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ABSTRACT

Vegetative systems have long been studied and evaluated as alternatives to conventional storage, treatment, and land application systems. This paper discusses the application of vegetative systems, primarily constructed wetlands, as a runoff treatment technology for small livestock operations. The approach used for two small dairies and one beef cattle feedlot is discussed. Cost data for these operations is included as well as nutrient reduction performance results from a three year sampling period for the KS Dairy.

KEYWORDS. constructed wetlands, runoff treatment, open lots

INTRODUCTION

Many swine operations have investigated and invested in wetlands as treatment technologies. Less work has been done utilizing wetlands for treatment of runoff from open lot operations. Surface flow wetlands show promise as a treatment technology for livestock waste systems. A surface flow wetland is defined as a constructed shallow impoundment(s) planted with rooted, emergent vegetation (Payne Engineering and CH2M Hill, 1997) and USDA-NRCS (1991) defines a constructed wetland as a treatment of agricultural wastewater that consists of adequate seepage control, a suitable plant medium for rooted emergent hydrophytic vegetation, the vegetation itself, wastewater flowing at a slow velocity through the system and the structural components needed to contain and control the flow (USDA NRCS, 1991).

Typical applications in animal feeding operation are to use constructed wetlands as a nutrient reduction mechanism for the purpose of reducing the land base required to apply the nutrients from a lagoon (Payne Engineering and CH2M Hill, 1997). Less work has been done to evaluate the application of surface flow wetlands for the treatment and containment of runoff from open lots. The ability of wetlands to treat nutrients has been well documented (Yang and Lorimor, 2000; Pratner et.al. 1999; Kadlec and Knight, 1995; Payne Engineering and CH2M Hill, 1997; Miller, 1999; Designed Organics, 1996). Wetlands can be utilized as an alternative to a conventional runoff containment system in certain applications (KSURE, 1999a; KSURE, 1999b, Yang and Lorimor, 2000). Criteria have been developed for wetland design (NRCS, 1998), but less work has been done to develop criteria for wetlands designed for open lot runoff. Open lots are unique in that nutrient loading is slug flow and during dry periods water may evaporate from the surface resulting in a dry cell. This unsteady loading is the primary difference between constructed wetlands for lagoons and for runoff treatment and makes their application for runoff more challenging.

Several projects in Kansas and Nebraska have investigated the application of constructed wetlands for small existing livestock operations. Funding for these projects have come from EPA, state non-point funds, and state environmental funding groups.

USING CONSTRUCTED WETLANDS AS A RETROFIT TOOL

Constructed wetland (CW) systems for the control and treatment of runoff are being evaluated in Kansas and Nebraska as part of a vegetative system for utilization of effluent or runoff nutrients from small animal feeding operations (AFO). Application of the type of vegetative system is influenced by terrain, soil type, and land availability. Other components of vegetative systems may include vegetative filter, terraces, and other alternative systems such as tree plantings. Retrofitting of existing livestock operations must take into account future expansion plans, therefore, the vegetative system must be designed accordingly. This can be done by over-sizing or by designing components to be versatile. The system must consider environmental regulations, reduction in nutrient loadings, management skills of the producer, and incorporation into the existing operation.

APPLICATION OF VEGETATIVE SYSTEMS

System one uses constructed wetland cells for a Nebraska beef cattle feedlot (Figure 1). This vegetative system utilizes a series of wetland cells without additional vegetative components. The overall system consists of a debris basin, a series of three wetland cells, clean water diversion, resizing of feedlot area and controlled water transfer between cells (Henry, 2001b). The overall drainage area is 5 acres with a total storage capacity in the basin and cells of 200,000 cubic feet. The overall system including the feedlot and constructed wetlands required 10 acres of land.

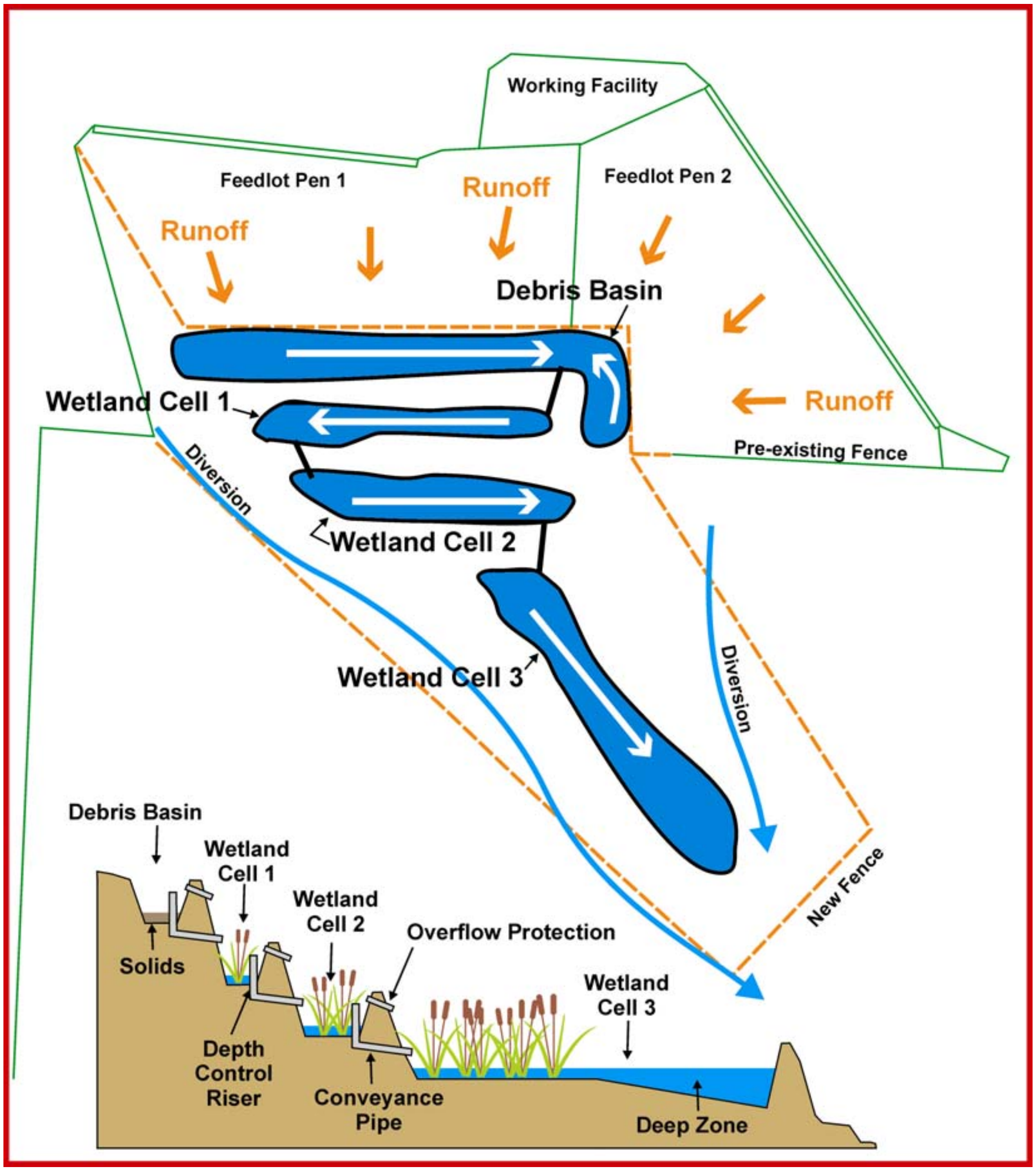

Figure 1. NE Beef Feedlot 3 cell wetland system

System two is a Nebraska dairy (Figure 2). The overall system includes a concrete manure storage structure, a debris basin and outlet structure, clean water diversion, resizing lots, one wetland cell, and water distribution to a vegetated field filter (Henry, 2001a). A new concrete manure storage structure was constructed adjacent to the free stall barn. The concrete storage structure's *inside dimensions are 18 meters by 24 meters by 1.2 meters (60' x 80' x 4'). The structure is designed for manure and sand storage for 120 days. The south wall of the basin has two porous dams, 2.4 meters by 1.2 meters (8' by 4') made of metal swine flooring panels to allow precipitation to drain from the storage into the wetland. The drainage area is 0.7 hectares (1.8 acres) and the total capacity of the debris basin and wetland is about 1,048 cubic meters (37,000 cubic feet).*

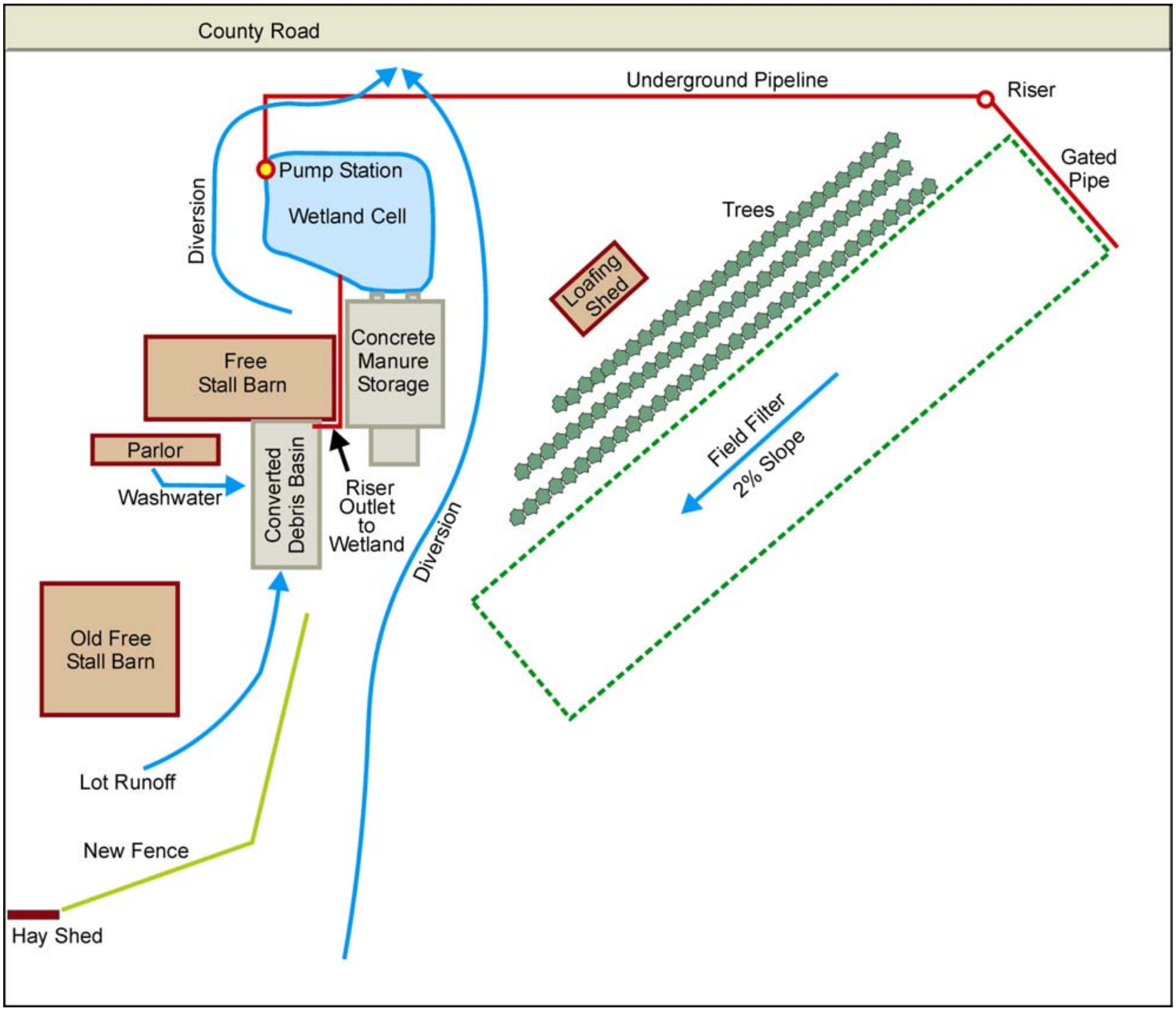

Figure 2. NE Dairy: Manure Storage, Debris Basin, Constructed Wetland and Furrow Filter

A Kansas dairy is system three (Figure 3). This system consisted of a concrete manure storage, two wetland cells, vegetative filter area and clean water diversion (Harner, 1994). It has a manure storage designed for manure and sand storage for 120 days, and has dimensions of 46.3 meters by 7.9 meters by 1.2 meters (4' x 26' x 152'). It has one porous dam that is 1.2 meters by 7.9 meters (4' x 26'). The vegetative filter area includes brome grass along with a 10 row tree planting as part of a Forest Stewardship Plan. The drainage area is less than 1 acre but the loafing area houses 100 cows. The vegetative system required about 3 acres of land including for clean water diversions. Total capacity of the first wetland cell is about 77,000 cubic feet.

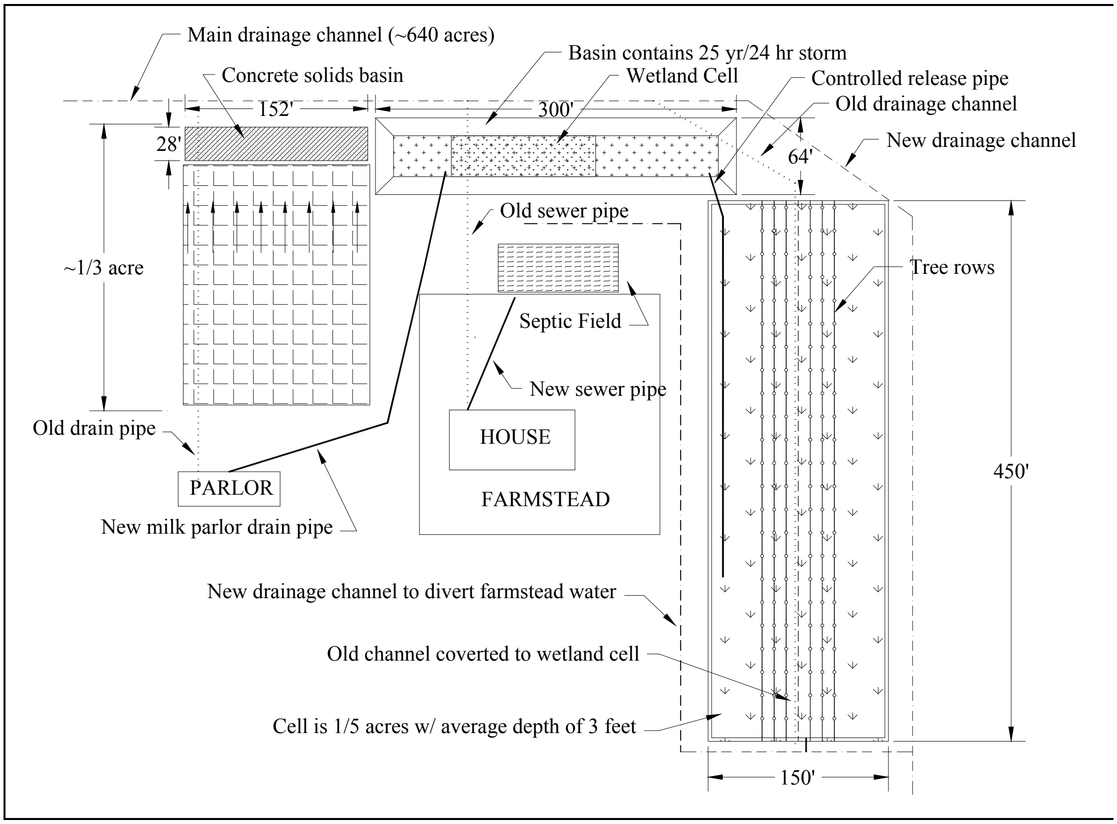

Figure 3. KS Dairy: Manure Storage, Debris Basin, Constructed Wetland and Tree Filter

COMPONENTS OF VEGETATIVE SYSTEMS

Clean Water Diversions

Diversion of clean water from the animal feeding areas may be the most critical component in minimizing the impact of these operations on water quality. Approximately, 20 to 30 percent of the project costs were related to construction of clean water diversions. Diversions were constructed to exclude drainage from upland crop fields, driveways, building roofs, and farmsteads. Clean water diversions were seeded to wheatgrass or brome and designed to accommodate a storm event more intense than the 25 year 24 hour runoff event (Hershfield, 1961).

Reallocation of Lot Space

Many times reallocation of open lot area is necessary to incorporate a runoff control strategy. Most small feeding operations have excessive lot space and therefore can afford to reduce or eliminate some of the space in order to create adequate space for a control system. However, an expense is incurred with the reduction of open lot space. For example, in Nebraska it was necessary to remove existing fencing in order to install the wetland systems and then replace the fencing after project completion. The cost of replacement fencing should not be neglected in the cost of installing the system because in these cases it was fairly substantial. For one operation lot space was reduced 46% through better lot planning. This required the removal of 366 meters (1,200 feet) of fence and installation of 274 meters (900 feet) of new fence. The other operation reduced lot space by 18% while still allowing adequate capacity needed by the producer. This required the removal of 323 meters (1,060 feet) of fencing and the installation of 716 meters (2,350 feet). Lot space requirements were determined from Murphy and Harner (2001).

Solids Storage - Debris Basin and Manure Storage

The system design components are shown in Figure 4. The second component of the design is the solids basin. The purpose is to segregate the solids from the liquid. Settling basins with retention times ranging from 30 minutes to 48 hours are generally used with beef feedlots. Longer detention times are preferred with vegetative systems to minimize solids bypass. Concrete storage basins are used with dairies such that the solid manure scraped from the open lots may be contained prior to land application. The NE Dairy converted an existing, inadequate manure storage to a debris basin (detention time of 9 hours). A second concrete basin was constructed to provide 120 days storage of the manure. The KS Dairy constructed a similar concrete basin to contain the solid manure. The beef cattle lot was constructed with an earthen basin designed with a 15 hour detention time.

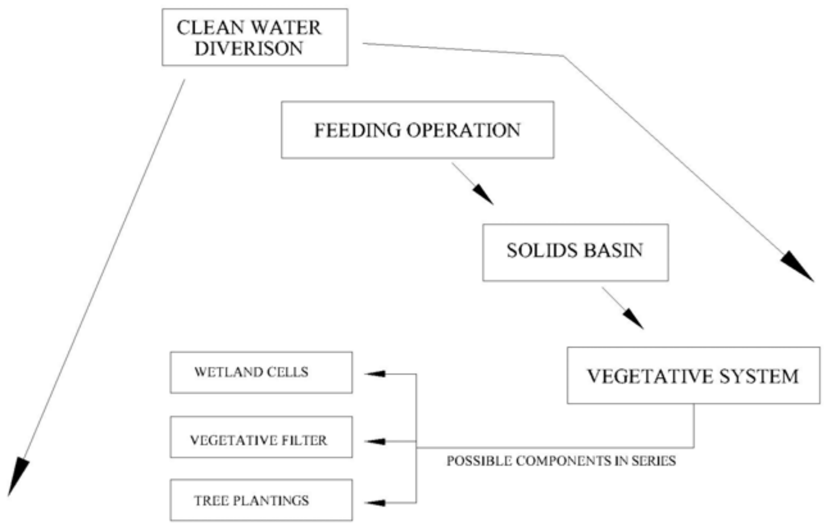

Figure 4. Components of Vegetative Systems

Controlled release of the water from the debris basin used weep walls on the dairies and perforated risers with the beef feedlot. The weep walls (porous dams) were designed to allow rainwater and effluent to drain from the solid material but did not provide for a set retention time.

Solid material from the milk parlor waste stream should be settled out prior to the vegetative system. NE dairy was able to utilize the old concrete manure basin as a settling basin for the wash water from the parlor. This basin also was the debris basin for the earthen lots on the dairy. No debris basin was used on the KS Dairy, however about 0.2 hectare (0.75 acre) drains into the manure storage which acts as a debris basin, settling out the solids before entering the wetland. The milk parlor water drained directly into the upper end of the vegetative system; however, the authors recommend runoff and manure be handled separately when possible.

Constructed Wetlands

Wetlands were sized using a nitrogen balance. It was assumed that a constructed wetland could treat 1,120 kilograms of nitrogen per hectare (1,000 lbs/ac). This loading rate was derived from literature and from loading rates used by some existing systems (Payne Engineering and CH2M Hill, 1997, Kadlec and Knight, 1995, CH2M Hill, Date Unknown). Loading rates of 2.2 and 2.8 kg of N/ha/day (2-2.5 lb N/ac/d) were used to size the wetland's surface area. Operating depths between 30 and 45 centimeters (12-18 inches) are used and with shallower depth (15-30 cm) (6 to

12 inches) preferred. Once the operating depth is determined, additional storage capacity for the design storm (25 year / 24 hour) runoff volume and 15-30 centimeters of freeboard were added to the cells.   In Nebraska, the wetlands were installed with soil liners after which a 30 centimeter layer of loose soil was placed in the bottom for the plants to grow in. This strategy was used to minimize root penetration of the constructed soil liners. Transplanting of wetland vegetation has proven to be more successful than seeding. The wetlands are all populated with either bulrush (Scirpus validus) or cattails (Typha latifolia). Wetland vegetation is slow to establish and takes between 2-5 years.

In order to maintain constant liquid level, each cell must be designed so that the liquid level can be controlled. The cells are designed to be maintained between a 30-45 centimeter liquid depth. For NE Dairy, a pump station consisting of a 6.7 kW (9 hp) Honda gasoline engine and a 1.5 m3/min (400 gpm) pump were used to control liquid levels. The pump gives the producer the ability to transfer effluent to the field filter when the wetland exceeds the operating depth. Underground pipe is used to convey the effluent to a filter strip a about a hundred meters away.

The KS Dairy uses a pipe set at the 45 centimeter depth to maintain the liquid level in the first wetland cell. The outlet is a gated pipe distribution system that flows into the second cell. The pipe is designed to distribute the liquid evenly across the cell. Recently a valve was added between cells 1 and 2 such that the liquid level in cell 1 rises to 60 cm prior to a rapid discharge into the tree filter. The water level in cell 1 then ranges from less than 10 cm to more the 60 cm depending on rainfall. A gated pipe is used to longitudinally convey and distribute liquid evenly across cell two. The tree filter (also referred to as cell 2) is contains brome and trees and rarely impounds water.

The beef cattle feedlot uses gate valves and risers between each adjacent pair of cells to manage the liquid depth. Special perforated risers were constructed to maintain 30-45 centimeters of water in the cells. Above 45 cm the riser is perforated and allows liquid to enter the conveyance pipe. However there is a gate valve on the conveyance pipe between each cell, so the producer has the ability to maintain water in a cell as needed. Each wetland has an overflow device placed at freeboard height in the event that the cell reaches capacity.

<u>Using Wetlands in conjunction with Filter Strips</u>

Both the KS and NE Dairies have coupled a vegetative filter and a wetland system. This coupling is advantageous because it minimizes the size of the impounded area and utilizes the natural nutrient and water holding capacities of the soil. The filters give the operator the ability to take advantage of dry periods to manage the wetland liquid levels. These are not land application areas and are solely dedicated to the treatment of runoff.

In the case of the KS Dairy the filter (also referred to as cell 2) utilizes trees and brome for vegetation. The filter area is bermed and only impounds water during precipitation events. A primary criterion for the KS Dairy filter was the nitrogen uptake capacity of the brome and trees.

In the case of the NE Dairy there was limited space to accommodate a wetland of sufficient size to meet the nitrogen criteria, so a small pumping system and vegetative furrow filter was designed to manage the residual nitrogen and runoff. This filter went a step further and was designed using irrigation equations to estimate travel time, opportunity time, runoff, and nutrient uptake. The filter was designed to not generate runoff and have at least an hour of travel time before reaching the end of the furrows. Gated pipe were used for both filters and is the preferred distribution system.

PERFORMANCE OF KS DAIRY CONSTRUCTED WETLAND

The KS Dairy was sampled between the spring of 1999 and spring of 2002. Samples were a composite of 4 samples taken at each of the 5 locations. Samples were analyzed for electrical conductivity, total dissolved solids, organic nitrogen, total Kjeldahl nitrogen, ammonia nitrogen, chloride, sulfur, sodium, potassium, phosphorus, and magnesium. Samples at the inlet are the average of sample locations 1 and 2, middle represents the average of sample locations 3 and 4 and the outlet data is from sample location 5 (Figure 5).

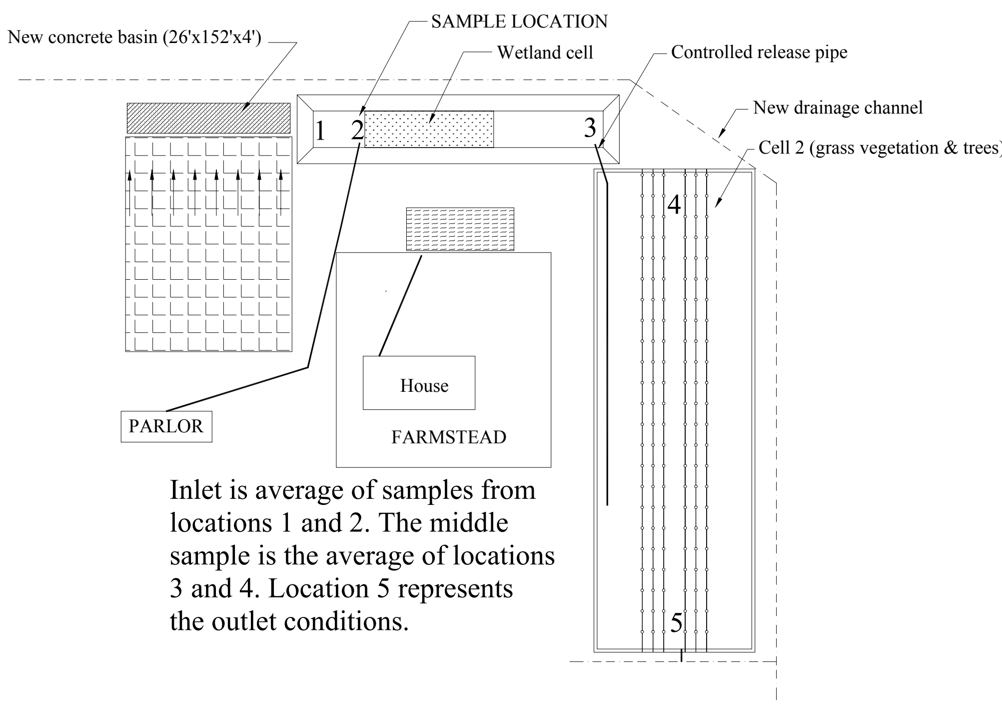

Figure 5. Location of where composite samples were taken at Dairy B.

Figure 5 shows the location where grab samples were taken during summer and fall of 1999 and falls of 2000 and 2001 and spring of 2002. Grab samples were the composite of 4 samples taken at each location. All samples were analyzed by commercial laboratories.

Figure 6 shows the average percent reduction during 10 random sampling periods between spring 1999 and spring 2002. Nitrogen and phosphorus were reduced by over 80 percent. Total dissolved solids were reduced by 58 percent. Fecal coliform bacteria was sampled during one period and reduced from 43,000 to 900 CFU/100 ml based on lab reports from the Kansas Department of Health and Environment (KDHE). The biochemical oxygen demand (BOD5) from KS Dairy was lowered from 350 to 23 mg/l from the upper to the lower end.

Figure 7 shows the average concentrations at the upper and lower end of the system as compared to the nutrients from samples taken from the concrete solids basins. The concentrations at the upper end of the system are at least one order of magnitude lower when compared to the solids basin. The lower end samples are at least two orders lower when compared to the solids basin and for most nutrients nearly one order lower when compared to the upper end. The ammonia concentrations reduce to below 10 mg/l as the water moves through the system.

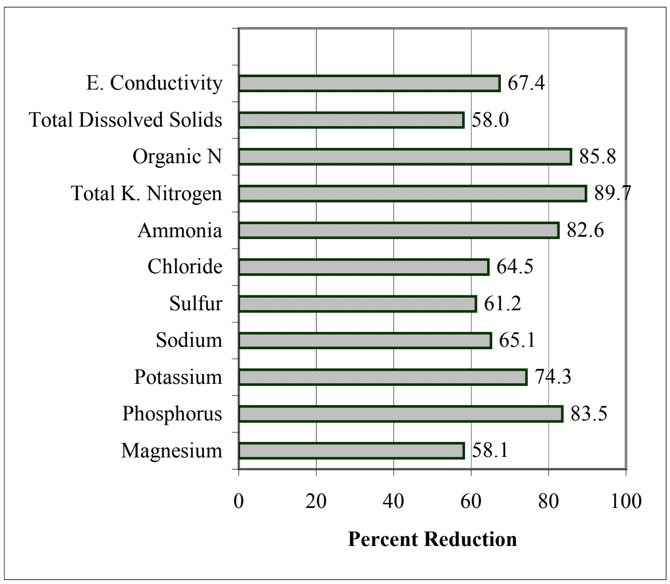

Figure 6. Overall average percent reduction in various nutrients sampled during the 3 year study period of the vegetative system at the KS Dairy.

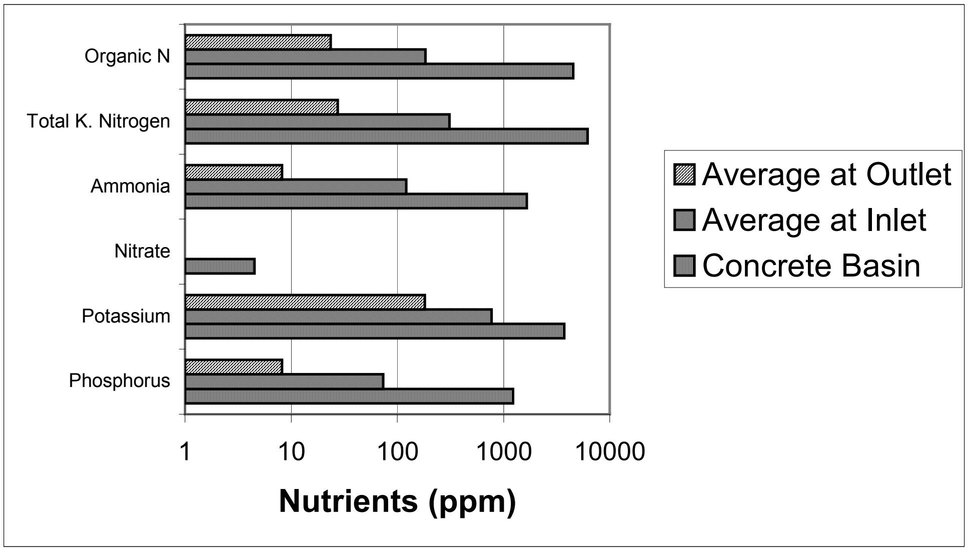

Figure 7. The average nutrient concentrations at the wetland inlet, outlet, and solids storage basin (KS Dairy).

Table 1. Comparison of Wetlands Performances in Percent Reduction

Wastewater Constituent	KS Dairy	KS Dairy 2a	National Averageb
Total Dissolved Solids	58	60	53
Ammonium-Nitrogen	82.6	95	48
Total Nitrogen	89.7	60	42
Total Phosphorus	83.5	65	42

a KS Dairy 2 is data from a second dairy utilizing a vegetative system in Kansas not discussed in this paper. As reported by Mankin (draft report for KDHE on performance of system).

b As reported by Harner and Barnes (draft report for KDHE on performance of system).

Table 1 shows a comparison based on percent reduction of different nutrients between the system at the KS Dairy, and KS Dairy 2, another wetland system being studied, and the national average reduction for wetlands used in treating livestock waste. The system at KS Dairy has better performance than the national average reported.

CONSTRUCTION COSTS

Table 2 outlines the construction costs of each component on an Animal Unit (AU) basis. Construction of wetlands and diversions reflect the bills from the contractors and all earthwork. "Pump and Pipe for Field Filter" refer to 121 meters (400') of underground pipe required to convey runoff water from a wetland pump (outlet structure) to the field filter. All materials such as risers, gate valves, and piping used in the wetland cells are included in "Constructed Wetland(s) Systems and Diversion." The hourly rate used to calculate producer labor was $12 per hour. Producer labor typically included ground preparation, planning, fence removal, seeding, etc. Engineering costs are not included in Table 2.

Table 2. Construction Costs of Wetland Systems for operations less than 300 AU's

Item	NE Dairyac ($/AU)	KS Dairyad ($/AU)	Beef Feedlotbc ($/AU)
Constructed Wetland(s) Systems and Diversions	$105	$100	$92
Concrete Manure Storage	$311	$148	N/A
Pump and Pipe to Field Filter	$58	$20	N/A
Replacement Fencing	Included in "Producer Labor and Misc."	N/A	$30
Producer Labor and Misc.	$111	$20	$43
Total System	$585	$318e	$165

a One dairy cow is equivalent to 1.4 AU

b One beef feeder is equivalent to 1 AU

c 2001 Construction Data from Nebraska

d Construction Data from Kansas

e Addition $25 per animal unit required to correct some household waste problems.

The cost to relocate an operation should be considered as an alternative to any retrofit. The cost to relocate the beef feedlot operation approached the cost of the wetland system, however, the working facility had just been updated and the owners were reluctant to abandon it. The cost to relocate the NE Dairy was much higher than the cost of the wetland systems because the dairy had recently constructed new housing.

Pumping costs are not included in the analysis and are an advantage that many wetland systems would have over a conventional runoff pond system. Therefore, the annual cost to pump a runoff containment pond could be used to offset the construction cost of a wetland system, since the wetland systems are not expected to need dewatering. The exception to the rule is the NE Dairy, which uses a pump as an outlet device to a filter strip. For the beef feedlot system, the issue of locating a large runoff pond on the neighbor's property would not have been agreeable to the neighbor. The neighbor was agreeable to a wetland because of the possibility of attracting wildlife and the aesthetic appeal of a wetland.

Suggested Improvements

Efforts are being made in Kansas to develop and study batch type vegetative reactor systems. At the KS Dairy, a valve was later placed between the upper and lower sections much like the beef feedlot system. Water is now allowed to accumulate in the upper section and then rapidly drain to create a plug flow. Placing valves between cells gives operators more control of the liquid levels in the wetland cells. It increases the management time required; however, it also increases the stake the owner has in the system and may improve the success and performance of the systems. Producers appear to be willing to manage the systems. Progress in Nebraska is just beginning to evaluate the performance of the recently constructed wetlands. Pathogen concentrations and reductions will be studied in the future after the systems have established vegetation.

Suggested Design Criteria

There are many challenges tied to the installation of control systems for existing operations. Criteria for small and existing operations should be simple and easy to work with, yet still meet state regulatory standards. Below are the author's recommended criteria that were used to design the NE systems. These are recommended as guidelines for the design of constructed wetlands for runoff treatment.

- The wetlands must contain the precipitation and runoff from a 25 year 24 hour runoff event.
- The native soils must be capable of meeting 0.635 cm per day (0.25 inches per day) of seepage (specific discharge).
- The wetland cells must have adequate surface area to treat the influent (runoff) nitrogen.
- Cells should not exceed 1.3 meters (4 feet) in depth (excluding freeboard requirements).
- Solids must be prevented from entering the wetland cells. Debris basin residence times should be greater than 15 hours.
- A water balance (precipitation, annual runoff, wastewater, evaporation, etc.) should be done to verify adequate capacity.
- The ability for the producer to manage liquid levels in the wetland cells should be present.
- Wetland vegetation must be present and easy to maintain.

Conclusion

Vegetative systems have been used to minimize the risk that small livestock operations present to the environment. They can be an alternative to a conventional holding pond or total containment system for some operators. Vegetative systems for the control and treatment of runoff have recently been constructed and are being monitored in Kansas and Nebraska. Performance of one system in Kansas shows nutrient reductions above the national averages for constructed wetlands. Reductions of TDS, NH3-N, TN, and TP were 58%, 83%, 90%, and 84% respectfully. The coupling of a wetland with other vegetative components appears to improve overall performance. The cost of installing a constructed wetland system, neglecting engineering costs, appears to be around $150/ AU for a complete constructed wetland system. Producers appear to be willing to manage the vegetative systems.

Acknowledgements

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