USE OF A FIELD DRAIN AND AN ARTIFICIAL WETLAND TO MINIMIZE GROUND-WATER CONTAMINATION FROM AN AGRICULTURAL SITE

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SUSQUEHANNA RIVER BASIN COMMISSION

The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland, New York, Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basinwide authority, the Commission's goal is to effect coordinated planning, conservation, management, utilization, development and control of basin water resources among the government and private sectors.

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Dwight Rohrer, a farmer in East Hempfield Township, has been extremely cooperative and supportive throughout the project. The Lancaster County Conservation District helped identify potential farm sites for the research project. The Pennsylvania Department of Environmental Protection, Bureau of Laboratories, performed all of the chemical analyses of water samples.

Special appreciation goes to Larry Taylor, a former employee of the Commission, who initiated this project in 1994, because he recognized the potential value of field-drain collection and treatment systems to reduce the quantity of nitrogen in shallow ground water and, ultimately, in the surface waters of the basin.

USE OF A FIELD DRAIN AND AN ARTIFICIAL WETLAND TO MINIMIZE GROUND-WATER CONTAMINATION FROM AN AGRICULTURAL SITE

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ABSTRACT

The Conestoga River Basin wetland study was designed to evaluate the potential for collecting and treating nitrate-contaminated shallow ground water in agricultural areas underlain by carbonate bedrock. It was performed in cooperation with the Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation. The project's three major elements are: (1) the design and installation of a field-drain collection and wetland treatment system at a farm in Lancaster County, Pa.; (2) monitoring and assessment of the ability of the constructed wetland to remove nutrients from the field drain discharge; and (3) an evaluation of the effectiveness of the drain in capturing shallow ground water with an analytical or numerical cross-sectional model.

The collection system consists of about 2,000 feet of 6-inch and 4-inch slotted plastic pipe installed between 3 and 5 feet below the land surface. Agricultural field drains can function like interceptor ditches and form effective barriers to down-gradient movement to shallow ground water. Flow from the field drain is directed to a small artificial wetland that is utilized as the treatment part of the process to remove the nitrogen from the water through denitrification.

The constructed wetland is an excavated basin that is 20 feet wide, 200 feet long, and 3 feet deep. The basin is lined with plastic film and filled with PennDOT grade 1-B gravel, with hay and manure added to provide an initial carbon source for denitrification. It is planted with a variety of native, emergent, herbaceous plant species, including soft stem bulrush, giant bur-reed, broad-leaved cattail and soft rush.

Review of the hydraulic performance of the wetland during the fall and winter of 1995 and 1996 indicated that during times of low inflow, the water level dropped rapidly rather than being maintained at the level needed for vegetation. Modifications to the design of the collection system and replacement of the wetland basin liner during the summer and early fall of 1996 improved performance. Total discharge from the field drain system accounted for about 28 percent of recharge for the six months of October 1996 through April 1997. A numerical model of a hypothetical field drain system indicated that the drain captures only shallow ground water and that ground water deeper than approximately 15 feet bypasses the drain and continues down gradient.

Water quality samples collected during this time period showed that the wetland is partly effective in removing nitrate. Samples collected in late April showed the maximum nitrate reduction of 47 percent. Unfortunately, drought conditions prevented further sampling and the effectiveness of the wetland treatment system is best characterized as promising, but inconclusive. The effectiveness of the collection and treatment system in this geologic setting needs further investigation, including study during years with average and greater than average precipitation.

INTRODUCTION

Nitrogen loading from the Susquehanna River has been identified as a major contributing factor to the decline of water quality in the Chesapeake Bay. Ground water, discharging from agricultural areas, is a primary source of the nitrogen that reaches the river.

A variety of techniques is being used in Pennsylvania to reduce the quantity of nitrogen in runoff from agricultural areas. One approach is to use modified tillage and cropping methods, often called Agricultural Best Management Practices (BMPs). However, many of the BMPs that are designed to reduce surface runoff (contour plowing, terracing, strip cropping, and no-till cultivation) cause an increase in the infiltration of precipitation to the ground-water system. Because the nitrogen from fertilizer or manure applied to farmed fields moves readily with the infiltrated water as dissolved nitrate, the BMPs can result in high concentrations of nitrate in the shallow ground water.

A second method involves reducing the amount and controlling the timing of fertilizer application. In a long-term study of surface and ground water in the Conestoga River Headwaters, Pa. (Lietman, 1997), reduction of nutrient applications in a 1.4-square-mile subbasin was beneficial in decreasing concentrations of nitrate in less than two years. However, a study of a farm near Enterline, Pa. (Takita and others, 1991), suggests that many years of reduced fertilizer application may be required to cause any significant decrease in the amount of nitrogen in ground water. Monitoring data showed that the nitrate concentration in three wells on the farm remained fairly constant, even though the fields had been completely unused and unfertilized for several years.

Several studies (Zheng and others, 1988a, 1988b; Gilbert and Gress, 1987) have demonstrated that artificial subsurface drainage systems can be very effective in capturing shallow ground water before it reaches a stream. Ground water under farmed fields generally flows down-gradient from areas of recharge to the nearest stream valley, where it discharges as baseflow to the stream. This down-gradient flow can be interrupted by tile or field drains, generally used to drain wet areas of the fields. The field drains collect shallow ground water and discharge it through a single outlet directly into ditches and feeder streams. Shifting the contaminated water from the subsurface to the surface presents an opportunity to treat the water before it discharges to a stream.

This concept has been tested at a demonstration site in Halifax, Pa., where the field drain discharge is directed to a small artificial wetland that acts as a natural treatment system to remove the nitrate (Taylor and others, 1994; and Taylor, 1996). The Armstrong Creek watershed is underlain by interbedded sandstone and shale bedrock. Overall, water treated by the wetland system had an average 25 percent reduction in the concentration of nitrogen, with a greater than 90 percent reduction during the summer months. However, before the general concept of using a field drain to collect shallow ground water and providing treatment with a small artificial wetland can be considered as a possible BMP, it should be tested in a variety of physical settings.

This project in the Conestoga watershed was designed to evaluate the collection and treatment technique in an agricultural area underlain by carbonate bedrock. It was performed in cooperation with the Pennsylvania Department of Environmental Protection[1], Bureau of Land and Water Conservation (reorganized as the Bureau of Watershed Conservation)[2].

The first phase of the project consisted of locating a suitable farm having a riparian zone suitable for field drain installation and wetland construction within the Conestoga River Watershed. This area has known problems of high nutrients in ground and surface water. The Conestoga River Watershed has about 63 percent agricultural lands, and had yields of total nitrogen of 25.6 and 24.8 pounds per acre per year during 1990 and 1991, respectively (Takita and Edwards, 1993). These yields of total nitrogen were the highest of streams measured in the Susquehanna River Basin. High levels of nitrates also have been measured in ground water in the carbonate-rock areas of Lancaster County, where nearly 90 percent of the wells sampled exceeded the U.S. Environmental Protection Agency (US EPA)

[1] Prior to 1995, the Pennsylvania Department of Environmental Protection was known as Pennsylvania Department of Environmental Resources.

[2] Prior to 1995, the Bureau of Watershed Conservation was known as the Bureau of Land and Water Conservation.

drinking water standard for nitrate (Meisler and Becher, 1971). The ground water had a median concentration of about 38 milligrams per liter (mg/l). The location of the project area within the Susquehanna River Basin is shown in Figure 1.

The project was initiated in early May 1994. Staff met with the Lancaster County Conservation District to visit potential farm sites, and identified one that appeared suitable for the development of the collection and treatment system. Water quality analyses on samples collected from several wells, a spring, and an intermittent tributary stream showed a clear indication of nitrate contamination of the shallow ground water, with concentrations as high as 39 mg/l as N.

A shallow auger hole drilled in late August 1994 indicated that the stream draining the Rohrer farm might be perched. Although such a condition was thought to make installation of a field drain and wetland very difficult to accomplish, a more suitable site could not be located. The field drain and wetland were designed and installed in November 1995. A subsequent performance evaluation indicated the need for modifications, which were completed in September 1996. Vegetation was planted in October. Water quality monitoring began in earnest in January 1997. Due to regional and local drought conditions during that summer and fall, flow through the system was not sustained, limiting data collection. Therefore, results are promising, but inconclusive.

Purpose and Scope

The project had three major elements: (1) the design and installation of a field-drain collection and wetland treatment system at a farm in Lancaster County, Pa.; (2) monitoring and assessment of the ability of the constructed wetland to remove nutrients from the field drain discharge; and (3) an evaluation of the effectiveness of the field drain system in capturing shallow ground water with an analytical or numerical cross-sectional model.

The description of the field drain and wetland includes the design at the time the project was planned and changes that were made as the project evolved. An evaluation of the field drain and wetland focuses on successes and problems of the installation, and includes suggestions for future design.

Description of the Study Area

The study area is located in north central Lancaster County, Pennsylvania (Figures 2 and 3). A farm having a riparian zone suitable for field drain installation and wetland construction was found along an unnamed tributary to the Little Conestoga Creek. The 2.5-square-mile subbasin is rural, with most development consisting of small farms. The land is gently rolling, with undulating broad valleys.

The field site is located within the Conestoga Valley Section of the Piedmont physiographic province. The underlying bedrock consists mainly of the Zooks Corner Formation of Cambrian age, which is comprised of thin- to thick-bedded, medium-gray, very finely crystalline dolomite, with some gray limestone. The Zooks Corner contains an abundance of noncarbonate minerals in the rocks, which cause these rocks to be somewhat more resistant to erosion than other carbonate rocks. The bedrock is weathered and fractured, and contains voids and sinkholes. Soils in the study area are predominantly Hagerstown and Duffield silt-clay loams that formed in residuum from the carbonate rock (U.S. Department of Agriculture, 1985). The area is fairly typical of the intensively farmed carbonate valleys in this physiographic province.

The field-drain monitoring site is located on a farm in East Hempfield Township, about one mile west of the Borough of East Petersburg. The general diversified farming operation consists of a small herd of beef animals, fruit trees (apples and peaches), tobacco, strip-cropped corn and soy beans, and other small grains. The monitoring facilities are located in orchards and cropped fields characterized by gentle slopes with drainage toward an intermittent stream channel.

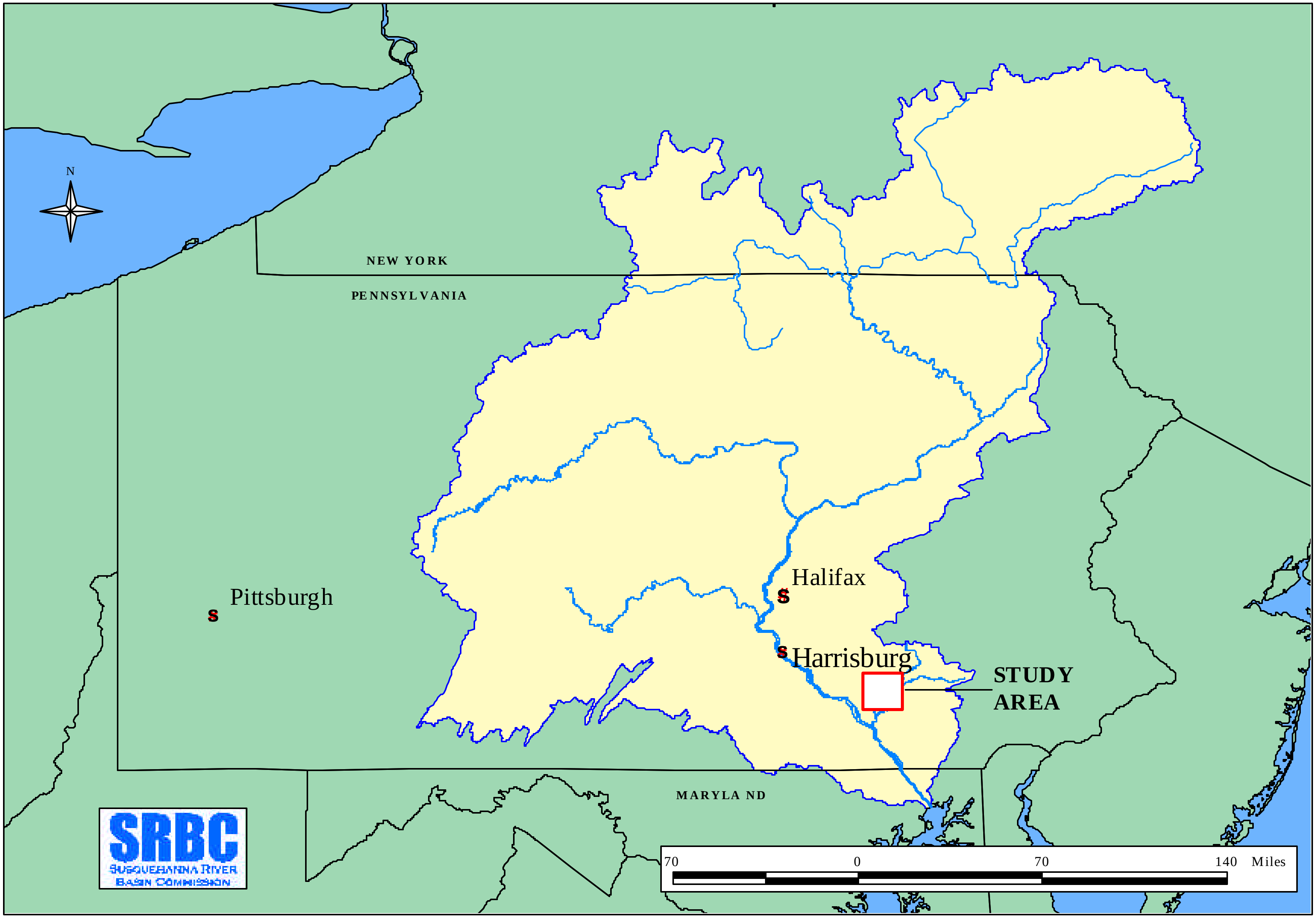

Figure 1. Regional Location Map

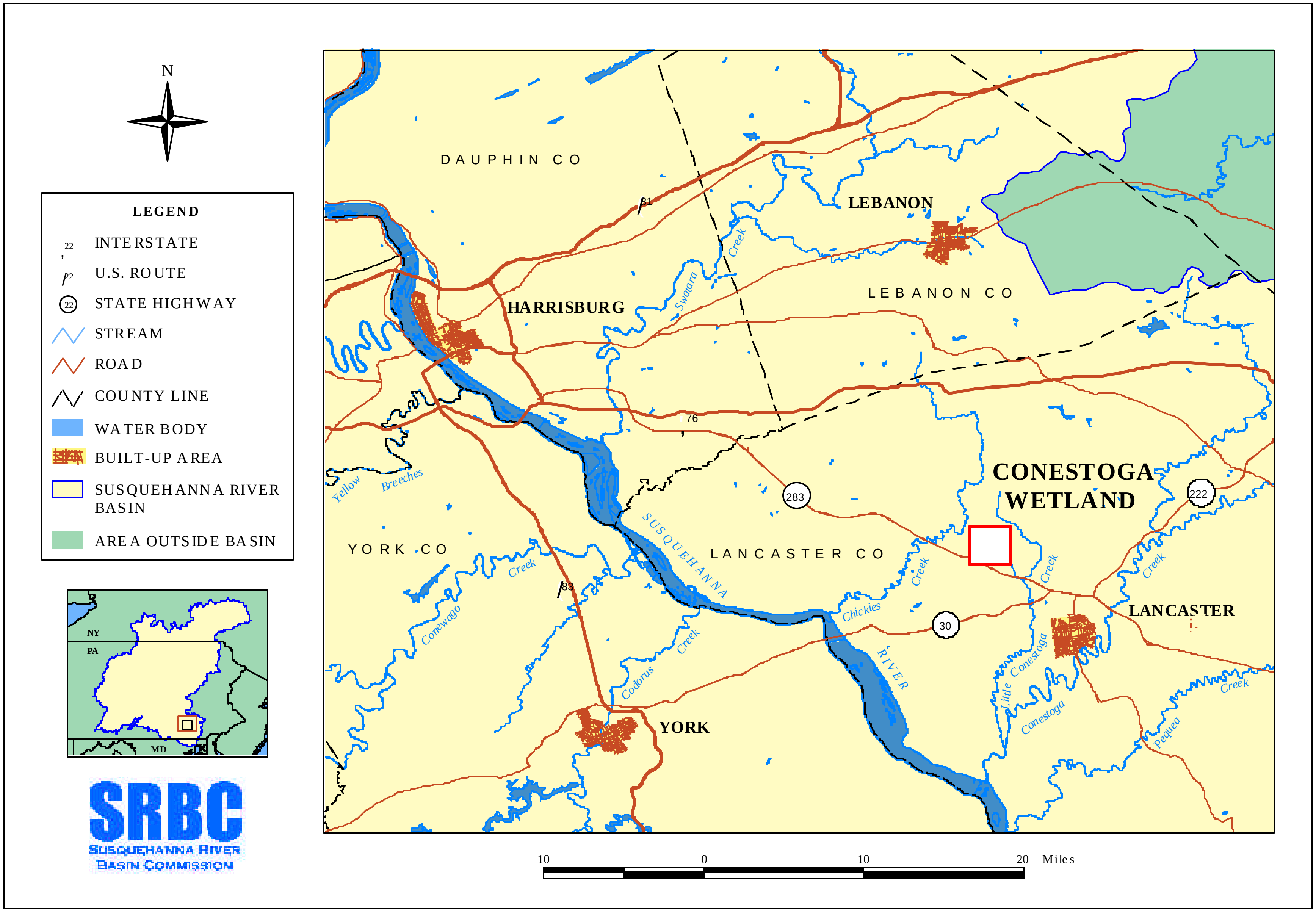

Figure 2. Location of the Study Area in Lancaster County

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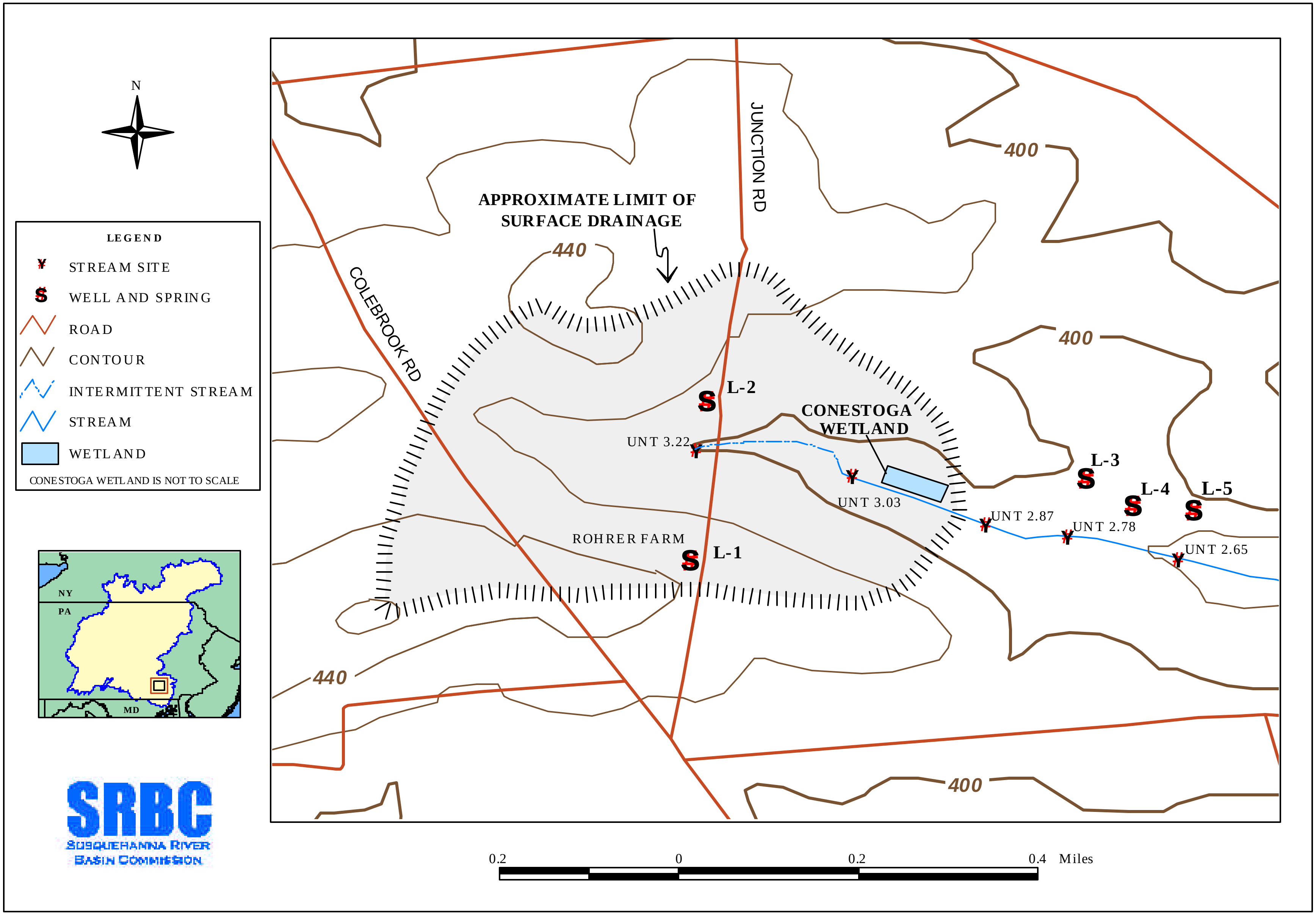


Figure 3. Topographic Map Showing the Location of Sampled Wells, Stream Sites, and the Wetland Treatment System

Monitoring Facilities and Sampling Procedures

Figure 4 shows the location of the collection and monitoring facilities on the farm. The collection system consists of 300 feet of solid pipe and 1,530 feet of 6-inch and 4-inch slotted pipe, installed between 3 and 5 feet below the land surface. Flow from the field drain is directed through the wetland, and measured at the outlet using a v-notch weir installed in a wooden junction box. Observations of flow were made weekly; there is no continuous record of flow at the outlet. The weir is adjustable to control the water level within the wetland cell.

Water quality samples were collected and field chemistry was analyzed weekly from the inlet through a vertical stand pipe and at the junction box at the outlet of the wetland. Samples were analyzed for total nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, total phosphorus, and total organic carbon. Sampling began in January 1996. The system was sampled for four months in 1997 before drought conditions became established in the lower Susquehanna River Basin. Unfortunately, after sampling during the week of April 30, 1997, there was no flow through the wetland for a period of several weeks. The last samples were collected on June 4, 1997, following a rainfall event. Observations of the wetland continued through fall 1997, but flow through the wetland was never reestablished, so no additional samples were collected.

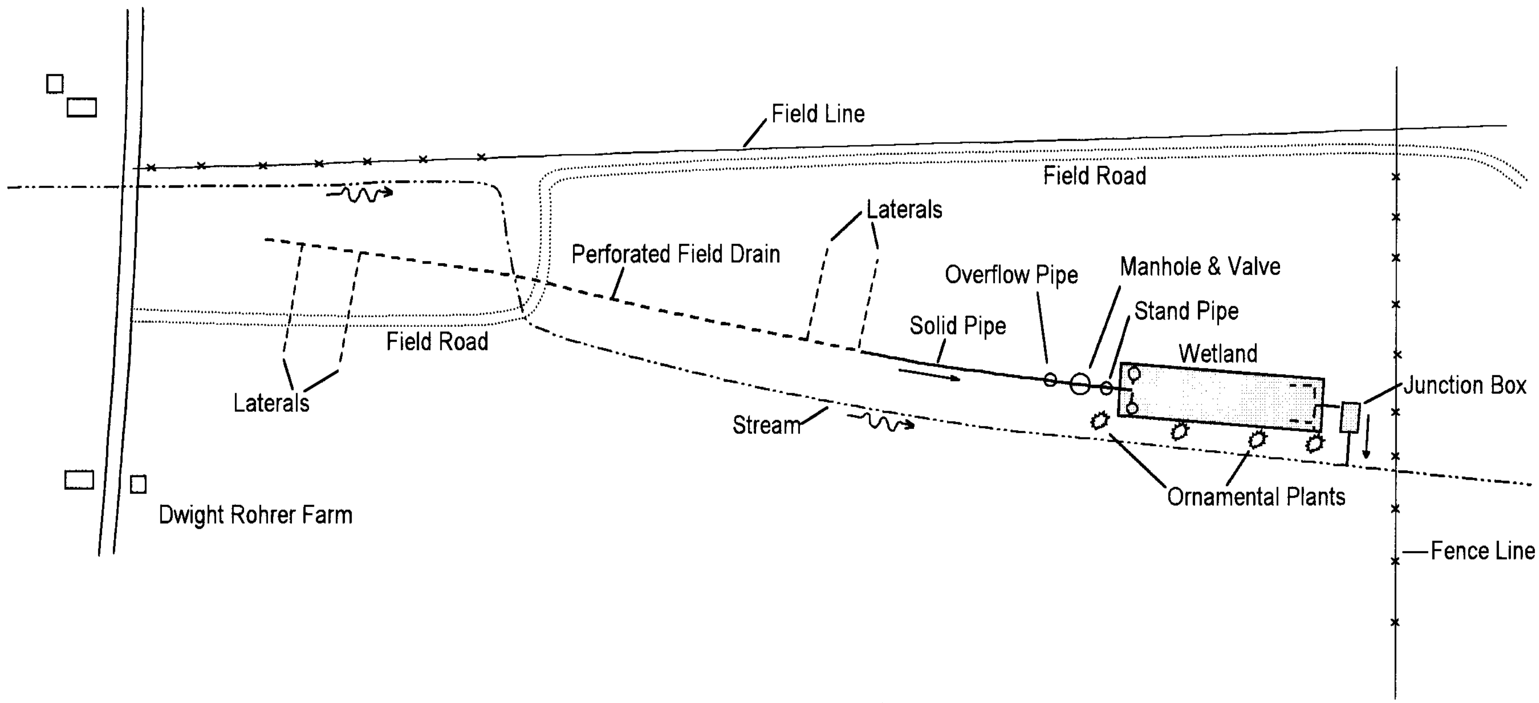


Figure 4. Schematic Plan View of Field Drain, Monitoring Facilities, and Wetland Cell

NITROGEN CHEMISTRY

Under natural conditions, the concentrations of dissolved nitrogen species in ground water are very low (the oxidized form of dissolved nitrogen, nitrate, is the most stable form in ground water). Nitrate generally occurs in high concentrations in ground water affected by human activities, including the application of commercial fertilizers and manure, and discharges of septic tank effluent. They are all potential sources of organic and ammonium nitrogen, NH_3, that can eventually convert to nitrate, NO_3, (a process called nitrification) and leach to the ground water.

The concentration of nitrate in ground water from the Zooks Corner Formation is about 16 mg/l as N (Taylor and Werkheiser, 1984). This relatively high concentration of nitrate is likely due to extensive fertilization of the intensely cultivated soils overlying these rock units. However, Lietman (1997) reports that in a regional study of the Conestoga River headwaters, dissolved nitrate concentrations in ground water were elevated in carbonate-rock areas regardless of land use, and commonly exceeded the maximum contaminant level (MCL) of 10 mg/l as N for drinking water. In water samples from areas underlain by noncarbonate rock of the Conestoga River headwaters, median dissolved nitrate concentration is reported to be 3.4 mg/l as N, and rarely exceeded the MCL.

In reducing environments, volatilization of nitrogen can occur when nitrate is reduced to nitrous oxide or nitrogen gas by the process of denitrification. There is generally a tendency for ground water to change from being oxic (oxidizing) to anoxic (reducing) with depth and distance along a flow path from recharge to discharge areas. Reducing ground water conditions are generally characterized by low dissolved oxygen, which can result in elevated concentrations of iron and manganese, as shown in an area underlain by interbedded sandstone and shale by Taylor (1996).

This could account for the apparent gradual decrease in nitrate concentration with increasing depth below the water table (Taylor and others, 1994; Taylor, 1996). In water quality sampling of wells, springs, and the stream conducted in September 1994, similar results were found at this field drain monitoring site underlain by carbonate rock (Table 1). Few data were available on water level and depth of water-bearing zones, thus no analysis of these factors is possible. Complete water quality analyses and physical data for wells are presented in Table A1 in the appendix. Water quality analyses for the unnamed tributary to Little Conestoga Creek are presented in Table A2 in the appendix.

Table 1. Variation of Ground-Water Quality With Depth

Site No.*	Water Source	NO_3 as N (mg/l)	NO_2 as N (mg/l)	NH_3 as N (mg/l)	Total Phos. (mg/l)
L-1	Deep well	7.97	0.020	0.44	0.02
L-2	Spring	13.50	0.030	0.02	0.05
L-3	Deep well	1.02	0.008	0.27	0.02
L-4	Shallow well	20.30	0.008	<0.02	0.04
L-5	Shallow well	22.10	0.040	<0.02	<0.02
UNT 3.22	Stream	39.70	0.016	0.03	0.07
UNT 3.03	Stream	21.20	0.098	0.02	0.08
UNT 2.87	Stream	19.10	0.018	0.03	0.04
UNT 2.78	Stream	20.80	0.042	0.09	0.65
UNT 2.65	Stream	20.30	0.020	0.04	0.08

*L = Well or Spring

UNT = Unnamed Tributary

Contamination of surface water by the shallow ground water would be expected, and the concentrations of nitrate in samples collected from the stream flowing through the farm are quite high (Table 1). The source of streamflow is primarily springs, and there is no significant riparian zone, found by Taylor (1996) likely to be effective in reducing the nitrogen concentration of surface waters in the Armstrong Creek Basin. In this valley underlain by carbonate rocks, the use of wetland collection and treatment systems may be a viable option to reduce the nitrate concentration in streamflow.

GROUND-WATER FLOW SYSTEM

The ground water in the study area occurs in, and moves through, the pore spaces in the weathered rock material, or regolith, and the fractures and solution openings in the underlying bedrock. The mantle of regolith includes all of the material from soil at the land surface to the bedrock, and is relatively porous and permeable. Water in the regolith moves downward to recharge the bedrock.

In general, the weathered mantle and the underlying carbonate rocks of Cambrian and Ordovician age in the Lancaster area form one complex, heterogeneous, water-table aquifer (Meisler and Becher, 1971). Ground water in these rocks occurs in bedding and cleavage planes, joints, faults, and other fractures. Where these openings have been enlarged by solution, large quantities of water can drain through the ground-water reservoir.

The flow system is recharged by precipitation that infiltrates the weathered mantle and percolates to the water table. In general, the water table is a subdued image of surface topography. The water table is commonly in the lower part of the weathered mantle, but also may be in the bedrock (Gerhart and Lazorchick, 1984).

The ground-water flow systems under the gently rolling lowlands developed on the Zooks Corner Formation can be characterized as being dominantly local, with flow paths that are generally less than a few thousand feet. Most ground water discharges in adjacent topographic low areas. Although streams are generally hydraulically connected to the water table, a shallow auger hole, constructed in late August 1994, suggested that the stream reach adjacent to the wetland is perched.

Limited ground-water quality data collected at the beginning of this study are shown in Table 1. Water quality data from two deep wells, one shallow dug well, two springs, and the small stream near the field-drain site indicated that shallow ground water has generally higher concentrations of nitrate than deeper ground water. Data are insufficient for defining two distinct geochemical zones like those found by Taylor and others (1994) in ground water underlying the Halifax farm.

FIELD-DRAIN COLLECTION SYSTEM

Agricultural field drains are commonly used to eliminate poorly drained or wet areas in cropped fields. At the Halifax site, when existing field drains continued to flow long after precipitation ended, it became apparent that the drains had been unintentionally set below the level of the water table. This fortuitous situation allowed the drains to function similarly to the interceptor ditches, like those used in the cleanup of oil spills. An interceptor ditch is a trench excavated to a depth below the water table, and generally located perpendicular to the direction of ground-water flow. The ditch creates a hydraulic barrier that captures polluted ground water from up-gradient sources in an aquifer, thereby preventing the polluted water from moving farther down gradient. This study was designed to collect shallow ground-water flow by intentionally installing the field drain below the natural ground-water table.

The field-drain collection system was constructed in fall 1995 (with modifications in July and September 1996) at the approximate location shown in Figure 4. The final collection system consists of 300 feet of solid pipe and 1,530 feet of slotted 6-inch and 4-inch pipe, installed between 3 and 5 feet below the land surface and 300 feet of 6-inch solid pipe. Four laterals connect to the main pipe, draining an area of about 90 acres.

During construction of the field-drain system, the level of the water table was determined using indirect methods. Results from shallow auger holes were inconclusive. The field-drain lines were located with guidance from the farmer, based on his knowledge of historically wet areas in his cropped fields, and placed at depths ranging from 3 to 5 feet. The depth of the inlet manifold in the wetland and the required tile-line slope controlled the installation depth of the field drain. During excavation, wet conditions were observed at the base of the trenches.

ARTIFICIAL WETLAND

The wetland was constructed in November 1995 at the approximate location shown in Figure 4. The wetland cell consists of a small, excavated basin approximately 20 feet wide by 200 feet long, with a depth of about 3 feet. The basin was primarily filled with over 600 tons of PennDOT grade 1-B gravel. Manure mixed with wood chips, supplied through the Holstein Breeders Association, was intermixed with the gravel and bales of straw were set across the width of the basin to supply sources of carbon. The basin was lined with a 4-mil polyethylene plastic to prevent infiltration of water from the wetland to the ground water.

Figure 5 shows a typical cross section of the wetland cell. The inlet is located near the base, and flow is distributed across the width of the cell by a 6-inch slotted pipe. To maintain subsurface flow through the gravel, the outlet is about one foot above the bottom of the cell. There is no gradient within the wetland itself. Flow is measured at the outlet using a v-notch weir, installed in a wooden junction box. There is insufficient gradient at the site for a second weir at the inlet to measure incoming flow. The farmer preferred the long, narrow shape of the wetland because it preserved much of the useable area of the field.

Design Modifications

The various modifications and enhancements to increase flow and duration of flow to the wetland are described in Table 2. A materials list for the field-drain collection system is shown in Table A3 in the appendix.

The hydraulic performance of the wetland was observed during the fall and winter of 1995 and 1996. Unfortunately, water levels in the wetland dropped rapidly during times of low inflow, indicating possible design problems of the collection system and the wetland. First, because the system was installed with a low gradient between inlet and outlet, it was suspected that water backed up into the inlet pipe when the gravel in the wetland became saturated. Second, because the inlet pipe was slotted, any water collecting there could infiltrate to the ground-water system. These problems were corrected in July 1996 (an extremely wet spring delayed construction), when 300 feet of slotted pipe in the collection system was replaced with solid pipe. At the existing drain pipe gradient, this distance was great enough to elevate the base of the drain pipe above the water level in the wetland.

An immediate improvement was noted in the flow to the wetland after pipe replacement. However, water losses from the wetland were still unacceptable. The water level needed for vegetation was not maintained during periods of low inflow. Since the only remaining source of water loss was the wetland liner, its replacement was considered. The liner installed initially was 4-mil polyethylene, and contained a large number of taped seams. Either the seams separated during the emplacement of the gravel, or a hole was torn in the plastic during installation.

The wetland cell was reconstructed during September 1996 to curb water losses. The cell has the same dimensions as the original cell; however, the 4-mil polyethylene liner was replaced with a 30-mil polyethylene liner. This new, heavier gauge liner was installed as a single sheet to avoid potential complications of improperly sealed seams. New inlet and outlet pipe boots also were installed. The original gravel, intermixed with

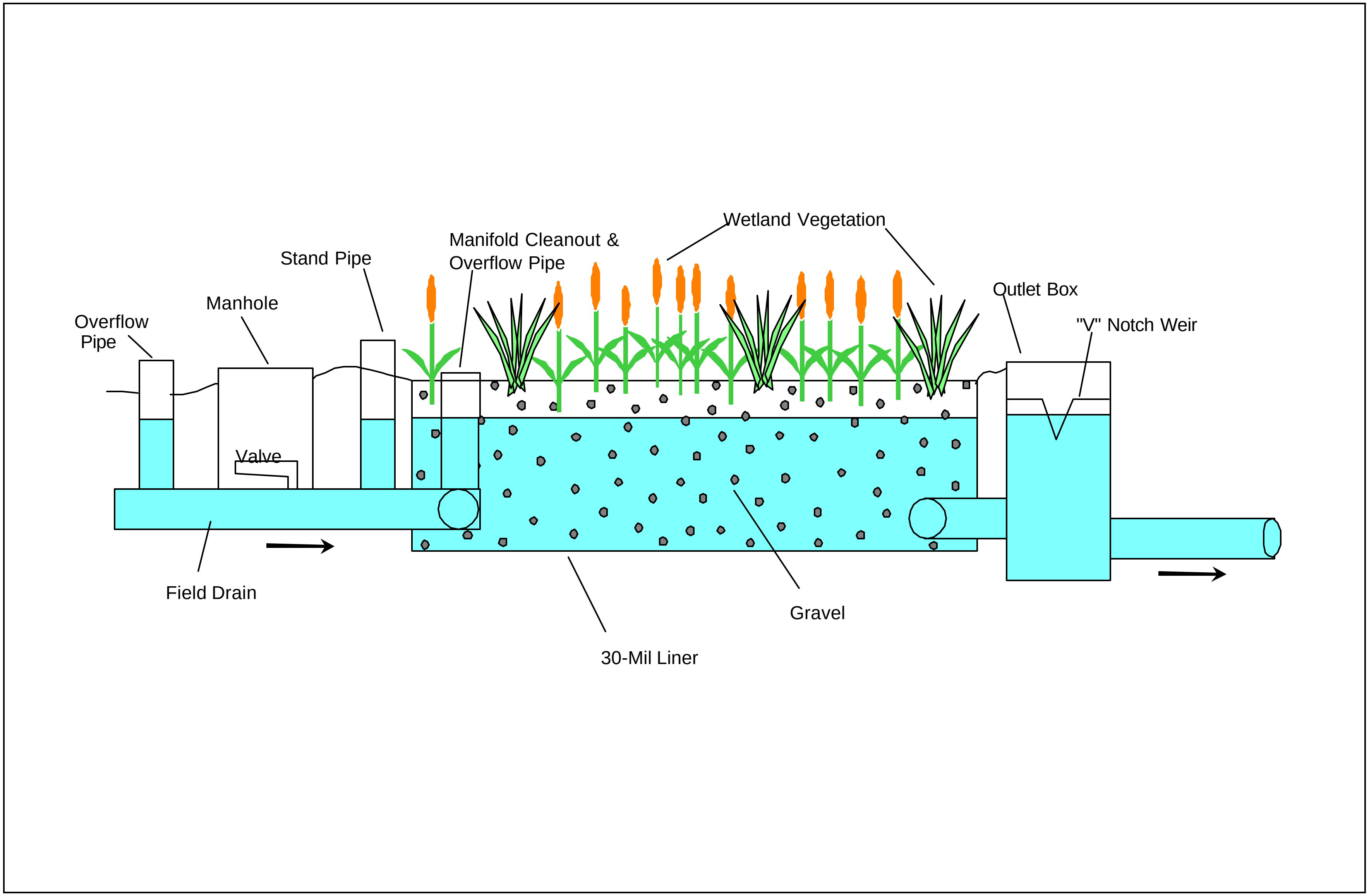


Figure 5. Cross Section Through the Wetland

Table 2. Construction Chronology for Field-Drain Collection System and Artificial Wetland

September 1994	Collected background water samples from local wells, springs, and stream.
November 1995	Excavated and constructed wetland, and installed 1,000 feet of slotted flexible main field drain, and two 100-foot laterals.
July 1996	Replaced lower 300 feet of slotted flexible drain with solid 6-inch flexible pipe.
August 7, 1996	Replaced lower 300 feet of 6-inch flexible pipe with solid 6-inch rigid pipe, gluing joints.
August 8, 1996	Installed two additional laterals to the drain field, a 100-foot section 1, 315 feet from the inlet and a 130-foot section 1,390 feet from the inlet, plus 400 feet of slotted pipe to the main drain at the up-gradient end.
September 5, 1996	Excavated gravel in wetland.
September 6, 1996	Installed new, heavier grade (30-mil polyethylene) liner, new boots at the inlet and outlet, and replaced gravel.
September 23, 1996	Installed 6-inch valve at the wetland inlet, and tried to pump water from the stream into the wetland. However there was insufficient streamflow.
October 3, 1996	Installed manhole at valve.
October 10, 1996	Raked gravel level.
October 16-18, 1996	Planted wetland vegetation.
April 11, 1997	Installed stream fords.

manure and straw, was replaced. Additionally, in the field-drain collection system, the 300 feet of solid pipe was excavated and replaced, this time applying adhesives to the pipe joints in an effort to further seal the system and prevent water losses. A valve and an overflow pipe were placed just above the wetland inlet, so that the wetland cell could be shut off from the field drain. The length of the drain was increased, and two laterals were added to direct more water through the treatment system.

The hydraulic performance of the reconstructed wetland was greatly improved. The hydraulic residence time in the cell, at the average flow of 2,900 cubic feet per day (measured from October 30, 1996, to April 23, 1997), was calculated to be about 1.65 days. This was within the design range of one to two days. Total discharge from the field drain system accounted for about 28 percent of the recharge from precipitation on the basin during the months of November through April. Discharge through the field drain and wetland is compared with mean monthly precipitation for Lancaster County in Figure 6. Discharge closely follows the trend of precipitation, with flow from the wetland declining rapidly after precipitation events. The water loss was surprising in light of the reconstructed and improved collection system. To address continued concern about leakage from the wetland, the inlet valve was closed and water levels in the wetland were observed after 7 days. Water levels in the wetland dropped significantly

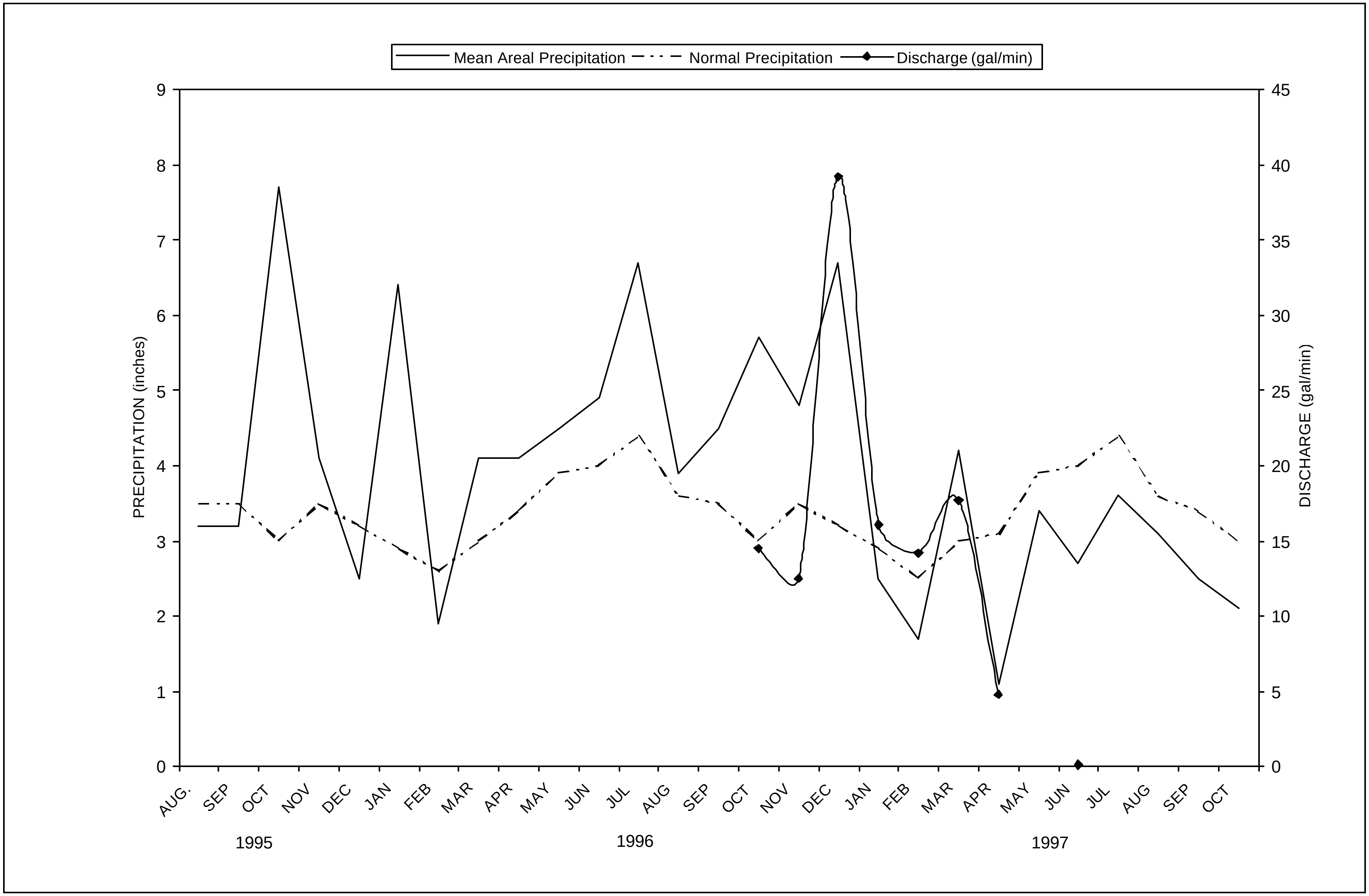


Figure 6. Comparison of Actual Precipitation, Normal Precipitation, and Flow at Outlet

and there was no discharge at the outlet. This suggests that the liner likely is leaking, although some loss may be due to evaporation.

Wetland Vegetation

Vegetation was planted during October 1996. The quantities and varieties of plants are listed in Table 3, along with information concerning wetland indicator status, water tolerance, salinity tolerance, and growth characteristics. All of the emergent, herbaceous plant species are native to the northeastern United States. Generally, the plants selected tolerate inundation or saturation for 75 percent of the growing season, are fast-spreading, and offer some appeal to wildlife. About 4,000 seedling plugs and tubers were planted. Additionally, nine trees were planted near the wetland to improve wildlife habitat.

Effectiveness

The treatment process consists of directing the flow from the field drain through a standpipe, used for collecting water quality samples and measuring water level, and into the wetland. Water leaves the wetland through the outlet, where it flows to the small stream. A box installed at the outlet of the cell provides for water quality monitoring, flow determination, and water level control.

Tables A4 and A5 in the appendix provide a summary of the water quality data from the inlet and outlet of the wetland treatment system. Samples collected in April show a 20 to 42 percent reduction in the concentration of nitrogen in the discharged water, with the reduction increasing during the month. Maximum nitrate reduction of 47 percent occurred in the sample set collected on April 30. Unfortunately, drought conditions prevented further sampling until June, and these data are probably not reliable due to the prior extended dry period.

Effectiveness of the wetland treatment system is best characterized as inconclusive. Even with only minimal plant growth, nitrate reduction looked promising in late spring. Treatment efficiencies were expected to improve significantly in the summer months, when both higher temperatures and lower flows occur. Taylor (1996) identified several factors that seem to control the nitrate removal efficiency of the wetland. The most important seem to be flow (and residence time), temperature, dissolved oxygen, and amount of available carbon.

Table 3. Wetland Plants in the Conestoga Basin Wetland

Herbaceous Emergent Plants

Genus/Species Common Name	Number	Wetland Indicator Status	*Water Tolerance*	Height Range	Rate of Spread	Comments
Sparganium eurycarpum Giant bur-reed	800	Obligate Wetland	permanent inundation 0-1 ft	up to 7 ft	fast	Good for sediment stabilization; high waterfoul, muskrat Canada goose food value.
Typha latfolia Broad-leaved cattail	800	Obligate Wetland	permanent inundation 0-12 inches	up to 6 ft	fast	Forms dense, persistent stands; good cover/nesting; waterfoul eat rootstock/seed; muskrat eat stems/rootstock; flowers May-June.
Scirpus validus Soft stem bulrush	1600	Obligate Wetland	permanent inundation 0-12 inches	6-10 ft	rapid	Tube-like stems; drooping seed clusters at top; good vertical accent; moderate wildlife value; flowers June-September.
Juncus effusus Soft rush	500	Facultative Wetland (FACW+)	irregular inundation	3-4 ft	slow	Often grows in tussocks or hummocks; avifauna eat seed.
Scirpus atrovirens Green bulrush	150	Obligate Wetland	regular inundation 0-6 inches	2-7 ft	rapid	Flowers June-September.
Carex lurida Lurid sedge	150	Obligate Wetland	irregular inundation	1-4 f	medium	Densely tufted culms; inflated peringyna.

Trees

Genus/Species	Number	Common Name	Water Tolerance	Mature Height (ft)	Aerial Spread (ft)	Comments
Betula nigra	3	River birch	seasonal inundation	50-75	35-50	Can grow 30 to 40 ft. in 10 yrs.; seeds June-August eaten by birds.
Amelanchier canadensis	3	Shadbush (Serviceberry)	seasonal inundation	35-50	35-50	Dark purple berries; high food value for songbirds; flowers May-July.
Cercis canadensis	3	Eastern Redbud	moist soils	30-40	10-20	BOBWHITE and some songbirds known to eat seeds; flowers March-May.

GROUND-WATER FLOW MODEL

A cross-section or profile model was prepared to evaluate the ability of the field drain to limit the movement of down-gradient ground-water contamination. The U.S. Geological Survey modular model (MODFLOW-96) was the computer code selected for model development, because of its ease of use and widespread availability (Harbaugh and McDonald, 1996). Information for a fully calibrated model of the site was not available; therefore, the model is of a hypothetical field-drain site under steady-state conditions, having physical parameters similar to the actual drain site. The modeling exercise can serve as an interpretive tool for understanding drain function and is similar to that used by Taylor (1996) at the field-drain site in Halifax.

The three-dimensional model was used in slice orientation to represent a section of the aquifer oriented parallel to the direction of ground-water flow. Steady-state flow was simulated for a cross-section 1,200 feet wide by 100 feet deep. A grid with 1,160 active cells, each 5 by 20 by 5 feet, was used for the simulation. The physical dimensions of the model were chosen so that they do not affect the flow field near the drain.

The boundary conditions and other modeling simplifications are shown in Figure 7. Constant head nodes were used to represent the water table gradient and a discharge zone, and a drain is placed midway between the boundaries. The drain is simulated using the drain package available in MODFLOW-96, with drain elevation set to 390.0 feet, about one foot lower than the water table elevation. Drain conductance is controlled by the size and frequency of the openings in a drain tile, as well as the backfill around the tile. For purposes of this model, an initial value of drain conductivity from the literature was used (Anderson and Woessner, 1992, p. 164) and then adjusted by trial and error by comparing simulated and measured discharges. A single transmissivity of 50 square feet per day (ft^2/day)was used to simulate the carbonate rock underlying the site. Published values for the Zooks Corner Formation elsewhere in Lancaster County range from less than 50 to 34,000 ft^2/day, according to Leitman (1997). The lower value was used because it was closer to modeled values of Gerhart and Lazorchick (1984). The horizontal/vertical anisotropy ratio was estimated to be 20:1. Recharge was set equal to the average annual recharge for the area, which was 0.386 feet per day.

Figure 8 shows the portion of the model near the field drain. The initial flow conditions without the drain are shown in the top diagram. The equipotential lines and sample flow lines shown indicate a flow pattern typical of recharge or intermediate areas having a discharge point to the left of the diagram. The bottom diagram in Figure 8 shows how the equipotential lines are deflected as a result of inserting a drain. The drain is modeled as a line sink, oriented perpendicular to the aquifer slice. Water is being diverted to the drain to an approximate depth of 8 feet (the exact depth of the dividing flow line cannot be determined from this modeling approach). Water below the 15-foot level continues to move toward the left side of the diagram and, thus, bypasses the drain.

Several simulations were performed to study the effect of recharge on the effectiveness of the drain. In these simulations all parameters were held constant, except the recharge rate. Average recharge was compared with 75 percent of average recharge and 50 percent of average recharge. In general, the depth of the dividing flow line increases as recharge decreases. At 75 percent of average recharge, the depth of the dividing flow line is generally greater than 12 feet. At 50 percent of average recharge, the water table falls below the elevation of the bottom of the drain and the drain ceases to flow.

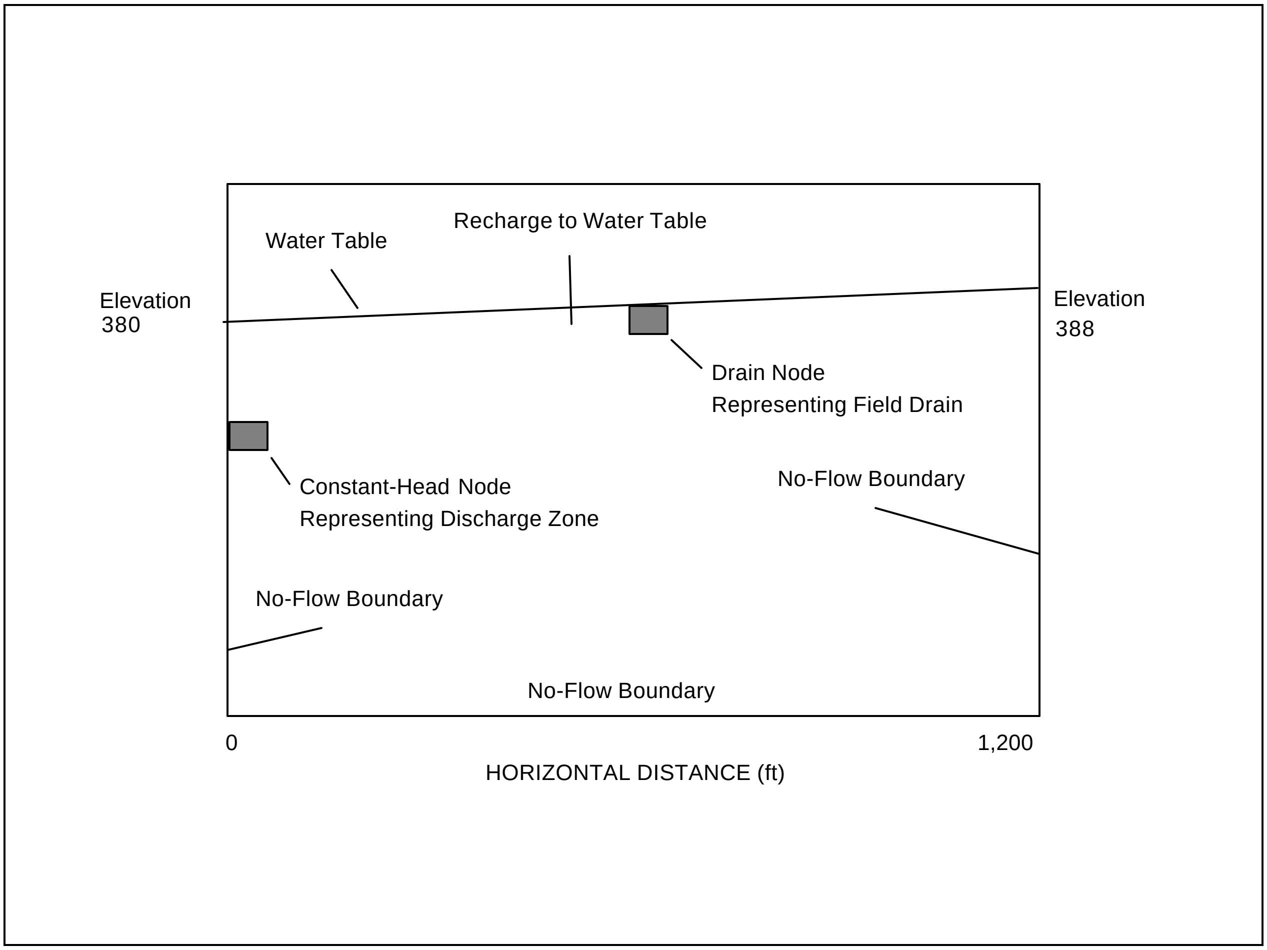
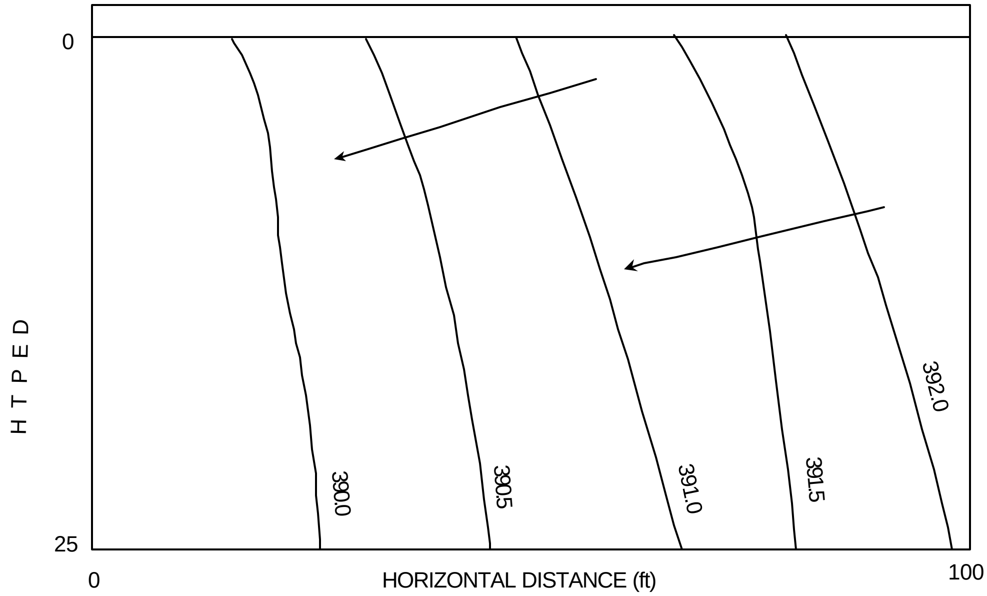
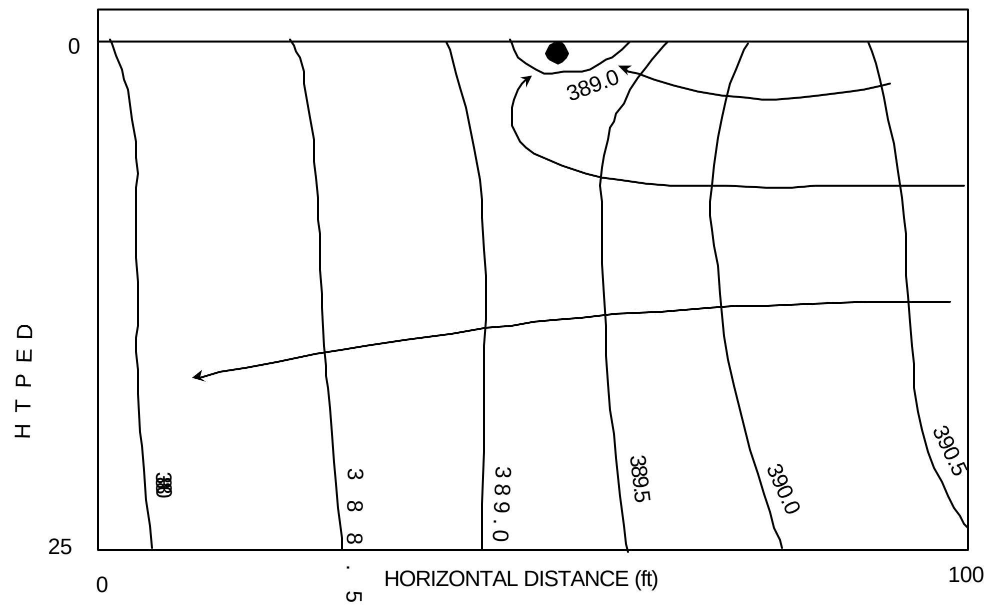


Figure 7. Boundary Conditions and Assumptions Used in the Profile Model



INITIAL FLOW



FLOW WITH DRAIN

Figure 8. Effect of a Field Drain on Ground-Water Flow

CONCLUSIONS

Using the limited water quality data collected from the wetland monitoring site in Lancaster County, several conclusions can be made:

1. In low-relief carbonate terrain, as characterized by the area underlain by the Zooks Corner Formation, nutrient-contaminated ground water can be treated using small, artificial wetlands, providing field drains can be designed to capture a significant portion of the shallow ground water. Use of these systems could help minimize the contamination of shallow ground water down-gradient from farms, however, further investigation is needed.

2. The constructed wetland is partly effective in removing nitrogen, but an evaluation of effectiveness is inconclusive at this time. Results from the final sampling looked promising when drought conditions forced suspension of data collection. Water quality data should be collected during years with average precipitation to evaluate the wetland's effectiveness with average drain flows.

3. In basins with a thick weathered zone underlain by carbonate rocks, installation of field drains that can function as interceptor ditches may be difficult. Unless the collection system is below the natural water table and can reliably capture most shallow ground water, any results from the treatment process are likely to be inconclusive because of flow bypassing the system. During dry periods, the integrity of the wetland may be threatened.

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Appendix

Table A1.   Record of Wells and Water Analyses

Location Site No.*	Owner	Well Depth (ft)	Casing Length (ft)	Temperature (°C)	NO_3 as N (mg/l	NO_2 as N (mg/l)	NH_3 as N (mg/l)	Total N (mg/l)	Total Phos-phorus (mg/l)	Total Carbon Organic (mg/l)
L-1	Dwight Rohrer	500	80	N/A	7.97	0.020	0.44	8.39	0.02	3.5
L-2	Bollinger Farm	2	N/A	18.0	13.50	0.030	0.02	12.50	0.05	2.8
L-3	Dudley Rohrer	250	50	13.0	1.02	0.008	0.27	1.38	0.02	1.1
L-4	Dudley Rohrer	2	N/A	19.0	20.30	0.008	<0.02	19.10	0.04	2.1
L-5	Rolland Bollacker	15	N/A	16.0	22.10	0.040	<0.02	20.90	<0.02	1.4

Table A2. Water Quality Analyses for the Unnamed Tributary to Little Conestoga Creek

Site No.*	Temperature (°C)	NO_3 as N (mg/l)	NO_2 as N (mg/l)	NH_3 as N (mg/l)	Total N (mg/l)	Total Phos-phorus (mg/l)	Total Organic Carbon (mg/l)
UNT 3.22	15.0	39.70	0.016	0.03	21.60	0.07	1.60
UNT 3.03	15.0	21.20	0.098	0.02	17.20	0.08	2.1
UNT 2.87	15.0	19.10	0.018	0.03	19.70	0.04	1.2
UNT 2.78	14.0	20.80	0.042	0.09	18.50	0.65	3.8
UNT 2.65	13.0	20.30	0.020	0.04	30.90	0.08	12.7

UNT = Unnamed Tributary

Table A3. Materials List for the Field-Drain Collection and Treatment System

Quantity	Material
1,000 feet	6-inch slotted corrugated flexible plastic pipe and couplings (main field drain)
300 feet	6-inch solid corrugated flexible pipe
300 feet	6-inch solid rigid pipe and pipe cement
430 feet	4-inch slotted corrugated plastic pipe (laterals)
70 feet	Slotted and solid schedule 40 PVC (manifolds at inlet and outlet of wetland)
1	6-inch ball valve
2	230’ x 200’ 30-mil MDPE (medium density polyethylene) liner
842 tons	#1 limestone gravel (wetland and pipe bedding)
2	Pipe boots for inlet and outlet of wetland
	Pipe boot seal tape
4	Tees (stand pipe and manifold)
1	3’ x 5’ x 4’ Pressure treated plywood junction box with 90° “v” notch weir
1	4’ x 30” corrugated metal pipe (manhole)
50 pounds	Contractor’s mix grass seed
46 tons	Quarry stone—stream crossing liner (Ford)
15 bales	Hay
3 loads	Wood chips and manure mix

Table A4. Conestoga Wetland Sample Analyses—Inlet

Date	Nitrogen, Total (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Total Phos-phorus (mg/l)	Total Organic Carbon (mg/l)	Temp-erature (°C)	pH (units)	DO (mg/l)	Conduct-ance (umhos/cm)
01/29/96	19.7	0.02	0.004	1.10	0.060	1.70	6.10	6.85	3.10	700
02/07/96	22.6	<.02	0.004	15.20	0.040	1.30	5.80	6.90	7.60	820
02/15/96	23.9	<.02	<.004	20.80	0.060	1.30	6.20	7.35	9.30	840
02/22/96	18.7	<.02	<.004	21.05	0.050	1.60		6.95		810
03/01/96	19.7	<.02	<.004	19.60	0.060	1.30	7.00	7.00	7.70	815
03/07/96	22.9	<.02	0.008	23.10	0.040	1.70	7.20	7.20	6.40	845
03/14/96	21.0	<.02	<.004	23.10	0.020	1.30	7.60	7.00	6.10	820
03/20/96	20.0	<.02	0.008	22.20	0.050	1.60		7.00		850
04/03/96	16.1	<.02	<.004	15.73	0.110	1.30	7.80	7.15	8.20	830
04/11/96	22.6	<.02	0.004	21.77	0.030	1.20	9.40	7.00	5.90	870
04/18/96	21.9	0.02	0.004	21.78	0.090	1.20	8.90	7.15	5.20	830
04/25/96	25.8	<.02	0.012	23.22	<.02	1.40	9.60	7.00	5.10	815
08/14/96	12.3	0.1	0.062	10.50	0.120	7.70				
10/30/96	22.9	<.02	0.014	21.53	0.240	1.40	13.90	7.20	5.10	860
11/06/96	23.9	<.02	0.006	21.77	<.02	1.70		6.85		880
11/20/96	23.5	<.02	0.006	21.54	<.02	1.20	17.00	6.75	6.50	860
12/04/96	21.6	<.02	0.008	20.30	0.240	1.10	20.00		7.40	
12/10/96	21.3	<.02	0.004	20.80	0.040	1.60	9.70	6.75	4.30	775
01/08/97	25.1	0.18	<.01	24.17	0.020	1.60	15.00	7.00	4.00	850
01/15/97	25.5	0.14	<.01	23.42	0.020	1.80	14.00	6.70	7.20	845
01/22/97	25.1	0.09	<.01	23.05	<.02	2.30	16.50	7.05	7.30	850
01/29/97	21.2	0.16	0.73	19.62	0.050	4.80	9.00	6.80	4.80	790
02/06/97	21.8	<.02	0.18	20.21	0.020	2.00	6.50	7.55	5.50	775
02/12/97	26.9	0.05	0.078	22.56	0.020	1.80	5.80	7.05	6.63	775
02/18/97	25.0	0.03	0.04	20.62	0.130	4.00	6.10	6.98	7.06	779
02/26/97	22.3	0.04	0.01	21.74	0.020	1.30	6.60	7.20	7.37	790
03/05/97	21.1	<.02	0.01	20.10	0.030	1.70	6.30	7.00	7.02	785
03/12/97	28.9	0.04	<.01	20.58	0.020	1.10	7.10	7.40	6.91	732
03/18/97	31.3	0.04	<.01	20.86	0.020	1.10	7.30	7.50	6.74	742
03/25/97	33.8	0.03	<.01	18.26	0.040	1.10	7.70	7.02	6.58	797
04/02/97	30.2	<0.02	<.01	25.61	0.020	1.30	8.00	7.35	6.58	802
04/09/97	25.4	<0.02	0.02	26.20	0.030	2.00	8.60	9.30	7.22	681
04/16/97	36.1	<0.02	<0.01	23.80	0.070	1.60	8.90	7.35	7.05	786
04/23/97	20.6	<0.02	<0.01	19.45	0.090	1.40	9.10	7.05	6.81	780
04/30/97	18.6	0.02	<0.01	17.96	0.040	1.50	9.90	7.05	7.55	764
06/04/97	20.8	0.27	0.07	19.20	0.170	4.10	12.80	6.30	4.55	938

Table A5. Conestoga Wetland Sample Analyses—Outlet

Date	Discharge (cfs)	Nitrogen Total (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Total Phos-phorus (mg/l)	Total Organic Carbon (mg/l)	Temp-erature (°C)	pH (units)	DO (mg/l)	Conduct-ance (umhos/cm)
01/29/96	0.0983	19.0	0.02	0.004	1.10	0.060	1.60	4.00	7.01	4.60	720
02/07/96	0.0106	21.0	<.02	0.012	14.80	0.050	1.70	1.90	7.00	1.10	820
02/15/96	0.0076	20.6	<.02	0.016	19.90	0.040	1.60	3.90	7.35	0.00	825
02/22/96	0.0510	16.6	<.02	0.024	20.30	0.050	2.00		7.00		815
03/01/96	0.0106	19.0	<.02	0.014	21.29	0.050	1.80	3.70	7.35	6.30	805
03/07/96	0.0025	19.4	<.02	0.014	18.90	0.070	1.30	5.40	7.25	0.00	870
03/14/96	0.0001	20.3	<.02	0.034	18.10	0.050	1.50	5.10	7.35	0.00	850
03/20/96	0.0392	18.4	<.02	0.04	19.40	0.050	3.20		7.35		775
04/03/96	0.0292	17.1	<.02	0.02	16.68	0.030	1.90	9.10	7.25	4.40	820
04/11/96	0.0076	19.4	<.02	0.006	19.35	0.030	1.70	6.60	7.35	2.20	815
04/18/96	0.0263	17.1	0.02	0.02	19.58	0.030	1.80	7.90	7.30	0.00	810
04/25/96	0.0003	18.4	<.02	0.046	17.86	0.030	1.90	12.20	7.15	0.00	830
08/14/96	NA	19.0	<.02	0.012	16.90	0.030	1.60				
10/30/96	0.0323	19.7	0.04	0.022	19.10	0.030	1.90	9.40	7.45	0.00	860
11/06/96	0.0235	19.7	0.05	0.028	18.59	<.02	1.90		7.20		900
11/20/96	0.0323	22.6	<.02	0.012	21.04	0.020	1.40	12.00	6.85	4.00	870
12/04/96	0.0698	20.6	<.02	0.012	20.30	0.020	1.20	12.00			
12/10/96	0.1047	21.0	<.02	0.01	20.56	0.020	1.50	8.80	6.95	6.90	780
01/08/97	0.0429	27.5	<.02	<.01	23.82	<.02	1.40		7.00		850
01/15/97	0.0263	25.0	0.04	<.01	23.30	<.02	1.50	4.00	7.15	9.80	870
01/22/97	0.0142	24.3	<.02	0.01	22.51	<.02	1.70	8.00	7.35	6.20	870
01/29/97	0.0600	21.7	0.06	0.54	19.39	0.080	5.40	5.00	6.95	6.40	790
02/06/97	0.0600	20.9	<.02	0.06	19.61	0.020	1.80	3.60	7.75	10.20	725
02/12/97	0.0185	20.9	0.07	0.01	19.86	0.020	2.00	2.40	7.20	7.85	725
02/18/97	0.0292	22.7	<.02	<.01	20.15	0.030	3.60	5.30	7.10	10.50	782
02/26/97	0.0185	21.3	<.02	0.03	20.50	0.070	1.40	1.60	7.35	4.74	815
03/05/97	0.0235	20.3	<.02	0.02	19.48	0.020	1.70	3.70	7.20	7.57	805
03/12/97	0.0263	32.3	<.02	0.02	20.00	0.050	1.30	1.50	7.40	8.54	800
03/18/97	0.0647	29.0	<.02	<.01	20.16	<.02	1.10	1.70	7.45	8.02	800
03/25/97	0.0429	34.4	<.02	<.01	25.39	<.02	1.30	1.90	7.20	4.42	808
04/02/97	0.0292	31.1	<.02	<.01	28.92	0.030	1.60	5.20	7.55	8.15	788
04/09/97	0.0142	25.2	0.02	0.02	29.30	0.020	2.30	4.50	7.55	5.97	783
04/16/97	0.0076	25.9	0.25	0.11	15.48	0.030	2.00	9.90	7.45	0.95	749
04/23/97	0.0025	16.0	0.09	0.07	15.00	0.020	1.70	10.70	7.20	0.45	693
04/30/97	0.0003	10.8	0.31	0.19	9.46	0.120	2.90	13.60	7.10	1.17	636
06/04/97	0.0002	19.4	0.03	0.01	17.87	0.080	3.30	12.80	6.10	1.66	942