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Quantity and Quality of Seepage from Two Earthen Basins Used to Store Livestock Waste in Southern Minnesota During the First Year of Operation, 1997-98

Water-Resources Investigations Report 99-4206

U.S. Department of the Interior
U.S. Geological Survey

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CONVERSION FACTORS, ABBREVIATIONS, AND UNITS OF CONCENTRATION

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter
acre	4,047	square meters
gallon (gal)	3.785	liter
inches per day (in./d)	2.54	centimeters per day
foot per day (ft/d)	.3048	meter per day
gallon per day (gal/d)	3.785	cubic meters per day
gallons per acre per day (gal/acre/d)	9.353×10^{-7}	cubic meters per square meter per day
pound (lb)	.4536	kilograms
degrees Fahrenheit (°F)	5/9 x (°F - 32)	degrees Celsius

Concentrations of chemical constituents in water samples are given in milligrams per liter (mg/L) and are reported as dissolved. Milligrams per liter is a unit of concentration that expresses the amount of a chemical constituent in solution as the mass (milligrams) of the constituent per unit volume (liter) of water. Concentrations reported as dissolved represent the amount of a constituent in a water sample that passes through a 0.45-micrometer membrane filter.

Concentrations of chemical constituents in water samples also are given in milliequivalents per liter, which are units of concentration based on amounts of chemical constituents in solution that combine with each other. One milliequivalent of a chemical constituent has a mass in milligrams that is equal to the sum of the atomic weights of the atoms that comprise the constituent divided by the number of charges associated with the constituent. Thus one milliequivalent of Ca^{++} (calcium ion), which has an atomic weight of 40 and a charge of plus two, has a mass of 20 milligrams. In most natural water samples that have the meq/L of each of the chemical constituents accurately determined, the total meq/L of cations (positive ions) is equal to the total meq/L of anions (negative ions).

Quantity and Quality of Seepage from Two Earthen Basins Used to Store Livestock Waste During First Year of Operation in Southern Minnesota, 1997–98

By James F. Ruhl

ABSTRACT

Numerous earthen basins have been constructed in Minnesota for storage of livestock waste. Typically, these basins are excavated pits with partially above-grade, earth-walled embankments and compacted clay liners. Some have drain tile installed around them to prevent shallow ground and soil water to discharge into the basins. Environmental concerns associated with the waste include contamination of ground water by nitrogen compounds and pathogens.

The U.S. Geological Survey, in cooperation with the MPCA (Minnesota Pollution Control Agency), studied the quantity and quality of seepage from two earthen basins used to store livestock waste in southern Minnesota during the first year of operation. One basin (site A), located at a small dairy farm, holds a manure-silage mixture, milkhouse wastewater, and local runoff; the other basin (site B), located at a large hog farm, holds a manure-water mixture from a nearby gestation barn. Monitoring systems were installed below compacted clay liners in portions of the sidewalls and bottoms of the basins to determine the quantity and quality of the seepage.

Total seepage flow from the site A basin ranged from about 900 to 2,400 gal/d (gallons per day) except during April 1998 when the flow increased to about 4,200 gal/d. Seepage flow in areal units, which closely correlated with flow in gal/d, generally ranged from about 0.07 to 0.18 in./d (inches per day), which exceeded the recommended maximum design rate of 0.018 in./d established by the MPCA. Seepage flow commonly was greater through the sidewalls than through the bottom.

Seepage from the site A basin (based on 11 samples each from the bottom and sidewall) had chloride concentrations of 220–350 mg/L (milligrams per liter); ammonium-N (nitrogen) concentrations of 2.40 mg/L or less (except for one concentration of 18.4 mg/L); nitrate-N concentrations of 5.24 mg/L or less; and organic-N concentrations of 6.97 mg/L or less. Ground water would be enriched in chloride and diluted in inorganic-N from mixing with basin seepage. Fecal *Coliform* bacteria, although abundant in the basin wastewater, were present in very small amounts in the seepage.

Total seepage flow from the site B basin generally ranged from 400 to 2,200 gal/d except during 1-month and 3-month periods when the flow ranged from about 3,800 to 6,200 gal/d. Seepage flow in areal units generally ranged from about 0.025 to 0.15 in./d, and, as at the site A basin, exceeded the MPCA recommended maximum design rate of 0.018 in./d. Seepage flow in areal units generally correlated with the flow in gal/d except through the sidewalls when the basin was unfilled. Except during the first three months of the study, seepage flow was greater through the sidewalls than through the bottom.

Seepage from the site B basin (based on 10 samples each from the bottom and sidewall) had chloride concentrations of 11 to 100 mg/L; ammonium-N concentrations of 2.58 mg/L or less; nitrate-N concentrations of 25.7 mg/L or less (except for one concentration of 146 mg/L); and organic-N concentrations of 0.92 mg/L or less. Nitrate-N concentrations in the seepage exceeded the U.S. Environmental Protection Agency (1996) MCL (maximum contaminant level) of 10 mg/L in 17 of 22 samples. Background ground-water quality, however, indicated that nitrate-N concentrations were greater than the MCL prior to operation of the basin. Fecal *Coliform* bacteria, as at the site A basin, were abundant in the basin wastewater, but not in the seepage.

INTRODUCTION

During the current decade (1990's) a large number of earthen basins have been constructed in Minnesota for storage of livestock waste and more of these basins are expected to be constructed in the future. These basins are excavated pits with partially above-grade, earth-walled embankments. Some of these basins have underlying compacted clay liners that consist of native or non-native, heavy clay material. Some of these basins also have drain tile installed around the perimeter to prevent shallow ground and soil water from discharging into the basins.

The MPCA (Minnesota Pollution Control Agency) has established permit requirements and design criteria for construction of earthen basins in Minnesota (Wall and others, 1998). The permit applications must include a report prepared by a registered professional engineer that includes information about the construction site, such as the type, texture, and moisture content of the soils, and the design plans for the basin and related facilities, such as a drainage system. Construction reports must also be submitted by the professional engineer to the MPCA after completion of construction.

The design criteria for earthen basins have become more stringent since 1991. These criteria require, with some exceptions, that earthen basins have cohesive, compacted clay liners, and, at sites where high water tables may hinder construction and operation of the basins, drainage systems to protect the liners. These criteria were established to meet the following goals: (1) that high water tables at or near land surface do not hinder construction and operation of the basins; and (2) that seepage from the earthen basins do not exceed (0.018) in./d (equivalent to 488 gal/acre/d) when the basins are filled with wastewater.

Citizens and public officials are concerned about potential environmental effects associated with the waste stored in these basins. These concerns include: (1) unpleasant odors and potentially harmful health effects from gases (ammonia and hydrogen sulfide); and (2) contamination of ground and surface water by nutrients (nitrogen and phosphorus), micro-organisms (viruses, bacteria, and protozoa), chloride, animal pharmaceuticals (antibiotics and hormones), and trace metals (arsenic and selenium).

The USGS (U.S. Geological Survey) conducted a two-year (1997–98) cooperative study with the MPCA and NRCS (Natural Resources Conservation Service) of two newly constructed earthen basins in southern Minnesota (fig. 1). The study was done to evaluate the quantity and quality of seepage from the basins during the first year of operation. Monitoring systems were installed at the two basins to determine the quantity and quality of seepage through compacted clay liners that underlie portions of the sidewalls and bottoms of the basins.

One of the study basins is used to store a manure-silage mixture plus milkhouse wastewater and local runoff at a small dairy farm (hereinafter referred to as site A); the other basin is used to store a manure-water mixture from a nearby gestation barn at a large hog farm (hereinafter referred to as site B). The presence of large amounts of contaminants in the seepage could result in degraded ground-water quality near the basins. Results of the study will be used by state and local officials for improved management and protection of ground water near such basins.

PURPOSE AND SCOPE

The purpose of this report is to describe the quantity and quality of seepage through compacted clay liners of two earthen basins used to store livestock waste in southern Minnesota during the initial year of operation. Most of the field data for this study were collected between April 1997 and June 1998. Seepage monitoring systems were installed at each of the two basins to determine the quantity and quality of seepage from portions of the bottoms and sidewalls.

EXPLANATION

•A Earthen basin - letter is site identifier

Figure 1. Locations of earthen basin study sites with seepage monitoring systems.

Additionally, perimeter tile drainage was monitored at each of the two basins to determine quantity (site A only) and water quality. Five nested pairs of monitoring wells were installed (4 at site A and 1 at site B) to measure water levels and to describe local ground-water flow.

PREVIOUS INVESTIGATIONS

The environmental effects of livestock waste storage facilities have been studied because of increased use of these facilities for livestock waste management. Potential environmental effects associated with these facilities, particularly earthen basins, concern public officials, livestock producers, and citizens. The seepage from earthen basins may contain forms of inorganic and organic chemical constituents and micro-organisms that could contaminate ground and surface water. Many studies about earthen basin storage facilities, therefore, have addressed potential effects of seepage from the basins on the quality of ground and surface water. Nearly all of these studies have been conducted at basins that either did not have compacted clay liners or had compacted clay liners that did not meet design criteria equivalent to that established by the MPCA.

The rate of seepage from earthen basins with stored livestock waste depends partly on the hydraulic gradient at the basin-wastewater interface, and partly on the hydraulic conductivity of soil material that underlies the basin-wastewater interface (Barrington and Broughton, 1988). This soil material is commonly compacted to decrease its hydraulic conductivity and thereby act as a liner to reduce seepage. Hydraulic conductivities of silty-clay and clay loam soil cores from earthen basins, determined from permeability tests using wastewater, ranged from about 1×10^{-5} to 3×10^{-2} ft/d (Chang and others, 1974; Hills, 1976; Phillips and others, 1983; Barrington and others, 1983; Roswell and others, 1985; Albrecht and Cartwright, 1989; and Barrington and Madramootoo, 1989). Hydraulic conductivities of soil cores from an earthen basin sidewall, determined from permeability tests using a high conductivity salt solution infiltrate, ranged from about 0.20 to 250 ft/d (McCurdy and McSweeney, 1993).

The rate of seepage from earthen basins with stored livestock waste also depends on formation of physical seals at the basin-wastewater interface. These seals consist of matted layers of particulate organic material from the livestock waste that are bound up with soil particles at or just below this interface. The effectiveness of the seals to retard seepage flow depends on the retention of organic waste solids within the pore spaces of these soil particles (Roswell and others, 1985; Barrington and others, 1987). Several investigations have reported that the seals may rupture from cyclic freezing and thawing and wetting and drying (Ciravolo and others, 1979; Ritter and Chirnside, 1987; and McCurdy and McSweeney, 1993). These ruptures, which typically are cracks, can develop in exposed areas of the sidewalls of the basins as the wastewater levels rise and fall.

Some estimates of the quantity of seepage flow from earthen basins with stored livestock waste are based on permeability tests and mass water balances (decreases in basin-wastewater storage adjusted for evaporation). Albrecht and Cartwright (1989) reported a seepage flow rate through an experimental, compacted earthen liner of about 45 gal/acre/d from *in situ* field permeability tests. Barrington (1985), testing sandy soil with a physical waste-mat seal, reported a seepage rate of about 440 gal/acre/d from *in situ* field permeability tests. Estimates of seepage flow based on mass water balances from three studies ranged from 365 to 3,200 gal/acre/d (Davis and others, 1973; Robinson, 1973; Hegg and others, 1979; and Ham and DeSutter, 1999).

Constituents analyzed for this study include nitrogen compounds, chloride, and fecal *Coliform* bacteria. The USEPA (U.S. Environmental Protection Agency) has established a MCL (maximum contaminant level) for nitrate-N (ntirate nitrogen) of 10 mg/L (U.S. Environmental Protection Agency, 1996). A MCL is a health-based drinking water standard that sets a maximum permissible level for a contaminant in water delivered to any user of a public water system. A MCL for ammonium has not been established by the USEPA. Ammonium in surface water at elevated levels, however, is toxic to fish. Although chloride consumption in drinking water does not pose a risk to human health, the USEPA (1996) has established a SMCL (secondary maximum contaminant level) of 250 mg/L for chloride. A SMCL is a non-enforceable standard that sets a recommended maximum level for a contaminant in water delivered to any user of a public water system. SMCL's are based on aesthetic properties of water that affect staining, taste, and odor.

The presence of fecal *Coliform* and related bacteria in water generally indicates contamination from animal waste. Although many types of *Coliform* bacteria are not themselves pathogenic, the presence of these bacteria indicates the presence of other types of bacteria that may be pathogenic (Hem, 1985).

The concentrations of nitrogen compounds in earthen basin seepage may change because of the following chemical transformations: (1) ammonification, which is the conversion of organic nitrogen to ammonium; (2) nitrification, which is the conversion of ammonium to nitrate; (3) denitrification, which is the conversion of nitrate to nitrogen gas; and (4) dissimilatory nitrate reduction, which is the conversion of nitrate to ammonium. Ammonification and nitrification generally occur where dissolved oxygen is available; whereas, denitrification and dissimilatory nitrate reduction generally occur where the dissolved oxygen concentration is small (<0.01 mg/L) (Freeze and Cherry, 1979). Chloride is a nonreactive solute that typically does not change in concentration from chemical, biological, or radioactive processes.

Studies of earthen basins with stored livestock waste have reported conflicting results about their effects on local ground-water quality. Results of these studies are based on chemical analyses of soil samples from cores, ground-water samples from monitoring wells, and soil-water samples from suction lysimeters. Some of these studies indicate insignificant or minor long-term effects on ground-water quality (Sewell, 1978; Dalen and others, 1983; Ritter and others, 1984; Miller and others, 1985; Huffman and Westerman, 1995; and Fonstad and Maule', 1996). Some of these studies indicate short-term degradation of ground-water quality because of temporary leaks through ruptures in the physical seals of the basins. Many studies, however, indicate that wastewater contaminants from these basins may result in significant, long-term degradation of ground-water quality (Norstedt and others, 1971; Miller and others, 1976; Ciravolo and others, 1979; Hegg and others, 1979; Phillips and others, 1983; Egboka, 1984; Ritter and Chirnside, 1987; Culley and Phillips, 1989; Gangbazo and others, 1989; and Westerman and others, 1993). These studies link the contamination primarily to: (1) incomplete development or long-term breakdown of the physical seals of the basins; (2) basins in predominantly coarse-textured soils without compacted clay liners; or (3) wastewater overflow from the basins.

The present study is an outgrowth of an ongoing study by the MPCA, NRCS, University of Minnesota, and Morrison County begun in 1993 of an earthen basin at a small dairy farm in Morrison County in central Minnesota (fig. 1). The quantity and quality of seepage from this basin is being monitored with a seepage monitoring system that is very similar in design and operation to that used in the present study (Wall and others, 1998). Results from the first three years of monitoring at the Morrison County site indicate that seepage from the basin contained only small portions of the nitrogen, phosphorus, potassium, and sulfate, but somewhat greater portions of the sodium and chloride, that were present in the manure. The total inorganic nitrogen content in the seepage was less than 10 mg/L three years after the start of the operation of the basin. Seepage flow rates from the basin were greater through the sidewalls than through the bottom. Overall average seepage rates were 102 gal/d through the sidewalls and 5 gal/d through the bottom.

SITE SELECTION AND BASIN AND MONITORING SYSTEM DESIGN

The NRCS designed the site A basin and the two monitoring systems; an engineering firm designed the site B basin (figs. 2 and 3). Local contractors constructed the two basins and their monitoring systems. Swanberg (1997) provides a detailed description of the design, construction, and operation of the two basins and their monitoring systems. Construction of the two basins and their seepage monitoring systems began during October 1995 at site A and during August 1996 at site B. Both basins became fully operational during spring 1997.

Selection of the study site basins was based on the following criteria: (1) the basins would be representative of basins in Minnesota in terms of their design, operation, and site characteristics; (2) the basins would have compacted clay liners; and (3) the landowners would allow installation of seepage monitoring systems during construction of the basins and access to the sites for maintenance of the monitoring systems and collection of field data. The basin at site A, however, did not completely meet the second criterion. At this site, the compacted clay liner was limited to the vicinity of the monitoring system.

Perimeter drain tile was installed around each of the two study-site basins at elevations 2–6 ft lower than the bottom of each basin and monitoring system. The perimeter drain tile was graded to route water by gravity flow into a perimeter drain tile sump. Additionally, a center drain tile was installed below the bottom of each basin. At the site A basin the center drain tile connects directly to the perimeter drain tile. At the site B basin the center drain tile connects to a sump from where water is pumped into a tile line that drains directly into the perimeter drain tile sump. The purpose of the perimeter and center drain tiles is to lower the hydraulic head level of shallow ground water in the area bounded by the perimeter drain tile below the bottom elevation of the basin and monitoring system, and thereby prevent seasonal or permanent saturated soil conditions around and below the basin and monitoring system.

If the hydraulic head level in the area bounded by the perimeter drain tile is lowered below the bottom elevation of the basin and monitoring system, ground water is hydraulically disconnected from wastewater in the basin and from seepage in the monitoring system. Under these conditions, ground water would not discharge into the basin or monitoring system, and basin seepage would flow through unsaturated soil material before mixing with ground water. Additionally, some of the basin seepage would probably be intercepted by the perimeter and center drain tiles. Thus, under those conditions, perimeter and center tile drainage may be a mixture of ground water and basin seepage.

If, on the other hand, the hydraulic head level in the area bounded by the perimeter drain tile is not lowered below the bottom elevation of the basin and monitoring system, ground water is hydraulically connected to wastewater in the basin and to seepage in the monitoring system. Under these conditions, ground water may discharge into and mix with basin wastewater, depending on the hydraulic gradient at the ground-water/wastewater interface. Additionally, ground water may discharge into the monitoring system and mix with basin seepage, depending on the hydraulic gradient at the ground-water/monitoring system interface.

The monitoring systems consist of impermeable, 30 mil (0.030 inch) PVC (polyvinyl chloride) sheets placed below the compacted clay liners (figs. 2 and 3). The PVC sheets function as geomembrane liners that intercept seepage through the compacted clay liners. The compacted clay liner at site A extends out to a margin of about 20 ft beyond the edge of the geomembrane liner. The compacted clay liner at site B extends throughout the basin. The geomembrane liners were graded to route intercepted seepage to perforated PVC collection pipes that drain into nearby sumps. Divider walls separate the intercepted seepage from the sidewall and bottom portions of the basins. Thus, the quantity and quality of seepage was

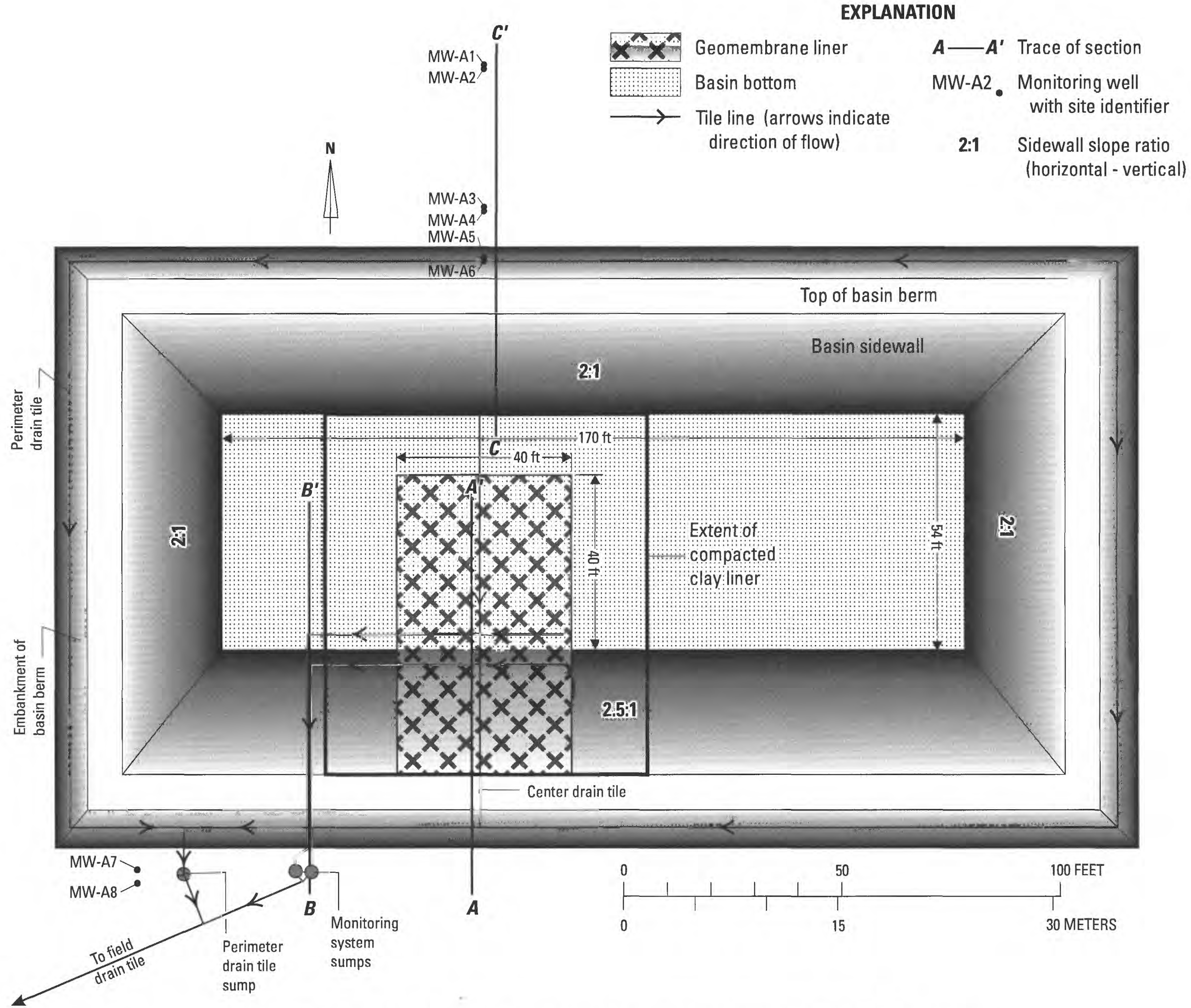

Figure 2. Plan view of the site A basin and seepage monitoring system near New Ulm, Minnesota.

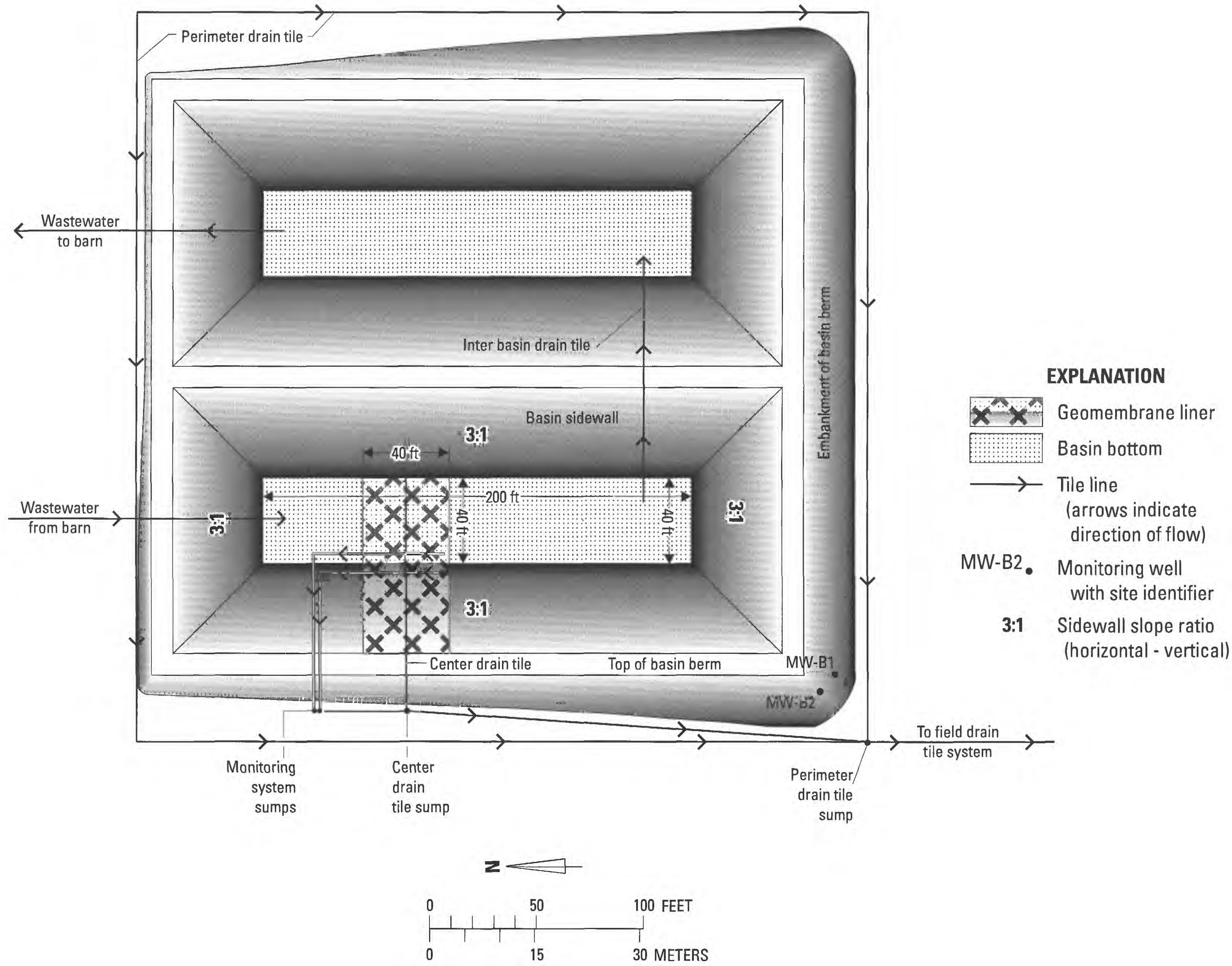

Figure 3. Plan view of the site B basin and seepage monitoring system near Owatonna, Minnesota.

separately monitored for sidewall and bottom portions of each of the two basins.

The portions of each basin with geomembrane liners are 40-ft-wide strips that extend from the top of one of the sidewalls down to the base of that sidewall, and 40 ft from the base of that sidewall across the bottom of the basin. A 1-ft thick sand drain separates the geomembrane liners from the bottoms of the compacted clay liners. Soil material directly below the geomembrane liners was compacted to break up clods, force down rocks and pebbles, and create an otherwise smooth layer that would not result in punctures of the liners. Figure 4 shows a cross-sectional view of the monitoring system at site A. A cross-sectional view of the monitoring system at site B would be essentially the same as that shown in figure 4 for site A except for a slightly more moderate side slope (3:1 instead of 2.5:1).

The sumps for the monitoring systems, perimeter drain tile at site A, and center drain tile at site B, were equipped with submersible sewage ejector pumps. These pumps periodically (several to many times per day) pumped out water that collected in these sumps whenever the volume of the water reached a pre-set volume. The pumped water was routed into adjacent field drain tile systems that discharged into local drainage ditches. At site B the perimeter drain tile sump was not equipped with a pump. Water in this sump flowed by gravity into the adjacent field drain tile system.

ENVIRONMENTAL SETTING AT THE TWO STUDY SITES

Site A is located in Newton Township in the NW1/4 of section 15, T111N, R31W, in Nicollet County (fig. 1). The basin was constructed in a low, flat, wet area near the main barn. The water table during the time of spring rains and snowmelt typically is within 1–2 ft of land surface; at other times the water table may be as much as 5–6 ft below land surface. The soil series is Clarion silty loam (undulating phase) (U.S. Department of Agriculture, 1994). The parent materials of the soil comprise post-glacial and glacial units (Tom Alvarez, Natural Resources Conservation Service, written commun., 1995). The post-glacial unit is surficial alluvium that consists of mostly clay that is soft, not well drained, moist to wet, of high plasticity, and about 5.5 to 7.5 ft thick. The underlying glacial till consists of sandy clay that is firm to very firm, moist to wet, and of medium plasticity. Grain-size distributions of two soil samples from the till are shown in table 1. The moisture content of six soil samples ranged from about 23–25 percent. The vertical hydraulic conductivities of the compacted clay liner determined from permeability tests on two core samples were 1.58×10^{-4} and 6.79×10^{-4} ft/d (tests conducted by the NRCS).

Site B is located in Claremont Township in the SE1/4 of section 2, T107N, R18W, in Dodge County (fig. 1). The basin was constructed in gently rolling terrain where the water table is about 15–20 ft below land surface. The soil series is predominantly Floyd silty clay loam and Clyde silty clay loam (U.S. Department of Agriculture, 1961). The soil, which is not well drained, consists of clayey sand or sandy clay with a little gravel (Robert Mensch, Mensch Engineering, written commun., 1994). Soil borings indicate that the surficial unit is a silt loam that ranges in thickness from about 2–3 ft. Below the silt loam is a clay loam that is as much as 23 ft in thickness, and below the clay loam is either a loamy sand or sandy loam. Grain-size distributions of two soil samples, one each from the silt loam and clay loam, are shown in table 2. The moisture content of 10 soil samples ranged from about 5 to 17 percent. The vertical hydraulic conductivities of the compacted clay liner determined from permeability tests on two core samples were 5.66×10^{-5} and 3.4×10^{-5} ft/d (tests conducted by the NRCS).

METHODS OF INVESTIGATION

Badger, Recordall II Turbo Meters were used to measure cumulative flow (gallons) through the monitoring system sump outlets at the two study sites. Flow readings were manually recorded at intervals of two to six weeks throughout the duration of the study. (Flow readings were not recorded between early November 1997 and early February 1998 because of periodic freeze-up of water in the meters.)

At site A the same type meter used in the monitoring system sumps was used to measure flow from the perimeter drain tile sump. Perimeter tile drainage flow (gal/d) was derived from the flow readings. Perimeter tile drainage flow was not estimated at site B. Center tile drainage flow was not estimated at either of the two study sites.

The USGS installed four nested pairs of MWs (monitoring wells) at site A and one nested pair of MW's at site B (figs. 2 and 3) to collect ground-water level data. The depths of these wells ranged from about 4 to 12 ft. The upper 2–3 ft of soil material at each well location consisted of overburden fill material from excavation of the basins. None of the wells, therefore, penetrated more than 10 ft of native soil material. Thus, none of the wells required Minnesota State Health Department permits for their construction.

The well casings were flush-threaded, 2-inch inside-diameter, PVC. The screens were 6-inch-long, flush-threaded, machine-slotted (0.010-slot) PVC. The monitoring wells (except MW-A5 and MW-A6) were installed with a USGS hollow-stem, rotary hydraulic auger drill rig. These wells were completed as

Table 1. Grain size distribution of two soil samples from the site A basin
[--, no data]

Sample number	Sieve size (millimeters) 0.002	0.005	0.02	0.05	0.074	0.105	0.25	0.84	2.0
	clay and silt				sand				
	Percent finer by dry weight								
1	29	35	54	80	86	--	--	--	100
2	27	35	51	73	75	79	89	98	100

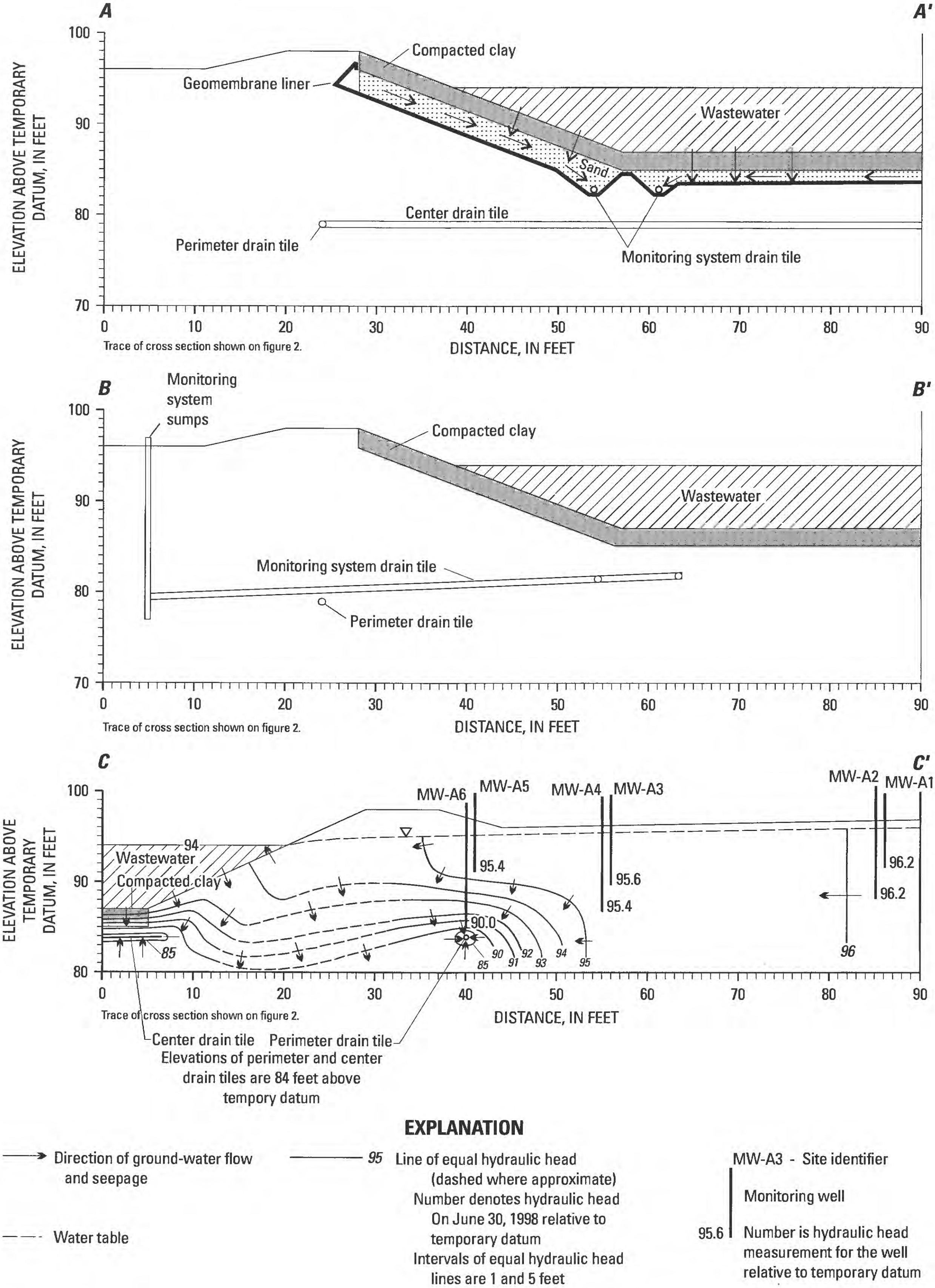

Figure 4. Cross-sectional views of earthen basin and seepage monitoring system along traces *A-A'* and *B-B'* and conceptualized hydrogeologic section along trace *C-C'* at site A near New Ulm, Minnesota.

Table 2. Grain size distribution of two soil samples from the site B basin
[--, no data]

Sample number	Sieve size (millimeters)														
	0.002	0.005	0.02	0.05	0.074	0.105	0.25	0.84	2.0	4.76	9.525	12.7	19.05	25.4	38.1
	clay and silt				sand						gravel				
	Percent finer by dry weight														
1	21	26	35	56	56	62	75	89	92	93	94	94	94	94	100
2	21	28	41	60	64	79	87	93	96	97	98	99	100	--	--

follows: washed, medium to coarse sand was used to back-fill the holes around the well screens; bentonite grout was pumped into the annular spaces above the sand packs to within 3–4 ft of land surface; and a 7-ft long protective steel casing was cemented in place around the well heads to divert surface drainage. MW-A5 and MW-A6 were installed with a portable (trailer mounted), 3-inch outside-diameter solid-stem, gasoline-powered auger drill rig. The casings of these wells were hand-driven into the boreholes.

Elevations of the water-level measuring points for each well were surveyed from a temporary datum locally established at each of the two study sites. Water-level depths below these measuring points were measured with an electric tape. Ground-water hydraulic heads, relative to the temporary datum, were determined at each well screen from the water-level depths. Elevations of measuring points on top of the basin berms also were surveyed from the temporary datum at each of the two study sites. Wastewater hydraulic head, relative to temporary datum, was derived from the distance from these measuring points to the wastewater surface and basin sidewall slope.

Ground-water/basin wastewater interaction is evaluated from comparisons of hydraulic heads of basin wastewater and ground water, and (at site A only) from comparisons of flow rates of basin seepage and perimeter tile drainage. This interaction consisted of ground-water discharge into basin wastewater, or recharge of ground water by basin seepage. Some basin seepage, however, may have been intercepted by the perimeter drain tile and thus contributed to perimeter tile drainage rather than to ground-water recharge.

Prior to operation of the basins and monitoring systems, which began during spring 1997, perimeter tile drainage samples were collected for water-quality analyses (3 times at site A between May and August 1996 and 2 times at site B during September 1996). As soon as livestock waste was introduced into the basins, seepage and center tile (site B only) drainage samples, plus additional perimeter tile drainage samples, were collected for water-quality analyses. These samples were collected approximately bi-weekly during the first two months of operation, monthly during the third month of operation, and approximately bi-monthly during the next ten months of operation. Additionally, six basin wastewater samples (three from each basin) were collected for water-quality analyses.

Basin seepage samples from sites A and B, perimeter tile drainage samples from site A, and center tile drainage samples from site B, were collected from their respective sumps with a peristaltic pump. Perimeter tile drainage samples at site B were collected in a bottle placed below the perimeter tile drain inlet to the sump. Three wastewater samples were collected at each study site. The first two sets of samples were grab samples collected from near the wastewater surfaces at points about 10 ft from the edge of the wastewater shoreline during May and June 1997. The third wastewater sample from site A was collected during agitation of the manure-wastewater mixture. The third wastewater sample from site B was collected from the tile line that drains into the collection basin from holding tanks in the gestation barn. Procedures used to treat and store water samples are described by Fishman and Friedman (1989) and Koterba and others (1995).

During collection of samples, field measurements were made of the following physical and chemical properties: temperature, specific conductance, pH, dissolved-oxygen concentration, and oxidation-reduction potential. These properties were measured with a portable Hydrolab sonde calibrated at the start of each sampling day. Chemical analyses to determine concentrations of major ions and nitrogen and phosphorus compounds were done at the USGS NWQL (National Water Quality Laboratory) in Arvada, Colorado.

Samples were chemically analyzed to determine concentrations of: ammonium-N, nitrite-N, ammonium-plus-organic-N, nitrite-plus-nitrate-N, and chloride. The concentration of organic-N was computed by subtraction of the concentrations of ammonium-N from that of the ammonium-plus-organic-N. (In a few cases the reported concentrations of ammonium-N were greater than the ammonium-plus-organic-N because of the precision in the NWQL's analytical procedures for these constituents. In such cases the concentrations of organic-N are considered to be zero.) The concentration of nitrate-N commonly is much greater than the concentration of nitrite-N, thus the concentration of nitrite-plus-nitrate-N, which is reported, is considered to be equivalent to the concentration of nitrate-N in this report unless otherwise noted. The concentration of inorganic-N was computed by addition of the concentrations of nitrate-N and ammonium-N.

A small subset of the samples also were chemically analyzed to determine concentrations of orthophosphate, total dissolved phosphorus, calcium, magnesium, sodium, potassium, sulfate, and fluoride. Additionally, a small portion of the samples were analyzed to determine alkalinity (bicarbonate ion concentrations were determined from the alkalinities). The MRLs (minimum reporting limits), which are the minimum concentrations that can be reliably reported for constituents, of the nitrogen and phosphorus compounds were: 0.020 mg/L for ammonium-N, 0.010 mg/L for nitrite-N, 0.050 mg/L for nitrite-plus-nitrate-N, 0.010 mg/L for orthophosphate, and 0.010 for total dissolved phosphorus. None of the other constituents that were analyzed had concentrations that were less than their respective MRL.

Water samples also were analyzed at the USGS office in Mounds View, Minnesota to determine colony counts (reported as the most probable number per 100 ml (milliliters) of sample water) of fecal *Coliform* bacteria. The counts were made on membrane filters inoculated with unfiltered sample water serially diluted with sterile, buffered water to grow ideal colony counts of 20 to 60 per filter. The counts were made after the filters had been incubated in petri dishes half-filled with bacterial growth media for 24 hours at 35° C.

Thirteen quality-assurance/quality-control samples were collected and analyzed in accordance with protocols described by Koterba and others (1995). These samples included: four field/equipment blanks, one office blank, and eight replicates. The field/equipment and office blanks consisted of water provided by the NWQL that was free of inorganic compounds. These blanks were treated and processed in the same manner and with the same equipment as was used for environmental samples. Analyses of these blanks indicated if samples could have been contaminated—either from inadequate procedures used to clean sampling equipment or from shipping and handling. The replicates consisted of environmental water collected sequentially and immediately after environmental water had been collected for regular samples. Analyses of the replicates indicated sample variability attributable to sample collection or to handling and processing.

All four field/equipment blanks were analyzed to determine concentrations of nitrogen compounds, three field/equipment blanks were analyzed to determine concentrations of chloride, and one field/equipment blank was analyzed to determine concentrations of phosphorus compounds and of calcium, magnesium, sodium, potassium, sulfate, and fluoride. The office blank was analyzed to determine concentrations of nitrogen compounds. The concentrations of these constituents in the blanks either were less than their respective MRL or greater than the MRL by not more than 0.047 mg/L (table 3). These results indicate that cleaning and handling procedures used in the office and in the field did not result in significant cross-contamination of water samples by sampling equipment between visits to sample sites or at the USGS office in Mounds View, Minnesota.

The replicates were analyzed to determine concentrations of many of the same chemical constituents that were analyzed in regular environmental samples. All eight replicates were analyzed to determine concentrations of nitrogen compounds; two replicates were analyzed to determine concentrations of phosphorus compounds and of calcium, magnesium, sodium, potassium, chloride, sulfate, and fluoride. The concentrations of these constituents in replicate and environmental samples generally did not differ by more than 5 percent. In cases where the concentrations differed by more than an absolute value of 5 percent, the absolute difference in concentrations was not greater than 1 mg/L (table 4 in supplemental information). These results indicate that the water samples remained stable from the time of collection to the time of chemical analyses, and that the procedures and equipment used did not contaminate the samples and bias the reported analytical results.

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QUANTITY AND QUALITY OF SEEPAGE FROM BASINS

Seepage flows in gal/d are presented for the sidewalls and bottoms of each basin. The values were extrapolated from the flow readings, days between readings, and areal extents of the sidewall and bottom portions of the monitoring systems relative to the total areas of the sidewalls and bottoms. The seepage flows through the sidewalls and bottoms were combined to estimate total seepage flows

Table 3. Method reporting limits and concentrations of dissolved constituents in office and field blank water samples.
[all concentrations in mg/L; <, less than; --, no data; numbers in parentheses are differences in contituent concentrations between blank water samples and method reporting limits]

Dissolved constituent	Date	Method reporting limit	Field/equipment blank concentration	Office blank concentration
Nitrogen, nitrite plus nitrate	6/18/97	0.050	--	0.090 (0.040)
	6/19/97		0.084 (0.034)	--
	7/30/97		<.050	<.050
	5/11/98		<.050	--
Nitrogen, ammonium	6/18/97		--	<.020
	6/19/97	.020	<.020	--
	7/30/97		<.020	.028 (.008)
	5/11/98		.067 (.047)	<.020
Nitrogen, ammonium plus organic	6/18/97	.20	<.20	<.20
	6/19/97		<.20	--
	7/30/97		<.20	--
	5/11/98		<.20	--
Phosphorus	5/11/98	.01	<.10	--
Orthophosphate	5/11/98	.010	.016 (.006)	--
Calcium	5/11/98	.020	.034 (.014)	--
Magnesium	5/11/98	.01	<.01	--
Sodium	5/11/98	.20	<.20	--
Potassium	5/11/98	.10	<.10	--
Chloride	7/30/97	.10	<.10	<.10
	5/11/98		<.10	--
Sulfate	5/11/98	.10	<.10	--
Fluoride	5/11/98	.10	<.10	--

(in gal/d) of the basins. (Total seepage flows estimated for the site A basin probably were less than the actual total seepage flows because of the limited extent of the compacted clay liner.)

Seepage flows in areal units (in./d) are presented for the sidewalls and bottoms of each basin. The values were directly related to the seepage flows in gal/d and were inversely related to the areas of infiltration. These areas remained constant for the bottoms of the basins but varied directly with the height of the wastewater column for the sidewalls. Total seepage flows (in areal units) of the basins were computed as weighted averages of the values for the sidewalls and bottoms based on their respective areas of infiltration.

Water types of individual samples of basin sidewall and bottom seepage, perimeter tile drainage, and center tile drainage at site B, are shown graphically on trilinear plots. These plots show relative proportions of major and minor ions (calcium, magnesium, sodium, potassium, chloride, nitrate, and bicarbonate) in milliequivalents per liter for each sample. Additionally, concentrations of ammonium-N, ammonium-plus- organic-N, nitrate-N, and chloride in samples from the previously mentioned sources plus basin wastewater are shown graphically on time-series plots. These plots show concentrations of the constituents in milligrams per liter for each sample at the time of sample collection. Annual losses of dissolved inorganic nitrogen from the basins were estimated from the concentrations of inorganic-N and flow rates of the seepage.

Site A Basin

This basin provides one year storage of animal waste from approximately two-hundred, 1,000-pound animal units, washwater from milking operations in an adjacent barn, and local runoff from an adjacent 0.34-acre concrete ramp. The bottom dimensions of this basin are 54 ft by 170 ft (fig. 2). The interior side slope ratios are 2:1 (horizontal:vertical) except along the side with the monitoring system, where the side slope ratio is 2.5:1. The depth below grade to the bottom of this basin is about 8 ft. The depth below the top of the sidewall embankment to the bottom of this basin is about 12 ft.

Seepage and Perimeter Tile Drainage Flow

Total seepage flow during the one-year period of record ranged from about 900 to 2,400 gal/d except within a 1-month period when the flow increased to about 4,200 gal/d (fig. 5). The total seepage flow increased from about 1,600 gal/d in mid June 1997, the beginning of the period of record, to about 2,400 gal/d in mid August, then decreased to about 1,900 gal/d by late November 1997. The total seepage flow rapidly increased to about 4,200 gal/d during early April 1998, and then rapidly decreased to about 900 gal/d by mid May and remained nearly constant until late June 1998, the end of the period of record.

Total seepage flow in areal units ranged from about 0.07 to 0.18 in./d except within a 1-month period when the flow increased to about 0.28 in./d. These flow rates exceeded the recommended maximum design rate of 0.018 in./d established by the MPCA for earthen basins (Wall and others, 1998). Continued monitoring of the seepage flow rate will determine if the rates observed during the first year of operation remain stable or decrease over time because of development of physical seals. The seepage flow in areal units closely correlated with the seepage flow in gal/d because of the small changes in wastewater depth.

The relation of seepage flow to wastewater depth could not be evaluated because the monitoring system did not have the capability to determine the sensitivity of seepage flow to the small range of fluctuation in wastewater depth. The wastewater depth in the basin, which was filled to capacity or near capacity during the period of record, fluctuated within about a 3-ft range. The depth increased from about 6 ft in early June to about 7.5 ft in late July 1997, then remained nearly constant until about April 1998, when the depth increased to about 9 ft, the peak depth during the period of record. The depth decreased to about 7 ft by late June 1998, the end of the period of record.

Except during July 1997, total seepage flow during the period of record was greater through the sidewalls than through the bottom. This difference was greatest during early April 1998, when seepage flow was about 3,600 gal/d through the sidewalls and about 600 gal/d through the bottom. The high seepage flow through the sidewalls may have resulted from ruptures in physical seals that had formed at the basin-wastewater interface of the sidewalls. Freezing and thawing of portions of the sidewalls exposed to the atmosphere by declines in basin wastewater levels may have led to the ruptures.

Basin seepage flow (total) correlated approximately with perimeter tile drainage flow during June to August 1997, the first three months of the period of record (fig. 6). During this time basin seepage flow increased from about 1,600 to 2,400 gal/d and perimeter tile drainage flow increased from about 2,700 to 3,500 gal/d. The increase in perimeter tile drainage flow during this three-month period probably was attributable to increased soil moisture and shallow ground-water recharge from precipitation. After this three-month period, changes in basin seepage flow and perimeter tile drainage flow did not correlate with each other. From August 1997 to February 1998 perimeter tile drainage flow decreased to about 800 gal/d, but basin seepage flow varied over a much smaller range (from about 2,400 to 1,900 gal/d). During February to April 1998 perimeter tile drainage flow increased from about 800 to 2,400 gal/d, but basin seepage flow increased over a greater range—from about 2,000 to 4,200 gal/d. The increased perimeter tile drainage flow probably was caused by increased recharge from spring snowmelt and thawing of soil moisture. The increased basin seepage flow may have resulted from ruptures in physical seals that had formed at the basin-wastewater interface, particularly along the sidewalls. Both basin seepage and perimeter tile drainage flow were fairly constant during May and June 1998, the final two months of the period of record.

The relation of basin seepage to perimeter tile drainage flow indicates that, in addition to soil water and shallow ground water, basin wastewater may have entered the perimeter drain tile, and that, in addition to basin wastewater, soil water and shallow ground water may have entered the monitoring system. The proportions of these sources of water that entered the perimeter drain tile and monitoring system, however, cannot be determined from the perimeter tile drainage and basin seepage flow data.

Water levels in nested pairs of shallow monitoring wells fluctuated in response to precipitation (fig. 6). Water levels in MW's-A1 through -A6, located on the north side of the basin, were about 4–5 ft higher than water levels in MW-A7 and MW-A8, located on the southwest side of the basin (fig. 2). These water levels indicate a hydraulic gradient from the north to the southwest side of the basin. During late May to late June 1998 water levels in MW-A5 and MW-A6, located directly above the perimeter drain tile on the north side of the basin, were higher than the bottom of the basin. Thus, in the area bounded by the perimeter drain tile hydraulic head levels of shallow ground water were higher than the bottom elevation of the basin. During that period shallow ground water was hydraulically connected to basin wastewater and to the monitoring system. The perimeter and center drain tiles, therefore, were unable to completely prevent potential ground-water discharge into this basin because of the poorly drained soils and shallow (1–6 ft below land surface) water table.

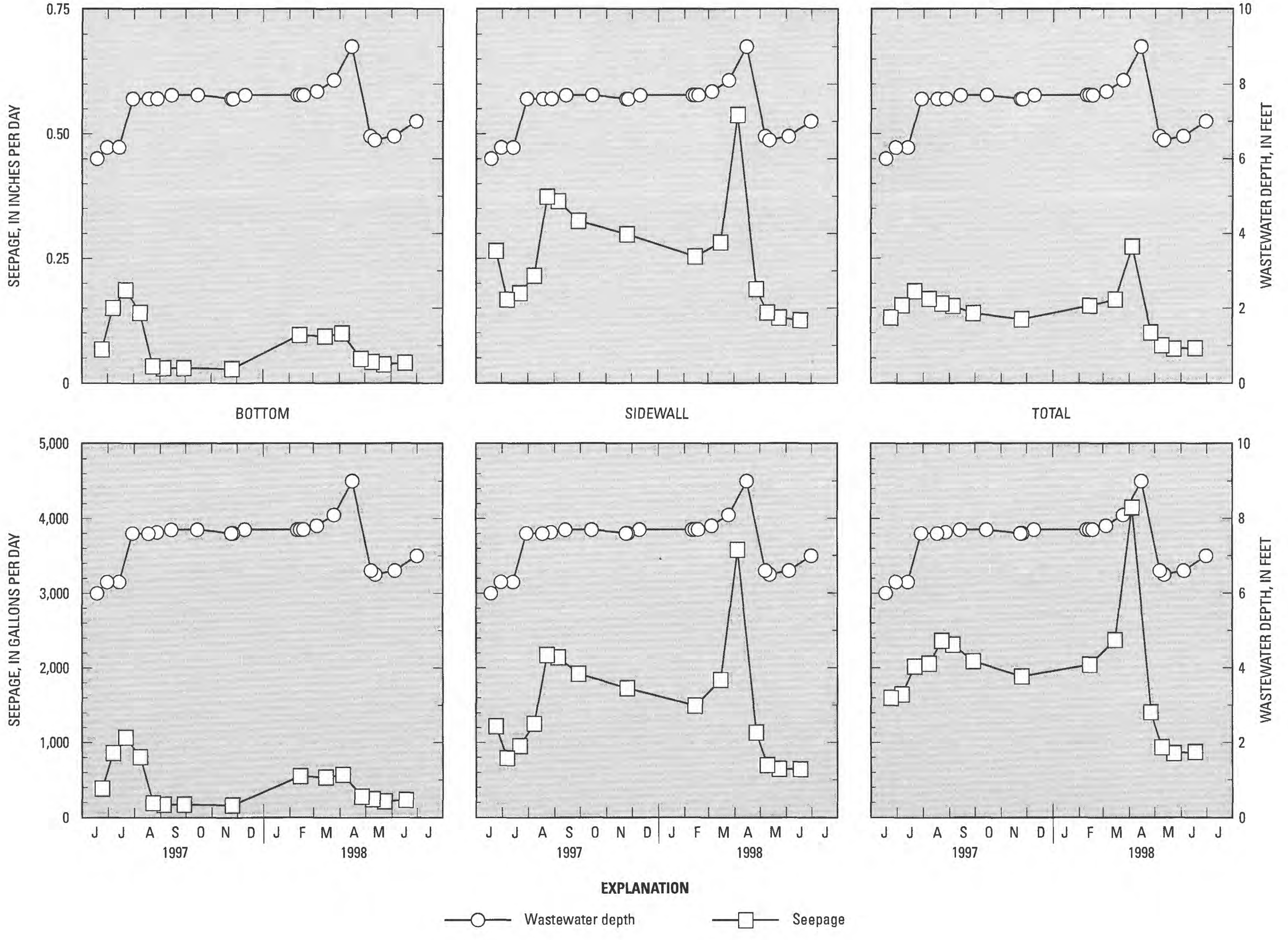

Figure 5. Wastewater depth and basin seepage for site A near New Ulm, Minnesota, June 1997-June 1998.

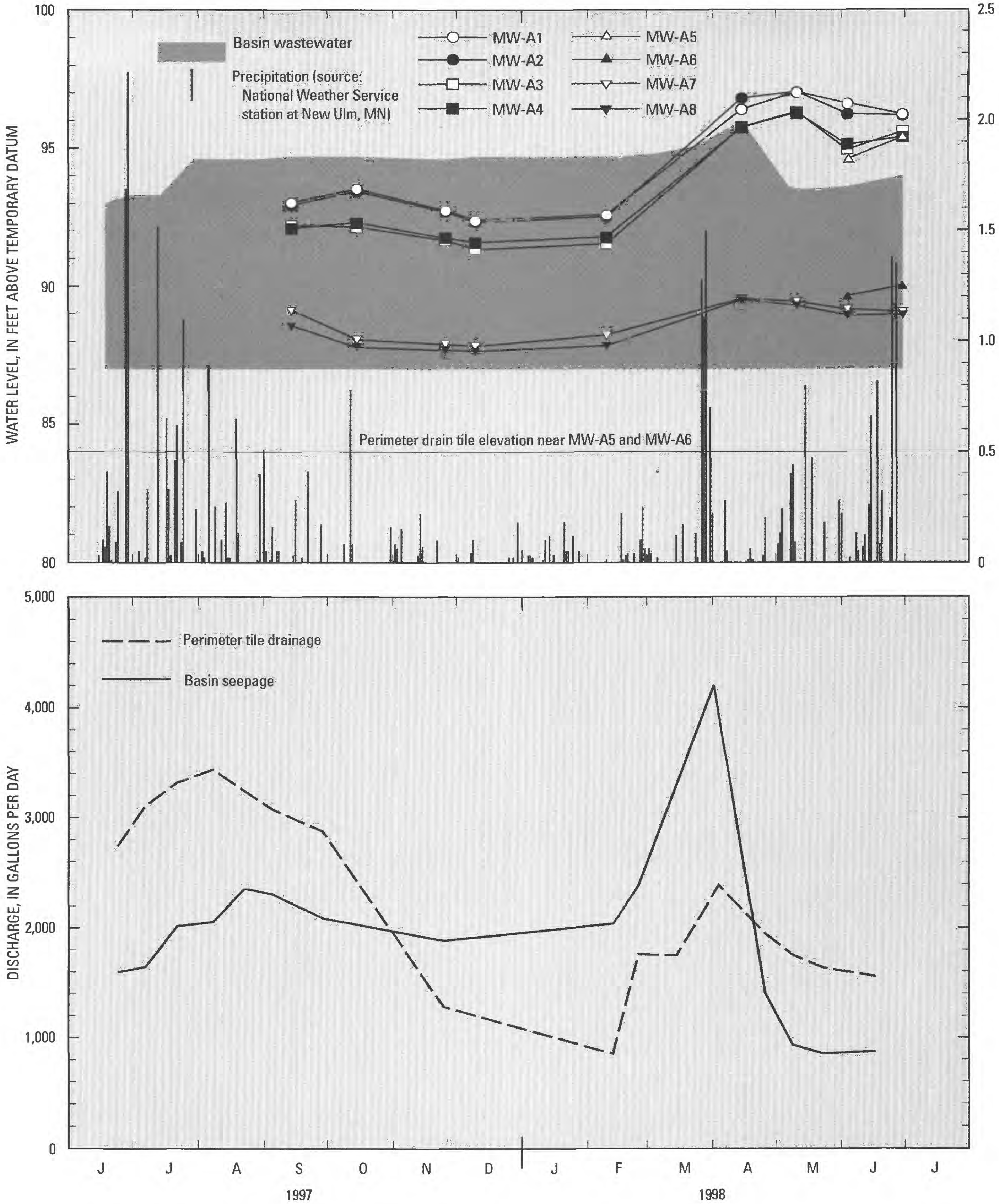

Figure 6. Precipitation, perimeter tile drainage, basin seepage, and observation well and basin wastewater levels, for site A near New Ulm, Minnesota, June 1997-June 1998.

The basin wastewater level was higher than the local water table during September 1997 through March 1998. During this period, hydraulic gradient conditions allowed basin wastewater to recharge local ground water. During early April 1998 to late June 1998, however, water levels in MW's-A1 through -A5 indicate that the water table on the north side of the basin was higher than the basin wastewater level. During this period hydraulic gradient conditions allowed ground-water discharge into the north side of the basin.

The conceptualized hydrogeologic section in figure 4 shows a ground-water flow net based on hydraulic heads measured on June 30, 1998 in MW's-A1 through -A6 and in the basin wastewater column. Water-level measurements from MW's-A1 through A4 indicate that hydraulic heads of shallow ground water at these well locations were constant or nearly constant with depth. Water-level measurements from MW-A5 and MW-A6, however, indicate that hydraulic heads in shallow ground water at these well locations decreased with depth.

The flow net indicates that in the immediate vicinity of MW-A1 and MW-A2, located about 45 ft from the perimeter drain tile, the movement of shallow ground water was predominantly horizontal toward the basin, and that the perimeter and center drain tile did not result in downward ground-water flow in the immediate vicinity of these two wells. The flow net also indicates that in the shallow ground-water zone between the basin and MW-A3 and MW-A4, the movement of ground water had both horizontal and vertical flow components. Thus, within this zone the perimeter and center drain tiles appeared to cause downward ground-water flow. The flow net also shows that the water table was slightly higher than the basin wastewater surface, and that the basin-wastewater interface along the northern sidewall may have been both a ground-water discharge zone (upper part) and a ground-water recharge (seepage) zone (lower part).

Water Quality

Each of two basin sidewall seepage samples, two basin bottom seepage samples, and four perimeter tile drainage samples, were calcium-magnesium bicarbonate type water (fig. 7). These samples had similar proportions of cations, but different proportions of anions. The proportions of anions in the perimeter tile drainage samples consisted of approximately 62–68 percent bicarbonate, approximately 18–23 percent chloride plus nitrate, and approximately 14–20 percent sulfate. The seepage samples had lesser proportions of bicarbonate (approximately 40–55 percent) and slightly greater proportions of chloride plus nitrate (approximately 22–29 percent) and sulfate (approximately 22–32 percent). Samples from the monitoring system and perimeter drain tile sumps, therefore, contained water from separate sources that differed in anionic composition and that possibly mixed with each other in unknown proportions.

Concentrations of nitrogen compounds in 3 perimeter tile drainage samples collected before the start of the operation of the basin were similar to those in 11 perimeter tile drainage samples collected after the start of the operation of the basin (fig. 8). During the study, organic-N concentrations ranged from 0.72 to 5.48 mg/L, and inorganic-N concentrations ranged from 1.2 to 18.8 mg/L. The inorganic-N consisted of similar amounts of ammonium-N, which had concentrations that ranged from 2.58 to 10.5 mg/L (except for one concentration below the detection limit of 0.020 mg/L), and nitrate-N, which had concentrations that ranged from 1.18 to 12 mg/L (table 5 in supplemental information). In most of the samples, including the three collected before the start of the operation of the basin, the nitrate-N concentrations exceeded the presumed natural background level of 2 mg/L (Mueller and others, 1995). Chloride concentrations in the 3 samples collected before the start of the operation of the basin (120–140 mg/L) increased slightly in 10 samples collected after the start of the operation of the basin (140–160 mg/L). These concentrations, although less than the USEPA (1996) SMCL of 250 mg/L, were considerably greater than the median concentration of 11 mg/L determined for chloride in ground-water samples from shallow glacial-drift wells throughout Minnesota (Ruhl, 1987). The elevated concentrations of nitrogen compounds and chloride prior to the start of the operation of the basin likely was related to past years of feedlot runoff into the study site.

During operation of the basin, concentrations of chloride and nitrogen compounds in the perimeter tile drainage and basin seepage differed from each other (fig. 8). Basin seepage had greater chloride concentrations (220–350 mg/L), and generally lesser inorganic nitrogen compound concentrations (table 5). In basin seepage the organic-N concentration (1.46–6.37 mg/L) was similar to that in perimeter tile drainage, but the inorganic-N concentration, which ranged from 0.42 to 6.97 mg/L (except for one concentration of 19 mg/L), was less than that in perimeter tile drainage. The inorganic-N in the basin seepage mostly consisted of nitrate-N, which had concentrations of 5.24 mg/L or less (all being less than the USEPA (1996) MCL of 10 mg/L), and to a lesser extent ammonium-N, which had concentrations of 2.40 mg/L or less (except for one concentration of 18.4 mg/L). These differences in water quality between perimeter tile drainage and basin seepage indicate that ground water would have been enriched in chloride and diluted in inorganic nitrogen as a result of mixing with the seepage.

The chloride concentrations in ground water, basin seepage, and perimeter tile drainage, and flow rates of the basin seepage and perimeter tile drainage, were used to estimate the proportions of basin seepage and ground water in the perimeter tile drainage. The following solute balance equation for chloride relates the contributions of ground water and basin seepage to the perimeter tile drainage:

$$(Q_{gw} \times Cl_{gw}) + (Q_{seep} \times Cl_{seep}) = (Q_{per} \times Cl_{per}) \qquad (1)$$

where

Q_{gw} = Ground-water contribution to perimeter tile drainage (gal/d);

Cl_{gw} = Chloride concentration in ground water (mg/L)—(mean chloride concentration in three perimeter tile

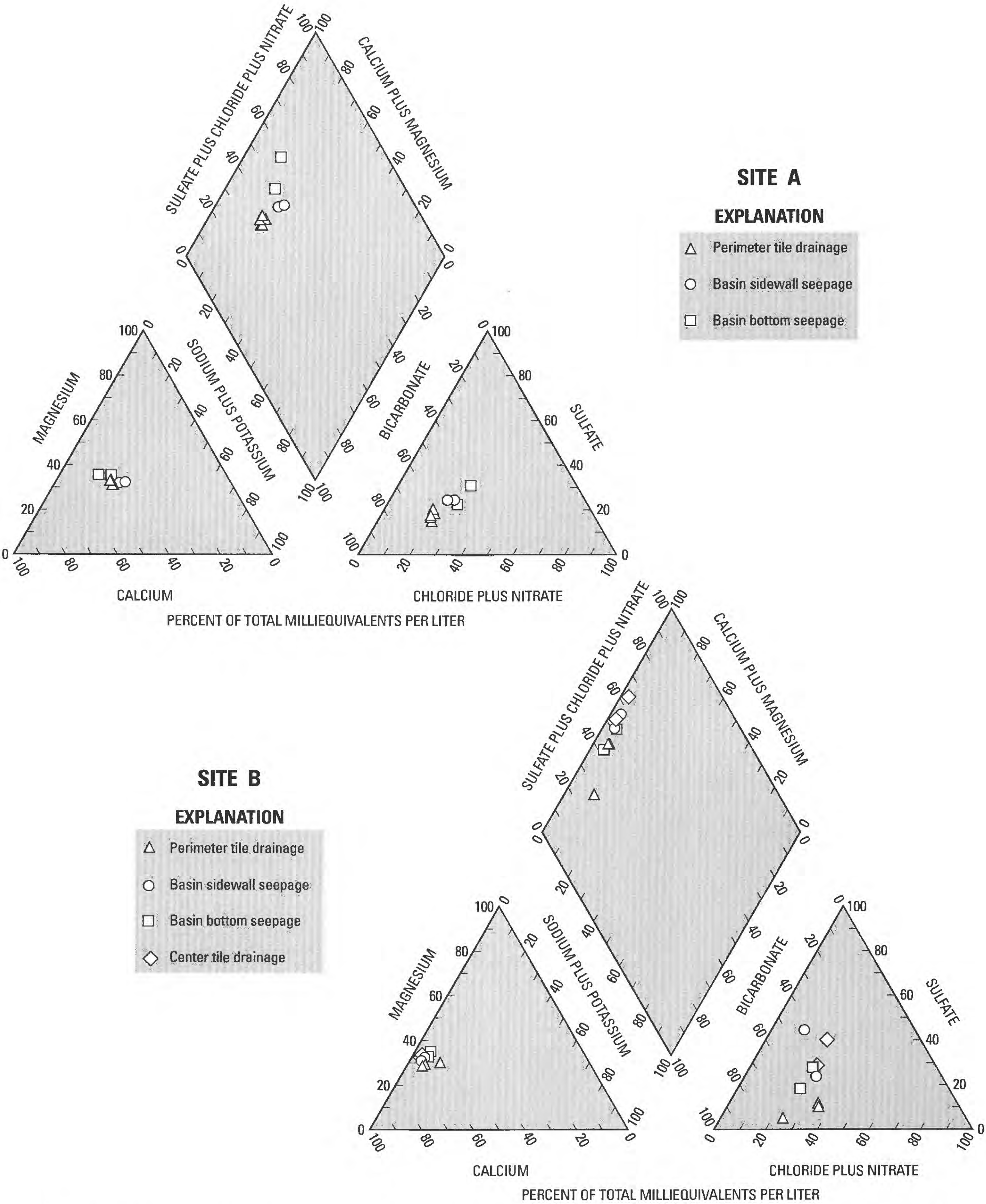

Figure 7. Ionic composition of water samples from perimeter and center (site B only) tile drainage and basin bottom and sidewall seepage, for sites A and B near New Ulm and Owatonna, Minnesota, respectively, 1996-98.

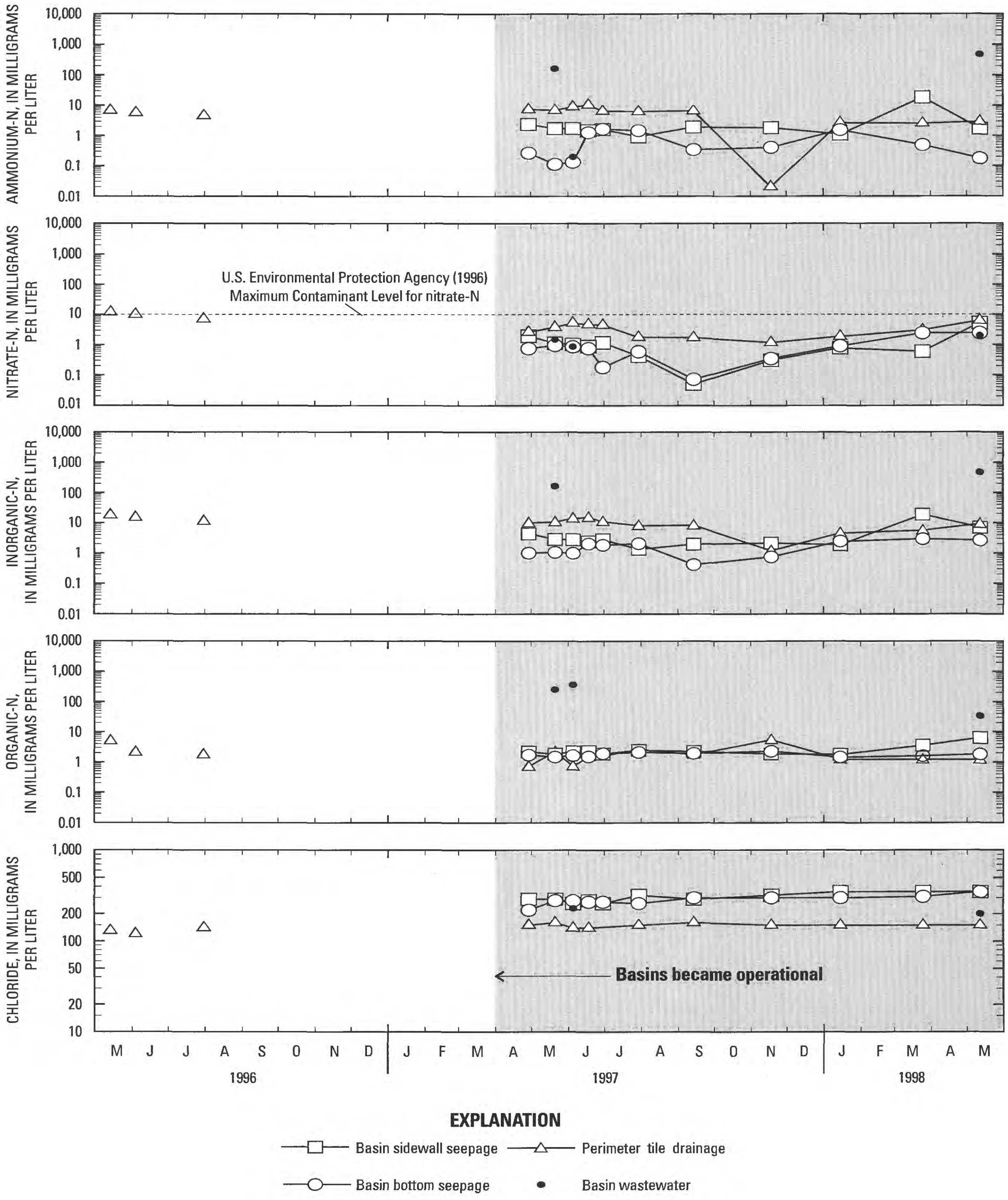

Figure 8. Concentrations of nitrogen compounds and chloride in water samples from sidewall and bottom seepage, perimeter tile drainage, and basin wastewater, for site A near New Ulm, Minnesota, 1996-98.

drainage samples collected in 1996, prior to operation of the basin);

Q_{seep} = Seepage contribution to perimeter tile drainage (gal/d);

Cl_{seep} = Chloride concentration in basin seepage (mg/L)—(weighted average of chloride concentrations in sidewall and bottom seepage);

Q_{per} = Perimeter tile drainage (gal/d); and

Cl_{per} = Chloride concentration in perimeter tile drainage (mg/L).

Equation (1) assumes a constant chloride concentration in the ground-water contribution to perimeter tile drainage. Additionally, chloride concentrations in the perimeter tile drainage are assumed to be the result of mechanical dispersion during mixing of ground water and basin seepage. Chloride typically behaves as a conservative (nonreactive) solute in water—chemical or biological changes that would reduce or increase its concentration are insignificant.

The basin seepage contribution to the perimeter tile drainage can be expressed as the residual of perimeter tile drainage minus its ground-water contribution:

$$Q_{seep} = Q_{per} - Q_{gw}. \qquad (2)$$

This expression for Q_{seep} in equation (2) was substituted for Q_{seep} in equation (1) to derive the following equation for Q_{gw}:

$$Q_{gw} = (Q_{per} \times (Cl_{per} - Cl_{seep}))/(Cl_{gw} - Cl_{seep}). \qquad (3)$$

The ground-water contribution to perimeter tile drainage was solved from equation (3), and the seepage contribution to perimeter tile drainage was then solved from equation (2).

The portion of basin seepage that contributed to perimeter tile drainage, calculated for each of the eight sampling dates given in table 5 from June 18, 1997 to May 12, 1998, ranged from 7 to 19 percent. These results indicate, therefore, that about 81 to 93 percent of the basin seepage recharged the ground water, and that the source of perimeter tile drainage was predominantly ground water. The annual loss of inorganic-N from the basin in the seepage (May 1, 1997–May 1, 1998) was about 16 lbs.—about 7 lbs. through the sidewall and about 9 lbs. through the bottom. Based on these estimated losses of inorganic-N and the portion of basin seepage that recharged the ground water, the annual inorganic-N load to the ground water from basin seepage was about 13 to 15 lbs.

Three basin wastewater samples had inorganic-N concentrations of 1.03, 167, and 478 mg/L, and organic-N concentrations of 34, 255, and 370 mg/L. The inorganic-N in the two samples with high concentrations mostly consisted of ammonium-N (concentrations were 165 and 476 mg/L). The nitrate-N concentrations in the three basin wastewater samples were 2.02 mg/L or less. Strong reducing conditions in basin wastewater, indicated by dissolved oxygen concentration measurements of 0.1 and 0.3 mg/L, inhibited oxidation of organic nitrogen and ammonium to form nitrate. Chloride concentrations in two samples were 200 and 230 mg/L—concentrations that were elevated relative to background concentrations normally found in shallow ground water in Minnesota, but still less than the USEPA SMCL of 250 mg/L.

Compared to basin seepage, basin wastewater had concentrations of ammonium-N and organic-N that were more than 10 times greater, concentrations of chloride that were slightly less, and concentrations of nitrate-N that were similar. The portion of dissolved ammonium-N and organic-N in basin wastewater transported by seepage into ground water, therefore, appeared to be small. The fate of the ammonium-N in basin wastewater may have been: (1) volatilization into the atmosphere as ammonia (NH_3); and (2) sorption to soil particles within the compacted clay liner (ammonium-N typically is not a mobile ion). Additionally, some of the ammonium-N and organic-N in the basin wastewater may have become incorporated into particulate matter that settled out as solid material that was subsequently removed by mechanical means and applied as fertilizer to croplands. A small amount of ammonium-N initially present in the seepage may have been oxidized into nitrate because of slightly greater dissolved oxygen concentrations (0.5–7.0 mg/L) in the seepage relative to basin wastewater.

Colony counts of fecal *Coliform* bacteria in each of two basin wastewater samples were 10,000 and 24,000 (table 5). Colony counts in six seepage samples, three each from the sidewall and bottom, were 1. These results indicate that fecal *Coliform* bacteria in the wastewater were not released from the basin in the seepage. Soil sediment particles within the compacted clay liner probably absorbed a large portion of the bacteria. Continued monitoring of bacterial concentrations in the seepage will determine if the amounts of bacteria released from the basin begins to increase because of diminished absorption capacity in the compacted clay liner.

Site B Basin

This basin is part of a two-stage waste handling operation that consists of adjacent, paired basins and a wastewater circulation system. The basin with the monitoring system is a collection basin that receives wastewater that flows into it by gravity through a buried tile line from concrete holding tanks underneath a nearby swine gestation barn. Waste solids settle out of the wastewater to the bottom of the collection basin. The wastewater then flows by gravity from this collection basin into an adjacent holding basin; from there the wastewater is pumped back through a buried tile line into the gestation barn for reuse in flushing. The bottom dimensions of each of these basins are 40 ft by 200 ft (fig 3). The interior side slope ratios are 3:1. The depth below grade to the bottoms of these basins is about 14 ft; the depth below the top of the sidewall embankments to the bottoms of these basins is about 20 ft.

Seepage Flow

Total seepage flow during the one-year period of record ranged from about 400 to 2,200 gal/d except during 3-month and 1-month periods when the flow ranged from about 3,800 to 6,200 gal/d (fig. 9). The total seepage flow increased from about 400 gal/d in early May 1997, the beginning of the period of record, to about 1,500 gal/d by early July. Between late July and early September, however, the total seepage flow ranged from about 4,200 to 6,200 gal/d. From late September to late June 1998, the end of the period of record, the total seepage flow ranged from about 1,500 to 2,200 gal/d except when the flow increased to about 3,800 gal/d in early April 1998.

Total seepage flow in areal units ranged from about 0.025 to 0.15 in./d except during 3-month and 1-month periods when the flow increased to as much as 0.43 in./d. As at the site A basin, these flow rates exceeded the recommended maximum design rate of 0.018 in./d established by the MPCA (Wall and others, 1998). Continued monitoring of the seepage flow rate will determine if the first-year flow rates remain stable or decrease over time.

The seepage flow in areal units generally correlated with total seepage flow in gal/d except through the sidewalls during periods of wastewater level change. From early September to late October 1997 wastewater depth decreased from about 12 to 4 ft. During this period flow through the sidewalls decreased from about 4,500 to 1,500 gal/d, but flow in areal units, after an initial decrease from about 0.28 to 0.20 in./d, increased to about 0.36 in./d as the basin wastewater was drawn down to its lowest level. From early February to early April 1998 wastewater depth increased from about 3.5 to 9.5 ft. With the rise in the basin wastewater level during this period, flow through the sidewalls increased from about 1,400 to 3,000 gal/d, but flow in areal units initially decreased from about 0.37 to 0.17 in./d, and then increased to about 0.31 in./d. Seepage flow in gal/d through the sidewalls, therefore, was inversely correlated with seepage flow in areal units during the period when the wastewater was falling to or rising from its lowest level as the basin was emptied and refilled. During that period flow in areal units was very sensitive to the reduced area of infiltration.

Seepage flow (in gal/d) through the sidewalls varied in direct relation to wastewater depth during the first 12 months, but not during the final 2 months, of the period of record. Wastewater depth varied very little from the beginning of the period of record to early July 1997, but then increased from about 6 to 12 ft by early September 1997. While wastewater depth increased, seepage flow through the sidewalls increased from about 300 to 4,500 gal/d. From early September to early November 1997 wastewater depth decreased to about 4 ft as wastewater was pumped out of the basin and applied to croplands. Seepage flow through the sidewalls decreased to about 1,500 gal/d during this period. Both wastewater depth and seepage flow through the sidewalls in mid February 1998 were similar to what they were in early November 1997. From mid February to early April 1998 wastewater depth increased to about 9.5 ft and seepage flow through the sidewalls increased to about 3,000 gal/d. From early April to early May 1998 wastewater depth and seepage flow through the sidewalls decreased to about 8 ft and 1,600 gal/d, respectively. From early May to late June 1998, the end of the period of record, wastewater depth increased to nearly 10 ft and seepage flow through the sidewalls decreased slightly to about 1,200 gal/d. Thus seepage flow through the sidewalls was unaffected by wastewater depth during the final two months of the period of record.

Seepage flow (in gal/d) through the bottom appeared to vary in direct relation to wastewater depth during the first 3 months, but not during the final 11 months, of the period of record. After about the first two months of the period of record, seepage flow through the bottom increased with wastewater depth—from about 800 to 3,000 gal/d by mid July 1997. Seepage flow through the bottom then decreased to about 200 gal/d by late September 1997 even though wastewater depth did not start to decrease until mid September. Physical seals that formed at the basin-wastewater interface on the bottom may have retarded seepage flow and caused this decrease. Evidence for the formation of physical seals is that after late September 1997, seepage flow through the bottom did not exceed about 800 gal/d and did not vary in relation to wastewater depth.

Seepage flow through the bottom and sidewalls were about the same during late April–late July 1997. After this period, seepage flow was greater through the sidewalls than through the bottom—an indication that physical seals that had formed at the wastewater interface of the basin were more porous along the sidewalls than the bottom. Formation of the seals along the sidewalls, compared to that along the bottom, may have been less complete, and therefore thinner. Also, freezing and thawing of portions of the sidewalls exposed by declines in wastewater levels may have resulted in ruptures of the sidewall seals.

MW-B1 and MW-B2, which are located between the perimeter drain tile and the basin (fig. 3), were dry throughout the study. MW-B1 was screened about 5.5 ft above the bottom elevation of the basin and about 8.5 ft above the elevation of the nearest section of perimeter drain tile; MW-B2 was screened about 0.5 ft above the bottom elevation of the basin and about 3.5 ft above the elevation of the nearest section of perimeter drain tile. The hydraulic head of shallow ground water in the area bounded by the perimeter drain tile, therefore, was not more than 0.5 ft higher, and very possibly was lower, than the bottom elevation of the basin. The absence of water in these monitoring wells suggests that ground water at this site probably was not hydraulically connected to basin wastewater or to the monitoring system. Unlike at the site A basin, the perimeter and center drain tile were able to prevent potential ground-water discharge into this basin because of the deeper (15–20 ft below land surface) water table.

Water Quality

Each of two basin sidewall seepage samples, two basin bottom seepage samples, two center tile drainage samples, and three perimeter tile drainage samples, were calcium-magnesium bicarbonate type water (fig. 7). These samples had similar proportions of cations but different proportions of anions. The proportions of anions in the perimeter tile drainage samples consisted of approximately 55–72 percent bicarbonate, approximately 25–35 percent chloride plus nitrate, and approximately 5–12 percent sulfate. The seepage samples had lesser proportions of bicarbonate (approximately 42–58 percent) and chloride plus nitrate (approximately 12–30 percent) but a

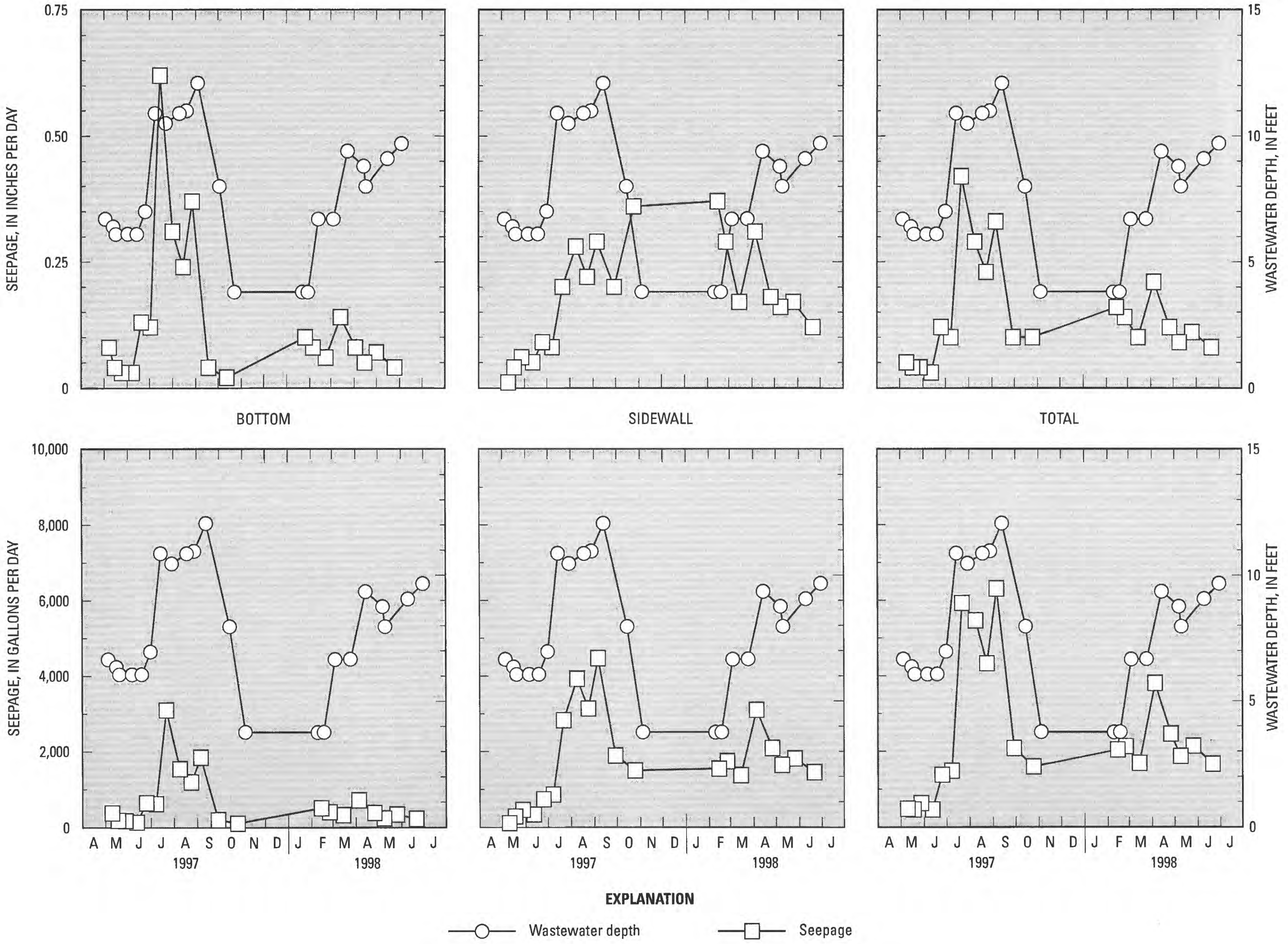

Figure 9. Wastewater depth and basin seepage for site B near Owatonna, Minnesota, May 1997-June 1998.

greater proportion of sulfate (approximately 18–45 percent). These differences suggest, as at the site A basin, that the perimeter tile drainage and basin seepage samples contained water from separate sources that differed in anionic composition and that possibly mixed with each other in unknown proportions. The proportions of bicarbonate, chloride plus nitrate, and sulfate in the center tile drainage were approximately 35–48 percent, approximately 25 percent, and approximately 28–40 percent, respectively. The water type of the center tile drainage was similar to that of basin seepage.

Chloride concentrations in two perimeter tile drainage samples collected before the start of the operation of the basin were similar to those in nine perimeter tile drainage samples collected after the start of the operation of the basin (fig. 10). The chloride concentrations ranged from 48 to 83 mg/L—somewhat greater than normal background levels in shallow ground water but less than the USEPA (1996) SMCL of 250 mg/L. Although the inorganic-N concentrations did not increase appreciably from before to after the start of the operation of the basin, the ammonium-N concentrations in the two perimeter tile drainage samples collected before (0.050 and 0.080 mg/L) the start of the operation were about 3 to 4 orders of magnitude less than those in the nine perimeter tile drainage samples collected after (15.9–159 mg/L) basin operation began. The concentrations of nitrate-N, however, did not change appreciably from before to after the start of the operation of the basin. The nitrate-N concentration ranged from 13.7 to 48 mg/L, except for one concentration below the 0.050 mg/L MRL. The organic-N concentrations increased from before (0.12 and 0.15 mg/L) to after (1.0–82.1 mg/L) the start of the operation of the basin. Thus most of the increase in nitrogen compounds in the perimeter tile drainage from before to after the start of the operation of the basin was attributable to increases in ammonium-N and organic-N. The increased concentrations were much greater than that historically detected in ground water in Minnesota—the median ammonium-N concentration in ground water based on water-quality data compiled for 608 wells in the state was less than 0.1 mg/L, and the median organic-N concentration in ground water based on water-quality data compiled for 1,067 wells in the state was less than 0.5 mg/L (Wall and Montgomery, 1991).)

The high nitrogen concentrations may have been related to antecedent conditions at the site. Feedlot runoff and nitrogen-based fertilizer applications to croplands could have resulted in large background levels of nitrogen compounds in the ground water. The high concentrations may also have been linked to the wastewater, but not as seepage through the compacted clay liner. The wastewater could possibly have entered the perimeter drain tile directly through a secondary permeability crack in the bottom or sidewall of the basin, and thereby bypassed the compacted clay liner. If wastewater was the source of the nitrogen, however, an increase in the chloride concentration in the perimeter tile drainage, which was not observed, would have been expected. The source of the high nitrogen concentrations in the perimeter tile drainage, therefore, could not be conclusively determined from this study.

Three basin wastewater samples had large concentrations of inorganic-N (764, 864, and 2,022 mg/L) and organic-N (189, 336, and 480 mg/L). The inorganic-N mostly consisted of ammonium-N (concentrations in each of the three samples were 761, 864, and 2,020 mg/L). Concentrations of nitrate-N in the three samples were small (<0.050, 2.12, and 2.56 mg/L). Reducing conditions in the wastewater, indicated by 2 small dissolved oxygen concentration measurements of 0.2 and 0.4 mg/L, either prevented nitrification or resulted in denitrification. Chloride concentrations in two basin wastewater samples were 220 and 340 mg/L, which exceeded the USEPA (1996) SMCL of 250 mg/L. Basin wastewater concentrations of chloride, therefore, were greater than perimeter tile drainage concentrations of chloride, which remained fairly stable before and after the basin became operational.

Compared to basin wastewater, basin seepage had lesser concentrations of inorganic-N (4.85–28.3 mg/L except for one concentration of 146 mg/L), organic-N (0.14–0.92 mg/L), and chloride (11–100 mg/L). The inorganic-N mostly consisted of nitrate-N (3.89–25.7 mg/L except for one concentration of 146 mg/L). The processes of nitrogen loss from this basin appeared to be similar to those described for the basin at site A. The annual inorganic nitrogen loss in the seepage flow from this basin estimated for May 1, 1997 to May 1, 1998 was 264 lbs. About 91 percent of this loss was through the sidewalls, attributable in large part to the inorganic-N concentration of 146 mg/L observed in a sidewall seepage sample collected January 15, 1998.

Compared to center tile drainage, basin seepage had similar concentrations of nitrogen compounds and chloride. These similarities, plus the similarity in water type, suggest that basin seepage was the predominant source of water in the center tile drainage. The indications that shallow ground water was not hydraulically connected to the basin or the monitoring system supports the suggestion that basin seepage was the predominant source of water in the center tile drainage.

Basin seepage at this site was potentially a major source of nitrogen in the local ground water—nitrate-N concentrations in the seepage exceeded the USEPA (1996) MCL of 10 mg/L in 17 of 22 samples. Sources of nitrogen in the local ground water other than basin seepage, however, also were important, considering that nitrate-N concentrations in the two perimeter tile drainage samples collected before the start of the operation of the basin also exceeded the MCL.

Colony counts of fecal *Coliform* bacteria in one basin wastewater sample was 29,000 (table 6 in supplemental information). Colony counts in four seepage samples, two each from the sidewall and bottom, and in two center tile drainage samples, were 1. Thus, fecal *Coliform* bacteria in basin wastewater were not released from the basin in the seepage. As at site A, continued monitoring of fecal *Coliform* bacteria in the seepage will determine if the bacterial concentrations remain stable or increase with time.

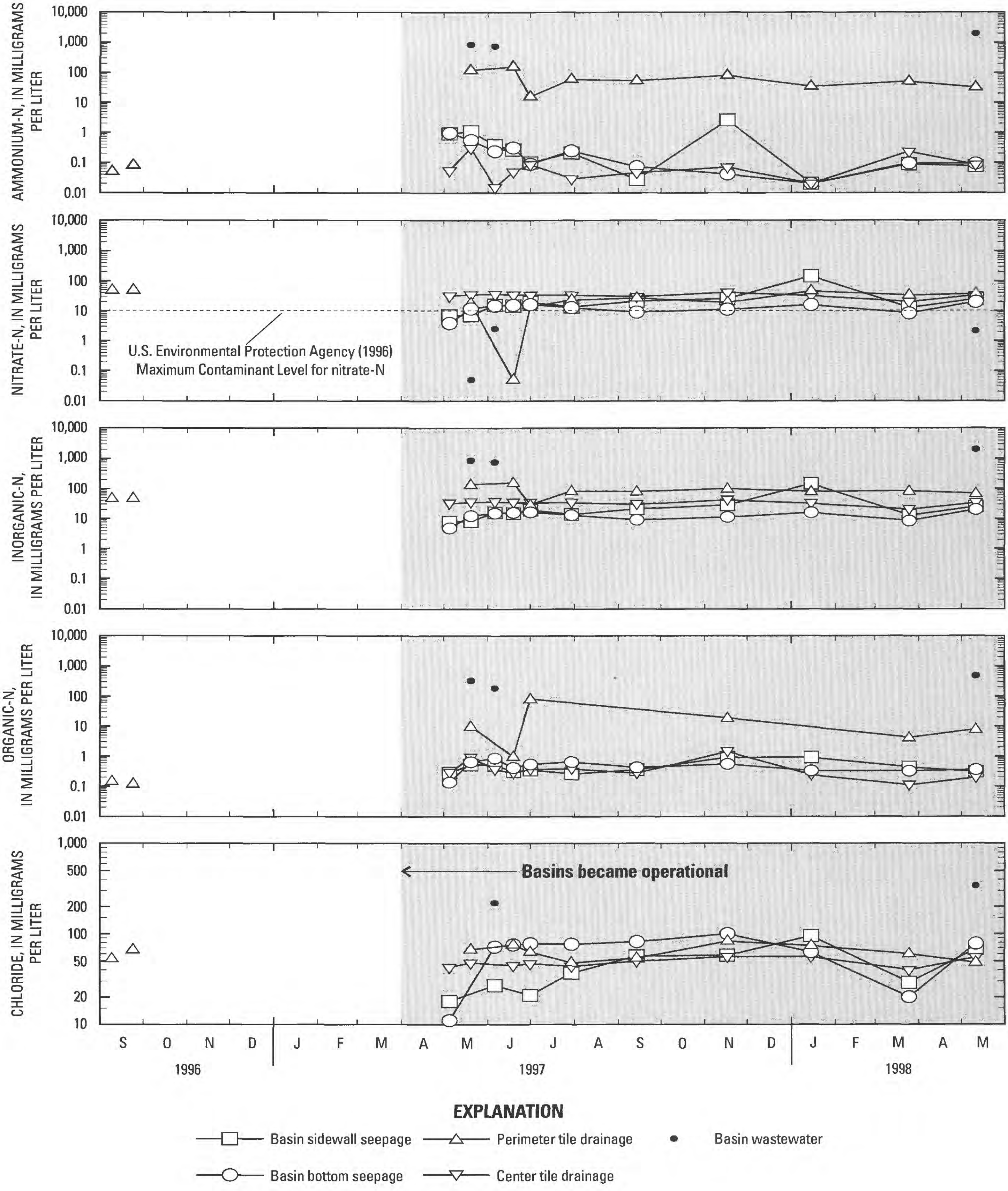

Figure 10. Concentrations of nitrogen compounds and chloride in water samples from sidewall and bottom seepage, perimeter and center tile drainage, and basin wastewater, for site B near Owatonna, Minnesota, 1996-98.

SUMMARY

Numerous earthen basins have been constructed in Minnesota for storage of livestock waste. Typically, these basins are excavated pits with partially above-grade, earth-walled embankments that have underlying compacted clay liners to retard seepage flow. Drain tile is installed around the perimeter of many of these basins to prevent shallow ground and soil water from discharging into the basins. The waste stored in these basins are associated with the following environmental concerns: (1) degraded air quality from gases that result in unpleasant odors and potentially harmful health effects; and (2) degraded quality of ground and surface water from contamination by nutrients, micro-organisms, chloride, animal pharmaceuticals, and trace elements.

The U.S. Geological Survey conducted a two-year (1997–98) study with the MPCA (Minnesota Pollution Control Agency) and Natural Resources Conservation Service of two newly constructed earthen basins in southern Minnesota. The study was done to evaluate effects of seepage from the basins on ground water during the initial year of operation. Monitoring systems were installed below compacted clay liners in portions of the sidewalls and bottoms of the basins to determine the quantity and quality of the seepage.

The monitoring systems consisted of impermeable, 30 mil (.030 inch) PVC (polyvinyl chloride) sheets that were graded to route intercepted seepage to perforated PVC collection pipes that drained into nearby sumps. Divider walls separate the seepage to allow the quantity and quality of the seepage to be separately monitored for portions of the sidewalls and bottoms of the basins.

One of the basins (site A) is located at a small dairy farm. This basin holds a manure-silage mixture, milkhouse wastewater, and local runoff. The dimensions of the bottom of this basin are 54 ft by 170 ft; the sidewall slope ratios are 2:1 (horizontal: vertical) (except for the sidewall with the monitoring system, which has a slope ratio of 2.5:1). The depth below grade to the bottom of this basin is about 8 ft; the depth below the top of the sidewall embankment to the bottom of this basin is about 12 ft.

The other basin (site B) is located at a large hog farm. This basin holds a manure-water mixture from a nearby gestation barn. This basin is part of a two-stage waste handling operation with a wastewater circulation system. The monitoring system basin is a collection basin that receives wastewater directly from the gestation barn. Wastewater in the collection basin flows by gravity into an adjacent holding basin, from where the wastewater is pumped back into the gestation barn for reuse in flushing. The dimensions of the bottoms of these basins are 40 ft by 200 ft; the sidewall slope ratios are 3:1. The depth below grade to the bottoms of these basins is about 14 ft; the depth below the top of the sidewall embankments to the bottoms of these basins is about 20 ft.

Total seepage flow from the site A basin ranged from about 900 to 2,400 gal/d except during early April 1998 when the flow increased to about 4,200 gal/d. Total seepage flow in areal units, which closely correlated with flow in gal/d, varied from about 0.07 to 0.18 in./d except during early April 1998 when the flow increased to about 0.28 in./d. These flow rates were greater than the recommended maximum design rate of 0.018 in./d established by the MPCA. Long-term monitoring of the seepage flow will be required to determine if the flow rates decrease over time because of development of physical seals.

The relation of seepage flow to wastewater depth could not be evaluated at the site A basin because of the small range (about 3 ft) in fluctuation of wastewater depth. Seepage flow commonly was greater through the sidewalls than through the bottom. The greatest difference occurred during early April 1998, when flow was about 3,600 gal/d through the sidewalls and about 600 gal/d through the bottom. The high flow through the sidewalls may have been attributable to ruptures in physical seals at the basin-wastewater interface.

Seepage from the site A basin was calcium magnesium bicarbonate type water. Based on 11 samples each from the bottom and sidewall, the seepage had chloride concentrations of 220–350 mg/L (milligrams per liter); ammonium-N (nitrogen) concentrations of 2.40 mg/L or less (except for one concentration of 18.4 mg/L); nitrate-N concentrations of 5.24 mg/L or less; and organic-N concentrations of 6.97 mg/L or less. Based on background quality, ground water would be enriched in chloride and diluted in inorganic-N from mixing with basin seepage. Colony counts (most probable number) of fecal *Coliform* bacteria in 2 basin wastewater samples were 10,000 and 24,000, but in 6 seepage samples were 12 or less. Thus fecal *Coliform* bacteria were not released from the basin in the seepage.

Total seepage flow from the site B basin ranged from about 400 to 2,200 gal/d except during late July to early September 1997 and early April 1998 when the flow ranged from about 3,800 to 6,200 gal/d. Total seepage flow in areal units varied from about 0.025 to 0.15 in./d except during late July to early September 1997 and early April 1998 when the flow increased to about 0.43 in./d. As at the site A basin, these rates were greater than the MPCA recommended maximum design rate of 0.018 in./d. Continued monitoring will be required to determine if the seepage flow rates remain stable. The seepage flow in areal units generally varied in direct relation to the flow in gal/d except through the sidewalls when the basin was unfilled.

Seepage flow through the sidewalls generally varied in direct relation to wastewater depth. This relation was evident during early July to early September 1997 when sidewall seepage flow increased with wastewater depth, during early September to early November 1997 when sidewall seepage flow decreased with wastewater depth, and again during mid February to early April 1998 when sidewall seepage flow increased with wastewater depth. Except during the first three months of the study, seepage flow through the bottom did not vary directly with wastewater depth.

Seepage flow was about the same through the bottom and sidewalls during the first three months of the study. Afterwards seepage flow was greater through the sidewalls. Physical seals at the basin-wastewater interface of the sidewalls may have ruptured from freezing and thawing, and thus retarded seepage flow less effectively than the seals at the basin-wastewater interface of the bottom.

Seepage from the site B basin was calcium magnesium bicarbonate type water. Based on 10 samples each from the bottom and sidewall, the seepage had chloride concentrations of 11 to 100 mg/L; ammonium-N concentrations of 2.58 mg/L or less; nitrate-N concentrations of 25.7 mg/L or less (except for one concentration of 146 mg/L); and organic-N concentrations of 0.92 mg/L or less. Nitrate concentrations (as N) exceeded the USEPA MCL (maximum contaminant level) of 10 mg/L in 17 of 22 samples. Background quality of the ground water, however, indicated that nitrate concentrations exceeded the MCL prior to the start of the operation of the basin. Colony count of fecal *Coliform* bacteria in one basin wastewater sample was 29,000, but counts in 4 seepage samples were 1. Thus, fecal *Coliform* bacteria were not released from the basin in the seepage.

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Supplemental Information

Table 4. Concentrations of dissolved constituents in environmental and replicate water samples
[all concentrations in mg/L; <, less than; *, not calculated because either environmental or replicate water sample concentration was less than method reporting limit]

Dissolved constituent	Date	Environmental sample concentration	Replicate sample concentration	Concentration difference between environmental and replicate samples	Percent difference between environmental and replicate sample concentrations
Nitrogen, nitrite plus nitrate	6/18/97	4.75	4.86	-.11	-2.3
	7/30/97	1.79	1.75	.04	2.2
	6/18/97	0.888	0.728	.160	18
	6/18/97	.759	.517	.242	47
	9/9/96	48	48	0	0
	5/11/98	33.2	33.5	-.3	-.90
	7/30/97	.592	.613	-.021	-3.4
	7/30/97	.420	.449	-.029	-6.9
Nitrogen, ammonium	6/18/97	10.5	9.91	.59	5.6
	7/30/97	6.30	6.07	.23	3.7
	6/18/97	1.50	1.80	-.30	-20
	6/18/97	1.28	1.31	-.03	-2.3
	9/9/96	0.050	0.040	.010	20
	5/11/98	.084	.077	.007	8.3
	7/30/97	1.48	1.45	.03	2.1
	7/30/97	.930	1.27	-.340	-37
Nitrogen, ammonium plus organic	6/18/97	12	11	1	8.3
	7/30/97	8.9	7.9	1.0	11
	6/18/97	3.8	4.4	-.6	-16
	6/18/97	2.8	3.1	.3	9.7
	9/9/96	0.20	0.30	-.10	-50
	5/11/98	.28	.31	-.03	-11
	7/30/97	3.6	3.4	.2	5.9
	7/30/97	3.4	3.6	-.2	-5.9
Total phosphorus	9/9/96	<0.010	0.010	*	*
	5/11/98	<.010	<.010	*	*
Orthophosphate	9/9/96	.010	.010	0	0
	5/11/98	<.010	<.010	*	*
Calcium	9/9/96	170	170	0	0
	5/11/98	180	180	0	0
Magnesium	9/9/96	45	45	0	0
	5/11/98	58	58	0	0
Sodium	9/9/96	17	17	0	0
	5/11/98	10	10	0	0

Table 4. Concentrations of dissolved constituents in environmental and replicate water samples (Continued)
[all concentrations in mg/L; <, less than; *, not calculated because either environmental or replicate water sample concentration was less than method reporting limit]

Dissolved constituent	Date	Environmental sample concentration	Replicate sample concentration	Concentration difference between environmental and replicate samples	Percent difference between environmental and replicate sample concentrations
Potassium	9/9/96	1.0	1.0	0	0
	5/11/98	1.8	1.8	0	0
Chloride	6/18/97	140	140	0	0
	6/18/97	280	280	0	0
	6/18/97	270	270	0	0
	9/9/96	53	54	-1	-1.9
	5/11/98	55	56	-1	-1.8
	7/30/97	260	250	-10	-4
	7/30/97	320	310	10	3.1
	7/30/97	150	150	0	0
Sulfate	9/9/96	67	69	-2	-3.0
	5/11/98	210	220	-10	-4.8
Fluoride	9/9/96	.20	.20	0	0
	5/11/98	.23	.21	.02	8.7

Table 5. Water-quality data for the site A basin near New Ulm, Minnesota

[°C, degree Celsius; µS/cm, microsiemens per centimeter; mv, millivolts; ml, milliliters; K, indicates nonideal colony count; <, less than; --, no data]

	Date	Temperature, field (°C)	Specific conductance, field (µS/cm)	Specific conductance, lab (µS/cm)	pH, field (standard units)	pH, lab (standard units)	Alkalinity, total, lab, (mg/L as $CaCO_3$)	Oxygen, dissolved, field (mg/L as O)	eH, field (mv)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite+nitrate, dissolved (mg/L as N)	Nitrogen, inorganic, dissolved[1] (mg/L as N)
Perimeter tile drainage	5/14/96	--	1,890	1,820	6.6	7.0	698	--	--	6.80	3.70	12.0	18.8
	6/4/96	--	1,900	1,860	6.8	6.8	667	--	--	5.60	0.020	10.0	15.6
	7/31/96	--	--	2,120	--	6.9	736	--	--	4.59	.100	7.13	11.7
	4/29/97	9.0	2,270	--	6.7	--	--	--	--	7.38	.011	2.64	10.0
	5/21/97	8.0	2,320	2,260	6.5	7.0	809	5.7	--	6.97	.032	3.80	10.8
	6/5/97	--	2,130	--	6.1	--	--	0.3	176	9.06	.011	5.27	14.3
	6/18/97	--	2,120	--	6.7	--	--	.2	146	10.5	<.010	4.75	15.3
	6/18/97	9.5	2,120	--	6.7	--	--	.2	146	--	--	--	--
	6/30/97	11.5	2,120	--	6.4	--	--	.2	--	6.56	<.010	4.53	11.1
	7/30/97	11.0	2,100	--	6.3	--	--	.2	139	6.30	.845	1.79	8.09
	9/14/97	12.5	2,070	--	6.4	--	--	.4	174	6.61	<.010	1.73	8.34
	11/18/97	10.0	2,000	--	6.6	--	--	.3	--	<0.020	.010	1.18	1.20
	1/15/98	8.5	1,900	--	6.6	--	--	.4	336	2.67	<.010	1.88	4.55
	3/25/98	8.5	1,980	--	6.9	--	--	3	--	2.58	.021	3.05	5.63
	5/12/98	9.0	1,930	2,060	6.4	6.8	725	.2	314	2.90	<.010	6.27	9.17
Sidewall seepage	4/29/97	10.0	3,100	--	6.8	--	--	--	--	2.40	0.139	1.95	4.35
	5/21/97	8.5	3,140	3,070	6.5	6.9	974	--	--	1.74	.114	1.13	2.87
	6/5/97	10.5	3,000	--	6.3	--	--	1.0	224	1.77	.076	1.03	2.80
	6/18/97	9.5	2,990	--	6.5	--	--	1.4	187	--	--	--	--
	6/18/97	9.5	2,990	--	6.5	--	--	1.4	187	1.50	.151	.888	2.39
	6/30/97	11.5	2,930	--	6.4	--	--	1.4	--	1.62	.173	1.18	2.80
	7/30/97	10.5	3,130	--	6.4	--	--	.5	--	.930	.014	.420	1.35
	9/14/97	12.0	2,990	--	6.2	--	--	.7	193	1.93	.019	<.050	1.98
	11/18/97	9.0	2,960	--	6.5	--	--	2.4	--	1.83	.011	.305	2.14
	1/15/98	7.0	2,960	--	6.7	--	--	3.5	360	1.10	.024	.781	1.88
	3/25/98	7.5	3,410	--	6.9	--	--	4.0	--	18.4	.115	.596	19
	5/12/98	9.5	2,940	3,430	6.5	6.9	1,030	1.6	349	1.73	.111	5.24	6.97
Bottom seepage	4/29/97	9.5	2,280	--	6.9	--	--	--	--	.266	.066	.748	1.01
	5/21/97	8.5	2,480	1,910	6.6	7.0	581	--	--	.113	.070	.959	1.07
	6/5/97	9.5	2,480	--	6.1	--	--	2.5	285	.133	.016	.862	1.00
	6/18/97	10.0	2,680	--	6.5	--	--	2.4	201	1.28	<.010	.759	2.04
	6/18/97	10.0	2,680	--	6.5	--	--	2.4	201	--	--	--	--
	6/30/97	11.0	2,880	--	6.4	--	--	2.1	--	1.67	<.010	.180	1.85
	7/30/97	11.0	2,770	--	6.3	--	--	1.7	196	1.48	<.010	.592	2.07
	9/14/97	11.5	2,490	--	6.3	--	--	1.2	273	.344	.019	.072	0.42
	11/18/97	8.5	2,670	--	7.1	--	--	6.3	--	.406	.033	.346	.75
	1/15/98	7.5	2,700	--	6.8	--	--	5.9	362	1.54	.012	.908	2.45
	3/25/98	7.5	2,970	--	7.7	--	--	7.0	--	.491	.037	2.45	2.94
	5/12/98	9.5	3,040	3,160	6.5	6.9	952	4.6	345	.177	.020	2.46	2.64

Table 5. Water-quality data for the site A basin near New Ulm, Minnesota (Continued)

[°C, degree Celsius; µS/cm, microsiemens per centimeter; mv, millivolts; ml, milliliters; K, indicates nonideal colony count; <, less than; --, no data]

	Date	Nitrogen, ammonium+ organic, dissolved (mg/L as N)	Nitrogen, organic, dissolved[1] (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	*Coliform*, fecal, (colonies /100 ml)
Perimeter tile drainage	5/14/96	12	5.20	2.20	1.60	180	75	71	48	130	160	0.40	--
	6/4/96	7.8	2.20	1.10	1.10	190	80	79	49	120	170	.40	--
	7/31/96	6.4	1.81	.186	.215	220	92	90	59	140	240	.50	--
	4/29/97	8.1	0.72	--	--	--	--	--	--	150	--	--	--
	5/21/97	9.2	2.23	.069	.056	230	102	87	51	160	220	.39	1
	6/5/97	9.8	0.74	--	--	--	--	--	--	140	--	--	K12
	6/18/97	12	1.50	--	--	--	--	--	--	140	--	--	--
	6/18/97	--	--	--	--	--	--	--	--	--	--	--	--
	6/30/97	8.2	1.64	--	--	--	--	--	--	--	--	--	--
	7/30/97	8.9	2.60	--	--	--	--	--	--	150	--	--	--
	9/14/97	8.4	1.79	--	--	--	--	--	--	160	--	--	--
	11/18/97	5.5	5.48	--	--	--	--	--	--	150	--	--	--
	1/15/98	3.9	1.23	--	--	--	--	--	--	150	--	--	--
	3/25/98	3.8	1.22	--	--	--	--	--	--	150	--	--	--
	5/12/98	4.1	1.20	.081	.122	190	86	73	44	150	210	.48	K2
Sidewall seepage	4/29/97	4.6	2.20	--	--	--	--	--	--	290	--	--	--
	5/21/97	3.6	1.86	.039	.033	300	137	149	83	290	430	.40	1
	6/5/97	4.0	2.23	--	--	--	--	--	--	260	--	--	1
	6/18/97	--	--	--	--	--	--	--	--	--	--	--	--
	6/18/97	3.8	2.30	--	--	--	--	--	--	280	--	--	--
	6/30/97	3.5	1.88	--	--	--	--	--	--	260	--	--	--
	7/30/97	3.4	2.47	--	--	--	--	--	--	320	--	--	--
	9/14/97	4.2	2.27	--	--	--	--	--	--	290	--	--	--
	11/18/97	3.7	1.87	--	--	--	--	--	--	320	--	--	--
	1/15/98	2.9	1.80	--	--	--	--	--	--	350	--	--	--
	3/25/98	22	3.60	--	--	--	--	--	--	350	--	--	--
	5/12/98	8.1	6.37	.046	.022	320	158	182	110	350	480	.54	1
Bottom Seepage	4/29/97	2.0	1.73	--	--	--	--	--	--	220	--	--	--
	5/21/97	1.6	1.49	.105	.089	280	122	80	24	280	420	.31	1
	6/5/97	1.8	1.67	--	--	--	--	--	--	280	--	--	1
	6/18/97	2.8	1.52	--	--	--	--	--	--	270	--	--	--
	6/18/97	--	--	--	--	--	--	--	--	--	--	--	--
	6/30/97	3.6	1.93	--	--	--	--	--	--	270	--	--	--
	7/30/97	3.6	2.12	--	--	--	--	--	--	260	--	--	--
	9/14/97	2.3	1.96	--	--	--	--	--	--	300	--	--	--
	11/18/97	2.7	2.29	--	--	--	--	--	--	300	--	--	--
	1/15/98	3.0	1.46	--	--	--	--	--	--	300	--	--	--
	3/25/98	2.1	1.61	--	--	--	--	--	--	310	--	--	--
	5/12/98	2.0	1.82	.042	.022	310	151	154	6.4	350	410	.50	1

Table 5. Water-quality data for the site A basin near New Ulm, Minnesota (Continued)

[ºC, degree Celsius; µS/cm, microsiemens per centimeter; mv, millivolts; ml, milliliters; K, indicates nonideal colony count; <, less than; --, no data]

	Date	Temperature, field (ºC)	Specific conductance, field (µS/cm)	pH, field (standard units)	Oxygen, dissolved, field (mg/L as O)	eH, field (mv)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite+ nitrate, dissolved (mg/L as N)	Nitrogen, inorganic, dissolved[1] (mg/L as N)	Nitrogen, ammonium+ organic, dissolved (mg/L as N)	Nitrogen, organic, dissolved[1] (mg/L as N)	Chloride, dissolved (mg/L as Cl)	*Coliform*, fecal, (colonies/ml)
Basin wastewater	5/21/97	21.5	4,610	7.1	0.3	--	165	0.095	1.5	167	420	255	--	10,000
	6/5/97	18.5	5,490	6.9	.1	-11	0.154	.330	.873	1.03	370	370	230	24,000
	5/12/98	--	--	--	--	--	476	1.08	2.02	478	510	34	200	--

Table 6. Water-quality data for the site B basin near Owatonna, Minnesota

[°C, degree Celsius; µS/cm, microsiemens per centimeter; mv, millivolts; ml, milliliters; K, indicates nonideal colony count; <, less than; --, no data; *, not determined]

	Date	Temperature, field (°C)	Specific conductance, field (µS/cm)	Specific conductance, lab (µS/cm)	pH, field (standard units)	pH, lab (standard units)	Alkalinity, total, lab, (mg/L as $CaCO_3$)	Oxygen, dissolved, field (mg/L as O)	eH, field (mv)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite+ nitrate, dissolved (mg/L as N)	Nitrogen, inorganic, dissolved[1] (mg/L as N)
Perimeter tile drainage	9/9/1996	--	1,320	1,320	--	6.6	374	--	--	0.050	0.030	48.0	48.1
	9/24/1996	--	1,400	1,420	--	6.7	410	--	--	.080	.030	48.0	48.1
	5/20/1997	7.0	1,990	--	6.8	--	--	--	--	120	.159	17.8	138
	6/19/1997	10.5	2,330	2,200	7.1	7.4	1,030	--	--	159	.011	<0.050	159
	7/1/1997	--	--	--	--	--	--	--	--	15.9	.579	13.7	29.6
	7/30/1997	12.5	1,570	--	7.0	--	--	3.1	128	60.1	3.91	23.1	83.2
	9/14/1997	13.5	1,680	--	7.0	--	--	2.5	234	53.8	1.12	26.8	80.6
	11/17/1997	10.5	1,970	--	7.1	--	--	3.5	--	80.9	.760	19.0	99.9
	01/15/1998	6.0	1,690	--	7.5	--	--	8.3	374	34.7	.255	45.7	80.4
	3/25/1998	--	1,640	--	7.2	--	--	--	--	50.8	1.06	33.2	84.0
	5/11/1998	10.0	1,510	1,530	7.0	7.1	577	3.1	351	32.1	.538	36.9	69.0
Sidewall seepage	5/5/97	--	971	--	7.7	--	--	--	--	.919	.527	6.91	7.83
	5/20/97	9.5	1,030	--	7.4	--	--	--	--	1.08	.117	7.07	8.15
	6/6/97	9.5	1,160	--	7.0	--		6.8	285	.378	.112	15.6	16.0
	6/19/97	10.5	1,220	1,150	7.0	7.4	300	--	--	.266	.151	14.8	15.1
	7/1/97	11.5	1,170	--	7.0	--	--	7.1	--	.098	.107	19.3	19.4
	7/30/97	10.5	1,020	--	7.1	--	--	5.4	360	.210	.135	13.7	13.9
	9/14/97	12.5	1,150	--	7.0	--	--	7.0	370	.027	.391	21.1	21.1
	11/17/97	9.0	1,100	--	7.1	--	--	4.0	--	2.58	.119	25.7	28.3
	1/15/98	6.0	2,330	--	8.0	--	--	12.0	352	< .020	.029	146	146
	3/25/98	--	709	--	8.1	--	--	--	--	.088	.024	12.8	12.9
	5/11/98	10.0	1,150	1,070	6.8	7.2	320	6.6	368	.076	.066	25.0	25.1
Bottom seepage	5/5/97	--	905	--	7.4	--	--	--	--	.964	.144	3.89	4.85
	5/20/97	8.5	1,130	--	7.5	--	--	--	--	.555	1.61	11.8	12.4
	6/6/97	9.5	1,170	--	7.4	--	--	9.2	294	.236	1.02	14.9	15.1
	6/19/97	10.0	1,240	1,180	7.2	7.7	320	--	--	.313	.417	15.6	15.9
	7/1/97	11.5	1,220	--	7.1	--	--	8.5	--	.089	.104	16.4	16.5
	7/30/97	11.0	1,230	--	7.2	--	--	8.3	361	.245	.142	12.8	13.0
	9/14/97	12.5	1,200	--	7.1	--	--	10.2	373	.073	.044	9.06	9.13
	9/17/97	8.5	1,400	--	7.6	--	--	8.0	--	.041	.019	11.2	11.2
	1/15/98	6.0	1,120	--	7.5	--	--	6.2	374	< .020	.021	15.9	15.9
	3/25/98	--	594	--	7.9	--	--	--	--	.095	.027	8.36	8.46
	5/11/98	10.0	1,260	1,280	6.9	7.3	426	8.6	398	.092	.012	19.9	20.0
Center tile drainage	5/5/97	9.5	1,370	--	6.9	--	--	--	--	.055	.199	32.0	32.1
	5/20/97	7.5	1,350	--	6.8	--	--	--	--	.301	< .010	34.6	34.9
	6/6/97	9.0	1,440	--	6.7	--	--	3.6	290	.015	.027	36.1	36.1
	6/19/97	11.5	1,920	1,400	6.7	7.1	279	--	--	.050	< .010	34.5	34.6
	7/1/97	11.0	1,470	--	6.6	--	--	2.2	--	.086	.027	33.7	33.8
	7/30/97	10.0	1,510	--	6.6	--	--	1.8	377	.029	.030	33.8	33.8
	9/14/97	12.0	1,430	--	6.4	--	--	1.2	377	.046	.066	30.0	30.0
	11/17/97	9.0	1,440	--	6.7	--	--	3.4	--	.070	.048	41.5	41.6
	1/15/98	6.0	1,260	--	7.0	--	--	5.8	390	< .020	.013	31.9	31.9
	3/25/98	--	1,550	--	7.7	--	--	--	--	.230	.056	20.0	20.2
	5/11/98	9.5	1,360	1,390	6.7	7.1	350	4.0	356	.084	< .010	33.2	33.3

Table 6. Water-quality data for the site B basin near Owatonna, Minnesota (Continued)

[°C, degree Celsius; µS/cm, microsiemens per centimeter; mv, millivolts; ml, milliliters; K, indicates nonideal colony count; <, less than; --, no data; *, not determined]

	Date	Nitrogen, ammonium+ organic, dissolved (mg/L as N)	Nitrogen, organic, dissolved[1] (mg/L as N)	Phos- phorus, dissolved (mg/L as P)	Phos- phorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	*Coliform*, fecal, (colonies /100 ml)
Perimeter tile drainage	9/9/1996	0.20	0.15	< 0.010	0.010	170	45	17	1.0	53	67	0.20	--
	9/24/1996	.20	.12	< .010	< .010	190	53	22	1.0	66	85	.20	--
	5/20/1997	130	10	--	--	--	--	--	--	67	--	--	--
	6/19/1997	160	1.0	.234	< .010	99	36	44	91	76	15	.32	--
	7/1/1997	98	82	--	--	--	--	--	--	63	--	--	--
	7/30/1997	50	*	--	--	--	--	--	--	48	--	--	--
	9/14/1997	53	*	--	--	--	--	--	--	54	--	--	--
	11/17/1997	100	19	--	--	--	--	--	--	83	--	--	--
	01/15/1998	33	*	--	--	--	--	--	--	74	--	--	--
	3/25/1998	55	4.2	--	--	--	--	--	--	60	--	--	--
	5/11/1998	40	7.9	.032	<.010	150	47	22	23	48	37	.20	1
Sidewall seepage	5/5/97	1.2	0.28	--	--	--	--	--	--	18	--	--	--
	5/20/97	1.6	.52	--	--	--	--	--	--	--	--	--	--
	6/6/97	.89	.51	--	--	--	--	--	--	27	--	--	1
	6/19/97	.58	.31	.017	<.010	180	52	10	6.3	26	300	.16	--
	7/1/97	.45	.35	--	--	--	--	--	--	21	--	--	--
	7/30/97	.47	.26	--	--	--	--	--	--	37	--	--	--
	9/14/97	.38	.35	--	--	--	--	--	--	57	--	--	--
	11/17/97	3.5	.92	---	--	--	--	--	--	58	--	--	--
	1/15/98	.94	.92	--	--	--	--	--	--	95	--	--	--
	3/25/98	.52	.43	--	--	--	--	--	--	29	--	--	--
	5/11/98	.38	.30	.018	.018	160	50	11	6.0	68	150	.22	1
Bottom seepage	5/5/97	1.1	0.14	--	--	--	--	--	--	11	--	--	--
	5/20/97	1.2	0.65	--	--	--	--	--	--	--	--	--	--
	6/6/97	1.1	0.86	--	--	--	--	--	--	72	--	--	1
	6/19/97	.73	0.42	.036	<.010	160	52	15	4.9	76	180	.13	--
	7/1/97	.63	0.54	--	--	--	--	--	--	78	--	--	--
	7/30/97	.89	0.65	--	--	--	--	--	--	77	--	--	--
	9/14/97	.50	0.43	--	--	--	--	--	--	82	--	--	--
	9/17/97	.59	0.55	--	--	--	--	--	--	100	--	--	--
	1/15/98	.35	0.33	--	--	--	--	--	--	63	--	--	--
	3/25/98	.42	0.33	--	--	--	--	--	--	20	--	--	--
	5/11/98	.45	0.36	.019	.025	160	58	15	5.0	78	130	.19	1
Center tile drainage	5/5/97	0.34	0.29	--	--	--	--	--	--	43	--	--	--
	5/20/97	1.2	.90	--	--	--	--	--	--	48	--	--	--
	6/6/97	.38	.37	--	--	--	--	--	--	--	--	--	1
	6/19/97	.33	.28	<.010	<.010	200	61	10	2.7	45	300	.20	--
	7/1/97	.45	.36	--	--	--	--	--	--	47	--	--	--
	7/30/97	.41	.38	--	--	--	--	--	--	44	--	--	--
	9/14/97	.32	.27	--	--	--	--	--	--	50	--	--	--
	11/17/97	1.5	1.4	--	--	--	--	--	--	56	--	--	--
	1/15/98	.26	.24	--	--	--	--	--	--	56	--	--	--
	3/25/98	.34	.11	--	--	--	--	--	--	40	--	--	--
	5/11/98	.28	.20	< .010	< .010	180	58	10	1.8	55	210	.23	1

Table 6. Water quality data for the site B basin near Owatonna, Minnesota--Continued

[°C, degree Celsius; µS/cm, microsiemens per centimeter; mv, millivolts; ml, milliliters; K, indicates nonideal colony count; <, less than; --, no data; *, not determined]

	Date	Temperature, field (°C)	Specific conductance, field (µS/cm)	pH, field (standard units)	Oxygen, dissolved, field (mg/L as O)	eH, field (mv)	Nitrogen, ammonium, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite+ nitrate, dissolved (mg/L as N)	Nitrogen, inorganic, dissolved[1] (mg/L as N)	Nitrogen, ammonium+ organic, dissolved (mg/L as N)	Nitrogen, organic, dissolved[1] (mg/L as N)	Chloride, dissolved (mg/L as Cl)	*Coliform*, fecal, (colonies /100 ml)
Basin wastewater	5/20/97	15.0	7,550	7.7	0.2	--	864	<0.010	<0.050	864	1,200	336	--	--
	6/6/97	20.5	7,390	7.8	.4	42	761	.400	2.56	764	950	189	220	29,000
	5/11/98	--	--	--	--	--	2,020	.738	2.12	2,022	2,500	480	340	--

[1] For purposes of calculating inorganic and organic nitrogen, concentrations reported less than the MRL are considered equal to the MRL.

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