River at Muscoda, Wisconsin	13,376	727
WWTP in Twin Cities and Upstream	12,273	3,212

STUDY TOPIC 9: WHAT IS THE IMPACT OF ANIMAL AGRICULTURE ON WATER QUANTITY AND AVAILABILITY (SUSTAINABILITY OF WATER SUPPLY)? HOW DOES THE USE OF WATER BY ANIMAL AGRICULTURE COMPARE WITH THAT OF OTHER INDUSTRIES IN MINNESOTA?

Livestock water use in Minnesota includes water for consumption, and associated on-farm non-consumption use for the production of milk, meat, eggs and wool. Most of the non-consumption water use on livestock farms is for cleaning of equipment and facilities, with dairy and swine farms being the largest users in this category. The total amount of water consumed by livestock each day in Minnesota is estimated to be about 55 million gallons. The total daily water use on livestock farms (including consumption) is roughly 166 million gallons per day.

In comparison to water used by animals, the total water used in Minnesota for power generation, public usage, industrial processing, irrigation and other uses per day is roughly 3.25 billion gallons in 1994. The 166 million gallons of water used in livestock enterprises represents only 5% of the state water usage each day.

Confined animal feedlot operations require placement of concentrated numbers of animals in unpaved or partially paved areas. Virtually all studies affirm that concentrated animal populations and animal traffic cause increased soil compaction. In feedlots, a dense soil layer typically exists near the soil surface that decreases water intake. This dense soil layer impedes infiltration, causing greater runoff volumes and peak flows. From 50 to 85% of the annual rainfall can runoff from feedlots that have from one-quarter to three-quarters of their area covered with concrete, but much of this runoff can be controlled with detention basins and diversions.

STUDY TOPIC 10: HOW DOES ANIMAL MANURE COMPARE TO OTHER TYPES OF WASTES PRODUCED IN MINNESOTA AS A SOURCE OF WATER POLLUTION?

The primary sources of nutrients that cause water pollution in Minnesota include animal waste, human waste, migratory wildfowl wastes, fertilizers, and recycled nutrients from the soil. Estimating the relative magnitude of the impacts from each source is a difficult task involving several assumptions. The results of this exercise are summarized in the following table:

Table B: Minnesota Estimates of Nutrient Production From Various Sources

Source	Total Nitrogen Flux	Total Phosphorus Flux
	——— U.S. tons/yr———	
Execreted Animal Manure	2444,566	68,862
Excreted Human Waste	14,503	6,855
Migratory Wildfowl	2,987	1,613
Fertilizer Sales	729,702	130,866
Soil Organic Matter	946,577	—
Various Nitoren Credits	288,322	—
Atmospheric Deposition	134,000	—
Crop Removal by Harvest	879,500	197,700

It is important to avoid direct comparisons of some of these numbers. The nitrogen and phosphorus from human waste and migratory wildfowl are discharged directly into streams and rivers, while only a small fraction of the animal waste eventually reaches surface waters. Much of the nitrogen from animal waste is volatilized to the atmosphere during storage, handling, and application of the manure. Only a portion of the nutrients in animal which is eventually applied to land enters streams and rivers through runoff, erosion, and tile drainage.

It is possible to make some rough comparisons between the nutrient contents of animal wastes, fertilizers, and crop removal. Amounts removed by harvest are estimated at 879,500 tons of nitrogen per year and 197,700 tons of phosphorus per year. The amount of phosphorus removed at harvest is nearly equal to the combined amounts of phosphorus from fertilizer and animal manure, suggesting that very little excess phosphorus is available for losses to the environment.

An evaluation of the total nitrogen budget is much more difficult than that for phosphorus. At this time we do not have values for some of the major sinks of nitrogen. Using what is known, the amount of nitrogen removed at harvest is roughly 10% less than the amount potentially available in fertilizer and excreted manure. Since significant losses of nitrogen from manure can occur by volatilization during storage, handling, and application, the amounts of nitrogen removed at harvest are probably quite close to the total amount of nitrogen available for crop uptake from fertilizers and manures. When other nitrogen sources such as soil organic matter, various nitrogen sources and atmospheric deposition are considered, there is a clear state-wide excess of nitrogen applied as fertilizer and manure. We do not know if the unaccounted for nitrogen sinks would balance the excess at this time. If they do not, then the state-wide excess is a potential risk for degradation of surface and ground water quality.

INTRODUCTION

The Generic Environmental Impact Statement (GEIS) on Animal Agriculture was authorized and funded in 1988 by the Minnesota State Legislature and ordered by the Environmental Quality Board. The GEIS is composed of three phases, of which this report is the first phase. The first phase is a literature review, the second is research on knowledge gaps identified through the literature review, and the third is preparation of the actual GEIS which involves evaluation of existing and alternative practices and the formulation of policy options for animal agriculture.

The EQB has requested assistance in studying twelve topic areas broadly classified as addressing Social, Economic, Environmental, or Health concerns associated with animal agriculture. This report addresses the environmental concerns associated with Water Resources, including questions dealing with water quality and water quantity. The ten specific scoping questions which we were requested to answer, along with the primary writers for each answer, include:

1. To what extent are groundwater and surface water affected by or at risk from animal manure storage, handling, and application? Primary writer D. J. Mulla.
2. How do the effects or risks (from #1) affect the use of water by humans for drinking, recreation, and other purposes? Primary writer D. J. Mulla
3. How do the effects or risks (from #1) affect fish and wildlife (such as fish kills due to pollution)? Primary writer J. Perry
4. What are the health risks to humans from contamination of ground and surface waters from animal manure storage, handling, and application? Primary writers S. Goyal, B. Wheeler, and C. Alexander
5. To what extent are surface waters affected by or at risk from allowing pastured animals (primarily cattle) access to surface waters? Primary writer B. Vondracek
6. How do the various impacts in #1 to #5 vary by species, operation, system type, management, geography, geology, watershed characteristics, and concentration of livestock facilities? Primary writer D. J. Mulla
7. What are the current and potentially available best management practices and mitigation technologies to prevent against ground and surface water pollution from manure storage, handling, and application, and to what extent are they effective? Primary writers G. Randall and D. J. Mulla
8. To what extent does Minnesota animal agriculture contribute to the hypoxia problem in the Gulf of Mexico? Primary writer D. J. Mulla
9. What is the impact of animal agriculture on water quantity and availability (sustainability of water supply)? How does the use of water by animal agriculture compare with that of other industries in Minnesota? Primary writers J. Linn and G. Sands
10. How does animal manure compare to other types of wastes produced in Minnesota as a source of water pollution? Primary writer D. J. Mulla

CRITIQUE OF SCOPING QUESTIONS

Answering the scoping questions from a review of the literature proved to be challenging. While many useful references were found that were pertinent to the scoping questions, individual studies tended to be limited to a single type of animal operation, a specific set of site characteristics, and a particular geographic location. The primary difficulties encountered included:

- Scoping questions were often worded in very general fashion, leaving the possibility of interpretations that vary depending upon stakeholder perspectives. This is particularly true of scoping questions #1, 3, 5, and 6. For these questions, it would be particularly useful to identify the specific combinations of factors whose impact is desired.

- Separating the impacts of animal agriculture from the impacts from fertilizers, human waste, and wildfowl waste was not easy, whether dealing with water contaminant concentrations or loads, with pathogens, or with fish kills. In both surface and ground water, degradation in water quality is often the result of multiple effects which cannot easily be separated. This issue is particularly relevant to scoping questions #1, 2, 6, 8, and 10.

- Comparing the relative impacts of a wide variety of animal operation characteristics and animal species across different soil, climatic, and geologic characteristics as requested in scoping question #6 was often not possible based on the reviewed literature. The individual impacts under specific conditions could be obtained, but comparisons of a wide range of species and operations for a similar set of site characteristics are not commonly reported in the literature.

- In a few cases, results from one study contradicted the results in another study. Our conclusions are based upon the preponderance of results from all studies reviewed.

In some cases the original scoping questions did not request information that our group deemed to be pertinent to the GEIS. Some of these gaps include:

- What are the geographic relationships between existing patterns in water quality degradation and animal agriculture?

- What are the various alternatives to existing animal agricultural practices, and what is the impact of these alternatives on water quality?

- How does age of animal operation facilities influence their potential for pollution of water?

- What relationships and trade-offs exist between air quality and water quality degradation from manure holding basins?

- How long does it take to restore water quality in watersheds that have been impaired by animal agriculture?

- What are the impacts of animal trampling on runoff and infiltration in feedlots and grazed areas? How do runoff and erosion from various types of animal operations differ as a function of type of operation and site-specific characteristics such as climate, slope, and soil type?

In some cases, we have addressed these issues in our report. In other cases we have not, and it would be fruitful for additional effort to be spent in obtaining information to answer the question during the second phase of the GEIS.

STUDY TOPIC 1: TO WHAT EXTENT ARE GROUND WATER AND SURFACE WATER AFFECTED BY OR AT RISK FROM ANIMAL MANURE STORAGE, HANDLING, AND APPLICATION?

GENERAL OVERVIEW OF WATER QUALITY ISSUES

Surface and ground water are precious resources to be protected from various types of pollution arising from animal agriculture. Surface waters can be degraded by excess nutrients (nitrogen and phosphorus), pathogens, and oxygen demanding organic materials whose effect is measured using chemical or biochemical oxygen demand (COD or BOD). Nutrients and oxygen demanding organic materials in excessive quantities can lead to diminished oxygen levels in water, as measured by dissolved oxygen. Ground waters can be degraded by excess nutrients and pathogens. Degradation can also occur with less well studied substances such as heavy metals and hormones.

Degradation of water quality can take many forms. Excessive quantities of pathogens (bacteria, viruses, and protozoa) can cause disease in humans, especially the very young or old, or the ill. Diseases carried by bacteria include salmonellosis, diseases carried by viruses include hepatitis, and diseases carried by protozoa include cryptosporidia (CAST, 1996). Phosphorus in excess quantities stimulates the growth of algae, leading to potential eutrophication of waters as algae die, decompose, and reduce oxygen levels in the water. Eutrophication can cause the death of fish and other aquatic organisms, as well as other physical and chemical changes in the water quality of a lake, stream, or river. Not all forms of phosphorus contribute equally to growth of algae. The soluble form (orthophosphate-phosphorus) is much more bioavailable than the form bound to soil particles (particulate phosphorus).

Excess nitrogen in surface waters can also lead to eutrophication. Nitrogen (N) occurs in different forms, with the most common being ammonia, ammonium, organic nitrogen, and nitrate. Ammonia in excessive quantities can produce an oxygen demand similar to soluble phosphorus, and can be toxic to fish (CAST, 1996). Ammonium is the ionized form of ammonia, and the conversion between the two forms depends upon temperature and pH. Ammonium is also easily converted to nitrate. Nitrate in excessive quantities can cause methemoglobemia, which can be fatal to human infants. Organic forms of nitrogen and free ammonia are estimated using the total Kjeldahl nitrogen measurement.

Finally, degradation of water can occur when it contains excess quantities of organic materials which consume oxygen as they decompose. The oxygen consumption potential is measured using biochemical oxygen demand (BOD) or chemical oxygen demand (COD). When surface waters become polluted, their use for drinking water, fishing, boating, swimming, and other tourism uses is reduced.

Numerical water quality standards are commonly expressed as concentrations (mass per volume). The most common units for concentrations are micrograms per liter (ug/L) which is roughly equivalent to parts per billion (ppb), and milligrams per liter (mg/L) or milligrams per kilogram (mg/kg) which are both roughly equivalent to parts per million (ppm). Concentrations of pathogens are commonly expressed as colony forming units (CFU) per hundred millileters (mL), where CFU is the number of colonies formed after growing pathogens on an agar plate.

Table 1: Selected Numerical Water Quality Standards for Common Minnesota Lake and Stream Uses

Usage Class	Unionized Ammonia	Numerical Standard Dissolved Oxygen	Fecal Coliform
	Cug/LC	Bmg/Lb	CFU/100ml
Class 2A	16	5	200
Class 2Bd	40	5	200
Class 2B	40	5	200
Class 2C	40	5	200

Water quality standards (Table 1) are often not a good indicator of the potential for eutrophication of surface waters. Dodds et al. (1996) studied 1,400 rivers and streams throughout North America, Europe, and New Zealand, and found that critical concentration levels for the onset of eutrophication were 1.5 mg/L of total nitrogen and 0.075 mg/L of total phosphorus. EPA guidelines for critical concentrations of total P in streams and lakes are 100 ug/L and 50 ug/L, respectively. Eutrophication is often assessed using chlorophyll a levels, a measure of the phytoplankton biomass present. Chlorophyll a concentrations greater than roughly 35 ug/L are often perceived by the public to be associated with eutrophic conditions that limit swimming and aesthetic uses of lakes (Heiskary and Wilson, 1989).

In an excellent review by Wall and Johnson (1996), several factors affecting impairment of water quality from land application of manure were described. Impacts on surface water quality can also occur from surface runoff from feedlots, and as a result of spills from manure storage lagoons. Surface water can also be impacted from tile drain effluent on lands receiving manure applications. Impacts on ground water quality can occur by leaching losses from lands receiving applications of manure, as well as from seepage and leakage of manure waste storage lagoons. The information in the review by Wall and Johnson (1996) is complementary to the findings of this study in that they summarize much of the older literature, and a copy of their review is being provided to members of the EQB and CAC. The following two sections review more recently published literature dealing with the impacts of animal agriculture on surface and ground water quality.

EFFECTS OF ANIMAL AGRICULTURE ON WATER QUALITY FROM SURFACE RUNOFF

Runoff can carry organic forms of nitrogen, particulate and soluble phosphorus, pathogens, and oxygen demanding organic matter into rivers and streams. This section reviews the magnitudes of pollutant losses in runoff from various land uses and animal manure management practices at the watershed and plot scales.

COMPARISON OF CAUSES OF IMPAIRED RIVERS AND STREAMS FOR VARIOUS LAND USES

Water quality of rivers and streams can be degraded by runoff from a variety of land uses, including urban runoff, and runoff from agricultural cropland receiving fertilizer, cropland receiving manure and fertilizer, feedlots, animal grazing pastures, rotaional grazing pastures, forests, or natural prairies. The relative magnitude of this impact on watersheds is dependent upon site-specific characteristics such as climate, landscape, soils, and intensity or management of land uses. In this section we review references that deal with the impacts from various land uses on water quality.

Smith et al. (1997) used the Spatially Referenced Regression on Watershed (SPARROW) attributes method to study the factors affecting total nitrogen and total phosphorus loads in 414 surface streams and rivers in the U.S. (Table 2). They found that roughly half of the total nitrogen (TN) in impaired watersheds was caused by fertilizer applications. Livestock waste was a less significant source, contributing 15% of the total nitrogen load in seriously impaired watersheds. This TN load represented 24% of the nitrogen generated by manure. Roughly one-third of the total phosphorus (TP) load in impaired watersheds was attributable to livestock waste, and this TP load represented 7.2% of the phosphorus generated by manure. Non-agricultural land generated another one-third of the TP load, while fertilizer applications generated one-fifth of the TP load. From this study, we can conclude that impairment of watersheds is caused by a variety of sources. For phosphorus, the major sources are livestock waste and non-agricultural land, with fertilizers being less important. For nitrogen, the major source is fertilizer, with smaller contributions from non-agricultural land, livestock waste, and point sources. Some of the nitrogen in atmospheric deposition may also originate from animal agriculture, due to volatilization of ammonia from animal manure and subsequent redeposition.

Table 2: Percent of Load Contirbuted in Impaired Watersheds by Various Factors (Smith et al. 1997)

Source	Total Nitrogen	Total Phosphorus
	——— % of Load———	
Point Sources	7.9	10.6
Fertilizer application	21.0	47.9
Livestock waste application	37.7	15.4
Non-agricultural land	33.4	18.0
Atmospheric deposition	0	8.2

In the central U.S., a General Accounting Office report to the U.S. Senate (GAO, 1995) concluded that in the midwestern U.S. manure is the source for 37% of the nitrogen and 65% of the phosphorus loading to watersheds. These figures are greater than those obtained by Smith et al. (1997) for the entire U.S., indicating the greater impact of animal manures on surface water quality in the midwest than the nation as a whole.

Rather than evaluating the percent load contributed by animal manures, Ritter (1998) and Sweeten (1998) compared and contrasted the annual losses of total nitrogen and total phosphorus from various land uses (Table 3). They found that direct runoff from feedlots contained excessively high amounts of nitrogen and phosphorus, while losses in runoff from nonpoint agricultural land uses exhibited a wide range of impacts depending upon the specific type of management and site conditions. In general, losses from urban land uses (per unit area) were comparable in magnitude to losses from agricultural nonpoint sources, while losses from forested systems were less. Nutrient losses from cropland, fields receiving manure applications, and grazed pastures were all of comparable magnitude. The lowest losses in runoff occurred with rotational grazing and native prairie, and with well managed cropland or grazed pastures. These results do not account for the differences in total acreage of each land use (the total impact would be obtained by multiplying acreage by rates of loss). After doing so, the total losses from agricultural nonpoint land uses would be much greater than the total losses from urban areas or feedlots due to the differences in total acreage.

Table 3: Typical Runoff Losses of Nitrogen and Phosphorus from Various Land Uses

Land Use	Runoff Losses Total Nitrogen Flux	Total Phosphorus Flux
	——— lb/ac———	
Grazed pastures	0.5–8.7	0.36–4.1
Rotational grazing	1.3	0.8
Native Prairie*	0.9	0.1
Forest	2.7–11.6	0.03–0.9
Land applied dairy manure*	2.5–3.3	0.4–0.5
Cropland	0.09–11.6	0.05-2.6
Urban	6.3–8.0	0.98-5.0
Uncontrolled Feedlot	89–1,428	8.9–553

*Minnesota data

Shuyler (1992) estimates that nonpoint sources generate 82% of the nitrogen and 68% of the phosphorus loading to Chesapeake Bay. Wastewater treatment plants are the primary point source contributor for the remaining 18% of the nitrogen and 32% of the phosphorus. Animal waste in the Chesapeake Bay represents 0.04% of the basin land uses, but generates 22% of the nitrogen loads and 7% of the phosphorus loads in the basin. Five of the ten major watersheds in the Chesapeake Bay Basin generate 93% of the nitrogen loads from animal wastes and 94% of the phosphorus loads. Because most of the animal operations in the Chesapeake Bay have less than 1000 animal units, they were not required to have discharge permits. Because of this, Shuyler (1992) states that much of the nonpoint source pollution from animal wastes in the Chesapeake Bay originates in runoff from unpermitted animal production facilities, rather than runoff from lands where manure is applied.

Three adjacent watersheds in Maryland with primarily cropland, animal pasture grazing, and forest land use were monitored for over 14 years (Correll et al., 1995). No fertilizer was applied in the pasture watershed, and no manure was land applied in the cropland watershed. The results of this monitoring (Table 4) indicate that cropland was the greatest contributor to water quality degradation in the watersheds studied, with the exception of organic phosphorus. Animal grazing on pastures had much lower impacts on water quality than cropland production.

Sharpley et al. (1998b) studied a 40 ha catchment in eastern Pennsylvania with distinct differences in land use. Plant available phosphorus concentrations in surface soil were <30 mg/kg in woodlands, between 100-200 mg/kg in grazed pastures, and >200 mg/kg in cropped fields receiving manure and fertilizer. Phosphorus loss to streams was greatest in near stream areas with high levels of plant available phosphorus in the soil. These near-stream areas should be targeted for P source reduction and management of runoff and erosion because they generate the majority of phosphorus entering streams.

Table 4: Nutrient Losses from Various Land Uses in Maryland

Water Quality Parameter	Watershed Discharge Loss (lb/ac)			
	Cropland	Pasture	Forest	Highest Loss
Total Organic Nitrogen	2.8	7	1.4	Cropland
Nitrate-Nitrogen	3.4	0.5	0.1	Cropland
Total Ammonium-Nitrogen	0.4	0.2	0.2	Cropland
Total Nitrogen	6.7	1.4	1.7	Cropland
Total Organic Phosphorus	1.1	0.2	1.6	Forest
Total Phosphate Phosphorus	1.2	0.2	0.2	Cropland
Total Phosphorus	2.4	0.3	0.3	Cropland

Patni et al. (1985) compared the levels of bacteria in streams draining manured cropland, unmanured cropland, and uncultivated land in Canada. Liquid dairy manure was applied to flat poorly drained lands during dry weather, not to frozen ground, and was plowed under after application. No significant differences in the fecal coliform or fecal streptococci levels of manured and unmanured watersheds were observed. Elevated fecal coliform levels in unmanured soils were from geese, ducks, seagulls, groundhogs, and muskrats. Storing manure for from 6-30 weeks in outside covered concrete storage tanks before application reduced fecal bacteria counts in manure by 3 orders of magnitude, making pathogen levels in manured lands comparable to those in unmanured lands.

Wiggins (1996) developed an accurate method for identifying fecal streptococci from waste matter of turkeys, chickens, dairy cattle, beef cattle, humans, and wildlife in the presence of five antibiotics. Discriminant analysis of the antibiotic resistance patterns from each source was used to classify the source of fecal streptococci in water samples from two streams draining agricultural areas in Virginia. The source of fecal streptococci in Cooks Creek was 59% beef cattle, 18% dairy cattle, 11% human, 11% wildlife, 1% chickens, and 0% turkeys. In Muddy Creek the sources were 68% beef cattle, 15% wildlife, 8% chicken, 6% dairy cattle, 2% turkeys, and 1% human. Thus, in these two watersheds, over 80% of the fecal streptococci were from domestic livestock. The much greater contribution from livestock sources in this study compared to the study above by Patni et al. (1985) could be due to land application of fresh manure or uncontrolled runoff from feedlots in the Virginia study.

The results of the study by Wiggins (1996) may not be readily extrapolated to other regions. This is particularly true in unsewered rural areas of Minnesota where high water tables and poorly drained soils are present. In these areas, individual sewage treatment systems (septic tanks and drainfields) may not be installed, resulting in the direct discharge of large quantities of pathogens from human waste into ditches, creeks, and streams without significant treatment. The Minnesota Pollution Control Agency (MPCA, 1994a) has estimated that in the Minnesota River basin 45% of the 68,000 septic tanks discharge directly (and illegally) to surface waters without treatment.

The main points observed from references in this section include:

■ Livestock waste can contribute significantly to phosphorus loads in surface waters (7-65% of total load), although another major source is non-agricultural land. Livestock waste usually contributes less significantly to nitrogen loads (15-37% of total load). However, the primary source of watershed impairment from nitrogen is fertilizers.

■ Nutrient losses per unit area in runoff can be greater in magnitude from croplands, manured croplands, and grazed pastures than from rotationally grazed lands, forest lands, or natural prairies. Losses from well managed cropland or grazed pastures can be comparable to the small losses observed on rotationally grazed lands.

■ Critical areas for phosphorus loss to streams and lakes are typically those areas high in soil available phosphorus in close proximity to waterbodies.

■ Feedlot runoff contains extremely large loads of nutrients and oxygen demanding substances, and if not properly collected and prevented from entering surface waters, this runoff can severely degrade surface water quality.

■ Fecal bacteria in surface waters from manured lands is often not significantly different from pathogen levels in surface waters from unmanured lands if the manure has been stored and aged before land application. Natural wildlife can be a significant source of fecal bacteria leading to surface water quality degradation.

■ Fecal bacteria in surface waters from lands receiving fresh manure applications can be a significant proportion (over 80%) of the fecal bacteria carried in surface waters. Where illegal discharge of septic tanks to surface waters occurs, human waste can also be a significant source of pathogens in surface waters.

Plot Scale Studies on Nutrient and Pathogen Losses from Agricultural Activities

Runoff Losses

Nutrient Losses in Runoff

Sharpley et al. (1998a) stated that losses of nitrogen and phosphorus in runoff are affected by rate, method and timing of manure application, tillage, rainfall intensity and timing, and slope steepness. Other important factors for phosphorus losses include erosion rate, soil phosphorus levels, soil phosphorus sorption saturation levels, and proximity to waterbodies (Wall and Johnson, 1996). Finally, the crop to which manure is applied influences the amount lost in runoff.

One of the most commonly asked questions is whether there is any difference in runoff losses of nutrients from manured versus fertilized cropland. To answer this question, Gangbazo et al. (1995) applied fertilizer and hog manure to a Coaticook silty loam cropped to corn in fall, spring, or split between fall and spring. Plots with fertilizer plus hog manure had significantly higher ammonium-N losses in runoff than plots receiving only fertilizer. Losses of ammonium-N from the control (160 lb N/ac fertilizer) were 1.1 lb/ac/yr, losses from the spring applied fertilizer (160 lb N/ac) and manure (321 lb N/ac) were 1.1 lb/ac/yr, losses from the spring applied fertilizer (160 lb N/ac) and fall applied manure (321 lb N/ac) were 2.8 lb/ac/yr, and losses from the split application of 160 lb N/ac fertilizer in spring, 160 lb N/ac manure in fall and 160 lb N/ac manure in spring were 1.6 lb/ac/yr. Thus, when applied at equivalent rates of nitrogen, runoff losses of nutrients were equivalent for fertilizer and manure applications. Also, the worst management practice was fall application, followed by split application. Spring application of manure had runoff losses comparable to the spring application of fertilizer.

In an extension of their studies from 1995, Gangbazo et al. (1997) applied 136 lb N/ac as fertilizer or hog manure to fall chisel plowed plots with a silty clay loam texture and a 7% slope. There were no significant differences in loads of nitrogen or phosphorus lost in runoff for fertilized versus manured plots receiving equivalent rates of nutrient input. During snowmelt runoff, 90% of the water loss was in runoff, while in early spring after snowmelt runoff, 92% of the water loss was in tile drainage. Total spring loads were 40 to 70% of the total annual nutrient loads lost in runoff and drainage.

Another common question relates to the effect that manure application rate has on runoff losses. Daniel et al. (1995) studied the effect of poultry litter and swine manure application rate on runoff losses from a Captina silt loam with a slope of 5%. They found the following results (Table 5):

Table 5: Runoff losses (lb/ac) as a function of manure application rate and source of manure for a rainfall intensity of 2 inch/hr

	—Treatment—				
Water Quality Parameter	Control	Poultry	Swine	Poultry/Swine	
		—194 lb N/ac—		—388 lb N/ac—	
		—lb/ac—			
Ammonia-N	0.0	3.3	3.8	5.8	7.5
Nitrate-N	0.0	0.0	0.0	0.0	0.0
Total Kjeldahl-N	0.2	8.0	5.2	18.2	11.2
Total Phosphorus	0.0	1.1	1.3	2.4	4.3
Orthophosphate	0.0	1.1	1.3	2.1	4.3
Chemical Oxygen Demand	2.4	39.4	31.8	46.3	71.2

These results show that application of manure at excessive N rates (388 lb N/ac) significantly degraded water quality of runoff (ammonia, phosphorus, COD) compared to the control which received no manure. No nitrate was observed in runoff at any rate of application because nitrate is soluble and leaches through the soil without entering runoff. They also show that losses of pollutants increase with rate of manure applied. Finally, they show that swine manure runoff tends to be more polluting for ammonia, total phosphorus, and COD than poultry litter if applied at excessive rates, probably because mixing bedding with poultry manure to make litter reduced the availability of pollutants for runoff.

Runoff losses can be significantly influenced by method of application. Ross et al. (1979) found that injection of liquid dairy manure in a Maury silt loam soil greatly reduced the concentrations of COD, nitrogen, and dissolved oxygen in runoff compared to surface applications. Rates of runoff were also reduced on plots with injected manure.

A few large storms generally produce the majority of the runoff and erosion from agricultural fields (Larson et al., 1997). Delaying the time between application of manure and rainfall by 1 day reduced concentrations by at least 80% (Ross et al., 1979). Daniel et al. (1995) also found that runoff losses were worst for the first storm following application of manure, and that runoff losses doubled as rainfall intensity doubled.

Wall and Johnson (1996) conducted an extensive review of the impacts of various cropping systems on runoff losses of phosphorus. They concluded that runoff losses of total phosphorus were generally much smaller for natural woodland, natural prairie, and forested land than for cropland receiving manure applications. Losses of total phosphorus from manured alfalfa were generally less than losses from manured corn.

Long (1979) showed that dairy manure applications of 20 tons/ac to bermudagrass on a sandy loam caused slight increases in BOD, ammonium-N, and nitrate-N levels in runoff compared to plots receiving no manure. No serious long-term effects on runoff water quality would occur from these applications.

We can conclude from these references on surface runoff losses of nutrients that:

- The most significant components of losses in surface runoff are for ammonium, total and orthophosphate phosphorus, and oxygen demanding organic materials. Nitrate-nitrogen is rarely a significant component of surface runoff.

- Nutrient losses in runoff from manured or fertilized fields were much greater than losses from unmanured or unfertilized control plots.

- Nutrient losses in runoff increased with the rate of manure or fertilizer applied.

- Losses of nitrogen and phosphorus in runoff from manured and fertilized fields were not significantly different if the manure and fertilizer were applied at equivalent rates of nitrogen content.

- Nutrient losses in runoff from manured fields decrease when manure is injected or if manure is stored for several weeks before land application.

- Nitrogen losses in runoff from manured fields are least when manure is applied in spring (especially late spring), and greatest when manure is applied in fall.

- Nutrient losses in runoff from manured fields increase when the time between land application and rainfall is brief, especially for intense rainfall events.

- Nutrient losses in runoff from manured fields are usually excessive when land application to snow or frozen soils occurs.

■ Losses of phosphorus in runoff are generally greater when manure is applied to corn rather than alfalfa or grass, but can be negligible when erosion and runoff are controlled on corn fields using conservation tillage. In comparison, phosphorus losses in runoff from manured corn are generally greater than losses from natural prairie, woodlands, and forest lands.

Pathogen Losses in Runoff

Surface water quality is deemed to be impaired if an indicator of pathogens, fecal coliform, is present in counts greater than 200 Colony Forming Units (CFU) per 100 mL of water. Fecal coliform is not typically a health risk to humans, but it is potentially an indicator of other pathogens that can pose a health risk, such as salmonella.

Culley and Phillips (1982) studied fecal bacteria in surface from 0.2 acre sandy clay loam plots receiving liquid dairy manure, fertilizer or no fertilizer for six years. Liquid manure was applied at three rates, and was either plowed under after harvest, plowed under in spring prior to seeding, or plowed under with split applications in spring and fall. In one treatment, manure was applied to snow or frozen ground. Fecal bacteria levels in runoff from manure applied in fall or spring at any rate were not significantly different from fecal bacteria counts in fertilized or unfertilized plots, and were from one to two orders of magnitude greater than the primary contact level of 200 CFU/100 mL. Application of manure to snow or frozen ground resulted in significantly greater counts of fecal bacteria in runoff than any other treatment.

Cooke et al. (1997) studied fecal coliform and fecal streptococci in surface runoff in relation to fall, late winter, and spring applications of manure at rates of 150 and 300 lb/ac N by either injection or broadcast. An inorganic fertilizer control receiving 150 lb N/ac was also included. Fecal bacteria levels in surface runoff were consistently high for all treatments (commonly between 5,000 and 50,000 CFU/100 mL), including the unmanured treatment.

Edwards et al. (1997) studied fecal bacteria in runoff from grazed versus ungrazed and manured versus unmanured fields ranging from 1.5 to 3.7 acres in size for three years. Fecal coliform in runoff exceeded 200 CFU/100 mL 89% of the time for all runoff events, and there were no significant differences in fecal coliform levels in runoff for grazed versus ungrazed or manured versus unmanured plots. This lack of difference could be due to die-off of fecal bacteria during the time between application and runoff. The ratio of fecal coliform to fecal streptococci was not a reliable indicator of the source of fecal bacteria in runoff.

From this section we can conclude:

■ There were no significant differences in fecal bacteria levels in surface runoff (all levels were greater than primary contact limits) from manured versus unmanured or grazed versus ungrazed lands. This is due to fecal bacteria from natural wildlife, and die-off of bacteria in manure after storage or land application.

■ Rate, method, or timing (spring versus fall) of manure application has little effect on fecal bacteria counts in surface runoff.

■ Fecal bacteria counts in surface runoff are significantly greater after application of manure to snow or frozen soil than after application at any other time of year.

Hormone Losses in Runoff

There has recently been much concern over the presence of estrogen and estrogen-like compounds in surface waters. These hormones, when present in high concentration, are linked to reduced fertility, mutations, and death of fish. Shore et al. (1995) summarized the estrogen and testosterone concentrations from various sources (Table 6), including chicken litter:

Table 6: Hormone Concentrations found in Various Sources

Source	Estrogen	Testosterone
	——— ng/L———	
Raw sewage effluent	40-200	16-700
Septic tank effluent	40-130	——
Aqueous extract of sludge	18-70	10-173
	——ng/g dry wt——	
Chicken litter	14-533	133-670

Little is known on losses of hormones from land application of manure, and no studies have been conducted on the impact to human health of hormones in drinking water from manured watersheds. Four streams in the Conestoga River watershed had testosterone levels ranging from 1.2 to 4.1 ng/L and estrogen levels ranging from 0.8 to 2.9 ng/L (Shore et al., 1995). Three of the sampled sites were affected by fields receiving poultry litter, and one was affected by a sewage treatment plant. Runoff from a field receiving poultry litter had from 5-23 ng/mL estrogen. Testosterone is thought to be more susceptible to leaching losses than estrogen, while estrogen is more likely to be lost by runoff than leaching.

Nichols et al. (1998) stated that fish exposed to 0.25 ug/L of estradiol (an estrogen hormone) often have gender changes, while fish exposed to from 10-200 ug/L can die. Concentrations of estradiol in runoff from a field receiving poultry litter were reduced 94% from 3.5 ug/L with no vegetative filter strip to 0.2 ug/L with a 60 ft wide vegetative filter strip. Vegetative filter strips as narrow as 20 ft were found to be very effective at reducing concentrations of estradiol in runoff. In another study, Nichols et al. (1997) found that a 42-46% reduction in runoff concentrations of estradiol from plots receiving poultry litter could be attained by amending the litter with alum.

These studies on hormones in runoff from manured lands are very limited. They show that hormones are present in animal manures, and in surface waters from watersheds where animal waste is applied. Hormones in runoff from manured lands can be significantly reduced by treatment of runoff with vegetative filter strips. Sources of hormones other than animal waste are also very important in surface waters.

Insecticide Losses in Runoff

There has been almost no research on losses of pesticides in runoff from manured lands. Pote et al. (1994) showed that losses of cyromazine (used to control flies in poultry litter) in runoff increased with the rate of poultry manure applied and the intensity of rainfall. Percent losses of cyromazine were 10 and 13% at low and high rates of manure under low intensity rainfall, and 23 and 24% at low and high rates of manure under high intensity rainfall. The impacts of these losses on surface water quality are of unknown magnitude or extent.

Tile Drainage Losses

Nutrient Losses in Tile Drainage

The major factors which influence losses of nutrients through tile drains include rate of application, timing of application, form and method of application, tillage, and cropping system. The impact of each of these factors will be described below.

Many studies on the effect of manure application rate on tile drain losses of nitrate have been conducted. Kanwar et al. (1995) showed that nitrate concentration and yields in tile drains located in Iowa increased with the rate of nitrogen applied. In another Iowa study, Cook and Baker (1998) applied swine lagoon effluent to no-till soil at rates of 1.1 (1X rate) and 3.3 (3X rate) inches. Tile lines were monitored for nutrient levels. A control with no added manure was also included. Tile drainage for the 1X manure treatment and the control were very similar in nitrate loads (<4.5 lb/ac), total Kjeldahl N (<0.05 lb/ac), and total phosphorus (<0.02 lb/ac). The high rate (3X) manure treatment had significantly higher levels of water pollutants, with nitrate levels of 8.9 lb/ac, total Kjeldahl loads of 2.7 lb/ac, and total phosphorus loads of 0.5 lb/ac. Thus, increasing the rate of applied manure to excessive rates causes greater losses of nutrients through tile drains.

Baker et al. (1975) showed that phosphorus can leach to tile drains if manure is applied at excessive rates. Hergert et al. (1981) monitored soluble P in tile drains before and after applying moderate to high amounts of dairy manure to a poorly drained silt loam. The probability of exceeding 30 ppb soluble P before manuring (5%) or after manuring with the moderate rate (8%) were much lower than after manuring with the high rate (47%). Losses of soluble P were roughly 5-10 times greater in surface runoff than tile drainage from manured plots.

Heckrath et al. (1995) studied P leaching to tile drains from soils differing in long-term management at Rothamsted, U.K. Soils received no P, P in manure at 35.7 lb/ac, or fertilizer at 31.2 lb/ac for 100 years. Losses of P from manured plots were comparable to losses in control plots, and significantly lower than losses in fertilized plots. Soil test P levels (using the Olsen test) greater than 60 mg/kg were associated with significant increases in P losses through tile drainage.

There have been questions about the relative impact of manure versus fertilizer on losses of nitrogen through tile drain systems. Two important studies have been conducted to answer this question. In Iowa, Hegde and Kanwar (1997) showed that nitrate losses in tile drainage were 15.2 lb/ac from application of Urea Ammonium Nitrate (UAN) fertilizer and 9.5 lb/ac from an equivalent spring application of liquid swine manure. All concentrations of nitrate were below the drinking water Maximum Contaminant Limit (MCL) of 10 mg/L. Nitrate losses from a very high application rate of swine manure were actually decreased (from 9.5 lb/ac) to 7.1 lb/ac due to enhanced denitrification resulting from high organic carbon in applied manure and wet soil conditions. In Minnesota, Randall et al. (1999a submitted) studied nutrient losses in subsurface drainage water from dairy manure and urea applied to corn at two rates. There were no significant differences in tile drain losses of nitrate-N, total P, and orthophosphorus-P concentrations between manured and fertilized plots. Losses of nitrate-N were greater than 10 mg/L at all rates and forms applied, while losses of phosphorus in tile drainage were negligible.

Hardeman et al. (1997) showed that increasing the rate of swine manure application from 150 to 300 lb N/ac increased the nitrate levels in tile drains, independent of whether the manure was applied in fall or injected during spring. Hardeman et al. (1998) found no significant differences in tile drainage losses of nitrogen from applications of fertilizer, fall injected swine manure, winter broadcast swine manure, and spring injected swine manure.

Tillage and cropping system can influence nitrate losses from manured fields through tile drain systems. In Iowa, Kanwar et al. (1998) studied nitrate levels in tile drains from plots in crop rotations of alfalfa-corn, corn-soybean-oat-clover strip cropping, corn-soybeans, or continuous corn. Tillage included no-till or chisel plow, and nitrogen was applied either as swine manure or UAN fertilizer. Highest losses occurred with a chisel plowed continuous corn plot (24.1 lb N/ac/yr) receiving high rates of manure and with a no-tilled corn-soybean plot (21.4 lb N/ac/yr) receiving agronomic rates of N fertilizer. A chisel plowed corn-soybean plot receiving high rates of manure lost 15.2 lb N/ac /yr, while an alfalfa corn rotation lost 8.9 lb N/ac/yr. In another study, Foran et al. (1993) showed that tilling soils prior to application reduced pollution. They also found that solid manure applications did not pollute tile drains, while liquid manure injection did.

From these references on nutrient losses in tile drainage effluent, we conclude that:

- The most significant component of subsurface tile drain effluent losses is nitrate-nitrogen. Soluble and total phosphorus losses are generally negligible in comparison to their losses in surface runoff. Losses of ammonium-nitrogen and oxygen demanding organic materials are generally lost in much smaller quantities through subsurface tile drain effluent than through surface runoff.

- Nutrient losses in subsurface tile drainage increase with rate of manure or fertilizer applied, unless very high rates of manure are applied on wet soil, when denitrification reduces the losses of nitrogen. Nitrate losses in tile drains from manured fields are typically less than or equal to losses from fertilized fields receiving equivalent rates of nitrogen.

■ Liquid manure applications cause more risk for nitrate leaching to subsurface tile drains than surface applications of solid manure, especially when liquid manure is injected.

■ Manure applications to continuous corn will typically cause greater losses of nitrate-N in subsurface tile drainage than manure applications to other crops, all other factors being equal.

■ Losses of phosphorus through subsurface tile drainage systems are typically negligible, unless very high rates of manure are applied, or the soil test phosphorus levels have built up to excessive levels.

■ No research on the impact of surface tile inlets on nutrient losses from land application of manure through tile drainage systems has been published in peer reviewed journals.

Losses of Pathogens through Tile Drainage

Cooke et al. (1997) described the four main factors affecting survival of enteric bacteria in soil including physiochemical soil properties, atmospheric conditions, biological interactions, and application methods. Factors affecting transport of bacteria through soil included soil physical properties and soil environmental and chemical factors. Fecal coliform and fecal streptococci in tile drains were studied in relation to fall, late winter, and spring applications of manure at rates of 150 and 300 lb/ac N by either injection or broadcast. An inorganic fertilizer control receiving 150 lb N/ac was also included. Higher pathogen levels were likely in tile drainage when manure was injected rather than broadcast. There was no clear effect of rate of manure application on fecal bacteria counts in tile drains. Fecal bacteria levels in control plots receiving no manure were usually below 10 CFU/100 mL. Fecal bacteria levels in tile drains below manured plots were often between 10 and 200 CFU/100 mL.

Geohring (1994) showed that liquid manure applied during the spring to tile drained land was likely to produce very high levels of E. Coli bacteria and ammonium-N, unless the tile drain outlet is temporarily blocked for a day. He recommended that liquid manure applications should be adjusted for soil texture and available water holding capacity, with fine textured drier soils having the capacity for greater amounts of manure application than coarse textured, wetter soils. Manure application rates were also found to depend upon soil type and residue cover, with greater rates allowed on coarser textured soils with significant crop residue cover than on bare, finer textured soils.

Geohring et al. (1998) showed that fecal coliform from surface applications of dairy manure was rapidly transported to subsurface tile drains in fine sandy loam through macropores if the soil was wet before application or a heavy rainstorm occurred within hours of manure application. Rapid transport of solutes has also been observed through soil macropores to tile drains (within roughly an hour after the onset of precipitation) under conditions typical of Iowa and Minnesota (Everts et al., 1989).

Hegde and Kanwar (1997) found that fecal coliform and fecal streptococci counts increased with manure application rate for the two months following application. Maximum counts of fecal coliform (50 CFU/100 mL) and fecal streptococci (70 CFU/100 mL) did not always correspond to the largest storm events.

Cook and Baker (1998) applied swine lagoon effluent to no-till soil at rates of 1.1 (1X rate) and 3.3 (3X rate) inches. Tile lines were monitored for fecal bacteria. A control with no added manure was also included. Tile drainage for the 1X manure treatment and the control were very similar in fecal coliform or fecal streptococci (usually 100,000 CFU/100 mL). The high rate (3X) manure treatment had significantly higher levels of water pollutants, with fecal bacteria counts exceeding 1,000,000 CFU/100 mL.

Stoddard et al. (1998) studied survival and leaching of fecal coliform and fecal streptococci in a soil receiving dairy manure with spring or fall application and no-tillage or conservation tillage. Manure significantly increased fecal bacteria in leachate (3,000 to 60,000 CFU/100 mL) compared to unmanured soils. Neither tillage nor timing of manure application affected fecal coliform concentrations in leachate.

Randall et al. (1999a submitted) studied pathogen losses in subsurface drainage water from dairy manure and urea applied to corn at two rates. E. coli was found in 24% of the tile drain water samples from manured plots, but no E. coli were found in tile drain water from fertilized plots.

Somewhat contradictory results were observed for transport of fecal bacteria to tile drains. The main conclusions appear to be:

- Manured soils generally, but not always, produced significantly greater levels of fecal bacteria in tile drain effluent than unmanured soils.

- The effect of manure application rate on fecal bacteria levels in tile drainage was not conclusive. The effect of manure application timing on fecal bacteria levels in tile drainage was also not conclusive.

- Fecal bacteria levels in tile drain effluent increased when manure was injected rather than broadcast.

- Transport rates of fecal bacteria to tile drain effluent from land applied manure could be very quick in medium textured soils with macropores.

Effects of Manure Storage Facility Spills and Feedlot Runoff on Surface Water Quality

Catastrophic spills from large manure storage facilities can occur primarily through overflow following large storms or by intentional releases. A third mechanism, collapse of a sidewall is less frequent, and has never occurred in Minnesota (personal communication, Gregory Johnson of the Minnesota Pollution Control Agency). According to Mancl and Veenhuizen (1993), Pennsylvania has about 30 water quality violations each year from animal lagoon spills. Ohio had about 35 violations during 1989, of which 16 caused fish kills. Indiana has 10 fish kills and 25 water quality violation each year. Hallberg (1996) stated that runoff from manure is the number one cause of fish kills in Iowa. According to a report on animal waste pollution by the U.S. Senate (1997), 40 animal waste spills killed 670,000 fish in Iowa, Minnesota, and Missouri during 1996. In 1995 there were 20 spills in those three states, which killed 55,000 fish.

Ackerman and Taylor (1995) stated that 40% of the nearly 80,000 confined animal farming operations in Illinois do not comply with state regulations on discharges to water. Between 1972 and 1992 there were 133 fish kills from discharges of manure. Three case studies were presented (Table 7) showing the effects of feedlot runoff on stream water quality. These results show that direct entry into surface waters of manure from feedlot runoff, storage basin spills, or frozen soil runoff has a devastating local impact on water quality (primarily low oxygen, and high ammonia, phosphorus, and BOD).

Table 7: Water Quality Impact Upstream and Downstream of Manure Spills and Manure Runoff from Frozen Cropland in Illinois

Event	Water Quality Impact	
	Upstream	Downstream
1000 Hog Feedlot Spill	——— mg/L———	
Dissolved Oxygen	6.8	0.0
Ammonium-N	0.7	56.0
	0.3	31.0
Total Phosphorus		
500 Cattle Manure Storage Tank Spills		
Disolved Oxygen	8.2	0.2
Ammonium-N	0.06	60.0
Swine Manure Applied to Frozen Cropland		
Ammonium-N	—	11.0
Biochemical Oxygen Demand	—	200.0

According to a U.S. Senate report (1997), 35 million gallons of animal waste spilled in North Carolina during 1995, killing 10 million fish. Serious spills occurred in North Carolina 30 times from 1995-1996. Mallin et al. (1997) studied the impacts for single cases involving a poultry and a swine waste lagoon spill on water quality of receiving streams in North Carolina (Table 8). The poultry waste lagoon spilled 8.6 million gallons of waste into the Cape Fear River at high flow during a 25 year storm event. The hog waste lagoon released 2 million gallons of waste into a nearby creek at low flow. The lagoons served 75,000 chickens and 6,500 hogs. Dissolved oxygen levels from the poultry spill were as low as 1.0 mg/L 56 miles downstream of the spill, and resulted in 200 fish being killed. Dissolved oxygen levels from the hog lagoon spill reached as low as 0.1 mg/L, and did not recover for two weeks when a significant rainfall occurred. Maximum total Kjeldahl nitrogen levels recorded in the streams from the poultry and hog lagoon spills were 92 mg/L and 47 mg/L, respectively. Maximum levels of ammonia-N from the poultry lagoon spill were 1.2 mg/L, while levels of ammonia reached 45.2 mg/L from the hog lagoon spill. Maximum levels of soluble orthophosphate phosphorus reached 6.9 mg/L from the poultry spill, and 11.5 mg/L from the hog spill. Fecal coliform levels as high as 14,000 and 1,700 CFU/100 mL were measured from the poultry and hog lagoon spills, respectively. The hog lagoon spill into a stream at low flow conditions caused serious increases in chlorophyll a and phytoplankton blooms.

Table 8: Extreme Values Measured in North Carolina Streams after Manure Lagoon Spills

Water Quality Parameter	Poultry Lagoon Spill	Hog Lagoon Spill
	——— mg/L———	
Dissolved Oxygen	0.3	0.1
Total Kjeldahl Nitrogen	92.1	47.0
Ammonia-N	1.2	45.2
Orthophosphate	6.9	11.5
Chlorophyll a	0.006	0.1

Westerman and Overcash (1980) compared runoff of pollutants from a dairy open feedlot and a pasture irrigated with dairy lagoon waste. Runoff from the feedlot was 21% of the precipitation, while runoff from the pasture was 10% of precipitation. Water quality impacts of the pasture were less than the impacts of runoff from the feedlot, as shown by the mean concentrations of various pollutants in runoff (Table 9):

Table 9: Nutrient Concentration in Runoff from a Dairy Feedlot and Manured Pasture

Parameter	Dairy Feedlot	Manured Pasture
	——— mg/L———	
Chemical Oxygen Demand	1185	181
Total Kjeldahl Nitrogen	76	13.2
Nitrate-Nitrogen	4.5	8.0
Total Phosphorus	34	7.2

There are several important conclusions that can be drawn from references in this section:

- The impacts on surface water quality and aquatic life from manure lagoon spills, feedlot runoff, and applications of manure to frozen ground can be devastating.

- The number of documented serious water quality pollution problems involving manure lagoon spills and feedlot runoff is generally several tens of events per year in each of the states with high concentrations of feedlots.

- Compared to the several thousands of feedlots in most states, the number of water quality pollution problems causing documented fish kills from lagoon spills and feedlot runoff is typically a small fraction of the total number of operations. An exception to this is the Chesapeake Bay area, where feedlot spills and runoff generate a large fraction of the water quality pollution problems.

Effectiveness of Surface Quality Remediation Strategies in Various Watersheds

A frequently asked question pertains to the length of time required to restore polluted lakes and rivers by implementing best management practices in the contributing watershed. Although not requested by the scoping questions, we undertook a literature review of case studies in which the effectiveness of watershed restoration activities to correct water quality problems resulting from animal agriculture was documented. There are many such case studies published as project reports and agency documents which were not reviewed here because they are not a part of the peer reviewed scientific literature. These could be reviewed at a later stage of the GEIS process, if needed.

Garrison and Asplund (1998) studied the effect of reducing phosphorus loadings on lake water quality in a 3003 ac Wisconsin watershed. Phosphorus losses from animal waste storage facilities were reduced by 46% and from cropland runoff by 19%, but these improvements had a negligible impact on water quality of a lake at the mouth of the watershed. Total phosphorus levels in the lake increased from 29 ppb before implementation of pollution control measures to 44 ppb fifteen years after implementation. Chlorophyll a levels increased from 9 to 13 ppb over the same time period. The increased impairment of the lake after reductions of phosphorus losses was due to a failure to control cropland runoff adequately, which accounted for 76% of the phosphorus loading.

Gallichand et al. (1998) attributed 90% of the point source pollution in the Belair River watershed near Quebec to leaking liquid manure tanks and manure piles. Improved manure storage facilities and septic tanks, and electric fences near streams were installed throughout a 1,310 ac experimental watershed to improve water quality. In addition, fertilizer applications were reduced, fall application of manure was reduced from 70% to 13%, and spring and summer applications were split. No improvements were made in an adjacent control watershed. Maximum concentrations of total phosphorus and dissolved phosphorus decreased significantly in the experimental watershed, but not the control watershed, during two years of monitoring after improvement. Fecal bacteria counts were not measurably affected by the watershed improvements. In spite of the improvements, total phosphorus concentrations in the improved experimental watershed still exceeded critical levels (0.03 mg/L) for protection of aquatic life 94% of the time.

Hession et al. (1995) stated that the threshold between eutrophic and mesotrophic lakes occurs at 10 ug/L chlorophyll a. Total Maximum Daily Load (TMDL) values for total phosphorus in an Oklahoman watershed were obtained by adjusting annual load using a water quality model until chlorophyll a levels were reduced to 10 ug/L, giving a TMDL of 587 lb P/day. The model predicted that doubling the mass of total phosphorus spread on land from manure would increase chlorophyll a from 10.4 to 10.9 ug/L. Nonpoint sources generated 75% of the total phosphorus loading to the watershed. To meet TMDL values through control of only point sources of phosphorus would require a 72% reduction in point source discharges of phosphorus. To meet TMDL values only through control of nonpoint sources would require a 22% reduction in phosphorus applied to the land.

Schuler (1996) described the restoration of Lake Shaokatan in southwestern Minnesota. This lake was heavily impaired by excessive nitrogen and phosphorus levels, and had nuisance algal blooms and algal toxins which occasionally caused the death of cattle and dogs who drank from the lake. It was determined that a significant proportion of the nutrient load to the lakes was generated by three swine operations and one dairy farm. After corrective measures were taken in 1993 to reduce nutrient loads from these operations, the lake water quality improved significantly. From 1994 to 1996 the average lake total phosphorus concentrations decreased from 270 ppb to less than 160 ppb. Noxious algal blooms and algal scums also disappeared.

These studies indicate that the success in cleaning up water quality degradation due to animal agriculture depends on accurate identification of the source of pollution. Addressing manure waste lagoon spills and feedlot runoff when runoff from manured lands is the major pathway for pollution will not lead to successful cleanup. Similarly, addressing runoff from manured lands will not lead to successful cleanup if lagoon spills and feedlot runoff are the major sources of impaired water quality. In the best case, restoration of water quality can occur in as little as a few years, in the worst case water quality may never be restored if the major sources of pollution are not addressed.

CAUSES OF IMPAIRMENT FOR GROUND WATER

Impact of Various Land Uses on Ground Water Quality

Ground water is an important source of drinking water, particularly for rural residents. Nitrate-N concentrations in excess of 10 mg/L in drinking water are associated with the often fatal blue-baby syndrome (methemoglobemia). Sources of nitrate contamination of drinking water can include fertilizers, animal waste, and human waste. Ground water can also become contaminated with pathogens that cause illness in humans (see this report, scoping question #4 for additional details). Sources of pathogens in drinking water can include animal waste, wildlife waste, and human waste. The following section discusses the impact of animal manure on ground water quality.

Andres (1995) studied nitrate leaching to ground water in Sussex County, Delaware, which has the greatest number of chicken broilers in the U.S. Soil loading rates from nitrogen in manure averaged 241 lb/ac. Fertilizer nitrogen was applied at an average rate of 43 lb N/ac. Ground water wells exceeded the nitrate drinking water standard of 10 mg/L 20% of the time. The median nitrate concentration was 9.8 mg/L in intensive poultry areas and 5.8 mg/L in areas without intensive poultry. This study shows that intensive animal agriculture on coarse textured soils can lead to nitrate levels in ground water that frequently exceed the drinking water maximum contaminant limits.

Richards (1997) showed that nitrate levels in ground water from Ohio, Indiana, Illinois, Kentucky, and West Virginia were strongly correlated with (in decreasing level of impact) well depth, history of well water levels, type of well, proximity to rivers, proximity to cropland, proximity to barnyards, and lawn chemical usage. Cropland effects were much more significant than proximity to barnyards or usage of lawn chemicals.

Rural ground water wells often show simultaneous contamination by nitrates and fecal coliform (Fedkiw, 1992), because of barnyards, silos, feedlots, buried or stacked organic material, and septic system effluent near fractured well linings or casings, old wells, and poorly located wells. This means that quite often, the pathway for well contamination is flow from surface soils directly down well linings or casings, rather than leaching through soil to ground water.

Huysman et al. (1993) studied the polluting effects of manure on ground water by tracking tetracycline and oleandomycin resistant Clostridium perfringens in shallow ground water below (pig) manured versus unmanured sandy plots. Counts of antibiotic resistant Clostridium as high as 100 CFU/100 mL were detected below manured plots, while they were nearly absent below unmanured plots.

McMurry et al. (1998) studied fecal coliform transport through soil amended with poultry manure. They found that coliform were transported primarily through macropores. Tillage practices which disrupted macropore continuity delayed the transport of fecal coliform, without reducing peak concentrations appreciably.

We can conclude from the references in this section that many factors influence contamination of ground water by nitrates or fecal bacteria. These factors include the depth and condition of the well, the type of soil and geologic material above the aquifer, the location of the well, the land use surrounding the well (particularly cropland), and the density of animals and manure handling and application practices. Ground water contamination from animal agriculture is most likely to occur when intensive animal agriculture occurs in regions having coarse textured soils, shallow ground water, and heavy precipitation.

Impact of Manure Storage Facility Seepage on Ground Water

In addition to the problem of land applied manure, ground water can become contaminated when manure storage basins leak, causing nutrients in the manure to leach downward towards ground water. The reasons why this problem occurs and the factors which promote it are reviewed below.

Miller et al. (1985) studied self-sealing of earthen liquid manure storage ponds, and found that a seal usually formed within 12 weeks of construction. McCurdy and McSweeney (1993) found that earthen-lined dairy manure storage basins had seepage losses primarily because of freezing, earthworm activity, roots, and pedogenesis. Most of the pollutants were lost to ground water through macropores in the sidewalls.

Ciravolo et al. (1979) studied the factors associated with leakage of wastes from anaerobic swine lagoons in Virginia on sandy and sandy loam or sandy clay loam soils. Leakage was minimal for lagoons on sandy loams with finer texture subsoils. Leakage was significant for the lagoon in sandy soil. Failure of the seal was related to drying of the lagoon bottom during excessive pumping of waste, and release of gas from below the seal. No contamination of ground water at any location by fecal coliform, copper, phosphate or zinc was observed. Contamination by chloride (max conc. 272 ppm), ammonium-N (max conc. 358 ppm), and nitrate-N (max conc 100.8 ppm) was considerable for the lagoon on sandy soil.

Culley and Phillips (1989a) monitored nitrogen and phosphorus seepage beneath earthen manure storage pits constructed in sand, sandy loam, and clay loam. Depth averaged orthophosphorus concentrations monitored during four years increased from less than 10 ppb to over 250 ppb beneath the pit constructed in sand, while nitrate-N concentrations increased from less than 5 ppm to over 50 ppm. Seepage losses were much less for pits constructed in sandy loam and clay loam soils.

Culley and Phillips (1989b) found that the factors controlling nitrate-N seepage from unlined earthen manure storage pits included the saturated hydraulic conductivities of the soil and the pit seal, the height of the water table, and the rate of decrease for hydraulic conductivity in unsaturated soil beneath the pit. Leakage rates were significantly greater for pits constructed in coarse textured soils than in fine textured soils.

Ritter and Chirnside (1990) studied clay-lined anaerobic lagoons constructed in sandy loam or loamy sands and containing hog or beef waste. Seepage beneath the hog lagoon was due to drying and cracking of the liner after liquid levels were pumped below design levels. Average ammonium-N and nitrate-N concentrations beneath the seeping hog lagoon were 968 and 40.5 mg/L, respectively. Limited seepage was observed beneath the beef waste lagoon, where average ammonium-N and nitrate-N concentrations were 12.1 and 9.1 mg/L, respectively.

Wall et al. (1998) studied seepage from a 600,000 gallon clay-lined earthen manure storage system for a 100 cow dairy operation in central Minnesota. Seepage averaged 5 gal/d from the bottom and 102 gal/d from the sidewall during the first 3 years of operation. The main contaminants leached were sodium and chloride, with very small fractions of nitrogen and phosphorus leached. Monitoring of 13 newly constructed earthen basins and lagoons in Minnesota found little evidence that seepage was affecting ground water at 12 of the 13 sites.

We conclude that, under certain circumstances, seepage from manure holding basins and lagoons can have a very serious impact on ground water quality, especially from nitrate-N and ammonium-N. These impacts are greatest with unlined earthen manure storage systems, and lined pits constructed in coarse textured soils. Seepage losses generally occur when the sidewalls become cracked or develop macropores. Lined basins and lagoons which are properly constructed, engineered, and managed are generally not a serious threat to ground water quality, unless constructed in coarse textured soils or karst terrain. Unlined earthen manure storage systems may develop a slowly permeable seal after several weeks of operation, but generally pose a much greater risk for pollution of ground water by seepage than lined storage facilities.

Animal waste from feedlots can get into the ground water via many potential routes, including the following:

- Continual leakage of waste lagoons/basins or pits, where:
  -clay-lined and unlined earthen basins or pits develop root cracks, wetting/drying cracks, secondary soil structures, erosion of the bottom or sides from agitation or scraping by equipment when cleaning out the basins, etc.;

-concrete basins or pits develop structural cracks (such as from differential settling), and/or chemically corrode from the waste;
-plastic-lined basins or pits leak along poorly sealed seams, or where punctured from rocks, equipment, etc.
-unknown tile lines exist below a basin or pit, which forms a direct hydraulic conduit to the ground water.

■ The potential for basin leakage to a drinking water aquifer is significantly increased in areas of geological susceptibility.

■ Episodic waste release from lagoons/basins, pits, or waste-handling equipment can develop from:
-waste-handling spills;
-overtopping of the basins or pits;
-catastrophic failure of the basin sidewalls or dikes, such as by penetration by cleaning equipment;
-hydraulic failure from excessive water pressure such as during flooding events or if tile lines cannot keep ground water levels low enough;
-erosion (soil piping) and subsequent failure of the basin sidewalls or dikes.

■ Releases to ground water can occur from land application of the wastes due to:
-disposal of manure by over-application (above agronomic rates) in restricted areas;
-application over tile drains, surface inlets, sinkholes, undetected focused recharge areas, etc.;
-routine application at approved agronomic rates on fields that have already received other fertilizers.
-all of the above ground water contamination potentials are aggravated when heavy rains occur shortly after the land application.

The most difficult problem in detecting contamination is in ground water contamination because it is usually an "invisible" problem; only rarely are there obvious signs of basin, lagoon, or pit deterioration during normal use. The second most difficult problem with ground water contamination is that it is usually detected only after the fact. Therefore, an aquifer can be seriously impacted before it is known.

STUDY TOPIC 2: HOW IS THE USE OF WATER BY HUMANS FOR DRINKING, RECREATION, AND OTHER PURPOSES AFFECTED BY WATER QUALITY DEGRADATION?

There are two approaches for assessing the degree to which surface waters are degraded by pollution, namely; by evaluating existing water uses and quality using narrative and numerical criteria. Narrative criteria usually address questions such as:

- ■ Are the fish safe to eat?
- ■ Are opportunities for fishing and boating limited by pollution?
- ■ Is it safe to swim in the river or lake?

- Are there noxious aquatic plants or algae?

Numerical criteria are framed in terms of water quality standards. These standards vary depending upon the type of classification for the waterbody. Lakes and rivers are classified according to their potential uses. The primary use classifications for Minnesota lakes and rivers include (Minnesota Rules 7050):

- Class 1C waters. The quality of Class 1C waters of the state shall be such that with treatment consisting of coagulation, sedimentation, filtration, storage, and chlorination, or other equivalent treatment processes, the treated water will meet both the primary (maximum contaminant levels) and secondary drinking water standards issued by the United States Environmental Protection Agency. The primary drinking water maximum contaminant level (MCL) of interest here is that nitrate-nitrogen levels will not exceed 10 mg/L. This standard applies whether the source of drinking water is from surface or ground waters.

- Class 2A waters. The quality of Class 2A surface waters shall be such as to permit the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface waters is also protected as a source of drinking water.

- Class 2Bd waters. The quality of Class 2Bd surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface waters are also protected as a source of drinking water.

- Class 2B waters. The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface water is not protected as a source of drinking water.

- Class 2C waters. The quality of Class 2C surface waters shall be such as to permit the propagation and maintenance of a healthy community of indigenous fish and associated aquatic life, and their habitats. These waters shall be suitable for boating and other forms of aquatic recreation for which the waters may be usable.

DRINKING WATER

Drinking water for 1 million Minnesota residents of the Twin Cities metropolitan area originates primarily in the surface waters of the Upper Mississippi River basin. Many residents of south central Minnesota and the Red River basin also derive their drinking water from surface water sources. Many rural residents in southwestern, southeastern, and central Minnesota derive their drinking water from ground water wells. About a million

Twin Cities metropolitan area residents also derive their drinking water from ground water wells.

One of the greatest concerns for water quality is the problem of drinking water contamination from pathogens. The 1994 Cryptosporidium outbreak in Milwaukee sickened 403,000 people and cost $37 million in lost wages due to sickness (Smith, 1994). The water treatment plant was not operating properly during the Milwaukee Cryptosporidium outbreak due to high turbidity. It is not known whether the source of the cysts was human sewage, livestock along the rivers, or slaughterhouses.

Le Chevallier et al. (1991) surveyed 66 U.S. surface water treatment plants mostly located in Pennsylvania, W.Virginia, Ohio, Indiana, and Illinois for Giardia and Cryptosporidium cysts in drinking water. Giardia cysts were found in 81% of the untreated and 17% of the drinking water samples, while Cryptosporidium cysts were found in 87% of the untreated and 27% of the drinking water samples. Either Giardia or Cryptosporidium cysts were found in 39% of the samples. Concentrations of cysts for both Giardia and Cryptosporidium were highly correlated with fecal coliform levels and turbidity.

Several typical water treatment methods were evaluated for their effectiveness in removing cysts. It was found that granulated activated carbon filter systems had cysts 61% of the time, while sand, mixed-media, or dual-media filters had cysts 17 to 36% of the time. Removal of cysts was strongly enhanced by reductions in turbidity during the treatment process. Most of the cysts remaining in finished drinking water were nonviable and inactivated, meaning that settling, filtration, and chemical treatment of water contaminated by cysts typically results in drinking water that is not a human health hazard. These treatment processes do not always operate at maximum efficiency during periods when thereare high turbidity levels, and it is during these times that a human health risk from cysts may occur.

The Minneapolis water treatment plant is currently considering enhanced filtration and treatment techniques to address concerns for Giardia and Cryptosporidium in drinking water for the Twin Cities metropolitan area. Pell et al. (1994) states that Giardia cysts in public drinking water caused 18% of the water borne gastroenteritis between 1971 and 1985 in the U.S. The American Society for Microbiology (1999) states that up to 900,000 illnesses and 900 deaths occur each year from waterborne microbial infections. By law, drinking water plants must remove 99.9% of giardia cysts using water supply protection, disinfection, and filtration.

There have been 14 documented incidents of cryptosporidium disease outbreaks in U.S. and Canada since 1984 (Frey et al., 1998). Four of these events were linked to nonpoint source agricultural pollution, the others were primarily caused by septic tank and human sewage contamination. The primary sources of cryptosporidium protozoa include wildlife, domestic livestock, and humans. Young calves (1-3 weeks old) are most likely to carry the cysts, and should be kept in clean and dry housing. About 59% of all beef and dairy farms have cryptosporidium in livestock. Cryptosporidium cysts in livestock manure can be inactivated by drying, liming, and composting. Manure from infected calves should not be placed on land near water or on frozen soils.

GROUND WATER

There are roughly 450,000 private wells used to supply drinking water to Minnesota residents. Wall (1991a) estimates that roughly 7% of these wells have nitrate-N levels exceeding the maximum contaminant level (MCL) of 10 mg/L. There are another roughly 1,700 public community water supply wells in Minnesota, of which roughly 1% have nitrate levels greater than the MCL.

The percent of these contaminated wells that are affected by animal agriculture is unknown. It is known that several pathways exist for contamination of ground water by animal agriculture (Wall, 1991b), including:

- Direct leaching from outdoor animal holding areas
- Runoff and subsequent infiltration
- Runoff into unused wells, improperly sealed wells, and sinkholes
- Runoff to surface water that eventually discharges to ground water
- Leaching beneath manure storage areas
- Application of manure in excess of crop nutrient uptake requirements
- Leaching beneath abandoned feedlots
- Leaching from animal burial pits or improper composting of dead animals

See the response to scoping question #6 for a state-wide summary of ground water contamination patterns by nitrate.

EPA 305(B) SUMMARY REPORTS ON THE QUALITY OF LAKES, RIVERS, AND STREAMS

The U.S. Environmental Protection Agency (EPA) under Section 305(b) of the Clean Water Act requires states to assess and estimate the extent to which waterbodies meet the goals of the Clean Water Act and attain water quality standards. A note of caution is warranted for EPA 305(b) reports. These reports are based only on surveyed or monitored waterbodies, which may be a small proportion of all existing waterbodies. Furthermore, the waterbodies selected for survey and monitoring may be biased towards the most polluted waterbodies.

Results from the 1996 nationwide 305(b) survey are reported below in terms of the total miles surveyed which fully support, are threatened, partially support, do not support, or cannot attain these goals and standards. For simplicity, waters are given a summary use support classification of good (fully supporting all uses or threatened for one or more uses) or impaired for one or more uses (not supporting, or not attaining).

Table 10: Nationwide 305(b) Report (1996 Summary)

Report Factor	Rivers and Streams	Lakes
Total Extent of Waterbodies	3.6 million miles	41.7 million acres
Surveyed Extent of Watervodies	0.7 million miles	17 million acres
Waterbodies with Good Status	64%	61%
Waterbodies with Impaired Status	36%	39%

Roughly 19% of all rivers and streams, and 40% of all lakes (excluding the Great Lakes) were surveyed in 1996 (Table 10). Of the surveyed waterbodies, 64% of the rivers and streams, and 61% of the lakes were classified as good quality. Overall, agriculture was the leading source of pollutants and stressors in 25% of surveyed rivers and streams, and in 19% of surveyed lakes.

The remaining 36% of rivers and streams, or 39% of lakes were classified as impaired, meaning that they did not support or could not attain the goals and standards set forth in the Clean Water Act and state regulations. The primary cause of impairment in 70% of the rivers and streams classified as being impaired was agriculture. Of these agriculturally impacted rivers and streams, non-irrigated cropland production was the leading cause of impairment (36%), followed by irrigated cropland production (22%). Other causes of impairment (Table 11) were rangeland (12%), pastureland (11%), feedlots (8%), animal operations (7%), and animal holding areas (5%). Animal agriculture can indirectly influence the impact on surface water quality from both irrigated and non-irrigated cropland production through land applications of manure, so the impacts of animal agriculture on surface water quality may be underestimated based on the reporting method used for data in Table 11.

Table 11

Type of Agricultural Activity	%Contribution to Inpairment in Rivers and Streams from All Agricultural Sources
Non-irrigated Cropland Production	36
Irrigated Cropland Production	22
Rangeland	12
Pastureland	11
Feedlots	8
Animal Operations	7
Animal Holding Areas	5

The Minnesota Pollution Control Agency assesses the ability of state surface waters to support swimming and aquatic life on a five year cycle. Reports on use support have been completed for the Minnesota River and the Red River basins. These assessments are consistent with the two major goals of the Clean Water Act, to ensure that surface waters are swimmable and fishable. The assessments are based upon narrative and numeric criteria described in the previous section, and waters are classified into fully supporting, partially supporting, supporting but threatened, or not supporting the beneficial uses.

Table 12: Minnesota 305(b) Report (1994 Summary)

Report Factor	Rivers and Streams	Lakes
Total Extent of Waterbodies	91.9 million miles	3.3 million acres
Surveyed Extent of Watervodies	12.2 million miles	2.4 million acres
Waterbodies with Good Status	40%	83%
Waterbodies with Impaired Status	60%	17%

In the state of Minnesota, 31% of the rivers and streams and 73% of the lakes were surveyed and/or monitored for the 1994 305(b) report (Table 12), the last year for which statewide data summaries are published. Of the surveyed and monitored waterbodies, about 60% of the rivers and streams, and 17% of the lakes were classified as being impaired. Agriculture was identified as the cause of 90% of the impaired river miles, and 64% of the impaired lake acres. No additional information was available on the degree to which various types of agricultural activities (cropland, feedlots, rangeland, etc.) caused impairment. Besides agriculture, other causes of nonpoint source pollution included land disturbance, habitat modification, urban areas, and construction activities.

RIVERS

Results from the 1996 assessment for the Minnesota River (Senjem, 1997) indicate that its tributaries are generally poor in supporting the aquatic life that would be found under natural conditions. Conditions are very poor for swimming in the tributaries. In general, the support for aquatic life is better in the mainstem of the Minnesota River than its tributaries. The following table summarizes the assessment of rivers in the Minnesota River basin.

These results show that from 50-100% of the assessed tributary river miles in the Minnesota River basin do not adequately support aquatic life. This results in reduced diversity of fish and other aquatic life, and predominance of undesirable fish species. None of the tributaries is fit for swimming, primarily because of high levels of fecal bacteria.

Table 13: Percent assessed miles of tributaries to the Minnesota River not supporting beneficial uses for swimmability and fishability based on assessment by the Minnesota Pollution Control Agency (Senjem, 1997).

Tributary	Aquatic Life	Swimming
	—Percent Not Supporting—	
Pomme de Terre	64	100
Lac Qui Parle	52	100
Chippewa	95	100
Redwood	61	100
Cottonwood	62	100
Blue Earth	80	100
Watowan	77	100
Le Sueur	97	100

The most common indicators of impairment in the tributaries of the Minnesota River basin included oxygen depletion, turbidity, bacteria, and habitat alteration. The most common suspected pollution sources were agricultural nonpoint sources, hydrologic modifications, urban runoff, and land disposal of wastes. Impacts from municipal discharges and construction activities were less common sources of pollution. No information is available to specifically identify the miles of streams and rivers impacted by animal agriculture.

LAKES

Over eighty percent of the lakes in the Minnesota River basin were also assessed. Only 38% of the lakes fully support swimming. Of assessed lakes, 40% did not support swimming. More information on degradation of lakes is provided in the response to question 6.

STUDY TOPIC 3: IMPACTS OF LIVESTOCK MANAGEMENT ON FISH AND WILDLIFE

There are many reports in the literature which suggest that well-managed livestock grazing is compatible with a healthy riparian ecosystem but that practices and their impacts should be viewed as site specific testable-hypotheses rather than generic practices to be widely applied (Clark, 1998). It is to be expected that grazing and riparian systems should be compatible to some degree. Prairie ecosystems had large numbers of bison for thousands of years (Bradley and Wallis, 1996). However, those bison probably were migratory and did not concentrate in the riparian areas. Clearly, they had great impact during their migrations; however, after a relatively short and intense impact on a specific area, they moved on allowing riparian zones and in-stream communities to recover (Fitch and Adams, 1998)

Today, impacts of livestock grazing on stream and riparian ecosystems are widespread; for recent reviews see Kauffman and Kreuger (1984), Platts (1991), Fleischner (1994), Knapp and Matthews (1996). Much of the better known impact has been reported from the western United States. For example, a survey of stream riparian zones which rated conditions on a poor-good scale (Table 14) found widespread disruption of stream ecosystems.

Table 14: Percent of stream riparian condition reported to be in poor, unsatisfactory and/or fair condition (Armour et al., 1994).

Location	Percentage	Condition
Tonto National Forest, Arizona	80-90%	Unsatisfactory
Modoc National Forest, California	78%	Unsatisfactory
Sawtooth National Forest, Idaho	37%	Poor
One Ranger District in Nevada	90%	Poor
One Ranger District in Baker Oregon	60%	Poor to Fair

Damage to riparian zones and streams has been widely addressed (e.g., Leopold, 1975; Armour, 1977; Behnke, 1977; Kennedy, 1977; Marcuson, 1977; Van Velson, 1979; Claire and Storch ,1983; Duff, 1983). In general, that damage includes loss of riparian vegetation and resulting alterations of stream morphology, a lowered groundwater table and decreased dry season stream flow, increased summer water temperature and increased substrate icing in winter (Armour et al., 1994).

It is widely recognized that poorly managed grazing results in degradation of riparian areas (Fitch and Adams, 1998). However, we know relatively little about the specific livestock practices which result in specific impacts. Further, very little evidence of livestock impacts clearly relates to Upper Midwestern water bodies. For example, Larsen et al. (1998) reviewed more than 1500 scientific papers dealing with livestock management. They report that 428 of those articles were directly related to grazing impacts on riparian zones and fish habitat. Of those, only 89 were experimental, where treatments were replicated and results were statistically valid. They concluded that there are several limitations of riparian grazing studies, including (1) inadequate description of the grazing management practices or treatments, (2) weak study designs, and (3) lack of pre-treatment data (Larsen et al., 1998). It was not clear that any of those 89 instructive papers dealt with Midwestern streams, nor that results from Intermountain West conditions are applicable to Minnesota.

From the cited literature reviewed in this section we can conclude the following:

- Un-managed or poorly managed livestock practices result in riparian degradation and significant impacts on fish and wildlife.
- There is little conclusive evidence in the literature about the degree of impact expected from specific livestock practices
- More significantly for our purposes, very little of the existing scanty evidence is clearly relevant to Upper Midwestern water bodies.

RIPARIAN ZONES AND THEIR ADJACENT WATER BODIES

Riparian areas are ecotones (i.e., edges between two systems of different character) and they have high edge to area ratios (Odum, 1978). As such, they are very open ecosystems, with large energy, nutrient and biotic interchanges with aquatic systems on inner margin (Cummins, 1974; Odum, 1978; Sedell et al., 1974) and upland terrestrial area (Odum, 1978). Riparian zones have much higher diversity and productivity than do the adjacent uplands. Streams and wetlands in the forested areas of Minnesota are heterotrophic, depending on external sources for their carbon. In such systems, the riparian produces detritus that drives up to 90% of secondary productivity in the stream (Cummins and Spengler, 1978; Kauffman and Kreuger, 1984). Waters in the more open areas of Southwestern Minnesota are autotrophic, having greater levels of in-stream productivity. However, they are equally dependent on the character of their riparian zones (Perry and Vanderklein, 1996).

Overall, the riparian /stream ecosystem is the most productive type of wildlife habitat, benefitting greatest number of species (Ames, 1977; Hubbard, 1977; Miller, 1951; Patton, 1977). Riparian zones which had their vegetation removed and rip rap placed along the shore line had 93% fewer bird numbers and 72% fewer bird species. In other nearby riparian areas which were cultivated, there were 95% fewer birds and 32% fewer bird species (Kauffman and Kreugger, 1984)

SEDIMENT, NUTRIENTS AND ORGANIC MATTER

Sediment is the most prevalent aquatic pollutant in streams in North America (Waters, 1995; See Question 5 for review). We know that livestock management often causes changes in sediment load, nutrient content and organic matter in streams and may cause changes in lakeshores. There is some evidence that sediment and nutrients associated with livestock has a negative impact on fish and invertebrates (See below). However, those finding have most frequently been reported from the semi-arid areas such as the western and southwestern parts of the US. We have very limited data on the specific contributions of various livestock management practices in the Midwest.

IMPACTS OF LIVESTOCK MANAGEMENT ON FISH AND WILDLIFE HABITATS

Fish, amphibians, birds and insects rely on water's edge habitats (e.g., undercut banks, overhanging vegetation) for habitat and food. Cattle trample banks, caving in overhangs and creating erosion (Trimble and Mendel, 1995). If livestock management changes those habitats, impacts to the populations will be seen. Williams et al. (1992) found that there were differences in vegetation overhang, aquatic habitat and recent erosion in some of the grazed and retired reaches in their New Zealand streams but these results were highly site specific.

In a similar recovery study, Meyers and Swanson (1996) compared the recovery from abusive grazing in Nevada streams. They measured and found that bank stability, defined as the lack of apparent bank erosion or deposition, improved through the recovery period on both streams. However, periodic grazing and flooding decreased stability more on Summer Camp Creek than flooding alone on Mahogany Creek. Their conclusion was that grazing exacerbated the natural variation due to flooding and stream bank erosion.

Grazed areas consistently have reduced canopy shading, stream depths and bankfull heights and greater stream widths than do ungrazed streams (Knapp and Matthews, 1996). The degree to which that geomorphological change is evident is dependent on grazing intensity. In at least one instance (Hayes, 1978), slough-off or bank caving due to cattle passage increased as forage removal exceeded 60%; below 60% removal, banks remained stable (Kauffman and Kreuger, 1984)

Large woody debris (LWD) is a very important element of stream ecosystems. It provides stable substrate, diverts the energy of the water, offers some carbon and energy resources, and structures local habitat (Davis and Perry, In Preparation).We did not find evidence that cattle grazing changed density or quality of LWD in Midwestern streams. In some cases (e.g., in Nevada) in-stream habitat quality was decreased under grazing conditions because LWD was removed from streams due to the increased flashiness of the hydrology; this was reversed when a riparian area was released from the pressures of grazing. In that latter case, tree cover increased as much as 35% (Meyers and Swanson, 1996). It is apparent that cattle grazing increases fine sediment deposition in stream reaches with high volumes of large woody debris (Sidle and Sharma, 1996).

Although nearly all of the grazing literature deals with streams, lakes and lakeshores are critical habitat in Minnesota. At least one study has examined the impacts of livestock grazing on lakes. They concluded that, although heavy grazing of lakeshores is clearly detrimental to marginal vegetation, low levels of grazing may be an appropriate management tool in areas of some lakes. In these latter situations, grazing will damage some local vegetation patches, but overall promote more diverse inshore habitats for plants and wildlife (Tanner, 1992).

From the literature reviewed in this section we can conclude the following:

- Cattle (and perhaps other livestock) increase streambank erosion, reducing habitat availability for both terrestrial and aquatic animals
- Large woody debris in and near the stream channel is a major component of habitat and its prevalence is usually decreased in grazed areas
- We have limited information suggesting that lakeshores and larger rivers are significantly less susceptible to impact than are streams.

IMPACTS OF LIVESTOCK MANAGEMENT ON MACROINVERTEBRATES

Macroinvertebrate animals, primarily insects represent critical elements of the aquatic ecosystem. They are a highly diverse community, they represent ecosystem biodiversity, they serve as fish food, they perform a wide range of ecosystem functions such as energy and nutrient cycling, and they are valuable indicators of ecosystem health (Perry and Vanderklein, 1996). In 1988, Rinne said "Studies on how grazing impacts aquatic invertebrates are nonexistent in the literature". Although that is not true today and indeed was not true in 1988, it does demonstrate that we really do not know enough about invertebrate responses to grazing.

Impacts on macroinvertebrate densities

We know that land clearing for pasture leads to hill slumping and siltation. That silt buries the lateral bars along the stream channels, rendering this habitat unsuitable for invertebrates. Some of the most important habitats and most important invertebrate communities are in the hyporheos, the interstices among the rocks below the stream bottom. That community is (or can be) negatively impacted by livestock. For example, Boulton at al. (1997) found that the vertical depths of the hyporheic zones along the thalweg at two pasture sites were significantly less than those at exotic pine and native forest sites. There was no evidence in their study to support the related hypothesis that the hyporheic zone of pasture sites contained more fine sediment. However, fewer individuals and taxa occupied the hyporheic zone of streams draining pasture than other sites, and with some important groups such as water mites were completely absent (Boulton et al., 1997).

Terrestrial invertebrates are an important food source for fishes, and they are dependent on the quality and structure of riparian vegetation. In New Zealand streams, the mean biomass and numbers of terrestrial invertebrates that entered tussock grassland and forest streams was more than three times the biomass that entered pasture streams. Mean abundance and richness of terrestrial invertebrates drifting in the stream (and therefore more readily available to the fishes) was not significantly different among land-use types (Edwards and Huryn, 1996)

In a study comparing stream reaches which were and were not subject to grazing, Wohl and Carline (1996) found significant negative impacts on benthic invertebrates. One and a half miles along Cedar Run and 2.5 mi along Slab Cabin Run were subject to grazing pressure; there was no riparian grazing along Spring Creek, the reference stream. Densities of benthic macroinvertebrates were significantly higher in Spring Creek (the reference condition) than in the other streams. Although there were marked differences in stream communities among streams with and without riparian grazing, the authors admit that other watershed attributes could have had some influence on these streams. There was inadequate experimental control to rule out extraneous influences.

Although we cannot demonstrate clear relationships between a variety of grazing densities or other livestock management activities and stream impacts, we agree with Rinne (1988) that macroinvertebrates may be more suitable than fish for detecting grazing impacts, primarily because they are more diverse and more easily sampled and analyzed.

There have been isolated reports of other problems with the integrity of the aquatic ecosystem under grazing conditions. For example, elevated concentrations of nutrients downstream of pastures caused increased growths of filamentous bacteria. This is a common situation in many nutrient enrichment conditions, such a below sewage outfalls. However, in at least one instance in a grazing study, those bacteria were reported to colonize the gills and body surface of aquatic insects. As a result, there were significantly lower densities of insects (up to 66% less) at downstream sites and those insects that were present were unhealthy (Lemly, 1998).

Impacts on macroinvertebrate species composition

The specific composition (i.e., numbers of species as well as specific species presence and absence) can serve as an indicator of some impacts. The hyporheos of some streams subject to grazing, for example contained fewer taxa (i.e., reduced "richness") and fewer individuals. The hyporheos was dominated by ostracods, nematodes and elmid larvae. The former two taxa are frequently found in the hyporheos but elmids are typically eppigean (i.e., cave-dwelling). Water mites, commonly found in the hyporheos of most streams were conspicuously absent from pasture sites (Boulton et al., 1997) indicating that conditions were outside their levels of tolerance.

Under conditions where grazing was excluded for a decade, aquatic macroinvertebrate populations were markedly different in density and biomass. Grazed sites had increased densities and biomass of tolerant forms and strikingly reduced overall densities and biomass of total invertebrates. There were also significant differences in "community composition", as seen by biotic condition and mean chi square indices. All metrics together indicated that the invertebrate community in the grazed areas was significantly impacted (Rinne, 1988).

The ways that aquatic invertebrates gather food and process energy is indicative of the role they play in the community. If we group all organisms which process energy in a similar way, we can develop Functional Feeding Groups (Perry and Vanderklein, 1996). Such grouping allows us to evaluate the degree to which the stream function has been impacted by some practice. We would expect to see that shredding and collecting were the predominant insects in most streams where the riparian zone is healthy and grazing impacts are minimal. Higler and Repko (1981) found just such a situation in the headwaters of a stream, and then detected a significant change in which shredders were significantly reduced and filterers were increased as they moved downstream in a Dutch watershed in which farmers were raising 50,000 calves and in which there was a high concentrations of manure. They further reported that most invertebrates were restricted to higher velocity reaches. These findings offer an avenue for further development of specific monitoring tools that could use Functional Feeding Groups to measure impacts in Minnesota streams.

The structure of the riparian vegetation plays a dominant influence on the health of the macroinvertebrate community; that vegetative structure is strongly influenced by grazing. As others have found however, that relationship is stream-size dependent. For example, in one analysis of small streams (catchment areas 1.2-3.8 mi^2, widths 3.2-13.1 ft), intensive grazing by cattle was shown to greatly reduce shading by riparian vegetation, resulting in substantial increases in daily maximum temperatures during summer. Marked changes in invertebrate communities were associated with those habitat modifications. In general, taxa favored by cool water and low periphyton abundance (e.g., Plecoptera, *Paraleptamphopus caeruleus, Deleatidium* sp., and *Helicopsyche albescens*) decreased in density, whereas densities of taxa favored by an abundance of periphyton (e.g., Chironomidae and *Oxyethira albiceps*) increased. In contrast, differences in physical habitat and invertebrate communities were minor between paired grazed and riparian-protected reaches of the larger streams (catchment areas 3.8-12.7 mi^2, median widths 19.7-52.5 ft) where grazing had little or no effect on stream shading. The authors conclude that their results indicate that in small streams, with median natural channel widths below about 19.7 ft, the effects on benthic invertebrates *decrease* in the following order: channelization > intensive grazing by cattle > extensive grazing by cattle and/or sheep (Quinn et al., 1992).

From the references reviewed in this section we can conclude that:

- Both terrestrial and aquatic invertebrate densities in streams are reduced when streams are subjected to grazing pressure; recovery of those communities after grazing pressure is removed requires several years to a decade or more
- Livestock impacts are stream-size dependent; invertebrate communities in small streams (e.g., 1st to 3rd order, <16 ft width) are much more susceptible than are those in larger systems
- Invertebrate communities are diverse, productive and relatively well understood; as such, they are more useful as livestock biomonitors than are fish communities.

EFFECTS OF LIVESTOCK ON FISH AND FISH COMMUNITIES

There is consensus among many authors that grazing degrades stream fish communities. Brown trout biomass was initially reported to be 31% greater in un-grazed areas in certain Montana streams (Gunderson, 1968). Brown trout biomass was later shown to be 3.4 times greater in same area (Marcuson, 1977). However, both analyses are subject to interpretation because the grazed sections had been cleared by the Corps of Engineers, making comparisons difficult (Platts, 1988). Storch (1979) reported that game fish were 77% of the total fish population in un-grazed streams and only 24% in grazed systems. However, the sites chosen for comparison were not clearly comparable (Platts, 1988). Starostka (1979) found that trout populations were “about the same” in grazed and un-grazed areas but offered no pre-grazing data as a comparison. Duff (1977) showed trout biomass in enclosures was 3.6 times greater than in an upstream grazed area; however, another area upstream of the grazing has beaver dams and 1.5 times the biomass of the un-grazed area. Keller et al. (1979) showed remarkable aquatic habitat changes after removal of grazing, but had no pretreatment data for comparison.

Wohl and Carline (1996) studied two stream reaches that were subject to grazing: Cedar Run had about 1.6 mi of grazed margin, Slab Cabin Run had 2.5 mi. They were able to use Spring Creek as an un-grazed reference site. They found that densities of wild brown trout were 5-23 times higher in Spring Creek (the reference condition) than in the two grazed streams, Cedar Run and Slab Cabin Run. They conclude that although there were marked differences among streams with and without riparian grazing, other watershed attributes could have had some influence on these streams. These findings are typical in that grazing and livestock impacts to fish communities are demonstrated and then the authors (or another reviewer) concludes that the experimental design really did not allow a definitive result. In fact, Platts (1988) concludes that there is a bias in the literature because of poor design, lack of reference and pre-impact data. He suggests that we clearly can see that past grazing has impacted streams, but impacts today are less clear.

In a study of cumulative effects of riparian disturbance by grazing on the trophic structure of high desert trout streams (Li et al., 1994), watersheds with greater riparian canopy had higher standing crops of rainbow trout *Oncorhynchus mykiss*, lower daily maximum temperatures (range, 61-73 degree F compared with 79-88 degree F), and perennial flow. Watershed aspect influenced the response of trophic structure to grazing influences. Standing crops of rainbow trout were negatively correlated with solar radiation and maximum temperature in watersheds flowing northward. A different relationship was observed for a set of watersheds with a southern aspect, perhaps due to the presence of spring seeps and stream desiccation in the heavily grazed stream. Trout biomass was negatively correlated with solar radiation, whereas positive relationships were found for discharge and depth. Algal biomass was positively correlated with solar insolation, total invertebrate biomass, and herbivorous invertebrate biomass in all watersheds. Invertebrate biomass was not significantly correlated with rainbow trout standing crop.

Those riparian impacts affect many aspects of stream fish communities. Stream sections subject to grazing had more spawning habitat and higher Golden trout densities than un-grazed sections (Knapp et al., 1998). That golden trout study population was limited by spawning habitat; spawning habitat availability influenced the production of age-0 trout as well as recruitment into the adult population. Cattle grazing widened the study streams, producing more habitat for the Golden trout. That response probably is related to niche separation, where the Golden trout uses more open areas than its competitors. The increased hydraulic forces from grazed landscapes provided an advantage to the Golden trout, and a disadvantage to other competitors. However, growth rate of the trout was not impacted as expected. Apparently, individual growth rates of Golden trout are negatively density dependent. Therefore, reductions in densities associated with grazing resulted in grazing-related decreases in trout growth rates (Knapp et al., 1998).

Cedar Run and Slab Cabin Run (described above) showed significant negative impacts on Brown trout (*Salmo trutta*). Compared to the un-grazed Spring Creek, substrate permeability of Brown trout spawning sites was lowered, suggesting reduced population viability (Wohl and Carline, 1996). In other areas, similar impacts to trout spawning have been reported (VanVelson, 1977; Keller et al., 1979)

Non-game fish are critical portions of the fish community and the stream ecosystem but we have little information about livestock impacts on them. On a Kentucky watershed with significant amounts of swine rearing, stoneroller minnows, bluntnose minnows and common shiners, all omnivores, increased in autumn in a downstream direction, fall suggesting nutrient enrichment from the livestock (Hoyt et al., 1994). Van Velson (1979) studied a stream a community eight years after cattle had been excluded. He found that “rough” fish were 88% of community before exclusion and 1% after 8 years exclusion. In contrast, Rainbow trout represented 1% of the total number of individuals before exclusion and 97% after.

Fish kills associated with livestock management

There has been a wide variety and an increasing number of fish kills associated with livestock management in Minnesota in the last several years. However, data about those incidents are sparse and uncoordinated.

One report (Harken et al., 1997) reported that there were more than 40 manure spills in 1996 in Minnesota, Iowa and Missouri; they estimated that those spills killed 670,000 fish. The Minnesota Pollution Control Agency reported on a 100,000 gallon manure spill which killed nearly 700,000 fish in Renville County (Minnesota PCA Press Release, 20 Feb 1998).

The Minnesota PCA (L. Ganske, personal communication, 21 June 1999) provided the following information regarding recent livestock-related fish kills. There were several spills each year that had fish-kill impact (Table 15). However, manure-related discharges are not the most common cause of fish kills (Table 16) and there is a significant difference in the information tabulated by various sources.

Table 15. Minnesota Fish Kills

Year	No.[1]	Location	Summary of impact
1994	1	Mud Creek, Rock County	Killed 200 minnows
1995	2	Medary Creek, Lincoln County	Killed 19,640 fish
		Drainage ditch, Lyon County	Killed 296 fish
		Total reported for year	19,936 fish
1996	6	Peter Lake, Hennepin County	No fish reported killed
		Minnesota River, Hennepin County	
		Marble Creek, Blue Earth County	
		Ditch, Goodhue County	
		Wetland, Meeker County	
		Beaver Creek, Renville County (truck accident)	
1997	9	East Fork of Beaver Creek, Renville County	Killed 650,000 fish
		Speltz Creek, Winona County 130 minnows	Killed 130 minnows
		Total reported for year	605,000 fish
		Incidents also occurred in:	
		Clear Lake, Sherburne County;	
		Minnesota River, Nicollet County	
		Cottonwood River, Lyon County	
		County ditch, Le Sueur County	
		Buffalo Creek, McLeod County	
		Spring Lake, Scott County	
		County ditch, Le Sueur County	
1998	10	Beaver Creek, Renville County	Killed 3,632 fish
		Dexter Creek, Mower County	Killed 254,879 fish
		Buffalo Creek, Sibley County	Killed 130 fish
		Waterloo Creek, Houston County (fish kill occurred in Iowa)	Unknown
		Total reported for year	258,641fish
		Incidents also occurred in:	
		South Fork of Crow River, Meeker County	
		North Branch Root River, Olmsted County	
		Co. ditch #59, Renville County	
		County ditch, Renville County	
		Blue Earth River, Blue Earth County	
		Beaver Creek, Renville County	

[1]Number of incidents where manure was released into surface waters

Table 16. Summary of fish kill incidents tabulated by cause during the three-year period 1996-1998 (summarized by the Associated Press and updated by Lee Ganske, Minnesota PCA):

Manure 6	Winter kill 6	*Columnaris* bacteria 14	Thermal shock 7	Low flow oxygen 3
Milk spill 2	Parasites 1	Silage leachate 1	Shampoo spill 1	Ammonia 1
Chlorine 1	Sugar beet wastes 1	Unknown 17		

Summary of fish kills and livestock impacts to fishes

- ■ A few large spills cause significant impact
- ■ It is widely believed that there are many spills that go un-reported
- ■ Minnesota does not have any coordinated system of tracking manure-related (or other) fish kill information
- ■ Livestock impacts to game fish have been intensively studied, primarily in the western United States
- ■ Most studies have concluded that grazing negatively impacted the fish population but based that conclusion on very weak or flawed experimental designs
- ■ In only very few cases are there data describing impact to the overall fish community and those data are inconclusive
- ■ Minnesota has not implemented a system for tracking fish kills (associated with livestock or other influences). At least two agencies have responsibility for responding to fish kills but fish kills are not regularly recorded and reported.

INFLUENCE OF LIVESTOCK ON BIRDS

Livestock has been widely reported to cause significant decreases in wildlife species and numbers (e.g., Ames, 1977; Townsend and Smith, 1977; Tubbs, 1980; Wiens and Dyer, 1975; Kauffman and Kreuger, 1984). However, in some cases other influences (e.g., either mammals or birds nest-predators) are more significant on hatching success than trampling by livestock or disturbance due to road use (Liker and Szekely, 1997). Therefore, as with fisheries and other aquatic resources, results are equivocal.

Lincoln's Sparrows (a small passerine which breeds in montane meadows) are potentially vulnerable to local extirpation because of their insular distribution, low population density, and fluctuating habitat conditions. Heavy damage from livestock grazing drastically increases the probabilty of local extirpation (Cicero, 1997). More than 20 years of relief from grazing had little influence on the habitat structure or bird species composition of a pinyon-juniper woodland. In general, habitat changes had been such that the bird community did not respond that quickly. Livestock grazing also indirectly affected the nesting success of some songbird species via the influence of grazing on cow bird abundance (Goguen and Matthews, 1998). Those nest parasites are a significant influence on songbirds in many habitats.

One possible link between livestock grazing and bird population declines in arid regions is variation in nest predation rates (Ammon and Stacey, 1997). In a study comparing a montane riparian community subdivided by a fence, one side of which traditionally has been summer-grazed, and the other side rested from grazing for 30 years Ammon and Stacey (1997) found that ground vegetation was more abundant, willows (Salix spp.) less abundant, and vertical vegetational diversity was lower on the grazed relative to the rested side. Predation rates on real nests were higher on the grazed side compared to the rested side. Predation on artificial nests in streamside willows that differed in abundance across the fence suffered greater predation rates on the grazed compared to the rested side. Livestock grazing may affect nesting for riparian birds by reducing streamside vegetation, increasing detectability of nests or through changes in predator assemblage.

Both the presence of waterbirds and their densities has been shown to increase in association with livestock in coastal areas. In many of these coastal (which may have some analogy to Minnesota lakeshoers), habitat has been reclaimed as pastureland. These open, exposed pasture landscapes offer valuable habitats to nonbreeding waterbirds. Colwell and Dodd (1995) suggest that grazing in coastal pastures can be used as an intentional management practice to provide a mosaic of vegetation heights. This resulting mosaic would yield greater waterbird diversity as well as higher densities of some species. In fact, Colwell and Dodd (1995) suggest that, although shorebird use did not correlate with use of pastures by cattle, grazing by livestock is probably the most effective means by which to achieve habitat characteristics attractive to shorebirds while maintaining compatible human uses on private lands. Several years earlier, Kaufman and Kreugher (1984) had concluded that when properly managed, grazed areas might even increase numbers of some bird species.

That pattern, as would be expected, appears to be true only for species which can take advantage of the more open landscape and its spatial distribution of food, predators and competitors. For example, the Redshank, a relatively rare British coastal bird does not excel under such conditions. Norris et al. (1998) conclude that their analysis of Redshank survey data, together with primary data they collected, suggest that heavy grazing is a significant threat to saltmarsh habitats and breeding Redshank, on a national scale.

On a more positive note, waterfowl probably respond positively to some levels of livestock use. Although spring grazing reduced nest densities of gadwall and blue-winged teal, nest density of gadwall increased after spring grazing was terminated. During the study, the amount of grass/ brush increased, whereas the amount of brush and brush/grass decreased on control and treatment fields (Kruse and Bowen, 1996). Although those authors measured habitat changes and nesting success, they did not comment on total or species specific waterfowl density nor on food availability. It is clear that habitat needs of a variety of species of wildlife that depend on grasslands need to be considered when deciding how to manage habitat (Kruse and Bowen, 1996). It also is clear that habitat alone does not make a population nor a community . The increased nutrient loads which enter the water from well managed grazing might not elicit a favorable response from the entire aquatic community, but might be expected to provide increased food resources for many waterfowl species.

Similarly, Paine et al (1996) suggest that for many grassland songbird species, pastures represent some of the best available breeding habitat in the Upper Midwest. There is increasing interest in intensive rotational grazing (IRG) among Midwestern livestock farmers, which may result in an expansion of pasture hectares in the region. Those authors tested 3 rotational grazing systems: a 1-day dairy rotation stocked at 24 head ac^{-1} a 4-day beef rotation at 6 head ac^{-1}, and a traditional, non-intensive 7-day rotation at 3 head ac^{-1}. Paddock size (0.5 ac) and nest density (15 nests $paddock^{-1}$ were held constant. Trampling damaged a mean of 75% ($\pm$ 3.1%) of the nests for all 3 treatments during 8 consecutive replications. While the 7-day treatment exhibited a pattern of greater nest trampling during cattle grazing periods than during rumination periods, this pattern was less evident in the 4-day treatment and absent in the 1-day treatment. Increasing vegetation height-density and percent vegetation cover were associated with reduced nest trampling fates, but pasture forage production and removal were not associated with nest damage (Paine et al., 1996).

Overall, several studies have shown that livestock has negative impacts on birds (c.f., Dambach and Good, 1940; Overmire, 1963; Owens and Myers, 1973; Reynolds and Trost, 1980; Smith, 1940; as well as the papers cited above). Many of these changes have been summarized by Fleischner (1994). However, in higher precipitation and higher productivity areas (perhaps like west-central Minnesota) grazing results in a more patchy landscape, increasing habitat diversity (Ryder, 1980). Many landscapes do recover from grazing abuses in a relatively short time. Duff (1979) found a 350% increase in songbird and raptor populations after an eight year release from grazing. Crouch (1982) found more ducks, more upland game birds, and twice as many terrestrial birds after seven year s release from grazing. However, grazed areas seem to offer had significantly more habitat for aquatic and shoreline birds (Cowell and Dodd, 1995). Mosconi and Hutto (1982) found significant increases in species composition and foraging guilds of birds in lightly grazed areas compared to heavily grazed. Kauffman (1982) and Kauffman et al. (1982) no significant impact on total avian density, but did find a differential use among species and guilds, in which grazed areas had more insectivores and un-grazed areas had more granivores. Thus, Kauffman and Kreuger (1984) conclude that grazing effects on birds are neither uniform nor clear.

The publications reviewed in this section indicate that:

- Livestock grazing often reduces canopy density and therefore habitat for riparian birds. That in turn reduces densities and diversity of some passerine species
- Some birds excel in the more fragmented riparian habitat that results from grazing and that same pattern is true for many species which rely on grassland habitats
- Shorebird populations (especially coastal species) appear to be positively impacted by low levels of grazing; it is not clear that the same responses would be shown in Minnesota waterbirds
- No evidence suggests that waterfowl are negatively impacted by livestock, although those waterfowl are dependent on aquatic invertebrates and may be secondarily impacted by changes in food availability.

IMPACTS OF LIVESTOCK ON WILDLIFE

Grazing can be a useful tool to enhance wildlife habitat (Holechek et al., 1982). However, grazing must be carefully managed to control the frequency, intensity and timing of livestock access to insure compatible use with wildlife. Improved livestock management will facilitate more streamside vegetation and increase the abundance and diversity of terrestrial habitat (Platts, 1991).

Livestock in arid regions often concentrate their grazing in riparian areas that may lead to degradation of native vegetation and effect wildlife populations. Hayward et al. (1997) found that small mammals at a desert wetland (cienaga) in southwestern New Mexico were 50% more abundant on 2 plots from which livestock were excluded over a 10-year period than on 2 similar grazed plots. Incorporating a few livestock exclosures of moderate size as an alternative management strategy could benefit a variety of species of wildlife in riparian areas (Hayward et al., 1997).

Mule deer home ranges, determined with radio collars, increased in area as cattle grazing level increased from ungrazed to heavily grazed in a montane forest and mountain meadow in the Sierra Nevada, California (Loft et al., 1993). Home ranges of cattle were larger with heavy grazing than with moderate grazing. Deer and cattle were attracted to the patchily distributed meadow-riparian and aspen habitats, but some deer exhibited temporal partitioning by avoiding such areas when cattle were present. In the absence of grazing, meadow-riparian habitat comprised a greater proportion of deer home ranges than during grazing, but during moderate and heavy grazing, a greater proportion of montane shrub habitat was included within deer home ranges, likely because cattle also preferred meadow-riparin and aspen habitat (Loft et al., 1991). Deer shifted habitat use by reducing their use of habitats preferred by cattle and increasing their use of habitats avoided by cattle. Deer also spent more time feeding and less time resting with increased cattle stocking rates (Kie et al., 1991). Deer increased their time spent feeding by shortening the length of resting bouts and including more feeding bouts each day, not by increasing the length of each foraging bout. Cattle were generally indifferent to the presence or absence of deer.

We did not find other evidence that livestock management significantly alters habitat or populations of large mammals. However, such a relationship seems self evident in many areas of the US where extensive lands have been deforested, fenced and converted to grazing. In those areas, habitat has changed, food resources have changed and predator-prey relationships have changed. Clearly, there are impacts of cattle on wolves in Minnesota and impacts of wolves on cattle. The extent and significance of that interaction and the wisdom of selected management alternatives is a very active area of debate and policy discussion. We have chosen to exclude those issues from this review because they are discussed elsewhere in a diverse and complex scientific and decision sciences literature.

With regard to small mammals and other wildlife, livestock impacts are seemingly species specific and perhaps site specific. When properly managed, grazed areas might increase numbers of some mammal species (Kauffman and Kreugher, 1984). For example, Rosenstock (1996) reported that un-grazed patch and macrohabitat sites had more surface litter, greater perennial grass cover, and taller perennial grass plants, but treatment response varied among sites. Small mammal responses were apparent only at the macrohabitat scale, where un-grazed sites had 50% greater species richness and 80% higher abundance. Small mammal reproductive activity and biomass were not affected by rest from grazing at either scale. Duff (1979) did find a very large (350%) increase in small mammal populations after eight years of rest from grazing. That seemingly contradictory pattern is seen in greater depth in the summaries provided by Fleischner (1994).

These references on wildlife impacts show that:

- Overall, it is apparent that the literature is somewhat diverse and appears contradictory
- there are a variety of responses and some species clearly are provided an advantage under livestock-impacted conditions
- the specific nature of the site and the surrounding landscape will strongly influence wildlife responses
- there is a dearth of controlled, replicated experiments upon which to base these conclusions.

ENDOCRINE DISRUPTION AND OTHER PHYSIOLOGICAL IMPACTS ON FISH AND WILDLIFE

There are increasing reports of hormone disruption and anomalous development in many species. That has been attributed to anthropogenic as well as certain naturally occurring substances. Increased susceptibility to disease pathogens is frequently reported. In some cases, that is seen as anomalous development of sexual behavior or function. This process and its effects in mammals was extensively reviewed by Elliott (1998). Many scientists are suggesting that endocrine disruption from exposure to a wide range of chemicals is the generic cause of these anomalies (Davis and Foushee, 1996). At least two papers have reported estrogens in runoff on lands that were intensively grazed (Shore et al., 1995; Nichols et al., 1997). However, attributing impacts to “endocrine disruption” or the presence of a hormone is more symptomatic than causal. We have made very little progress to date in understanding specific cause-effect relationships between landscape management practices and responses in the endocrine system of various animals.

The problem has received very high level attention. For example, recently the Executive Office of the President (Executive Office, 1998) summarized the problem and issued a call for research. That paper reported that the largest endocrine disruption research efforts are in human health, which is clearly dominant over ecological and exposure research. However, endocrine disruption ecological research and studies in immunotoxicity are very limited. It is clear that on-going research addresses only a few species and a limited number of compounds. There is a dearth of either observational or experimental field data; most studies are laboratory mammals although there are several fish studies which rely on field observations (see below).

These compounds are important because they are capable of altering hormone pathways that regulate reproductive processes. In general, the ecological implications of that disruption has not been recognized. One limitation in improving that recognition has been development of techniques to predict and more accurately assess the ecological relevance of exposure to endocrine-disrupting compounds (Arcand-Hoy and Benson, 1998). A workshop was held recently among 30 international scientists from a wide variety of disciplines to assess the status of those methods. That group reached consensus that mammalian test methods generally are suitable for assessing a variety of potential effects in mammalian wildlife. However, it was not clear from their discussions that those tools would serve adequately for other classes of vertebrate wildlife. There are tests useful for bird and fish species but they are not suitable for routine screening. The group concluded that too little is known at present about the biological role of estrogens and androgens in reproduction and development of invertebrate species to recommend any specific assays (Ankley et al., 1998).

In the few cases where cause and effect have been demonstrated (e.g., alligators, Bald Eagles; Arcand-Hoy and Benson, 1998; Crain, 1998) anthropogenic chemicals such as PCBs and common herbicides have been shown to be the cause. Some authors have hypothesized that similar permanent, organizational changes occur in a variety of wild reptiles exposed to endocrine-disrupting contaminants (Crain and Guillette, 1998). In Lakes Apopka and Okeechobee, for example, alligators exposed to atrazine had significant sexual dysfunction (Crane, 1998).

Those impacts have been duplicated experimentally in common carp (*Cyprinus carpio*). Gimeno et al. (1998) exposed carp for 3-months to sublethal concentrations of two compounds (4-tert-pentylphenol, TPP and 17 beta -estradiol, E2). After exposure, the testes showed progressive disappearance of spermatozoa and spermatogenic cysts, and a higher incidence of pathological alterations with time at all TPP and E2 concentrations (e.g. fibrosis, vacuolation and atrophy of the germinal epithelium). Those fish exposed to the highest E2 concentration did not produce any milt. Goodbred et al. (1996) conducted a field study seeking the same kinds of occurrences. They examined a series of biomarkers in common carp. They did not find a significant regional difference in steroid hormones detected for males, but females from the Northern and Southern Midcontinent (including the Upper Midwest) were significantly different from other regions of the country in one or both hormones. Contaminants that had significant (a=0.05) correlations with biomarkers were organochlorine pesticides, phenols and dissolved pesticides. There was evidence that fish in some streams are be experiencing endocrine disruption. Because their data were highly variable, they conclude that future studies should shift to more intensive study of fewer sites, including reference and contaminated sites (Goodbred et al., 1996).

Matthiessen and Gibbs (1998) studied Tributyltin (TBT), a common industrial chemical. They suggest that there is “abundant and undisputed field data” that link TBT to a variety of effects in snails. The principal phenomenon observed is disruption of the sexual development of the animals. This may result in reduced breeding success and (in its final implication) population disappearance. They conclude that TBT-induced masculinization in gastropods, imposex and intersex, is the clearest example of endocrine disruption described in invertebrates to date that is unequivocally linked to a specific environmental pollutant.

The specific causes of such endocrine disruption are not clear. Laboratory bioassays are successful in identifying certain mechanisms abut often conclude that there are multiple mechanisms involved (e.g., in trout, as studied by Tremblay and Van Der Kraak, 1998). That multiple cause @ conclusion is to be expected because we put a large variety of compounds into the environment, where they interact with each other. Results are always complex. For example, Montagnani et al. (1996) presented results of a study on the overall oestrogenic potential of sewage effluent being discharged into a river. They found high levels of oestrogenic potential in the effluent and also in stream water upstream from any sewage-treatment works so it was difficult to attribute any change to the effluent itself. We know that many insecticides, herbicides and fungicides exhibit weak endocrine activity, based on various laboratory assays (Sumpter and Sohoni, 1998).

These issues are of concern in a Livestock GEIS because a) these impacts are often attributable to agricultural if not livestock practices and b) we know so very little about cause and effect. Hampson et al. (1995) commented that many endocrine disruptions have been shown to be due to agricultural chemicals, and then they documented the relative contribution of a variety of chemical inputs to provide context. For example, they state that approximately 1% of all applied pesticides enter surface water. In Ontario, approximately 13 tons of pesticides of concern could enter surface water and eventually reach the Great Lakes. This is higher than the estimated 8.5 tons of cadmium, mercury, and PAHs coming from municipal and industrial point sources in Ontario. Matthiessen (1998) concludes that the real and potential effects of those chemicals on fish and molluscs is so significant that action is appropriate. He states that, while more research is required to make firm predictions of the population-level consequences of endocrine disruption, and to develop effective hazard identification tests for these substances, it would be prudent to begin making voluntary regulatory controls where possible in view of their undoubted potential for environmental damage.

From these references we can conclude that:

- Endocrine disruption is a poorly understood science today
- We have no evidence that livestock management causes endocrine disruption in any fish or wildlife species
- The changes caused by livestock are consistent with those known to cause endocrine disruption
- Clearly, any regulation that attempts to regulate the suite of "potential endocrine disrupting chemicals will be of interest and concern to the people and agencies concerned with decision making based on a livestock GEIS.

CONCLUSIONS

- Vegetation responses to livestock management are highly site specific, primarily because ecosystems are highly variable in space and time (Larsen et al., 1998).
- Livestock damage in small to medium sized, relatively stable streams leads to widening of the channel but not necessarily to significant decreases in overall fish habitat (Williams et al., 1992).
- Several authors have concluded that a significant amount of caution is needed in making even coarse inferences from one area to another (Williamson et al., 1992) and that management practices must be stream-specific (Meyers and Swanson, 1991).
- Several studies have shown negative impacts of livestock on birds (Dambach and Good, 1940; Overmire, 1963; Owens and Myers, 1973; Reynolds and Trost, 1980; Smith, 1940). However those effects are not uniform among locations or times (Kauffman and Kreuger, 1984).
- Small mammal responses are usually apparent only at relatively site specific scales (Rosenstock, 1996).

■ It is clear that we have limited information upon which to judge the applicability of those literature results to local conditions or to generalize or predict real and potential impacts of livestock management in the Upper Midwest.

STUDY TOPIC 4: HUMAN HEALTH RISKS FROM WATER POLLUTED BY ANIMAL AGRICULTURE

The question of what potential human health effects may result from animal agriculture, via water, is difficult to answer because it involves a complex set of factors. There are basically two types of risks in drinking water which are related to animal agriculture: excessive nitrate levels and pathogens. Much of our knowledge about these two has been gained over the past fifty years, especially during the past two decades. However, as more information has become available, more questions have been raised, many of which are difficult to study or assess.

Nitrate is a common contaminant found in many wells in Minnesota. It has been known since the mid-1940s that too much nitrate in drinking water can cause serious health problems for infants. Some researchers have even suggested that nitrate may also play a role in the development of some cancers. However, several studies involving nitrate and cancer over the past two decades have ended with ambiguous results. Therefore, we must conclude at this time that, to the best of our knowledge, there is no clear evidence that nitrate ingestion results in an increased cancer risk. Obviously, more work needs to be done to provide a definitive answer to whether there is any relationship of nitrate to cancer.

A pathogen is an organism which causes disease in a susceptible host. Knowledge about potential human pathogens has grown at an exponential rate. In addition, the explosion of new technological breakthroughs has allowed chemical and biological constituents to be detected at several orders of magnitude lower concentration in water (albeit with variable levels of precision, depending on the parameter being sought) than was possible only a few years ago.

The relevant fields of science bearing upon this question have broadened in the last two decades, as it has become obvious that numerous areas of expertise must be successfully integrated into a cohesive understanding. Such fields of study range from the laboratory-based sciences, including microbiology, animal health and veterinary medicine, chemistry, and (human) medical pathology; human health risk management; field-based sciences of geology, soils, hydrogeology, climatology, ecology, and animal and crop husbandry; and waste treatment and waste disposal technology.

Another important complexity in answering this question lies in the rapid rates of change in some of the pathogens: drug-resistance has induced significant selective changes in the pathogen populations. At the same time, new strains, types, and groups of pathogens are being identified on a regular basis.

One of the most important factors may be the changes within the human population itself. It has been estimated that by the year 2010 (barely a decade from now) approximately 20% of the human population will be classified as particularly “vulnerable” to health effects of pathogens and chemical pollutants. “Vulnerable” segments of the population will include infants and the elderly, and all those people whose immune systems are compromised. The latter group includes persons undergoing cancer therapy; organ transplant patients (who must remain on anti-rejection medications); as well as those who have the human immunodeficiency virus (HIV), which causes AIDS (acquired immunodeficiency syndrome). This is a serious and sobering prediction. It means that one in every five persons will be particularly vulnerable; that at least one person in most families will have a particular vulnerability to potential health hazards.

Everyone needs clean drinking water to survive. This projection on vulnerable populations requires that old assumptions about clean water cannot be summarily overlooked. Consideration of public health demands that “acceptable” levels of water quality can no longer be defined by a negligible risk to a healthy adult. This and other assumptions will need to be re-evaluated. The new standard will need to consider risk levels in vulnerable populations. This new standard will be part of the challenge in answering the question of what human health effects may be caused by animal agriculture, via water.

PATHOGENS IN ANIMAL MANURE

The utilization of animal manure on agricultural land used for raising crops and grazing animals is a low-cost means of manure disposal and soil amendment. However, animal manure may contain a variety of microorganisms which may be pathogenic to humans and/or animals. The major types of pathogens include: bacteria, viruses, parasite eggs, protozoa, and fungi. Indeed, pathogenic bacteria and viruses have been isolated from feedlot wastes (Hrubant, 1973; Derbyshire et al. 1966). The application of manure on pastures and/or fodder crops may, therefore, result in: groundwater contamination, internal and/or external contamination of crops, translocation of pathogens to grazing animals, surface water contamination via run-off, and generation of contaminated aerosols (Table 17).

Table 17: Potential pathways of pathogen transmission

1.	Contamination of surface drinking water supplies.
2.	Contamination of ground water supplies.
3.	Direct contact with contaminated environment e.g., recreational use of water.
4.	Transmission by inhalation of contaminated aerosols.
5.	Contact with contaminated surfaces.
6.	Transmission via contaminated vegetables to homes and hospitals.
7.	Transmission from contaminated environments via insects.
8.	Concentration of pathogens by shellfish.
Risk to animals:	
1.	Transmission to farm animals having contact with contaminated surface waters.
2.	Transmission to farm animals having contact with contaminated grazing land.
3.	Transmission by direct inhalation of contaminated aerosols.
4.	Transmission from polluted surface waters via wild birds.
5.	Transmission from contaminated environments via insects.

Contamination of surface water may pose a problem when these resources are used as a source of recreational or drinking water. The potential of disease transmission to humans and animals from land application of animal manure will depend upon: (a) the microbiological quality of manure, which in turn depends upon the type of treatment it has received; (b) the survival of pathogens for a sufficient period of time and in sufficient numbers; and (c) the significance of this route of transmission as compared to other potential infection routes (Table 18).

Table 18: Factors affecting transmission and pathogenicity

1.	Minimum infective $dose_{50}$.
2.	Number of pathogens present in manure.
3.	Frequency and seasonality of pathogen occurrence in manure.
4.	The effect of manure treatment, if any, on number of pathogens present.
5.	Survival of pathogens in the environment.
6.	Removal of pathogens by soil following land application of manure.
7.	Significance of this route v/s others in pathogen transmission.
8.	Host susceptibility.

During the past 30 years, there have been major changes in livestock production practices including intensification, which has generated large quantities of manure by individual feedlot enterprises. Under conditions of confinement housing in which little or no bedding is used, composting is not workable, and the manure has to be handled in semi-solid or liquid form. Sometimes this is spread on land as a daily operation but, more frequently, liquid manure is stored in underground or above ground tanks for days to months before it is spread on land. The material may then be transported and spread by spray; from tankers or by pumping through an irrigation system. It has been estimated that the farm livestock in the U.S. produce at least 10 times the amount of biological wastes produced by the human population (Heald and Loehr 1971). For example, 1000 pigs excrete 2-3 tons of feces/day which if mixed with urine and litter, amount to 6 tons of manure/day (Wray et al.,1975).

Pathogens that may be present in animal manure

Animal manure may contain bacteria, viruses, and protozoa which may cause disease in humans and/or animals. Table 19 shows some of the pathogens that may be present in manure. It should be recognized that this list of pathogens is not static; new pathogens are constantly being recognized and the significance of the old ones changes because of advances in analytical techniques and changes in animal agriculture. Microorganisms are also subject to change because of mutation and adaptation. Diseases that are common to humans and animals are called zoonoses. Zoonotic agents are described as the ones that are naturally transmitted between humans and vertebrate animals. Table 19 shows the relative risks of bacterial diseases that can be transmitted between humans and animal via water.

Table 19. Pathogens that may be present in animal manure

Pathogen Name	Disease Name	Symptoms in Humans
Salmonella sp.	Salmonellosis	Fever and gastrointestional disorders
Escherichia coli		Nausea, dehydration, and bloddy diarrhea, particularly in infants. Particularly severe form, sometimes fatal
Leptospira interrogans	Leptospirosis (Weil's disease)	Fever, headache, chills, rash, hemorrhagic infections of the kidney, liver, and nervous systems; rarely fatal
Listeria monocytogens	Listeriosis	Fever, muscle aches, nausea, diarrhea, convulsions, stillbirth
Campylobacter jejuni	Campylobacteriosis	Diarrhea, nausea, abdominal pain, fever
Histoplasma capsulatum	Histoplasmosis	Fever, respitory symptoms, chest pain, dry cough. Chronic pulmonary disease can be fatal
Cryptosporidium parvum	Cryptosporidiosis	Watery dirrhea, stomach cramps. Sometimes fatal
Giardia lamblia	Giardiosis	Diarrhea, abdominal cramps, ausea
Viruses such as adenovirus, enteroviruses, reoviruses, and rotaviruses	Viral infections	Fever, hepatitis, paralysis, headache, neusea, rash, maningititis, epidemic vomitting, eye infections, or respiratory infections depending on the virus involved

(a) Bacteria: Bacteria that are pathogenic to humans and/or animals may also be present in animal manure and may survive for some period of time in the environment. Treatment and/or storage of manure will result in degradation of bacteria. Thus, the microbiological quality of manure depends upon the amount of time it has been stored and if it has received any treatment. The pathogenic bacteria may enter a new host by ingestion or inhalation. The major symptom caused by most of these bacteria is diarrhea but they may also cause generalized or localized infections (Table 20). Salmonella is an enteric bacterium that is of concern to both humans and animals. Enterotoxigenic, enteroinvasive, and enteropathogenic strains of E. coli can also be pathogenic and have been found in the water environment. Even the non-pathogenic serotypes of E. coli may be of concern because of their ability to drug resistance to other enterobacteria. As a recently recognized cause of diarrhea, Campylobacter is now believed to be of major concern throughout the world. It now seems that Campylobacter is the single most common bacterial cause of diarrhea in several countries. Infection with Campylobacter jejuni may result in asymptomatic infection, mild symptoms or severe disease. Wastes from dairies and abattoirs that handle tuberculous animals, will almost certainly contain M. tuberculosis. Farm animals grazing on contaminated pastures may become infected.

Table 20. Relative risks of bacterial transmission between humans and animals via water.

Bacteria	Disease	Level of risk
Clostridium tetani	Tetanus	Low Risk
Brucella melitensis	Brucellosis	Low Risk
Bacillus antracis	Anthrax	Low Risk
Erysipelas rhusiopathiae	Erysipelosis	Low Risk
Leptospira spp.	Leptospirosis	Medium Risk
Yersinia enterocolitica	Yersiniosis	High Risk
Salmonella spp.	Salmonellosis	High Risk
Mycobacterium tuberculosis	Tuberculosis	High Risk
Atypical mycobacteria	Mycobacterial infections	High Risk
Escherichia coli	Colibacillosis	High Risk
Campylobacter jejuni	Campylobacteriosis	High Risk
Listeria monocytogenes	Listeriosis	High Risk

(b) Drug resistant bacteria: The use of antibiotics in animal agriculture is considered to be a potential threat to human health because of the generation of drug resistant bacteria. The antibiotics do not in themselves cause resistance among bacterial populations, rather they select resistant clones which are already present in the flora. The presence of drug resistance in bacterial pathogens is of concern but drug resistant non-pathogenic bacteria are also important because they can transfer their resistance to pathogenic bacteria by conjugation. The incidence of antibiotic resistance among E. coli isolates from man and animals can vary with the population surveyed. Thus, their prevalence is greater in intensively reared calves, pigs and poultry but less in grazing cattle and sheep because the latter have little or no exposure to antibiotics. Also, the incidence of drug-resistant coliforms is higher in children than in adults, and is higher among adults from rural areas (who have contact with animals) than among adults living in towns (Linton et al., 1972). The handling of animal carcasses can also result in the establishment of drug-resistant E. coli of animal origin in humans (Hinton, 1986).

The drug resistant strains of E. coli readily colonize the intestinal tracts of young animals and may persist in the fecal flora of humans and pigs even without antibiotic selection pressure (Hinton, 1986). E. coli isolates from calves tend to be more resistant to antibiotics than those from adult cows (Hinton, 1986). It has been suggested that the multiply resistant E. coli strains which colonize calves during the first week of life, are probably derived from the farm environment and are selected by the use of antibiotics in calves which had been reared on the premises during previous years. The overall level of drug persistance in E. coli remained unchanged during seven weeks of slurry storage and E. coli was found to survive for at least 15 months in a slurry tank (Hinton and Linton, 1982). Tetracycline resistance is relatively common in E. coli isolates from pigs. E. coli isolates from chickens are usually resistant to streptomycin, sulphonamides, and tetracycline. In one study, the medical, rather than the veterinary, use of tetracyclines was found to be responsible for the relatively high incidence of tetracycline resistant E. coli isolates from man (Richmond and Linton, 1980).

(c) Viruses: More than 110 different types of human enteric viruses can be excreted in human feces and may be found in raw municipal sewage. Although the number of viruses in sewage is reduced upon sewage treatment, they are not completely eliminated. The viruses get further diluted when treated sewage is discharged in surface waters. Although they can not multiply in the environment, they can survive for much longer periods than bacteria. The use of treated sewage as soil amendment can also result in surface water pollution because of run-off. It is important, therefore, to detect the presence of viruses in water and soil to determine the safety of their usage. However, it is difficult to detect the presence of these viruses in surface waters by conventional methods unless a large quantity of water is first concentrated in to a small volume that can be conveniently assayed for viruses. We have developed techniques for the concentration and detection of human enteric viruses from large volumes of water, wastewater, soil and sludges (Gerba and Goyal, 1982). Similar techniques for the concentration and detection of animal enteric viruses do not exist and hence there are no data on the virological quality of raw animal manure, treated manure, water, soil, fodder, etc.

Human enteric viruses have been found to gain access to groundwaters during land application of wastewater. Climatic conditions, soil type and possibly management practices of soil flooding appear to be some of the factors controlling virus migration through soil. Previous studies have indicated that adsorption of viruses to the soil matrix plays a major role in virus retention as sewage-laden waters percolate through the soil (Gerba et al., 1975). Thus, factors influencing adsorption phenomena will determine not only the efficiency of virus removal during percolation of wastewater through soil but their long-term behavior. Among the factors known to influence virus adsorption to surfaces are pH, salt concentration, the nature of the adsorbent, type of virus, and time and flow rate (Gerba et al., 1975). It is also known that elution of viruses from surfaces is possible under appropriate environmental conditions (Gerba et al., 1975)

Previous studies indicate that certain management practices may be useful in controlling the migration of viruses into groundwater during the land application of wastewater (Lance et al., 1976). Utilizing 98-in columns of sandy loam soil, these authors found that migration of viruses after a rainfall could be minimized if the soil was re-flooded with sewage shortly after the rain. Few studies exist on the survival of enteric viruses in soils

(Bagdasar'yan, 1964; Lefler and Kott, 1974; Hoadley and Goyal, 1976). These studies were largely concerned with virus survival near the soil surface and were limited in scope in that they involved the study of only a few viruses and soil types. These studies need to be expanded to include several animal and bacterial viruses under a variety of environmental conditions which would more closely approximate those found in the subsurface environment.

(d) Protozoa: Giardia and Cryptosporidia are considered to be the two most important waterborne protozoa. A large outbreak of waterborne outbreak of Cryptosporidia occurred in Milwaukee, Misconsin in 1993. More than 400,000 people were affected in that outbreak. These protozoa are significant because they can not be inactivated by the commonly used disinfection procedure. To remove these pathogens, one has to resort to water filtration.

Risk to humans from water pollution by animals

Some incidents of human disease attributable to contact with livestock waste have been reported. Stanley et al. (1998) isolated Campylobacter jejuni from groundwater in the Arnside area of Cambria. Some of the strains isolated were of the same biotype as the ones from a dairy farm situated within the hydrological catchment of the polluted spring indicating that the groundwater was a vehicle for bacterial transmission. In a study of a farmworker community in Zimbabwe, Campylobacter spp. were common in chicken faeces but not in houseflies or household stored drinking water (Simango and Rukure, 1991) indicating that chickens were the main potential source of Campylobacter in the homes of farmworkers.

In a longitudinal study of four dairy farms, it was suggested that E. coli O157:H7 was disseminated from a common source on these farms and that this strain could persist in the herd for up to 2 years (Shere et al., 1998). In a Russian study, Gordeiko and Pushkareva (1990) detected Yersinia in 25.4% of water samples taken from wells situated in the zone of irrigation with sewage water from a swine-breeding complex. Conversely, no Yersinia was isolated from wells that were remote from the irrigation zone. They also established an epidemiological relationship between a case of Yersinia infection and the use of infected well water.

Prokopcakova and Pospisil (1984) conducted serological surveys for leptospirosis in rodents, cattle and humans in the vicinity of two large water reservoirs in Eastern Slovakia. Sera from 243 rodents, 168 cattle, and 876 humans were examined; 8.2%, 7.7%, and 3.2%, respectively were positive. The presence of antibodies to the same Leptospira serovar in humans, cattle and rodents indicated the existence of close contact among humans and animals with the possibility of acquiring water-borne infection in recreation zones. An epidemic of hemorrhagic fever caused by Leptospira was reported in rural Nicaragua following heavy flooding. A case-control study revealed that the illness was associated with walking in creeks, having household rodents, or owning dogs with titers of $\geq$1:400 to Leptospira. Leptospira spp. were isolated from case-patients and from potential animal reservoirs. Most likely, this epidemic resulted from exposure to flood waters contaminated with urine from infected animals, particularly dogs.

Five boys from a small town in rural Illinois developed leptospirosis after swimming in a small pond. Leptospira interrogans serovar grippotyphosa was isolated from urine of 2 cases and from pond water. A high seroprevalence for L. grippotyphosa was also found in animals near the pond indirectly suggesting the transmission of the organism from area animals to humans.

Rhodococcus coprophilus and associated actinomycetes were isolated consistently from feces of farm animals, poultry reared in proximity to farm animals and wastewater polluted with animal fecal wastes but not from samples of human feces. The fecal coliform to fecal streptococci ratio could not distinguish between human and animal fecal samples but R. coprophilus to Actinomyces ratio could (Mara and Oragui, 1981). Introduction of organic farming practices on a farm in south-west England was responsible for the introduction of environmental mycobacteria on that farm. The change in the profile of environmental mycobacteria has important implications for the immunological priming of humans and animals (Donoghue et al., 1997).

A marked peak in human cases of cryptosporidiosis was noticed in the Sheffield area in 1986. Epidemiological investigations suggested a waterborne outbreak of cryptosporidiosis, the possible source of which was cattle on a farm adjacent to the reservoir complex (Rush et al., 1990). In another study, 249 surface water samples were tested for parasites in 2 adjacent British Columbia, Canada, watersheds: the Black Mountain Irrigation District (BMID) and the Vernon Irrigation District (VID) both of which serve rural agricultural communities active in cattle ranching. Giardia cysts were not detected in the raw water samples collected from lake sources at the headwaters of both watersheds but were found in 100% and 97% of water samples at BMID and VID intakes, respectively. Significantly higher levels ($P < 0.05$) of Giardia cysts were found at the BMID intake than at the VID intake probably because cattle have access to creeks in the BMID watershed, whereas access is restricted in the VID watershed. Peak concentrations of both parasites coincided with calving activity. Fecal samples from cattle were positive in both watersheds: 10% in the BMID and 50% in the VID watersheds. No fecal sample was positive for Cryptosporidium. Thus, the differences in patterns of parasite contamination and cattle management practices may contribute to the unique watershed characteristics although they may be topographically similar and geographically adjacent (Ong et al., 1996).

Bates et al (1994) isolated vancomycin-resistant Enterococcus faecium (VRE) from raw sewage, farm animals and uncooked chickens. Two ribotyping patterns were found among isolates from animals and sewage and those from clinical sources. A blood and a urine isolate from separate hospital patients and porcine isolates shared the same ribotyping pattern and a stool isolate from a patient in the community and sewage isolates shared another pattern. This led them to suggest that animals might serve as a reservoir of VRE. We would like to suggest that humans may also serve as the source of organisms for animals.

Derbyshire and Brown (1978) isolated 10 porcine enteroviruses, 2 porcine adenoviruses and 1 coronavirus from 32 samples of pig slurry. Concentration of the same samples by adsorption with polyelectrolyte yielded more viruses. No virus was isolated from 12 samples of slurry from dairy cows nor from 6 slurry samples from a calf-rearing unit. A porcine enterovirus was isolated from soil samples, collected 1, 2 and 8 days after pig slurry was spread on hay stubble. Two porcine enteroviruses were isolated from surface run-off from land on which pig slurry was routinely spread. However, none of the 36 samples of ground water were positive.

Even during the slaughtering process, Aeromonas has been found to spread from the intestinal contents of chicken carcasses to processing water to chicken carcasses (Akan et al., 1998). Eighty samples of wastewater from four slaugherhouses were examined. The slaughtering of pigs contributed more to contamination of wastewater with Salmonella than did the slaughtering of cattle. The cleaning and scraping of the gut also increased the bacterial load of wastewaters (de Zutter and van Hoof, 1980).

STUDIES SHOWING NEGLIGIBLE EFFECT OF ANIMAL MANURE ON HUMAN HEALTH:

During routine examination of bathing areas near North Sea in Germany, Salmonella contamination was detected for the first time in 1988. To define the source of contamination, strains isolated from seawater and rivers were studied by molecular marker methods. The plasmid profile and antibiotic resistance patterns excluded the surrounding cattle industry as a source (Graeber et al., 1995). The presence of Salmonella in North Sea coastal water did not correlate with the presence of fecal indicator bacteria (Tobias and Heinemeyer, 1994). Also, Salmonella from agricultural sources proved to be irrelevant in this study.

Jones et al. (1980) examined 882 samples of settled sewage, sewage sludges and final effluents from eight sewage treatment plants. Of these samples, 68% were positive for Salmonella. Isolation frequencies from settled sewage, raw sludge, and anaerobically digested sludge were 85%, 87%, and 96%, respectively. Fewer isolations were made from final effluent (24%) and processed sludges (58%). Samples usually contained less than 200 salmonellae/100 mL. They argued that such low concentrations should not lead to disease in animals if suitable grazing restrictions are followed.

Smeltzer *et al.* (1979) spread cattle manure on experimental plots at the rate of 54 tons/ac/yr. The manure was applied to 2 plots at 6-monthly intervals while a further 2 plots received monthly applications. Samples of manure soil, run-off and groundwaters were examined for bacteria. Comparison of the bacterial counts from samples from the test plots to those of the control plots showed that no change occurred in the levels of coliforms or faecal coliforms over the 3 years of manure application. One hundred and fifty-seven isolations of Salmonella were made from the soil and water samples, but only 51 could be attributed to manure. No difference was observed in the effects of different application frequencies.

Escherichia coli serotype O157:H7 has become a major foodborne pathogen for the young and the elderly. The association of non-bovine products with outbreaks suggests that other vehicles of transmission may exist for this pathogen (Feng, 1995). Remote, supposedly pristine water samples have been found to be contaminated with Giardia cysts in the Yukon (Roach et al., 1993).

RISK TO FOOD ANIMALS FROM THE USE OF MUNICIPAL SLUDGE IN AGRICULTURE

It is a common practice to "blame" animal agriculture if a zoonotic agent is found to be the cause of an outbreak. It should be noted, however, that human sewage/sludge can and have served as a source of pathogens to animals. High levels of Salmonellae can be found in sludge and they can survive for weeks in sludge, grassland, and stored grass (Hess and Breer, 1975; Hess *et al.*, 1974). A study of 26,646 cattle in Switzerland between 1969 and 1978 revealed an increased isolation rate from cattle at times of year at which sludge was applied. Studies of carrier rates and serotypes in cattle grazing on sludge-treated pastures also indicated a positive association between the two and a cycle of infection (man-sludge-animal-man) emerged. Based on these studies, the Swiss authorities now treat sludge by pasteurization and anaerobic digestion before applying it on land (Breer et al., 1983).

In the Netherlands, several investigations have revealed that animal meat is the most important source of Salmonella infection in man and that a relatively high number of clinically health food animals, including poultry, are carriers (Edel et al., 1973, 1977, 1978). These studies have also demonstrated the existence of complex cycles of transmission which involve feedstuff, meat, patients, healthy carriers, sewage effluent, surface water, insects, birds, rodents, and food animals (Edel et al., 1973).

Several well-documented cases exist in which salmonellosis in cattle was caused by contamination of pasture with crude sewage or septic tank wastes (Anon, 1977). The risk to grazing animals from the spread of sludge on pastures will depend upon: the density of human population, the incidence of human salmonellosis, the extent of sewage and sludge treatment, agricultural practices, stocking density of animals, and weather. The presence of pathogens in sewage sludge will contribute to overall environmental contamination. However, this is not the only source of bacteria. It is important, therefore, to assess the contribution of bacteria to the environment from other sources as well as it is important to ascertain the background levels of bacteria before sludge application. Sludge spreading may increase the carrier rate in cattle and pigs which may pose a threat to humans through the contamination of meat, milk, dairy products, and working surfaces in kitchen.

Taylor and Burrows (1971) reported infection in calves that grazed on pastures to which a slurry containing 10^6 Salmonella dublin/mL had been applied a day previously. In a later study, 10^5 S. dublin/ml failed to infect calves when allowed to graze 7 days after spreading slurry (Taylor, 1973). Ayanwale et al. (1980) found that goats raised on corn silage grown on sludge-amended land did not become infected with Salmonella even though Salmonella was present in sludge.

Dorn et al. (1985) conducted a 3-year prospective epidemiologic study on 47 farms in Ohio receiving annual applications of 0.9-4.5 dry tons of treated sludge per acre. A total of 164 persons (78 families) participated. As a control, 46 farms were studied that did not use sludge. From these control farms, 130 persons (53 families) participated. No significant difference was found in disease occurrence in man or domestic animals on sludge farm or control farm. This was attributed to the use of low sludge application rates that were in accordance with Ohio and the U.S. Environmental Protection Agency guidelines. These authors cautioned against using these data to predict health risks associated with sludges containing higher levels of pathogens and with higher sludge application rates and large acreages treated per farm than used in this study.

SURVIVAL OF PATHOGENS IN THE ENVIRONMENT:

The microorganisms in animal manure are inactivated after exposure to the environment but they may survive for long enough period to be of public health and/or human health concern (Table 21). The native microflora in water and soil may sometimes inhibit pathogens. For example, when enterococcal isolates from dung water of 25 cattle farms in northeastern Slovakia were screened for bacteriocin production, Enterococcus faecalis V24 strain was found to produce a heat stable, largely hydrophobic bacteriocin with a strong inhibitory effect against Gram-negative bacteria (Laukova et al., 1998a, 1998b). The average total count of enterococci was $5x10^3$ CFU/mL. Enterococcus faecium was the predominant species (25%) followed by Ent. casseliflavus (19.2%), Ent. faecalis (9.6%), Ent. avium (1.9%), and Ent. durans (1.9%).

Table 21: Survival times of excreted pathogens in soil at 68-86^{o}F

Pathogen	Survival Time (days)
Viruses	
Enteroviruses[a]	<100 but usually <20
Bacteria	
Fecal coliforms	<70 but usually <20
Salmonella spp.	<70 but usually <20
Vibrio cholerae	<20 but usually <10
Protozoa	
Entamoeba histolytica cysts	<20 but usually <10
Helminths	
Ascaris lumbricoides eggs	Many months

[a] Includes polio-, echo-, and coxsackieviruses.

Storage of animal slurry will reduce the number of pathogens present over time. Swine manure, for example, is stored in a pit at one end of the building, or in an outdoor lagoon, or in an underground tank. After 3 weeks of storage, Listeria monocytogenes could be detected in only one of the initially nine positive faeces samples. Two months after inoculation of stored liquid pig manure, stored liquid cattle manure and soil with L. monocytogenes, this bacterium could not be traced in any of these materials. Radishes (Raphanus sativus) and carrots (Daucus carota), sown in soil inoculated with L. monocytogenes, were gathered after 3 months and examined for the presence of L. monocytogenes. Three of six radish samples were found to be positive. Remarkably, however, all carrot samples (six) were free of L. monocytogenes (Van Renterghem et al., 1991).

In Germany, Salmonella was detected in 50% and 36% of samples of biowaste and fresh compost, respectively. The seepage water from these sources was found out to be a reservoir of Salmonella; Salmonella enteritidis survived in seepage water for 42 days at 5^0C (Knop et al., 1996). In lake water, Campylobacter jejuni survived longer than C. coli both at 4^0C and 20^0C (Korhonen et al., 1991). Both species survived better in filtered than in untreated water suggesting that predation and competition for nutrients may affect the survival of bacteria in the aquatic environment. Salmonella were found in the environment of a dairy two years after the occurrence of a clinical outbreak of salmonellosis. Samples of recycled flush water were positive for Salmonella indicating that hardy organisms can become established in the environment of modern free-stall dairies that use recycled water in their manure flush systems (Gay and Hunsaker, 1993). Similar results were noted in another study in which Escherichia coli K-12 survived for at least 28 days in sterile water but declined from $3x10^6$ to <10 cells per mL in 147 hrs in non-sterile water (Bogosian et al., 1992).

Olsen (1995) determined the survival of Serpulina hyodysenteriae in a lagoon that received effluent from a confinement building housing swine dysentery-infected swine. The organism could be isolated from lagoon water 5-6 days after the removal of shedder swine from the building indicating that the facility should remain idle for more than 5 to 6 days before repopulating with unexposed swine. In a study to identify possible environmental sources of infection on Etosha National Park, Namibia, Lindeque and Turnbull (1994) detected Bacillus anthracis in water and soil samples collected from sites not associated with known cases of anthrax. However, higher rates were found in water from waterholes in the western part of the Park at the time of an outbreak in elephants. They also found that the viability of bacilli in soil and water was limited. Porcine reproductive and respiratory virus (PRRSV) was shown to survive for 9-11 days in city and well water indicating that contaminated water may serve as source of this virus for other animals (Pirtle and Beran, 1996).

TREATMENT OF SLURRY TO REDUCE PATHOGEN LEVELS

Attachment to particles influences not only sedimentation of (oo)cysts in surface water but also their behavior in drinking water treatment processes. Thus, the sedimentation velocity of Cryptosporidium parvum oocysts and Giardia lamblia cysts attached to secondary effluent particles increased with particle size whereas the sedimentation velocities of freely suspended (oo)cysts was too low to cause significant sedimentation in surface water or reservoirs (Medema et al., 1998).

INDICATOR BACTERIA AS SURROGATES FOR PATHOGENS

Coliform bacteria have been used for more than 80 years as water quality indicators. Fecal coliforms have been particularly useful in indicating fecal pollution of water sources. In one study, the source of Campylobacter jejuni in groundwater was traced to a dairy farm. However, the organism was not isolated in the absence of fecal indicator bacteria (Stanley et al., 1998). Unfortunately, these indicators are not infallible. Thus, de Souza et al. (1992) tested water samples from 113 drinking water places located on 60 different farms in Botucatu County, S. Paulo, Brazil and found 15% to be positive for Salmonella.

Interestingly, no relationship was found between fecal coliforms and Salmonella. The presence of Salmonella in North Sea coastal water did not correlate with the presence of fecal indicator bacteria (Tobias and Heinemeyer, 1994).

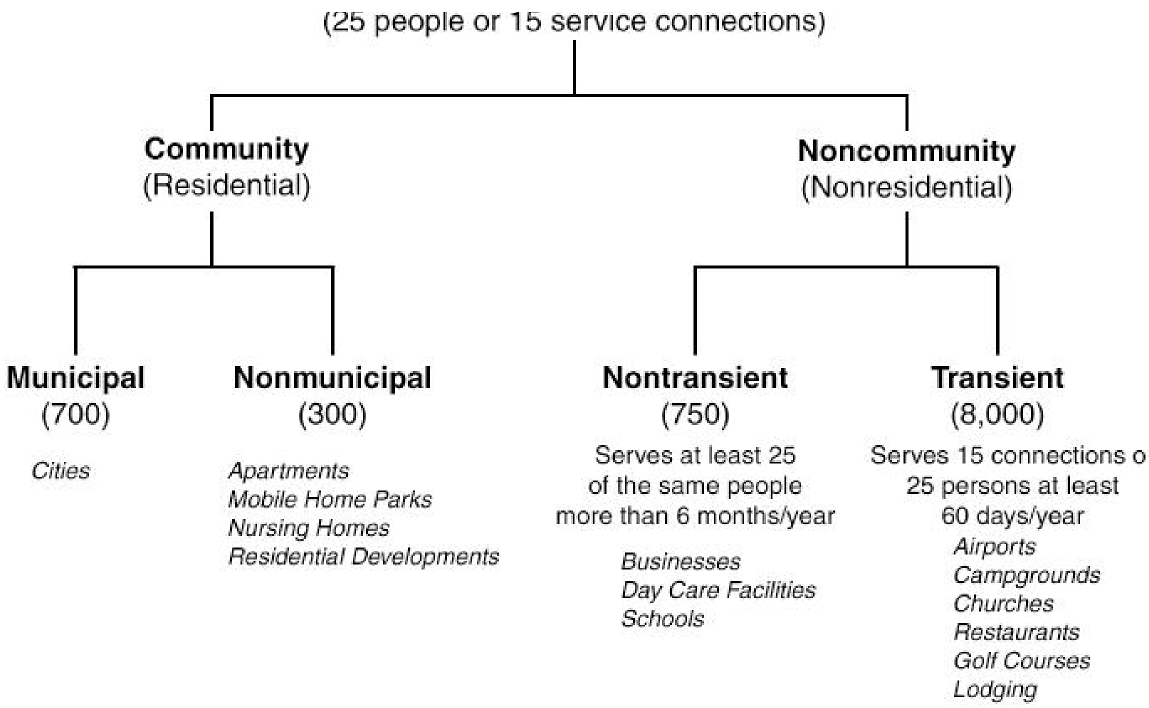
Many studies have shown that indicator bacteria are not good at predicting the virological quality of water because of their absence in water from which viruses were subsequently isolated. Lucena et al. (1994) advocated the use of Bacteroides fragilis phage to indicate the virological quality of water. They determined the concentrations of fecal bacteria, somatic and F-specific coliphages, and phages infecting B. fragilis in naturally occurring black mussels (Mytilus edulis) obtained from four sampling sites with different levels of fecal pollution. They concluded that, under the environmental conditions studied, the fate of B. fragilis phages in marine environment resembled that of human viruses more than any other microorganism examined. It is often important to determine the source of water pollution e.g., if it as human fecal pollution or animal pollution. The ratio of fecal coliform to fecal streptococci has been used to differentiate between human and animal pollution. Discriminant analysis of antibiotic resistance pattern in fecal streptococci has also been used to differentiate between human and animal sources of fecal pollution in natural waters. A total of 1,435 isolates of fecal streptococci from cattle, poultry, human, and wild-animal wastes were examined for their ability to grow in the presence of four concentrations of five antibiotics (chlortetracycline, halofuginone, oxytetracycline, salinomycin, and streptomycin). Discriminant analysis of antibiotic resistance pattern correctly classified human versus animal isolates at an average rate of 95% (Wiggins, 1996).

Male-specific bacteriophage (MSB) have been advocated as indicators of fecal pollution. To compare the relative impact of animal and human fecal wastes on the densities of MSB, Calci et al. (1998) examined 1,031 fecal samples from animals and humans in addition to 64 sewerage samples. All animal species were found to harbor MSB, although the great majority excreted these viruses at very low levels. They concluded that in areas affected by both human and animal wastes, wastewater treatment plants were the principal contributors of MSB to fresh, estuarine, and marine waters.

AUTHORITY FOR DRINKING WATER PROTECTION IN MINNESOTA:

The Environmental Health Division of the Minnesota Department of Health (MDH) is responsible for protecting Minnesotans from potential health hazards in the drinking water, restaurants, lodging facilities, homes, places of work, and the broader natural environment (Fig. 1). The hazards are not limited to pathogens; radiation, and physical and chemical contamination are also of importance.

Fig. 1: Types of public water supply systems



The following discussion addresses various programs for protecting drinking water quality:

The Drinking Water Protection Program is designed to enforce the federal Safe Drinking Water Act (SDWA) for public water supply (PWS) systems across Minnesota (Fig. 1). The areas of oversight include:

- to evaluate water quality sampling and analysis standards required by the SDWA and to ensure that performance of PWS systems in Minnesota meet or exceed the SDWA standards (Table 22).
- routine and regular testing of drinking water by PWS sanitarians in close cooperation with PWS system operators (Fig. 2).
- certification and training of PWS operators.
- administration of the federal Drinking Water Revolving Fund (DWRF) which provides loans to PWS systems for upgrades to meet water quality criteria.
- regular sanitary surveys of the PWS systems, including wells and distribution systems.
- plan review of all PWS system modifications and upgrades, including watermains.
- protection from contamination of public drinking water sources (including groundwater wells and surface water) through the Source Water Protection program, to help public water suppliers properly manage the area which recharges water to their drinking water sources.
- A Nitrate Work Group was formed to develop a nitrate contamination mapping program and to (i) identify areas with nitrate contamination in the state; (ii) identify hydrogeologic and well construction factors that control nitrate distribution in

groundwater; (iii) determine if nitrate contamination problems are increasing, decreasing, or remaining the same across the state; and (iv) develop guidelines to prevent further non-point source contamination.

- The Health Risk Assessment Program evaluates many types of potential health hazards. With regard to drinking water, this program:
- evaluates health risks from chemicals that have been, or potentially could be, detected in drinking water sources of either surface water or groundwater origin in Minnesota.
- evaluates National Primary Drinking Water Standard for each chemical and if these standards provide adequate protection for drinking water conditions in Minnesota.
- establishes Health Risk Limits in Minnesota drinking water (Table 22).

Fig. 2: Number of Community PWS Systems that Exceed Safe Drinking Water Standards

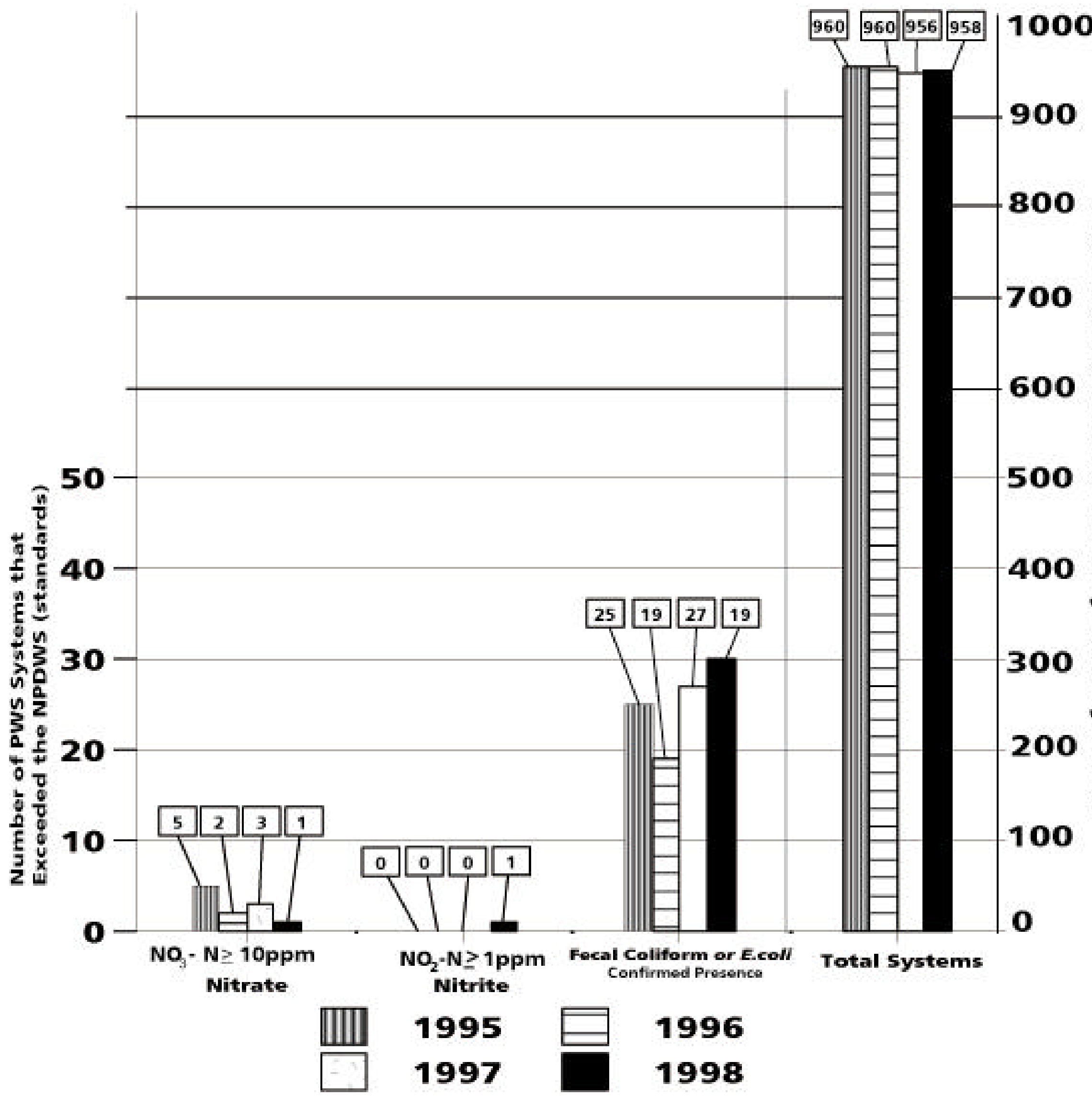


Table 22: Standards for Nitrate, Nitrite (as Nitrogen) and Bacterial Contaminants

				MDH Health Risk Limits
Contaminant	MCLG *	MCL **	BAT #	HRL
Nitrate (as NO_3-N)	10 mg/L	10 mg/L	a, b	10 mg/L (or ppm)
Nitrite (as NO_2-N)	1 mg/L	1 mg/L	a, b	(none established)
Total Nitrate + Nitrite (as N)	10 mg/L	10 mg/L	a, b	(none established)
Total Coliform	absence	presence+	c	(none established)
Fecal Coliform or E. coli	absence	presence	c	(none established)

* MCLG: Maximum Contaminant Level Goal: This is broadly considered to be an ideal limit, but is not an enforceable goal, if it is lower than the MCL.

** MCL: Maximum Contaminant Level: This is a specific enforceable standard. Where the MCL is equal to the MCLG, it supercedes the goal and becomes an enforceable limit.

BAT: Best Available Technology: These water treatment processes are considered to be capable of removing the contaminant to meet the NPDWS limits, as follows:

a = ion exchange a treatment method by which the contaminant is chemically removed from the potable water supply.

b = reverse osmosis a treatment method by which the contaminant is removed from the potable water supply by a chemical pressure gradient.

c = disinfection and/or protection of wells from contamination by appropriate placement and construction of the wells.

+presence:All PWS systems test for coliform bacteria. They need only determine the presence (positive) or absence (negative) of total coliforms (rather than a total count). If a PWS sample has a positive result for total coliforms, it must be confirmed by repeat sampling. A determination must be made if the water is positive for fecal coliforms or E. coli. If the samples are positive for total coliforms, fecal coliforms, or E. coli, then the PWS system must notify the State, and issue a public notice for its consumers (as provided by the Code of Federal Regulations, title 40, chapter I, part 141, subpart C, section 141.21). The MDH PWS program requires a boil advisory be published, as part of the public notice.

The Site Assessment and Consultation (SAC) Program investigates environmental hazards at identified sites. In regard to drinking water, this program:

- investigates the source of the hazard e.g., landfills, spills, and illegal or improperly designed disposal sites in cooperation with any other state agency with oversight authority and with the Minnesota Pollution Control Agency.

- ■ identifies the areal extent of the hazard in surface water and/or groundwater and how the hazard is spreading downstream or to other parts of the aquifer.
- ■ identifies drinking water sources (wells or surface water intakes) that could be impacted by the hazard.
- ■ identifies whether any contaminants associated with the hazard may need evaluation by the Health Risk Assessment Program e.g., any chemical which does not currently have a National Primary Drinking Water Standard or Health Risk Limit.

The Policy, Program, and Analysis (PPA) Program evaluates proposals for development in Minnesota, which meet certain established thresholds for state-level review. In regard to drinking water, this program:

- ■ reviews many types of projects, to ensure that drinking water sources are adequately protected, and that all requirements of the state Public Water Supply program, the state plumbing code, and the state code for wells and borings are being met.

- ■ the following lists most of the programs under which project reviews are conducted:

-Federal Environmental Assessments;
-Environmental Assessment Worksheets;
-Environmental Impact Statements;
-Alternative Urban Areawide Reviews);
-Department of Trade and Economic Development projects;
-Housing and Urban Development projects;
-other special reviews

- ■ the following types of projects are included in the above review program categories:

-new, enlargement, or improvement of existing, federally-regulated facilities, such as airports, corrections facilities, pipelines, electrical transmission lines, etc.;
-new residential and/or suburban development;
-housing rehabilitation, including low- and moderate-income rehabilitation;
-sewer and water improvements, and extensions of services to new areas of development;
-new, or repair of existing, flood-control facilities including dikes, levees, stormwater conveyances, etc.;
-new construction, and structure rehabilitation, within the 100-year floodplain: -agricultural feedlots:
-new, or improvement of existing, transportation corridors (e.g., roads).

WATER QUALITY STANDARDS IN MINNESOTA

Public Water Supply (PWS) water quality standards are initially established by the Environmental Protection Agency (EPA) on the basis of the existing scientific literature concerning treatment technologies and occurrence of each particular contaminant. These standards are called the National Primary Drinking Water Standards (NPDWS) and are legally enforceable at public water supplies.

The MDH has additionally reviewed the scientific literature, and has performed health risk analyses for numerous contaminants, while also considering the particular environment and expected uses of that contaminant in Minnesota. The MDH Health Risk Limits (HRL) are usually as stringent, or more stringent, than the EPA NPDWS; but they are advisory in nature and are not legally enforceable. However, there are many chemicals which have had a health risk analysis done by the MDH for which there is no limit established by the EPA, and vice versa in a few cases (Table 22).

NITRATES

Nitrates are natural compounds composed of one nitrogen and three oxygen atoms. Nitrate is very soluble in water. Nitrate can be derived from various biological and chemical processes, and various biochemical reactions can affect the concentration of nitrate. Nitrogen inputs into the soil include natural nitrogen fixation by plants, plant decay, decay of human and animal manure, fertilizer addition to the soil, and certain industrial or waste disposal inputs. In some circumstances, nitrate will undergo denitrification to become nitrogen gas. When nitrogen gas is near the land surface, it will escape into the atmosphere. Under other conditions, the nitrogen will undergo nitrification and dissolve in downward-percolating rainwater to form nitrate. Nitrate is easily transported through the soil, and can leach downward through soil and bedrock aquifer(s) to the water table. When the nitrate gets to the water table, it can move easily through the aquifer with water. Under some aquifer conditions, it can remain as nitrate for a substantially long time; under other conditions, it can denitrify to form nitrogen gas. With so many complex and competing reactions possible, if humans prevent excessive nitrogen inputs at the land surface, nitrate concentrations in groundwater can improve (i.e., diminish) with time.

Water samples can be easily and cheaply tested for nitrate. Nitrate results are reported as some value equivalent to the nitrogen content only, and is read as nitrate-nitrogen (abbreviated NO_3-N). The units are in milligrams per liter (mg/L) or as parts per million (ppm), depending on how the laboratory procedure is done. (These units are, for most purposes, equivalent).

Nitrate represents a health risk to infants under the age of six months, because it can cause an acute and potentially fatal condition called methemoglobinemia. (This is the so-called blue baby syndrome because the oxygen in an infants system is removed from the blood in a biochemical reaction involving the nitrate; thus they appear to be suffocating.) The National Primary Drinking Water Standard (NPDWS) or drinking water limit for nitrate-nitrogen, set by the United State Environmental Protection Agency (EPA), is 10 mg/L (10 ppm). Infants, and pregnant and nursing mothers, are advised to not drink water from any source with nitrate-nitrogen levels exceeding this standard.

SURFACE WATER TREATMENT RULE:

Surface waters (streams, rivers, lakes, wetlands, overland runoff, etc.) have been shown, through repeated testing, to carry contaminants from the land surface. Such contaminants, including organic and inorganic chemicals as well as microbiological pathogens, can come from both, natural and human influences on the environment. Some of those contaminants can cause a risk to the health of anyone drinking from a surface water source. However, some PWS systems must rely on surface water source(s), due to the lack of groundwater availability, or the cost of obtaining groundwater. There are 23 PWS municipal systems in Minnesota which rely directly upon surface water supplies (Table 23).

Table 23. Minnesota municipal surface water supplies

Community	Population Served	Source	Community	Popula-tion Served	Source
Aurora	2,225	St. James Mine Pit	International Falls	8,686	Rainy River
Beaver Bay	150	Lake Superior	Mankato	31,477	Minnesota River + Blue Earth River
Biwabik	1,428	Canton Pit	McKinley	230	Corsica Pit
Chisholm	5,170	Fraser-Humphrey Pit	Minneapolis	480,526	Mississippi River
Duluth	85,511	Lake Superior	Moorhead	30,200	Red River
E. Grand Forks	8,000	Red Lake River	St. Cloud	58,253	Mississippi River
Ely	3,982	Burntside Lake	St. Paul	395,988	Vadnais Lakes + Mississippi River
Eveleth	5,000	St. Mary's Lake	Silver Bay	1,950	Lake Superior
Fairmont	11,506	Budd Lake	Thief River Falls	8,285	Red Lake River
Fergus Falls	12,600	Wright Lake (Otter Tail River)	Two Harbors	3,651	Lake Superior
Grand Marais	1,217	Lake Superior	Virginia	11,495	Missabe Mountain Mine Pit
Hoyt Lakes	2,348	Colby Lake	—	—	—

The Surface Water Treatment Rule (SWTR) is an EPA Rule which requires water treatment in lieu of water testing because it regulates contaminants which are difficult to detect, yet pose acute health risks. Outbreaks of waterborne diseases, such as giardiasis, have been linked to untreated drinking water from surface water sources. Recent research has determined that microbial diseases which were previously poorly understood, such as cryptosporidiosis, may endanger public water supplies which are inadequately treated. For example, the Cryptosporidium outbreak in Milwaukee may have made as many as 400,000 people ill in 1993. Numerous human diseases can be transmitted by both wild and farm animals. In addition, many pathogens can remain viable for a considerable time after leaving the host animal (Von Huben, 1991). Table 24 lists EPA standards for pathogens and associated water quality for PWS systems which have surface water sources, or where the groundwater may be directly influenced by a surface water source (U.S. EPA, 1995).

Table 24. EPA Standards for surface water treatment

Contaminant	MCLG
Giardia lamblia	0
Viruses	0
Legionella	0
Turbidity *	non-turbid
HPC **	none

■ Turbidity is the amount of particles in water which do not readily settle out of water, including such items as clays, fine silts, and some colloidal materials. A non-turbid water sample has visual clarity. It is measured using laboratory or field equipment which passes a light through the sample, and determines the level of light which is deflected (or refracted) by particles. The result is given as, "Nephelometric Turbidity Units,"or NTU. Studies have demonstrated that suspended particles reduce the effectiveness of disinfection.

In addition, many pathogens frequently attach or adsorb to particles in water; and, in doing so, they have been shown to be able to "hide" from the disinfectant. Therefore, the turbidity of the water is important to reduce and control by treatment methods. The residual turbidity after treatment is a significant parameter in evaluating the effectiveness of the treatment method.

**HPC means the heterotrophic plate count bacteria. These are bacteria that can be identified using a laboratory technique called the plate count method. Many of these bacteria would not normally be a danger to persons in good health, but can cause severe sickness, or even death, to vulnerable populations (Von Huben, 1991).

An explosion of research in the last several years has brought to light numerous other potential health risks from newly discovered strains of bacteria, new viruses only recently identified, and protozoal parasites. With increasing use of antibiotics in raising animals, especially broad-spectrum antibiotics as well as those routinely used in humans, it may be predicted that more-resistant strains of these pathogens, as well as new mutants, will emerge. In fact, it is likely they will emerge at rates that outpace the ability of scientists to identify, classify, and determine effective treatments against them.

The Surface Water Treatment Rule became law on December 31, 1990. It requires water treatment for PWS systems using surface water, or using a groundwater source which is considered to be under the direct influence (UDI-GW) of surface water. Examples of some groundwater sources which fall into this category are shallow wells, springs, wells in creviced or cavernous formations, infiltration galleries, and wells near a body of surface water. These are water sources that are considered to be in danger of surface water contamination (Von Huben, 1991). Each state was required to identify which PWS systems are considered UDI-GW systems within 5 years of the effective date of the law. The MDH PWS program determined that there are no UDI-GW municipal community systems in Minnesota.

The Surface Water Treatment Rule requires disinfection of all surface water systems and the UDI-GW systems. The rule also requires filtration by each of these PWS systems, unless a system can meet certain additional, stringent water quality criteria. This is a performance-based rule and the standards set by this rule are given in Table 25 (U.S. EPA, 1995). However, systems with poor source water quality may be required to meet higher reduction goals in order to ensure adequate protection (Von Huben, 1991). The MDH requires that all PWS surface water systems must disinfect as well as filter their water.

Table 25. EPA Performance Standards for Surface Water treatment

Criterion	Standard
Turbidity	< 5 NTU at all times < 0.5 NTU in 95% of all samples
Disinfection	99.9% effective
Giardia	99.99% effective
Viruses	0.2 mg/l at entry
Residual	

Rather than attempting to directly measure Giardia cysts or viruses, this rule requires systems to demonstrate that they routinely meet the above criteria, on the basis of what combination of treatment methods are used (such as, sedimentation and/or filtration, and disinfection), and how well the treatment plant is operated. In addition, the SWTR requires protection of source water.

The sedimentation process allows suspended solids to settle out of raw water, which also removes a large number of microorganisms. A coagulant, such as alum, an iron salt, or a polymer is often used for quicker and more efficient sedimentation. When raw water is filtered through a bed of granular material (usually sand and/or anthracite), a large percentage of microorganisms is removed along with suspended matter and particles.

Disinfection involves the addition of a specified chemical to water which has already passed through a sedimentation and/or filtration process. If a sufficient quantity of the disinfectant remains in contact with the water for a specified time, microorganisms will be killed or inactivated. Chlorine is the most common disinfectant used for drinking water in the U.S., but ozone, chlorine dioxide, and chloramines are also frequently used. The computation used to ensure that disinfection is adequate is known as "CT," which multiplies the concentration (C) of the disinfectant by the time (T) in contact with the water. This computation is used to derive the removal/inactivation performance for Giardia and viruses.

SOURCE WATER PROTECTION PROGRAM IN MINNESOTA:

Public water systems using surface water, must strive to protect their sources from contamination (Von Huben, 1991). The Source Water Protection (SWP) program at MDH has been established to help public water suppliers establish and implement protection plans for their water sources. Community PWS systems and non-transient non-community PWS systems (Fig. 1) are required to develop such plans and hence the following discussion is confined to those systems only. There are approximately 1750 PWS systems which will be developing their plans over the next seven years.

The MDH SWP program developed the Minnesota Wellhead Protection Rule, based on the requirements established by the EPA. The PWS systems were rank-ordered, based on vulnerability of their water source and population served. The higher the rank, the sooner each system will be phased into the planning process. Each PWS system will need to identify where their water sources are recharged; that is, the area over which precipitation accumulates and then travels to the water intake, over a period of 10 years. For a well, the recharge area will be delineated as the land over which water moves into the soil, and then to the well through an aquifer. An assessment of aquifer vulnerability to contamination is conducted to determine the scope of the plan for managing potential contamination sources. For surface waters, the recharge area includes those areas within the watershed which are higher (upgradient) than the water intake.

The next part of the process is developing a plan for source water protection. A commitment of local people served by the PWS (the community, or the owners of the non-transient non-community system) is necessary to develop the plan. This local planning group must understand what potential there may be for contamination, and how to address that potential. This requires developing some additional information about the recharge area, including: what land uses now exist within the recharge area; which uses, if any, have a potential to contaminate the water; and how to evaluate the costs and benefits of different land uses and compare them with the costs of treatment, in the event of contamination. The local planning group must also decide what types of land uses they consider appropriate, and which land uses they feel may need to be addressed by management strategies. The final part of the process is the implementation of the plan and the enforcement of any ordinances. The entire planning process is facilitated by planners from the MDH SWP program, who will also provide educational references as needed; however, all decisions will be locally made and enforced.

SOURCE WATER PROTECTION PROGRAM FOR MAJOR CITIES:

The cities of Minneapolis, St. Paul, and St. Cloud have joined together in a Clean Water Partnership project, called the Upper Mississippi River Source Water Protection Initiative. As part of this project, MDH will be working with these cities to prepare plans for protecting their surface water intakes. The cities have been testing for Cryptosporidium and feel that their treatment plants will handle any pathogen that may be present in their intake water. However, they want to take a proactive approach to identifying all potential contamination sources which may impact their water supply. It will be about two years before the source water plans for the cities of Minneapolis and St. Paul are drafted.

STUDY TOPIC 5: TO WHAT EXTENT ARE SURFACE WATERS AFFECTED BY OR AT RISK FROM ALLOWING PASTURED ANIMALS ACCESS TO SURFACE WATERS?

Grazing by livestock has been reported to have numerous interrelated effects on the landscape which directly or indirectly affects water quality. There is a continuum of effects, most reported degradation of water quality is related to overgrazing. A general conclusion is that unmanaged grazing leads to overuse and degradation, primarily in riparian areas (Fitch and Adams, 1998). Grazing has a myriad of effects on the landscape. Heavy grazing can reduce vegetative cover, compacts the soil, reduces infiltration, increases runoff, erosion and nutrient and sediment yield. In riparian zones, trampling the streambanks decreases erosional resistance of the streambank and contributes to sediment yield (Trimble and Mendel, 1995), vegetation removal increases solar insolation and leads to higher stream water temperature (Li et al., 1994). Excrement input either in the uplands or into water bodies can lead to elevated levels of pathogens. Fish and aquatic invertebrates are sensitive to sediment input, water temperature and excess algae and plant growth due to nutrient input (Waters, 1995).

In contrast, low or moderate grazing have effects that are much less significant than heavy or unmanaged grazing (Trimble and Mendel, 1995). However, relatively few comprehensive studies have been done at the watershed level about the environmental impact of pastures. Correll (1996) concluded that low intensity grazing of pastures that are not fertilized does not usually cause significant nutrient or sediment impacts on surface waters, unless livestock have unconstrained access to water and/or the riparian buffers. Due to efficient nutrient recycling, these low intensity systems are similar in impact to native vegetation and very much better than annual row crop systems. On the other hand, pastures that receive heavy applications of fertilizer or stored manure often harm receiving waters, and their impacts can exceed those of annual row crop systems. Correll (1996) concluded that rotational grazing reduces impacts, whereas winter grazing increases impacts.

Most studies in our literature search have reported on effects in the arid,western United States (see reviews by Kauffman and Krueger, 1984; Platts, 1991; Fleischner, 1994; Trimble and Mendel, 1995; Fitch and Adams, 1998; Larsen, 1998; Strand and Merritt, 1999 and bibliography by Van Deventer, 1992). Larsen et al. (1998) suggest that caution should be used when interpreting most past literature, because many studies were not experimental with replicated treatments and statistically valid results, rather they are before and after treatments with no baseline data. Very little literature has been conducted and published for grazing practices in the Midwest.

SEDIMENT

Sedimentation is recognized as the most prevalent and damaging pollution in streams in North America (Waters, 1995). In streams surveyed in 1996, the most common agricultural pollutant was silt, which was a contributing factor for 50 % of streams considered impaired (USEPA, 1996). Sediment associated with livestock grazing occurs during snowmelt or heavy rainfall, when removal of vegetation and compaction combine to facilitate overland flow (Gardner, 1950; Bryant et al., 1972; Owens et al., 1983; Orodho et al., 1990). In addition to snow melt during winter or spring, rainfall intensities of 1.0 to 1.4 inches/hour can be expected on average every two years across Minnesota (Huff and Angel, 1992). This means that significant runoff is likely to occur at any given site on an average of every other year, because few soil conditions allow infiltration of this precipitation rate. As with other loss pathways, runoff amounts will vary with soil, weather, plant, and animal factors. For example, in the Netherlands, runoff occurs even on gently sloping soils in winter, because precipitation exceeds the infiltration capacity of heavy-textured soils (Steenvoorden et al., 1986). The fate of many pollutants in water bodies is determined by the sorption, storage, and transport by sediment (Fairchild et al., 1987; Taylor et al., 1994). Sedimentation from livestock grazing can be heavy enough to blanket stream beds with silt, but more commonly, leads to a gradual decrease in the depth of pools (Quinn et al., 1992; Sidle and Sharma, 1996).

Many invertebrates in streams require relatively silt-free habitats. These organisms live in the interstitial spaces between rocks in the bottom of streams (Minshall, 1984). Excess amounts of sediment deposited in the stream bottom, can fill spaces between rocks (interstitial spaces), thereby reducing suitable habitat. Invertebrates that require interstitial spaces tend to decline along with their habitat, and are usually replaced by burrowing taxa which prefer silt habitats (Lenat et al., 1979; Lenat et al., 1981; Lemly, 1982). Taxa that dwell in interstitial spaces are generally the most important prey items for fish that feed on invertebrates; burrowing taxa are not as desirable as food items (Waters, 1995). Siltation of cobble and gravel also covers hard substrates required for algal growth. Thus, invertebrates that scrape algae from hard substrates for food will decline, whereas invertebrates that filter food from the water column will increase. The density of invertebrates may decrease with the loss of invertebrates sensitive to siltation, but often densities remain the same or even increase due to high abundances of burrowing taxa (Lenat et al., 1979). Invertebrate diversity is often reduced with siltation because of the loss of intolerant species (Lemly, 1982).

Olness et al. (1975) provide a comparison for sediment delivery watersheds with rotational grazing, continuous grazing and croplands in Oklahoma. Precipitation was similar across watersheds. Runoff ranged from 4 to 13 in, with the highest values for two continuously-grazed watersheds. Associated sediment delivery was highest for the two continuously-grazed watersheds (8 and 10 tons/ac), but had the highest erosion index, none of the other watersheds yielded more than 4.4 tons/ac. One rotationally-grazed watershed yielded the lowest sediment (0.5 ton/ac), and the other was similar to wheat and alfalfa fields (~ 1.0 ton/ac). Three watersheds devoted to cotton had sediment yields from ~ 2.0 to 4.0 tons/ac.

Mwendera and Saleem (1997a) report heavy to very heavy grazing pressure (1.2 to 1.7 animal-unit-months ac^{-1} significantly increased surface runoff and soil loss and reduced infiltrability of the soil on a natural pasture Ethiopian highlands on 0.025 ac plots. Fine textured soils were more susceptible to trampling effects than coarse textured soils, and reduction in infiltration rates was greater on soils which had been tilled and exposed to very heavy trampling (Mwendera and Saleem, 1997a). In related studies, Mwendera and Saleem (1997b) and Mwendera et al. (1997) report that for the same % vegetative cover, more soil loss occurred from plots on steep rather than gentle slopes, and that gentle slopes could withstand more grazing pressure without seriously affecting the ground biomass regeneration compared to steeper slopes. Slopes exceeding 5.8% are likely to suffer soil erosion even under moderate grazing pressure. They recommend a need for developing 'slope-specific' grazing management rather than making blanket recommendations for all slopes.

Naeth and Chanasyk (1996) quantified the effects of rainfall and snowmelt induced runoff and sediment yield from sloped areas of the foothills fescue grasslands of Alberta, Canada. The effects of two grazing intensities (heavy and very heavy) for two durations (short duration and continuous throughout the growing season) were compared to an ungrazed control between June 1988 and April 1991. Snowmelt was the dominant source of runoff and snowmelt runoff was higher from the heavily grazed areas than from the very heavily grazed areas, due to the higher standing vegetation which accumulated snow in the former areas. However, sediment yields as a result of snowmelt were generally low in all areas. Only a few summer storms caused runoff. Runoff volumes and sediment yields from summer rainstorms were low, due to low rainfall and to generally dry antecedent soil moisture conditions. The greatest risk of summer runoff, and thus sediment yield, appears to occur in August (Owens et al., 1989; Naeth and Chanasyk, 1996).

Annual sediment concentration decreased by more than 50% and the amount of soil lost decreased by 40% during a 5-year period when cattle were fenced out of the stream relative to a 7-year period were a beef cow herd had access to a 64-ac watershed (Owens et al., 1996). Average annual soil losses were reduced from 1.1 to 0.62 ton/ac while annual precipitation averages were similar during each management period.

Owens et al. (1997) studied runoff and sediment losses from a small pastured watershed in eastern Ohio for 20 years. In Period 1, a beef cow herd grazed it rotationally during the growing season for 12 years and was fed hay in this watershed during the dormant season (high animal density with feeding). During the next 3 years of this study (Period 2) there was summer rotational grazing only. There was no animal occupancy on this watershed during the last 5 years (Period 3). Annual runoff was more than 10% of precipitation during Period 1 (4.7 inch) and less than 2% during Periods 2 and 3 (0.55 and 0.24 in, respectively). The decrease in annual sediment loss was even greater with the change in management, yielding 2015, 130, and 8 lb/ac for the three respective periods. Over 60% of the soil loss during Period 1 occurred during the dormant season. Low amounts of runoff and erosion from three adjacent watersheds with summer-only grazing supported the conclusion that the increased runoff and erosion during Period 1 resulted from the non-rotational, winter feeding on pastures. When the management was changed, the impacts of the previous treatment were not long lasting, changing within a year.

In a related study in Ohio, Owens et al. (1989) found the largest monthly average sediment concentrations were 0.8 g/L for 2 yr without the presence of livestock, 1.3 g/L for 3 yr with 17 cows grazed during the summer months only, and 3.2 g/L for an additional 6-yr period with all-year grazing with hay being brought in for winter feed. Annual sediment losses were 0.09, 0.53, and 0.94 ton/ac, respectively, across the three grazing levels.

After exclusion of grazing ("retirement") from the banks of most perennial streams, erosion-prone hillslopes, and remnant pockets of native forest from a 28 mi^2 mixed pasture/forested watershed in New Zealand sediment loads changed by -85% (Williamson et al., 1996).

Gilley et al. (1996) report sediment concentration in runoff was significantly higher in twice-over rotational grazing and season-long grazing than undisturbed CRP land, but was less than areas that were hayed or burned in North Dakota even though the amount of runoff was similar (Table 26).

Table 26: Soil Loss from Fields Differing in Grazing Practice.

Sediment Treatment	Soil Runoff	Conc.	Loss
	(in)	(ppm $x10^3$)	(lb/ac)
Undisturbed	0	0.00	0
Grazing (twice)	1.2	1.57	401
Grazing (season)	1.2	1.62	401
Hayed	1.1	2.30	508
Burned	1.5	2.28	1008

Summary of sediment effects:

- ■ Sediment yield increases with increasing grazing pressure, lowest levels related to ungrazed or "retired" riparian areas.
- ■ Fine textured soils were more susceptible to trampling effects than coarse textured soils.
- ■ Soil loss increases with steeper slopes.

PATHOGENS

Due to the threat of contamination of drinking water by pathogenic microorganisms, livestock excrement input to streams is an important human health concern (Strand and Merritt, 1999). Fecal material deposited along or directly into streams elevates concentrations of phosphorus and nitrogen (Lemly, 1982). Concentrations in runoff water can be several orders of magnitude larger than contact standards (Giddens and Barnett, 1980; Coyne and Blevins, 1995). Similarly large concentrations of pathogens can occur in runoff from pastures that do not receive stored manure, due to defecation by wildlife and cattle (Edwards et al., 1993). Nutrient enrichment can lead to increased production of heterotrophic microbes that can reduce dissolved oxygen concentration (Harris et al., 1994).

Bacteria from livestock can enter streams in runoff or are deposited directly when animals have access to the stream (Sherer et al. 1988). Benthic sediments have been found to harbor significantly higher concentrations of enteric bacteria than the overlying water. Fecal coliform and fecal streptococci organisms have demonstrated significantly longer survival, half-lives from 11 to 30 d and 9 to 17 d, respectively in sediment laden waters than in those without sediment (Sherer et al., 1992). Sherer et al. (1988) artificially resuspended stream sediments at three sites on five occasions in a watershed with active grazing. They found 0.02 to 8.2 billion fecal coliform ft^{-2} and 0.009 to 60 billion fecal streptococci ft^{-2} during the resuspending trials. The higher counts were related to cattle access to the stream.

Edwards et al. (1997) found there were no consistent relationships between the presence of cattle and fecal coliform and fecal streptococcus runoff concentrations from four Northwest Arkansas fields over three years. Runoff amount had no effect on runoff concentrations of fecal coliform or fecal streptococcus. Each field was grazed and fertilized, with two fields receiving inorganic fertilizer and two receiving animal manure. Higher concentrations were observed during warmer months. Runoff FC concentrations exceeded the primary contact standard of 200 Colony Forming Units/100 mL during at least 89 percent of all runoff events and the secondary contact standard of 1000 CFU/100 mL during at least 70 percent of the events. In contrast, Teidemann et al. (1987, 1988) found significant increases in fecal coliform with increased intensity of grazing management in Oregon across 13 watersheds with four management strategies. Two watersheds with the highest level of grazing management exceeded 200 fecal coliform 100 mL-1 (Tiedemann et al., 1987, 1988). Gary et al. (1983) report bacteria densities were significantly higher along a pasture when 150 cattle were grazed compared to when 0 or 40 cattle were grazed in a Colorado front range stream.

Summary of references dealing with pathogens:

- There are conflicting reports on the effects of grazing intensity and fecal coliform delivery to streams.
- Bacteria from livestock can enter streams in runoff or are deposited directly when animals have access to the stream.
- Benthic sediments harbor significantly higher concentrations of bacteria than the overlying water.

TEMPERATURE

Temperatures during summer and winter were significantly different among three streams in Pennsylvania, at least in part, related to the absence of shading due to a nearly complete lack of woody vegetation along two streams which were grazed (Wohl and Carline, 1996). Riparian forest clearing in the northeastern U.S. resulted in increases in temperature of from 3.6-9.0 degree F (Sweeney, 1993). The ungrazed stream was warmest in winter, coolest in summer, and had the narrowest range of mean daily temperature. In general, abundance and diversity of macroinvertebrates was highest in the ungrazed stream, which also supported the highest abundance of brown trout (Wohl and Carline, 1996). Carline and Spotts (1998) report that the two streams in the Wohl and Carline (1996) study responded favorably to stream bank fencing, bank stabilization and the installation of rock-lined aminal crossings. They found that total dissolved solids decreased by 50%, macroinvertebrate density increased by at least 70% in the two streams.

Li et al. (1994) reported that watersheds in eastern Oregon with greater riparian canopy, had higher standing crops of rainbow trout, lower daily maximum and perennial flow. Algal biomass was positively correlated with solar insolation. Total invertebrate biomass, and herbivorous invertebrate biomass was also positively correlated with algal biomass in all watersheds studied.

Quinn et al. (1992) state that small streams in New Zealand intensively grazed by cattle had greatly reduced shading by riparian vegetation, resulting in substantial increases in daily maximum temperatures during summer. Higher daily thermal fluctuations have also been associated with increased solar insolation (Kauffman and Krueger, 1984). In general, Quinn et al., 1992) found invertebrates favoured by cool water and low periphyton abundance decreased in density. Differences in physical habitat and invertebrate communities were minor between paired grazed and riparian-protected reaches of the larger where grazing by cattle and/or sheep had little or no effect on stream shading.

Overview of temperature effects:

- ■ Removal of streamside vegetation can increase mean temperature and temperature extremes.
- ■ Streams along wooded riparian zones may be cooler in summer and warmer in winter.
- ■ Relatively small changes in stream temperature can shift aquatic communities
  - a 3.6 degree F increase is sufficient to shift from a coldwater to warmwater assemblage.
  - an increase in stream temperature from 3.6 to 9 degree F is common when streamside vegetation is removed.

NUTRIENTS

Timmons and Holt (1977) provide levels of nutrient loss from a native prairie in west-central Minnesota that can be used to compare the effects of different grazing levels on nutrient loads in runoff. Depending on the nutrient of interest, 63 to 88% of the average annual nutrient loads were transported in snowmelt; however, averaged weighted concentrations for all chemical constituents were higher for runoff following rainfall. Total nitrogen and total phosphorus losses averaged 0.7 and 0.09 lb/ac, respectively, over a five year period. Cation losses ranged from 0.09 to 1.6 lb/ac and the order was K > Ca > Mg > Na in four of five years.

Elevated levels of nutrient input often results in dense growths of filamentous green algae, i.e., *Cladophora* spp. These dense growths differentially promote the production of some insect species, that replace a diverse assemblage of attached photosynthetic microorganisms. In addition, many herbivorous insects decline in abundance in response to dense filamentous blooms (Li et al. 1994). The dense filamentous algae reduces feeding efficiency of insectivous fish due to a switch in the insect prey base (Tait et al., 1994).

Cooper et al. (1995) found that during 12 years after retirement from grazing, dominant vegetation in the set-aside areas changed from pasture grasses to native tussock in pasture along the edge of a small stream in New Zealand. Riparian set-aside soils had an extremely high hydraulic conductivity in the surface horizon (250 inch h^{-1}) compared with that in the riparian grazed pasture (0.6 in hr^{-1}) indicating that surface runoff water transported into the zone would infiltrate, fill soil pores and emerge as subsurface flow at the stream edge. Phosphorus available for transport was highest in riparian set-aside soils, indicating P saturation of the zone. Nitrate pool size was strongly correlated to nitrifying potential, with both being extremely low in riparian set-aside. Microbial biomass was greater in riparian set-aside (1900 mg C g^{-1}) than riparian native (1460 mg C g^{-1}) or riparian pasture (1080 mg C g^{-1}). Cooper et al. (1995) imply that riparian set-aside has led to the development of a zone likely to supply runoff to the adjacent stream that is depleted in sediment-bound nutrients and dissolved N but enriched in dissolved P.

Owens et al. (1994) determined that concentrations of NH4-N, NO3-N, and total N increased throughout a 5-yr period of 200 lb N/ac annual fertilizer application to a grass-pasture grazed by beef cattle and reached levels that were usually in excess of 10 mg N/L. NO3-N concentrations in groundwater dropped rapidly after alfalfa was interseeded into the grass pastures and N fertilizer was no longer applied. NO3-N levels decreased from 17.7 to 9.3 mg N/L in a tall fescue-alfalfa area, whereas in two orchardgrass-alfalfa areas, levels decreased from 11.2 to 2.7 and from 8.3 to 3.6 mg N/L. The amount of N lost via subsurface flow decreased, but subsurface flow remained the main pathway for N loss compared with surface runoff or sediment-attached N (Owens et al. 1994).

In a related study in Ohio, Owens et al. (1989) found nutrient concentrations remained low across three grazing levels, with the exception of K concentration, which increased with all-year grazing. Concentrations of NO3-N, mineral-N, P, Ca, Mg, Na, and Cl were similar to or less than the concentrations from a nearby 43.7-ac wooded watershed that contained no pastured areas and received no agricultural inputs. Largest monthly average sediment concentrations were 0.8 g/L for 2 yr without the presence of livestock, 1.3 g/L for 3 yr with a 17 cows grazed during the summer months only, and 3.2 g/L for an additional 6-yr period with all-year grazing with hay being brought in for winter feed. Annual sediment losses were 0.09, 0.54, and 0.94 ton/ac, respectively across the three grazing levels. Although relatively few pastures are grazed in winter in Minnesota due to deep snow or cold conditions, increased use of grazing to provide feed for cattle, especially, implies that farmers need to keep pastures in good condition.

Management intensive grazing (MIG) is a grazing system designed to maximize both forage yield and quality. Cattle at a high stocking density are rotated frequently through a series of paddocks. The uneven recycling of N through feces and urine can increase NO3-N leaching. The extent to which NO3-N can leach from beneath urine and fecal spots under soil and climatic has not been studied extensively. Stout et al. (1997) determined NO3-N losses averaged across three years were 10.4, 15.0, 196.2, 214.1, and 281.0 lb ac^{-1} for the control, feces, and spring-, summer-, and fall-applied urine, respectively in a N-fertilized orchardgrass field in central Pennsylvania. These losses represent about 2% of the N applied in the feces and about 18, 28, and 31% of the spring-, summer-, and fall-applied urine N. Hack-ten Broeke et al. (1996) found that level of nitrogen leaching as the result of urination by cows depended upon soil type, moisture conditions and grazing intensity on two experimental, rotational-grazed plots in the Netherlands. They found that

NO-3-N levels rarely exceeded the European Coummunity's directive of 11.3 mg/l in a wet moderately grazed field, but was often exceeded in a drier more heavily grazed pasture. Correll (1996) indicates that pastures that receive heavy applications of fertilizer or stored manure often harm receiving waters, and their impacts can exceed those of annual row crops.

After exclusion of grazing ("retirement") from the banks of most perennial streams, erosion-prone hillslopes, and remnant pockets of native forest from a 28.3 mi^2 mixed pasture/forested watershed in New Zealand loads changed by -27% for particulate P, -26% for soluble P, -40% for particulate N, and +26% for dissolved N (Williamson et al., 1996). Calculated total phosphorus specific yields for the pasture portion of the watershed changed from 509 lb mi^{-2} yr^{-1} before retirement to 235 lb mi^{-2} yr^{-1} after retirement. Williamson et al. (1996) predicted that retirement reduced TP loads by 20% in the lake that receives runoff from the watershed. Phosphorus reduction was predicted to reduce the chlorophyll a concentration by about: 5 mg m^{-3}, and potentially shift the lake's trophic state from eutrophic to mesotrophic.

Total N in runoff from a cattle-grazed watershed ranged between <0.9 to 3.6 lb ac^{-1} yr^{-1}, whereas only 0.44 lb/ac yr^{-1} was measured in a nongrazed watershed over a three year period (Jawson et al., 1982). TN received in precipitation was equal to or greater than N lost in runoff from the grazed watershed. Nitrate-N levels in the runoff were normally <1 mg/l. Total P (TP) losses in runoff from the grazed watershed ranged from 0.09-1.2 lb ac^{-1} yr^{-1} and from <0.09 to 0.15 lb ac^{-1} yr^{-1} from the ungrazed area period (Jawson et al., 1982).

Concentrations of NH4-N, NO3-N, total P, soluble P and Cl- were 6, 45, 37, 48 and 78% greater, respectively, over a three year period were measured from a 6.2-ac cow-calf grazed pasture in Nebraska when livestock were grazing in comparison to periods when cattle were removed (Schepers and Francis, 1982). Total solids increased by 52% during grazing, but total organic C and COD only increased by 11 and 7%, respectively, whereas total Kjeldahl N concentration decreased by 19% (Schepers and Francis, 1982). Concentrations of NH4-N, total Kjeldahl N, total P, total organic C and COD were directly related to the density of grazing livestock (Schepers et al., 1982). Leachates from the standing plant material, surface litter layer, surface soil and manure deposits indicated manure and standing plant material were likely sources of most chemical constituents in runoff water (Schepers et al., 1982).

McColl and Gibson (1979) measured mean concentrations of Kjeldahl N, total P, Ca and K were 190, 150, 24 and 240 times higher, respectively, in surface runoff from a grazed and a fertilized hill pasture than those in rainfall over one year. Concentrations tended to be high in summer and were strongly related to grazing. The peak of nitrate concentration after grazing lagged approximately 2 weeks after the Kjeldahl N peak and probably depended on nitrification of ammonium from dung and urine.

Smith (1989) stated that sediment, phosphorus, particulate- and nitrate-nitrogen concentrations, during 71 run-off events over 22 months, were lower and varied significantly less at retired riparian pasture than at grazed riparian pasture sites. Smith

(1989) recommends riparian pasture retirement is an effective means of reducing surface run-off pollutant loads to waterways.

Table 27: Reduction (%) in nutrients in channelized surface run-off from two moderately steep hillslopes in New Zealand from riparian pasture retirement in relation to grazed pasture (from Smith 1989).

Water Quality Parameter	Percent Reduction
Total suspended solids	87
Volatile suspended solids	84
Particulate P	80
Dissolved P	55
Total Nitrogen	85
Nitrate-nitrogen	67

Nitrogen inputs to the Tomales, California, watershed (a rural area of 138 376 ac) from the atmosphere are about equal to outputs via runoff and groundwater flow (Freifelder et al., 1998). This balance was initially interpreted to suggest that the system was neither releasing nor taking up nitrogen. A more detailed budgetary analysis suggests otherwise. In their analysis, Freifelder et al. (1998), found that food imported for dairy cows and humans, waste management and milk export were incorporated into the nitrogen budget. Cattle contributions to the budget were influenced by nutrition as a function of age, lactation state and milk yield, as well as population density. The cow contribution distinguished grazing (i.e. internal nutrient cycling) from the introduction of nitrogen in feed grown outside the watershed, and the budget incorporated nitrogen losses due to waste management and export of milk. Food imported for cattle was almost 10 times the import for humans, but cows and humans contributed approximately equal net nitrogen additions to the system.   This inclusion of cows and humans in the nitrogen budget demonstrated that nitrogen inputs to the system exceed hydrological outputs by about 1.8 lb ac^{-1} yr^{-1}. Alternative sinks which may account for this 'extra nitrogen' include storage in biomass or soil organic matter; or loss from the system by the difference between nitrogen fixation and denitrification.

Overview of nutrient effects:

- Nutrient concentrations (various forms of N and P) in runoff increase with increasing grazing intensity.
- Retiring areas from grazing but maintaining grass vegetation reduces nutrient delivery, but dissolved N may be reduced differentially in relation to dissolved P.

VEGETATION REMOVAL

Impacts of vegetation removal can be placed into two categories: shifts in community structure and removal of biomass. Major changes in community structure and usually a reduction in the number of species have been reported in the western United States (see review by Kauffman and Krueger, 1984). Rooting depth of vegetation associated with shifts in community structure affects water uptake and soil characteristics. The impact of removal of biomass has often focused on riparian zones, because of the importance of woody vegetation to wildlife and the potential for alteration of the riparian microclimate. Cattle have significantly altered the size, shape, volume and quantities of live and dead willows. Cattle have also influenced the spacing of plants and the width of the riparian zone (Kauffman and Krueger, 1984). Riparian vegetation has a major influence on channel shape. Vegetation increases stream bank strength by binding the soil with roots and shields banks from erosion during high flows. Kauffman and Krueger (1984) report that bank sloughing increases when vegetation removal exceeds 60%. Streams with heavily vegetated riparian areas are narrower and deeper than those that flow through poorly vegetated areas.

In uplands, vegetation removal exposes soil to the energy of raindrops, facilitates sheet flow with an increase in the amount of runoff and the ability to move sediment. Rauzi and Hanson (1966) found that runoff from a heavily-grazed watershedwas 1.4 times higher than a moderately-grazed watershed and 9 times higher than a lightly-grazed watershed. Bari et al. (1995) examined the residual phytomass level necessary to adequately protect the soil against accelerated interill erosion in a temperate region of Pakistan. They found that a residual treatment with 2697 lb ac^{-1} phytomass resulted in the lowest erosion rates, whereas 557 lb ac^{-1} phytomass produced the highest erosion. Standing phytomass was the most important variable affecting erosion with foliar cover and basal cover also highly correlated to erosion.

Effects of vegetation removal:

- Vegetation removal exposes soil to the energy of raindrops, facilitates sheet flow, runoff and the ability to move sediment.
- In contrast, vegetation increases stream bank strength to resist erosion.
- Stream channels along heavily vegetated areas are deeper and narrower than along poorly vegetated areas.

EFFECTS ON STREAM MORPHOLOGY

Livestock grazing, as well as other land uses, can affect the energy balance in streams and produce negative effects on riparian equilibrium. There are a large number of complex, interrelated factors that determine riparian form and function that can be affected by livestock grazing which include stream discharge, sediment load, resistance of the banks and bed to movement of flowing water, vegetation and temperature. Changes in these variables will elicit an adjustment of the dynamic equilibrium of streams and their valleys. Cattle are agents of geomorphic change. Bohn and Buckhouse (1986) report streambank degradation is related both to the number of livestock grazed and the duration of grazing.

Unstable channel morphology and the loss of fish and invertebrate habitat is often attributed to cattle grazing practices in riparian areas in the western United States. Cattle grazing often causes large changes in channel morphology, causing wider, shallower stream channels (Knapp et al., 1998) with significant native vegetation overhang and extensive fish habitat to wide braided channels with little cover for fish or amphibians

(Williamson et al., 1992). A number of studies have examined effects of livestock by fencing riparian areas to exclude grazing and then noting the effects on riparian vegetation and stream morphology. Magilligan and McDowell (1997) selected four gravel-bedded, steep alluvial streams in eastern Oregon with cattle exclosures greater than 14 years old for an analysis of geomorphic adjustments following the removal of cattle grazing. Reductions in bankfull widths by 10 to 20 percent and increases of 8 to 15 percent in pool area were the most common and identifiable changes in the exclosures. Not all channel properties demonstrated adjustment, leading Magilligan and McDowell (1997) to suggest that perhaps 14 years is an insufficient duration for these variables to adjust.

Platts and Nelson (1985) examined two grazed and one ungrazed reach where grazing had been excluded for 11 years. Their ungrazed section demonstrated improved riparian vegetation and a deeper, narrower channel. However, exclusion of grazing for two years along a 0.6 mi section of a stream channel that had experienced historical grazing did not lead to substantial geomorphic recovery, indicating that it may take many years for the full benefits to be assimilated by the fluvial and riparian systems (Sidle and Sharma, 1996). However, Sidle and Sharma (1996) found that shifting the location of cattle grazing caused significant downstream impacts. Cattle moved into wet riparian areas upstream, causing decreases in thalweg depth (i.e., the location of the deepest portion of the channel), increases in fine sediment deposition in the channel, and loss of pool volume in these upstream areas. They also reported increases in deposition of fine sediment in reaches with high volumes of large woody debris (Sidle and Sharma, 1996). Pool/riffle ratio (a measure of fish habitat), as well as soil and vegetation stability varied significantly with cattle density (Meyers and Swanson, 1991). As pool/riffle ratios changed, other channel properties are seen to change as well.

Clarkson and Wilson (1995) found that bank damage by ungulates was the only variable solely influenced by land management practices in a generalized linear model ($R^2 = 0.7$) relating trout biomass and stream, riparian, and geomorphic habitat variables generated from 243 stations among 21 high-elevation trout streams over four years in the White Mountains area, east-central Arizona. The bulk of the bank damage was attributed to domestic cattle grazing. Channel width, was partly dictated by geomorphology but was also correlated with bank damage by ungulates and thus could be influenced by management strategies. Platts (1984) indicates that continuous, heavy grazing resulted in a stream reach that became four times wider and one-fifth as deep as an adjacent area that was only lightly grazed.

Myers and Swanson (1995) indicate that deferred rotation grazing led to improvement of aquatic and riparian habitats along three central Nevada streams, but that complete rest from grazing allowed the most improvement. Streambank soil stability, type and amount of vegetation cover, and quality of pools responded most to changes in grazing management. Complete rest improved channel and water width:depth ratios, channel entrenchment, bank angle, bank undercut, and bank depth. Width-to-depth ratios at base flow was significantly higher along bare ground transects.

These geomorphological changes are common, but not universal. Williamson et al. (1992) conducted a longitudinal survey which showed stock damage ranging from 0-25% of the channel length in grazed reaches. They found no statistical evidence that mixed sheep and cattle grazing on streambanks in floodplain streams in New Zealand led to rapid or severe deterioration in channel form, except in small streams (< 6.6 ft wide) under intensive grazing of wet streamside soils. They found that the dominant erosion mechanism, the undercutting of banks, was largely unaffected by grazing stream margins. As well, effects of riparian retirement on small streams varied depending on the stability of the stream channel, but was correlated with increased vegetation overhang. On larger streams with more actively meandering channels, retirement had comparatively little benefit, because any retirement or grazing effects were rapidly overtaken by channel migration. Finally, Williamson et al. (1992) concluded that, in contrast to channelization, grazing appeared only to have a minor effect on channel morphology in the streams they studied, because only very large differences could have been detected as a result of the variability in each reach.

Overview of effects due to channel morphology:

- Unstable channel morphology and the loss of fish and invertebrate habitat is often attributed to cattle grazing practices in riparian areas in the western United States.
- Stream channels along heavily vegetated areas are deeper and narrower than along poorly vegetated areas.
- Livestock management often causes local-scale changes in habitat, thereby impacting fish and invertebrates.
- Changes are much more pronounced in small streams than large ones; impacts on lakes are under-studied but appear to be minimal.
- The natural variance among stream channels, lakes and wetlands makes generic conclusions very tenuous. Most impacts and most Best Management Practices will be relatively site specific.

MEASUREMENT TECHNIQUES

Chokmani and Gallichand (1997) assessed a distributed indicator method with a geographical information system for predicting the potential for surface water pollution at the watershed scale. Water quality at the outlet of two watersheds, where animal production was dominant, was monitored on a continuous basis for one year. Observed water quality was related to land use, particularly the intense animal production. Chokmani and Gallichand (1997) found NH4-N, TP, dissolved oxygen and fecal colimorms affected surface water quality. Differences were noticed between observed water quality and that predicted by their model. They attributed the differences to neglecting some nutrient and sediment transport processes. However, their model identified zones, within each watershed, that could contribute to water pollution.

Fraser et al. (1998) present a geographical information system (GIS)-based transport model (SEDMOD) that provides an index of pathogen loading potential to streams by characterizing five key transport parameters: flow-path hydraulic roughness, gradient, and slope shape, stream proximity, acid a normalized soil moisture index. The SEDMOD model was applied to 12 subwatersheds (10 agricultural, 2 forested controls) of the Saw Kill, a tributary of the Hudson River, New York, and compared model predictions with measured fecal coliform (FC) levels. The transport model, combined with a livestock density GIS layer, could explain 50% of the variation in average FC discharge among the subwatersheds. In a multiple regression, predicted FC transport, mean water temperature, and mean turbidity could account for 80% of the observed variation in FC discharge.

MANAGEMENT STRATEGIES

Godwin and Miner (1996) demonstrated that off-stream watering areas are an effective alternative to stream fencing. Off-stream watering reduced the time animals spend at the stream under small acreage grazing conditions. An animal-operated pasture pump that pulled water from the creek was demonstrated to be a viable off-stream watering device. Sheffield et al. (1997) found that when given the choice, cattle drank from an off-stream water trough 92% of the time, compared to the time which they spent drinking from the stream on two commercial cow-calf operations in southwest Virginia. Stream bank erosion was reduced by 77%, as were concentrations of total suspended solids (90%), total nitrogen (54%), and total phosphorus (81%) when an alternative water source was provided. Similar reductions were observed in concentrations of fecal coliform and fecal streptococcus. Concentrations of nitrate and orthophosphorus were not reduced.

CONCLUSIONS:

- Overgrazing or unmanaged grazing can:
- Reduce vegetative cover and infiltration,
- compact the soil,
- increase runoff, erosion and nutrient and sediment yield.

In riparian zones, trampling the streambanks can:

- Decrease erosional resistance of the streambank and contributes to sediment yield.
- Vegetation removal increases solar insolation and leads to higher stream water temperature.
- Manure either in the uplands or into water bodies can lead to elevated levels of nutrients and pathogens.
- Fish and aquatic invertebrates are sensitive to sediment input, water temperature and excess algae and plant growth.

Low or moderate grazing have less significant effects than overgrazing

- but note caution voiced by Larsen et al. (1998)
  -current literature contains many studies that are not experimental with replicated treatments and statistically valid results.
- Little information relevant to upper Midwest is available in the literature.

FUTURE NEEDS

While it is clear that grazing can degrade water quality most work has been conducted in the arid western United States and not under the conditions prevalent in the Midwest. Future research should be directed toward replicated studies under controlled conditions that examine causation that should lead to better management practices and better policies (Clark, 1998). With few exceptions, little is known in the Midwest about sediment delivery rates, nutrient loading and pathogen transport in relation to grazing. In order to achieve these ends, 1) Baseline data are critical, and 2) data must be developed in a watershed and/or ecosystem approach (Rinne, 1988). For example, Rutt et al. (1993) developed a rapid assessment system that could predict (using only field data) the degree of impact on water quality. Such a tool for assessing and monitoring impacts in Minnesota would be useful and appropriate.

In the western United States, several grazing strategies have been employed to reduce the effect of grazing on riparian systems. Most agree with Myers and Swanson (1995), who indicate that deferred rotation grazing led to improvement of aquatic and riparian habitats, but that complete rest produced the most improvement. In the Midwest, managed rotational grazing has been adopted by a large number of dairy farmers, especially in Wisconsin. A controversy has developed because traditional best management practices, based on the experiences in the arid western United States, recommend that cows be excluded from the riparian zone. Exclusion of cows from the riparian zone is often unpopular with rotational graziers, because it is expensive and takes land out of production. However, managed rotational grazing effectively reduces the time cows spend in riparian areas and has been demonstrated to reduce the impact in and along streams in relation to continuous grazing (Sovell, 1997; Cox, 1998; Nerbonne, 1999; John Lyons, Wisconsin Department of Natural Resources, unpublished). Thus, research needs to be conducted to determine how to manage riparian areas so that forage can be utilized while minimizing the effects on water quality and fish and invertebrates.

STUDY TOPIC 6: HOW DO THE VARIOUS IMPACTS IN #1 TO #5 VARY BY SPECIES, OPERATION, SYSTEM TYPE, MANAGEMENT, GEOGRAPHY, GEOLOGY, WATERSHED CHARACTERISTICS, AND CONCENTRATION OF LIVESTOCK FACILITIES?

OVERVIEW OF MINNESOTA HYDROGEOLOGY

Soil and Geological Sediments

Minnesota has a wide diversity of soil and geological sediments. The primary focus in this section is the relative impact of these soils and sediments on surface and ground water pollution potentials. Pollution of ground water depends upon several factors (Knox and Moody, 1991), including depth to ground water, permeability and hydraulic properties of surficial soils and sediments, land management, and climatic factors. Major types of surficial soils and sediments in Minnesota include karst formations, coarse textured sands and outwash, fine textured silts and lake sediments, glacial tills, moraines, and peatlands (Fig. 3). Ground water pollution potentials are, in general, greater for the coarse textured sands and outwash or the karst formations than for other types of surficial soils and sediments. The fine textured silts, lake sediments, and glacial till soils tend to have poor internal drainage of water. As a result, they tend to have significant proportions of artificial drainage to remove ponded water and enhance agricultural productivity. Tile drainage water discharges to surface waters, so the fine textured silts, lake sediments, and glacial till soils have a potentially greater surface water quality impact than a ground water quality impact. Soils and sediments on moraines tend to have better internal drainage than the fine textured silts, lake sediments, and glacial till soils, and are generally located on steeper terrain, too. Depending upon site-specific characteristics, moraines have the potential to impact either surface water quality or ground water quality. Karst formations are similar to moraines in that they both have the potential to pollute either surface or ground water. Most of the karst formations are buried by a thin layer of fine textured loess, and are located on steep slopes. Thus, water runoff and erosion can be significant in the karst region, leading to potential impacts on surface water quality.

Precipitation and Runoff

Mean annual precipitation is highly variable in Minnesota (Fig. 4). The Red River basin receives from 19-26 inches, while the Minnesota River basin receives from 22-31 inches. The Upper Mississippi River receives from 23-30 inches, while the Lower Mississippi River receives from 30-33 inches. Average annual runoff rates vary with the precipitation patterns (Fig. 5). The Red River basin has average annual runoff rates of from 2-3 inches, while the Minnesota River basin has rates from 1-6 inches. The Upper Mississippi River has average annual rates of runoff ranging from nearly 4-7 inches, while the Lower Mississippi River has rates of from 7-8 inches.

Go to next section of Water Document

Fig. 31: Nitrogen Removal by Harvested Crop Per County Acres

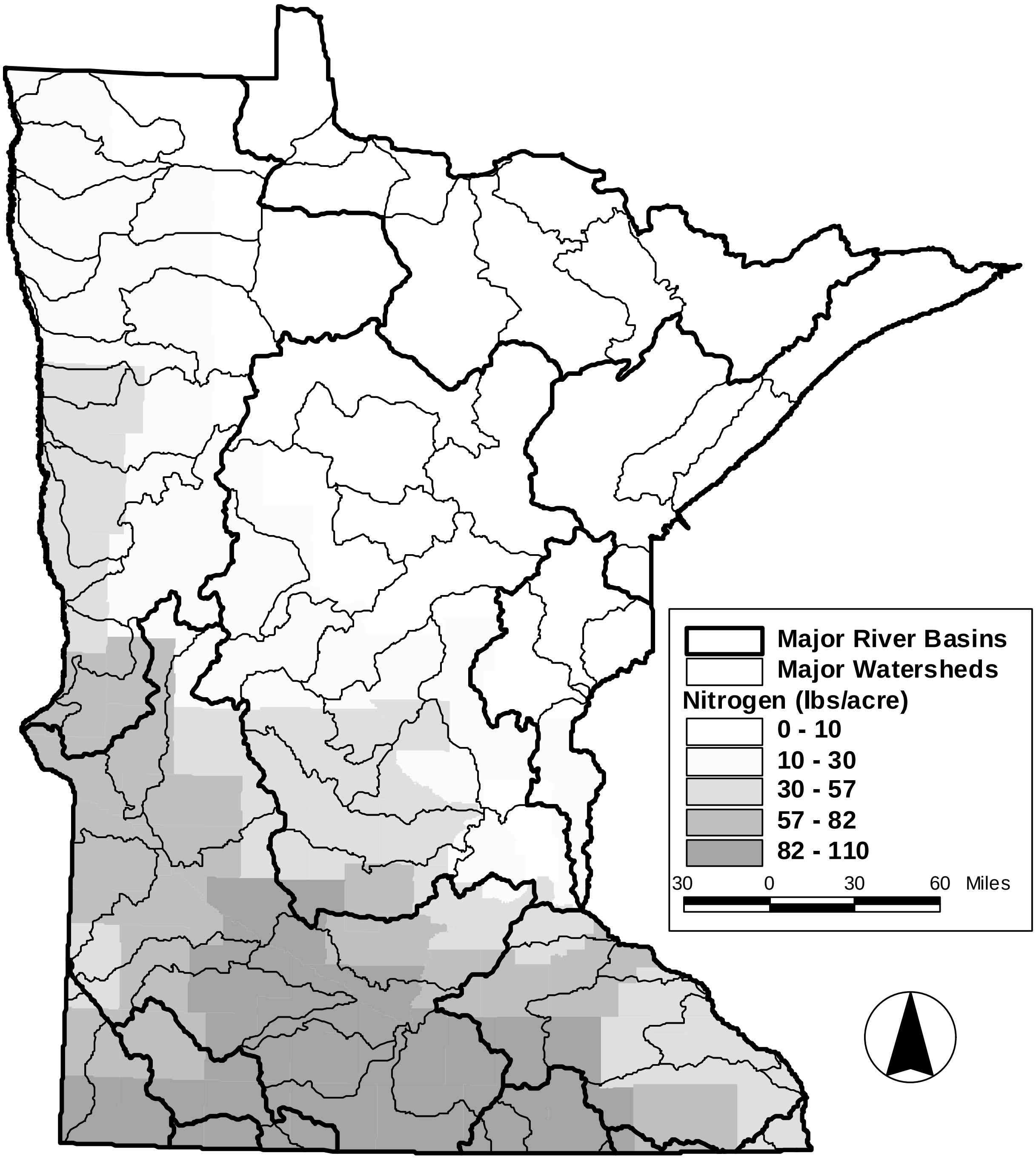


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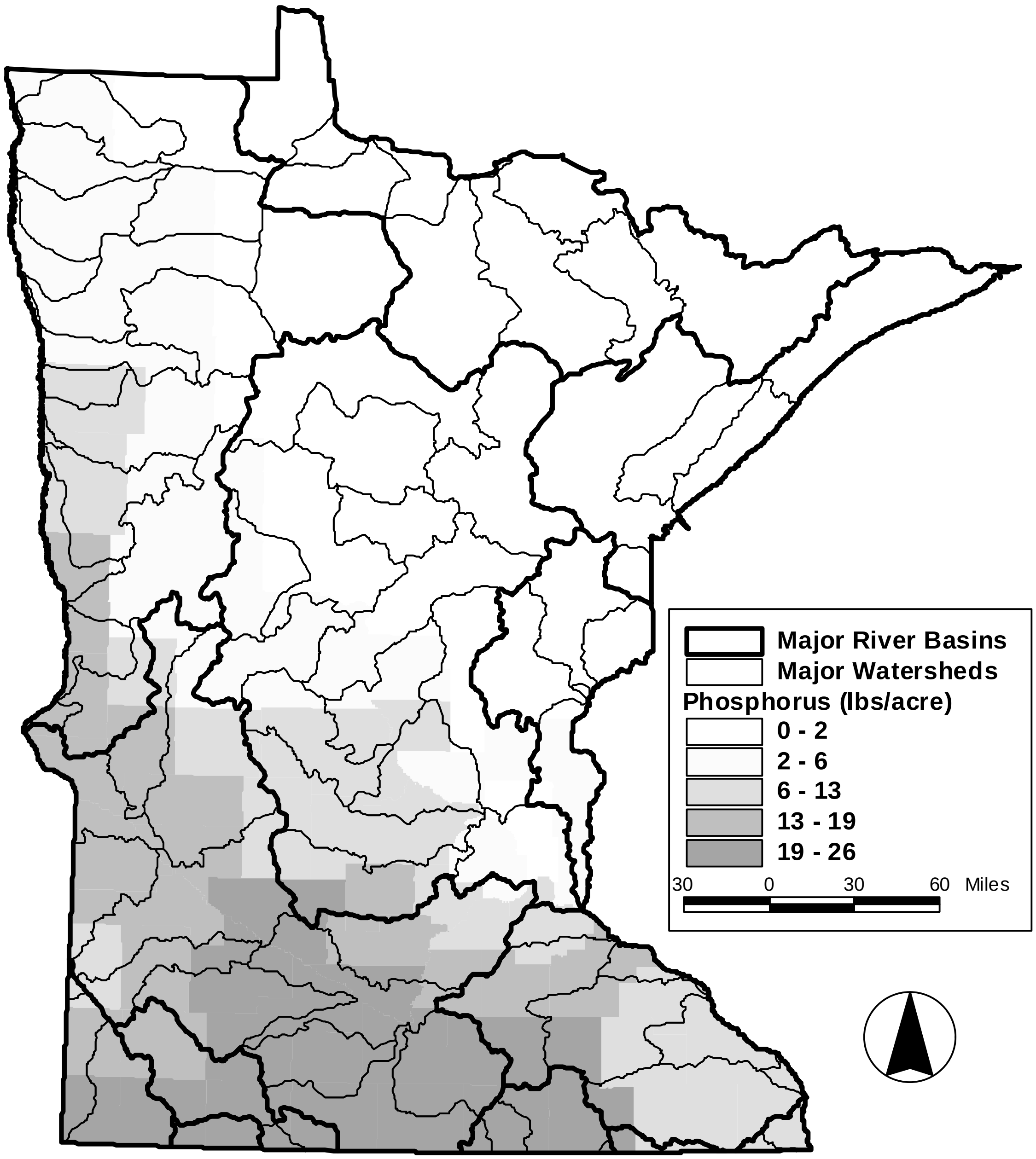
Fig. 32: Phosphorus Removal by Harvested Crop Per County Acres



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RECOMMENDATIONS FOR ADDITIONAL RESEARCH

Research on Sources of Pollution

- What are the total loads of phosphorus, nitrogen, and sediment in major watersheds of Minnesota's nine river basins? This information is needed to understand the potential percent contribution to these loads from animal agriculture.

- A statistical analysis relating Minnesota s animal densities, land use patterns, climate, soil and sediment properties, river channel hydrologic characteristics, depth to ground water, and surface or ground water quality impairment would be useful for identifying the specific contributions of animal agriculture to water quality impairment.

- There is a critical need to identify the surface waters of Minnesota which are most vulnerable to phosphorus, nitrogen, and pathogen pollution arising from animal agriculture. Models such as the phosphorus index approach could be used in this effort using geographic information sytems (GIS) analysis of state-wide patterns in animal manure production, fertilizer sales, landscape slope steepness, soil permeability and drainage status, and density of stream networks.

- There is a critical need for further research on methods for identifying sources of pathogens in Minnesota rivers.

- More research on hormones, metals, and pesticides in runoff from land applied manure is needed.

- A thorough analysis of nutrient budgets (inputs, outputs, sinks, and losses to the environment) for animal agriculture is needed at the farm scale for individual types of animal operations. A state-wide analysis of nutrient budgets using county level information would also be instructive in determining the potential losses to the environment of nutrients from animal operations. This analysis could also be useful in comparing the impacts on surface water quality of animal wastes versus wastes from fertilizers, wildfowl, and humans.

- No research is available in Minnesota to identify the extent of local redeposition of nitrogen after ammonia is volatilized from manure storage basins. Similarly, no research is available to identify the magnitude of nitrogen losses to the atmosphere by losses during crop senescence. In national studies, these two pathways for nitrogen losses to the environment have been assumed to be very important in Minnesota without any local data to support these assumptions.

- The temporal variation in nutrient loading to surface waters from wildfowl is poorly understood.

- Further study of endocrine disruption resulting from animal agriculture is needed, along with tools to better understand any impacts and their significance.

■ Research is needed to determine how the age of a feedlot affect its potential for pollution of surface and ground waters.

■ Research is needed to determine how runoff and erosion vary with the type of feedlot and its site characteristics.

■ Research is needed on the variation across the state of Minnesota in local water usage patterns by animal agriculture in comparison to local water availability from precipitation, and surface or ground waters.

■ Research is needed on the impacts of animal agriculture on water quality in Lake Pepin and the Lower Minnesota River between Jordan and Ft. Snelling relative to other sources.

Research on Best Management Practices for Water Quality Remediation

■ An analysis of the trade-offs and impacts on water quality from reducing ammonia volatilization in manure storage basins is needed.

■ Better methods (e.g. wetlands) are needed for treating liquid animal manure to reduce the nitrogen, phosphorus, and pathogen content before the manure is applied to land. Many options for such treatment are available for solid manure (composting, alum additions, etc.), but the options are limited for liquid manure.

■ The impacts on water quality of dietary modifications in animal feed (reductions in nitrogen and phosphorus, phytase additions, etc.) should be rigorously studied.

■ More information is needed on the effectiveness and length of time required for watershed restoration efforts in reducing lake and stream pollution from animal agriculture.

■ Improved equipment is needed for accurate control of manure application rates on land.

■ The impacts of surface tile intakes on delivery of phosphorus from animal manure to surface waters are poorly understood.

Research on Human Health Impacts of Pathogens

■ What public health risks from pathogens exist in surface waters used by 1 million residents of the Twin Cities metropolitan area?

■ Study is needed of the factors affecting survival of pathogens, especially animal viruses, in manure and in the environment.

■ Development of rapid methods is needed for the concentration and detection of animal viruses from large amounts of water, soil, and manure.

■ Development of accurate relationship between pathogens (viruses and protozoa) and indicators of pathogens (bacteria) in surface waters is needed.

Research on the Impacts of Animal Grazing on Water Quality and Stream Habitat

■ Further research on animal grazing practices (conventional pasture, rotational grazing) is needed in Minnesota to identify the water quality impacts of grazing, especially the issues of livestock exclusion and riparian protection in rotational grazing systems. Rapid assessment tools are needed to evaluate the impact of grazing on stream water quality. Research is also needed to evaluate the potential impacts on water quality from expanding the acreage of land in grazing operations, while reducing the acreage of row cropping systems.

■ Baseline data on grazing impacts on water quality and habitat should be collected in a spatially relevant framework (e.g., in the context of agroecoregions and stratified on the basis of livestock management intensity). Development of a predictive macroinvertebrate monitoring tool is needed which would be based on that base line data.

Research on Policy Issues Related to Water Quality Impacts of Animal Agriculture

■ What chlorophyll a levels should be used as an indicator of water impairment? Similarly, what levels of total phosphorus and bioavailable phosphorus in rivers are useful goals for cleanup strategies?

■ Research is needed to identify the scientific basis for setting critical soil test phosphorus threshold levels on a variety of Minnesota soil types. This would include study of the factors affecting bioavailability of phosphorus from manured soils, study of phosphorus sorption and desorption from various soil types in Minnesota, and evaluation of algal biomass produced in runoff from various locations.

■ Studies on the relationships between animal densities and land available for manure spreading are needed in Minnesota to help determine the critical animal density beyond which significant impairment of surface or ground water quality occurs.

■ Incorporation of both assessment and monitoring information in a watershed, landscape and cumulative effects context is needed, allowing decision makers to understand the broader implications of policy actions.

■ Research should be conducted so that the state-wide generic environmental impact statement on animal agriculture would be able to address the following informatio

How is animal agriculture actually practiced today in Minnesota? That is, an initial county-level feedlot study (named the "Part A" study for this document) should develop a standard feedlot inventory. The inventory should be used to comprehensively determine:

■ How many animal feeding operations are there in each county, watershed, etc.? Where are they located?
■ What are their respective sizes? What types of feedlots are they? What livestock do they raise?
■ Who owns the operation? Do they have an MPCA permit?

■ How is each facility managed, including how does each facility manage its animal wastes?
■ What runoff, if any, escapes and may be enriched from the animal waste? Is there any nutrient- or pathogen-enriched water recharging to the groundwater? (The latter question would be answered "yes" if there is obvious leakage/seepage into the ground; otherwise, if there is nothing visible, the only other possible answer from a site visit is "don't know". An accurate water balance evaluation, including careful measurements, would be required to provide any other answer, such as the quantitative amount of leakage, or that there is no leakage, because leakage to groundwater is usually an 'invisible' problem).
■ Are there any abandoned feedlots, or old, open or partially open feedlots that no longer have animals compacted the soil daily within the lot? If any of these exist,

1. where does the runoff go? how much?
2. is nutrient- or pathogen-enriched water recharging to the groundwater?
3. what types of low cost practices can be utilized to correct the majority of these open lot scenarios?
4. if the best solution involves moving the feedlot or installing very expensive pollution control measure, who pays? is there any funding source that could be identified, to help the landowner take that step?

■ Where are all nearby (private and public) water supply wells located, including the on-farm wells and wells on surrounding properties (say, within a 2-mile radius, and include drinking water wells and irrigation wells)? Determine the following for each:

1. What are the well depths, well ages, pumping capacities of each well, and from which aquifer(s) are they drawing water? Are there any records available from well installation?
2. For each well, has it had any known maintenance? Are there any records available from the repair work?

■ What is the environment each facility is located in, including the following: regional information on soils, geology, and hydrogeology (including interactions of surface waters and groundwaters with soils and bedrock, and how does it fit into the regional-scale geology and water systems)? Especially important are the careful characterization of sensitive geologic areas, where there is little or no protection of aquifers from land use impacts, including:

1. the karst area of southeastern Minnesota, where groundwater flows in solutionally-enhanced fractures and surface waters directly connect to groundwater via sinkholes, sinking streams, springs, and other types of flow;
2. other areas in Minnesota with significant groundwater flow through fractures;
3. the sand plains (glacial outwash areas) of Central Minnesota, and especially those areas with a history of irrigation agriculture that enhances surface water drawdown;
4. areas of alluvial sands (deposited by old meandering streams), which are typically of limited spatial extent, especially areas such as in southwestern Minnesota where the underlying crystalline bedrock does not provide any alternative aquifers;

5. other areas with enhanced surficial permeability (such as scattered sand and gravel deposits), where rural residents often use shallow sandpoint wells for their drinking water. (These can sometimes be detected by examination of geology resource maps which show existing and abandoned sand and gravel mines).

The inventory for feedlots should be developed so it can take advantage of existing knowledge in each county, and prevent duplication of effort. According to Mr. Terry Bovee and Mr. Mike Howe (Planners for the MDH Source Water Protection program), most counties have conducted some level of feedlot inventory for their Comprehensive Local Water Plan (the so-called "319" CLWP plans developed by each county, in coordination with the Board of Soil and Water Resources); however, all but a handful of counties have done a very preliminary type of study.

A Level I CLWP feedlot inventory is simply the locations of feedlots in the county (the same as question 1.a., above). A Level II inventory also investigates the information listed in questions 1.b. and 1.c. The highest level, Level III, additionally includes the information in question 1.d., and in questions 2.a., 2.j., 2.k., and 2.l (below). So far, most counties have used MPCA feedlot block grants or BWSR water plan block grant dollars to perform their inventories. The coordination of the proposed inventory for the GEIS, with the local County Water Planners and the MDH Source Water Protection program, will leverage available dollars to provide information for all three purposes (the CLWP, the Source Water Protection plan for each PWS, and for this GEIS study).

Using the information from Part A study (question 1, above) within each hydrogeological region, a stratified random sampling of livestock facilities (including the entire range of operation types and sizes) should be performed to determine impacts on water (a "Part B" investigation). This second, regional level of investigation must consider all potential impacts to surface waters and groundwaters. In a review of information on nitrate in groundwater in Wisconsin, a panel of experts from diverse disciplines has concluded that, on a statewide basis, about 90% of the nitrate detected in groundwater is from agricultural sources (fertilizer, manure, and legumes). Septic systems and other sources were shown to only contribute 9% and 1% respectively.

To get the most information about impacts to water, the randomization of livestock facilities should be employed after initially choosing those facilities with good information on well characteristics (age, depth, aquifer, etc.). (A second tier of randomization may need to be done for facilities without good well information; it is likely they would be biased toward older and/or smaller facilities, which may have significantly different impacts to the environment.) The Part B investigation must evaluate each different major hydrogeologic region, and should study the following:

- How does each facility store, remove, and sell and/or apply all animal wastes generated on the farm?

- For their manure storage system(s)(lagoons/basins, pits, manure packs, etc.), what are the ages of the systems, designs (earthen unlined lagoon, clay-lined lagoon, synthetic-lined or concrete-lined basin, etc.), history of maintenance, etc.?

■ Does the storage system have perimeter tile drainage? Where are all drainage tiles on the farm located? Can a sampling system be installed to study water quality parameters, and changes in those parameters over time, (to help address the question of how much leakage there is from the animal waste storage system)?

■ Could there be any old, unknown tiles beneath, or adjacent to, the lagoons, pits, etc. which could enhance underground leakage? (Old but forgotten drainage tiles have been found in Iowa, after livestock facilities were built, and the tiles were later determined to provide direct, but invisible, connections to groundwater because old tile lines frequently leak).

■ What evidence, if any, demonstrates whether, and how much, chronic leakage there is to groundwater or to overland runoff? (A carefully designed water budget protocol would be necessary over no less than a full year, including accurate measurements of all sources of water inputs to the manure system and water exports out to the environment, including direct measurements of evaporation off the wastewater storage lagoons, basins, etc).

■ What is the actual performance of their storage systems (lagoons/basins, pits, manure packs, etc.)? Include the following:

1. Have they needed to repair leaks?
2. Were the leaks (if any) to overland runoff, surface water, or groundwater?
3. Has the manager followed their filling and emptying schedules?
4. Have they had any emergencies, and, if so, what were the conditions and the solutions?
5. Compare similar designs of systems in different hydrogeologic areas. In some of the Iowa work, it has been proposed that even lined basins leak where the underlying sediments are permeable. (For instance, cracks develop in concrete basins from freeze-thaw heaving and chemical corrosion of the concrete; synthetic liners leak along poorly sealed seams; earthen basins leak because of the development of worm burrows, plant roots, secondary blocky soil structures, etc). Yet where underlying sediments are relatively impermeable, earthen basins may leak only very slowly or at a negligible rate. (If these things are also true in Minnesota, the hydrogeologic setting of a feedlot may have a great deal more effect on groundwater than the actual design of the system).

■ What kind(s) of waste treatment is/are used, if any, including the entire range from no treatment, to composting, to highly-designed wastewater and solids/sludge treatment (similar to municipal wastewater treatment systems)?

■ What are the physical, chemical, and biological parameters of the final (either untreated or treated) wastewater and solids/sludge?

■ What is left over to be disposed of, if anything, and how is it treated and disposed? (For example, how are carcasses disposed? Placental debris--which may be highly infective?)

■ What are the other land use practices of each facility? Which fields get manure? Which get chemical fertilization? Are legumes used for nitrogen fixation? Which fields get a combination of these and what combination?

■ At what rates, timing, and how evenly, are manure and fertilizers spread on the different fields? How is calibration of spreading equipment really done? At what frequency (among farmers) is over-application of nutrients practiced?

■ What type of pollution control measures are in place? Do they meet all requirements, if any, of their permit conditions? Do they meet the county standards?

What are the measurable effects of animal wastes on the environment? For each feedlot in the stratified sampling (Part B) investigation, on-site measurements should be made on: physical, chemical, (and biological--such as pathogens--where relevant) parameters, including:

■ Ammonia emissions and atmospheric deposition (to develop a total nitrogen budget);

■ Surface waters of the surrounding streams, wetlands, lakes;

■ Groundwaters in the area, including the water quality parameters for at least the uppermost two aquifers;

■ Water quality parameters from regional-scale surface waters and groundwaters, for comparison to the local results;

■ Small-scale (local) specific information on soil types, slope, bedrock geology, hydrogeology, permanent buffer strips and grassed waterways, terracing, etc. of the farm and nearest neighbor properties, and annual information from each crop field receiving manure or chemical fertilizer, including crops grown, rotation strategy, etc.

The above two sets of questions should be used to frame a study of the actual performance of animal manure management strategies, including the performance of lagoons and waste storage systems, controlling for age, design, maintenance, leakage, etc., as well as the performance of different land application strategies of waste as fertilizer. Similar holistic evaluations of non-livestock farms, and of natural or protected areas, such as parks, should be performed in similar environments across the state, in order to determine baseline (or background--i.e., unimpacted) parameters of each environment, and as a control, to evaluate what are the resulting effects of animal feeding operations on the regional environment.

The microorganisms which exist in animal waste have been shown in numerous studies to exist at widely differing levels of organisms, and which have extremely variable viability due to any of the following:

■ changes in water quality (including loss of oxygen, increase of oxygen, temperature changes, sunlight-induced death, dessication and re-wetting, etc.);

- ■ time since leaving host (livestock);

- ■ interactions among pathogens (food web dynamics), etc.

- ■ other factors, which may include transport between hydrogeologic regimes (direct surface water inputs into groundwater, such as in the karst area), etc.

Some of the more recent studies suggest there may be some pathogenic organisms which remain viable for dramatically longer times or over significantly longer travel paths, and continue to be a health threat, as water moves overland as runoff, or through soils, and into surface waters or into different types of aquifers.

To address this potential, an additional study ("Part C") should determine:

- ■ Which, if any, microbiological organisms, which are pathogenic to humans, survive longer than coliforms, including fecal coliforms and E. coli (the indicator organisms currently used for evaluating public water supply systems)?

1. Do they have a dormant stage, after which they can return to viability?
2. Can they survive some stressor, such as dessication, then become viable later?
3. What is the maximum time they can survive the stressor, and return to viability?

- ■ Which of these survive in different water qualities longer than the indicator organisms?

- ■ Which of these survive transport through different hydrogeologic regimes longer than the indicator organisms?

- ■ If there are pathogens which find their way into groundwater, under what conditions, if any can they remain viable long enough to emerge from a well and be a health threat? (Remember, that private drinking water wells often have no treatment at all. The water quality of all drinking water must be carefully protected, because private systems cannot be assumed to use treatment techniques.)

- ■ Can any pathogens be shown to remain a health threat <u>after</u> passing through water treatment techniques such as those required by the Surface Water Treatment Rule (SWTR)? This is a critical factor to study, to build on previous work (which has so far not identified significant health risks if SWTR treatment performance standards are met). However, this question needs continuing study because of numerous changing conditions e.g., continuing discovery of new strains of microorganisms, the emergence of new antibiotic-resistant strains, and the increasing size of vulnerable populations.

- ■ If there are any other microorganisms which would be more conservative indicators, can new tests be developed that would be cheap and easy to perform, similar to the coliform tests now available? (Obviously, something that is too difficult or expensive to test for would not be a practical indicator.)

■ Overall, should Minnesota consider using any other indicator organisms, either in addition to coliforms, or in place of coliforms, to evaluate pathogenicity?

After on-site measurements of physical, chemical, and biological aspects have been made, then models can be developed for each hydrogeologic region, to explicitly distinguish:

■ Nutrient imports and exports (including fertilizer, crop, soil, livestock, and manure pools);

■ Imports from fertilizer, feed, animals, etc.;

■ Losses to surface waters and groundwaters, and the atmosphere, as well as to other regions (via export of feed or animals).

Such models should be used to:

■ Simulate predicted changes in the density and distribution of livestock production, based on the regional ecosystem and present trends in agricultural management;

■ Evaluate alternative types of livestock operations. Alternative types would be those which operate in different ways (compared to the recent trends of the concentration of livestock in progressively larger operations), including:

1. dispersal of livestock onto more farms;
2. diversification of crops and livestock;
3. spatially closer links between nutrients, feed, and livestock;
4. and increasing reliance on on-farm, rather than purchased off-farm, nutrients (such as biological nitrogen fixation, more efficient nutrient cycling, etc.);

■ Predict changes to air quality, and to water quality parameters in the surface waters and groundwater systems (and therefore, to drinking water supplies). These predictions should include scenarios where the nutrient inputs are non-point sources (across large cropping areas), as well as point-sources (from accidental spills, from intentional discharges, from long-term seepage of lagoons and basins that may not be visible at the surface, etc.).

■ Predict what will be the costs to individual private well owners, and public water supply systems, if the water quality deteriorates from livestock agricultural inputs. Costs would include such items as:

1. drilling new, deeper well(s);
2. hauling water, if there is no potable water available at a greater depth;
3. buying (or supplying) bottled water to rural families;
4. and any increased costs for purchased water from distant sources, if local supplies deteriorate too much (i.e., so that the water quality exceeds drinking water standards for health).

These predictions and cost analyses should be given careful attention, to understand how present agricultural trends may be externalizing waste management costs to the greater environment, and thus as a burden upon the public health. Such predictions for alternative types of livestock operations should give a basis for comparison of what options there are, to maximize the best qualities of a healthy livestock economy and a healthy environment.

SUMMARY OF CURRENT RESEARCH

Investigators: *Michael Sadowsky*

Institution or Affiliation: *University of Minnesota*

Title of Study: *Sources of fecal pollution using DNA fingerprinting techniques*

Funding Agency: *Legislative Commission on Minnesota Resources*

Duration of Study: *July 1, 1999 to July 1, 2001*

Objectives: *To create a database of DNA fingerprints from fecal coliform and correlate to isolates obtained from watershed areas.*

Approach: *We will isolate E. Coli from known animal and human sources, produce DNA fingerprints, correlate to DNA fingerprints using environmental isolates.*

Progress: *None.*

Publications: *None.*

Investigators: *D. J. Mulla and P. Brezonik*

Institution or Affiliation: *University of Minnesota*

Title of Study: *Bioavailable phosphorus credits in payment for pounds program*

Funding Agency: *Minnesota Pollution Control Agency*

Duration of Study: *June1, 1998 to August 1, 1999*

Objectives:

■ Determine the relationship between soil physical and chemical characteristics and desorbable phosphorus for unmanured soils of the Minnesota River basin.
■ Determine the relationship between phosphorus sorption saturation, soil physical and chemical characteristics, and dissolved phosphorus in runoff for unmanured soils of the Minnesota River basin.
■ Determine the relationship between bioavailability of phosphorus, soil physical and chemical characteristics, and phosphorus sorption capacity for unmanured soils of the Minnesota River basin.

Approach:

■ Select specific watersheds and agroecoregions for soil sampling. Identify sampling sites, sampling protocols, and experimental designs. Collect soil samples.

■ Characterize soil physical and chemical properties including: organic matter content, pH, particle size distribution, Bray-1 available phosphorus, total phosphorus, calcium carbonate level, aluminum oxide and iron oxide content.

■ Evaluate bioavailability of phosphorus in samples using sodium hydroxide extraction, calcium chloride extraction, iron oxide resin strips, and algal bioassay.

■ Conduct experiments to determine phosphorus sorption saturation and desorbable phosphorus.

■ Conduct laboratory runoff experiments to determine dissolved phosphorus content in runoff under simulated storms.

■ Conduct statistical analysis to develop calibration curves between soil physical and chemical characteristics and:

5. desorbable phosphorus.
6. phosphorus sorption capacity.
7. phosphorus bioavailability.

Progress:

To date we have found an excellent relationship between calcium carbonate equivalent in soil and either total phosphorus or plant available phosphorus. Phosphorus sorption capacity is also strongly correlated with calcium carbonate equivalent. Algal bioassay experiments are in progress to determine bioavailability of P from various soils.

Publications: *None.*

Investigators: H. Murray, D. Allan, and D. J. Mulla

Institution or Affiliation: University of Minnesota

Title of Study: Sustainable Farming Systems

Funding Agency: Legislative Commission on Minnesota Resources

Duration of Study: September, 1996 to June 30, 2001

Objectives: Study the economic and environmental impacts of sustainable farming systems at 8 sites in the Minnesota River basin.

Approach: Comprehensive data from 8 on-farm research sites will be used to evaluate the impacts of alternative farming systems on the environment and on economic profitability. The farms studied include:

- Rotational grazing on pastures
- Ridge tillage in a corn-soybean rotation
- Conventional corn-soybean rotation with tree buffer strips and buried tile inlets
- Organic corn on rotationally grazed pastures
- Alfalfa fields

At each site automatic water samplers are installed to collect tile drainage from surface tile intakes and subsurface drains. Samples are being analysed for nitrate, ammonium, soluble and particulate phosphorus, bioavailable phosphorus, biochemical oxygen demand, and sediment.

Progress:

Monitoring results through 1998 show that alternative practices produced significantly less pollution of runoff and drainage water than conventional practices. Precipitation during 1997-98 in the growing seasons was below normal. A great number of runoff events have occurred during 1999 from all fields studied. The water samples from these events are currently being analysed.

Publications: *None.*

Investigator: D.E. Storm

Institution or Affiliation: OKLAHOMA STATE UNIVERSITY

Title of Study: DEVELOPING A RISKED BASED APPROACH TO WATERSHED/BASIN LEVEL NONPOINT SOURCE POLLUTION ASSESSMENT

Funding Agency: HATCH PROJ.

Duration of Study: 01 OCT 1997 TERM: 30 SEP 2002

Objectives: A risk-based systems approach to watershed/basin-level pollutant assessment and trading will be developed to address point and nonpoint sources of pollutants within agricultural and urban watersheds. The systems approach will integrate ecology, engineering, economics and political science to promote source water protection and address declining water quality from point and nonpoint source pollutant loading to surface waters.

Approach: The first step is to determine the pollutant loading a water body can assimilate without degrading ecological services, exceeding water quality standards, or exceeding local water quality objectives. To answer this question, a methodology for calculating Total Maximum Daily Loads (TMDLs) for nutrients and/or sediments will be developed. The next step is to identify the sources of specific pollutants within the watershed and characterize the pollutant-reduction potential for each source. The risk of exceeding a specific TMDL based on current land-use practices will be quantified using Monte Carlo simulation modeling. The final step will be to evaluate and optimize the opportunities for pollution reduction using economic cost/benefit analysis and policy compatibility modeling. These three steps will be combined into a systems approach to be applied on a watershed or basin level using a quantifiable uncertainty analysis.

Progress: Considerable progress have been made in developing methodologies to create TMDL for basins in Eastern Oklahoma. These techniques have regional and national applicability. Specifically, two new focused efforts are underway in the Lake Eucha Basin in northeast Oklahoma and Northwest Arkansas. The Objectives of the two projects are: 1) characterize N and P dynamics in four tributaries of Spavinaw by performing in-stream nutrient injection studies to evaluate seasonal impacts, compare biotic and abiotic sinks, evaluate flow regimes impacts, 2) using Matlock periphytometers, determine the in-stream limiting nutrient in Lake Eucha tributaries on a seasonal basis and assess the lotic ecosystem trophic status, 3) use stream periphyton and macroinvertebrate community structure to assess water quality in Lake Eucha tributaries, 4) characterize stream sediments and sediment-P interactions by measuring equilibrium P concentration, P buffering capacity, exchangeable P, particle size distribution, and sediment organic matter content in Lake Eucha tributaries, 5) develop recommendations for management of upland areas, 6) develop and implement a statistically valid soil sampling plan for measuring the soil test phosphorus for representative locations throughout the Oklahoma portion of the Lake Eucha basin for basin scale modeling, 7) convert SIMPLE to Microsoft NT operating system (SIMPLE, Spatially Integrated Model for Phosphorus Loading and Erosion, is a daily time step, continuous simulation, distributed-parameter modeling system developed to estimate watershed or basin scale sediment and phosphorus loading to surface waters). 8) compile required data and predict average annual runoff volume, sediment load, and dissolved and sediment-bound phosphorus loading to the surface waters of the Lake Eucha Basin. Conduct independent SIMPLE simulations using historical rainfall data to provide an estimate of current loading and loading from a range of soil phosphorus levels. Conduct continuous SIMPLE simulations using stochastically generated rainfall to estimate long term phosphorous loading impacts resulting from a variety of litter export scenarios.

Publications:

1. Haan, C.T., D.E. Storm, T. Al-Issa, S. Prabhu, G.J. Sabbagh, D.R. Edwards. 1998. Effect of parameter distributions on uncertainty analysis of hydrologic models. Transactions of the ASAE 41(1):65-71.

2. Matlock M. D., M. E. Matlock, D. E. Storm, M. D. Smolen and W.J. Henley. 1998. Limiting nutrient determination in lotic ecosystems using a quantitative nutrient enrichment periphytometer. Journal of the American Water Resources Association, 34(5): 1141-1147.

3. Ramanarayanan, T.S., D.E. Storm, M.D. Smolen. 1998. Analysis of Nitrogen Management Strategies Using EPIC. Journal of American Water Resources.

Investigator: J.B. Swan, R.M. Cruse, and K.J. Moore

Institution or Affiliation: IOWA STATE UNIVERSITY

Title of Study: CROP AND RUMINANT SYSTEMS TO CONSERVE MIDWESTERN UNGLACIATED SOILS AND WATER QUALITY

Funding Agency: HATCH PROJ.

Duration of Study: 01 OCT 1996 TERM: 30 SEP 2001

Objectives:

- Evaluate alternative forage production systems in intensive cattle management.
- Evaluate cattle response to alternative forages.
- Evaluate forage-grain-cattle management systems that conserve soil and water quality.

Approach: Kura clover will be evaluated as a living mulch for corn production. Macronutrient and soil pH requirements of cup-plant will be determined. Yield and composition of stockpiled forages and crop residues for wintering beef cows will be determined. Performance of heifers fed cup-plant will be compared with those fed alfalfa silage. Calf production, reproductive efficiency, forage selection and forage intake by beef cows grazing in year-around systems will be determined. Preferential transport of contaminants under ridge-tillage will be determined. Effects of crop rotation on soil and water quality will be evaluated. Economic analysis of alternative management-intensive grazing systems for beef cattle operations will be developed.

Progress: To determine the level of soil erosion protection achieved with a no-tillage (NT) corn and soybean sequence on a highly erodible low organic matter silt loam soil with restricted rooting depth, the effect of previous crop and soil depth on percent surface cover after planting and on crop yield was measured at the Lancaster Agricultural Experiment Station, Lancaster, WI. Soybeans followed corn in 1995 and 1997 and corn followed soybeans in 1996 and 1998. Percent surface cover increased 0.3% to 0.4% per cm soil depth after either crop. Corn yields averaged 10.4 Mg/ha in 1996 and 11.6 Mg/ha in 1998. Soybean yields averaged 4.5 Mg/ha in 1995 and 3.9 Mg/ha in 1997. In 1995 soybean yield increased 11 kg/ha for each cm increase in soil depth to red clay residuum (R2=0.56). Crop yield was not related to soil depth in 1996, 1997 or 1998.

Publications: No publications reported this period

Investigator: B.C. Joern

Institution or Affiliation: PURDUE UNIVERSITY

Title of Study: BIOGEOCHEMICAL CYCLING OF PHOSPHORUS IN SUSTAINABLE PRODUCTION SYSTEMS

Funding Agency: HATCH PROJ.

Duration of Study: 01 OCT 1996 TERM: 30 SEP 2001

Objectives:

- Validate a model that quantifies the amount of water-soluble P that can be leached from soils with different properties using soil profiles collected from manured fields.
- Determine the retention of specific P compounds present in animal manure by soils with different properties.
- Determine how feed management strategies that reduce total P excretion by swine and poultry impact manure P transformations.

Approach: Research conducted during this project period will include laboratory and field studies to validate a soil P retention model developed during the previous project period and to determine soil P retention dynamics for various P-containing compounds. Manure collected from animal feeding trials will also be used to assess the feasibility of reducing P excretion by monogastric animals using recently developed technologies. Results from this project will be used to develop a P indexing system that utilizes soil, crop, P source, and environmental factors to determine environmentally sustainable P management strategies for crop and livestock producers.

Progress: Phosphorus (P) is most often the nutrient that limits the productivity of freshwater ecosystems in the Midwestern United States. Agricultural fields can be non-point sources of P because high testing soils may release large quantities of soluble and bioavailable P via surface runoff, erosion, and leaching. Potential P based land application limits for animal manure mandate the development of simple, rapid, and reliable laboratory techniques for estimating potential edge of field losses of soluble and bioavailable P. We evaluated relationships among soil test P methods for soils with elevated P levels due to previous manure publications, and related these values to i) soluble P concentration (SPC) and bioavailable P (BAP). Of the soil test P methods evaluated, Bray P1 was most highly correlated to SPC and BAP. SPC was approximately 0.1, 0.25, 0.5, 1.0 and 2.0 mg P/L when Bray P1 exceeded 50, 75, 150, 200 and 500 mg P/kg, respectively. Amorphous Fe contents directly influence the relationship between BAP and Bray P1. We have adapted the SPC procedure for routine soil test purposes because it also is well related to BAP. The potential use of P based land application limits for animal manure has also increased the importance of optimizing animal feed P management. We evaluated the impacts of high available P (HAP) corn and phytase on P uptake and excretion by young pigs during a seven day digestibility trial. Our results show that, compared to the control diet, P uptake may be increased approximately 30 percent using HAP corn or phytase alone, but up to more than 50 percent when both phytase and HAP corn are present in the diet. Manure P excretion decreased 21, 23, and 41 percent below the control diet for the phytase, HAP corn, and HAP corn + phytase diets, respectively. This study clearly shows that diet modifications can dramatically reduce P excretion by young pigs. Improved dietary P management strategies may be used to offset the increase in land needed for sustainable pork production if P-based land application regulations are implemented.

Publications:

1. Brokish, J.A., B.C. Joern, and T.L. Provin. 1997. Using soil properties to predict soluble phosphorus losses from Indiana soils. Agron. Abstr. P. 329.

2. Baxter, C.A., B.C. Joern, O. Adeola, and P.A. Moore. 1998. Phosphorus excretion by pigs as influenced by high available phosphorus corn and phytase. Agron. Abstr. P. 349.

3. Brokish, J.A., and B.C. Joern. 1998. Soluble and bioavailable phosphorus in soils: a methods comparison. Agron. Abstr. P. 348.

4. Baxter, C.A., B.C. Joern, and O. Adeola. 1998. Dietary P management to reduce soil P loading from pig manure. In D. Franzen (ed.) Proceedings of the Twenty-eighth north central extension-industry soil fertility conference.

5. Brokish, J.A. 1998. Threshold phosphorus levels for Indiana Soils. M.S. thesis. Purdue University, West Lafayette, IN.

6. Moore, P.A., B.C. Joern and T.L. Provin. 1998. Improvements needed in environmental soil testing for phosphorus. pp. 21-30. In J.T. Sims (ed.) Soil Testing For Phosphorus: Environmental Uses and Implications. Southern Coop. Series Bull. No. 389. (A publication of SERA-IEG 17 USDA-CSREES Regional Committee: Minimizing Agricultural Phosphorus Losses for Protection of the Water Resource).

7. Sims, J.T., R.R. Simard, and B.C. Joern,. 1998. Phosphorus losses in agricultural drainage: historical perspective and current research. J. Environ. Qual. 27:277-293.

Investigator: P.G. Hartel

Institution or Affiliation: UNIVERSITY OF GEORGIA

Title of Study: STEROIDS IN RUNOFF WATER FROM PASTURES AND HAYFIELDS AMENDED WITH BROILER LITTER

Funding Agency: NRI COMPETITIVE GRANT PROJ.

Duration of Study: 01 JUL 1997 TERM: 30 JUN 1999

Objectives: We will determine estrogen and testosterone concentrations in runoff and subsurface drainage from pastures and hayfields amended with broiler litter.

Approach: Our approach is to use an existing field site near Eatonton, Georgia, and originally designed to assess N and P losses from broiler litter - amended pastures, to measure estrogen (as estradiol) and testosterone in runoff and subsurface drainage. Each of the eight field plots is sufficiently large (0.6 ha) to determine true "edge of field" losses. Four pastures and four hayfields will each be amended with broiler litter or left unamended (control). Estradiol and testosterone will be measured in runoff or subsurface drainage by enzyme immunoassay.

Progress: Research on endocrine disrupters has virtually ignored the contribution of natural hormones to the environment from animal and human wastes. Given their quantity and potency, these androgens and estrogens have considerable potential for adverse environmental effects. For example, broiler litter (a mixture of broiler manure, bedding material, feathers, and waste feed) contains 65 ng of 17 beta-estradiol and 133 ng of testosterone per g of dry weight. In 1997, the poultry industry produced over 10 billion kg of broiler litter, 90% of which was applied to pastures and hayfields. We determined the amount of testosterone and estradiol (and their conjugates) in runoff water from six sloping (4 to 8% grade), 0.8-hectare plots, each surrounded with an earthen berm to channel surface runoff. Each plot was instrumented to record temperature, rainfall, and runoff volume. Three of the plots were hayfields and three were pastures. Background levels of testosterone and estradiol ranged from 14-19 and 40-50 ng per liter in runoff, respectively. When cattle were placed on the plots, the levels of testosterone and estradiol increased to 18-36 and 100-140 ng per litter, respectively. When grazed plots were amended with 9,000 kg of broiler litter per hectare and a runoff event occurred one day after application, levels of testosterone ranged from 63-1000 ng per liter and estradiol from 150-2300 ng per liter. Of these amounts, approximately 40 to 50% of the estradiol and 50 to 90% of the testosterone were in their free state; the remaining percentages of estradiol and testosterone were as conjugates. In a runoff event 12 days after litter application, testosterone and estradiol ranged from 42-120 and 46-100 ng per liter, respectively. By 200 days after litter application, levels of testosterone and estradiol were essentially at background levels. After 17 months without any litter application and 10 months without animals, the levels of testosterone and estradiol were at background levels and ranged from 13-19 and 50-80 ng per liter, respectively. Our research suggests that a) testosterone and estradiol may pose a serious environmental problem if runoff events occur soon after litter application; b) testosterone and estradiol exist in variable percentages as conjugates; and c) cattle may contribute to the environmental hormone "load". Our study is the first to document estradiol and testosterone (and their conjugates) in runoff from large field plots amended with animal waste under natural conditions, and highlights the need to understand the environmental fate of these compounds.

Publications:

In Print Abstract: Finlay-Moore, O., Hartel, P.G., and Cabrera, M.L. 1999. Estradiol and testosterone in runoff water from pastures and hayfields amended with broiler litter. Keystone Symposium B5: Endocrine Disruptors, January 31-February 5, Granibakken, CA.

Investigators: Trlica, M. J.; Leininger, W. C.; Frasier, G. W.

Institution or Affiliation: COLORADO STATE UNIVERSITY

Title of Study: GRAZING IMPACTS ON INFILTRATION, RUNOFF, AND EROSION IN A MONTANE RIPARIAN ECOSYSTEM

Funding Agency: SPECIAL GRANT PROJ

Duration of Study: 01 SEP 1996 TERM: 31 AUG 1999

Objectives:

- Separate out effects of cattle trampling from grazing plus trampling on water infiltration, runoff, and sediment movement.
- Evaluate how differences in vegetation canopy and soil surface characteristics affect surface hydrology.
- Integrate these findings, with additional research, to define Best Management Practices for montane riparian ecosystems.

Approach: Steers will be allowed to trample or graze and trample riparian plots. A rainfall simulator will be used to create a high-intensity rainfall event over these plots, and sediment will be added to plots in overland flow. Runoff and sediment yield will be determined, and sediment migration will be measured

Progress: Agency managers are using information to design Best Management Practices for riparian filter strips** Grazing in riparian areas has often been considered to have negative impacts on soils, vegetation, and water quality. Many riparian areas are resilient and often respond favorably to management changes. Our results indicated that, even with heavy livestock grazing, sediment filtration in a montane riparian community was about 85% for a sandy loam sediment in a 10m buffer strip. The length of microchannels and density of vegetation stems were the major determinants of the filtration capacity of the buffer strip. However, runoff rates of overland flow and concentrations of nitrate-N, ammonia-N, and phosphate-P in the runoff from heavily grazed plots were much greater than from ungrazed or mowed plots. Nitrate-N, ammonia-N, phosphate-P and fecal coliform fluxes from grazed plots were 180%, 1350%, 2100%, and 2400% greater, respectively, than fluxes from control plots. Manure and urine deposited during heavy grazing increased the concentrations and fluxes of nutrients and fecal coliform bacteria in runoff water. Even with heavy grazing, the concentrations of nitrate-N and ammonia-N in runoff from grazed plots did not exceed the established EPA criteria of 10 mg/L and 5.1 mg/L (based on an average temperature of 5 C and pH of 7.5), respectively. However, the average concentration of fecal coliform from both grazed and control plots exceeded the EPA standard of 1000 CFU/100mL for secondary water contact

Publications:

1. Frasier, G.W., Trlica, M.J., Leininger, Leininger, W.C., Pearce, R.A., and Fernald, A. 1998. Runoff from simulated rainfall in 2 montane riparian communities. J. Range Manage. 51:315-322.

2. Pearce, R.A., Trlica, M.J., Leininger, W.C., Mergen, D.E., and Frasier, G. 1998. Sediment movement through iparian vegetation under simulated rainfall and overland flow. J. Range Manage. 51:301-308

3. Pearce, R. A., Frasier, G.W., Trlica, M.J., Leininger, W.C. Stednick, J.D., and Smith, J.L. 1998. Sediment filtration in a montane riparian zone under simulated rainfall. J. Range Manage.51:309-314

4. Pearce, R.A., Frasier, G.W. Leininger, W.C., and Trlica, M.J.. 1998. Sediment movement and filtration in riparian vegetation. Pp. 167-177. In: D. F. Potts (ed.) Rangeland Management and Water Resources. Proc. AWRA Specialty Conf., 27-29 May 1998. Reno, Nev

5. Alstad, K.P. 1998. Carbon and water relations of Salix as affected by browsing and hydrologic condition. M. S. Thesis. Colorado State Univ. Fort Collins, CO

6. Schenck, S.M., Trlica, M.J., and Leininger, W.C.. 1998. Restoration and recovery of a montane riparian plant community after a grazing disturbance. p. 10. In. Abstracts. Society for Range Management Annual Meeting. Guadalajara, Mexico. Feb. 8-12, 1998

7. Frasier, G.W., Trlica, M.J.and Leininger, W.C. 1998. Simulated rainfall runoff characteristics in riparian communities. p. 52. In. Abstracts. Society for Range Management Annual Meeting. Guadalajara, Mexico. Feb. 8-12, 1998

Investigators: Ribic, C. A

Institution or Affiliation: UNIV OF WISCONSIN

Title of Study: EFFECT OF ROTATIONAL GRAZING ON THE TERRESTRIAL BIRD COMMUNITY IN RIPARIAN ZONES OF SW WISCONSIN

Funding Agency: HATCH PROJ

Duration of Study: 01 OCT 1996 TERM: 30 SEP 2000

Objectives: The purpose of this study is to determine the differences in the avian community that result from using vegetative buffer strips and rotational grazing along riparian areas and to compare them to riparian areas that are continuously grazed. Specific objectives are

- to compare the vegetation structure in the three land use practices, particularly as related to the nesting and feeding habitat requirements of grassland birds,
- to compare the diversity and abundance of different guilds of song birds among the three practices, and
- to compare these results with the results from a concurrent water- quality study. This study will contribute to understanding if rotational grazing in riparian areas can benefit wildlife and protect water quality while allowing farmers to use riparian areas on their farms

Approach: We will replicate each of the 3 land use practices on up to 5 farms. General criteria for selection of study sites include: (1) study sites must all be located in Wisconsin's Driftless Area to minimize differences in ground water-surface water relationships, (2) the management regime should have been in place for at least five years to allow time for system responseto the regime, and (3) the vegetative buffer strips will be located on farms that have livestock. Because this study is being done in conjunction with a water-quality study, sites will be located near headwater areas, where the stream is large enough to support a viable trout community. Other variables that will be controlled include farm size, cattle stocking rate, herd size, and adjacent land use. We will work with the individual farmers to document the characteristics of the particular grazing regime used. For each management regime, the width of the study sites will encompass the entire riparian area, defined as the area of land adjacent to the stream in which vegetation and soil type are influenced by the stream's presence, and will extend at least 100 meters from the stream edge on both sides of the stream. At the minimum, categories of data collection will include species richness, abundance and diversity of riparian bird communities and surrounding upland bird communities, and riparian and upland area vegetation sampling for habitat characteristics

Progress: Bird community composition was compared between three riparian management options as part of a collaborative project assessing the influence of land use on riparian ecosystems. Birds were surveyed in 1996-98 using standard point counts on 12 sites along cold water streams; four rotational pastures, four continuous pastures, and four grassy (ungrazed) 20m buffer strips within row crop fields. The occurrence of special concern species (savannah sparrow, eastern meadowlark, bobolink), as well as overall bird abundance and diversity were compared between the three types of land uses and between the streamside (less than 10m from stream) and non-streamside(greater than 10m from stream) areas. In addition, twenty-five lowland and twenty-five upland continuous pastures were surveyed twice each year for two years with point counts in order to assess the relative importance of lowland (riparian) pastures for grassland bird species of concern. Buffer strips supported a higher abundance and diversity of birds within the streamside area than away from the stream, in the row crops. Due to the concentration of birds within the buffer strip itself, these sites supported an overall higher diversity and abundance of birds than either rotational or continuous pastures. In pastures there was no difference in bird abundance or diversity between rotational and continuous pastures, but continuous pastures did support a greater number of species of concern. This may be explained by the fact that continuous pastures were on average ...sensitive", i.e. they are more likely to occur on larger pastures. In addition, rotational pastures tended to be located in more wooded areas, which may be unsuitable to species that prefer relatively open, non-wooded landscapes. We are continuing research on potential landscape effects on species of concern. Preliminary analyses indicated that some grassland bird species of concern were generally more likely to be present on upland pastures than lowland, riparian pastures. Grasshopper sparrows, bobolinks, and eastern meadowlarks occurred more frequently on lowland pastures, while savannah sparrows, western meadowlarks, and upland sandpipers did not prefer either upland or lowland pastures. Upland sandpipers, however, occurred only on lowland pastures that also contained adjacent upland pasture. Overall, pastures appear to be more valuable for grassland birds than buffer strips located within row crops. The type of grazing management in a pasture, however, may be less important in determining grassland bird community composition than larger-scale factors such as the pasture size and characteristics of the surrounding landscape. In general, the lowland pastures that are associated with streams do not support some species of concern as frequently as upland pastures. Focusing conservation efforts on upland pastures may therefore be most effective

Investigators: Albrecht, K. A

Institution or Affiliation: UNIV OF WISCONSIN

Title of Study: INTEGRATED CROP, SOIL, AND ANIMAL MANAGEMENT SYSTEMS FOR UPPER MIDWEST UNGLACIATED SOILS

Funding Agency: HATCH PROJ

Duration of Study: 01 OCT 1996 TERM: 30 SEP 2001

Objectives: Evaluate alternative forage production systems for intensive cattle management

Approach: A system using kura clover (Trifolium ambiguum M.Bieb.) as a permanent ground cover and living mulch for sustainable corn production will be developed and tested. Four levels of kura clover suppression will be created by glyphosate application in early spring and corn will be sown with a no-till drill into the suppressed legume. Corn silage and grain yields and the ability of kura clover to meet total corn N needs will be determined. Recovery of kura clover by clonal growth from rhizomes the year after corn production will be measured. The agronomic performance of cup-plant (Silphium perfoliatum L.) as a long-lived, environmentally friendly, silage crop will be determined. Specifically, harvest management schedules and nutrient reuirements that will optimize persistence and forage yield and quality of this native prairie plant will be identified. Cup-plant's capacity to recycle nutrients in livestock will also be determined. The compatibility of several short and tall prairie grass species and domesticated forage and turf species in cup-plant production systems will be determined. Response variables to be measured include cup-plant yield, seasonal distribution of ground cover provided by the grasses, and rating of bird habitat potential

Progress: Six years of small-plot research have demonstrated that cup-plant has excellent agronomic potential in terms of yield, persistence, and laboratory measures of forage quality. We fed cup-plant silage to lactating dairy cows and discovered that we could feed 15% of the ration of dairy cows as cup-plant silage and not affect milk production. Milk production was depressed slightly but significantly when 30% of the ration was cup-plant. The silage contained significant amounts of butyrate, so the drop in milk production was likely do to poor fermentation of the silage. Although cup-plant silage contains more lactate than we have normally found in alfalfa or corn silages, the pH usually does not drop below 5.5. Our preliminary observations suggest that cup-plant has a high buffering capacity and it may be difficult to produce stable silage from this crop. Silage produced in 1998 had no detectable butyrate and will be fed in the next 2 months. Our earlier results demonstrated that cup-plant forage can accumulate substantial amounts of nitrogen and phosphorous. We have initiated a new experiment to test how much N and P the crop can remove and also how much of these nutrients it requires for production. After a two year experiment we concluded that kura clover can be used as a living mulch in corn without reduced corn silage or grain yields. The kura clover will recover to full production the following year. Our previous experiences demonstrated that if kura clover is not adequately suppressed, corn yields will be reduced. We initiated a new experiment in spring 1998 to determine the best management strategies to suppress spring growth of kura clover so that it does not interfere with corn establishment and early growth. Use of new herbicide resistant corn hybrids and their associated postemergence herbicides in this living mulch system allowed greater flexibility in control of kura clover competition.

We will continue evaluation of Liberty Link and Round-Up Ready hybrids in the kura clover living mulch system in 1999. Improved nitrogen-fixing inoculum strains for leguminous crops must be able to effectively competed for nodulation with indigenous strains, enhance legume productivity compared to that obtained with indigenous strains, and maintain stable expression of any added genes in the absence of selection pressure. A transposable element was constructed containing the tfx region, for expression of increased nodulation competitiveness, and the par locus for plasmid stability. The transposon was inserted into tetA f pHU52, a broad-host-range plasmid conferring the H2 uptake phenotype. The H2 uptake phenotype oxidizes the H2 and channels the resulting electrons through an electron transport chain that recovers most of the energy lost in H2 production in the form of ATP. The resulting plasmid, pHUTFXPAR, conferred the plasmid stability, trifolitoxin production, and H2 uptake phenotypes in the broad-host-range strain Sinorhizobium sp

Potential Implications: Because cup-plant tolerates very wet soil conditions, it could play a role in recycling agricultural nutrients from fertilizer and manure at the interface between conventional agricultural fields and wet-lands. The harvested and ensiled cup-plant, with nutrients that would have otherwise moved into wet-lands, would be fed to livestock. The kura clover living-mulch system for corn production continues to show promise as a means to reduce soil erosion and nitrogen fertilizer and herbicide inputs in corn production

Publications:

1. Zemenchik, R.A., K.A. Albrecht, C.M. Boerboom, J.G. Lauer, and R.M. Klemme. 1998. Agronomic, environmental, and economic implications of kura clover-corn intercropping. pp. 21-25, In American Forage and Grassland Council Proc., March 8-10, 1998, Indianapolis, IN

2. Albrecht, K.A., R.A. Zemenchik, and B.W. Kim. 1998. Kura clover: the persistent legume. pp. 50-52. In Proc. Wisconsin Forage Council, January 27&28, 1998, Eau Claire, WI

3. Albrecht, K.A., M. Rankin, and R.M. Sulc. 1998. PEAQ: A simple method to estimate alfalfa quality in the field. pp. 24-30. In Proc. Wisconsin Forage Council, January 27&28, 1998, Eau Claire, WI.

4. Albrecht, K.A. and B.W. Kim. 1998. Competition effects on kura clover rhizome development. Agronomy Abstracts. p. 107.

5. Woodfield, D., K.A. Albrecht, E.J Bures, and W. Green. 1998. Characterization and performance of Wisconsin white clover ecotypes. Proc. 15th Trifolium Conference. p. 15.

6. Albrecht, K.A. and B.W. Kim. 1998. Rhizome development of kura clover. Proc. 15th Trifolium Conference. p. 11

7. Albrecht, K.A. 1998. Kura clover-a promising legume for Wisconsin sheep pastures. Proc. 46th Spooner Sheep Day, p. 29

Investigators: Rusch, Donald

Institution or Affiliation: Wisconsin Cooperative Wildlife Research Unit, Madison, WI

Title of Study: The influence of cattle grazing on brown-headed cowbird parasitism rates: A determination of the parasitism-distance threshold

Funding Agency:

Duration of Study: 9/20/1995 to 8/31/1997

Objectives: In this study, we propose to address 3 separate research questions. First, we will continue to investigate the influence of grazing on songbird communities in Pinyon-juniper woodlands. We will use the BBIRD project methodology to survey bird abundance, nest success, and vegetation characteristics. Special emphasis will be placed on nesting success and the influence of nest site characteristics. Second, we will investigate cowbird movements and behavior. We will accomplish this using radio-telemetry to document movements associated with breeding, foraging, and roosting habitat. We will compare the use of Pinyon-juniper woodlands, ponderosa pine, and prairie grasslands. Behavioral traits of female cowbirds and the distance they move from grazing, with respect to rate of parasitism, are of special interest. Finally, we will test hypotheses regarding nest defense behavior of the western wood peewee and solitary vireo using taxidermic mounts of female cowbirds

Progress: (4/30/1999) Our research fulfills both an applied and basic research need. First, there is currently no other ongoing research that addresses the impacts of grazing on neotropical migrants in a widespread western habitat type such as Pinyon-juniper. Land managers face increasing amounts of scrutiny due to the federal lands grazing policies, but have little scientific data with which to make decisions pertaining to grazing impacts on biodiversity. Our research fills an applied need by developing management guidelines to mitigate the impacts of grazing on one aspect of biodiversity. Second, ecologists have long recognized the importance of larger herbivores in ecosystems, yet few attempts have been made to integrate their role in the ecosystem with that of other vertebrates. The intricate relationship of nest-parasite, host, and habitat poses a basic research mystery yet to be solved. Since 1992, we have documented avian communities in an ungrazed and grazed landscape, amassing a sample . . . exceeds 700 host nests. Our data base is unique; it will contribute basic biological information to better understand the complex interactions among vertebrates in the ecosystem. Work completed

Potential Implications: 1) Define the cowbird parasitism gradient at moderate distances from grazing. 2) Identify both the maximum threshold distance that cowbirds travel, and the minimum threshold distance where parasitism becomes compensatory. 3) Develop a model (logistic regression, kriging) to predict impacts of cowbirds on a primary host, the solitary vireo, at varying distances from grazing. 4) Identify grazing management strategies (spatial and temporal) that can be used to mitigate the impacts of parasitism on songbirds

Investigators: Undersander, Dan; Lyons, John; Bozek, Michael

Institution or Affiliation: Wisconsin Cooperative Fishery Research Unit, Stevens Point, WI

Title of Study: Using rotational grazing in riparian areas to control woody vegetation: Evaluating benefits to stream systems in Wisconsin

Funding Agency

Duration of Study: 7/1/1998 to 6/30/2000

Objectives: Stream ecosystems have been degraded by unrestricted livestock access across much of North America, including Wisconsin. Many farms in the Midwest rely on natural surface waters for watering livestock. Overgrazed riparian areas degrade water quality and fish habitat and decrease the quality and quantity of the fish population. Traditional Best Management Practices (BMPs) for farmers aimed at improving stream water quality and fishery resources have recommended that cattle be excluded from riparian areas in order to protect streamside vegetation and fish habitat. Cattle exclusion is often unpopular among Wisconsin farmers because it is expensive and takes land out of production. Nonetheless, fencing protects riparian areas by allowing vegetation to become more dense and full, which stabilizes streambanks. However, vegetation in fenced riparian areas changed rapidly from grasses to shrubs to trees and research southwestern Wisconsin suggests that stream habitat quality decreases as streambanks become wooded. If stream habitat and water quality decline as riparian areas become wooded, keeping riparian areas at some early stage of succession could benefit water quality and stream habitat. A new management practice that has been proposed to utilize riparian area forage and maintain good stream habitat and water quality is well-managed or intensive rotational grazing (IRG). Well-managed grazing allows farmers to utilize the production potential of riparian pastures while potentially protecting riparian vegetation and stream habitat quality. Determining how to best manage riparian areas so that forage can be utilized and aquatic habitats is a priority. While it is clear that unrestricted livestock access to streams is detrimental, it is not clear that fencing stock out and allowing conversion of these areas to woody vegetation is the best alternative. Habitat assessments and surveys of the biotic integrity of the fish community . . . be used to evaluate different riparian management strategies on cold and warmwater streams throughout southwestern and central Wisconsin. This project will help clarify the habitat and fish community differences resulting from maintenance of woody and grassy vegetation on streambanks and evaluate an alternative management practice to protect riparian areas and stream habitat and allow use by livestock.

Progress: (4/9/99) This project is currently in the project design phase

Investigator: P.A. Moore Jr., ; T.J. Sauer

Institution or Affiliation: AGRICULTURAL RESEARCH SERVICE

Title of Study: POULTRY WASTE MANAGEMENT

Funding Agency: USDA INHOUSE PROJ.

Duration of Study: 28 FEB 1997 TERM: 27 FEB 2002

Objectives:

- Evaluate the effects of various manure management strategies on the environmental impacts to air, water, and soil resources;
- study the factors that affect phosphorus chemistry and transport in soil, water, and manure;
- evaluate the factors that influence surface water runoff within watersheds;
- evaluate the ability to predict critical hydrologic areas within watersheds.

Approach: Research on the efficacy of alum treatment of poultry litter to reduce P runoff and inhibit ammonia volatilization will continue. Studies will be conducted on broiler litter, turkey litter, laying hen manure, liquid hog manure and cattle manure. Phosphorus runoff will be evaluated from grazed pastures fertilized with both alum treated and normal poultry litter. Other management practices, such as altering the amount of P in the diet of poultry and swine using phytase enzymes or low phytate corn, will also be conducted. Basic research on P transformations in soils and phosphate mineral solubility will also be conducted. Research on the factors affecting surface water runoff, such as soil properties, plant type, landscape position, slope, and grazing intensity will also be conducted. This information will be integrated into existing or new models to predict hydrologically active areas within watersheds.

Progress: Research was continued on the effects of treating poultry litter with aluminum sulfate (alum). The results from these studies indicate that treating litter with alum is a cost-effective best management practice that reduces the negative impacts of this important resource on the environment, while improving poultry production. Laboratory studies showed that alum could reduce ammonia loss from litter, even when applied at low rates. Results from small plot studies showed that normal poultry litter caused a buildup of soluble phosphorus in soils, while alum-treated litter did not, even at high rates. This research also showed that alum-treated litter did not cause an increase in aluminum runoff or uptake by plants. Although fescue yields were not significantly affected by fertilizer type, yields from plots fertilized with alum-treated litter were 7% higher than with normal litter. Results also showed that both normal and alum-treated litter caused an increase in soil pH, while ammonium nitrate caused a decrease in soil pH. In another small plot study, cattle manure was found to have little impact on phosphorus runoff from tall fescue plots, compared to poultry litter. In another small plot study, phosphorus runoff from manure from broilers fed diets containing either low phytic acid corn or phytase enzyme or a combination of the two was evaluated. Data from this study indicated that there were no significant differences in phosphorus runoff using these modified diets. A study on the effects of various native and improved pasture grasses on hydrology was also initiated. Data from this study indicated that tall fescue resulted in less runoff than native species. Soils data were also collected from pastures which will be used for research on methods to predict hydrologically active areas in watersheds. In cooperation with USGS scientists, two springs draining a pasture watershed have been instrumented to measure water quality parameters. Water balance measurements on two research watersheds were initiated to compare potential nutrient movement in surface runoff to streams with transport via percolation to groundwater. A collaborative study with the National Soil Tilth Laboratory was conducted to monitor odor from an animal waste lagoon. Phosphorus runoff was monitored from watersheds which were fertilized with either alum-treated or normal poultry litter. Results showed that alum use resulted in 70% less phosphorus runoff than normal litter. Field trials on the efficacy of alum to improve poultry production were continued in conjunction with personnel from industry, universities, and various government agencies. These trials, which were conducted in 15 states and British Columbia, involved over 20 million birds. This research has resulted in one patent being issued and several patents pending. The rights to these patents have been licensed to General Chemical Corporation, who is marketing the product Al+Clear (poultry grade alum) to poultry producers throughout the United States.

Publications:

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2. Edwards, D.R., M.S. Coyne, T.C. Daniel, P.F. Vendrell, J.F. Murdoch, and P.A. Moore, Jr. 1997. Indicator bacteria concentrations of two Northwest Arkansas streams in relation to flow and season. Trans.

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4. Edwards, D.R., T.C. Daniel, H.D.Scott, P.A. Moore, Jr., J.F. Murdoch, and P.F. Vendrell. 1997. Effect of BMP implementation on storm flow quality of two Northwestern Arkansas streams. Trans. ASAE

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7. Sauer, T.J., J.L. Hatfield, and J.H. Prueger. 1997. Over-winter changes in radiant energy exchange of a corn residue-covered surface. Agric. For. Meterol. 85:279-287.

8. Daniel, T.C. and Moore, P.A., JR. 1997. Managing phosphorus in manure: causes, concerns, and BMPs. pp. 15-16 in Southeastern Sustainable Animal Waste Mgt. Proc., Univ. Georgia Pub. ENG97-001.

9. Moore, P.A., Jr., T.C. Daniel, D.R. Edwards, and T.J. Sauer. 1997. Using aluminum sulfate to reduce ammonia emissions and ... litter. pp. 97-102 SE Sustainable Animal Waste Mgt. Proc. Univ. of Georgia

10. Moore, P.A., Jr., W.E. Huff, T.C. Daniel, D.R. Edwards, and T.J. Sauer. 1997. Effect of aluminum sulfate on ammonia fluxes from poultry ... broiler houses. Int. Livestock Envir. Symp. 2:883-891. ASAE, St.

Investigator: M.B. McBride; W.S. Reid, E. Harrison, S. Degloria, J. Duxbury, and T. Steenhuis

Institution or Affiliation: CORNELL UNIVERSITY

Title of Study: HEAVY METALS AND NEW YORK AGRICULTURE

Funding Agency: HATCH PROJ.

Duration of Study: 01 OCT 1997 TERM: 30 SEP 2002

Objectives:

- ■ Characterize heavy metal inputs to agricultural soils in N.Y. from commercial fertilizers, animal manures and sewage sludges.
- ■ Assess bioavailability of heavy metals in different source materials to selected crops on farms. Assess the impact of sludge-borne metals on groundwater quality.
- ■ Develop spatial data bases of heavy metal content of N.Y. soils to assist decision making about land spreading of metal-contaminated wastes.
- ■ Conduct detailed field-scale mapping of soil and crop metal contents on selected farms that have used sludges for some time.

Approach: Fertilizers and manures will be collected from various sources in N.Y. State, and analyzed for trace metals by ICP emission spectrometry. Analyses will also be conducted on surface soils and subsoils of representative farming regions of N.Y. in order to obtain baseline data. Greenhouse experiments will be conducted with undisturbed soil columns to assess the leaching potential of sludge-borne metals and the impacts of metals on sensitive forage crops. More detailed farm-scale analysis of trace metals in soils and crops will be conducted on farms where sewage sludge has been applied for substantial periods of time. These data will be used to develop balance sheets for metals in N.Y. farming systems, and to generate spatial data on metal distribution.

Progress: A number of sewage sludges, commercial fertilizers, liming products and dairy manures were analyzed by microwave HF acid digestion and inductively coupled plasma-mass spectrometry (ICP-MS) for 32 elements, including the important toxic trace metals. Generally, limestone materials, and nitrogen and potassium components of the fertilizers contained negligible concentrations of all the potentially toxic trace elements. The phosphate component, however, contained significant levels of cadmium, arsenic, uranium and vanadium. Manures had low concentrations of all potentially toxic trace elements and heavy metals , with the exception that total Zn and Cu averaged 187 and 134 mg/kg , respectively. Most manures had Cu less than 100 mg/kg, but one of the 20 manures had Cu above 1000 mg/kg. Further investigation revealed that this anomaly was probably due to manure contamination from the use of Cu salts in "hoof dips". Sewage sludges were found to be contaminated with numerous toxic trace elements, generally at much higher concentrations than those found in manures. Preliminary analysis of these survey results indicate little potential for long-term accumulation of most trace elements from conventional soil amendments, with the possible exception of Zn and Cu, which are added to feeds. The potential for soil contamination at the farm scale is much lower with conventional fertilizers than with sewage sludges.

Investigator: D.T. Hill, R.B. Muntifering, and W.C. Wood

Institution or Affiliation: AUBURN UNIVERSITY

Title: ANIMAL MANURE AND WASTE UTILIZATION, TREATMENT, AND NUISANCE AVOIDANCE FOR A SUSTAINABLE AGRICULTURE

Funding Agency: HATCH PROJ.

Duration of Study: 01 OCT 1996 TERM: 30 SEP 2001

Objectives:

- Develop management tools, strategies, and systems for land application of animalmanures that optimize productivity and are compatible with sustained land and water quality.
- Develop and evaluate constructed wetlands, riparian zones, and other vegetative systems for treating animal wastewaters.
- Develop physical, chemical, and biological treatment processes and engineering systems for management of manures and other wastes.
- Develop methodology, technology and mangement practices to reduce odors, gases, airborne mocroflora, particulate matter and other airborne emissions in animal production systems.
- Develop and evaluate feeding sysems for their potential to alter excretion of environmentally-sensitive nutrients by livestock.

Approach: Each participating scientist will b responsible for his specific objectives as in the past.

Progress: Work performed during 1997-98 involved the use of overland flow treatment of swine lagoon effluent in which a study was performed to determine the effects of loading rate on the chemical properties of a loamy sand soil. The results of the study show that the chemical properties of the soil were greatly modified with nitrate concentration in both the deep seepage (below the root zone of a pastureland grass) and runoff a great concern for the highest application rate (4 x typical fertilizer application rate, 2240 Kg N/ha-yr), The phosphate concentration was a concern in the runoff but not in the deep seepage. A study on constructed wetlands related plant fill ratio to water temperature in the cells. Un-vegetated control cells show greater variation of temperature year round when compared to either a 10% or 5% vegetated plant fill ratio. The 10% fill ratio cells had significantly higher temperature in the winter months that the 5% fill ratio. This data is useful in the design of constructed wetlands for nutrient removal since biological activity is directly related to temperature. Nitrogen (N) fluxes were studied in fescue pastures amended with broiler litter in Major Land Resource Areas of the Southeast (Coastal Plain (Alabama), Piedmont (Georgia), and Appalachian Plateau (Tennessee). Ammonia flux was generally less than 10 kg/ha, representing a loss of <6% of applied N. Denitrification flux ranged from -20 to 2500 g N2O-N/m2/hr, but was always <5% of applied N. Nitrogen budgets indicated a substantial surplus of N at all sites. Above- and below-ground N2O emissions resulting from swine waste applications were studied on three Alabama soils (Black Belt, Coastal Plain, and Appalachian Plateau). Greatest average N2O surface emission over a 16-d period was observed from Coastal Plain soil (466 mg N2O/ha/hr). However, greatest average N2O concentrations at depth were observed in Black Belt soil (6.9 L N2O/L soil air). The wastewater treatment efficiency of a two-tiered constructed wetland treating swine lagoon effluent was evaluated at three wastewater loading rates for 29 months. The purpose of the study was to determine the maximum loading rate that the wetlands could operate and achieve the wetland effluent criteria of the USDA/NRCS. For the high, medium, and low loading rates, the hydraulic retention times were 5.1, 7.8, and 10.5 days, respectively, which achieved BOD5 loading rates of 11.5, 5.8 and 3.7 kg/ha/day. The respective TKN loading rates were 19.8, 10.0 and 6.0 kg/ha/day. Effluents from the low and medium loading rates met the UDSA/NRCS criteria of <30 mg/L for BOD5 and total suspended solids (TSS). The ammonia criterion for effluent from wetlands treating municipal sewage is <10 mg/L. The low loading rate achieved an effluent ammonia level of 10.7 mg/L. The study indicated that BOD5 and TSS effluent criteria (<30 mg/L) were met but the ammonia criterion (<10 mg/L) is more difficult to achieve. An alternative to discharging the wetland effluent is to treat the wastewater sufficiently to eliminate odor and enteric pathogens and then recycle the water to flush manure from the swine facilities.

Publications:

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2. Liu, F., C.C. Mitchell, J.W. Odom, D.T. Hill, and E.W. Rochester. 1998. Swine lagoon effluent disposal by overland flow: I. Effects on forage production and uptake of N and P. Agronomy Journal. 89:900-904.

3. Liu, F., C.C. Mitchell, J.W. Odom, D.T. Hill, and E.W. Rochester. 1999. Effects of swine lagoon effluent application on chemical properties of a loamy sand. BioResource Technology. (In Press).

4. Kown, S.R. 1998 Animal Waste Management in Alabama: Challenges and Issues. Master of Engineering Report. Auburn University, Auburn, AL.

5. Payton, J.D. and D.T. Hill. 1998. Plant Fill Ratio Effects on Water Temperature in Constructed Wetlands for Poultry Lagoon Wastewater Treatment. ASAE Paper No. 98-4118. ASAE. St. Joseph, MI 49085.

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9. Bender, M.R. and C.W. Wood. 1998. Effects of swine waste application on above- and below-ground nitrous oxide emissions. p. 335. In: Agronomy Abstracts, ASA, Madison, WI.

10. Sullivan, D.G., C.W. Wood, M.L. Norfleet, and W.F. Owsley. 1998. Ammonia volatilization losses from a swine waste amended system. p. 334. In: Agronomy Abstracts, ASA, Madison, WI.

11. Wood, B.H. and C.W. Wood. 1998. Nutrient and heavy metal losses in runoff from broiler litter amended corn. p. 31. In: Agronomy Abstracts, ASA, Madison, WI.

12. Marshall, S.B., C.W. Wood, M.L. Cabrera, M.D. Mullen, and E.A. Guertal. 1998. Nitrogen budget for fescue pastures fertilized with broiler litter. p. 30. In: Agronomy Abstracts, ASA, Madison, WI.

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14. Bender, M.R. and C.W. Wood. 1998. Above- and below-ground N2O emissions from swine waste amended soil. p. 6. In: Southern Branch Agronomy Abstracts, ASA, Madison, WI.

15. Marshall, S.B., C.W. Wood, M.L. Cabrera, E.A. Guertal, and M.D. Mullen. 1998. Non-gaseous pathways for nitrogen flux following amendment of fescue pastures with broiler litter. p. 7. In: Southern Branch Agronomy Abstracts, ASA, Madison, WI.

16. McCaskey, T.A., N.K. Gurung, S.P. Lino, S.V. Panangala, A.K. Witherow and T.L. Shadell 1998. Constructed wetlands controlling E.coli O157:H7 and Salmonella on the farm. Highlights of Agri. Research, Alabama Agri. Exp.Station 45(1):9-10.

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Investigator: T.C. Daniel

Institution or Affiliation: UNIVERSITY OF ARKANSAS

Title of Study: IDENTIFICATION OF THRESHOLD SOIL TEST PHOSPHORUS LEVELS TO MINIMIZE EUTROPHICATION

Funding Agency: HATCH PROJ.

Duration of Study: 01 NOV 1996 TERM: 30 SEP 2001

Objectives: The overall objective of the research is to develop a method for identifying threshold soil test phosphorus levels above which no additional phosphorus should be added either from the application of manure or commercial fertilizer. This requires accomplishment of several subobjectives, including the development of a portable small-scale rainfall simulator and a method to determine the relationship between the amount of phosphorus added and the corresponding elevation in soil test phosphorus.

Approach: A small (1 m2) portable rainfall simulator will be constructed by integrating the use of more water efficient nozzles in combination with solenoids to produce uniform rainfall patterns. Given boundary conditions such as a 5 cm hr-1 storm and an upper level of 1 mg 1-1 of runoff phosphorus, cut-off levels of P will be identified by using data collected from the simulation runs in combination with soild test P values. The investigators will begin with a pilot project between Arkansas, Pennsylvania, and Texas. Values from the small simulator will be compared with those from the larger simulator conducted on soil varying in known levels of soil test P. Once perfected, the project will be expanded to other states, such as North Carolina, attempting to identify threshold levels of soil P.

Progress: Soils that contain high P levels can become a primary source of dissolved reactive P (DRP) in surface runoff, and thus contribute to accelerated eutrophication of streams and lakes. We compared results from several soil test P (STP) methods on a single soil and found they all gave results significantly correlated to DRP levels in runoff, but distilled H2O and NH4-oxalate methods gave the best correlations. We hypothesized that results might differ on other soils, so runoff studies were conducted on three Ultisols to determine which STP method accounts for DRP levels in runoff across soil series, and what effect site hydrology has on the correlation between STP and runoff DRP concentrations. Surface soil (0-2 cm depth) of pasture plots (7 percent slope) was analyzed by Mehlich III, Olsen, Morgan, Bray-Kurtz P1, NH4-oxalate, and distilled H2O methods. P saturation of each soil was also determined by three different methods. Simulated rain was applied at 75 mm h-1 to produce 30 min of runoff from each plot. All correlations of STP to runoff DRP were significant ($p<0.01$) regardless of soil series or STP method used, with most STP methods giving high correlations ($r>0.90$) on all three soils. For a given level of H2O-extractable STP, low runoff volumes coincided with low DRP concentrations. Therefore, when each DRP concentration was normalized for (divided by) the volume of plot runoff, correlations to H2O-extractable STP had the same ($p<0.05$) regression line for each soil. This identifies the importance of site hydrology in determining P loss in runoff, and may provide a means of developing a single relationship for a range of soil series. We conducted an experiment to investigate the hypothesis that seasonal changes in field conditions (especially soil moisture) and the practice of air drying soil samples prior to analysis may affect such correlations. Grass plots with a wide range of STP were randomly divided into two groups. In May (wet season), soil samples were taken from each plot in the first group, simulated rain was applied (75 mm h-1) to produce 30 min of runoff, and filtered runoff samples were analyzed for DRP. Each soil sample was analyzed for H2O content, sieved (2 mm), and split into two subsamples. One subsample from each plot was kept field-moist, and the other was air dried. Phosphorus saturation was determined only on air-dry soil, but all soil subsamples were analyzed by Mehlich III and distilled H2O methods. In August (dry season), the second group of plots received the same treatment. All correlations of STP to runoff DRP were significant ($p<0.01$), regardless of season or STP method. Water-extractable STP from air-dry soil (mean = 28.5 mg kg-1) and Mehlich III STP (mean = 145 mg kg-1) were not affected by season, but DRP concentration in August runoff (mean = 1.05 mg L-1) was almost double that in May (mean = 0.57 mg L-1), so the resulting correlations were affected. Water-extractable STP from field-moist soil was higher in August (mean = 23 mg kg-1) than May (mean = 16mg kg-1), and P saturation levels showed a similar trend. Runoff volumes were smaller in August, so season had little effect on mean DRP mass loss.

Publications:

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2. Lemunyon, J. and T.C. Daniel. 1998. Phosphorus management for water quality protection: A national effort. p. 1-4. In J.T. Sims (ed) Soil test phosphorus: Environmental uses and implications. USDA-CREES Regional SERA17 Committee bulletin No. 389.

Investigators: Collins Jr., E. R

Institution or Affiliation: VIRGINIA POLYTECHNIC INSTITUTE

Title of Study: BEST MANAGEMENT PRACTICES FOR REDUCING POLLUTION FROM CONCENTRATED LIVESTOCK OPERATIONS

Funding Agency: HATCH PROJ

Duration of Study: 01 OCT 1997 TERM: 30 SEP 2001

Objectives:

- Determine effectiveness of Dairy Loafing Lot Rotational Management System in reducing N, P, bacterial yield, and sediment loss.
- Provide a measure of water quality improvement afforded by installation of alternative off-stream watering systems.
- Provide a measure of water quality improvements afforded by installation of cattle travel lanes and improved stream crossings

Approach: Field studies on cooperating commercial farms to evaluate effectiveness of the three BMPs addressed in "Objectives". Objective 1 will be evaluated by comparing pre- and post-BMP runoff using automated and grab sampling, and using portable rainfall simulator to assure measurable cause and effect precipitation events. Objectives 2 and 3 will be evaluated using automated and grab sampling, as well as subjective observation of cattle grazing and watering practices

Progress: Work on nitrogen, phosphorus, and sediment loss from dairy loafing lots as affected by rotational vegetated paddocks included study sites on commercial dairy farms in two physiographically different regions of Virginia. Based on precipitation events generated by a rainfall simulator, it was concluded that total suspended solids (TSS), nitrate (NO sub 3), ammonia (NH sub 4), phosphate (PO sub 4), and total filterable phosphorus loadings from the grassed loafing paddocks Best Management Practice were reduced as compared to the bare "sacrifice" lot. Runoff was also reduced from the grassed loafing paddocks, allowing greater opportunity for rainfall infiltration and trapping of nutrients and other pollutants. Reduction in bacteria losses from study areas was inconclusive. Work on alternative water systems and watershed model for NPS assessment and demonstration was completed on three cooperator cattle farms in Franklin County, VA. Due to the lack of site condition controls and different weather conditions over the two-year study, statistically-based conclusions were not possible. However, distinct trends were observed that showed improvements in stream water quality after the off-stream watering systems were installed. Many dairymen are adopting the Dairy Loafing Lot Rotational Management System for improving cattle husbandry, and water quality on their farms. Demonstrations and local meetings have made growers and others aware of the advantages of the off-stream watering practice, and its possible impact on improving water quality

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3. Shukla, S.S. M.S. Thesis. 1998. Evaluation of odor-reducing commercial products for livestock waste. Virginia Polytechnic Institute and State University, Blacksburg, VA. 103 pp

4. Wooden, K.G., Cocke, R., Collins, E. R., and Johnson, D.M. 1998. Alternative water systems and watershed model for non-point source pollution assessment and demonstration. Final Project Report (Agreement No. C199-319-96-12) submitted to Virginia Department of Conservation and Recreation.175 pp

5. Younos,T.M., Mendez, A., Collins, E.R., and Ross, B.B. 1998. Effects of a dairy loafing lot-buffer strip on stream water quality. JWARA 34:4

Investigators: James F. Ruhl

Institution or Affiliation: U.S. Geological Survey

Title of Study: Quantity and Quality of Seepage from Two Earthen Basins Used to Store Livestock Waste in Southern Minnesota During First Year of Operation, 1996-97

Funding Agency: U.S. Geological Survey and Minnesota Pollution Control Agency

Duration of Study: 1996-1997

Objectives: Evaluate potential impacts of seepage from two representative earthen basins used to store livestock waste in Minnesota on local ground water.

Approach: Seepage monitoring systems were installed at two earthen basins. The systems were designed to measure the quantity of seepage from the sidewalls and bottoms of the basins. The systems also were designed for collection of seepage samples from the sidewalls and bottoms of the basins. The samples were chemically analyzed to determine concentrations of nitrogen compounds, chloride, and Fecal coliform bacteria.

Progress: Data-collection phase of the study completed. Report preparation near completion.

Publications: A U.S. Geological Survey Water Resources Investigations Report is expected to be published during the latter part of 1999 or the early part of 2000.

Investigators: Kent D. Becher, Kimberlee K.B. Akers

Institution or Affiliation: U.S. Geological Survey- Water Resources Division

Title of Study: Comparison of Water-Quality in Four Small Watersheds Containing Animal Feeding Operations in Iowa 1996-98.

Funding Agency: U.S.G.S.- National Water Quality Assessment Program (NAWQA)

Duration of Study: March 1996- September 1998

Objectives: To determine if there are differences in water-quality in small watersheds where there are different densities of animal feeding operations.

Approach: Water-quality data that were collected as part of the NAWQA were used to compare four different watersheds. GIS was used to delineate the drainage basins, locations of AFO's, and to determine manure inputs into each basin. Concentrations and yields of nutrients were compared between sites using a Wilcoxon Rank sums test.

Progress: Initial comparisons between sites indicate that there may be some relationships between AFO densities and water quality. Ancillary data sets (soil types, slope, organic carbon contents, etc.) are currently being used to determine if there are other factors for these statistical differences. The poster that will be presented at the AFO conference in Fort Collins, Colorado will present the results.

Publications: Currently, no publications on this issue are planned. However, there are several NAWQA reports that will include data from areas of Iowa with high densities of AFO's. Most of these reports are being prepared this year and should be published in 2000.

Investigators: Dana Kolpin (USGS), David Riley (U of I), Mike Meyer (USGS), Peter Weyer (U of I), and Mike Thurman (USGS)

Institution or Affiliation: U.S Geological Survey, University of Iowa – Center for Health Effects of Environmental Contamination

Title of Study: Occurrence of antibiotics in Iowa streams

Funding Agency: USGS, University of Iowa

Duration of Study: 1999

Objectives: Determine if antibiotics used for livestock production and human health are present in streams across Iowa

Approach: A network of 30 streams were selected across Iowa representing basins containing low to intense hog production. Samples collected during the first runoff even following snowmelt (a time when there is an increased likelihood of antibiotic transport to streams). Samples will be analyzed for a set of 20-30 antibiotics using reporting limits estimated to be between 0.05 to 0.2 ppb.

Progress: All water samples have been collected for this study. Awaiting analytical results from the laboratory

Publications: None to date

Other Comments: This is an initial reconnaissance project. More research may follow.

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