Evaluation of Four Milk House Wastewater Treatment Systems in Minnesota

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Acknowledgements

Collaboration was a key to the success of this project. Sixteen dairy producers participated in the project. In addition a collaborative team was created to guide and support the project. At the University of Minnesota, Kevin Janni took the leadership in obtain the funding for this project and David Schmidt was very involved in the design, installation and sampling of the 16 systems.

Organizations and agencies that collaborated and/or financially contributed to the project included the Minnesota Pollution Control Agency (MPCA), US Environmental Protection Agency (USEPA), Minnesota Agricultural Experiment Station, Carver County Extension, Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD), Carver County Environmental Services, Wright County Planning and Zoning, Winona County Feedlot Office, Winona County Soil and Water Conservation District, Goodhue County Feedlot Office, Goodhue County Soil and Water Conservation District, Bongard's Creamery, Metropolitan Council, Bio-Microbics, NCS Wastewater Solutions, Dyno2, Pirana, and Geoflow.

Dedication

This thesis is dedicated to my father Kilian Heger for always encouraging me to be whatever I wanted to be, for showing me kindness is always the right answer, and giving me the gift of conversation.

Abstract

This project evaluated and demonstrated effective techniques and/or systems to reduce environmental pollution contained in dairy milk house wastewater and disseminated the results to dairy producers in Minnesota. With federal Clean Water Act Section 319 funding, four new or modified milk house wastewater treatment systems were demonstrated and evaluated on sixteen farms in four counties in Minnesota. All of the treatment systems had a septic tank for primary treatment. The four types of systems installed included aeration, both aerobic treatment units and recirculating media filters with discharge to subsurface soil treatment systems, irrigation to cropland or pasture, and large soil surface infiltration areas covered with bark (bark beds). The systems were monitored for influent and effluent wastewater characteristics, water flow and overall system performance. Overall the systems removed 98-100% of BOD_5 and TSS, 90 to 100% of the phosphorous and 75 – 90% of the nitrogen. Lessons learned from the installation and monitoring of these systems have led to design guidelines for the selection, design, and installation of these milk house wastewater treatment systems. In addition a milk house wastewater treatment estimator was developed to document the removal of contaminants after installation of a milk house wastewater treatment system. The estimator was tested on the impaired Carver Creek watershed in Carver County, Minnesota where seven farms have direct discharge of milk house wastewater to tile lines. The estimator showed the overall impact of installing milk house treatment systems on these seven farms will be an annual removal of 10,778 pounds of BOD_5, 4003 pounds of TSS, 252 pounds of phosphorous and 336 pounds of nitrogen. Economically the removal of phosphorous per pound is much lower than many other potential practices, whereas nitrogen costs are more median; indicating watersheds facing nutrient impairment with small to mid-size dairies should focus improvements in this direction.

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Chapter 1: Introduction

The purpose of project was to evaluate and demonstrate effective techniques and/or systems to reduce environmental pollution contained in dairy milk house wastewater and disseminate the results to dairy producers in Minnesota. Many small and mid-sized dairy operations in Minnesota handle their manure as a solid and do not have a system to handle milk house wastewater that complies with Minnesota Feedlot Rules (Minnesota Rules Chapter 7020). For owners of these operations to become better environmental stewards, to remain economically viable, and to comply with current environmental regulations, they need economical and effective options for treating milk house wastewater. The United States Department of Agriculture and Minnesota Department of Agriculture data report that small and mid-sized dairy producers account for about 88% of the total dairy operations in Minnesota, which is obviously a significant audience for this project (MDA, 2002).

With federal Clean Water Act Section 319 funding, four types of milk house wastewater treatment systems were demonstrated and evaluated on sixteen farms in four counties in Minnesota. The systems needed to be effective in a cold climate and comply with state and federal regulations. All of the treatment systems had a septic tank for primary treatment. The four types of systems installed included aeration, both aerobic treatment units (ATU) and recirculating media filters (RMF) with discharge to subsurface soil treatment system (SSTS), irrigation to cropland or pasture, and large soil surface infiltration areas covered with bark (bark beds). The systems were monitored for influent and effluent wastewater characteristics, water flow and overall system performance (system performance measures differ with system type). A collaborative team guided and funded the research.

Chapter 2. Literature Review

a. General Milk House Characteristics

Some of the first work on milk house wastewater was published in 1979 by Lindley in Connecticut. This study documented that producers underestimate the quantity of discharge wastewater, but their estimates of pollutants in the discharge was reasonable for the calculation of a five day biochemical oxygen demand (BOD_5)and total solids (TS). Interesting laboratory tests showed a possible inhibition of biological treatment when high concentrations of sanitizers were utilized. In California, in 2006, water use was studied and ranged from 170 to 734 L $cow^{-1}day^{-1}$ (45 to 194 gal $cow^{-1}day^{-1}$) with an average of 290 L $cow^{-1}day^{-1}$ (± 147) (77 gal $cow^{-1}day^{-1}$ ± 39). For existing facilities they recommended installing water meters, while for new facilities estimates should be made based on site specific site conditions and management styles (Meyer et al., 2006).

b. Vegetated Filter Strips

A vegetated filter strip (VFS) constructed to treat milk house wastewater from a Vermont dairy farm was evaluated to determine its effectiveness in reducing TS, total phosphorous (TP) and nitrogen (N) concentrations and exports in surface and subsurface flow (Schwer and Clausen, 1989). The strip significantly reduced TS, and N on a concentration basis, and retained 95% TS, 89% TP, and 92% N on a mass basis. Retention was the greatest during the growing season and the poorest during snowmelt periods. Concentrations in subsurface outputs were greater than in surface runoff and over 75% of the mass export was in subsurface flow. Questions remain about the TP sorption and removal with VFS, but data does support that as long as the filter soils stay aerobic sorption with milk house wastewater will occur.

c. Media/Bark Beds

Several filter mounds with a dosing rate of 13 L m^{-2} d^{-1} were built to treat the milking center wastewater from a 200-cow dairy farm in central Michigan using unaerated shredded hardwood tree bark, passively aerated tree bark, hardwood tree wood chips, and styrofoam chips. Over the 50 week project, the shredded tree bark removed 90% or more of TP, ammonia (NH_4^+), total suspended solids (TSS), and E. coli bacteria. Wood chips were less effective, and styrofoam chips provided essentially no treatment with passive aeration of the shredded bark not significantly affecting pollutant removal (Rathbun et al., 2012).

d. Aerobic Treatment Units

Others have studied the use of ATUs for the removal of contaminants in dairy milk house wastewater. Lab scale studies were being conducted on milk house wastewater with an anaerobic/aerobic treatment system which removed 92% of N, 99% of BOD_5 and 81% of TS (Lindey, 1979). Granular sludge was generated for simultaneous nitrification, denitrification and phosphorus removal and studied on a laboratory scale in an ATU. According to the results, the aerobic system produced an effluent suitable for land irrigation (Amini et al., 2013). Larson and Safferman added recirculation and equalization into an ATU and found removals greater than 99% for BOD_5 and COD at a flow rate of 189 L/day (50 gpd) and a loading of 1.1 kg/day (2.4 lbs/day) BOD_5. In addition, average nutrient removal was 91% for ammonia, 59% for total Kjeldahl nitrogen (TKN), and 77% for TP. These values are higher than typically reported indicating recirculation and equalization provide a great benefit (2009). Tocchi et al. (2013) evaluated a three stage ATU design at various loading rates. The depletion of the pollutant load mainly occurred in the first reactor although a significant contribution to the removal of the slowly degradable organic matter was given by the two subsequent reactors.

Questions remain about the how the aeration regimes affect treatment. Many ATUs use constant aeration to meet the oxygen demand, but at a significant energy usage. Tocchi et al. (2012) evaluated various on/off cycles and found at 15min/45min and 30min/60min lead to lower bacterial diversity and reduced treatment with a reduction from 88-94% to under 70%. In Spain, researchers evaluated injecting pure oxygen into the chamber to create aerobic conditions and success relating to COD and TSS and contend this method shows promise at a reduced cost compared to anaerobic treatment (Martin-Rilo et al., 2014). A sequencing batch reactor (SBR) to treat dairy milking wastewater with average BOD_5 and chemical oxygen demand (COD) input levels averaging 1608 and 1010 mg L^{-1} was evaluated (Wu et al., 2008). The SBR was operated in fixed eight hour (h) cycles, each consisting of 1 h anaerobic, 3 h aerobic, 2 h anoxic, 1 h aerobic, 50 min settle, 10 min decant, and idle with a hydraulic retention time of 5.3 days. When loaded at 0.125 kg COD kg^{-1} mixed liquor suspended solids (MLSS) d^{-1} the unit achieved a COD removal efficiency greater than 99% and an effluent with COD and BOD_5 concentrations less than 55 and 25 mg L^{-1}, respectively. The average removal efficiencies for TKN, NH_4^+, TP, and TSS were 96.7%, 92.4%, 95.9%, and 96.6%, respectively.

e. Membrane

Farizoglu and Uzuner (2011) combined the aerobic treatment process with a membrane system achieving a 97% removal of COD with under three days of hydraulic retention time due to very high oxygen transfer rates. A membrane was also used following treatment with powdered activated charcoal and a coagulant. The quality of water after reverse osmosis was found to be comparable to that of process water used in the dairy and therefore can be reused by recycling back to the head of the production (Sarkar et al., 2005).

f. Anaerobic

Anaerobic processes have also been evaluated. Banu et al. (2007) used a two-stage hybrid upflow anaerobic sludge blanket reactor (UASB). UASB reactors are methane producing digesters which form a blanket of granular sludge which suspends in the tank. Wastewater flows upwards through the blanket and is degraded by the anaerobic microorganisms. The study on milk house wastewater found COD removals ranged between 97 and 99% with a methane content from 65 to 70% in stage I, and from 63 to 66% in stage II. The two-stage anaerobic treatment was found to be a better alternative for the complete treatment of dairy wastewater than high-rate anaerobic, anaerobic/aerobic, and two-phase anaerobic treatment methods. In a related study, the anaerobic treatment process was combined with a membrane bioreactor. The research was successful at documenting a 95% removal of COD while producing methane at an average rate of 73%. These values were achieved while maintaining an average flux rate through the membrane at a much higher rate than those found in similar anaerobic systems (Bunter et al., 2013).

g. Constructed Wetlands

Due to climatic concerns, constructed wetlands (CW) were not evaluated as part of this project, but there is a large research basis to indicate they should be considered. Although constructed wetlands have been utilized for wastewater treatment in warm climates, their performance in cold climates has been questioned. A study by Neman et al. (2000) documented a surface-flow wetland, designed to treat 2.65 $m^3\ d^{-1}$ of milk house wastewater in Connecticut in 1994. The overall percentage of mass retention was 94, 85, 68, 60 and 53% for TSS, BOD_5, TP, nitrate–nitrite and TKN, respectively. Mass retention was significantly greater during the summer than during the winter for all variables except fecal coliform (FC). The mass balance indicated that settling and increased storage was the largest removal mechanism. The treatment of wastewater in this wetland did not meet design outflow concentration criteria, most likely due to BOD_5 overloading. Similar results were found by Smith et al. (2006) in Atlantic Canada.

Another related study in the mountains of Italy documented similar removal of BOD_5 in summer and winter in an irregularly shaped wetland, but a reduced nitrate removal of 33% in winter compared to 71% in the summer (Gorra et al., 2014). In another cold weather study in Ontario, the effect of wastewater on the vegetation in the wetland was evaluated in two- stage wetland systems. Plant uptake accounted for 0.7% of TKN removal when the vegetated free water surface cells were considered together; however, in the second wetland cell with lower N and P loading rates, plants accounted for 9% of TKN, 21% of $NH4^+$ and 5% of TP removal. Specifically looking at cold weather CW operations, Munoz et al. (2006) established that vegetation and aeration can be effectively utilized in cold regions to prevent clogging and freezing, thereby reducing preferential flow paths.

Experiments have been conducted to evaluate improved TP removal with the use of steel slag in CW. Six systems were evaluated with horizontal and vertical flow but only three had an additional cell with the slag. The CW with the slag had significantly higher removals of P and NH_4^+.

Another study used diluted milk house wastewater in constructed wetlands to recover nutrients and reduce pollution using duckweeds. Areal removal rates for nutrients in primary duckweed wetlands were 194.9 ± 18.9 g $TN/m^2/yr$ and 13.0 ± 3.0 g $TP/m^2/yr$, while removal rates in secondary duckweed wetlands were 104.1 ± 13.1 g $TN/m^2/yr$ and 9.3 ± 2.1 g $TP/m^2/yr$ (Adhikaria et al., 2014). To evaluate if these results will continue over time, Woods et al. (2008) evaluated five years of phosphorous removal data. Mass reductions for the entire monitoring period was 52% for TP with a sustained TP adsorption capacity, with treatment being largely influenced by hydrology and fluctuations in wastewater loading rates and the authors recommend controlling hydrological loadings to maximize long term removal.

Others have combined the ATU process with CWs. By adding in an ATU the resulting CW was able to have a smaller overall footprint with documented removal rates of 82-96% for organics and solids along with a 76% for N and 19% for P (Merlin and

Gaillot, 2010). In another project by Morgan et al. (2008), slightly diluted milk house wastewater passed through a series of anaerobic, aerobic, and clarifier reactors and wetland cells before exiting the system. Regardless of wastewater strength, *E. coli* concentrations were consistently reduced by at least 99% from influent to effluent, with the majority of the reduction (76%) occurring in the first two reactors. TP was reduced 41%, total nitrogen (TN) 79%, and NH_4^+ 70% (Morgan and Martin, 2008). Karadag et al. (2014) contend that up-flow anaerobic packed filters are another option to consider due to their high tolerance against hydraulic shock loadings, yet more research on low temperatures is needed.

Several new issues have arisen regarding the concerns of estrogens in dairy milk house wastewater and greenhouse gas emissions. Cai et al. (2012) evaluated the removal of such hormones in a constructed wetland. The results demonstrate that CWS is an efficient system for the treatment of hormones in dairy wastewater, achieving a mean removal of 92%, although design modifications are needed to deal with peak hormone concentrations. Also in CW there are some concerns that these wetlands could be a source of greenhouse gases (GHG) as N can be volatilized to the atmosphere as ammonia NH_3 and negatively impacts air quality. A study in Nova Scotia, Canada assessed NH_3 volatilization from both surface flow (SF) and subsurface flow (SSF) CWs. Six constructed wetlands (three surface flow and three subsurface flow; 6.6 m^2 each) were loaded with dairy wastewater and GHG fluxes were measured. SF wetlands had significantly higher emissions of methane (CH_4) and nitrous oxide (N_2O) than SSF wetlands and therefore had 180% higher total GHG emissions (VanderZaag et al., 2010).

Chapter 3: Process Removal Mechanisms

Water quality can be significantly impacted by improper handling of milk house wastewater. This project focused on the treatment of four key chemicals of concern due to their documented impacts to surface and groundwater.

1. Organic material measured as BOD_5
2. Solids as measured by the total suspended solids (TSS)
3. TP in terms of milligrams per liter (mg/L) orthophosphate
4. N in terms of ammonia (NH_3), nitrite (NO_2-), nitrate (NO_3-), and organic nitrogen

For each of the treatment processes evaluated in this project a description of the contaminant removal process is included.

1. Septic Tank Treatment Processes

All the systems in this project started the treatment process with a septic tank. The purpose of the septic tank is to provide an environment for the first stage of treatment by promoting physical settling, flotation, and the anaerobic digestion of the milk house wastewater as shown in Figure 1.

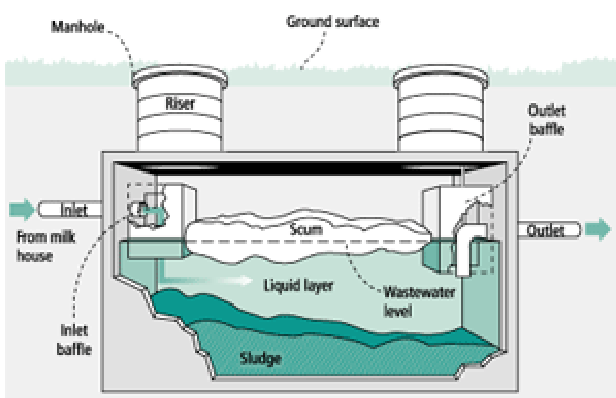

Figure 1. Septic tank cross section

The effluent that leaves the septic tank comes from the clear zone to minimize the solids loading on the downstream components of the system. The baffle, tee, or effluent screen at the outlet is designed to draw from the clear zone retaining floatable or settleable solids in the tank. Although the effluent from the septic tank is not highly treated, it is greatly clarified compared to the wastewater entering the tank. The BOD_5 and TSS reductions in a septic tank are due both to the reduction of solids and the anaerobic digestion process. BOD_5 and TSS levels are roughly cut in half in a properly operating septic tank (Magdorf, 1974). Another important function of the tank is storage of these accumulated solids. Septic tank solids include both biodegradable and nonbiodegradable materials; although many of the solids will decompose, some solids will accumulate in the tank. The tank is sized large enough to hold solids until maintenance is performed.

The septic tank is a gravitational settling device that provides a space for sedimentation and flotation to take place. Septic tanks allow the separation of solids from wastewater as heavier solids settle and fats, greases, and lighter solids float. This primary clarification improves the wastewater quality prior to further treatment in the downstream treatment units, such as the soil absorption field and many other secondary treatment processes. Thus the primary purpose of the septic tank is to provide relatively quiescent conditions to allow settleable solids to sink to the bottom and accumulate, and floatable solids to rise to the top and accumulate. This segregation and stratification that occurs is essential to the overall performance of the septic tank, and involves both ascending and descending matter. Also the flotation process is enhanced by the presence of oil and grease in the wastewater, which congeals on the small discrete particle surfaces, making them more buoyant. The accumulation of scum by flotation is a significant factor relative to the efficient removal of grease, oil, and floating solids.

The settling process requires time to occur, so the tank must be large enough to retain the wastewater in a turbulence-free environment for two to four days. Excessive flow and turbulence can disrupt the settling process, so tank volume, size, shape, and inlet baffle configuration are designed to minimize turbulence. Septic tank design allows for a quiescent zone in order to slow the velocity of the wastewater stream and optimize the settling of solids. In order to achieve this, the distance between the inlet and outlet should be maximized. A length to width ratio of at least 3:1 is preferable, with a recommended liquid depth of three feet (Seabloom et al., 2004).

Anaerobic and facultative biological processes in the oxygen-deficient environment of the tank provide partial digestion of some of the wastewater components. These processes are slow, incomplete, and odor producing. Gases (hydrogen sulfide, methane, carbon dioxide, and others) result from the anaerobic digestion in the tank. The gases accumulate in bubbles in the sludge that, as they rise, may re-suspend settled solids. This scenario often results when active digestion occurs during warm temperatures. Effluent screens can be added to systems to limit TSS from exiting the tanks.

The septic tank also provides primary anaerobic treatment (dissolved oxygen <0 .5 mg/L) of the raw wastewater. The overall anaerobic digestion process is described below:

$$\text{Organic matter} \rightarrow CH_4 + CO_2 + H_2 + NH_3 + N_2S$$

This occurs in a two-stage process. The first stage of this process is referred to as liquefaction where acid-forming bacteria partially digest the solids by hydrolyzing proteins and converting them to volatile fatty acids (VFA). For the most part, septic tank microbes assimilate the waste constituents in the absence of a respiration process and are commonly referred to as anaerobic microbes. In the anaerobic treatment process organic matter is broken down in a biological process that occurs in the absence of molecular oxygen where bound oxygen is present in other molecules, such as NO_3^-, sulfate (SO_4^{2-}), and carbon dioxide (CO_2). Anaerobic bacteria dominate in this state because they are able to metabolize in the absence of molecular oxygen. Anaerobic bacteria are significantly slower at oxidation and smaller in size than aerobic bacteria, but they are much more resilient to environmental changes.

If temperatures are warm enough the fatty acids are converted to methane (USEPA, 2002). The anaerobic digestion processes in tanks are affected by temperature in the tank and by substances that have an adverse impact on biological organisms. Higher temperatures will enhance the rate of biological processes and inhibiting substances will reduce it. Too high temperatures may liquefy fats, oils and greases (FOGs). Ideal temperatures in the tank allow for FOGs to solidify and bacterial activity to take place. Some factors that affect the way a tank functions include (UMN, 2011):

- strength (concentration) of the incoming wastewater;
- pH;
- introduction of harsh chemicals, drain cleaners, paint, or other inappropriate substances into the waste stream which may affect pH and biological activity;
- introduction of fats, oils and grease (FOG);
- highly variable flow patterns that affect detention time;
- introduction of pharmaceuticals;
- introduction of process discharge, including backwash from a water softener, and;

- lack of maintenance resulting in excess accumulation of solids, reducing effective volume and reducing detention time.

The decomposition by anaerobic bacteria known as ammonification readily changes organic nitrogen to ammonia, which then exits the tank. Although not the main purpose of the septic tank, there is, however, some removal of nitrogen resulting from the settling of solids and flotation of scum, amounting to 10 - 30% N (Oakley, 2005).

Phosphorus removal in septic tanks is largely a physical process, with some chemical precipitation occurring as well. Between 20 and 30% of total phosphorus in raw wastewater is separated out in the form of sludge in a septic tank (Wood, 1993). Orthophosphate may also be removed in septic tanks through mineral precipitation reactions particularly vivianite precipitation (Zanini et al., 1998).

2. Aerobic Treatment Unit Treatment Processes

An aerobic treatment unit (ATU) is a pretreatment component that provides for aerobic degradation or decomposition of effluent constituents by bringing the effluent into direct contact with oxygen. ATUs pretreat effluent by adding air to break down organic matter, reduce pathogens, and transform nutrients in what is known as the activated sludge (AS) treatment process as show in Figure 2.

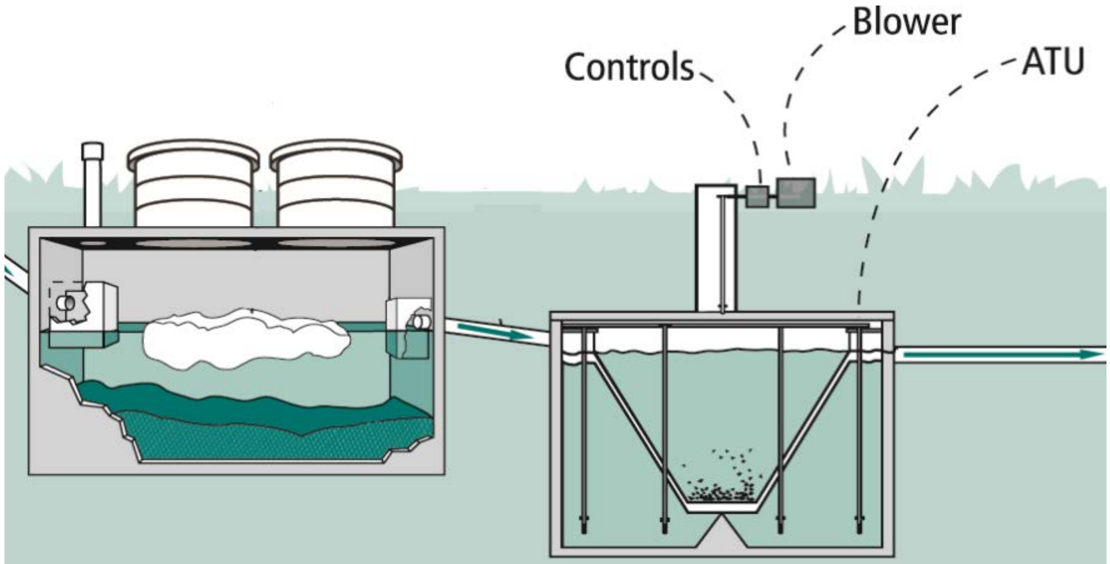

Figure 2. Aerobic treatment unit cross section.

Compared to conventional septic tanks, ATUs break down organic matter more efficiently, achieve quicker decomposition of organic solids, and reduce the concentration of pathogens in the effluent by a larger margin. ATUs work by creating a highly oxygenated (aerobic) environment for bacteria, usually by bubbling compressed air through the liquid in the tank. Aeration is provided by one of the following methods:

1. Mechanical aeration - introduction of air via mechanical means. A mechanical method of injecting air through orifices in pipes and plates. Streams of air serve to transfer oxygen and to provide vigorous mixing of the basin contents. Surface mixers or subsurface mixers with draft tubes where air is drawn down a hollow shaft and sparged into the fluid are also used. The bubbler or stirrer keeps the water agitated, so solids cannot settle out, and floating materials stay mixed.
2. Diffused aeration - introduction of air bubbles under pressure into a treatment unit using a compressor or blower and a diffuser. Submerged devices inject air into the effluent.

The smaller the bubble, the greater the oxygen transfer rate into the effluent. Additionally, bubbles formed deep within the chamber will have more pressure to drive the oxygen transfer and more time-of-contact with the air-water interface. One method of creating small bubbles is with porous ceramic diffusers. The small, interconnected passageways inside the ceramic matrix create a tremendous loss of air pressure and many points of outflow. This combination produces streams of small bubbles over the surface of the ceramic diffuser. In an ATU, the bubbler agitates the water so solids cannot settle out and floating materials stay mixed in the liquid. Well-designed ATUs allow time and space for settling while providing oxygen to the bacteria and mixing the bacteria and its food source.

Naturally occurring microorganisms consume the organic material in sewage. Commonly, bacteria and other microorganisms are considered to be undesirable components of effluent, yet only a small fraction of the microbes found in effluent are truly pathogenic. Aerobic effluent treatment encourages the growth of naturally-occurring aerobic microorganisms as a means of treating effluent. Such microbes are the engines of effluent treatment. Most decomposing microbes prefer aerobic conditions to anaerobic conditions. When dissolved oxygen is available, microorganisms in decomposing organic matter, primarily VFA, consume oxygen dissolved in the water through the following reaction:

$$VFA + O_2 + \text{aerobic organism} \rightarrow H_2O + CO_2 + \text{energy} + \text{residuals}$$

The treatment processes in an ATU biologically convert non-settleable (suspended, dissolved, and colloidal) organic materials to a settleable product using aerobic and facultative microorganisms; this is typically followed by clarification and sludge return. The result of the ATU treatment process is the conversion of organic pollutants into inorganic compounds and new microbial cells. The net production of cells (creation of new cells versus the death of old cells) will simply settle out or slough and media will form an accumulation of material which will eventually be removed from the unit. Effluent treatment in an ATU is different from that in septic tanks, both in the speed and quality of treatment. Bacteria in an ATU use oxygen to break down organic matter efficiently, achieving relatively quick decomposition of organic solids and reducing the concentration of pathogens in the effluent. In addition to their more effective removal of organic matter in effluent, ATUs generate far less hydrogen sulfide than do conventional septic tanks, creating fewer odor problems. Solids settle out of the effluent, and the clear effluent is distributed to a soil treatment system.

The sizing of aerobic systems is based on the flow, the addition of oxygen, the concentration of organic matter in the effluent, and the settling characteristics of the chosen system. Most ATUs operate as an intermittent-flow, complete mix tank, with constant volume reactors. Effluent flow is intermittent versus continuous because influent is not constant. Effluent enters the aeration chamber, where contents are thoroughly mixed to maximize the contact between dissolved oxygen, microbes, and effluent. Effluent moves out of the aeration chamber and into a clarifier. The rate of discharge is in direct proportion to the rate of inflow. Sequencing batch reactors (SBR) are the exception to this generalization. SBRs cycle the aeration system provides some energy savings and promotes nitrogen removal (temporary anoxic conditions). Care must be taken, as this technique can produce a poor settling biomass due to gas flotation and non-flocculating microbes.

For the ATU to perform, its microorganisms must be provided with an environment that allows them to thrive. Temperature, pH, dissolved oxygen, and other factors affect the natural selection, survival, and growth of microorganisms and their rate of biochemical oxidation. Overall, as temperature decreases, microbial activity decreases. Generally speaking, ATUs are buried, the soil acting as a sink for the heat generated by the activity within the treatment unit. The cold temperatures of the upper Midwest can cause reduced performance during the colder months of the year. In addition to ambient temperature, the influent's pH significantly impacts effluent treatment; the optimum pH for microbial growth is between 6.5 and 7.5.

All of the ATUs used in this study are attached growth or fixed film reactors wherein the microorganisms responsible for treatment colonize a fixed medium. Decomposition is limited to this area, and settling occurs outside of the bacteria's growing surface. This design tends to be the most expensive, but the effluent is consistently pretreated. These units typically operate with constant aeration, long detention times, low food-to-microorganism ratio, and low biomass accumulation. Problems due to bulking (the formation of chains or colonies of bacteria that do not settle or sink to the bottom as they should) in these tanks are uncommon, because the bacteria stay on the film, and there is no need for a system to return them from the settling chamber. This type of ATU generally provides the most consistent treatment because the bacteria are more stable.

Aerobic microorganisms use the fermentation process to reduce complex organic compounds to simple organic forms. Heterotrophs are microorganisms that use organic carbon for the formation of new biomass. These organisms are consumers and decomposers, and therefore depend on a readily available source of organic carbon for cellular synthesis and chemical energy. They are the primary workhorses in the oxidation of soluble BOD in wastewater treatment. In comparison, autotrophic microorganisms can create cellular material from simple forms of carbon (such as carbon dioxide). These organisms are at the bottom of the food chain. They do not depend on other organisms for the creation of complex organic compounds. Autotrophic microorganisms are important for the removal of nitrogen from wastewater in anoxic zones of the system.

In the aerobic process, organic nitrogen and ammonia are converted to NO_3^-. Under anoxic conditions, the NO_3^- is denitrified to N_2. Some ATUs are designed to also provide denitrification as part of their operation. Design modifications include intermittently supplying air and recirculate the nitrified wastewater into the anoxic regions within the treatment unit. Denitrification then occurs by anaerobic heterotrophs.

Because phosphorus is often a limiting nutrient in the natural ecosystem, eutrophication can occur when excess phosphorus is discharged to a surface water body. In wastewater, phosphorus can be bound in organic compounds and/or can be in the soluble phosphate (PO_4) form. Bacteria will assimilate a small portion of the orthophosphate during their growth process. Conceptually, this amount of phosphorous could be removed by sedimentation. Because residential ATUs operate in the endogenous phase, very little sludge wastage (and thus very little phosphorus removal) is provided. When a higher degree of phosphorus removal is needed, a more advanced wastewater treatment, such as chemical precipitation, will be required.

3. Recirculating Media Filter Treatment Processes

A recirculating media filter (RMF) uses coarse sand, gravel, peat, foam, textile, or other media for effluent treatment in addition to a septic tank, recirculation tank, and soil treatment system. The recirculation tank contains a blend of septic tank effluent and media filter effluent. This blend, combined with media with more pore space, allows for treatment of high strength wastewater such as from milk houses. The recirculation in a RMF system is beneficial in areas where nitrogen removal is desired and/or waste strengths are higher. As effluent moves through the filter, it becomes oxygenated. When it is captured in the recirculation tank, it becomes anoxic (low in dissolved oxygen) and bacteria can break down nitrates in the effluent and release N_2 back to the atmosphere in a process called denitrification. Multiple-pass recirculation processes also provide operation and maintenance benefits with respect to process flexibility in treating peak hydraulic surges and greater periodic organic loads due to the blended effluent which is applied to the top of the filter as shown in Figure 3.

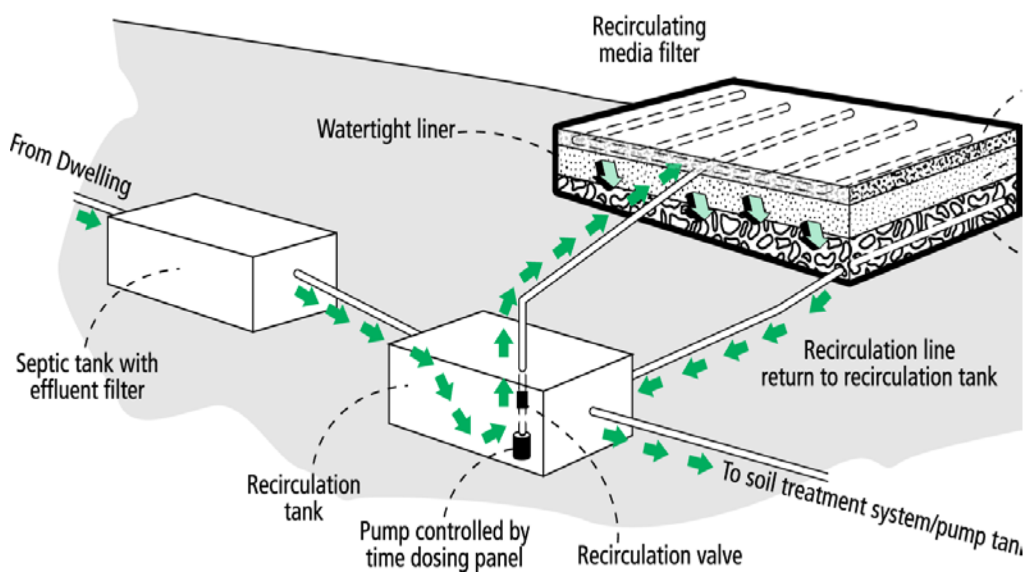

Figure 3. Recirculating media filter cross section.

Microorganisms play an essential role in treating the wastewater as it flows over media surfaces. A biologically active film of organisms forms on the surface of the media. Certain bacteria known as primary colonizers attach (via adsorption) to the surfaces and differentiate to form a complex, multi-cellular structure known as a biofilm. For this biofilm to form, proper environmental conditions are required. Sufficient moisture is the most important factor. Temperature and amount of readily available oxygen also play important roles. If these factors are present, a biofilm will form around a host particle. Adequate moisture has not been a problem in media filters, but adequate air movement through the system to provide the needed oxygen has been in some systems (Loudon et al., 2003). The moist media is nutrient rich, and the biofilm grows by entrapping organic material. During rest periods, the trapped organic matter is digested.

Many different types of heterotrophic bacteria are found in these biofilm flocs. Calaway (1957) discovered fourteen different species of heterotrophic bacteria in different levels of a single-pass filter. There was a presence of all species at all times, indicating that bacteria were adapted to that environment and were carrying on metabolic processes. These bacteria were in the upper layers, about the first twelve inches (30 cm), of the media. Insufficient food in lower levels resulted in most active organisms remaining in the top layer. Increasing dosing rates produced a marked increase in the number of bacterial species in the filter. Both nitrifying bacteria and denitrifying bacteria are present in filter media. Deeper in the media, organism populations are reduced, oxygen may be less available and reaction rates are lower. However, some nitrification appears to occur deeper as evidenced by the fact that deeper filters provide more ammonium reduction (Loudon et al., 2003). As long as the hydraulic or organic loading rate are kept in normal range, clogging does not develop significantly and sloughing is not a major concern. The lower portions of the filter media catch any material sloughed from above and maintain a consistently high effluent quality out the bottom of the filter.

4. Soil Treatment Processes in Bark Beds, Irrigation Systems and Soil Treatment Systems

Suitable soil is an effective treatment medium for wastewater because it contains a complex biological community. One tablespoon of soil can contain over one million microscopic organisms, including bacteria, protozoa, fungi, molds, and other creatures. The bacteria and other microorganisms in the soil treat the wastewater and purify it before it reaches groundwater. Aerobic bacteria provide treatment and function optimally in aerated soil because they prefer oxygen. If the soil is saturated and no oxygen is present, anaerobic bacteria function, but they provide insufficient treatment. Bacteria and total suspended solids have been found to be treated and removed in the first foot of most aerated soil under the system (Bouma, 1979).

The soil treatment and dispersal zone provides for the final treatment and dispersal of septic tank or aerobic pretreated effluent. To varying degrees, the soil treatment and dispersal zone treats the wastewater by acting as a filter, exchanger, or absorber by providing a surface area on which many chemical and biochemical processes occur. The combination of these processes, acting on the effluent as it passes through the soil purifies the water.

As effluent flows into a soil treatment area, it moves vertically through the distribution media to the biomat where treatment begins. The biomat is a biological layer formed by anaerobic bacteria, which secrete a sticky substance and anchor themselves to the soil, rock particles, or other available surfaces. Due to the carbon and nutrients present in the effluent, a zone of bacteria develops along the soil-media contact. When fully developed, the gray-to-black sticky biomat layer is considerably slower than flow through natural soil, allowing unsaturated conditions to exist in the soil. Unsaturated flow increases the travel time of effluent through the soil, ensuring that it has sufficient time to contact the surfaces of soil particles and microorganisms.

A developed biomat reaches equilibrium over time, remaining at about the same thickness and the same permeability if effluent quality is maintained. If the quality of the effluent leaving the septic tank or aerobic treatment process decreases, more food will be present for the anaerobic bacteria, which will cause an increase in the thickness of the biomat and decrease its permeability (Siegrist, 1987). If seasonally saturated conditions occur in the soil, aerobic conditions will no longer exist. Under these conditions the biomat will thicken, reducing its permeability and the effectiveness of effluent entering the soil.

Soil particles provide the surface areas that effluent must come in contact with under unsaturated flow. This contact provides treatment of the effluent by filtering the larger contaminants while adsorbing (e.g., attachment or binding) others. Because soil particles are negatively charged, they can attract and hold positively charged pollutants. Soils also contain minerals that bind with some pollutants and immobilize them.

The effluent contains both organic nitrogen and ammonium. The predominant form entering the soil is ammonium. The transport and fate of nitrogen underneath a soil treatment system is dependent upon the forms entering and the biological conversions that take place. All of these nitrogen transformations are microbially mediated and require suitable temperatures (above 5 degrees C), a usable source of carbon (organic matter) for energy, and suitable alkalinity. NO_3^- are formed by nitrification. Nitrification ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$) is an aerobic reaction, so it is dependent upon the availability of oxygen in the soil. Denitrification is another important nitrogen transformation in the soil environment below soil treatment systems. It is the only mechanism by which the NO_3^- concentration in the effluent can be reduced. Denitrification ($NO_3^- \rightarrow N_2O$-N_2) occurs in the absence of oxygen. For denitrification to take place, the nitrogen must usually be in the form of NO_3^-, so nitrification must happen before denitrification. Mound systems facilitate this process and typically reduce nitrogen concentrations by 32 to 70 percent (Magdorf et al., 1974; Eastburn and Ritter, 1984)). Additional studies have shown little total nitrogen removal below 31 at-grade systems in Wisconsin (Converse et al., 1991) and moderate rates of removal (7-15%) in laboratory studies (Van Cuyk et al., 2001). The transport of NO_3^- may occur by movement within solution, uptake in plants or crops, or denitrification. Since NO_3^- have a negative charge, they are not attracted to soils and are very mobile. The mobility of nitrate is further enhanced by the solubility of these ions in the soil water. Treatment of nitrates occurs to a limited extent by the following mechanisms.

- Uptake by vegetation: If soil treatment areas are kept near the surface, some of the nitrate will be taken up by surface vegetation during the growing season. In irrigation systems the size of the field was designed to meet the needs of the crop for both N and P.
- Denitrification: If the ammonium is nitrified to nitrate and then encounters a

saturated zone which lacks oxygen, the nitrate is converted to nitrogen gas and is lost to the atmosphere.

Once nitrates reach the groundwater, dilution with the native groundwater can mitigate this contamination. There is also a potential for some denitrification of the nitrate in the groundwater itself and when it enters a riparian area at a groundwater discharge zone.

The effectiveness of dilution is dependent upon the amount of nitrate entering from other sources in the area, including agricultural practices and other improperly functioning wastewater treatment systems, along with the hydrogeologic conditions of the groundwater system.

Since some groundwater is ultimately discharged to surface water, the quality of Minnesota's surface water is highly dependent upon the quality of its groundwater. Phosphorus is removed from wastewater in soil treatment systems by being chemically bound by minerals and held on exchange sites on soil particles. Iron, calcium, and aluminum are minerals that chemically bind with phosphates in a process called adsorption. When the adsorption sites are filled, newly added phosphorus must travel deeper in the soil to find fresh sites. Soils higher in clay content have more surface area and binding sites on the soil particles than soils high in sand. This means phosphorus movement is generally lower in finer-textured soils.

Phosphorus is also retained due to precipitation. Precipitation occurs when negatively charged phosphate anions react chemically with positively charged cations to form a solid mineral that is immobilized in the soil. Common cations that react with phosphate to form minerals are iron (both Fe^{+2} and Fe^{+3}), aluminum (Al^{+3}), and calcium (Ca^{+2}).

Phosphate also reacts with oxides of iron, aluminum, and calcium to form stable phosphate-metal complexes. The extent to which precipitation occurs in soil depends on a number of factors including soil pH, the oxidation/reduction status of the soil, the relative availability of cations to react with phosphate, and whether a soil is calcareous or non-calcareous. Non-calcareous soils tend to be acidic rather than alkaline. Cations such as iron and aluminum that can react effectively with phosphate are generally more available in non-calcareous soils. Although phosphate reacts with calcium in calcareous soils, it is more effectively immobilized by iron and aluminum in non-calcareous soils (Lombardo, 2006).

Precipitation and adsorption quickly and effectively retard the movement of phosphorus in many soils to the extent that there is a zone of phosphorus enrichment or accumulation within the first meter below systems. Numerous field and laboratory studies have documented these differences in phosphorus movement/leaching from soils below a soil treatment area (Sawhney, 1977; Bouma, 1979). If the treatment system is functioning correctly, and proper setbacks are maintained from surface waters and vertical separation from periodically saturated soil, problems from phosphorus movement to surface water or groundwater should be minimal. P removal is less effective once any remaining phosphorus reaches groundwater. The movement of phosphorus in groundwater is still slower however than the movement of more mobile, less reactive anions such as nitrate and chloride. Studies that have plotted the movement of groundwater plumes of septic system contaminants almost always show a considerably longer plume for nitrates and chlorides compared to phosphate, even in situations where conditions for phosphate immobilization may not be ideal. The extent to which phosphorus migration is retarded is variable and site specific.

Chapter 4. Additional Project Information and Results

a. Economics

Data was collected for the four systems installed including the cost for installation and annual operating costs as show below in Table 1. These cost do not include the parlor systems.

System	**Initial Cost**	**Average Cost**	**Operating Cost**
Irrigation	$6,000 – $10,000	$8,000	$150
Bark Bed	$6,000 – $10,000	$8,000	$150
ATU + trenches	$12,000 - $16,000	$14,000	$300
RMF + trenches	$12,000 - $16,000	$14,000	$200
Average Cost		$11,000	$200

Table 1. Economics of milk house wastewater treatment system.

The average cost was found by adding the average costs together and dividing by four. The operating cost were obtained from the product manufactures and the producers in the study.

b. Best management practices

In order to achieve similar treatment results as the systems in this project management and care of the systems is critical. Over the study the following list of best management practices were identified:

1. Waste milk aside from the small amount that remains in pipeline or bulk tank cannot enter the system. The location for disposal should be identified during the time of design.
2. A flow measuring devise should be installed prior to design to get an accurate estimate of water usage.
3. All measures should be taken to prevent manure, bedding and barn lime from entering the system.
4. Products for cleaning and sanitizing should be chosen with no or very low amounts of nitrogen and phosphorous.
5. The producer needs to have an arrangement with a septic maintainer/pumper to service their septic tank at the time of installation with a plan established for the appropriate interval which may adjusted over time as a history is developed.

c. Published papers

Numerous technical papers based on the work done for this project were prepared, presented and published. These documents are included in this summary and the citations are:

1. Christopherson, Heger, S., D.R. Schmidt, and K.A. Janni. 2004. Evaluation of aerobic treatment units in treating high strength waste from dairy milk houses. In Proc. Onsite Wastewater Treatment Conference. ed. Richard Cooke. pp. 172-177.
2. Schmidt, D.R., S. Heger Christopherson, P. Fryer, and K.A. Janni. 2005. Design recommendations for milk house wastewater treatment systems. ASAE Paper No. 054103, ASAE, St. Joseph, MI.

3. Janni, K., S. Heger Christopherson and D. Schmidt. 2009. Milk house wastewater flows and characteristics for small dairy operations. Applied Engineering in Agriculture. Vol. 25(3): 417-423.
4. Heger, S.F., D.R. Schmidt and K.A. Janni. 2010. Aerobic and media filter treatment systems for milk house wastewater on small dairy operations. Applied Engineering in Agriculture. Vol. 26(2): 319-327.

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Evaluation and Demonstration of Treatment Options for Dairy Parlor and Milk House Wastewater

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Abstract. Four different types of milk house wastewater treatment systems were installed on working dairy farms varying in size from 50-130 cows. The treatment systems demonstrated include two types of aerobic treatment units; two bark beds and spray irrigation. All of the systems include a primary treatment septic tank. In addition to system performance, design, management and economic aspects are being evaluated.

Water flow data was collected on eleven farms for one year with a range of a flow rates from 360 to 1670 liters/day (L/d) (95 - 441 gallons per day (gpd)) or from 11.0 – 24.2 L/d/cow (2.9 – 6.4 gpd/cow). Preliminary influent data has shown an average BOD_5 of 2220 mg/L, COD of 3360 mg/L, TSS of 1030 mg/L and FOG (Fats, Oils and Grease) of 650 mg/L. The aerobic treatment units preliminary removal efficiencies for BOD_5, COD, TSS, and FOG ranged from 44-94%, 32-94%, 61-82%, and 71-98%, respectively. The bark bed systems have worked without a problem although water samples from within the beds have not yielded sufficient quantities for analysis. The irrigation system did experience some freezing and odor issues but continued to operate through the winter. The average equipment and installation cost was nearly $10,000 with a range of $6,200 - $14,400. Challenges have arisen with higher than expected organic loading, colder than normal temperatures with little snow cover.

Keywords. Milk, milk house, milking parlors, waste treatment, bark, aerobic treatment, irrigation

Introduction

Many dairy producers handle manure as a solid and do not have environmentally sound techniques to handle their milk house wastewater. Large producers with strained storage capacity are also interested in additional options for milk house wastewater treatment. The milk house wastewater is typically composed of wash water used to clean the milking equipment, the pipeline, and the bulk tank on a dairy farm It also consists of cleaning agents as well as some residual milk which remains in the pipeline, receiver jar and bulk tank after emptying. The cleaning regime is usually comprised of four rinses per cycle (Malcolm, 1998). Prior to milking, a sanitizing agent (usually sodium hypochlorite, NaOCl) is rinsed through the pipeline. Following milking, fresh water is used to remove the residual milk. A hot alkaline detergent (often containing sodium hydroxide, NaOH and NaOCl) is then rinsed through to remove fats and oils. A final acid rinse (often a mixture of phosphoric acid, H_3PO_4, and sulfuric acid, H_2SO_4) is employed to prevent calcium buildup. Since milking parlors are extensively used in the US dairy industry, the cleaning operation obviously will produce a large volume of wastewater, which can account for up to 30% of the total wastewater volume (Wright and Graves, 1998). There is a concern about high organic loads, detergents and cleaners.

In the past dairy producers were allowed to discharge this effluent to surface waters with little or no treatment, but recent changes in Minnesota rules and enforcement prohibit this discharge. Wastewater from dairy milk houses poses a treatment challenge because of its high organic load.

With funding from the EPA 319 program through the Minnesota Pollution Control Agency a task force was formed to determine what appropriate methods where available to treat milk house wastewater. This task force has identified seven demonstration farms and installed milk house wastewater treatment systems on these farms.

Methods and Materials

This project is evaluating the technical and economic aspects of four milk house wastewater systems expected to be successful in a cold climate. These systems include two bark beds, two types of suspended growth aerobic treatment units and surface application using irrigation equipment. Water table and soil conditions at the cooperating farmer sites limited the wastewater system options that could be used.

All of the treatment systems have a traditional septic tank as the first treatment process. This tank provides a minimum of 24 hours of detention time, allowing soaps, bedding material and milk fats to float to the top forming a scum layer and the heavier solids including floor lime, dirt and biomass to accumulate in the sludge layer as shown in Figure 1. The tanks need maintenance when the scum or sludge layer is too deep (when top of sludge is within 31 cm (12 in) of the bottom of the outlet baffle or when the bottom of the scum layer is less then 8 cm (3 in) above the bottom of the outlet baffle). This will depend on the size of the tank and the use patterns, but it may need to be done annually at a minimum and bi-annually at a maximum. It is key that only residual milk from the pipelines and bulk tank enter the septic tank. Other “waste milk” is best dealt with by land applying with manure waste.

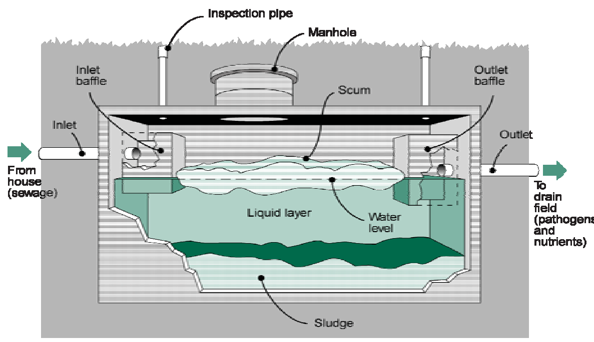

Figure 1. Cross-section of septic tank.

In the two bark systems and the irrigation system, an effluent filter was placed in the last septic tank to limit the amount of suspended solids sent to the treatment area.

Monitoring will be conducted for 18 months to provide quantitative data documenting initial and long-term system performance. All wastewater samples will be analyzed for total suspended solids (TSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), phosphorus (P), nitrogen (ammonia, nitrate, and total Kjeldahl), pH, temperature and fats/oils/grease (FOG). Sludge depth, solids accumulation, and scum depth will be monitored in the septic tanks. Beyond wastewater analysis, data will be collected on labor requirements, general system performance, economics, and operation and maintenance.

Bark Bed

The liquid from the septic tank is applied to a bark filter bed utilizing pressure distribution. The bark bed is a flat area with a perimeter soil berm, approximately 0.3 m (1 ft) high, filled with 0.6 – 0.9 m (2-3 ft) of bark. The bark bed treats the wastewater utilizing evaporation, biological activity and infiltration into the soil. The bark provides a carbon source for the aerobic microorganisms and a surface for them to grow on as they treat the wastewater in the bed. The bark also allows for better oxygen transfer to the effluent. It also helps prevent the soil from freezing, so the bed can operate all winter. The bark also serves as a wick, increasing the bed's evaporation qualities. Temperatures under the bark can hit 27 Celsius (80^{o} F), providing some composting benefits. Maine research has shown that years can go by without replacement of bark, although adding fresh bark occasionally will boost composting efficacy (Natzke, 2002).

The bark bed needs to be located on a fairly flat area. Bark beds are best sited in lighter texture soils with a lower watertable and lower bedrock. The minimum recommended distance to a high water table is 61 cm (24 in) (NRCS, 1996). The design for sizing the bark bed used both the organic loading rate and infiltration rate of the soil.

In both bark bed systems, the milk house wastewater flows by gravity through two septic tanks with an effluent filter in the last septic tank. The effluent then flows into a third tank with a pump, which distributes the effluent evenly over the width of the bark bed utilizing pressure distribution (Figure 2).

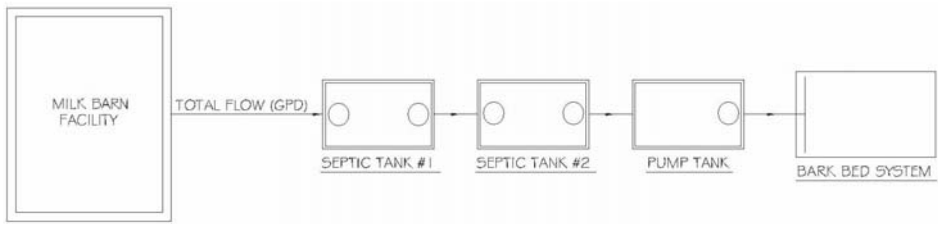

Figure 2. Bark bed flow diagram.

One traditional bark bed system was installed in a wooded area near the milk house. Small trees were cleared in an area to construct a bed that is 11 m (35 ft) by 17 m (55 ft). This sizing was based on a loading factor of 0.15 m^2/L/day (6 ft^2/gal/day). The distribution system runs across the top of the bed for a depth of 30 cm (12 in) and a width of 3 m (10 ft) as shown in Figure 3.

Figure 3. Bark bed installation.

A second bark bed was constructed using the same loading rate of 0.15 m^2/L/day (6 ft^2/gal /day) but the infiltration area was separated into two 30 m (100 ft) strips 3 m (10 ft) in width. This design modification was needed to account for specifics conditions at the farm site. The entire length and width have a rock base formed on the soil surface. The distribution pipe sits on top of the rock. The rock and distribution pipe were then covered with geotextile to prevent the bark from migrating downwards. Bark 0.6 to 1 m (2 to 3 ft) deep was placed over the geotextile (Figure 4)

Evaluation of the bark bed systems includes monthly flow monitoring and sampling of the septic tanks. Sludge and scum levels are monitored in the septic/pump tanks. Suction cup lysimeters were installed in both bark beds to sample effluent at various depths beneath the systems. To date these lysimeters have not produced enough effluent for laboratory analysis.

The average cost of the bark beds in this study was $6,200 (including all materials and labor).

Figure 4. Bark Bed Strip System.

Aerobic Treatment Units

In the aerobic systems, the milk house wastewater is pretreated in a septic tank. The effluent then flows into an aerobic treatment unit (ATU) where sufficient air is added to provide an environment suitable for aerobic bacteria. Aerobic bacteria are very effective at rapidly breaking down biodegradable waste into carbon dioxide and water. The ATUs were designed to achieve BOD_5 levels less than 25 mg/L, allowing the effluent to flow directly into surface waters according to Minnesota Rules 7020. Two types of aerobic treatment units are being used including a FAST® unit developed by Bio-Microbics, Inc. and Nibbler® developed by Bill Stuth and now manufactured and marketed by NCS Wastewater Solutions[1].

Evaluation of the aerobic systems includes monthly flow monitoring and sampling of septic/pump tanks and the effluent after the aerobic treatment unit. In addition to the above-mentioned parameters, the dissolved oxygen (DO) concentration is measured in the effluent from the ATUs. The minimum acceptable DO in an ATU is 1 mg/L, with a range of 2-7 mg/L being desirable. Sludge and scum levels are monitored in the septic/pump tanks.

The FAST (Fixed Activated Sludge Treatment) wastewater treatment process is an aerobic suspended growth system with a honeycomb type media suspended in the tank. The media provides a surface for the bacteria to live on. An electric blower provides air into the media. Aeration circulates the effluent, providing both food and oxygen to the bacteria as shown in Figure 5.

[1] Mention of trademark, proprietary product, or vendor is for information purposes only. No endorsement is implied.

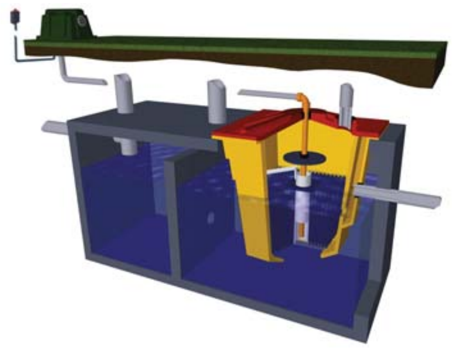

Figure 5. FAST Unit.

In the FAST systems the effluent flows from the milk house flows into one 2840 L (750 gal) septic tank. From the septic tank the effluent flows by gravity into a FAST High Strength 3.0 unit that is designed to remove approximately 2.7 kg (6 lb) of BOD_5 per day (Figure 6).

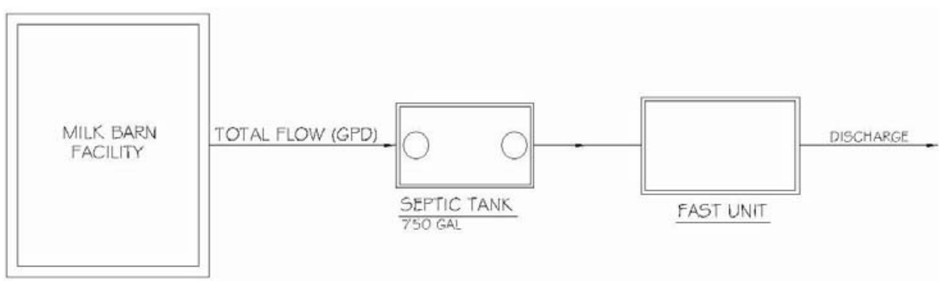

Figure 6. FAST flow diagram.

The average cost of the FAST systems, including materials and labor, in this study was $11,000.

Each Nibbler unit contains a specified number of pods designed to match the hydraulic and biological loading of the system. Pods are injection molded plastic cages (72 cm X 72 cm X 46 cm) (28 in X 28 in X 18 in) containing buoyant high surface area media with an airlift pump mounted in the center. Each pod is capable of treating 0.37 kg/day (0.81 lbs/day) of BOD_5 loading and a maximum of 521 L (137.5 gal) per day. Each unit in this study has an 1893 liter (500-gal) septic tank, a 3786 L (1000-gal) pump tank with time dosing and a Nibbler unit (Figure 7).

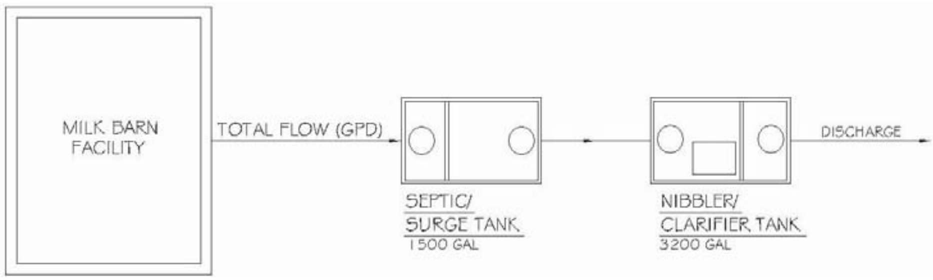

Figure 7. Nibbler flow diagram.

The Nibbler unit is a septic tank containing eight pods. A time controlled pump is located in the pump tank that regulates flow and provides even dosing. Air, forced by the blower through a pipe manifold, flows through the airlift pumps located in the center of each pod. The airlift pump consists of a one-inch air tube that delivers air to the center of the 15 centimeters (6 in) draft type approximately 36 cm (14 in.) below the liquid surface (Figure 8).

The average cost of the Nibbler systems in this study was $14,000 and included materials and labor.

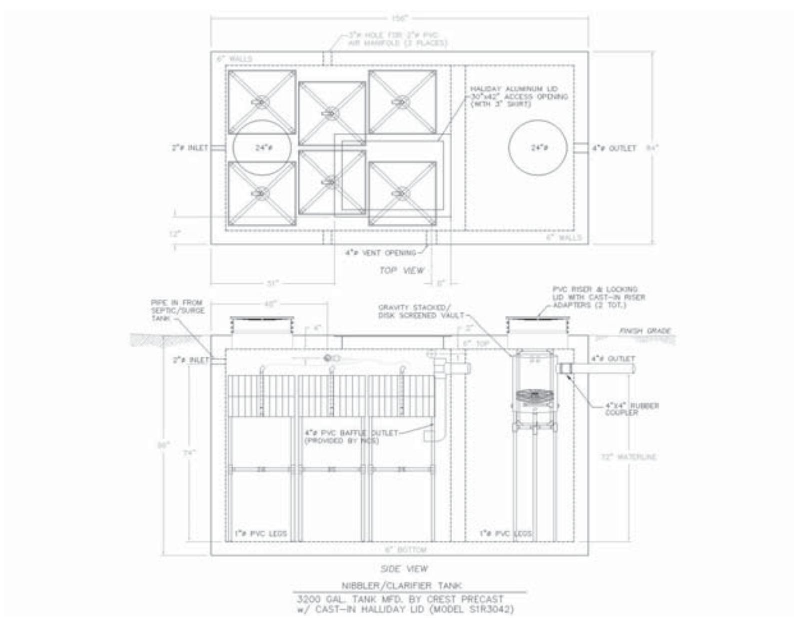

Figure 8. Nibbler Unit.

Irrigation

Surface application of milk house wastewater is another technique being evaluated. This technique is similar to using a filter strip or infiltration area to treat manure runoff from a feedlot. The challenge with this system is how to distribute the milk house waste to the filtration/infiltration area throughout the entire year considering that Minnesota winter temperatures are often subzero for extended periods of time. Year around irrigation was previously attempted with some success in New York (Winkler, 1989).

For this design two types of irrigation heads where installed. During the winter four "wobbler" heads (#10 Nozzle Senninger mini Wobbler ®[1]) are used which are more resistant to freezing, while in the summer a standard impact head is used (Rainberd[1] 85EHLDA ½ in nozzle, 40 psi, 75 ft radius). The effluent flows into a septic tank, followed by a pump tank. A high-head water pump is located in a screened pump vault (large effluent filter), which protects the pump and keeps the irrigation heads from clogging. The effluent then is pumped through 5 cm (2 in) pipe up to the irrigation area (Figure 9).

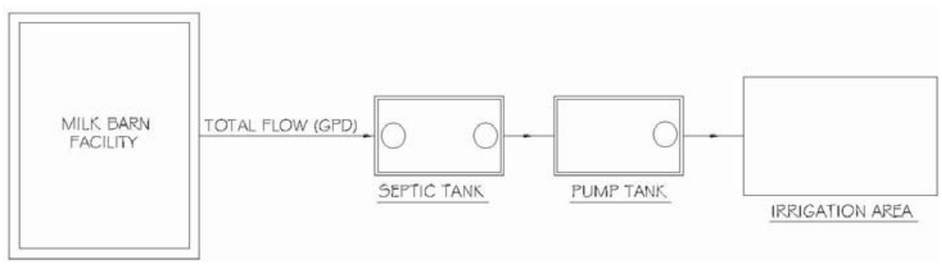

Figure 9. Irrigation flow diagram.

The riser pipes are insulated to reduce the chance of freezing. The effluent is then irrigated over a large area at agronomic rates. After the pump shuts off the effluent quickly drains back to the pump tank which reduces the potential for freezing (Figure 10).

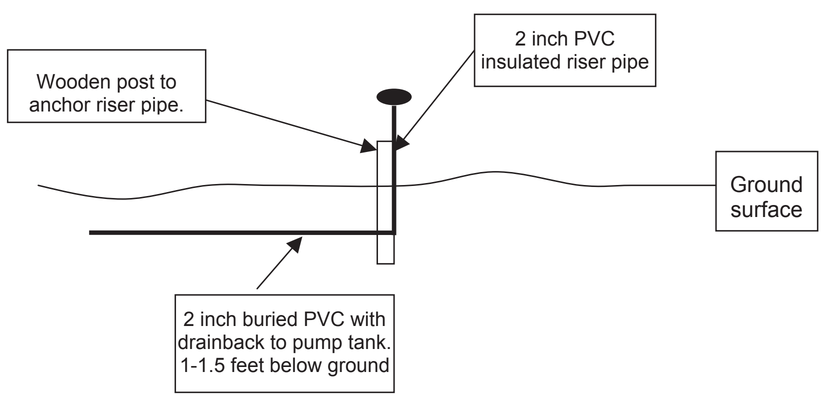

Figure 10. Irrigation diagram.

The irrigation installation cost was $6,200 (including materials and labor).

To evaluate the effectiveness of this system, effluent samples will be taken from the first septic tanks and from inside the screened pump vault. Soil cores were taken prior to application and during the project to determine impacts of nutrient application. Ponding and ice buildup will be monitored along with freezing of the piping system.

Results and Discussion

The quantity and quality of the wastewater discharged from a milk house varies greatly from farm to farm.

Flow Data

The estimates of volume of wastewater produced the milking system and milk house have a wide range from 13 to 42 L/d/cow (3.5 to 11 gpd/cow) (Wright and Graves, 1998). The Northeast Dairy Practices Council recommends using effluent design values of 26 to 38 L/cow/d (7 to 10 g/cow/d) on farms with up to 50 cows, 15 to 23 L/cow/d (4 to 6 gal/cow/d) for farms with up to 100 cows and 7 to 15 L/cow/d (2 to 4 gal/cow /d) on farms with up to 150 cows (Light, 1975). As a part of this study, flow meters were installed in water supply lines to the milk house on eleven farms. Average daily water flows are reported in Table 1. The data supports the concept that as the number of cows increases the amount of effluent produced per cow goes down.

Table 1. Flow and organic loading data from participating producers.

Farm	Number of Cows Milked	Milking System	Liters (Gal) per day	Liter (Gal) per Cow per Day	BOD_5 Influent (mg/L)	Kilograms (Pounds) of BOD_5 per Day	Type of Treatment System Installed
1	65	Stanchion	1238 (327)	18.9 (5.0)	NA	NA	NA
2	41	Stanchion	1287 (340)	31.8 (8.4)	NA	NA	FAST ATU
3	42	Stanchion	1143 (302)	27.3 (7.2)	3,900	4.5 (9.8)	Bark Bed
4	54	Stanchion	636 (168)	11.7 (3.1)	NA	NA	Yet to be installed
5	130	Stanchion	1424 (376)	11.0 (2.9)	3,600	5.1 (11.3)	FAST ATU
6	96	Flat Parlor	1670 (441)	17.4 (4.6)	2,925	4.9 (10.8)	NIBBLER ATU
7	25	Stanchion	496 (131)	19.7 (5.5)	NA	NA	NA
8	45	Stanchion	924 (244)	20.4 (5.4)	1,450	1.4 (3.0)	NIBBLER ATU
9	60	Flat Parlor	791 (209)	13.3 (3.5)	703	0.5 (1.2)	Bark strips
10	50	Stanchion	807 (213)	16.3 (4.3)	1,367	1.1 (2.4)	Irrigation

Influent Data

Before the systems were installed five influent samples were collected from each (participating farms. When septic tanks were present a sample was taken from the tank. In other situations wastewater from the milk house was collected in 38 liter (10 gal) buckets before going down the drain. This data was summarized and a BOD_5 of 1100 mg/L was used as typical BOD_5 value leaving a septic tank. The data collected in the first five months of this study has been much higher at 2220 mg/L (Table 2). Table 1 also shows the average influent BOD_5 value converted to kg/day. This shows a range of 700 –3,900 mg/L or 0.5 – 5.1 kg/day.

Controlling the amounts of milk disposed of in the clean up process is critical. Milk has a BOD_5 value of 100,000 mg/L (Wrights and Graves, 1999). Studies have indicated that over half of the solids present in milk house wastewater are of the colloidal or super-colloidal size (Millen, 1977). Due to the colloidal nature, septic tanks can provide minimal solids separation (Zall, 1972).

High levels of nutrients are also found in milk house waste. Cleaning chemicals and milk both contribute phosphorus. Cleaning chemicals, especially detergents and acid rinses account for the majority of P in the wastewater (Sherman, 1981), with the amount on a given farm highly dependent upon daily cleaning practices.

Table 2. Average effluent data after septic tank primary treatment.

Parameter	Average Value From Study	Range of Data in Literature*
BOD5 (mg/L)	2220	84 - 9700
COD (mg/L)	3360	1500 - 3100
TSS (mg/L)	1030	525 - 7787
FOG (mg/L)	650	NA
pH	6.3	6.0
Total Phosphorus (mg/L)	51	33 – 99
Ammonia (mg/L)	21	29 – 146
TKN (mg/L)	94	45 – 445
Nitrite+Nitrate (mg/L)	1	0.08 – 2.0

*Allen, 1973; Loehr, 1969; Millen, 1977; USDA-SCE, 1992; and Teague, 1999

Treatment System Observations and Data

Only four months of performance data has been collected. The systems are not yet working up to their potential due to the late fall start up with cold temperatures.

One challenge of this project was construction surprises. All installations were successful, but the older farmsteads in the study were full of buried pipe, drainage lines and electrical lines. This added to the installation costs due to the time needed to deal with these surprises.

The bark beds have worked without a problem. The only issue that arose was one of the effluent filters requires monthly cleaning while the other remained relatively clean.

The irrigation system had some freezing problems in 3 of the 4 risers, but continued to operate throughout the past winter with little snow cover and extended periods of temperatures below –18^o C (0^o F). The producer has also experienced odors for 30 minutes during and immediately following irrigation of the wastewater. Both types of aerobic treatment units are working at removing BOD_5, COD, TSS and FOG as shown in Table 3.

Table 3. Removal percentage with aerobic treatment units.

Parameter	Removal Range
BOD_5	44-94%
COD	32-94%
TSS	61-82%
FOG	71-98%

Since these aeration units are operating on a continuous basis, little phosphorus reduction in the treated effluent has been observed. Nitrification has not been effective to date, but it is expected to increase as tank temperatures and microorganism numbers increase and more effective BOD removal is achieved.

Conclusion

A demonstration and research project has been successfully initiated in Minnesota to evaluate effective treatment options for milk house wastewater treatment for small to mid sized dairy producers. The systems being evaluated include two FAST ATUs, two Nibbler ATUs, two bark beds and one irrigation system. The performance data is preliminary, but all the demonstrated technologies have shown the potential to dispose of milk house wastewater in an environmentally sound manner.

Acknowledgements

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Design Recommendations for Milkhouse Wastewater Treatment Systems

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Abstract. *Four different types of milk house wastewater treatment systems were installed on fifteen dairy farms in Minnesota. All of the treatment systems had a septic tank for primary treatment. Installed systems include aeration with discharge to tile lines or subsoil infiltration, irrigation to cropland or pasture, a large soil surface infiltration area covered with bark (bark beds),or a recirculating media filtration system with discharge to a subsoil infiltration area. All systems are being monitored for influent waste strength and flow and overall system performance (system performance measures differ with system type). System economics, operation and maintenance are also being documented. Lessons learned from the installation and monitoring of these systems has led to some general guidelines for the selection, design, an installation of these systems.*

Keywords. Milk house, milkhouse, treatment, disposal

Introduction

Many dairy producers handle manure as a solid and have limited options for handling liquid milk house waste in an environmentally sound manner. Dairy producers in Minnesota are not allowed to discharge untreated milk house wastewater to "waters of the state". However, it is difficult to enforce this rule because there are limited economical options for handling of this waste stream. Available alternatives for handling this wastewater are currently limited to short or long term liquid storage followed by application to cropland. Standard wastewater handling with septic tanks followed by soil infiltration have not been successful long term because of the high concentrations of fats and organic material in the waste going to the infiltration areas.

Milk house wastewater is typically composed of wash water used to clean the milking equipment, the pipeline, and the bulk tank on a dairy farm. It also consists of cleaning agents and residual milk, which remains in the pipeline, receiver jar, and bulk tank after emptying.

The typical milking equipment cleaning regime is usually comprised of four cycles. (Harvard, 2002).

1) *First rinse*- is performed immediately following the milking process. Its function is to wash out most of the excess raw milk remaining in the lines. This rinse usually removes up to 92% of the suspended solids.

2) *Detergent wash*- removes attached organic material. It immediately follows the first rinse. The amount of active chlorine is 100 mg/L. The amount of detergent added to the solution is dependent upon the hardness of the water and should create a solution with a pH greater than 11.

3) *Acid rinse*- The acid wash is used to remove the inorganic deposits from the piping, neutralize the alkaline detergent residues, and lower the pH to prevent bacteria from developing. Typically this is at a pH of 3.5.

4) *Sanitizing rinse*- is performed immediately before the milking process to ensure that the milk lines are free of any microorganisms that may have formed since the acid rinse. The sanitizer is usually chlorine-based with recommended chlorine content of 200 mg/L.

The cleaning operation produces a large volume of wastewater, which can account for up to 30% of the total wastewater volume from a dairy farm (Wright and Graves, 1998). There are concerns about treating wastewater with high organic loads, acids, detergents and cleaners.

With funding from two US EPA 319 grants administered through the Minnesota Pollution Control Agency and cooperation from other state and local agencies, fifteen farms installed milk house wastewater treatment systems in the fall of 2003. These systems are being monitored for wastewater flows and strength and system performance. The systems include Aerobic Treatment Units (ATUs) followed by soil infiltration (standard trench system or subsurface drip irrigation), Recirculating Media Filtration (RMF) with soil infiltration, large soil infiltration area covered with bark (bark bed), and daily irrigation to pasture or cropland. Aerobic treatment followed by discharge into field tiles is another alternative being evaluated in this study. Unfortunately, the data to date indicates that systems do not consistently meet the state surface water discharge standard of 25 mg/L BOD_5. As such, this method is no longer considered a viable option. Another option, not included in this study, is the option of short term storage (2-4 weeks) and land application.

Data is still being collected on these systems. However, preliminary information has led to the development of design guidelines for these systems. These guidelines will aid in site specific selection or recommendations of milk house wastewater treatment systems. Note that all of the systems installed in this study were based on designs that did not include toilet and shower waste.

Overview of Designs and Design Procedures

Design of milkhouse waste handling or treatment systems can be broken into four phases; 1) site evaluation, 2) preliminary designs for multiple options, 3) final design selection and 4) completion of final design.

- Site evaluation includes an interview with the farmer and a walk around the site to assess the status and location of current milk house waste disposal, and options for locating the new treatment system. This step also includes providing the farmer with an overview of the system options, assessing their preferred treatment options, and estimating wastewater flows.

- Data collected during the site visit is use to prepare preliminary designs for a variety of systems. Often, however, the site visit narrows the possible system options because of farmer preferences, and site layout and soil conditions.

- The preliminary design options can then be brought to back to the farmer and a final decision made on the appropriate system for the site.

- Additional data such as more accurate waste water flow data, more details on site elevations, soil type and texture, water table information, etc. are now collected to be used in the final system design.

These design steps require a good understanding of the design criteria for the individual system options. These criteria are the primary focus of this paper.

Wastewater Flow

The primary design parameter for all milk house wastewater systems is the wastewater flow. Most milk house wastewater is generated during the cleaning of the milkers, milk pipelines, receiver, and bulk tank. Depending on the milking schedule the milkers and pipeline are cleaned two or three times per day. The bulk tank is cleaned immediately after the tank has been emptied, typically once per day or once every other day.

Initial estimates of milk house wastewater flow can be estimated through an interview with the farmer regarding water usage. Knowing the volume of each wash and rinse cycle for the pipeline and bulk tank and other water usage such as washing machines will give a rough estimate of water use. However, these predicted flows must be used only as a starting point in the system design. In the current study, the flows predicted from these interviews did not always correlate with measured flows.

Data from this study indicate the amount of wastewater generated from the milk house was generally consistent from day to day on a given farm, however, between farms these flows varied considerably (figure 1). Data for figure 1 was collected using water flow meters installed on the water supply line to the milk house at the 13 farms in the study that do not have parlor wash water mixed with their milk house waste. (In figure 1, each point on the graph represents average values for a given.) In general, flow meters provide the most accurate estimate of wastewater flow for a given farm but placement of these flow meters is critical. Often there are faucets in the milk house that are used for other purposes such as mixing of milk replacer for the calves, washing of tractors or farm implements or filling of fertilizer or herbicide tanks. This water use may be recorded by the flow meter but does not enter the waste water treatment system. Farmers should document this usage to accurately determine the flows actually entering the wastewater handling system. Typically, the majority of water used in the milk house passes through a water softener so this is often the best location to install the flow meter. Two months of daily flow data provide representative data estimating of wastewater flows but continued monitoring of flow should be part of the operation and maintenance of the system.

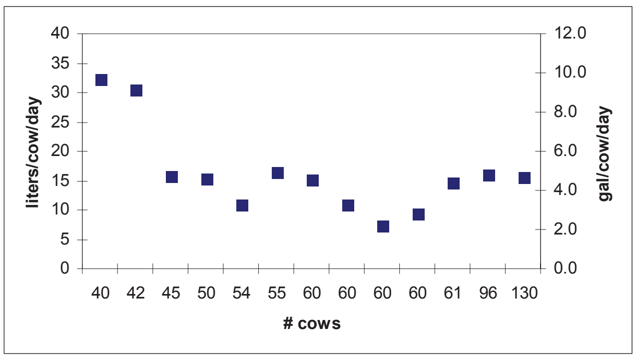

Figure 1. Measured flow per cow per day from 13 farms in study with no parlor wash.

A good option for estimating wastewater flows, better than the farmer interview but not as good as installing a flow meter, is the use of a standard conservative estimate of flow based on this study. Figure 1 shows values ranging from seven to 26 liters/cow/day (2 to 7 gal/cow/day). By using the high estimate of 26 liters/cow/day (7 gal/cow/day) it is likely that the waste handling system will be designed with enough capacity if parlor wash water is not included in the system.

Two of the farms included in this study had milking parlors that were washed with a high-pressure hose-end sprayer. Treatment system designs for these two farms included this effluent. These farms milked 100 and 130 cows and had combined wastewater flows (milk house and parlor wash) of 50 and 26 liters/cow/day (13.2 and 7 gal/cow/day) respectively. (It is unclear why there was such a large difference in water use but this variation suports the need to install water meters to get a accurate estimate of wastewater flows.)

Waste Characterization

The second critical input into all of the system designs is the waste characterization. Depending on the specific system some of the waste constituents are more important than others. For instance, BOD_5 concentrations are critical for sizing aerobic systems and soil infiltration area but are not critical in a surface irrigation system. However, the design of the irrigation system is based on annual loading and removal of nitrogen and/or phosphorus of the cropland or pasture.

Accurate sampling of the milk house effluent presents significant challenges. Direct sampling from the floor drain (where all of the wastewater must flow) seems logical but has proven challenging due to the nature of the effluent flows. As noted previously, there are several wash cycles with different waste characteristics in each cycle.Other effluent flows include washing of the milk house floor and other equipment or boots. Trying to estimate the "average" waste characteristics by discrete sampling of these widely varying effluent flows and concentrations is therefore, very difficult.

Fortunately, this effluent sampling can be simplified. All of the treatment systems require effluent pretreatment in a septic tank. As such, effluent can be characterized by the flows out of this primary treatment tank. This primary treatment removes some of the fats and solids which change the effluent characteristics but these values are the more appropriate average values to use in the system design. Figure 2 and 3 show the average values for effluent concentrations from the different farms in the study. These are the average values from between 10 and 15 monthly samples per farm. Average values for all the farms for BOD_5, TKN, and P are 1344, 64 and 54 mg/L, respectively. Maximum values for these same constituents are 4600, 200, and 358 mg/L. Unfortunately, some of these high concentrations were the result of large quantities of waste milk dumped into wastewater stream. This waste milk (milk from treated or fresh cows) must be kept out of the waste stream because of the large impact it has on waste strength and the subsequent impact on the waste water treatment system. Typically, 8-16 liters (2-4 gallons) of milk per day will be in the effluent however, one treated or fresh cow will contribute 26-40 liters per day (7-10 gallons per day) of milk which will significantly overload any of the proposed treatment systems. (Milk has an estimated BOD_5 concentration of 100,000 mg /L, Wright and Graves, 1998).

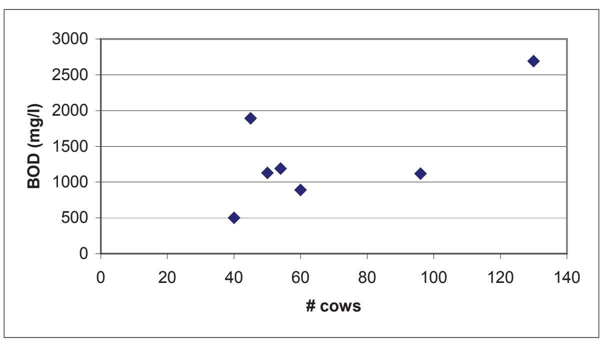

Figure 2. Average BOD_5 concentrations (10 to 15 monthly samples per farm) taken from outlet of primary septic tank.

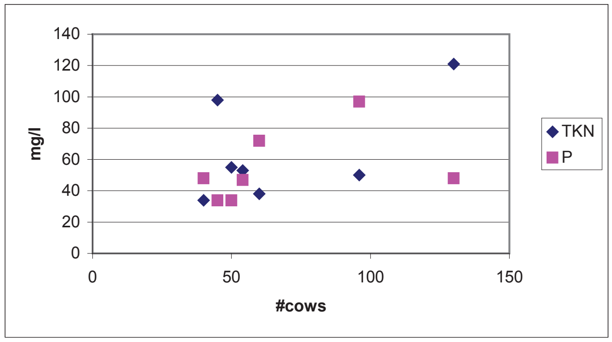

Figure 3. Average TKN and P concentrations (10 to 15 monthly samples per farm) taken from outlet of primary septic tank.

In general, the recommended design effluent concentration for BOD_5 is 1500 mg/L. This BOD_5 concentration is used in the design of the aeration systems, the recirculating media filtration system and the bark bed sizing. Annual production of nutrients is a critical design parameter for sizing of the irrigation system (figure 4). Average annual TKN and P production across all farms is approximately 0.4 kg/cow/yr (1 lb/cow/yr). Monitoring data also indicates that approximately 45% of this total nitrogen is in the ammonia form. Currently irrigation systems are designed on nutrient uptake by the crops as will be discussed in more detail below.

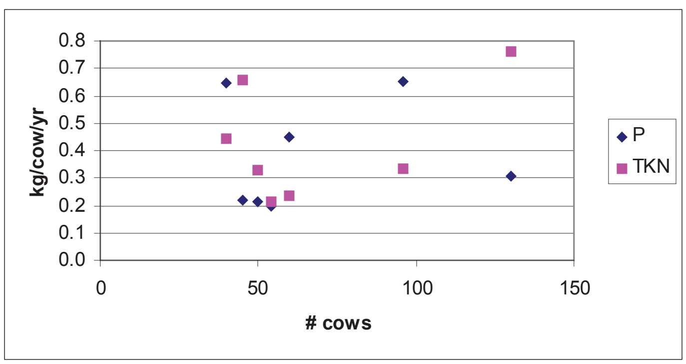

Figure 4. Average kilograms per year of nutrients produced (10-15 monthly samples per farm) taken from outlet of primary settling tank.

Specific System Design Criteria

Primary Treatment

All of the treatment systems options require a septic tank with inlet and outlet baffles. These tanks should meet all state-specific standards for construction or placement. This primary septic tank reduces settleable solids, fats, and grease. Another purpose of this primary septic tank is as a buffer between the final treatment system and the bulk tank should the entire bulk tank have to be dumped due to contamination. (If the bulk tank is contaminated and needs to be dumped, the septic tank can be pumped and then the bulk tank drained to the septic tank and the septic tank (with the waste milk) can be pumped again. This waste milk should be land applied.) The primary septic tank should be sized for a minimum of 3-day Hydraulic Retention Time (HRT) or the volume of the bulk tank whichever is greater. Effluent from the primary septic tank is pumped or flows by gravity into to the next phase of the treatment system. Tanks are typically installed with a minimum of 2 feet of soil cover over the top.

Bark Bed

A bark bed is a flat soil infiltration area covered with 50-75 cm (18-24 inches) of bark or wood shreds. This design allows good oxygen transfer to the effluent/soil interface which speeds the breakdown of the organic matter. The bark also keeps the infiltration area from freezing in northern climates and aids in evaporation of the effluent. Effluent is distributed to the soil infiltration area through a pressure distribution system. Figure 5 shows a schematic of a bark bed. Key to this design is the sizing of the soil infiltration area (area required) and effluent distribution system (pumps and pipes). Since this is a soil infiltration system, the bark bed should have a minimum separation distance to groundwater or bedrock of 60 cm (2 feet). This soil depth is needed to provide treatment of the wastewater.

The sizing of the soil infiltration area is based primarily on organic loading rate (BOD_5). Because soil plugging is a function of organic loading, an additional septic tank and commercial sized effluent filter installed after the primary septic tank is recommended. This additional treatment will lengthen the life of the soil infiltration area. Table 1 shows the recommended size of infiltration area needed based on the 1500 mg/l BOD_5, typical loading rates found in this study. These sizing factors are based on the soil texture and the ability of the soils to breakdown the organic matter and are approximately six or more that of typical home septic systems due to the higher organic loading. Multiplying the Soil Sizing Factor (SSF), found in Table 1, by the volume of effluent per day will give the area of soil infiltration are required.

Table 1. Soil Sizing Factors (SSF) based on 1500 mg/L loading rate. Use with caution – based on limited field data.

Soil Texture	Sizing Factor (m^2/100 Lpd)	Sizing Factor (ft^2/gpd)	Organic Loading Rate Maximum $kg/d/m^2$ $lbs/d/ft^2$
Coarse sand	11.5	5.0	0.01 (0.0020)
Medium sand, Loamy Sand	11.5	5.0	0.008 (0.0015)
Fine sand	23.0	10.0	0.006 (0.0012)
Sandy loam	17.5	7.6	0.006 (0.0011)
Loam	23.0	10.0	0.006 (0.0011)
Silt loam, silt	27.6	12.0	0.0035 (0.0007)
Clay loam, sandy clay, or silty clay	30.4	13.2	0.003 (0.0006)
Clay, sandy or silty clay	151.2	25.2	0.0025 (0.0005)

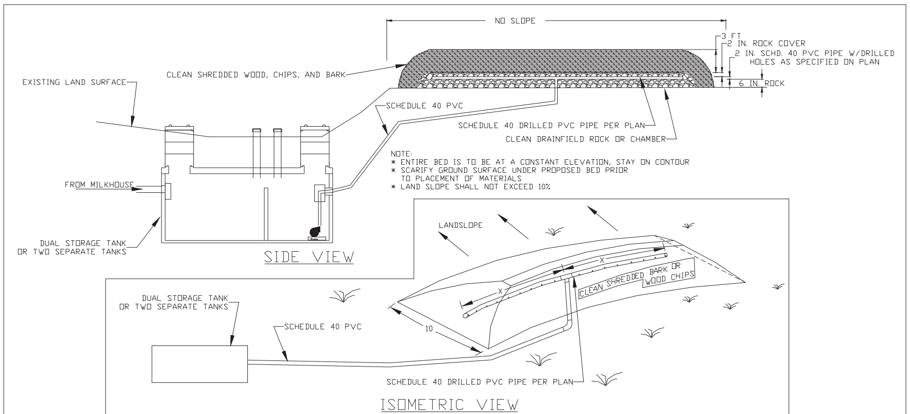

Fig. 5 MILKHOUSE WATER TREATMENT BARK BED SCHEMATIC

Data from this project and other previous studies (personal communication with Wisconsin researchers) indicates that effluent quickly moves downslope in a sloped bark bed or quickly channelizes in a level gravity flow system. This flow concentration results in effluent seeping out around the perimeter of the bark bed. To avoid this system failure, the soil infiltration area must be level and the effluent distributed through a pressure distribution system. The soil infiltration area can be in level strips along a contour or in one large flat area. Berms are not necessary around the infiltration area. The beds can be located in wooded areas or in open spaces. Large animals must be kept off the bark bed to avoid disturbing the bark and compacting the soil surface.

An effluent pump is used to supply the pressure distribution system. The pump is set in the pump compartment of a two compartment tank or in a separate tank. The pump tank must be sized for a 1-day HRT but is typically a minimum of 1900 liters (500 gallons). The pump is controlled by a high-low float with an alarm. A standard effluent pump can be used with the intake located a minimum of 15 cm (6 inches) off the bottom of the tank to avoid moving solids into the bark bed. The pump must be sized based on the pressure requirements of the system which include elevation, pressure losses in the pipe, and the required distribution pressure in the pipe (approximately 60 cm (2 ft) H_2O). Details on these calculations can be found in home septic system design manuals (http://septic.coafes.umn.edu).

Distribution of the effluent in the soil area can be done in two ways. Pressure distribution pipe can be laid on top of a gravel spreader (15-25 cm or 6-10 inches) of coarse gravel placed on the infiltration area or can be used with a chamber system. Gravel spreaders should be covered with a filter cloth to slow the plugging of the gravel by the bark. With the chamber, the distribution pipe is suspended at the top of the chamber with plastic ties. Large wide infiltration areas should be fed with multiple pressure pipes to insure even distribution. The pressure distribution will feed a soil area approximately 1.5 m (5 ft) wide on both sides of the distribution pipe. As such, spacing of these distribution lines should be at between 3 and 4 meters and bark should extend a minimum of 1.5 m (5 ft) on either side of the distribution lines. Hole sizing and spacing of these distribution pipes is a function of pressure and flow in the pipe and should be designed according standard methods found in septic system design manuals (http://septic.coafes.umn.edu).

It is critical to remember that the elevation of the pump tank and piping is such that the pipes can drain completely. Final slopes of 1% or more back to the pump tank are typical. The distribution system should also be set to dose the infiltration area at a minimum of once per day. During the winter months dosing less frequent than daily may result in a frozen system. During construction, heavy traffic on the soil infiltration area should be avoided. Once the distribution system is in place (either over the gravel spreaders or in the chambers) the bark or wood shreds are placed. There are currently no specific guidelines on the type of bark or wood shreds used. As discussed, the purpose of the shreds is to insulate the infiltration area, allow good oxygen transfer to the soil, and help evaporate some of the moisture. As such, the primary criteria is to have large pore spaces in the material. Breakdown of the wood material will occur over time reducing the porosity and restricting airflow. As such, hardwood bark or shreds are preferred to softwoods.

Irrigation

The irrigation system is also a large soil infiltration area where effluent distributed daily using a sprinkler system. Components of the irrigation system include a holding tank, pump, piping, and irrigation heads. Critical design inputs for the system are the effluent volume, nitrogen and phosphorus concentrations in the effluent, pump and piping requirements to meet the pressure needs of the irrigation heads, and elevations of all components to allow drainback (1% minimum). Figure 6 is a schematic of a typical irrigation system.

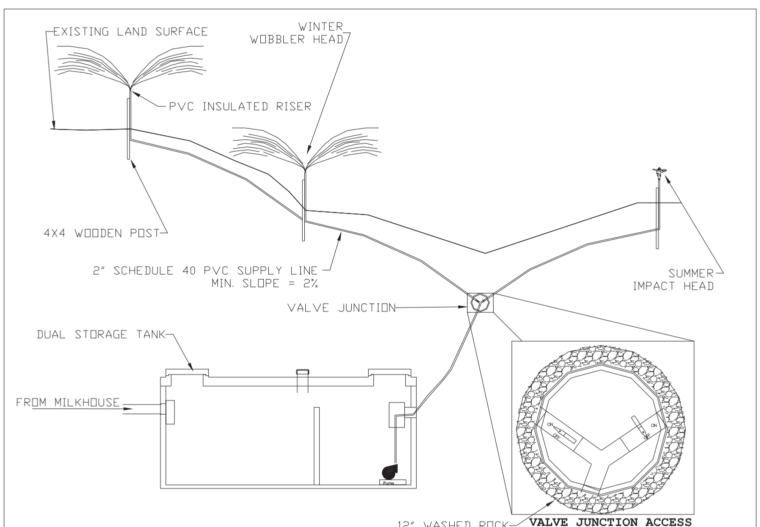

Fig. 6 MILKHOUSE WATER TREATMENT IRRIGATION SCHEMATIC

The primary design consideration for an irrigation system is the amount of pasture or cropland required for distributing and utilizing the nutrients in the effluent. These requirements could be based on either phosphorus (P) or nitrogen (N). Using the monitoring data from the current projects, one cow will produce approximately 0.55 kg/yr of P (1.2 lbs/yr) and 0.55 kg/yr of nitrogen (1.2 lbs/yr). However monitoring data indicates that approximately 45% of the total nitrogen in the effluent is in the ammonia form and will likely be lost through volatilization. This means approximately 0.30 kg (0.67 lbs) of nitrogen are available per year per cow.

Using these standard values for flow and concentrations the following equations can be used to determine approximate areas needed for nutrient distribution.

$A_P = 5500 / N_P \times \#cows$ (English units $A_P = 62400 / N_P \times \#cows$)

$A_N = 3000 / N_N \times \#cows$ (English units $A_N = 34000 / N_N \times \#cows$)

Where

- A_P and A_N are the area required for wastewater application in m^2 (ft^2) based on either P or N requirements
- N_P and N_N is the crop nutrient uptake in kg/ha (lb/acre) for P or N respectively.

The irrigation system typically is designed with more than one irrigation zone. Multiple zones are not required but allow flexibility in the distribution of nutrients and hydraulic loading of the irrigated zones. The zones can be managed for cropping or pasture needs allowing one zone to dry while applying on the other. Multiple zones also offers some backup should one zone fail by freezing or clogging. The total area of all the irrigation zones must be equivalent to the total area required based on the nutrient loading.

Irrigation zones are often designated by the type of irrigation head used. During the winter a Wobbler™ head is used. This is a frost proof head that emits effluent in a circular pattern with a diameter of approximately 15 m (50 ft). To date these heads have not frozen or clogged during winter application at the demonstration sites in Minnesota. Wobbler™ heads can also be used in the summer but typically a traditional impact head is used. Impact heads have a larger distribution area (30-45 m, 100-150 ft) which reduces the total number of irrigation heads and subsequent supply lines and riser pipes. Some types of impact heads also allow for part circle irrigation which allows for even greater flexibility in designing the irrigation zones. The performance data for the Wobbler™ and some select impact heads are given in Table 2. Design of these systems includes several calculations involving the balance of pressures and flows in the different zones along with the pump performance characteristics. A high-head effluent pump will typically meet the requirements of up to two impact heads or 10 Wobbler™ heads per zone.

Table 2. Performance data for select irritation heads (performance information reported in English units only)

Wobbler™ #18 purple 9/32 orifice						
psi	10	15	20	25	30	35
gpm	7.23	8.85	10.2	11.4	12.5	13.5
dia (3 ft ht)	52	54.5	55.5	56	56.5	57
Fluent-Master 4525-1-3/4", 0.25 inch nozzle (part circle)						
psi	30	35	40	45	50	-
gpm	9.4	10.2	10.9	11.5	12.1	-
dia (6ft ht)	110	114	116	118	120	-
Rainbird Part Circle 85EHD-LA 1-1/4 inch, 0/5 inch nozzle						
psi	25	30	35	40	45	-
gpm	33.8	37.1	40.1	42.9	45.6	-
dia (6ft ht)	120		142	150	154	-

Effluent from the primary septic tank flows (or is pumped) into a large holding tank that is used as a pump tank for the irrigation system. The holding tank should have enough capacity to hold 3 days of effluent in addition to the normal daily pumping volume. This additional storage capacity provides a margin of safety should a system failure occur or if irrigation needs to be suspended for crop harvesting. Once again, this holding tank (septic tank) must be constructed and placed according to state standards. The holding tank can be a single tank or additional tanks or tank compartments can be used to provide additional solids settling (primary treatment).

Effluent is pumped from this large holding tank through schedule-40 PVC distribution pipes and out through the irrigation heads using a high head effluent pump with high/low floats and a high-alarms system. A 24-hour timer is also recommended to allow for effluent pumping at a certain time of the day–either to avoid odor problems or to pump during the warm part of the day during winter months. The design pressure and flow for the system is a function of the number and type of irrigation heads used, the elevations of the heads, and friction losses in the pipes. The distribution pipe (typically 5-8 cm (2-3 in) diameter PVC pipe) is placed in trenches at a minimum soil depth of 45 cm (18 inches) to avoid freezing. Distribution lines must have a final minimum slope of 1% to insure drainback to pump tank. During construction the trenches for placing the distribution pipe should be excavated on a 2% grade to insure the minimum 1% final grade requirements are met throughout the pipe. Standard pressure pipe installation practices should be followed.

Irrigation heads are fed by riser pipes fed off the distribution lines. The Wobbler™ heads are fed with one-inch PVC riser pipes insulated with expanded foam. In the past, this foam has been protected by sliding 5 cm (2” PVC) pipe over the foam. This insulation provides some protection against frost. The elevation of these heads is not critical but typically the heads are placed above the maximum snow depth or 1.5 m (5-6 ft) above the soil surface.

The impact heads are fed with 5 cm (2 in) PVC pipe from the distribution lines. These are also mounted at 1.5 m (5-6 ft) or higher to allow for a greater spread diameter. Also, a high mounting height is critical when the effluent is being irrigated on a corn crop (head needs to be above the corn).

The riser pipe must be anchored to treated wooden posts set 1 m (3-4 ft) in the ground using galvanized pipe clamps. The soil around the posts must be well compacted or placed in concrete for maximum stability. This is especially critical for the impact heads.

Valves for controlling the irrigation zones must be accessible throughout the year and must be insulated or protected from freezing. Valves have been successfully located in the ground below the frost depth and accessed using a valve handle or through a large manhole (0.6 m (24 in) diameter) with a cover. Placing the valves on top of the septic tank cover and accessed via a manhole with cover is another viable option. Rigid foam can also be used to insulate the manhole if the valves are not set over the septic tank. There has been some evidence of rodent activity in one of the manholes with the valve assembly which could be prevented by backfilling around the outside with rock or gravel.

Aeration and Media Filtration

These treatment systems consist of a primary septic tank, the treatment unit (Aerobic Treatment Unit (ATU) or Recirculating Media Filter (RMF)) and a subsoil infiltration area. Both the ATUs and RMFs are designed to reduce the organic loading of the milkhouse waste down to levels similar to household septic waste (200 mg/L BOD_5). This reduction in wastewater strength allows the effluent to be distributed into a standard sized septic soil infiltration system. Therefore, the design of these systems is a function of wastewater strength and flow. To date, commercial ATUs and RMFs have been installed to accomplish this reduction in loading therefore calculations related to particular designs or sizing of these treatment systems are not included in this design guidance. Parameters for these designs, e.g. organic loading and flows, listed earlier in the paper, may offer commercial vendors more data to help in the appropriate sizing of treatment systems.

The ATUs are sized based on the required pounds of BOD_5 removal required per day and a hydraulic retention time in the ATU tank. The three types of ATUs used in this study had previous experience treatment wastewater from restaurants. This existing data was used to size the ATUs. At the beginning of this study little information was available about the waste strength exiting a primary treatment tank therefore estimates were made. On several of the sites the organic loading estimate was much lower then the actual loading.

RMF provide biodegradation or decomposition of wastewater constituents by bringing the wastewater into close contact with a well developed aerobic biological community attached to the surfaces of the filter media. The RMFs in this study use expanded polystyrene as the media. Gravel (3/4 to 2 ½ inch) is another option in RMF receiving high strength waste effluent. The RMFs are sized based on organic loading to the filter on a area basis of 5 mg BOD_5/cm/day (0.0096 pounds BOD_5/ft/day).

The media is contained in a watertight vessel either below the surface of the ground or wholly or partially elevated in a containment vessel. Proper function requires that influent to the filter be distributed over the media in frequent, cycled, uniform doses. In order to achieve accurate dosing, these systems require a timer controlled pump with associated pump chambers, electrical components and distribution network. This frequent, cycled dosing provides a constantly wetted media. The effluent is collected in the bottom of the filter and returned to the recirculating/mixing tank where it mixes with fresh septic tank effluent or a portion of the effluent is discharged to the final disposal component. Flow splitting mechanisms are used to control recirculation, flow splitting and discharge to the final disposal component. The treated wastewater is discharged to an approved final treatment/disposal component, usually a conventional sub-surface drainfield.

The soil treatment system following a ATU or RMF should have 60 cm (2 feet) of separation below the bottom of the system to the seasonally high water table or bedrock. This separation is critical to remove the remain organics and nutrients in the wastewater as well as assure the system functions hydraulically.

Table 1. Soil sizing factors (SSF) based on 1500 mg/l loading rate. (University of MN Septic Design Manual, http://septic.umn.edu/Professional/Worksheets/worksheets.htm)

Soil Texture	Sizing Factor (m^2/lpd)	Sizing Factor ft^2/gpd
Coarse sand	2.2	0.83
Medium sand	2.2	0.83
Loamy sand	2.2	0.83
Fine sand	4.3	1.67
Sandy loam	3.3	1.27
Loam	4.3	1.67
Silt loam, silt	5.2	2.00
Clay loam, sandy clay, or silty clay	5.7	2.20
Clay, sandy or silty clay	10.9	4.20

Selecting the Right System

Initial design calculations and interviews with farmers often result in reducing the number of potential type of treatment options available. Sites with high water table or limited soil depth to bedrock may limit the use of bark beds or the aerobic or gravel filter systems that discharge into subsoil infiltration areas. Some farm sites may not have enough available area for an irrigation system or site elevations do not allow for proper draining of the distribution pipe. Some system have been located over 100 m (330 ft) from the milk house because of site conditions. At times, all treatment systems may be viable and then the choice is up to the farmer. In some cases, a combination of systems may be appropriate. This combination might include a bark bed for winter and an irrigation system for the summer. This type of system would make some of the nutrients available for crop production and preserve the life of the bark bed. These combination designs are more difficult because of the different piping and pumping requirements for the different systems. They are likely more expensive than a single system. In general, the following considerations are key in choosing the appropriate system.

- Available area
- Depth to bedrock or water table
- Site elevations to allow for system drainback
- Milkhouse line elevation
- Soil texture
- Distance to surface water (a limitation of the irrigation system for spring runoff)
- Capital investment
- Operating cost
- Operation and maintenance requirements

System Economics

Unfortunately, limited information is available related to system economics. The systems currently installed were experimental and costs were highly variable. Table 3 lists the range of capital costs for the different system– both the total and the cost per cow. This variability is a function of site specific challenges with each of the systems. The wastewater flow volume has some influence as does the distance from the milk house to the treatment system. Other variable economic factors include electricity, pumping or gravity flow, additional septic tanks enhance pretreatment, and site preparation.

Table 3. Capital Investment for systems installed.

System Type	# cows	Cost	Cost/cow
ATU	60	$6,700*	$120
RMF	60	$13,000	$220
RMF	60	$16,000	$270
Bark Bed	60	$6,300	$105
Irrigation (includes parlor)	100	$10,000	$100
Irrigation	60	$6,800	$115
Aeration and Irrigation (includes parlor)	130	$25,000	$190

* Cost does not include a drainfield.

Operation and Maintenance

All of the systems require some operation and maintenance. The primary requirements are the pumping of the septic tanks and all treatment or holding tanks. Excessive buildup of solids in these tanks allows those solids to move into the secondary treatment or to the soil infiltration area. These systems are not designed for this additional loading. Septic tanks should be pumped on an annual basis and more frequently if solids are a problem. Monthly inspections of the tanks for scum and sludge buildup aids in determining when the tanks should be pumped. Solids of 18 inches or more on the bottom of the tank or a scum layer of 4-6 inches indicates it is time to pump the tank. This effluent can be land applied. An effluent filter can also be installed in outlet of the primary septic tank to reduce the loading on the secondary treatment system. This filter should also be checked and cleaned monthly.

Another management item discussed previously is the diversion of all waste milk (milk from treated and fresh cows) from the system. It is critical that all employees know that waste milk cannot enter the treatment system. Plumbing within the milk house will facilitate the diversion of this waste milk from the system. Rodent control may also be needed in valve boxes or in Bark Beds.

Beyond these operation and maintenance required for all systems are the system specific items. They are as follows:

- Bark Bed – Inspect for seepage around the perimeter of the bark bed. If necessary add additional bark. Over time, the bark will decompose and additional bark will be needed to maintain adequate cover over the soil infiltration area both to protect and insulate the soil.

- Irrigation – Irrigation zones must be adjusted for summer and winter operation or if soils become saturated. Monthly checks to make sure irrigation heads are not plugged and no concentrated flow is occurring.

- ATU or RMF – The life of the soil infiltration area following the ATU or RMF is directly related to the treatment efficiency. Monthly visual observations of the effluent will help indicate the performance of the unit. Semi-annual testing of the effluent will document system performance. BOD_5 concentrations in this effluent should remain below 200 mg/L. Other maintenance requirements may be recommended by the specific vendor.

Conclusions

Several treatment options for milk house waste are being evaluated. As with any waste handling system, not all options are suitable on all sites. Also, these options all require a capital investment and operation and maintenance. The design guidance provided in this document will assist in the selection and proper design of options that are currently available. Over time it is anticipated that more options will become available and more detailed and specific design guidance given on these existing options.

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Milk House Wastewater Flows and Characteristics for Small Dairy Operations

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Abstract. *Water meters were used to indicate milk house wastewater flow rates in the milk houses of 16 dairy operations with between 41 and 130 milking cows. Wastewater samples (7 to 21) were taken from the first septic tank providing primary treatment of the milk house water to measure pH, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), fats, oils and grease (FOG), total phosphorus, total Kjeldahl nitrogen (TKN), and ammonia nitrogen concentrations. Average water flow rates across the 14 dairy operations without parlors ranged from 8.6 to 35.3 L/d/cow. Milk house water use per cow per day on individual farms varied by between 146% and 400%. Overall average BOD_5 concentration across all sixteen operations was 1.44 g/L while individual farm averages ranged from 0.50 to 4.52 g/L. Overall average COD concentration was 2.26 g/L; farm averages ranged from 0.72 to 6.28 g/L. Overall average TSS concentration across all operations was 686 mg/L, farm averages ranged from 181 to 1,537 mg/L. Average FOG concentration was 477 mg/L, farm averages ranged from 45 to 1,334 mg/L. Median average pH level was 6.8, farm levels ranged from 5.9 to 8.0. Average phosphorus concentration across all operations was 56 mg/L, farm averages ranged from 18 to 101 mg/L. Average TKN concentration was 81 mg/L, farm averages ranged from 33 to 179 mg/L. Average ammonia concentration was 34 mg/L, farm averages ranged from 12 to 98 mg/L. Based on these results the authors recommend using 19 L/d/cow for the design milk house wastewater flow rate for milk houses for dairy operations with 130 or fewer cows. For sizing aerobic treatment units and infiltration systems, the authors recommend using 1.5 g/L for the design effluent BOD_5 concentration for a milk house only. For designing irrigation land application systems based on annual TKN and P per cow for milk house only sites, the authors recommend using 0.6 and 0.35 kg/cow/yr, respectively.*

Keywords. *Dairy, Wastewater, Milk house, Waste.*

Dairy producers that handle manure as a solid need environmentally sound techniques to handle their milk house wastewater. Dairy producers in Minnesota are not allowed to discharge untreated milk house wastewater to "waters of the state" (Minnesota Chapter 7020, 2003). Dairy producers with limited liquid manure storage capacity are also interested in options for handling milk house wastewater.

Systems for handling milk house wastewater include short- or long-term liquid storage followed by application to cropland, septic systems with soil infiltration field, constructed wetlands, grass filter strips, organic or bark bed filter systems, spray irrigation, lime flocculator with soil infiltration and aerobic treatment systems (Springman et al., 1995; Wright and Graves, 1998). Wastewater handling systems with septic tanks followed by soil infiltration have not been successful long term because of the high concentrations of fats and organic material in the waste going to the infiltration areas (Zall, 1972).

Milk house wastewater flow rates and characteristics are important inputs for the design of wastewater handling systems. Wastewater flow rates are a primary design factor for sizing treatment elements and land application or infiltration areas. The importance of wastewater characteristics depends on the specific system selected. BOD_5 concentrations are critical for sizing aerobic systems and soil infiltration areas but are not critical for sizing a surface irrigation system. Irrigation system design is based on annual nitrogen and/or phosphorus loading and application on cropland or pasture. Limited design and management information suggested a need for a study to measure milk house wastewater flows and characteristics.

This report summarizes the milk house wastewater flow and characteristics measured on 16 Minnesota dairy operations with between 41 and 130 cows being milked using pipelines, flat parlors, or parlors washed down after use. The results are compared with published milk house wastewater information.

Milk House Wastewater

Milk house wastewater system design depends on wastewater flow, organic loading, nutrient concentrations and other wastewater characteristics, climate, soil characteristics, site characteristics and management preferences. The wastewater flow depends on the milking system, cleaning

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methods, manure handling where the cows are milked, and other management factors.

Most milk house wastewater is wash water generated while cleaning milking units, milk pipelines, receiver, and bulk tank. Milking system cleaning produces a large volume of wastewater, which can account for up to 30% of the total wastewater volume from a dairy farm (Wright and Graves, 1998). The milking units and pipeline are cleaned either two or three times per day depending on the milking schedule. The bulk tank is cleaned immediately after the tank has been emptied, typically once per day or once every other day. Wash water includes cleaning agents and residual milk which remains in the pipeline, receiver jar, and bulk tank after emptying.

The typical milking equipment cleaning regime has four cycles. (Malcom et al., 1998; Harvard, 2002). The first rinse cycle is performed immediately following the milking process using fresh water. It washes out most of the excess raw milk remaining in the lines. This rinse usually removes up to 92% of the suspended solids (Harvard, 2002). The second cycle is a detergent wash, which immediately follows the first rinse. It removes attached organic material using hot water and an alkaline detergent. The amount of active chlorine is 100 mg/L (Harvard, 2002). The amount of detergent added to the solution depends on water hardness and should create a solution with a pH greater than 11. The third cycle is an acid rinse, which follows the detergent wash. It removes inorganic deposits from the piping, neutralizes the alkaline detergent residues, and lowers the pH to around 3.5 to prevent bacteria from developing (Harvard, 2002). The final cycle is a sanitizing rinse performed immediately before the beginning of milking to ensure that the milk pipelines are free of microorganisms that may have formed since the acid rinse. The sanitizer is usually chlorine-based with recommended chlorine content of 200 mg/L (Harvard, 2002). Sherman (1981) concluded that cleaning chemicals, especially detergents and acid rinses, could account for a majority of the phosphorus in milk house wastewater, with the amount on a given farm highly dependent on the daily cleaning practices.

Several studies have reported milk house wastewater characteristics (Loehr and Ruf, 1969; Allen et al., 1973; Millen et al., 1977; Malcolm et al., 1998; Teague and Gross, 2001). Table 1 summarizes the range of reported values.

Table 2 gives the wastewater flow and characteristics for dairy milk houses and milking centers with parlors and holding areas commonly used for design (NRCS, 1992; Wright and Graves, 1998; Lorimor et al., 2000). The water flow values may vary by up to 500% (Wright and Graves, 1998).

Methods and Materials

Sixteen dairy farms in four Minnesota counties (Carver, Goodhue, Winona, and Wright) participated in two grant funded projects reported here. Local technical advisory groups were established for each project. The advisory groups included representatives from the county environmental services agencies, dairy industry representatives, Extension and Natural Resources Conservation Service (NRCS).

Potential cooperating dairy producers were identified by the advisory group members. Producers interested in the project and willing to participate were visited to discuss milk house wastewater treatment system options. The producers selected were expecting to continue operation for five years or more, did not have liquid manure storage for handling their milk house wastewater, and were willing to have one of the treatment systems that the local technical advisory groups had decided to install and monitor for the project. Water use and wastewater characteristics data were collected between December 2002 and November 2004 for the first project and between December 2004 and October 2006 for the second project.

Water meters (Model 25 Recordall®, BadgerMeter, Inc., Milkwaukee, Wis.) were installed on all 16 farms. Care was taken when placing the water meters in the milk house waster supply lines to provide an accurate estimate of the wastewater flow. Most farms had faucets in the milk house that provided water used for other purposes such as mixing of milk replacer for the calves, washing of tractors or farm

Table 1. Published research dairy milk house wastewater characteristics (Loehr and Ruf, 1969; Allen et al., 1973; Millen et al., 1977; Malcolm et al., 1998; Teague and Gross, 2001).

Component	Range of Data in Literature
Total suspended solids (mg/L)	525-7,787
Biochemical Oxygen Demand (BOD_5) (mg/L)	84-9,700
Chemical Oxygen Demand (COD) (mg/L)	1,500-3,100
Total Kjeldahl Nitrogen (TKN) (mg/L)	20-445
Total phosphorus (mg/L)	33-99
Oil and grease (mg/L)	284

Table 2. Published dairy milk house and milking center wastewater characteristics used for design (NRCS, 1992; Wright and Graves, 1998; Lorimor et al., 2000).

Component	Units	Milk House	Milk House and Parlor	Milk House and Parlor with Holding Area Manure Excluded	Milk house and Parlor with Holding Area Manure Included
Volume	L/d/cow[a]	8.7	24	56	64
Moisture	%	99.72	99.40	99.70	98.50
Total solids	% wet basis (wb)	0.28	0.60	0.30	1.50
Volatile solids	g/L	1.54	4.19	2.19	12.0
COD	g/L	3.03	5.00	–	–
BOD_5	g/L	–	1.00	–	–
Nitrogen	mg/L	86	200	120	900
Phosphorus	mg/L	69	99	28	99
Potassium	mg/L	180	300	68	400

[a] 635-kg cow body weight.

implements, or filling of fertilizer or herbicide tanks. Cooperating producers recorded the amount of water used for these other purposes on a note pad by the flow meter. These other flows were subtracted from the total daily or quarterly flows. On most farms the majority of water used in the milk house passed through a water softener so this was often the best location to install the flow meter. Two months of weekly flow data was used to estimate wastewater flows initially. After the first two-month period, meters were read monthly for a year and at variable times during the second and third year of each project.

Wastewater samples were taken from the first septic tank after the milk house on each farm using tubing and a battery-powered peristaltic pump. Samples were taken from between the scum layer and settled sludge in the tanks through access holes in the tops of the tanks either over the middle of the tank between the effluent inlet and outlet or over the outlet. Samples were taken from the first septic tank because milk house wastewater has varying characteristics because of the different equipment wash cycles and water use patterns. Samples from the first septic tank between the floating scum and the settled solids represented the effluent entering the remaining treatment system. After collection the filled wastewater sample containers were immediately placed in coolers with ice and transported to a commercial laboratory for analysis within 24 h. The samples were analyzed for biochemical oxygen demand (BOD_5) using method SM 5210-B (APHA, 1998); chemical oxygen demand (COD) using EPA 410.4 (EPA, 1993a); total suspended solids (TSS) using SM 2540-D (APHA, 1998); fats, oil, and grease (FOG) using EPA 1664A (EPA, 1999); total phosphorus as phosphate (P_2O_5) using EPA 365.1 (EPA, 1993b); total ammonia nitrogen (NH_3) using SM 4500-NH_3 B,E (APHA, 1998); total Kjeldahl nitrogen (TKN) using SM 4500-N_{org} and 4500-NH_3 B,E (APHA, 1998); and pH using SM 4500-H^+ (APHA, 1998).

Septic tank capacities varied by farm and were recorded. Wastewater temperature in the sample containers was measured using a thermocouple and handheld digital display before they were put on ice.

Results

Water flow data and wastewater samples collected in the first study were collected between December 2002 and November 2004. Data for the second study were collected between December 2004 and October 2006. Monitoring periods varied from 270 days to 675 days with between 6 to 19 samples taken at each site (table 3).

Table 3 lists number of cows milked, milking system, first septic tank volume, sampling period, number of readings, average daily water flow, water flow ranges and average water flow per cows milked for the participating dairy operations. Milking cow numbers ranged from 41 to 130 cows. All of the farms milked cows twice a day. Constant cow numbers were used in the analysis even though the number of cows milked varied slightly during the study as cows freshened and were dried off. All of the stanchion / tie stall barns used pipeline milking systems throughout the barn while the flat parlors had shorter pipeline systems. Manure in the flat parlors was handled as a solid so no manure was washed into the milk house wastewater treatment system from the flat parlor floor. Two farms (i.e. #15 and #16) had milking parlors that were washed with a high-pressure hose-end sprayer so their wastewater flows included both milk house and parlor wash water.

Water Flow

Daily water flow data from this study indicated that the amount of wastewater generated from the milk house varied from sampling period to sampling period on a given farm and between farms depending in part on management. Average daily water flow rates ranged from 0.52 to 4.21 m^3/d. Daily water flow rates based on water meter data from between 1 and 4 months across all of the farms ranged from 0.34 to 5.84 m^3/d. Standard deviations ranged from 0.08 to 1.04 m^3/d but most were between 0.08 and 0.53 m^3/d. Two farms had 41 and 42 cows but used more water per day (1.43 to 1.45 m^3/d) than farms with 45 to 65 cows, which had water use rates from 0.5 to 1.2 m^3/d. Farms with more than 90 cows had water use rates from 1.7 to 4.2 m^3/d.

Average water flow rates per day per cow across the 14 farms with pipelines or flat parlor milking systems ranged from 8.6 to 35.3 L/d/cow. The median average flow rate was approximately 17.1 L/d/cow. Standard deviations ranged from 1.1 to 11.2 L/d/cow. The farms with 41 and 42 cows had the highest water flow rates per cow, 35.3 and 34.1 L/d/cow, respectively, among the 14 farms with pipelines or flat parlor milking systems. The other 12 farms had water flow rates per day per cow from 8.6 to 21.5 L/d/cow.

The two operations with milking parlors used 24.2 and 42.1 L/d/cow in the milk house and parlor. These milking parlor rates bracketed the water use rates of the farms with 41 and 42 cows but were more than the 12 other farms with pipelines and flat parlor milking systems. No consistent relation was seen between the flow rate per day per cow and cow number.

Milk House Wastewater Characteristics

Mean and standard deviation data for the 16 farms monitored are presented in tables 4 and 5. Average BOD_5 concentrations of the milk house wastewater in the first septic tank on each farm ranged from 0.50 to 4.52 g/L (table 3). The overall average across all 16 operations was 1.44 g/L and the median value was around 1.14 g/L. Mean BOD_5 levels observed in this study were similar to those reported in other studies. Weil (1991) reported a value of 1.53 g/L and Springman et al. (1995) reported an average of 2.09 g/L and values ranging from 0.08 to 9.70 g/L. These results were similar to the 1.0 g/L for milk house and parlors in table 1. BOD_5 concentrations are used for designing aerobic treatment systems. The average annual amount of BOD_5 per cow was 11.1 kg BOD_5/cow/yr based on the concentration in the first septic tank, the water flow rate, and number of cows milked.

Mean COD levels in the first septic tank ranged from 0.72 to 6.28 g/L (table 4). The overall average across all operations was 2.26 g/L and the median mean was approximately 1.7 g/L. The average COD level was 2.19 g/L for the 14 operations with only milk house wastewater (farms #1-#14). These COD concentrations are similar to the design levels, 3.0 and 5.0 g/L for milk house only and milk house and parlor, respectively, reported by others (table 2).

Table 3. Cooperating farm information and water use data.

Farm	Cows Milked	Milking System	First Septic Tank Compartment Volumes (m^3)	Sampling Period (month/year) (days)	No. of Readings	Average Daily Water Flow (m^3/d) (standard deviation)	Water Flow Range (m^3/d) (low-high)	Average Water Flow per Cow (L/d/cow) (standard deviation)	Water Flow Rate per Cow Range (L/d/cow)
1	41	Pipeline	3.8	03 Apr - 04 Nov (550)	13	1.45 (0.20)	1.17-1.95	35.3 (4.9)	28.5-47.6
2	42	Pipeline	1.9	03 Feb - 04 Nov (620)	13	1.43 (0.47)	0.90-2.29	34.1 (11.2)	21.3-54.5
3	45	Pipeline	3.8/1.9	03 Jan - 04 Nov (675)	19	0.80 (0.10)	0.68-1.03	17.8 (2.3)	15.2-22.8
4	50	Pipeline	3.8	02 Dec - 04 Nov (674)	14	0.86 (0.33)	0.46-1.86	17.2 (6.6)	9.3-37.2
5	54	Pipeline	3.8	03 Oct - 04 Nov (372)	9	0.63 (0.08)	0.56-0.82	11.6 (1.4)	10.4-15.1
6	60	Flat parlor	1.9	03 Jan - 04 Nov (649)	14	1.02 (0.18)	0.86-1.44	17.1 (3.0)	14.3-24.1
7	96	Flat parlor	2.3/3.8	03 Aug - 04 May (270)	9	1.74 (0.11)	1.60-1.91	18.1 (1.1)	16.6-19.9
8	130	Pipeline	2.8	02 Dec - 04 Nov (675)	19	2.31 (1.04)	1.32-5.05	17.8 (8.0)	10.1-38.8
9	50	Pipeline	3.8/1.9	06 Apr - 06 Oct (187)	6	0.65 (0.18)	0.45-0.88	13.0 (3.6)	8.9-117.6
10	55	Pipeline	7.6	04 Dec - 06 Oct (671)	15	1.18 (0.53)	0.69-2.13	21.5 (9.6)	12.5-38.7
11	56	Pipeline	3.8/1.9	04 Dec - 06 Oct (671)	14	0.89 (0.16)	0.68-1.15	15.8 (2.8)	12.2-20.6
12	60	Pipeline	3.8	04 Dec -06 Oct (671)	15	0.52 (0.09)	0.34-0.77	8.6 (1.5)	5.6-12.9
13	60	Pipeline	3.8	04 Dec - 06 Oct (671)	15	0.77 (0.10)	0.65-1.00	12.8 (1.7)	10.9-16.6
14	65	Pipeline	4.7	06 Jan - 06 Oct (271)	7	0.95 (0.22)	0.82-1.43	14.6 (3.4)	12.6-22.1
15	100	Parlor	5.7	04 Dec - 06 Oct (671)	15	4.21 (0.79)	3.29-5.84	42.1 (7.9)	32.9-58.4
16	130	Parlor	7.6	04 Dec - 06 Oct (671)	15	3.15 (0.66)	2.52-5.40	24.2 (5.1)	19.4-41.5

Mean total suspended solids concentrations in the first septic tank ranged from 181 to 1,537 mg/L (table 4). The average across all operations was 686 mg/L and the median mean was 400 mg/L. Weil (1991) reported suspended solids of 996 mg/L for milk house wastewater.

Mean fats, oils, and grease concentrations in the first septic tank ranged from 45 to 1,334 mg/L (table 4). The average across all operations was 320 mg/L and the median mean was approximately 150 mg/L. Weil (1991) reported an oil and grease concentration of 330 mg/L for milk house wastewater. The average annual total fats, oils, and grease leaving the first septic tank per cow was 2.35 kg/cow/yr.

The mean farm wastewater pH in the septic tanks ranged from 5.9 to 8.0 (table 4). The median average pH level was 6.8.

Mean phosphorus concentrations ranged from 18 to 101 mg/L (table 4). The average across all operations was 56 mg/L and the median average was approximately 47 mg/L. Published design values in table 1 are 69 and 99 mg/L for milk house only and milk house plus parlor wastewater. The average annual total phosphorus produced per cow was 128 kg/cow/yr.

Mean TKN concentrations ranged from 33 to 179 mg/L (table 5). The average across all operations was 81 mg/L and the median average was 56 mg/L. Ammonia concentrations ranged from 12 to 98 mg/L. The average ammonia concentration across all of the operations was 34 mg/L and the median average was approximately 25 mg/L. Design values in table 2 are 86 and 200 mg/L for milk house only and milk house plus parlor wastewater. The average annual TKN produced per cow was 227 kg/cow/yr.

Discussion

Water Flow

Wastewater flow is a critical design parameter for milk house wastewater systems. Properly placed water meters were an effective way to determine milk house water use and estimate wastewater flow. Only one dairy, farm #12, in the study had a mean measured water flow rate (8.6 L/d/cow) which was less than the published design flow rate of 8.7 L/d/635 kg cow for the milk house in table 2. The other 13 non-parlor dairy operations in this study had flow rates between 130% and 410% of the published design rate

Table 4. Mean and (standard deviation) of measured milk house wastewater characteristics.

Farm	No. of Samples	BOD_5 (g/L)	COD (g/L)	Total Suspended Solids (mg/L)	Fats, Oils, and Grease (FOG) (mg/L)	pH
1	15	0.50 (0.47)	0.72 (0.68)	215 (193)	86 (128)	7.0 (0.7)
2	12	4.52 (3.85)	6.28 (4.43)	1537 (1283)	1334 (951)	5.9 (0.9)
3	18	1.89 (0.72)	2.88 (1.32)	955 (965)	526 (510)	6.3 (0.3)
4	16	1.15 (0.45)	1.72 (0.78)	485 (263)	355 (298)	6.8 (0.3)
5	12	1.19 (1.06)	1.53 (0.97)	426 (272)	348 (432)	7.1 (0.4)
6	11	0.89 (0.29)	1.28 (0.44)	352 (116)	177 (78)	6.7 (0.5)
7	20	1.15 (0.57)	1.69 (0.81)	407 (200)	230 (162)	6.8 (1.0)
8	21	2.65 (1.20)	4.22 (1.64)	1015 (541)	852 (652)	6.2 (0.7)
9	13	0.79 (0.46)	1.16 (0.76)	181 (86)	68 (45)	7.5 (0.7)
10	14	0.82 (0.35)	1.19 (0.25)	396 (267)	127 (73)	6.7 (0.3)
11	7	0.67 (0.32)	0.92 (0.57)	216 (109)	88 64	6.5 0.2
12	14	1.06 (0.55)	1.73 (1.15)	339 (301)	100 74	7.2 0.5
13	14	1.34 (0.63)	1.84 (0.99)	375 (266)	67 (27)	6.3 (0.3)
14	7	0.54 (0.39)	0.99 (0.54)	225 (79)	45 (20)	8.0 (1.3)
15	14	1.13 (0.34)	2.30 (0.49)	862 (906)	100 (53)	7.1 (0.7)
16	13	1.75 (0.86)	3.34 (1.34)	698 (370)	186 (171)	6.8 (0.3)
All sites	221	1.44 (1.42)	2.26 (1.99)	580 (632)	320 (484)	6.8 (0.8)

(table 2). Wright and Graves (1998) noted that water use can vary by up to 500%. Milk house water use across the 14 dairy operations without parlors ranged from 8.6 to 35.3 L/d/cow, more than 411%. Water use at each farm varied by between 146% (farm #5) and 400% (farm #4).

One dairy operation with a parlor, #16, had a water use rate very near the 24 L/d/635 kg cow for a milk house and parlor listed in table 2. The other dairy operation with a parlor, farm #15, used 75% more water per day per cow.

Table 6 compares the mean measured water use rate from the 14 dairy operations with milk houses only to the published design water volume in table 2. Average water use by the 14 milk house only systems (18.7 L/d/cow) was over 200% the published design value (8.7 L/d/cow). Wastewater flow rates are very important for designing milk house wastewater treatment and land application systems expected to perform effectively for 10 or more years.

Milk house wastewater flows can be estimated through a farmer interview about water usage and completing a worksheet (Wright and Graves, 1998). A rough estimate of water use can be made knowing the volume of each pipeline and bulk tank wash and rinse cycle and water usage for other activities such as a washing machine or water softener. If these values are not known, guessed values can be used based on worksheet suggestions. Estimated water flows based on interviews for farms 1 through 8 did not correlate well with measured flows. The interviews did not provide information for good estimates. While these predicted flows can be used as a starting point in wastewater system design, our experience suggests that a well placed water meter monitored weekly for two months provides more reliable water use data. Continued monitoring of water flow should also be part of the operation and maintenance of a milk house wastewater system to determine if flows begin to exceed design values.

Another option for estimating wastewater flows, better than the farmer interview but not as good as installing a flow meter, is to use a standard conservative estimate of flow based on this study. Based on this study the authors recommend using 19 L/d/cow as the design wastewater flow rate for milk houses for dairy operations with 130 or fewer cows. Eleven out of the 14 dairy operations had average water use rates below the 19 L/d/cow level. Sixty eight percent of the 184 individual water flow rates obtained from the 14 dairy operations monitored for this study were below the recommended design water flow rate. It is noted that this

Table 5. Mean and (standard deviation) of milk house wastewater characteristics.

Farm	No. of Samples	Phosphorus (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)
1	15	47 (27)	33 (33)	19 (24)
2	12	59 (29)	179 (140)	12 (8)
3	18	34 (6)	98 (42)	42 (34)
4	16	35 (9)	56 (20)	22 (11)
5	12	47 (21)	53 (33)	24 (16)
6	11	72 (23)	38 (15)	15 (17)
7	20	101 (70)	50 (29)	24 (22)
8	21	47 (14)	121 (39)	19 (14)
9	13	18 (10)	44 (25)	28 (23)
10	14	64 (21)	46 (16)	26 (22)
11	8	87 (18)	55 (37)	27 (12)
12	14	39 (18)	83 (22)	52 (21)
13	14	35 (5)	89 (40)	61 (34)
14	7	28 (19)	43 (37)	16 (18)
15	14	20 (4)	110 (32)	45 (29)
16	13	45 (32)	174 (67)	98 (52)
All sites	223	49 (35)	81 (62)	34 (32)

wastewater flow rate is more than twice the published rate for milk house only in table 2.

Data from only two dairy operations with parlors was deemed an insufficient sample size to recommend a design wastewater flow rate combined milk house and parlor operations.

Hydraulic retention times through the first septic tank chamber ranged from 1.2 d for farm #8 to 7.4 d for farm #12. The average hydraulic retention time was 3.8 d. Hydraulic retention times would be expected to decrease as the scum layer and settled solids accumulate in the first septic tank.

Milk House Wastewater Characteristics

Accurate sampling of the milk house effluent was a significant challenge. Direct sampling from the floor drain (where all of the wastewater must flow) seemed logical but proved excessively challenging due to the intermittent and diverse nature of the effluent flows. Each part of the milking system wash cycle had different waste characteristics. Other effluent flows include water from washing the milk house floor and other equipment or boots. Trying to estimate "average" waste characteristics by discrete sampling of these widely varying effluent flows and concentrations was deemed too complicated for this study.

Table 6. Published milk house wastewater characteristics (tables 1 and 2) compared to measured mean and (standard deviation) values from 14 dairies monitored with milk houses only.

Component	Units	Literature Data Range (table 1)	Published Milk House Only Characteristics (table 2)	Study Average
Volume/Water use	L/d/cow[a]	–	8.7	18.7 (9.3)
COD	g/L	1.5-3.1	3.03	2.01 (1.52)
BOD_5	g/L	0.08-9.7	–	1.37 (1.07)
Nitrogen/ TKN	mg/L	20-445	86	71 (40.4)
Phosphorus	mg/L	33-99	69	51 (23.3)
Total suspended solids	mg/L	525-7,787	–	509 (390)
Fats, oil & grease	mg/L	284	–	314 (370)

[a] 635 kg cow body weight.

Since all of the treatment systems had septic tanks to provide primary treatment, the septic tank represented an integrated sampling location. Experience prior to initiation of this study suggested that the septic tank samples need to be taken from between the scum layer and the settled solids in the septic at either the outlet or middle of the tank. Sampling at the septic tank inlet was avoided because the sample could contain the cleanest wastewater from the acid rinse step of the pipeline and bulk tank washing regime. The first rinse would be expected to contain most of the residual milk and milk has a BOD_5 level around 100,000 mg/L (Loehr, 1974; Wright and Graves, 1998). Wastewater from later rinses would be expected to have less organic matter.

Septic tanks provided primary treatment where soaps, bedding material, milk fats, and other materials that can float to the top form a scum layer while heavier materials including floor lime, dirt, and biomass can sink and accumulate in a sludge layer. Sampling in the septic tank allowed the milk house wastewater to receive some primary treatment before the samples were collected for analysis. The septic tank concentrations, which had this primary treatment, provide good values for designing milk house wastewater treatment system, assuming that all systems will have septic tanks for primary treatment.

The cooperating producers were requested to not put colostrum and waste milk down the milk house wastewater drain because the treatment systems were not designed to handle the organic load of waste milk. One dairy operation had an undersized pipeline which led to milk being collected in the sanitary trap daily, which was initially allowed to go down the drain. Plumbing was added later to redirect the milk to the gutter. Occasionally producers put waste milk down the drain so some wastewater samples presumably had very high BOD_5 and COD levels because of waste milk. These samples were retained in the data since it was not possible to determine which contained waste milk.

Table 6 summarizes select average wastewater characteristics in the first septic tank from the milk house only sites participating in this study with published literature and design values given in table 1 and 2. Average values from this study were comparable to previous studies.

Conclusions

Water flow through milk houses on 16 dairy operations with less than 130 milking cows was monitored and wastewater samples from the first septic tanks were analyzed. The average water use rates observed were higher than published design values but within expected variation. Author recommendations based on this study are:

- Use weekly water use data collected for at least two months from a water meter properly located in a dairy farm milk house to estimate milk house wastewater flows in existing dairy operations.
- Use 19 L/d/cow for a design milk house wastewater flow rate for milk houses only for dairy operations with between 40 and 130 cows.
- Use 1.5 g/L for the design effluent BOD_5 concentration for a milk house only for sizing aerobic treatment units and infiltration systems.
- Use 0.6 kg/cow/yr for the annual TKN production per cow for the milk house only sites for designing irrigation land application systems.
- Use 0.35 kg/cow/yr for the annual P production per cow for the milk house only sites for designing irrigation land application systems.

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Aerobic and Media Filter Treatment Systems for Milk House Wastewater on Small Dairy Operations

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Abstract. *Four different aerobic treatment systems were installed downstream of one or more septic tanks to treat milk house wastewater on nine dairy farms with between 41 and 130 cows. Seven farms had pipeline milking systems, one farm had a flat parlor and one had a milking parlor where parlor wash water entered the milk house wastewater treatment system. Two Biomicrobics FAST® systems, two NCS Nibbler® systems, three Pirana® units, and two Reactor Dynamics, Inc. DYNO2® units were installed. System performance was monitored over 1 to 2 years by measuring water use and collecting wastewater samples.*

Mean water flow rates and wastewater concentrations varied widely. Mean water flow rates through the eight milk houses with pipeline milking systems or a flat parlor ranged from 0.63 to 2.31 m^3/d. After primary treatment in septic tanks, influent entering the aerobic treatments systems on the eight farms had average BOD5 concentrations from 296 to 2,650 mg/L and Oils and Grease (O&G) from 58 to 852 mg/L. The aerobic treatment systems on the eight farms had average discharge concentrations for BOD5 and O&G that ranged from 89 to 534 mg/L and 9 to 173 mg/L, respectively. Equipment and installation costs for the eight systems ranged from $6,700 to $16,500.

The aerobic treatment units and recirculating media filters used were able to reduce organic levels in milk house wastewater to levels acceptable for final treatment and dispersal in soil treatment units. Small dairy producers with limited options can use aerobic treatment units and recirculating media filters as part of a milk house wastewater treatment system.

Keywords. *Dairy, Aerobic Treatment Wastewater, Milk house, Waste.*

Milk house wastewater includes wash water from cleaning milking equipment, pipelines, and bulk tanks after milking is completed or the bulk tank is emptied. An initial rinse removes residual milk, which remains in the pipeline, receiver jar, and bulk tank after emptying. Subsequent washing generates wash water which includes cleaning and sanitizing agents, a hot alkaline detergent, and an acid rinse (Malcom et al., 1998; Harvard, 2002). Milking equipment cleaning produces a large volume of wastewater, which can account for up to 30% of the total wastewater volume from a dairy farm (Wright and Graves, 1998). Milk house wastewater often includes manure, bedding. and other organic matter, lime and dirt dropped from boots as people walk through the milk house. This material is flushed down the milk house floor drain when the floor is washed. Milk house wastewater may also include water softener discharge water. Several studies have reported milk house wastewater characteristics (Loehr and Ruf, 1968: Allen et al., 1973; Millen et al., 1977; Malcolm et al., 1998, Teague and Gross, 2001; Janni et al., 2008). Milk house wastewater poses a treatment challenge because of its high organic load, chemical usage, and strength and flow variability.

Systems for handling milk house wastewater include short- or long-term liquid storage followed by application to cropland, septic systems with soil infiltration, constructed wetlands, grass filter strips, organic or bark bed filter systems, spray irrigation, lime flocculator with soil infiltration, and aerobic treatment systems (Springman et al., 1995; Wright and Graves, 1998). Wastewater handling systems with septic tanks followed by soil infiltration have not been successful long term because of the high concentrations of fats and organic material in the waste going to the infiltration areas (Zall, 1972).

This article describes the performance of nine milk house wastewater treatment systems installed on Minnesota dairy operations with between 41 and 130 milk cows. The systems used either one of three commercial aerobic treatment unit systems (ATUs) or a recirculating media filter system (RMF) as part of the overall treatment system. The aerobic treatment units used blowers to directly introduce air into the milk house wastewater to maintain aerobic conditions in treatment tanks. The recirculating media filter had unsaturated media covered with microbial growth that was repeatedly dosed with milk house wastewater to reduce biochemical oxygen demand (BOD_5) and remove suspended solids. The overall purpose of two grant funded projects reported here was to install, monitor, and evaluate the technical and economic aspects of several milk house wastewater treatment systems in a cold climate. The design and performance of additional

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systems was summarized in other reports (Christopherson et al., 2003; Schmidt et al., 2005).

Methods and Materials

The two projects reported here were funded through separate US EPA 319 grants administered by the Minnesota Pollution Control Agency. Each project had an advisory group that included representatives from the county environmental services agencies, dairy industry, Extension, and Natural Resources Conservation Service (NRCS). Potential cooperating dairy producers were identified by advisory group members. Producers interested in the project and willing to participate were visited to discuss milk house wastewater treatment system options. The producers selected were expected to continue operation for five years or more, not have liquid manure storage for handling their milk house wastewater, be willing to install one of the aerobic treatment systems selected by the advisory group, and cooperate with system monitoring. Additional farm selection information is in Janni et al. (2008).

Milk house wastewater system design depends on wastewater flow, organic loading, nutrient concentrations, and other wastewater characteristics, climate, soil characteristics, site characteristics, and management preferences. To collect initial wastewater flow data, water meters (Model 25 Recordall®, BadgerMeter, Inc., Milwaukee, Wis.) were installed in milk house water supply lines of the nine farms. Two months of flow data was used to estimate wastewater flows at the beginning of each project. Additional wastewater flow information was collected during subsequent monitoring phases of the two projects and reported in Janni et al. (2008).

At the beginning of the study when potential project participants were visited, before any systems were installed, 10 wastewater samples were taken from 10 different farms visited. These 10 initial samples were used to estimate a BOD_5 influent organic loading rate for sizing the first five aerobic treatment systems installed in 2002 or 2003. Wastewater samples were taken from existing septic tanks when available or milk house discharge when septic tanks were not available. The BOD_5 results from these initial samples are summarized in the Results section and were used by aerobic treatment system manufacturers to size their systems. Estimated BOD_5 influent organic loading rates for sizing the last four aerobic treatment systems installed in 2004 or 2006 were based on data collected in 2003 and 2004 and reported by Janni et al. (2008). Septic tank capacities varied by farm and were recorded. Information about existing and added septic tanks is given in the farm descriptions in the Results section.

Wastewater samples were taken from the last septic tank prior to the ATUs or RMFs. Samples were taken from between the scum layer and settled sludge in the tanks through access holes in the tops of the tanks either over the middle of the tank between the effluent inlet and outlet or over the outlet. These samples represented the primary treated effluent leaving the septic tank and entering the ATUs or RMFs for aerobic treatment and were labeled influent in the results section.

Wastewater samples after aerobic treatment were taken downstream from each ATU or RMF from either a drop box or a pump tank or chamber. These samples represented the treated effluent leaving the ATU or RMF for either surface discharge or dispersion to the subsoil treatment systems and were labeled effluent in the results section. Specific ATU effluent sampling locations are described in the secondary treatment section.

Filled wastewater sample containers were stored on ice in coolers until analyzed at commercial laboratories. The samples were analyzed for biochemical oxygen demand (BOD_5) using method SM 5210-B (APHA, 1998); chemical oxygen demand (COD) using EPA 410.4 (EPA, 1993a); total suspended solids (TSS) using SM 2540-D (APHA, 1998); oil and grease (O&G) using EPA 1664A (EPA, 1999); total phosphorus as phosphate (P_2O_5) using EPA 365.1 (EPA, 1993b); total ammonia nitrogen (NH_3) using SM 4500-NH_3 B,E (APHA, 1998); total Kjeldahl nitrogen (TKN) using SM 4500-Norg and 4500-NH_3 B,E (APHA, 1998); and pH using SM 4500-H+ (APHA, 1998). Wastewater temperature in the sample containers was measured using a Type K thermocouple and handheld digital display (Omega® Digital Thermometer 450-AKT. Stamford, Conn.) before they were put on ice. Dissolved oxygen (DO) was measured periodically using a test kit (CHEMets – Dissolved Oxygen K-7501, Calverton, Va.)

Primary Treatment

All of the treatment systems had one or more septic tanks for primary treatment prior to the aerobic treatment systems. The tanks were required to meet state-specific standards for construction and placement and have inlet and outlet baffles. The septic tanks were typically installed with a minimum of 30 cm of soil covering the tank to provide insulation during cold weather.

The septic tanks served two key purposes. They allowed soaps, bedding material, and milk fats to float to the top forming a scum layer and heavier solids including floor lime, dirt, and biomass to accumulate in a sludge layer. The septic tank also served as a buffer between the bulk tank and aerobic treatment system elements should the entire bulk tank need to be dumped due to contamination. Milk has a reported BOD_5 concentration of 100,000 mg/L (Wright and Graves, 1998). The secondary aerobic treatment systems were not designed to treat waste milk. To protect the aerobic treatment systems if milk in the bulk tank becomes contaminated or unusable and needs to be dumped the waste milk can be loaded into equipment and land applied or the septic tank pumped, the bulk tank drained to the septic tank and the septic tank (with the waste milk) pumped again. The septic tank contents and waste milk can be land applied. As the septic tank fills with wastewater the scum and sludge layers will reestablish. Both options for handling waste milk are acceptable practices for protecting the ATUs or RMFs.

Except for one farm, the primary septic tanks were sized to provide a minimum of 3-day hydraulic retention time (HRT) or the volume of the bulk tank whichever was greater. Effluent from the primary septic tank was pumped or flowed by gravity into the aerobic treatment systems.

During the project the septic tanks had all solids and liquids removed by pumping when either the scum was too thick or the sludge layer was too deep. The scum layer was deemed too thick if the bottom of the scum layer was less than 8 cm above the bottom of the outlet baffle. The sludge was too deep when the top of the sludge was within 30 cm of the bottom of the outlet baffle. Time between septic tank emptying depended on the size of the tank and organic loading patterns, but pumping was typically needed annually at a minimum and bi-annually at a maximum.

Secondary Treatment

Effluent from the primary treatment septic tanks flowed into either one of three types of ATU (i.e. Nibbler®, FAST®, or Pirana®) or a RMF unit (i.e. DYNO2®). The treatment goal for the Nibbler® and FAST® systems was 25 mg/L BOD_5 to allow surface discharge of the aerobically treated milk house wastewater. The target treatment goal for the Pirana® and DYNO2® systems was 175 mg/L BOD_5 because the effluent was distributed through a subsurface infiltration area. Manufacturers of the three types of ATUs used in this study reported that their units had been used to treat restaurant wastewater. ATU and RMF system designs are a function of wastewater strength and flow. The ATUs installed were sized by the manufacturers based on kg of BOD_5 removal per day, daily wastewater flow rate, and a hydraulic retention time in the ATU tank.

FAST® Aerobic Treatment Units

Fixed Activated Sludge Treatment (FAST®) aerobic treatment units were installed to treat milk house wastewater on two dairy farms. These units were developed by Bio-Microbics, Inc. (Shawnee, Kans.). The FAST® unit had an aerobic suspended growth system with a honeycombed media where bacteria attached. The growth systems were suspended in 10.3 m^3 aeration tanks. The units installed were High Strength FAST 3.0 units with 1.1-kW electric blowers that provided air to the media. The aeration process agitated the effluent, distributing food and supplying oxygen to the bacteria. Treated effluent from the FAST® units was collected from drop boxes connecting the unit to subsoil tile lines.

Nibbler® Aerobic Treatment Units

Nibbler® units were installed on two dairy farms. The units were manufactured and marketed by NCS Wastewater Solutions (Puyallup, Wash.). Each Nibbler® unit contained six pods designed to match the hydraulic and biological loading of the system. Pods were injection molded plastic cages (72 × 72 × 46 cm) containing buoyant high surface area media. Each pod was capable of treating 0.37 kg/day of BOD_5 loading and a maximum of 521 L of wastewater per day. The Nibbler® units were placed in 13,600-L aerated tanks containing six pods each with 0.14 m^3 of media per pod. A time controlled pump located in a pump tank prior to the aerated tank regulated flow and provided even dosing. Air, supplied by a 1.1-kW blower through a pipe manifold, flowed through a 2.5-cm air tube that delivered air to the center of the each pod approximately 36 cm below the liquid surface. Treated effluent from the Nibbler® units was collected from drop boxes connecting the unit to subsoil tile lines.

Pirana® Aerobic Treatment Units

Pirana® units (SludgeHammer, Petoskey, Mich.) were installed on three dairy farms. The model S-86 units were inoculator/generator units with 0.07-kW blowers with diffusers, 13.9 m^2 of fixed film media, and a bacterial pack. The Pirana® units were placed in concrete aerobic treatment tanks following the primary treatment septic tanks. The number of Pirana® units installed depended on the wastewater organic loading rate. Treated effluent from the Pirana® units was collected from the pump tank downstream of the tank with the diffusers, fixed film media and bacterial pack.

DYNO2® Recirculating Media Filter Units

DYNO2® RMF units (Reactor Dynamics, White Bear Lake, Minn.) were installed on two dairy farms. The units breakdown wastewater constituents by circulating wastewater through an aerobic biological community attached to the filter media surfaces. The DYNO2® units used expanded polystyrene as the media. Gravel (2 to 6 cm) is another option in RMF units receiving high strength waste effluent. The RMFs were sized based on organic loading of the filter area, 5 mg BOD_5/cm^2/day.

DYNO2® units were contained in watertight vessels installed even with the ground surface. Wastewater was distributed over the media in frequent, cycled, uniform doses. The systems required a timer controlled pump, pump compartment, electrical components, and distribution network to dose the media, keeping it wetted. Effluent collected at the bottom of the filter was returned to the recirculating/mixing tank where it mixed with fresh septic tank effluent. Periodically a portion of the effluent was discharged to the subsurface infiltration area. Flow splitting mechanisms were used to control recirculation and discharge to the subsurface area. Treated effluent from the DYNO2® units was collected from the pump compartment.

Subsurface Infiltration Area

Subsurface infiltration was planned for five of the aerobic treatment systems. The Pirana® ATU used in the first project had a Geoflow® drip tubing distribution system. All other installations used typical trench subsurface treatment systems following the aerobic treatment. All of the infiltration areas had at least 60 cm of separation below the bottom of the system to the seasonally high water table or bedrock. This separation distance was critical for removing the remaining organics and nutrients in the wastewater as well as assuring the systems functioned hydraulically.

Results

Results from the initial 10 grab samples were summarized and a BOD_5 of 1,100 mg/L was used as typical BOD_5 value leaving a septic tank and entering the aerobic treatment systems. Subsequent wastewater sampling found much higher BOD_5 concentrations leaving the septic tanks and feeding the aerobic treatment systems (Janni et al., 2008) This meant that the aerobic BOD_5 removal needed was greater than initially expected and used in the aeration system designs for the first four aerobic installations, Farms 1-4. Systems designed for Farms 6-9 used an estimated influent BOD_5 concentration of 1,400 mg/L based on data collected in 2003 and 2004 and reported by Janni et al. (2008).

Treatment Systems

Table 1 summarizes dairy farm and wastewater treatment system information for the nine operations that had aerobic treatment systems. Milking cow numbers ranged from 41 to 130 cows. All but two farms, 4 and 9, had pipeline milking systems that ran throughout tie-stall barns. Farm 4 had a flat parlor, which had less milk pipeline than the farms with pipeline systems in tie-stall barns, and handled manure in the flat parlor as a solid not adding the manure to the milk house wastewater. With less milk pipeline, farm 4 was expected to have less residual milk in its wash water. Farm 9 was a milking parlor that was washed with a high-pressure hose-end sprayer; the wastewater contained both milk house wastewater and parlor wash water. All of the farms milked cows two times a day. None of the farms in the study collected the first rinse with residual milk and diverted it from their wastewater treatment system in an effort to reduce the organic load to be treated. The aerobic treatment tank volumes and aeration power used listed in table 1 are based on manufacturer supplied information. Farm 9 had five Pirana® units. Farms 1 through 5 participated in a study between December 2002 and November 2004 while farms 6 through 9 were part of a second study between December 2004 and October 2006 (table 2). Table 2 gives the number of times wastewater samples were collected, average daily water flow rates over the sampling period, average water flow per cow, and the range of values water flow rates between sampling dates for each farm. The hydraulic retention times in the septic and aerobic tanks listed in table 2 were based on average daily flow rates and neglected accumulated sludge in the tanks.

Farms 1 and 2 had FAST® units and very different total septic tank capacities and HRTs. Farm 1 had an existing single compartment 3.8-m^3 septic tank. A new single compartment 2.8-m^3 tank was added bringing the total septic tank capacity to 6.6 m^3 based on an initial average daily water flow of 2.04 m^3/day. The measured average daily flow rate and septic tank HRT on Farm 1, based on 20 months of water use monitoring, were 1.45 m^3/d and 4.5 d, respectively (table 2). Farm 2 had an existing septic tank that was abandoned and not used with the new system. A 2.8-m^3 septic tank was installed based on an initial average daily water flow of 1.56 m^3/d. The measured average daily water flow rate and septic tank HRT on Farm 2, based on 24 months of water use monitoring, were 2.31 m^3/d and 1.2 d, respectively (table 2). Septic tank effluent flowed by gravity into 10.2-m^3 concrete tanks with FAST® units on both Farm 1 and 2. HRT in the aerated tanks were 7.0 and 4.4 d on Farm 1 and 2, respectively. Both FAST® units had blowers powered by 1.1-kW electrical motors.

Farms 3 and 4 both had new dual compartment septic tanks with 1.9- and 3.8-m^3 capacities, installed prior to concrete tanks with Nibbler® units. The second 3.8-m^3 tanks served as pump compartments with time controlled pumps that regulated flow and dosed the Nibbler® units. Both Nibbler® units had blowers powered by 1.1-kW electrical motors.

Table 1. Farm and treatment system information.

Farm	No. of Cows	Milking Systems	Total Septic Tank Volume (m^3)	Aerobic Treatment System	Aerobic Treatment Tank Volume[a] (m^3)	Design BOD_5 Removal[a] (kg/day)	Aeration Power[a] (kW)
1	41	Pipeline	6.6	FAST®	10.2	2.7	1.1
2	130	Pipeline	2.8	FAST®	10.2	2.7	1.1
3	45	Pipeline	5.7	Nibbler®	1.9	3.0	1.1
4	96	Flat parlor	6.1	Nibbler®	1.9	3.0	1.1
5	54	Pipeline	3.8	Pirana®	3.8	1.3 to 2.7	0.07
6	55	Pipeline	3.8	Pirana®	7.6	1.3 to 2.7	0.07
7	50	Pipeline	5.7	DYNO2®	7.0	NA	-
8	60	Pipeline	3.8	DYNO2®	7.0	NA	-
9	130	Parlor	7.6	Pirana®	15.2	6 to 14	0.37

[a] Based on manufacturer information.

Table 2. Daily wastewater flow rates and average hydraulic retention times (HRT) in the septic tanks and the aerobic treatment systems.

Farm	Sampling Period (month/year)	No. of Samples	Average Daily Water Flow (m^3/d)	Water Flow Range (m^3/d) (low - high)	Average Water Flow per Cow (L/d/cow)	Water Flow Rate per Cow Range (L/d/cow)	Avg. Septic HRT (d)	Avg. Aerobic System HRT (d)
1	04/03 - 11/04	15	1.45	1.17-1.95	35.4	28.5-47.6	4.5	7.0
2	12/02 - 11/04	21	2.31	1.32-5.05	17.8	10.1-38.8	1.2	4.4
3	01/03 - 11/04	18	0.80	0.68-1.03	17.8	15.2-22.8	7.1	2.4
4[a]	08/03 - 05/04	20	1.74	1.60-1.91	18.1	16.6-19.9	3.5	1.1
5	10/03 - 11/04	12	0.63	0.56-0.82	11.7	10.4-15.1	6.0	6.0
6	12/04 - 10/06	14	1.18	0.69-2.13	21.5	12.5-38.7	3.2	6.4
7	04/06 - 10/06	13	0.65	0.45-0.88	13.0	8.9-17.6	8.7	10.8
8	12/04 - 10/06	14	0.77	0.65-1.00	12.8	10.9-16.6	4.9	9.1
9[b]	12/04 - 10/06	13	3.15	2.52-5.40	24.2	19.4-41.5	2.4	4.8

[a] Flat parlor.
[b] Milking parlor.

Farm 5 had a new 3.6-m^3 septic tank installed prior to a dual compartment tank (3.6/1.8 m^3) that housed the Pirana® unit. A single Pirana® unit was in the first compartment of the dual compartment tank. A rotating screen filter and 0.75-kW pump were in the second compartment. The pump dosed 1000 m of Geoflow® drip tubing in a subsoil infiltration area separated into four zones. The tubing was placed 30 cm deep in a clay loam soil with 46 cm of separation to the limiting soil condition.

Farm 6 had a pipeline milking system and three existing 3.8-m^3 septic tanks. The first tank provided primary septic tank treatment. A Pirana® unit was added to the second tank and the third tank was used as a pump tank to dose subsurface rock trenches for infiltration.

Farm 7 had a new dual compartment (3.8/1.9 m^3) septic tank installed to provide primary treatment prior to a DYNO2® unit. Farm 8 had an existing single compartment 3.8-m^3 septic tank that provided primary septic treatment prior to a DYNO2® recirculating media filter unit installed for this project.

Farm 9 was the only farm in the study with a parlor milking system where manure from the parlor was added to the milk house wastewater. The treatment system had three new 7.6-m^3 septic tanks installed. The first tank provided primary treatment. The second tank had five Pirana® units installed. The third tank was a pump tank supplying an irrigation system in the summer and a bark bed system in the winter.

Average daily water flow rates of the farms with pipelines or flat parlors (Farms 1-8) ranged over the entire sampling period from 0.63 to 2.31 m^3/d (table 2). Farm 2 had the greatest water flow rate range between sampling periods among the farms with pipeline milking systems, ranging from 1.32 to 5.05 m^3/d (table 2). Farm 9, which had a parlor, had flow rates that ranged from 2.52 to 5.40 m^3/d. Janni et al. (2008) reported that daily water flows were generally consistent from day to day on the farms but varied between farms.

Influent and Effluent Characteristics

Mean and standard deviation wastewater influent and effluent characteristics are summarized in table 3 for the nine systems. Influent samples were taken from the middle or outlet of the last septic tanks prior to the ATUs or RMFs and represented the organic and nutrient concentrations entering the secondary treatment units. Effluent samples were taken downstream from the ATUs or RMFs from either a drop box or a pump tank or chamber and represented the organic and nutrient concentrations leaving the ATUs and RMFs. The characteristics are biochemical oxygen demand (BOD_5); chemical oxygen demand (COD) total suspended solids (TSS); oil and grease (O&G); total phosphorus as phosphate (P_2O_5); ammonia (NH_3); total Kjeldahl nitrogen (TKN); and pH. Percent mean concentration changes were calculated using equation 1. Negative percent change indicated a concentration reduction in the ATU or RMF.

$$PC = 100 \cdot \frac{Cout - Cin}{Cin} \tag{1}$$

where

PC = percent change (%)

Cout = mean effluent concentration – wastewater leaving ATU or RMF (mg/L)

Cin = mean influent concentration – wastewater entering ATU or RMF (mg/L)

The mean influent characteristic data reported here is a subset of the data in Janni et al. (2008). The values in the larger study were similar to the concentrations reported in other studies (Loehr and Ruf, 1968; Allen et al., 1973; Millen et al., 1977; Weil, 1991; Springman et al., 1995; Malcom et al., 1998; Teague and Gross, 2001) and published design values (NRCS, 1992; Wright and Graves, 1998; Lorimor et al., 2000). The BOD_5 concentrations reported here are similar to those reported by Weil (1991). Springman et al. (1995) reported an average BOD_5 concentration of 2,090 mg/L with values ranging from 80 to 9,700 mg/L.

Mean milk house wastewater BOD_5 concentrations averaged over the sampling period entering the ATUs or RMFs varied by as much as a factor of 9 (i.e. 296 mg/L for Farm 1 vs. 2,650 mg/L for Farm 2). Mean COD concentrations varied by a factor of 8 (i.e. 520 mg/L for Farm 1 vs. 4,220 mg/L for Farm 2). The highest mean O&G concentration (852 mg/L on Farm 2) was 14.7 times the lowest O&G concentration (58 mg/L on Farm 1). Many standard deviations indicated large concentration variation in the influent concentration on most farms. For example, Farm 2 had a BOD_5 concentration standard deviation of 1,200 mg/L. The lowest BOD_5 concentration standard deviation was 178 mg/L for Farm 1. The large variations in concentrations and wastewater flow rates indicate large variations in organic and nutrient loading of the ATUs and RMFs.

Mean BOD_5, COD, TSS, and O&G influent concentrations at Farm 2 were consistently the highest. Farm 2 had an undersized pipeline system which led to milk entering the milk house wastewater system. Milk has a BOD_5 concentration around 100,000 mg/L (Loehr, 1974; Wright and Graves, 1998). Farm 2 also had the second highest average daily water flow, 2.31 m^3/d, and only a single 2.8-m^3 septic tank for primary treatment, which produced the lowest average septic tank HRT of 1.2 d. The residual milk, higher water flow rate, limited septic tank capacity, and low septic tank HRT led to consistently higher influent loads to the FAST® treatment system. Near the end of the project modifications were made to direct more waste milk to the manure gutter.

Farm 1 had the lowest overall mean influent BOD_5 (296 mg/L), COD (520 mg/L), TSS (147 mg/L), O&G (58 mg/L), TKN (25 mg/L), and ammonia (15 mg/L) concentrations. Farm 7 had the lowest overall mean phosphorus (18 mg/L) concentrations.

Farm 9 had the highest overall mean BOD_5 (1,370 mg/L), COD (3,250 mg/L), and TSS (965 mg/L) effluent concentrations leaving the ATUs or RMFs. Farm 9 was the single parlor milking system in the projects that had both milk house wastewater and parlor wash water go through the aerobic treatment system. Among the pipeline systems, Farm 2 had the highest overall mean BOD_5 (534 mg/L), COD (1,720 mg/L), TSS (914 mg/L), and O&G (173 mg/L) effluent concentrations leaving the ATUs or RMFs. Farm 4, which had the flat parlor, had the next highest overall mean BOD_5, COD, TSS, and O&G effluent concentrations (497 mg/L, 1,146 mg/L, 433 mg/L, and 109 mg/L, respectively).

Based on overall mean influent and effluent concentrations the ATUs and RMFs were effective are reducing influent concentrations by between 22% (Farm 9) and 91% (Farm 3). Overall mean influent COD concentrations were reduced by between 3% (Farm 9) and 86% (Farm 8). Farm 9, with the milking parlor, had the lowest percent reductions in BOD_5 (22%) and COD (3%).

Farms 5 through 8 used subsoil infiltration areas and the target BOD_5 concentration was 175 mg/L. Based on overall mean effluent concentrations over the study period, Farms 5 (169 mg/L), 6 (108 mg/L) and 8 (151 mg/L) were able to meet the target 175 mg/L BOD_5 concentration. Farm 1 (89 mg/L) and Farm 3 (117 mg/L), while not able to meet the surface discharge 25 mg/L BOD_5 concentration target, were able to meet the 175-mg/L BOD_5 subsoil infiltration area target concentration.

Influent pH ranged from 6.2 (Farm 2) to 7.5 (Farm 7). Effluent pH ranged from 7.2 to 7.9.

Individual effluent temperatures ranged from 4°C to 31°C, with most ranging from 12°C to 25°C.

Most of the aerobic treatment systems were able to maintain DO concentrations in the effluent greater than 1 mg/L. All of the effluent DO readings on Farms 1, 3, 5, 6, 7, and 8 were ≥1 mg/L. Farm 2 had one DO reading <1 mg/L and Farm 4 had four DO readings <1 mg/L. Farm 9, the parlor milking system, had 5 out of 11 DO readings <1 mg/L.

High nutrient concentrations were found in milk house wastewater. Cleaning chemicals and milk both contain phosphorus. Cleaning chemicals, which include detergents and acid rinses, account for the majority of phosphorus in the wastewater (Sherman, 1981). The amount of phosphorus in the effluent on a given farm is highly dependent upon the amount and type of cleaning materials used. Milk protein contains nitrogen, which adds to the milk house wastewater nutrient concentrations observed.

Controlling the amounts of milk disposed of through the wastewater system in the clean up process is critical. Milk has a BOD_5 value of 100,000 mg/L (Wright and Graves, 1998). Studies have indicated that over half of the solids present in milk house wastewater are of the colloidal or super-colloidal size (Millen et al., 1977). Due to the colloidal nature, septic tanks can provide minimal solids separation (Zall, 1972).

Treatment System Loads

System performance was impacted by wastewater flow rate, primary treatment retention time which affects the aerobic systems influent strength and system management. Table 4 summarizes the mean influent and effluent loads per day per cow calculated by multiplying the mean water flow rate per cow in table 2, averaged across all of the sampling period, by the mean influent or effluent concentrations in table 3 averaged across the sampling period.

The aerobic systems in the first study, Farms 1 through 4, were designed using an influent BOD_5 of 1,100 mg/L and two initial months of water flow data. The FAST® units on Farms 1 and 2 and the Nibbler® units on Farms 3 and 4 were designed to deal with a maximum of 2.7 and 3.0 kg/day, respectively. Farm 2 had an overall mean influent BOD_5 concentration of 2,650 mg/L, which produced a BOD_5 load over 6 kg/d to reduce the effluent to 25 mg/L. Farm 3 had an

Table 3. Mean and (standard deviation) influent and effluent concentrations entering and leaving ATUs, percent change and pH.

Farm		BOD_5 (mg/L)	COD (mg/L)	TSS (mg/L)	O&G (mg/L)	Phosphorus (mg/L)	TKN (mg/L)	Ammonia (mg/L)	pH
1	Influent	296 (178)	520 (355)	147 (134)	58 (68)	51 (25)	25 (17)	15 (15)	7.0 (0.6)
	Effluent	89 (91)	190 (155)	77 (62)	9 (9)	27 (21)	17 (16)	10 (13)	7.7 (0.4)
	% Change	-70%	-63%	-48%	-84%	-47%	-32%	-33%	
2	Influent	2,650 (1,200)	4,220 (1,640)	1,015 (541)	852 (652)	47 (14)	121 (39)	19 (14)	6.2 (0.7)
	Effluent	534 (296)	1,720 (1,820)	914 (1,760)	173 (476)	38 (15)	113 (62)	24 (23)	7.6 (0.3)
	% Change	-80%	-59%	-10%	-80%	-19%	-7%	26%	
3	Influent	1,340 (190)	1,920 (570)	369 (210)	223 (124)	33 (11)	73 (16)	44 (15)	6.8 (0.6)
	Effluent	117 (70)	449 (201)	144 (110)	11 (9)	26 (6)	63 (28)	34 (19)	7.9 (0.3)
	% Change	-91%	-77%	-61%	-95%	-21%	-14%	-23%	
4[a]	Influent	1,940 (1220)	3,060 (2,180)	881 (698)	463 (407)	86 (16)	99 (74)	46 (55)	6.4 (0.5)
	Effluent	497 (344)	1,150 (720)	433 (274)	109 (140)	68 (9)	54 (13)	20 (13)	7.2 (1.2)
	% Change	-74%	-62%	51%	-76%	-21%	45%	-57%	
5	Influent	1,190 (1,060)	1,530 (970)	426 (272)	348 (432)	47 (21)	53 (33)	24 (16)	7.1 (0.4)
	Effluent	169 (106)	543 (627)	197 (137)	30 (80)	39 (16)	37 (24)	12 (10)	7.8 (0.7)
	% Change	-86%	-65%	-54%	-91%	-17%	-30%	-50%	
6	Influent	820 (350)	1,190 (250)	397 (267)	127 (73)	64 (21)	46 (16)	26 (22)	6.7 (0.3)
	Effluent	108 (93)	272 (82)	118 (88)	16 (20)	39 (14)	32 (9)	24 (32)	7.8 (0.2)
	% Change	-87%	-77%	-70%	-87%	-39%	-30%	-8%	
7	Influent	790 (460)	1,160 (760)	181 (86)	68 (45)	18 (10)	44 (25)	28 (23)	7.5 (0.7)
	Effluent	447 (250)	672 (349)	102 (72)	28 (18)	20 (10)	42 (23)	32 (20)	7.4 (0.4)
	% Change	-42%	-42%	-44%	-59%	11%	-5%	14%	
8	Influent	1,340 (630)	1,840 (990)	375 (266)	67 (27)	35 (5)	89 (40)	61 (34)	6.3 (0.3)
	Effluent	151 (133)	262 (146)	67 (59)	28 (36)	34 (5)	73 (55)	48 (37)	7.2 (0.2)
	% Change	-89%	-86%	-82%	-58%	-3%	-18%	-21%	
9[b]	Influent	1,750 (860)	3,340 (1,340)	698 (370)	186 (171)	45 (32)	174 (67)	98 (52)	6.8 (0.3)
	Effluent	1,370 (367)	3,250 (806)	965 (320)	140 (44)	35 (4)	210 (19)	140 (14)	7.6 (0.3)
	% Change	-22%	-3%	38%	-25%	-22%	21%	43%	

[a] Flat parlor.
[b] Milking parlor.

Table 4. Mean ATU influent and effluent loads and removals per day per cow.

Farm		BOD_5 (g/d/cow)	COD (g/d/cow)	TSS (g/d/cow)	O&G (g/d/cow)	Phosphorus (g/d/cow)	TKN (g/d/cow)	Ammonia (g/d/cow)
1	Influent	10.47	18.39	5.20	2.05	1.80	0.88	0.53
	Effluent	3.15	6.72	2.72	0.32	0.95	0.60	0.35
	Removed	7.32	11.67	2.48	1.73	0.85	0.28	0.18
2	Influent	47.09	74.99	18.04	15.14	0.84	2.15	0.34
	Effluent	9.49	30.56	16.24	3.07	0.68	2.01	0.42
	Removed	37.60	44.43	1.80	12.07	0.16	0.14	-0.08
3	Influent	23.82	34.13	6.56	3.96	0.59	1.30	0.78
	Effluent	2.08	7.98	2.56	0.20	0.46	1.12	0.60
	Removed	21.74	26.15	4.00	3.76	0.13	0.18	0.18
4[a]	Influent	35.16	55.37	15.97	8.39	1.56	1.79	0.83
	Effluent	9.01	20.77	7.85	1.98	1.23	0.98	0.36
	Removed	26.15	34.60	8.12	6.41	0.33	0.82	0.47
5	Influent	13.88	17.85	4.97	4.06	0.55	0.62	0.28
	Effluent	1.97	6.34	2.30	0.35	0.46	0.43	0.14
	Removed	11.91	11.51	2.67	3.71	0.09	0.19	0.14
6	Influent	17.59	25.53	8.52	2.72	1.37	0.99	0.56
	Effluent	2.32	5.84	2.53	0.34	0.84	0.69	0.51
	Removed	15.27	19.69	5.99	2.38	0.53	0.30	0.05
7	Influent	10.27	15.08	2.35	0.88	0.23	0.57	0.36
	Effluent	5.81	8.74	1.33	0.36	0.26	0.55	0.42
	Removed	4.46	6.34	1.02	0.52	-0.03	0.02	-0.06
8	Influent	17.20	23.61	4.81	0.86	0.45	1.14	0.78
	Effluent	1.94	3.36	0.86	0.36	0.44	0.94	0.62
	Removed	15.26	20.25	3.95	0.50	0.01	0.20	0.17
9[b]	Influent	42.40	80.93	16.91	4.51	1.09	4.22	2.37
	Effluent	33.20	78.75	23.38	3.39	0.85	5.09	3.39
	Removed	9.20	2.18	-6.47	1.12	0.24	-0.87	-1.02

[a] Flat parlor.
[b] Milking parlor.

overall mean BOD_5 concentration of 1,340 mg/L and a BOD_5 load slightly over 1 kg/d. Water flow rates measured on some farms were also higher later in the study than the initial measurements used for design purposes on each farm. The Nibbler® units on Farms 3 and 4 were installed without a clarifying tank after the aerobic tank. The manufacturer began to recommend that clarifying tanks be installed in future systems after the study was underway.

Phosphorus (P) levels decreased in eight of the nine units. In the ATUs P is bound up in the sludge that settles out in these units and is removed when the sludge is removed. In the RMFs P may also settle out in the recirculation tank and be absorbed to the media in the filter. No sludge P measurements were taken. The unit that had an increase in P was likely due to sampling inaccuracy. Samples were collected from both tanks within minutes so the wastewater collected at the outlet of the unit was not the same wastewater collected as influent in the last primary treatment septic tank because of HRT. This sampling inaccuracy applies to the increases in TSS and NH_4 in table 3 as well.

The effluent treatment goal on Farms 1 through 4 was BOD_5 concentrations of 25 mg/L or less. The treatment system on Farm 1 was able to meet this treatment goal early in the study until the owner began to manually shut off the aeration blower to conserve energy. A timer was added to the system to allow the operator to better manage intermittent aeration. The treatment systems on Farms 2 through 4 were not able meet the BOD_5 concentration effluent treatment goal of 25 mg/L because the influent BOD_5 concentrations were significantly higher than the 1,100 mg/L design value used to size the systems.

Operation and Maintenance

Operational challenges arose during the first year of the first study. All of the FAST® and Nibbler® systems experienced airflow restrictions in the air supply lines in the spring of 2003 due to frost heaving. The airlines were dug up and reset. Both FAST® blower housings started to melt from the motor heat and the blowers had bearing problems. The blowers were replaced in the summer of 2003 and modifications were made to the "doghouse" to prevent further overheating. Farm 3 had an initial odor issue related to higher than expected organic loading which resulted in insufficient oxygen concentrations in the aerobic treatment unit tank.

Treatment Systems Costs

The treatment systems installed were experimental and not consistent across the farms, depending in part on site conditions and availability of existing usable septic tanks. The costs presented here include both capital costs and installation costs. The FAST® systems on Farms 1 and 2 cost $10,000 and $10,700, respectively, but neither include costs for subsurface infiltration areas. Nibbler® systems on Farms 3 and 4 cost $15,400 and $12,600, respectively. They also did not include costs for subsurface infiltration areas. The Pirana® system and Geoflow® drip tubing subsurface distribution system installed on Farm 5 cost $15,300. The Pirana® system and subsurface infiltration area installed on

Farm 6 cost $6,700. The DYNO2® systems and subsurface infiltration areas installed on Farms 7 and 8 cost $16,000 and $13,000, respectively. The wastewater treatment system on Farm 9, with the milking parlor, cost $30,500. The system included five Pirana® units, an irrigation distribution system, and a bark bed land application system for alternating summer and winter use.

Operation and maintenance costs include the electrical operating cost to run the blowers. The FAST® systems on Farms 1 and 2 and the Nibbler® systems on Farms 3 and 4 had 1.1-kW motors on their blowers. Farm 1 had a timer installed to reduce blower run time to reduce electrical operating costs. The other systems had blowers and/or pumps, too. Pump use for dosing the media in the DYNO2® recirculating media filter units depended on the hydraulic and organic loading, which impacts electrical operating costs.

All of the systems required pumping of the septic tanks at least annually and more frequently if settled solids or accumulated scum are a problem. Producers were encouraged to conduct monthly inspections to monitor septic tank accumulations. Producers were advised to pump the septic tanks when settled solids at the bottom of the tank were 48 cm or more deep or the scum layer was more than 10 cm thick. Septic tank effluent was applied to available crop land. Septic tank pumping frequency data was not recorded.

Producers were encouraged to monitor ATU and RMF performance and follow the manufacturer's operation and maintenance guidelines. Some ATU and RMF manufacturers offer maintenance agreements that provide annual performance evaluations and system maintenance.

Design Guide

Wastewater flow information reported by Janni et al. (2008), the results from this project and performance of additional systems summarized in other reports (Christopherson et al., 2003; Schmidt et al., 2005), were used to develop a milk house wastewater design guide available on the web (Schmidt et al., 2008).

Summary and Conclusions

Four different aerobic treatment systems were installed on nine dairy farms with between 41 and 130 cows to evaluate effective aerobic treatment options for milk house wastewater treatment. The systems included FAST® aerobic treatment units at two farms, Nibbler® aerobic treatment units at two farms, Pirana® aerobic treatment units at three farms, and two DYNO2® recirculating media filter systems at two farms. All nine systems reduced milk house wastewater strength. Four of the nine systems were not able to consistently reduce mean BOD_5 concentrations to less than 25 mg/L to allow surface discharge because influent BOD_5 concentrations were higher than the design value used for sizing the systems. Five of the nine systems were able to reduce mean BOD_5 concentrations to less than 175 mg/L the design concentration sought prior to discharge to a subsurface infiltration area.

Aerobic and media filter treatment systems can be used to treat milk house wastewater. The systems need to be designed to handle varying wastewater flow rates and BOD_5 concentrations. Janni et al. (2008) provide recent milk house wastewater flows and characteristics for dairy operations with 130 cows or less that can be used to design aerobic and media filter treatment systems. People planning to use aerobic treatment units or recirculating media filters may want to provide five days of hydraulic retention time for primary treatment prior to aerobic treatment. People may also want to use time dosing of the aerobic treatment units or recirculating media filters to reduce the variation in wastewater flow through the aerobic treatment components. Additional data is needed for milking parlors where manure from the parlor is included in the milk house wastewater.

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Chapter 5. Estimator Background and Watershed Evaluation

As a result of the project, dairy farmers across Minnesota can and have installed milk house wastewater treatment systems. In many of these projects cost share dollars assisted with the installs through funding by the Board of Water and Soil Resources (BWSR). In 2013, BWSR contracted with the University of Minnesota to develop an estimator to provide a consistent reliable method of determining the pollutant load removal from installing these practices as required by the legislature. This resulted in the development of the Milk House Wastewater Improvement Estimator (MWIE). It is a spreadsheet-based model that calculates annual pollutant loads from problematic milk house wastewater systems and accounts for the benefits of a range of milk house wastewater improvements. The User Guide is provided at the end of this Chapter. The MWIE was tested on a small watershed to document and evaluate it. The first 319 project included in this research took place in Carver County including the Carver Creek Watershed which covers 55,076 acres. Portions of Cologne and Carver and all of Waconia are within the watershed as shown in Figure 4. Currently, the dominant land use is agriculture (54%) with the remaining 46% composed of natural (18%), developed (5%), water (9%), and wetland (9%) (Carver County, 2015).

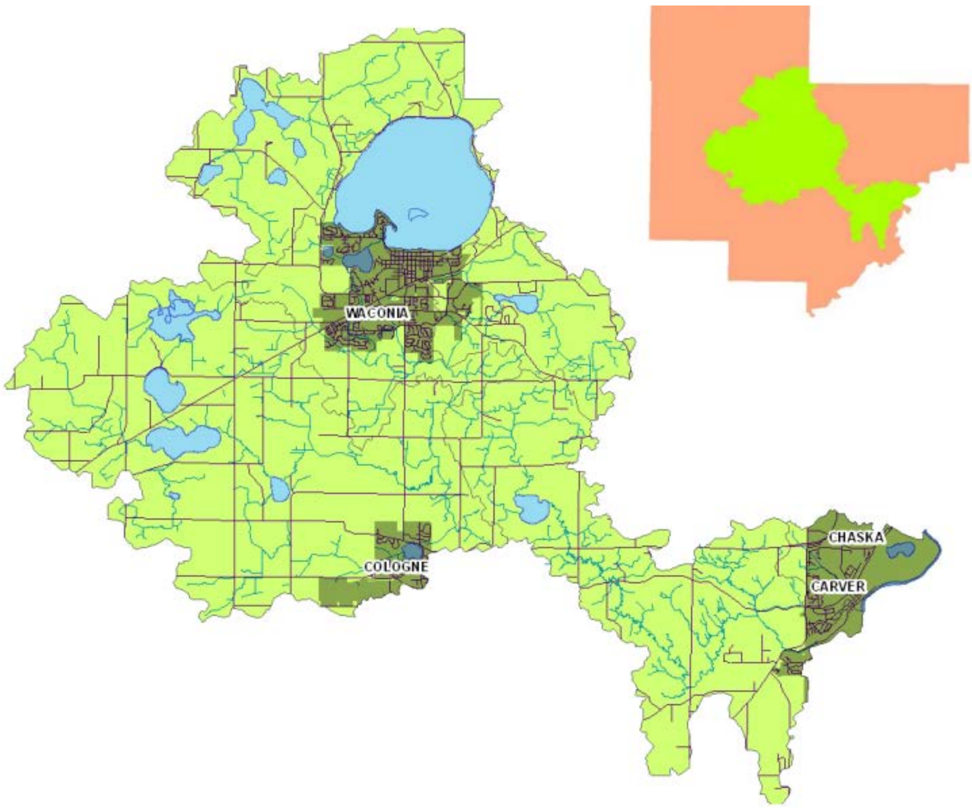

Figure 4. Carver Creek watershed.

There are 16 lakes in the watershed and eleven have water quality data for at least one year. Only one lake, Waconia, falls within the North Central Hardwood Forest (NCHF) ecoregion as average for nitrogen and phosphorous, with the remaining having negative levels above the average. There are approximately 89 miles of streams within the watershed with four active stream sampling stations with phosphorus and nitrogen above the NCHF ecoregion averages. The fecal coliform levels routinely exceed the state standard of CFU/100mL (MPCA, 2010). Carver Creek has a higher concentration of nitrogen (measured as nitrate) than almost all of the other streams monitored by Metropolitan Council in the Minnesota River basin (2014).

Goose, Hydes, Benton and Miller Lakes were placed on the 2002 Minnesota State 303(d) list of impaired waters, and Winkler Lake on the 2004 list. Each was identified for impairment of aquatic recreation (swimming) due to excess nutrients (CCWMO, 2010). Eight of the lakes in the watershed have completed or in progress of total daily maximum load (TDML) studies and implementation plans related to phosphorous impairments. From the complete TMDLs, impacts from feedlots have been identified as a priority area for improvement (Carver County, 2010). A TMDL implementation plan has been developed for Hydes, Goose, Benton, Winkler and Miller Lake. Based on Minnesota standards for nutrients, the TMDL establishes a numeric target of 60 ug/L total phosphorus concentration for all shallow lakes in the North Central Hardwood Forest ecoregion representing Goose, Miller, Benton and Winkler Lakes and 40 ug/L total phosphorus concentration for all deep lakes in the North Central Hardwood Forest ecoregion representing Hydes Lake. To meet these goals a 95% reduction in the phosphorous load is needed (CCWMO, 2010). For these five lakes, it is estimated that 7,372 pounds per year of phosphorus are entering these five lakes from external sources.

Within the Carver Creek watershed there are seven dairies that have non-compliant discharges of milk house wastewater (Brinkman, 2015). All of this milk house wastewater is currently going directly into tile lines that then discharge to surface water. The milk house improvement estimator (MWIE) (Heger, 2015) was used to determine the impacts of improving these seven farms. None of the farms has a method to measure the flow (Q) of water to/from the milk house; therefore the value of five gallons per cow per day was assumed based on data gathered in this study (Janni et al., 2009) as shown in table below. The Q was found to have a standard deviation of 2.5 gallons per cow. The equation is:

Q in GPD = number of cows X 5 gal per cow

Farm	Number of Cows	Q = Estimated Flow (gallons per day)
1	29	145
2	45	225
3	50	250
4	50	250
5	55	275
6	65	325
7	75	375

Table 2. Number of cows and estimated flow.

Since the seven farms all have stanchion barns with a pipeline to carry the milk to the milk house the median concentration (C) values gathered for stanchion barns were used to estimate the current loading of BOD, TSS, P and N, respectively 2141 mg/l, 795 mg/l, 50, mg/l and 83 mg/l. For each of these the standard deviations were 1420 mg/l, 632 mg/L, 25 mg/l and 62 mg/L. The results are shown below in Table 3 in pounds (lbs) per year (yr). Using the median values as estimates introduces more uncertainty for all the removals, but due to the largest range in TSS, this data is error prone, followed by N, BOD and P. The equation used to determine the pounds of contaminant load (CL) is:

CL in lbs/yr = C in mg/l X Q in gpd X 3 65 days/yr X 8.34 lbs/million gal

Farm	BOD_5 (lbs/yr)	TSS (lbs/yr)	P (lbs/yr)	N (lbs/yr)
1	946	351	22	37
2	1468	545	34	57
3	1631	606	38	63
4	1631	606	38	63
5	1794	666	42	70
6	2120	787	50	82
7	2466	909	57	95
Totals	12,056	4470	281	467

Table 3. Estimated contaminant load for the seven farms.

The total phosphorus load from these seven farms of 281 lbs/year is less than 4% of the overall load identified in from external loads in the TMDL implementation plans, but because these systems are directly discharging to tile lines versus non-point pollution they would still be likely targets for fixes. In addition, these farms are directly contributing organic material (BOD_5 and TSS), nitrogen and coliforms to the lakes and streams in the watershed.

The MHIE then calculates for each farm the removal of the contaminants for a range of practices. Based on research gathered in this study and other related research the removal percentages were applied to the practices. All of the systems use septic tanks for primary treatment. A percentage of the contaminants will be lost in the septic tank and is estimated at 50% for BOD and TSS (Magdorf, 1974), 20% for nitrogen (Oakley, 2005) and 25% for phosphorous (Lombardo, 2006). The septic tank removals are included in the overall “System” removals.

A portion of the systems have additional pretreatment through an ATU or RMF. In these 319 studies, RMFs had an average removal of 10% of nitrogen, whereas the ATUs were effective in converting a majority of the ammonium to nitrate the overall removal of total nitrogen was not significant (Janni et al., 2008). The overall removal of contaminants in the ATU and RMF system include the trench system as well which followed the units.

The final treatment and dispersal occurred in a soil treatment in a trench system, bark bed or irrigation system. The soil treatment component has the most variability in published research as it based on numerous soil and design variables. Subsurface treatment with soil removal 100% of the organic material as measured by BOD_5, TSS and P. Since the soils in this watershed are not sandy or loamy sand and effluent is being evenly distributed at the surface covered with bark or shallowly below the surface a 50%

removal of nitrogen is estimated (Tetra-Tech, 2012). This 50% removal was added to the 25% removal in the septic tank for the bark bed and ATU systems.

The irrigation systems were designed to both assure a majority of the wastewater is absorbed, by limiting slope and application rates, into the soil and meet the nutrient requirements of the crop. Several factors decrease the 100% removal of contaminants including winter application, saturation of pores during wetter time periods and surface runoff. In an EPA report from 1974, 85% removal of N and a 90% of P is estimated using surface spray irrigation along with 98% removal of BOD and TSS. A summary of the removal efficiencies (RE) is shown below in Table 4.

Contaminant/ System	**Bark System**	**Irrigation System**	**ATU System**	**RMF System**	**Average Removal**
BOD_5	100	98	100	100	99.5
TSS	100	98	100	100	99.5
Nitrogen	75	85	75	85	80
Phosphorous	100	90	100	100	99.5

Table 4. Contaminant removal efficiencies by system and averaged.

Since it is unknown which system a producer will install the average removal was used to calculate the overall removal of contaminates. Such an evaluation maybe performed in a watershed to show the potential benefit of moving forward with an enforcement program tied to dairy milk house discharges. Carver County is not requiring reporting or tracking the management of the systems; therefore a 10% reduction in overall removal was included in the model. Long term management of these systems is critical to achieving the long term reduction of pollutants. Experience during these 319 projects found that many producers do not have the time or resources to actively manage their milk house wastewater systems. Therefore a strong county role is beneficial to assure management is being performed.

Table 5 below documents the removal by farm using the averaged values from the table above. The average pounds removed of each contaminant was found for each of the seven farms using the following equation:

CL in pounds/yr X RE% X Management Reduction of 10%

The row labeled “Total (100%)” represents if all the farms installed a milk house treatment system. This value was then used to estimate the removals if only five (71%) or three (43%) farms installed the practice. The average removal was found by adding together all farms removal for a given contaminant and dividing by seven. All of these are estimates and therefore average removal seems appropriate.

Farm/Cows	**BOD_5 Removal (lbs/yr)**	**TSS Removal (lb/yr)**	**Phosphorous Removal (lbs/yr)**	**Nitrogen Removal (lbs/yr)**
1/29	847	315	20	26
2/45	1314	488	31	41
3/50	1460	542	34	46
4/50	1460	542	34	46
5/55	1607	597	38	50
6/65	1899	705	44	59
7/75	2191	814	51	68
Total (100%)	10,778	4003	252	336
5/7 farms (71%)	7699	2859	180	240
3/7 farms (43%)	4619	1716	108	144
Average removal	1540	572	36	48

Table 5. Contaminant removal summary.

This data documents that even with as few as three producers participating, the overall impact to the Carver Creek watershed will remove 4,619 pounds of BOD_5, 12,716 pounds of TSS, 108 pounds of phosphorous and 144 pounds of nitrogen. All of the above calculations are based on assumptions and average values. This assessment assumes that the systems designed and installed will perform at least as well as those installed during the research project. Another large assumption is that the producer will use and manage the system properly.

An evaluation was done to determine the sensitivity of the results based on several of the assumed values. The first variable considered was the flow. The model assumes 5 gallons per day per cow, but in the study a range of 2.3 to 9.3 g/cow was found. These values were used to calculate the range in removals and the data is presented in Chart 1. The variance in flow makes a larger influence on BOD and TSS removals than the nutrients of N and P.

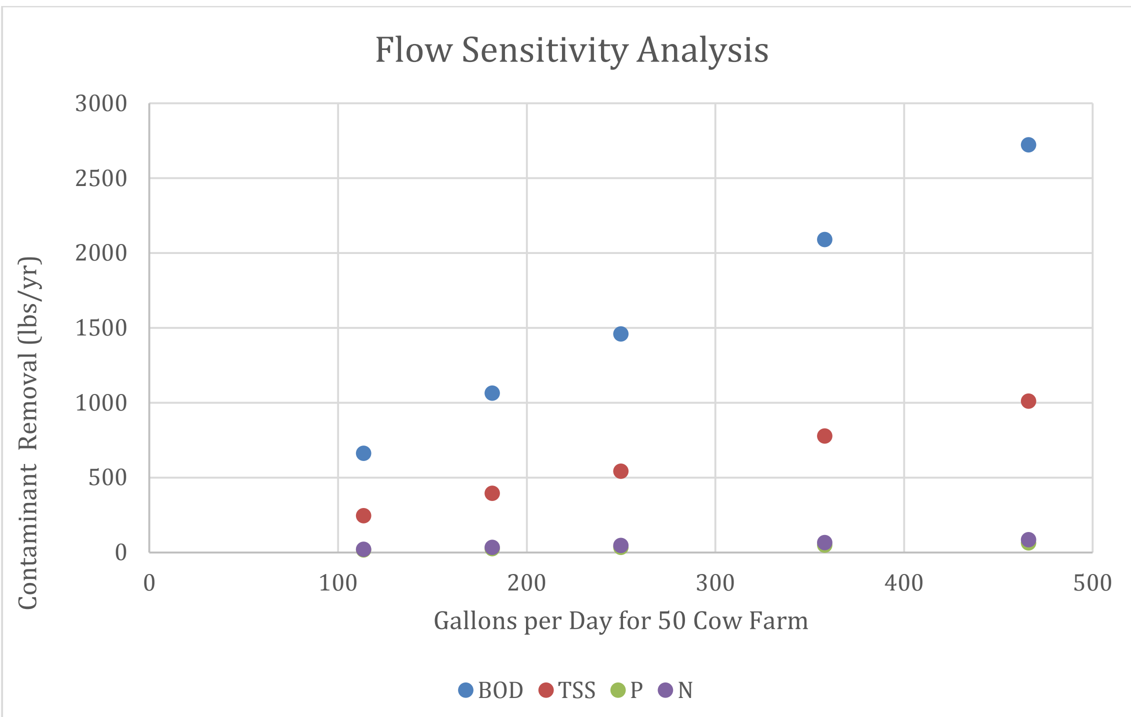

Figure 5. Removal of contaminant estimates at varying flow inputs.

There is also uncertainty in the input values for the contaminants. Evaluating the standard deviation range for BOD and N was performed across farms ranging in size from 25 -75 cows holding Q steady at the value at 5 gallons/cow. For smaller operations the difference is much smaller compared to larger producers. This points out that to truly have accurate estimates of removal actual flows and wastewater characteristics from the farm are important.

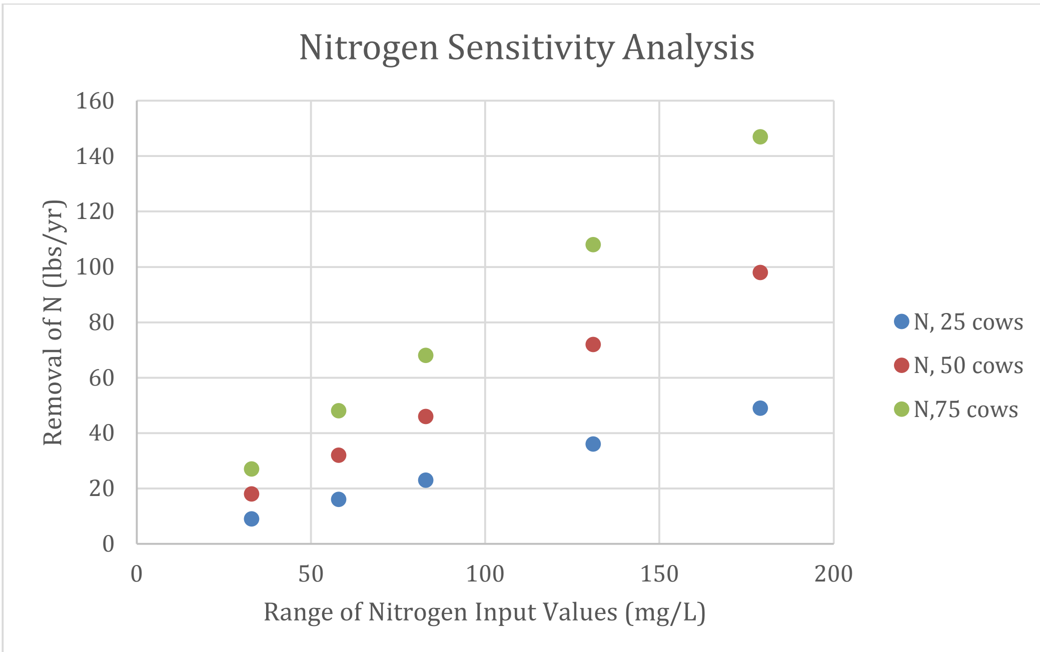

Figure 6. Removal of nitrogen and varing nitrogen inputs.

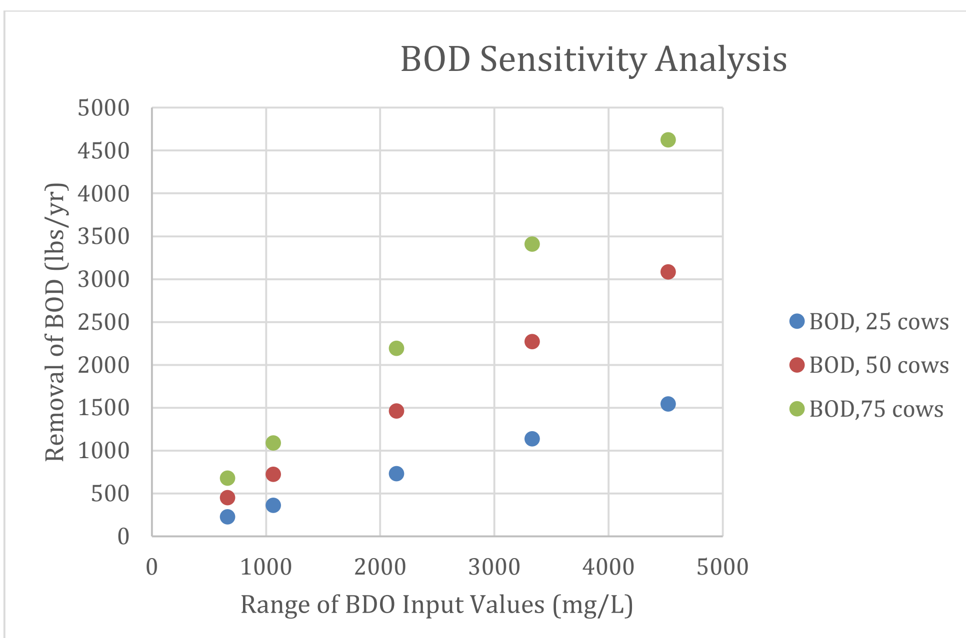

Figure 7. Removal of BOD and varing BOD inputs.

The removal of contaminants was also determined on a cost per pound of removal. As presented in Table 1 in Chapter 4 the average cost of installation for the milk house systems was $11,000 with an average annual operating cost of $200. The installation and ongoing operation costs were annualized assuming a 3% inflation rate with an assumed design life of 20 years. Over 20 years the average cost was found to be $16,735. The average annual removal for each contaminant was then take from Table 5. The cost per pound of contaminant was calculated using the following equation:

$16,735 ÷ Contaminant in pounds = $ cost per pound

	BOD_5	**TSS**	**Phosphorous**	**Nitrogen**
Cost per Pound	$0.5	$1.5	$23.2	$17.4

Table 6. Cost per pound of removal for milk house wastewater systems.

These values were compared to other potential removal techniques focusing on phosphorous which is primary impairment in this watershed. Lazarus et al. (2014 and 2015), estimates the following cost per pound for the various techniques:

Technique	**Cost per Pound P**	**Cost per Pound N**
Riparian buffers	$45.8	$16.3
Cover crop on corn and soy	$2088.8	$36.7
Control drainage	$64.5	$2.4

Table 7. Cost per pound of removal of N and P for other practices.

This data indicates that the reductions achieved in P removal are one of the lowest cost options available to producers and watersheds which include small to mid-sized dairy farms. The cost of removing nitrogen with milk house treatment systems will be more of a median value per pound of removal.

MILK HOUSE IMPROVEMENT USERS GUIDE

Funding Provided By:
Legislative – Citizen Commission on Minnesota Resources

July 8th, 2015

University of Minnesota, Water Resources Center

Onsite Sewage Treatment Program

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

USE OF THE GUIDE

This Guide provides guidance to users of the Milk house Improvement Estimator (MWIE) August 2015 Version. This document is designed to assist the user with data entry and interpretation. A reference list which the spreadsheet is based on is included.

The MWIE 2015 will be updated based on input from users. If you have any questions or comments, please feel free to contact Sara Heger at the University of Minnesota (sheger@umn.edu). Your comments will allow us to continuously improve the MWIE.

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AUTHOR

This document and spreadsheet were created by Sara Heger. Please contact her at sheger@umn.edu or 612-625-7243 with questions or comments about the spreadsheet.

Milk House Improvement Estimator (MWIE) Users Guide

BWSR is the Minnesota Board of Water and Soil Resources, and it administers programs that prevent sediment and nutrients from entering our lakes, rivers, wetlands, and streams; enhance fish and wildlife habitat; and protect wetlands. BWSR receives appropriations from the Clean Water, Land & Legacy Amendment to pay for on-the-ground conservation projects that provide multiple benefits for water quality and wildlife habitat. Increasingly, BWSR grant funds have been used to upgrade failing milk house wastewater systems. Part of receiving these grants is submitting data about the pollutant load removal and there was previously no standardized approach to reporting these results as required by the legislature. Therefore the Milk House Wastewater Improvement Estimator (MWIE) was developed. It is a spreadsheet-based model that calculates annual pollutant loads from problematic milk house wastewater systems and accounts for the benefits of a range of milk house wastewater improvements. This tool is intended for use on projects where the producers cannot add the milk house wastewater to liquid manure storage. This paper provides an introduction to the MWIE, as well as tips and instructions for using it. This paper accompanies the Microsoft Excel file with the title **MWIE_June 2015.xlsx**. The Excel file can be downloaded at http://www.bwsr.state.mn.us/outreach/eLINK/ . It can be modified to fit different regulatory requirements and systems across the US.

SECTION 1. ESTIMATOR STRUCTURE AND OVERVIEW

The MWIE has three steps: 1. Calculating Existing Pollutant Loads; 2.Calculating Removals with "Future" or Installed Management Practices (Figure 1). The data is entered in the gold cells and the results are reported in the maroon cells. The gold section of the worksheet summarizes the calculations completed in the maroon data entry section.

Figure 1. Spreadsheet flowchart.

Contaminants of Concern
Due to their documented impacts to surface and ground water the contaminants of concern addressed in this model are discussed below. There are two values identified for each parameter one for a parlor milking system, the other for a pipeline system. Generally speaking a parlor is an isolated room or separate building to which cows kept on a loose-housing system are taken for milking. On

the other hand a pipeline is typically is installed above the cow stalls and the cows are milked in sequence by moving from one cow to the next down the row of stalls. If you are uncertain which type of milking system the system has contact the producer or designer of the system.

Biochemical oxygen demand, five-day(BOD_5) : quantitative measure of the amount of oxygen consumed by bacteria while stabilizing, digesting, or treating biodegradable organic matter under aerobic conditions over a five-day incubation period; expressed in milligrams per liter (mg/L) . Assumed value for milk house wastewater is 1845 mg/l for a parlor milking system and 2141 for a pipeline milking system (Janni et al., 2009).

Solids, total suspended (TSS): measure of all suspended solids in a liquid, typically expressed in mg/L; to measure, a well-mixed sample is filtered through a standard glass fiber filter and the residue retained on the filter is dried to a constant weight at 103 to 105 degrees C; the increase in the weight of the filter represents the amount of total suspended solids (CIDWT, 2009). Assumed value for milk house wastewater is 870 mg/l for a parlor milking system and 795 for a pipeline milking system (Janni et al., 2009).

Phosphorus (P): chemical element and nutrient essential for all life forms, occurring as orthophosphate, pyrophosphate ($P_2O_7^{-4}$), tripolyphosphate ($P_3O_{10}^{5-}$), and organic phosphate forms; each of these forms, as well as their sum (total phosphorus), is expressed in terms of milligrams per liter (mg/L) elemental phosphorus; occurs in natural waters and wastewater almost solely as phosphates; excess levels of phosphorous in fresh surface waters may contribute to eutrophication. Assumed value for milk house wastewater is 74 mg/l for a parlor milking system and 50 for a pipeline milking system (Janni et al., 2009).

Nitrogen (N): essential chemical element and nutrient for all life forms; molecular formula (N2), constitutes 78 percent of the atmosphere by volume; nitrogen is present in surface water and groundwater as ammonia (NH_3), nitrite (NO_2-), nitrate (NO_3-), and organic nitrogen; excess levels of nitrogen in marine areas may contribute to eutrophication. Assumed value for milk house wastewater is 95 mg/l for a parlor milking system and 83 for a pipeline milking system (Janni, et al., 2009).

A summary of the raw wastewater constituent concentrations used in the model is shown in Table 1.

Contaminant	Parlor Value	Pipeline Value
BOD (mg/l)	1845	2141
TSS(mg/l)	870	795
P (mg/l)	74	50
N (mg/l)	95	83

Table 1. Raw wastewater characteristics used in model.

Primary Data Sources

For this spreadsheet to provide accurate estimates of removal of contaminants three key data parameters are needed for each system:

1. Estimated flow
2. Existing system status – used to calculate existing pollutant load
3. Type of new system installed – used to calculate removals

If any of this data is unknown when the user is entering data, the spreadsheet will make assumptions which are described in each section.

Calculating Existing System Pollutant Load

The spreadsheet allows two options for determine the flow of wastewater from the milk house:

1. Flow meter data – This is the best option for design a system and evaluating the current pollutant load
2. Use the number of cows to estimate the flow using 5 gallons per day per cow

This results in the following values:

Cows	Gallons per Day
25	125
50	250
75	375
100	500
125	625

Table 2. Gallons per day of estimated wastewater production based on the number of cows.

The user then enters the type of existing system with the choices of discharge:

Previous System Coding	
NA =	Not available
1 =	Surfacing to lake, river, stream, wetland or ditch including tile line
2 =	Surfacing to the ground with high probability for runoff (slopes greater than 5%)
3 =	Surfacing to the ground with medium probability for runoff (slopes from 1-5%)
4 =	Surfacing to the ground with low probability for runoff (slopes less than 1%
5 =	Holding Tank/Pump & Haul
6 =	Underground treatment system that is not surfacing

Table 3. Previous system types and code.

If the user does not know the status of the existing system the spreadsheet assumes a value of 1. The tool then determines how much of the pollutant load the existing system was removing using the following percentages

Contaminant	Existing System Status					
	1	2	3	4	5	6
BOD_5	0	0	0	0.5	0.75	0.5
TSS	0	0	0	0.5	0.75	0.5
Nitrogen	0	0	0	0.25	0.75	0.25
Phosphorous	0	0	0	0.5	0.75	0.5

Table 4. Removal percentages for existing systems based on system type.

Calculating Reduction in Load with New System

The user enters the type of new system installed. For more information about the design of these systems see: http://www1.extension.umn.edu/agriculture/manure-management-and-air-quality/wastewater-systems/

The option included in this estimator are connecting to large storage device with land application or installing a new milk house wastewater treatment system (MWTS) from the list below:

New System Coding	
NA =	Not available
1 =	Bark bed
2 =	Irrigation System
3 =	Holding Tank/Pump & Haul
4 =	Aerobic treatment unit with subsurface treatment system
5 =	Media filter with subsurface treatment system
6 =	Flocculator with subsurface treatment system
7 =	Vegetated Treatment Dosing System

Table 5. New system types and codes.

When a new MWTS is installed the model uses the values in Table 4 to calculate the reduction in contaminants. Most new systems are estimated to remove 100% of the BOD_5 and TSS and phosphorus as they all have a minimum of 2 feet of soil treatment or a pretreatment unit followed by a soil treatment system that in combination will achieve this level of treatment (Bouma, 1979, Heger et al., 2010). There is one acceptation which is a holding tank/pump and haul as there may be times of the year when the effluent is land applied and the effluent may run off. The 100% removal of phosphorus is based on field and laboratory studies documenting phosphorus removal below soil treatment areas (Sawhney, 1977; Bouma, 1979). If the soil treatment system is functioning correctly, and proper setbacks are maintained from surface waters and vertical separation from periodically saturated soil, problems from phosphorus movement to surface water or groundwater should be minimal in most systems and soils in Minnesota.

Nitrogen removal varies by type of system installed. Below ground systems are estimated at 75%. Above ground application is estimated from 80 – 85% with the biggest factors being the potential for runoff and the harvesting of a crop.

Contaminant	**New System**						
	1	2	3	4	5	6	7
BOD_5	100	98	75	100	100	100	100
TSS	100	98	75	100	100	100	100
Nitrogen	75	85	75	75	85	50	80
Phosphorous	100	90	75	100	100	100	100

Table 6. Removal percentages for new systems.

Calculating Impacts of Management

Under section three of the spreadsheet the model quantifies if the system management will be actively tracked by the local governmental unit. All MWTS shall regularly, but in no case less frequently than annually, have their tanks evaluated to determine if the septic tanks need cleaning and then an evaluation of the remainder of the system. BWSR assumes that when system are installed they are appropriately managed so the system has a long term benefit to the environment. The tool will reduce the removal of contaminants by 10% if the system will not be managed.

SECTION 2. DATA ENTRY OVERVIEW

The MWIE is a simple model with relatively minimal data input. This section describes some components of the MWIE and is designed to facilitate the data input process, as well as some tips for tracking down and avoiding errors in the model.

Color Coding

In order to make data entry easier, cells are coded in two colors: gold and maroon.

GOLD CELLS must be filled in.

MAROON CELLS have been calculated, and typically should not be overridden. They represent "bottom line" calculations, such as load reductions or final loads. If the user wants to override maroon cells he/she must go to the Review Tap and select Unprotect Sheet. *NOTE: If the worksheet is manipulated/changed in any way please indicate the change in the worksheet itself under comments.*

"Pop-Up" Guidance and Comments

Many pieces of input data require a decision on the part of the user. By clicking on many of the purple cells, a "popup" message will appear with guidance for data values (Figure 2).

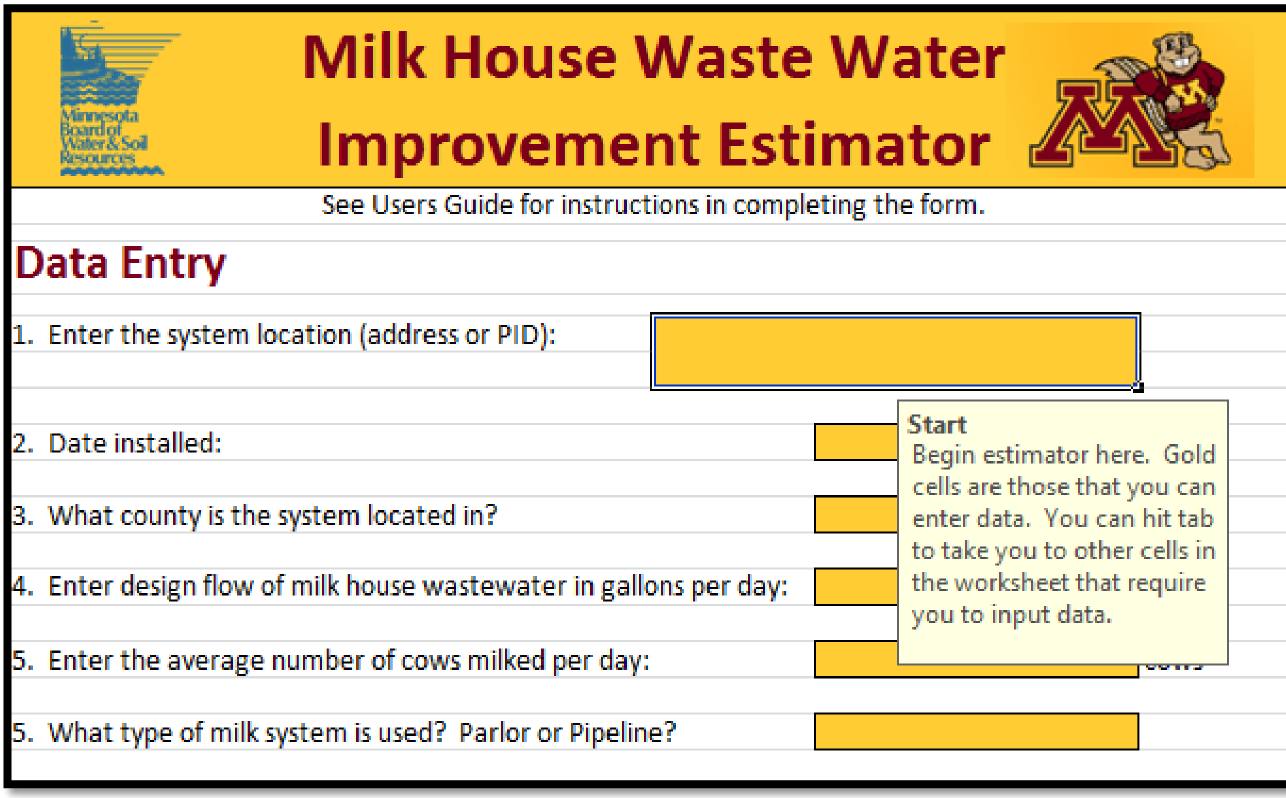
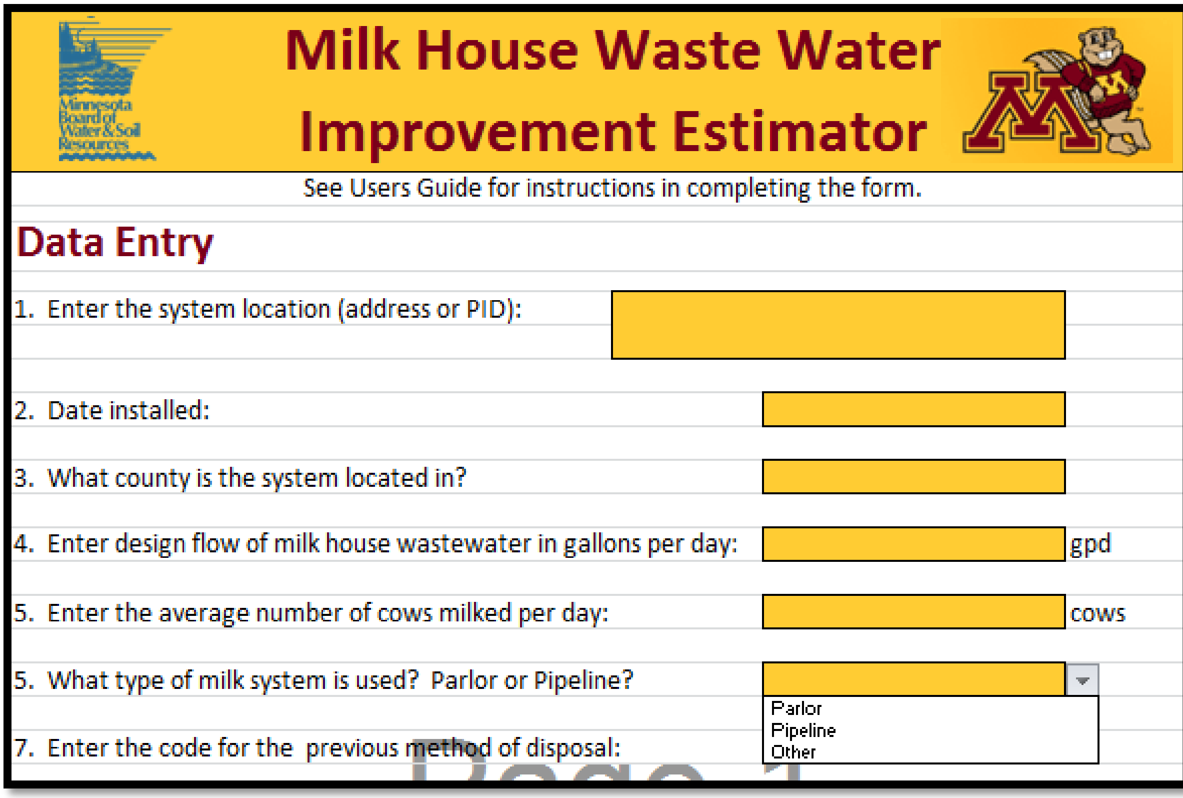


Figure 2. Example of pop-up guidance.

Pull-Down Menus

While many of the data in the MWIE require a number value, some of the inputs are multiple choice such as number of bedrooms or result in a "yes/no". The MWIE uses "pull down menus" for these questions. For these cells, the user should not (and cannot) select an option that does not appear in the menu (Figure 3).


Milk House Waste Water Improvement Estimator

See Users Guide for instructions in completing the form.

Data Entry

1. Enter the system location (address or PID):
2. Date installed:
3. What county is the system located in?
4. Enter design flow of milk house wastewater in gallons per day: gpd
5. Enter the average number of cows milked per day: cows
5. What type of milk system is used? Parlor or Pipeline?
Parlor
Pipeline
Other
7. Enter the code for the previous method of disposal:

Figure 3. Example of pull-down menu.

Locked Cells

To make the spreadsheet application consistent the non-purple cells are locked/write protected. The other benefit this provides is that the user can "Tab" from purple cell to purple cell during data entry. If the user is applying this model in other applications or needs greater flexibility the worksheets can be unprotected under Review, Unprotect Sheet. *NOTE: If the worksheet is manipulated/changed in any way the user is instructed to indicate the change in the worksheet itself under comments.*

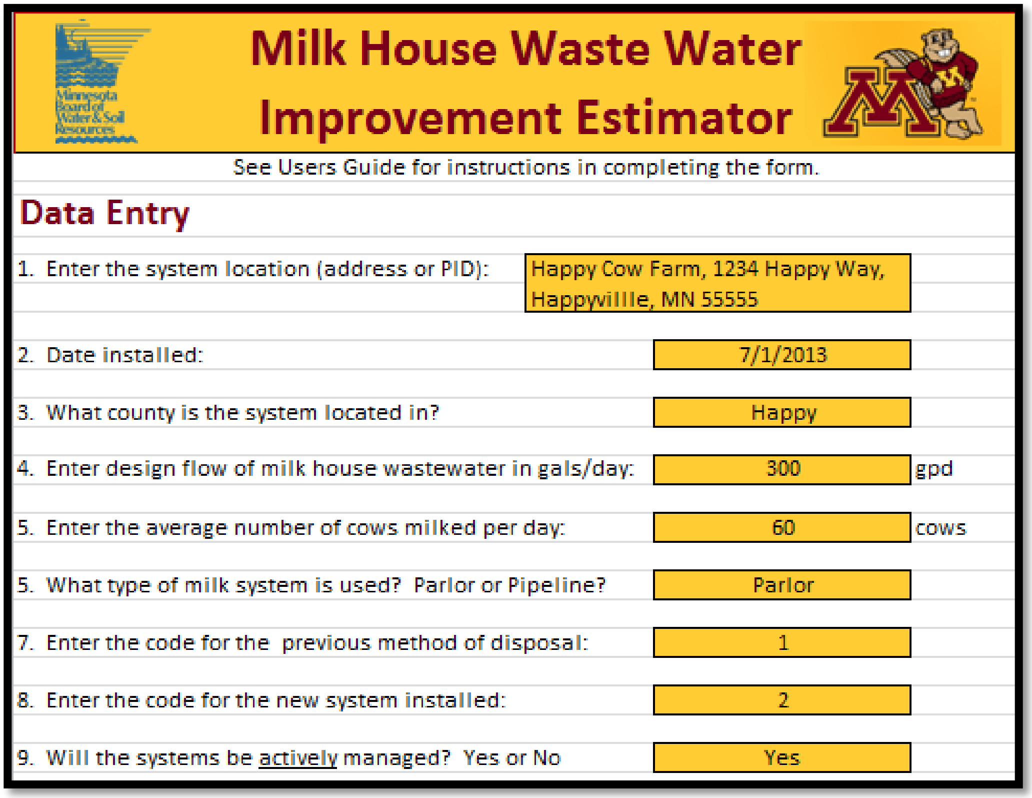
SECTION 3. DATA ENTRY DETAILS

This section describes in detail the data entry requirements of each section of the MWIE.

1. Enter the system location identifier. This can either be the parcel identification number or the address. If at the time of submitting an application the address is unknown enter "Unknown".
2. Enter the date the new system was or will be installed.
3. Enter the county the system is located in.

4. Enter the design flow of the milk house wastewater treatment system. If you do not know this information contact the designer/engineer for the project.
5. Enter the number of cows on average milked per day.
6. Enter what type of milking system is used, either a parlor or pipeline, or other.
7. Select the appropriate existing disposal system code from the drop down menu as shown in Table 3. If you do not know this information contact the designer/engineer for the project. If this information is unknown by anyone enter "NA"
8. Select the appropriate new system code from the drop down menu as shown in Table 5. If you do not know this information contact the designer/engineer for the project. If this information is unknown by anyone enter "NA".
9. The next step is select "Yes" or "No" from the drop down list regarding management. In order to answer this question "Yes" the LGU must have a program to <u>actively</u> track the proper maintenance of systems that are being funded under this project. If the maintenance tracking is left solely up to the property owner enter "No".

Below in Figure 4 you will see an example of a farm that had a system with 60 cows milked in a parlor which had previously discharged to a ditch and installed an Irrigation System that will be activity managed.



Milk House Waste Water Improvement Estimator

See Users Guide for instructions in completing the form.

Data Entry

1. Enter the system location (address or PID):	Happy Cow Farm, 1234 Happy Way, Happyvillle, MN 55555	
2. Date installed:	7/1/2013	
3. What county is the system located in?	Happy	
4. Enter design flow of milk house wastewater in gals/day:	300	gpd
5. Enter the average number of cows milked per day:	60	cows
5. What type of milk system is used? Parlor or Pipeline?	Parlor	
7. Enter the code for the previous method of disposal:	1	
8. Enter the code for the new system installed:	2	
9. Will the systems be actively managed? Yes or No	Yes	

Figure 4. Example diagram of completed data entry for a system.

RESULTS

Under Results from the MWIE are reported. The table provides the additional removal of Biochemical Oxygen Demand, Total Suspended Solids along with the nutrients Nitrogen and Phosphorous based on the data entered after the new system has been installed. The results are all in pounds and tons of contaminant removed Figure 6 below shows the output for the systems inputted in Figure 5.

Results

	Pounds	Tons
Additional BOD_5 Removed per Year	1687	0.84
Additional TSS Removed Per Year	795	0.40
Additional Phosphorus per Year	67.4	0.03
Additional Nitrogen per Year	69	0.03

Comments:

Figure 5. Table of Results.

SUMMARY

The Milk house wastewater improvement estimator is a spreadsheet based tool to estimate the impacts of upgrading milk house wastewater systems. It was implemented in 2014 in Minnesota and was refined in 2015.

Chapter 6. Conclusions and Future Research Needs

a. Conclusions

This project was successful in developing, validating, sampling and evaluating four systems to reduce the contaminant load form diary milk house for smaller dairy operations without access to large storage devices. Milk has a very high BOD_5, around 100,000 mg/L. The milk house wastewater systems used for this project were not designed to handle waste milk such as form treated cows. It was learned that producers needed to make management changes to reduce the amount of waste milk that entered the milk house wastewater treatment system. The initial data collected underestimated typical organic loading and as a result of this work a minimum of three days of hydraulic retention time should exist in the septic tank with up to six days being ideal for all milk house systems due to the high organic loading.

During the installations at the generally older farmsteads of the producers participating in the study the study encountered buried pipe, drainage lines and electrical lines. These unexpected obstacles found during installation added to the installation costs due to the time needed to deal with them. Several farms had domestic wastewater combined with the milk house wastewater. The wastewater systems used for this project were not designed to treat human wastes and did not meet onsite sewage treatment rules for treating human wastes. Electrical installation costs were higher than estimated.

Water table and soil conditions at the cooperating dairy farm sites limited the wastewater system options that could be used. All of the sites had fairly heavy soils and high water tables. Other treatment options may be available for sites in other parts of Minnesota with other soil types and hydrological conditions.

All of the installed systems require regular maintenance and proper operation to maintain performance. The primary treatment septic tanks should be pumped when the sludge layer is more than twelve inches thick or the scum layer is more than six inches thick. ATUs must be serviced by supplier representatives at the frequency required by the manufacturer, but no less than once per year.

The ATUs and RMFs in this project were the first of their kind to treat milk house waste water. They were found to have the highest up front cost system with a corresponding higher maintenance need they the other two systems evaluated. Several of the ATUs had noticeable offensive odor during start up while others had some foaming. As the aerobic bacteria became established, these problems abated – typically within the first two to four months. In heavily textured soils, settling around the ATU was a problem. Proper backfilling techniques are necessary to limit this problem. Although the ATU's were able to significantly reduce the organic loading (BOD_5) of the milk house waste, it is unlikely that these systems could be designed and operated to consistently achieve BOD_5 concentrations less than 25 mg/l without significant additional costs in additional equipment and monitoring. As a result of this experience, aerobic treatment systems should be used solely as a pretreatment option for subsoil infiltration or a bark bed. The ATUs were generally effective at reducing the organic load to an effluent quality that could be dispersed to the soil for final treatment. Based on the experience with the first stage of the project, the RMFs were installed with drain fields following. Focusing on stanchion barns, the removal in the ATUs and RMFS of BOD_5 ranged from 42-89%, TSS from 0-82%, phosphorous from 3 to 47% and nitrogen from 0 – 20%. With drainfield following these systems there was a 100% removal of BOD_5, TSS and phosphorous and a 75% removal of nitrogen.

Bark beds were found to be a relatively low cost systems with minimum management. The bard bed design used initially in this design called for header pipe along the short end of a rectangular bed systems, but due to the failure of the bark bed system with gravity distribution, pressurized distribution systems with multiple laterals are recommended for bark bed systems to uniformly apply the wastewater to the soil. It is recommended that the sizing of the infiltration area be larger than the recommended soil organic loading rates due to the variability in the wastewater from farm to farm. The bark beds are effectively at removing 100% removal of BOD_5, TSS and phosphorous and a 75% removal of nitrogen.

For the first time, this project was successful in demonstrating and testing year round surface irrigation systems with milk house wastewater. The initial producer in part I of the study experienced some odors for 30 minutes during and immediately following irrigation of the wastewater. The application was adjusted to coincide with times when the odors will not be noticed. During the first winter the aluminum riser pipes in the irrigation system fatigued and broke. These riser pipes were replaced with 1 inch PVC surrounded by foam insulation and attached to 4 x 4 in. treated posts set in the ground two to three feet. It is unclear if the insulation on the riser pipes is necessary. The irrigation systems remove an estimated 98% of BOD_5, 85% of TSS and phosphorous and 90% of the nitrogen.

Based on the findings of this project the MHIE tool was developed to estimate the removal of contaminants when the varying systems are installed. To have the best estimates it is recommended that flow data be gather versus estimated based on cow numbers.

b. Future research needs

Results from this research have provided the ability to design effective systems that will perform in Minnesota, but a number of questions concerning milk house wastewater treatment systems remain. Future research should focus on the following questions:

1. Are current design guidelines adequate? Many of the wastewater treatment systems are still are designed according to the guidelines of the NRCS (1991). Do these procedures result in the best design? If so, under what circumstances does it function at a maximum? Can adjustments to the guidelines be made that will improve performance? With present data, it is difficult to determine whether any given design is preferable. Results are not easily comparable since systems of various designs treat different wastes, use different pretreatment structures, and are in different areas of the U.S. Different design methods could be used to construct a number of systems at a single site, to test their effectiveness in treating the same wastewater under the same conditions.
2. Should the design be based on BOD loadings or on other parameters? The range of systems evaluated were all impacted by the organic loading, but often hydraulics are the only parameter evaluated during design.
3. Are site specific results applicable to other areas? What climatic conditions must be met in order for systems to be effective? Should designs be different for

different regions? Evaluate the use of constructed wetlands in Minnesota for milk house wastewater.

4. How can the cost to the farmer be minimized? Research concerning the use of wastewater treatment systems should focus on maximizing their potential for contaminant removal while minimizing their cost. The goal of research on all animal wastewater treatment structures is to foster the widespread treatment of animal wastewater in order to protect the quality of surface and groundwater. When is the use of anaerobic digestion and the capturing of energy a feasible options for small to mid-sized dairy producers?
5. Evaluate long term impacts to the soil and groundwater. There is the risk particularly with phosphorous and nitrogen of accumulation, lack of treatment and a plume of effluent with elevated levels reaching a surface water or groundwater. Longer term data collection with down gradient monitor wells should be done to evaluate this concern.
6. Evaluate different cleaners and sanitizers to sanitize the equipment but with reduced contaminant loading focusing on a reduction of phosphorous and strong persistent disinfections such as quaternary ammonia.
7. How effective are these systems over the long term based on varying producer's management styles both inside and outside the milking facility?
8. Could the MHIE be improved by including additional farm data related to site characteristics?

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