Evaluation of Silage Leachate and Runoff Collection Systems on Three Wisconsin Dairy Farms

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Abstract

As farm enterprises have grown and farming systems have changed, an increasing number of Wisconsin livestock producers are using bunker silos, stacking pads, silo bags and commodity storage sheds more extensively. These storage facilities can allow for rapid harvest, increased flexibility and improved performance of ensiled materials; but concerns have arisen regarding water quality. The potential of high concentration flow moving from these storage facilities to waters of the state needs to be evaluated. Current silage runoff collection systems are designed based on the “first flush” concept used in the urban setting regarding pollutants in storm water runoff. Identified in urban research, first flush events are events where a majority of the contaminants are transported in the initial runoff volume. Subsequent to initial first flush collection, flow from feed storage facilities is sent to a secondary treatment, which is often a vegetated treatment area (VTA). Treatment of all water from feed storage facilities is required up to 25% of the 25-year, 24-hour storm design established in *Natural Resources Conservation Service Conservation Practice Standard Code 629, Waste Treatment.* This research evaluated silage leachate system performance on three private farms in Wisconsin from 2012 to 2014. The concentration and loading of sampled constituents from events to both collection systems and overflow to vegetated treatment areas was evaluated. Minimal leachate was observed. Only events associated with precipitation were large enough to initiate sampling. This study found that concentrations of monitored constituents were negatively correlated to flow, thus loading throughout runoff events was relatively consistent in respect to flow. Therefore, alternative system designs to collect low flow in comparison to first flush will increase the collection system loading efficiency.

1.0 Introduction

Over the past twenty years, Wisconsin has seen tremendous changes in the harvesting and storage of feed for ruminant livestock. As dairy farm expansion continues, the number of operations adopting farming systems that allow for the rapid harvest and proper storage of large quantities of feed continues to increase. This shift in feed storage has produced a move away from the typical upright silage storage facilities (silos) to horizontal storage facilities (bunkers, piles, or bags). The use of horizontal silage storage facilities can increase the speed of harvest and provide high quality feed when properly managed.

Ensiling feed preserves it for long term storage through fermentation. Crops are harvested and packed into bunkers by repeatedly driving over them with heavy machinery as feed is added. The compression of the feed allows more to be stored per area and reduces the amount of air within the feed. Once a bunker is full, it is covered and sealed to prevent air from entering, and the ensiling process begins. There are four stages to this process: aerobic, fermentation, stable, and feed-out. Aerobic microbial activity will occur until the oxygen in the feed is used up. During this process, water is released and nutrients are lost. Once oxygen is used up, conditions become anaerobic and fermentation begins. Fermentation reduces the pH (lactic acid) so that only the desired microbes (bacteria) can function. When all of the sugars in the feed are used up, microbial activity is minimal and the feed becomes stable and is preserved as long as air is not reintroduced. When it is time to feed the livestock, the bunkers are opened up for access to the silage and the feed-out phase begins. During this time, microbial activity is reactivated and spoilage will occur if the feed-out rate is less than the spoilage rate.

Silage leachate is the liquid produced in feed storage facilities from compaction and ensilage of harvested crops and is not unique to horizontal storage facilities. Crops (typically corn or hay in Wisconsin) harvested at high moisture levels can produce leachate in any storage facility. Leachate has the potential to be a significant pollutant due to its nutrient content and high

Table 1: Typical constituent concentrations of silage leachate compared to liquid dairy manure.

Constituent	Silage Leachate	Liquid Dairy Manure
Dry Matter	5% (2-10%)	5%
Total Nitrogen	1,500 - 4,400 mg/l	2,600 mg/l
Phosphorus	300 - 600 mg/l	1,100 mg/l
Potassium	3,400 - 5,200 mg/l	2,500 mg/l
pH	4.0 (3.6 - 5.5)	7.4
Biochemical Oxygen Demand (BOD_5)	12,000 - 90,000 mg/l	5,000-10,000 mg/l

Source: Wright and Vanderstappen (1994) and Ontario Ministry of Agriculture Food and Rural Affairs, Agdex No. 723.

biological oxygen demand (Table 1). Silage runoff is precipitation induced flow from feed storage facilities as a result of rain/snowmelt flowing through stored feed, litter, and spoilage piles. Silage runoff also has the potential to have negative environmental impacts. Wright & Vanderstrappen (1994) have observed feed storage flow increase with dairy farm expansion. As a result of increased use of bunker silage facilities, concerns have arisen about the potential for silage leachate and feed runoff to flow from storage facilities to waters of the state.

The majority of leachate is produced in the first two weeks after bunker filling, regardless of the moisture level when harvested and stored (Bastiman 1976). Crop moisture levels at harvest is the primary factor influencing leachate production (Bastiman 1976). Crop moisture levels at harvest are closely monitored by farmers for multiple reasons. Silage (both corn and hay) harvested at greater than prescribed moistures has an increased prevalence of Clostridia bacteria. These bacteria produce nitrogen compounds and butyric acid that can result in:

- reduced animal feed intake
- reduced silage protein levels
- increased spoilage
- ketosis - a serious health and productivity problem in dairy cows

Other risks associated with improper silage management are listed in Table 2. Some are more common than others and vary in severity. Proper silage management not only produces quality feed and reduces health risks, but also reduces leachate production and resulting runoff risk. Farmers participating in this study, in addition to farmers that were initially contacted to participate, indicated that stored feed would likely not be fed to lactating cows if a leachate event occurred and great care was taken to prevent this from happening.

Table 2: Spoilage and health risks (human and/or animal) associated with improper silage management.

Reduce feed value	Reduce palatability	Toxic gas production
Botulism	Lung, liver, & kidney damage	Allergic reactions
Reproductive problems	Immune suppression	Aflatoxicosis
Listeriosis	Ketosis	Death

Source: Elferink et. al. (1999) and NRCS (1995)

Most feed storage areas are constructed from impervious materials such as concrete or asphalt. This does not allow for infiltration and results in a high potential for runoff. High potency liquid on an impervious surface increases the risk for negative impacts to water quality downstream from these storage structures. Potential impacts on surface and groundwater quality include: nutrient loading, decreased dissolved oxygen levels in the water, and vegetative die-off that would otherwise filter flow and uptake nutrients. Because of this risk, treatment systems are mandated by *Natural Resources Conservation Service Conservation Practice Standard Code 629, Waste Treatment (NRCS Code 629).*

Feed storage treatment systems most commonly consist of both a leachate collection system and a vegetative treatment area (VTA). Current leachate collection systems are designed based on the “first flush” concept used in the urban setting regarding pollutants in storm water runoff. Identified in urban research, first flush events are events where a majority of the contaminants are transported in the initial runoff volume. The first flush concept for feed storage facilities is believed to maximize the constituent load per volume collected. Subsequent to initial first flush collection, flow from feed storage facilities is sent to a secondary treatment, commonly a VTA.

Per NRCS Code 635, Vegetated Treatment Area, “The conveyance system to the vegetated treatment area shall be designed for a minimum flow rate produced by the runoff from 25% of the peak flow of the 25-year, 24-hour storm event. The remaining portion of the 25-year, 24-hour runoff, which is expected to have negligible levels of contaminants, shall be diverted around the VTA in a non-erosive manner so as not to inundate the VTA.” The sizing requirement for both the leachate collection system and VTA can be customized to best fit the individualized farm requirements of storage and land for VTAs. Thus, increasing the percent of the first flush collected decreases the required VTA size and vice versa. Additional factors including feed storage area size, VTA soil thickness, VTA soil fines and VTA slope also determine the required sizing of VTAs. Applicable NRCS Practice Standard Codes for feed storage treatment systems are: Waste Treatment (629), Waste Transfer (634), Vegetated Treatment Area (635) and Waste Storage (313) with additional requirements for Concentrated Animal Feeding Operations in Wisconsin Administrative Code NR 243, Animal Feeding Operations.

It is important to understand the properties of silage runoff to ascertain if the design requirements are adequate, deficient, or excessive to comply with “no discharge” requirements while minimizing storage and handling costs. Collected first flush is most commonly sent to manure storage facilities. This increase in the amount of liquid going to storage can create manure application challenges and a need for more storage capacity. Secondary VTA treatment often takes land out of production or limit its use, so proper sizing of these VTAs is also important for farmers. These challenges can have a negative impact on farming operations. However, if not enough feed storage flow is collected or treated, the environment can be negatively impacted. Therefore, characterizing first flush and remaining volume of silage runoff is imperative to assess the most optimum system design to protect water quality while minimizing the collection of low strength silage runoff.

There are several methods used in urban runoff research to determine first flush and many are subjective. There are two types of first flush. The first type is *concentration first flush*, defined as having the highest constituent concentrations in the beginning of an event. Batroney (2007) describes an event with a concentration first flush as having three stages; i) a high initial concentration ii) followed by a sharp decline iii) then a relatively low and constant concentration for the remainder of the event. Weber (2010) defines concentration first flush as the peak concentration of a constituent occurring within the first 30% of the runoff volume. If acute toxicity is the concern, collection based on concentration first flush analysis may be the most viable option.

The second type is *mass (or load) first flush*, defined as having the highest constituent loading in the beginning of an event. To determine mass first flush, mass-volume curves are most commonly used. These curves normalize an event by using cumulative percent mass and cumulative percent volume for each event. An event with uniform distribution would have the same percent load as volume at any point in the event and would be represented as a straight line (commonly called the bisector line). One interpretation (Helsel 1979) states that if the curve goes above the bisector line at any point, it indicates a first flush. Geiger (1987) considers a deviation of positive 0.2 or greater from the bisector line significant; however, this deviation can occur anywhere along the bisector. A study done by Alias (2013) states that when a first flush occurs, the first 10% runoff volume is significant and first flush continues until 40% volume.

A more quantitative approach has been taken by several researchers. An arbitrary point on the plot is chosen as a benchmark with which to compare the curves from their data. Some of these include 80% of an event's load occurring by 20% of an event's volume (80/20) (Stahre & Urbonas 1990), 50/25 (Wanielista & Yousef 1993), 40-60/25 (Vorreiter & Hickey 1994); 80/30 (Bertrand-Krajewski et. al. 1998); and 40/20 (Deletic 1998). There is no standard definition that quantitatively defines a first flush.

Limited research has been done on silage runoff, so based on the best available information, current technical standards (Natural Resources Conservation Service Conservation Practice Standard Code 629 and 635) dictate system design criteria and sizing of VTAs based on the amount of first flush collected. NRCS Code 629.V.C.1.c.1 requires all leachate be collected on applicable farms. NRCS Code 635.V.D.1 further establishes that VTAs need to be designed to treat a minimum flow rate produced by the runoff from 25% of the peak flow of the 25-year, 24-hour storm event. The remaining portion of the 25-year, 24-hour runoff, can be diverted from entering the VTA as this remaining water is expected to have negligible levels of contaminants.

The United States Environmental Protection Agency has recently expressed concerns to the Wisconsin Department of Natural Resources about current operation/design of VTAs meeting Wisconsin Pollutant Discharge Elimination System "no discharge" requirements in Section 243.142(2)(b)4 Wisconsin State Statutes. Total containment up to a 25-year, 24-hour storm event could potentially be mandated for future system design unless alternative systems to more effectively collect high concentration silage runoff can be designed and/or modification and operation of VTAs to ensure "no discharge" can be established.

The current and future designs of runoff collection systems for feed storage facilities could benefit from a study characterizing individual runoff events. This research evaluated the quantity and quality silage runoff on three private farms in Wisconsin from 2012 to 2014. The objectives of this study were to characterize nutrient concentrations and other constituents in silage runoff throughout flow events to validate the existence of a first flush and to identify parameters that effect the concentration and loading of these parameters on an annual basis.

The concentration and loading of sampled constituents from events to both collection systems and overflow to VTAs was evaluated, allowing for the assessment of nutrient loading to VTAs via overflow of runoff from collection systems. Data from this study will also be utilized to evaluate current and future leachate collection system design to maximize loading per volume collected.

2. Material and methods

2.1. Study design and implementation

Leachate collection systems are designed to collect flow from the feed storage areas. Flow not collected by the collection system (overflow) usually goes to a VTA or filter strip for treatment. Collectively, the collection system and VTA are referred to as a treatment system. The proposed study design for monitoring existing silage leachate collection systems incorporated an "upstream/downstream" design that evaluates the constituents in flow at three stages of the treatment system (Figure 1). This study design was discussed and approved by the Leachate Study Oversight Committee established for this project.

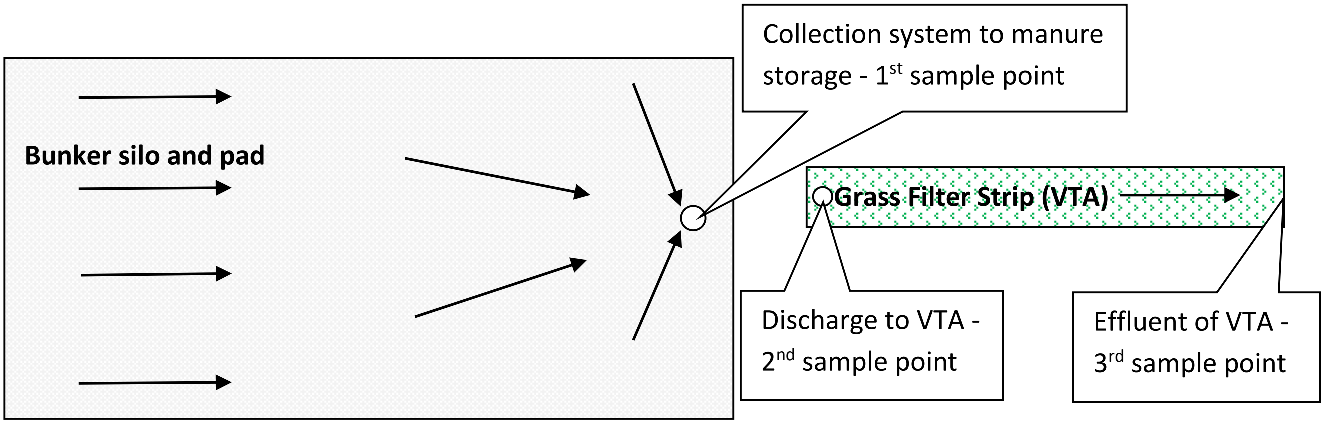


Figure 1. Leachate collection system monitoring design with sampling at three points.

UW Discovery Farms staff contacted Land Conservation Departments, Natural Resource Conservation Service staff, University of Wisconsin-Extension staff, agricultural producers, private consultants and other related industry personnel to identify suitable sites and potential cooperators for the leachate study. From these meetings, 26 farms were contacted and 17 farms were toured to determine the interest and monitoring feasibility. Of the farms toured, eight farms met the criteria for both moderate to high interest and monitoring potential.

The information from the eight farms was presented to the UW Discovery Farms Steering Committee to determine ranking of farms and these farms were contacted for participation in the order of ranking. One unexpected challenge of the original study design was the potential to collect a sample at the third sample point at the end of the VTA. Of all the farms toured, not a single site could be monitored at the VTA effluent. Installing a berm at the end of any of the VTAs observed would have caused excessive erosion from channeling of the liquid and would also be cost prohibitive.

2.2. Site descriptions

2.2.1. Farm A leachate collection system

Feed storage bunker size: 2.89 acres
Designed first flush depth collected: 0.05 inches
Leachate collection system built: 2011

Total impervious area: 3.79 acres
VTA size: 3.22 acres (3.19 acres required)

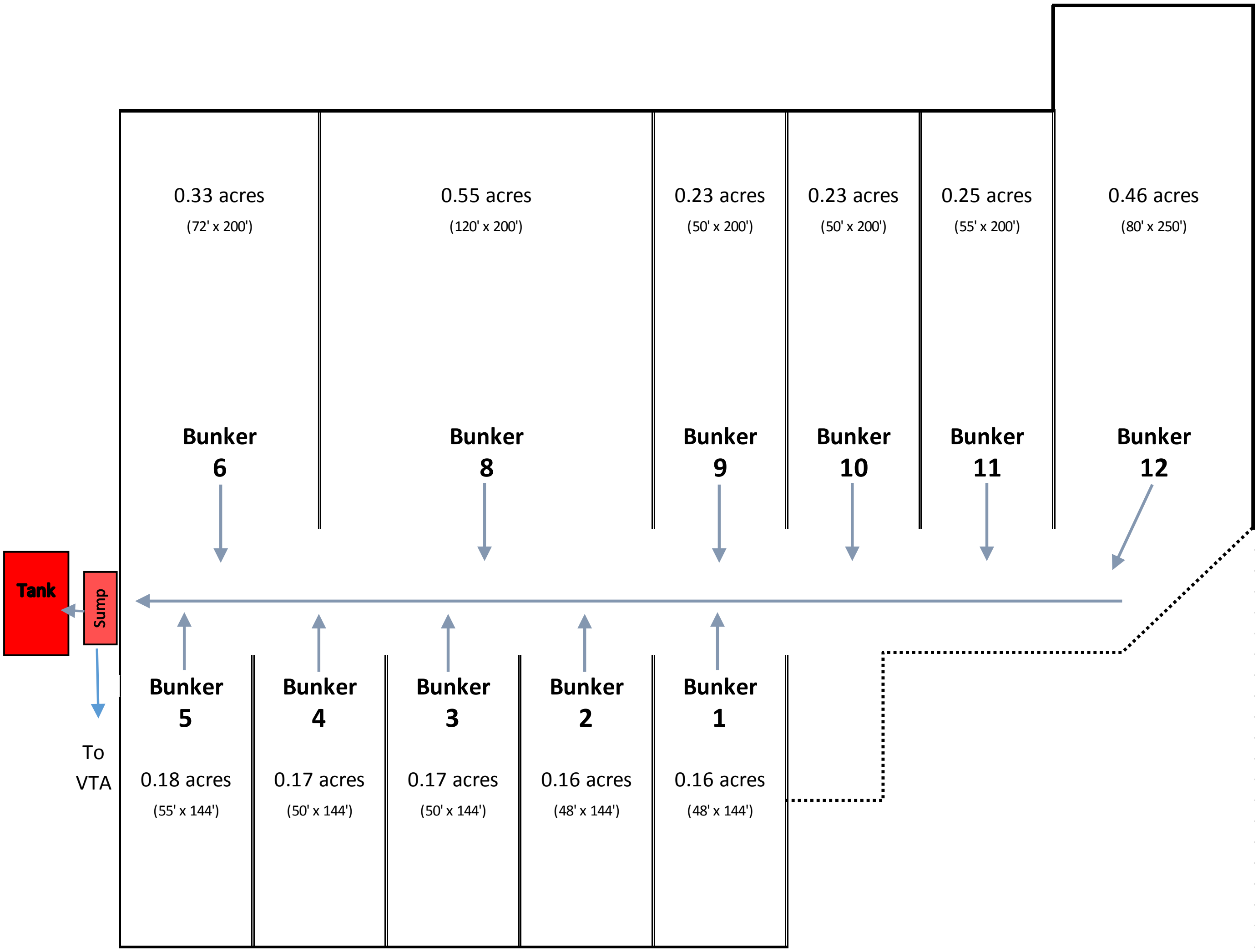


Figure 2: Feed storage bunker and leachate collection system layout for Farm A.

<u>General system function:</u>
Flow from bunkers comes to a combined flow channel (Figure2) and solids are separated out by a picket strainer (Figure 3). The separated liquid fraction of the flow flowing through the picket strainer flows to a 700 gallon collection sump and to a four-inch pipe in the bottom of the collection basin (Figure 4) that leads to the 8,000 gallon collection tank.

Figure 3: Particulate removed by picket strainer.

As fluid levels rise in the collection tank to collect the "first flush" of an event, a high level float switch turns on the 200 gpm pump and the liquid from the collection tank is pumped to the manure storage for a period of 40 minutes (up to a total volume of 8,000 gallons) or until the low level switch is activated. After a 24-hour period from when the pump was activated, the pump is again activated to empty the collection tank to remove stored liquid (up to a total volume of 8,000 gallons).

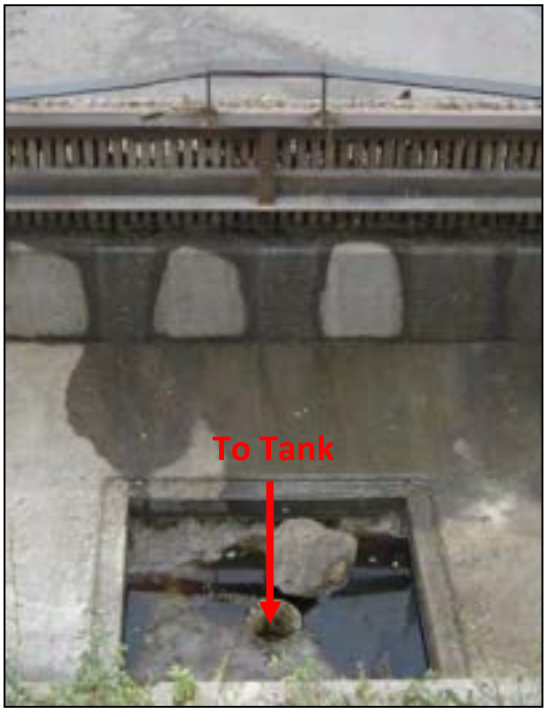


Figure 4: Leachate to collection tank.

Figure 5: Sump overflow to VTA.

Liquid from drain tiles both under the bunker and around the perimeter empty into the collection tank. The tank is pumped down to between a 1.5 to 2 foot level. This allows for a remaining volume of approximately 1,500 gallons of liquid from the previous event to remain in the tank. In addition, approximately 450 gallons of liquid backflows after the pump shuts off as a portion of the line from the tank to the manure storage drains back into the collection system tank. The incoming liquid not only mixes with this liquid remaining in the tank, but also is mixed with subsequent liquid entering the tank. There were no other options for monitoring the tank liquid at other locations at Farm A because they were inaccessible. Overflow to the VTA occurs when initial pumping of fluid from the collection tank ceases and the tank fills to capacity or if flow overwhelms the 4-inch line from the collection sump to the tank and fills the sump to capacity (Figure 5).

2.2.2. Farm B leachate collection system

Feed storage bunker size: 1.41 acres
Designed first flush depth collected: 0.05 inches
Leachate collection system built: 2012

Contributing drainage area: 3.5 acres
VTA size: 1.58 acres (1.47acres required)

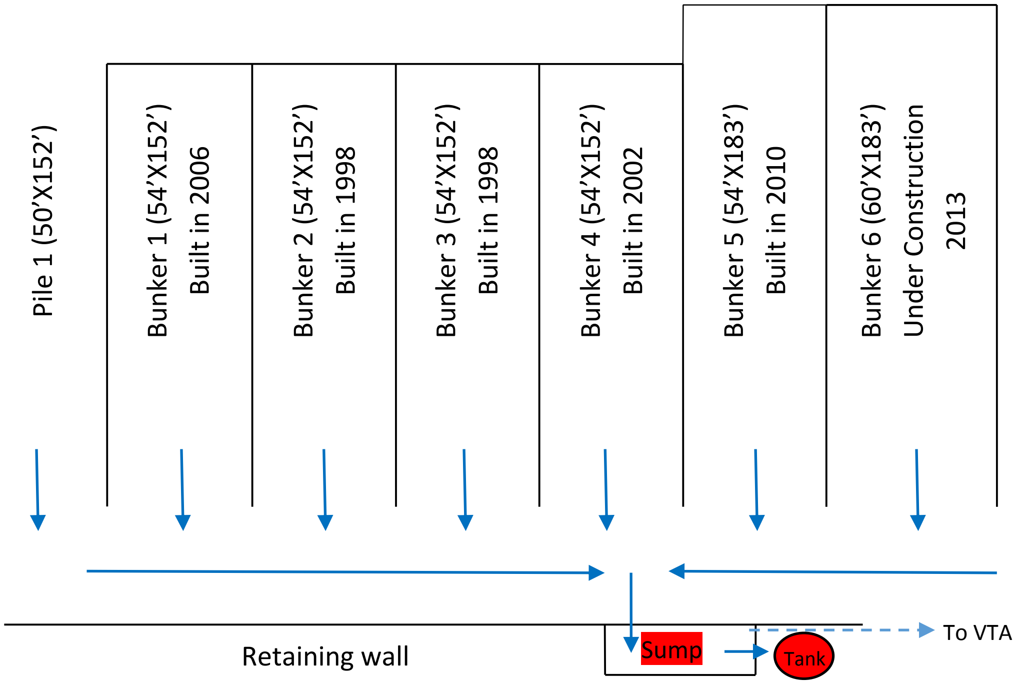


Figure 6: Feed storage bunker and leachate collection system layout for Farm B.

General system function:

Bunkers are sloped to a retaining wall that directs flow to a collection sump (Figures 6 and 7). As fluid accumulates in the collection sump, the feed particles float to the top and are held by the wooden pickets as the liquid fraction flows underneath (Figure 8). This design is termed a "flotate trap." The particulates collected in the sump can be easily removed by a skid steer.

Figure 7: Retaining wall and collection sump (flotate trap).

Figure 8: Wood pickets remove particles in the flotate trap.

The separated liquid fraction of the flow flowing below the wooden pickets flows through a 10-inch pipe (identified as 1 in Figure 9) to the 1,200 gallon collection tank. As fluid levels rise in the collection tank to collect the first flush of an event, a low level float switch turns on the 385 gpm pump and the liquid from the collection tank is pumped to the manure storage for a period of 3 minutes (up to a total volume of 1,150 gallons) and is deactivated for 3 hours. If the level hits the high float switch, the pump will be deactivated for a 24-hour period. If the high float switch is triggered, the pump is again activated to empty the collection tank to remove stored liquid at the end of the 24 hour delay (up to a total volume of 1,150 gallons). The 6-inch pull-pipe can be removed to drain remaining liquid from the collection sump to ease particulate removal (Figure 9). Liquid from drain tiles both under the bunker and around the perimeter also empty into the collection tank.

Overflow to the VTA occurs when initial pumping of liquid from the collection tank ceases and the tank fills to capacity or if flow overwhelms the 10-inch line from the collection sump to the tank. Overflow to the VTA flows through a 12-inch pipe (identified as 2 in Figure 9).

Because of the recent installation of the leachate collection system, the delay for the high float delay switch was not installed when this study began. Once the high float switch was triggered, the pump would need a manual reset. We asked the farmer to not install the delay switch for the first year of this study so we could manually pump while installing our monitoring equipment and to also determine how the system would function if designed without the delay or if the delay malfunctioned. The delay was installed during the winter of 2013/14.

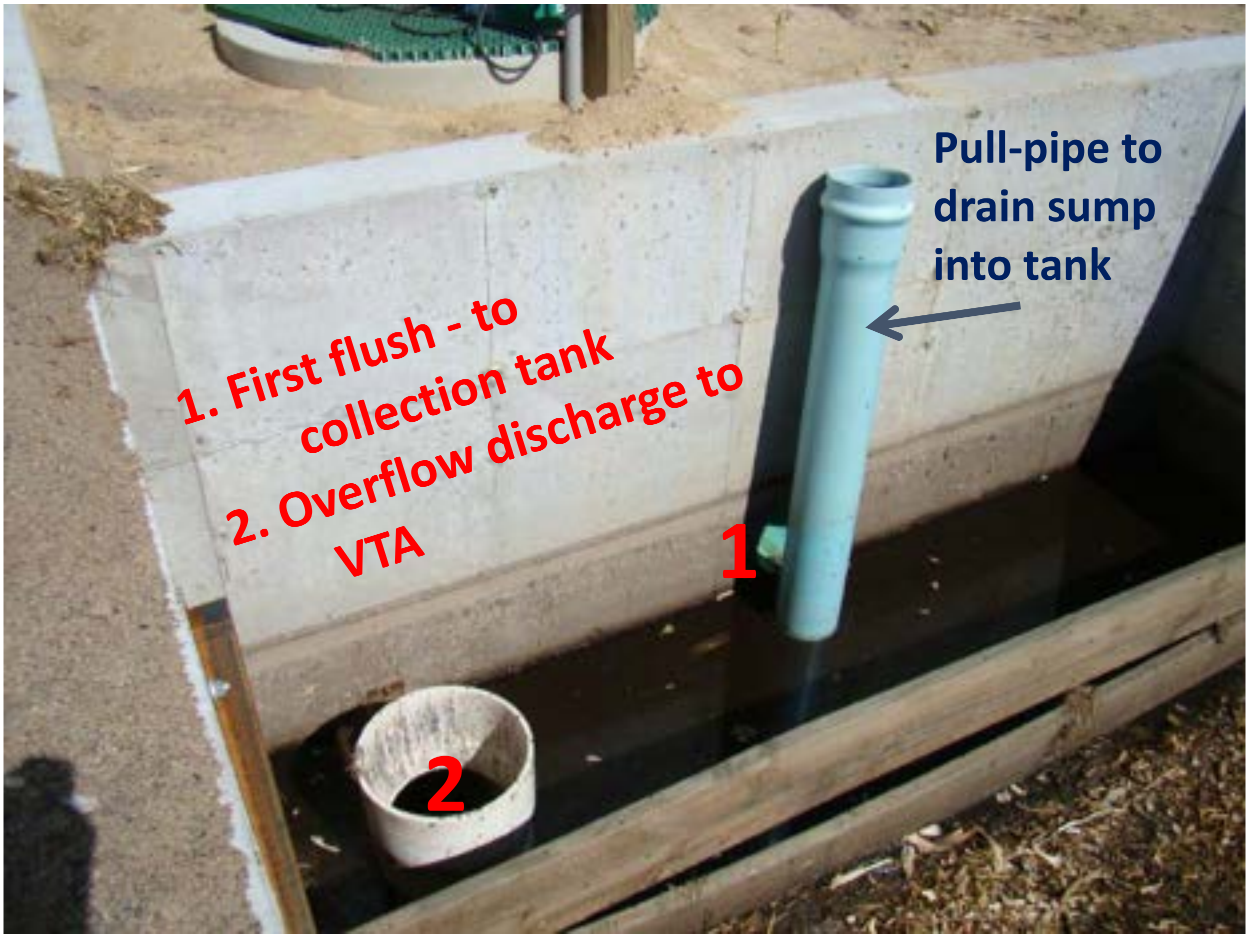


Figure 9: Flow to collection tank, overflow to VTA, and pull-pipe for sump drainage.

2.2.3. Farm C leachate collection system

Feed storage bunker size: 0.48 acres
Designed first flush depth collected: 0.20 inches
Leachate collection system built: 2009

Total impervious area: 0.63 acres
VTA size: 0.46 acres (0.41 acres required)

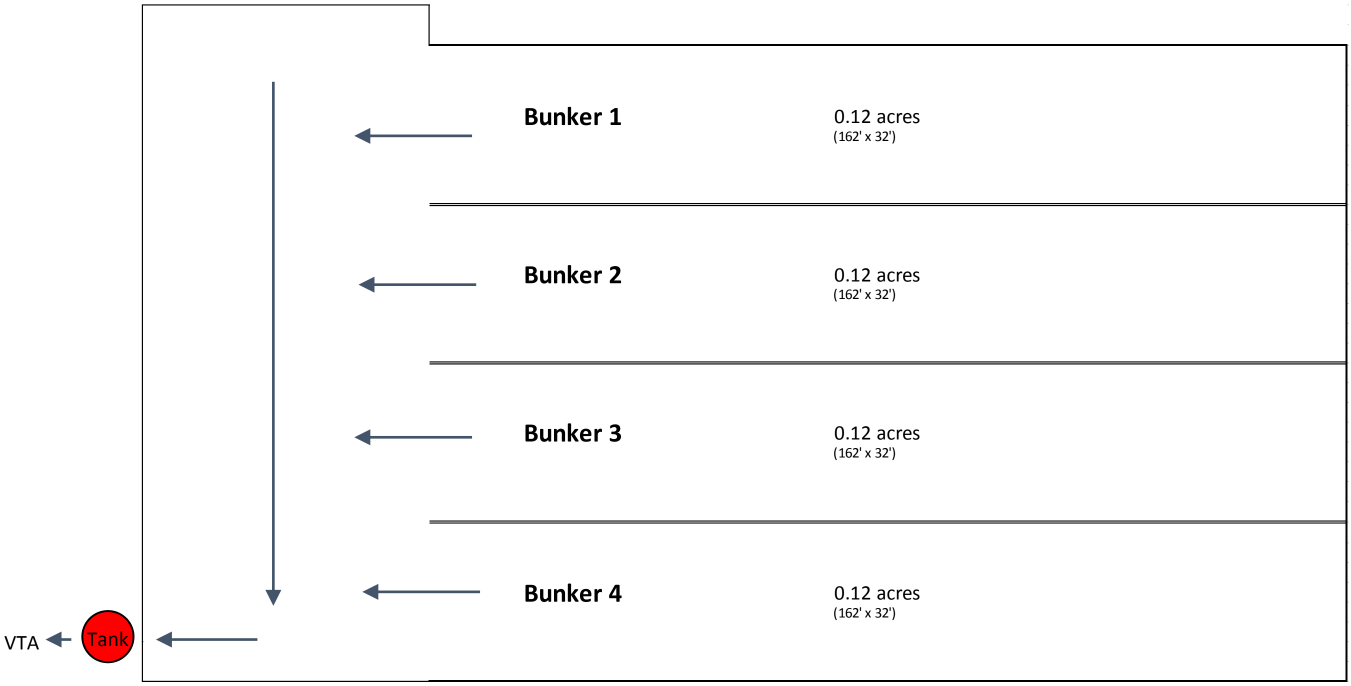


Figure 10: Feed storage bunker and leachate collection system layout for Farm C.

<u>General system function:</u>
Flow from bunkers is sloped to a flow channel that terminates at an 800 gallon collection tank (Figure 10) and enters the tank from a manhole at the top of the tank (Figure 11). As fluid levels rise in the collection tank to collect the first flush of an event, a 160 gpm pump is turned on at 7-foot depth and the liquid from the collection tank is pumped to the manure storage for a period of 40 minutes (up to a total volume of 6,400 gallons) or until the level in the tank goes down to 1 foot. After a 12-hour period from when the pump was activated, the pump is again activated to empty the collection tank to remove stored liquid (up to a total volume pumped of 700 gallons). Because of the shallow depth of the tank, the pump is pulled during the winter months to prevent damage and reinstalled in the early spring when ice thaws in the tank.

Figure 11. Liquid flows into manhole at the top of the collection tank

Figure 12: Overflow to VTA from collection tank.

Figure 13: Overflow outlet.

Overflow to the VTA occurs when initial pumping of liquid from the collection tank ceases and the tank fills to capacity or if flow overwhelms the capacity of the 160 gpm pump. Flow from the collection tank occurs from a 12-inch line at the top of the collection tank that outlets to the VTA (Figures 12 and 13). Unlike the other two farms, this farm has a flow through design. When the tank is full, flow continues out the other side to the VTA; whereas, at the other farms, when the tank is full, flow bypasses the tank to get to the VTA.

In the summer of 2011, the sonar level detector in the tank failed. The farmer was going to install high and low level floats to replace the sonar level detector as monitoring equipment was being installed. Discovery Farms initially asked the farmer to not install the floats so we could actuate the pump controller via our monitoring equipment. As Discovery Farms and USGS staff encountered many issues with the pump control actuation, the system could not be operated by Discovery Farms monitoring equipment. Discovery Farms had planned to control pump operation in early 2012, but upon further consideration decided that the continued manual operation of the sump pumping would be a good opportunity to compare a failed system to a properly functioning system when repaired in early 2014.

The sump was manually pumped by the farmer or Discovery Farms staff at the end of each storm from the date of monitoring equipment installation through the early winter of 2013 when the pump was pulled to prevent freezing. The plan was that in the early spring of 2014, when the pump was reinstalled to resume pumping, floats would be installed in the sump to control the pump to resume the automated pumping of the sump. This would allow for a comparison between the two full years of data, one with the system in manual operation and one with the system in automatic operation. Unfortunately, farm events outside of Discovery Farms control, did not allow for continued sampling and data collection was ended.

2.3. Instrumentation

2*.3.1. Monitoring stations*

At each sampling location aluminum enclosures were used to house equipment designed to measure flow (discharge), collect water samples and provide two-way communications that facilitated data collection and real-time programming (Figure 14). To monitor and record conditions, each farm had two site cameras. One camera captured photos of the feed storage area as a whole. The other captured photos specific to the area near the leachate collection system. These photos were used to assess conditions and the possible effects they had on the data. A tipping bucket rain gauge was also installed at each site to collect farm specific rainfall data.

Figure 14: Equipment enclosure.

Sampling equipment inside the aluminum enclosures was set up the same at all sites. Each site consisted of three main components: data logger, bubble system, and sampler (Figure 15). A Campbell Scientific CR10X data logger with a custom USGS program was used to remotely read and store sensor data and control station equipment. A non-submersible pressure transducer, coupled with a nitrogen bubbler system, was used to monitor the liquid level either in the collection tank or the waterway that handled overflow. The system transmits nitrogen gas at a known rate and pressure through 3/8 inch black bubble tubing. Liquid levels measured by the system were then recorded by a data logger. Flow was calculated from measurements of liquid level. An automated, refrigerated, 24-

Figure 15: Sample equipment inside the enclosure.

bottle ISCO® 3700R sampler was used to collect samples. Samples were pumped through a Teflon-lined sample intake line into 1-liter, polypropylene bottles housed in a refrigerator. Enclosures were locked with a padlock to prevent unauthorized access.

2.3.2. Farm A

To monitor the tank level and collect fluid samples from the collection tank (Site L1), the sample and bubble lines for depth measurement were attached to a schedule 80 PVC pipe that was used for rigidness and resistance to corrosion. The bubble line was attached one foot from the bottom and the top of the sample line strainer was attached two feet from the bottom (Figure 16). The low level switch was two feet from the bottom to keep the pump covered with liquid so both the bubble tube and sample line strainer would remain submerged at all times. The PVC pipe was secured to the collection tank pump mounting apparatus via an existing rigid metal pipe (Figures 17 and 18).

Figure 16: Sample and bubble line placement.

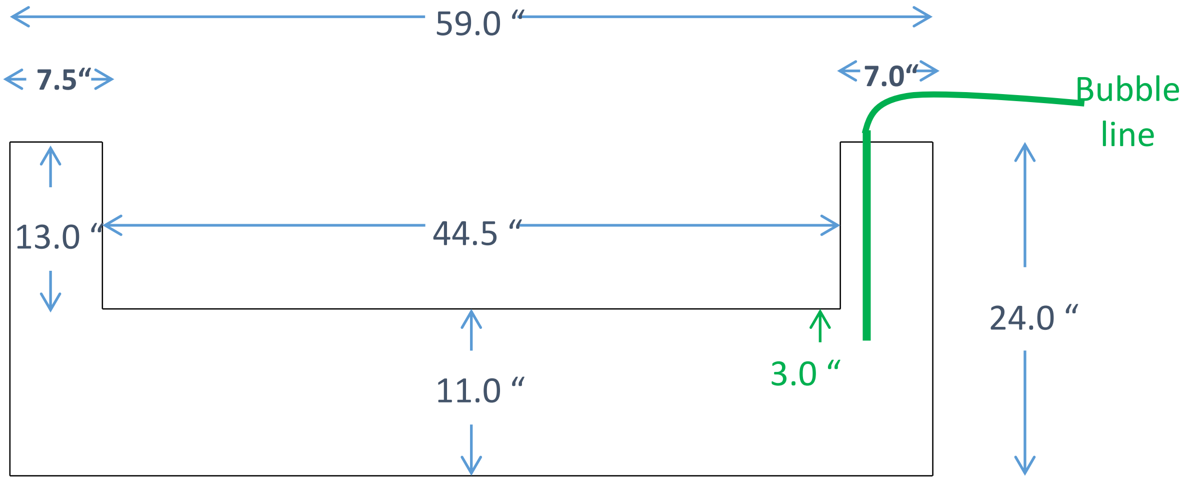
Figure 17: PVC pipe attachment.

Figure 18: Final installation with protective ENT pipe.

Low wattage (3 watt/foot) heat tape ran the length of the sample line to prevent the line from freezing during the winter. The sample line was also wrapped with pipe insulation and covered in duct tape to protect the line from both damage and freezing (Figures 17 and 19). Both the sample line and bubble line were run through Electrical Nonmetallic Tubing (ENT) to protect them from damage and sunlight degradation (Figure 18).


Figure 19: PVC pipe extending to tank bottom.

The monitoring options were quite limited for the overflow to the VTA (Site L2). Because of the unique dimensions and the lack of elevation drop from the concrete cutout in the collection sump to a concrete flow channel, the use of a trapezoidal flume was not practical in this location. Therefore, a custom designed weir plate was constructed using 1/4" 304 stainless steel to resist corrosion. An engineering diagram of the weir plate dimensions can be seen in Figure 20.



All measurements in inches

Figure 20: Stainless steel weir plate dimension diagram.

The weir plate was attached to the inside of the concrete cutout in the collection sump using a combination of silicone and concrete mounting screws (Figure 21). Specific care was taken to ensure the lip of the weir plate was level during installation to ensure accuracy of flow measurements. The bubble line was installed 3 inches below the lip of the weir plate (8 inches from the bottom of collection sump) and the sample line strainer was centered 2.5 inches below the lip of the weir plate (Figures 20 and 21).

Figure 21: Sample & bubble line placement on the weir plate.

Figure 22: Final installation with flow.

The initial flow event showed even distribution of flow across the weir plate lip (Figure 22). Similar to collection tank installation, low wattage heat tape ran the length of the sample line to prevent freezing. The line was also wrapped with pipe insulation and covered in duct tape for insulation and protection (Figure 21). Both the sample line and bubble line were run through ENT tubing for additional protection.

Initial flow data collected indicated that calculated flow volumes were greater than the total precipitation that fell on the known impervious area of the bunker pad. Therefore, calibration of the weir plate was required by secondary flumes. This proved difficult because of the lack of relief downstream of the weir plate. To accomplish the calibration, a two-stage approach was implemented. Low-flow calibrations were performed with a v-notch flume as seen in Figure 23 and middle-flow calibrations were performed with a makeshift flume of known outlet dimensions (Figure 24).

Figure 23: Low-range calibration flume.

Figure 24: Mid-range calibration flume.

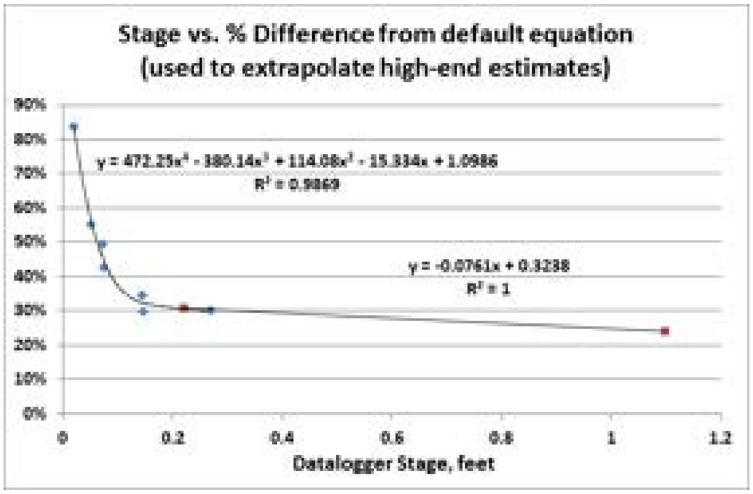


Figure 25: Extrapolation of high end flow.

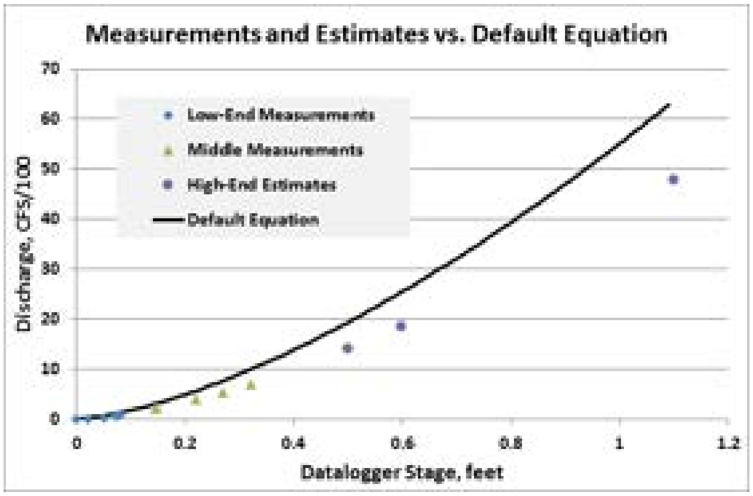


Figure 26: Plotted calibration points

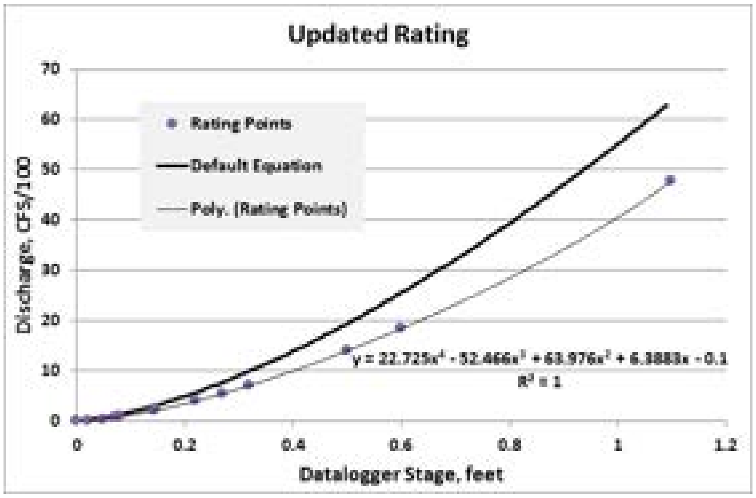


Figure 27: Final rating curve and equation.

Data collection for the secondary flumes proved to be difficult to obtain because Discovery Farms staff had to be onsite to take flow measurements during an event. Because the duration of flow events was short and forecasting of flow event timing was challenging, multiple unsuccessful attempts were made before needed data was obtained. High flow estimates were performed by USGS staff by plotting stage versus percent difference between the measurement points and the default equation.

As observed in Figure 25, data collected began flattening out at around 30% error at about 0.2 feet. Extrapolating the slope, the error was estimated to be approximately 22% lower than monitored in the weir plate at the max stage of 1.1 feet. It should be observed in Figure 26 that the error low end measurements markedly increased with decreasing stage. At the lowest collected calibration point value, in the more accurate secondary flumes, the flow was over 80% less as compared to the weir plate values. This was an understood limitation with the weir plate design, but was necessary so as to not impede flow and change the function of the leachate collection system from the way it was designed.

The values of the low-flow data collected in the V-notch flume and middle-flow data with the makeshift flume were plotted with extrapolated high flow estimates and compared to the default weir plate equation (Figure 26) and a "finalized" rating curve was developed (Figure 27). This rating curve correlated well to the flow volumes produced by precipitation events of the known impervious area and was used for all flow calculations at Site L2.

In the final year of the study, a conductivity probe was installed at Site L2. The purpose was to gather data to determine if conductivity was a good metric for determining runoff strength. These probes are relatively inexpensive yet robust making conductivity metering a desirable option for in situ monitoring.

2.3.3. Farm B

To monitor the tank level (Site L3), the bubble line for depth measurement was attached to a galvanized steel pipe one foot from the bottom (Figure 28). The steel pipe was then bolted to the collection tank pump mounting apparatus (Figure 29).


Figure 28: Bubble line placement on galvanized pipe.


Figure 29: Pipe attachment.

To collect fluid samples from flow to the collection tank, the sample line strainer was attached to a stainless steel plate (Figure 30). A damming device (not liquid tight so liquid can drain when there is no flow) was constructed to back-up liquid in the pipe to cover the sample line strainer to ensure sample collection (Figure 31). The stainless steel plate securing the sample line strainer was secured to the 10-inch line from the collection sump to the tank by bolting the plate to the PVC pipe (Figure 32).

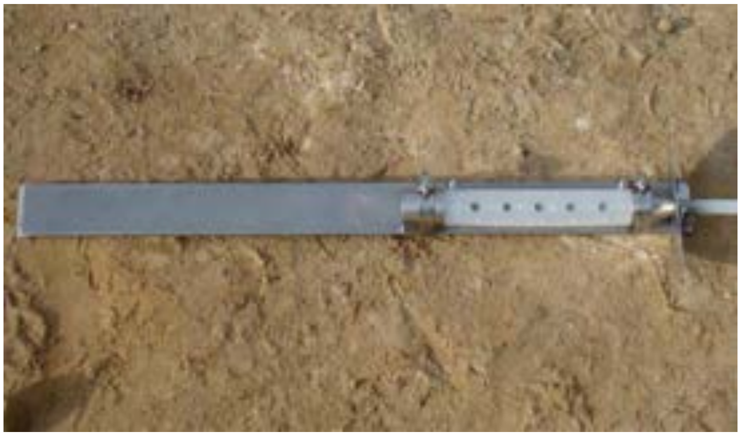


Figure 30: Sample line strainer attached to steel plate.

Figure 31: Damming device.

Figure 32: Sample and bubble lines installation and attachment on pipe.

Low wattage (3 watt/foot) heat tape ran the length of the sample line to prevent the line from freezing during the winter. The sample line was also wrapped with pipe insulation and covered in duct tape to protect the line from both damage and freezing. Both the sample line and bubble line were run through ENT to protect them from damage and sunlight degradation.

The monitoring options were again quite limited for the overflow to the VTA as a result of the system design at Site L4. The overflow to the VTA from the 12-inch pipe (identified as 2 in Figure 9) is split underground to multiple outflow points to the VTA so no options existed to monitor the pipe outlet to the VTA. The only feasible option was to use a tile drainage flow control device to measure flow in the pipe. An Agri Drain® (Figure 33) was installed inline just downstream of the intake for the overflow to the VTA (identified as 2 in Figure 9) and the installed device can be observed in the center of Figure 34.

Figure 33: Agri Drain to measure flow in pipe.

Figure 34: Installed Agri Drain.

In the final year of the study, a conductivity probe was installed at the L4 overflow site. The probe would gather real-time conductivity measurements similar to Farm A to more accurately define conductivity readings throughout individual runoff events.

The bubble line and sample line strainer were attached to a 5-inch stoplog that controlled flow through the 12-inch pipe, allowing for a flow volume calculation based on depth of liquid in the Agri Drain (Figure 35). This stoplog could be raised and lowered in the Agri Drain allowing for the installation and access of the bubble and sample lines (Figure 36). Low wattage heat tape

Figure 35: Sample and bubble line in Agri Drain.

Figure 36: Sample line strainer attached to stoplog.

ran the length of the sample line to prevent freezing. The sample line was also wrapped with pipe insulation and covered in duct tape for insulation and protection. Both the sample line and bubble line were run through ENT tubing for additional protection.

Figure 37: Tile drainage from bunker storage coming into the collection tank.

Farm B tank monitoring did have an inlet pipe that was accessible, so values are accurate representations of changing concentrations. However, an issue that did not become evident until the installation of equipment, is the entrance point of liquid from combined drain tiles both under the bunker and around the perimeter. Liquid from the tiles enters directly into the collection tank through a pipe that is separate from surface flow (Figure 37). This posed a challenge for the current monitoring design because the level measurement in the tank accounts for both surface flow and liquid coming from the tile system. Therefore, if there is tile flow causing the level to increase in the collection tank, the sampler could be triggered to collect a sample when there is not liquid coming from the surface, through the 10-inch line from the collection sump to the tank, and no sample would be collected. It was thought that this situation would have a large potential benefit for future monitoring as the tile and surface flow could be separated out to determine the water quality of each. This had not been possible in other monitoring projects. However, budget restrictions did not allow for that to happen.

2.3.4. Farm C

Figure 38: Sample and bubble line placement (tank).

To monitor the tank level and collect samples from the collection tank, the sample and bubble lines for depth measurement were attached to a stainless steel pipe that was used for rigidness and resistance to corrosion at Site L5. The bubble line was attached one foot from the bottom and the top of the sample line strainer was attached two feet from the bottom (Figure 38).

Low wattage (3 watt/foot) heat tape ran the length of the sample line to prevent the line from freezing during the winter (Figure 39). The sample line was also wrapped with pipe insulation and covered in duct tape to protect the line from both damage and freezing. Both the sample line and bubble line were run through ENT to protect them from damage and sunlight degradation (Figure 39). There were plans to move the sample line, in spring of 2014, from the tank to the manhole inlet to get a better representation of changing water quality; however, data collection ended before this was done.

To monitor the overflow to the VTA at Site L6, sample and bubble lines were installed in a removable section of a 12-inch culvert that was secured on either end by ferncos (Figures 40 and 42). The internal dimensions of the pipe were used for flow calculations based on depth and slope of the culvert. Because of backwater conditions in the culvert, an area velocity flow meter was subsequently installed to more accurately calculate flow during backwater conditions (Figure 43). A damming device was constructed to "back-up" liquid in the culvert to cover the sample line strainer to ensure sample collection (Figure 41). This device was not liquid tight so liquid could drain once flow stopped.

Figure 39: Lines attached to stainless steel pipe.

Figure 40: Sample and bubble line placement.

Figure 41: Sample line strainer damming device.

Figure 42: Sample and bubble line installed.

Figure 43: Area velocity flow meter installed.

Figure 44: Sample tube fix.

The original design of the sample strainer and damming device proved problematic during high flow periods. We hypothesize that an airlock would form in the strainer as air was pumped out of the sample line during the rinse process before a sample was collected. The strainer was removed and the problem persisted. The second attempt of removing the damming device, with the sample line still pointed upstream, did not fix the problem. The sample line was finally installed perpendicular to flow and the tip was cut at a 45-degree angle and this reduced the problem (Figure 44). We still had an occasional problem at peak flow rates. Troubleshooting continued, but because data collection ended early, another design was not utilized.

2.3.5. Real-time conductivity probe installation at Farms A and B

Figure 45: Decagon conductivity probe attachment at Farm B.

To monitor real-time conductivity, a Decagon® ES-2 Electrical Conductivity Sensor was installed at Farms A and B. The Farm A was installed on July 22nd, 2014 by attaching the probe to the upstream side of the weir plate adjacent to the bubble line at approximately the same liquid level. The probe at Farm B was installed on July 17th, 2014 by attaching the probe to unistrut slightly higher than the liquid level at the bubble line (Figure 45). When the Farm B probe was installed, the bubble line was moved and attached to the unistrut for easier access and maintenance. The unistrut was lowered and rigidly attached to the Agri Drain® on the upstream side of the stoplog. Conductivity readings were recorded every minute at both sites.

2.4. Sample collection and analysis

The sampling scheme for this study was designed to detail the constituents of concern from leachate collection system runoff while staying within sample analysis budgetary limits. From preliminary feed storage flow data collected by Dr. Becky Larson with the University of Wisconsin-Biological Systems Engineering Department, key parameters for flow were discussed to identify the most prominent constituents in feed storage flow and those constituents that were of greatest water quality concern. A cost analysis of each of the constituents was performed to determine how to best characterize constituents to fit within budgetary limits of the project.

Dr. Larson's laboratory provided sample analysis "at cost" for this project, greatly reducing analysis costs. In addition, University of Wisconsin students assisted with sample preparation and analysis to reduce analysis costs and provide additional educational benefits and experiences to students. Water quality parameters, method of analysis, and detection range are shown in Table 3.

The final determination of sampled constituents is as follows:

- pH - pH values are typically acidic with feed storage leachate and are often a good indicator of potency towards surface and groundwater quality. This can increase the acidity of the water and can cause minerals in the soil to become soluble and release metals, such as iron and magnesium, which can contaminate water supplies. The effects on groundwater can exist for extended periods of time because it is contained, which slows the oxidation of organic acids. These organic acids can also produce unpleasant odors in a water supply. The acidic pH and odors of the organic compounds in leachate can cause impairment of both surface and groundwater resources.

- Total Solids (TS) - the amount of solids is important to potentially correlate the amount of litter from feed storage and spoil piles that may influence leachate concentration and loading values. Dense mats of debris can smother and kill vegetation and choke waterways. Total solids can have an effect even as smaller particles. Particles suspended in water absorb solar radiation, which increases water temperature. Higher water temperatures limits the amount of dissolved oxygen present exacerbating the issue caused by other constituents. With high turbidity, light is scattered as it shines through the water, limiting light to vegetation and affecting the ability of sight-feeders to feed. From a strictly fish approach, there are numerous other affects including increased stress and related impairments, to mortality, depending on the degree of turbidity and time.

- Chemical Oxygen Demand (COD) - COD was selected as compared to Biological Oxygen Demand (BOD) because COD is a much faster, more accurate test. COD does not differentiate between biologically available and inert organic matter, and it is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values. The high content of sugars and other organic compounds in leachate can use up large amounts of oxygen in water; thus, deoxygenating it. This takes away needed oxygen from fish and other aquatic organisms. This occurs as aerobic microorganisms break down organic material and scavenge oxygen during the process. According to the Natural Resources Conservation Service (1995), one gallon of leachate can lower dissolved oxygen levels of 10,000 gallons of river water below critical levels for fish survival. Fish are most sensitive to high COD/BOD in the summer and early fall period when warm water temperatures result in high microbial activity to break down organic compounds. Also, warmer water is unable to hold as much dissolved oxygen as cooler water. Specific to riverine systems, late summer through late winter is typically when flow is lowest; therefore, reducing the amount of dilution.

- Total Phosphorus (TP) - the total amount of phosphorus in all forms (both particulate and dissolved). Phosphorus is the limiting nutrient in freshwater systems. When excess phosphorus is introduced, vegetative and algal growth are accelerated. Algal blooms can deoxygenate water, create toxins, and reduce the aesthetics and recreational use of water bodies. Excess vegetative growth interferes with fish spawning and rearing, aesthetics, and recreation. When vegetation dies, the decomposition of the plant material can deplete oxygen levels in the water.

- Soluble Reactive Phosphorus - more commonly referred to as Dissolved Phosphorus (DP) is bioavailable to plants and aquatic organisms. For the same reasons as total phosphorus, dissolved phosphorus can have an adverse effect on water quality. However, phosphorus in the dissolved form is more quickly assimilated for algal and aquatic plant growth than other forms.

- Particulate Phosphorus (PP) (calculated) - particulate phosphorus values were calculated by subtracting DP from TP. Through natural chemical reactions, particulate phosphorus can convert to dissolve phosphorus.

- Total Kjeldahl Nitrogen (TKN) - is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+). This analysis does not account for nitrate (NO_3^-) and nitrite (NO_2^-), leachate research conducted by Becky Larson's laboratory has shown nitrate and nitrite values to be very low in leachate because of the acidic nature of the liquid. Faulkner et. al. (2010), in their study of VTAs, also found low nitrate mass in the effluent to the VTA. It can be assumed that TKN values are very close to total nitrogen values. In saltwater systems, nitrogen is typically the limiting nutrient causing algal blooms and subsequent depletion of oxygen. Although, most nitrogen being in the TKN "form" does not mean its form will not convert through natural chemical reactions. Nitrate from both direct runoff of stored feed and the conversion of organic and ammonium nitrogen, can leach through soil and impact groundwater resources. Nitrate contamination of groundwater is a health concern for both humans and livestock.

- Ammonia (NH_3) - Research conducted by Dr. Larson has shown significant ammonia levels in leachate. Groundwater contaminated by leachate has been shown to have elevated levels of ammonia and nitrates. In the ammonia form, nitrogen can kill fish and other aquatic animals, destroy benthic communities, and can contribute to dense mats of algal and fungal biomass in the water. Specific to riverine systems, late summer through late winter is typically when flow is lowest; therefore, reducing the amount of dilution. Fish are less tolerant of ammonia when water temperatures are cold, which is typically in late fall through early spring.

Table 3: Water quality sample analysis parameters

Parameter	Method	Detection limit
Ammonia (NH_3)	EPA 350.1 v.2‡	0.05 mg N L^{-1}
Conductivity	Standard Method 2510-B	0.01 µS cm^{-1}
Total Phosphorus (TP)	EPA 134-A.3†	0.006 mg P L^{-1}
Soluble Reactive Phosphorous (SRP)	EPA 365.1 v.2‡	0.005 mg P L^{-1}
pH	EPA 150.1†	
Total Chemical Oxygen Demand (COD)	EPA 410.4†	1 mg L^{-1}
Total Kjeldahl Nitrogen (TKN)	EPA 351.2 v.2‡	0.15 mg N L^{-1}
Total Solids (TS)	EPA 160.3†	0.1 mg L^{-1}

† (USEPA, 2009) ‡ (USEPA, 1993)

The sampling scheme devised for the leachate project was different between the first flush collection system and the overflow to the VTA. Samples for the first flush collection system were all discrete samples from set collection volumes that ranged between sites based on tank storage volume: L1 (Farm A) = 1000 gallons, L3 (Farm B) = 500 gallons and L5 (Farm C) = 200 gallons. From the collection of the first samples until April 2013, many samples were collected as the tank was filling to determine any chemistry changes at the beginning of an event. Because of budgetary restrictions, sampling was scaled back to only take one sample per pump down event to determine loading. This sample was targeted for the middle of the pump down to best represent the collected volume’s chemistry during the pump down.

The sampling scheme for the overflow to the VTA was performed by interval composite sampling to account for events of varying volumes. The impervious area for each feed bunker was determined and the volume from a 2-inch rain event was calculated to optimize sample coverage for an average storm using 24 bottle automated refrigerated samplers (ISCO 3700R sampler, Teledyne ISCO Inc., Lincoln, NE). After snowmelt and large spring rain events, the numbers were adjusted for optimum sample coverage. Finalized intervals for each site can be seen in Table 4.

Table 4. Sample volume (gal) intervals per bottle for composite sampling at sites that overflow to the VTA.

	Samples					
Site	1	2-6	7-11	12-16	17-21	22-24
L2 (Farm A)	1,000	1,000	5,000	10,000	20,000	50,000
L4 (Farm B)	1,000	1,000	5,000	10,000	20,000	50,000
L6 (Farm C)	333	333	1,666	3,333	6,666	16,666

For each event, the initial and final samples collected were discrete. Additional samples were composite samples with equal volumes taken from each bottle. The following is an example of the sample analysis for a 19 bottle event at L2:

1. Sample 1 = Discrete sample bottle 1 (represents first 1,000 gallons)
2. Sample 2 = Composite samples of bottles 2 - 6 (composite represents next 5,000 gallons, 1,000 gallons each sample)
3. Sample 3 = Composite samples of bottles 7 - 11 (composite represents next 25,000 gallons, 5,000 gallons each sample)
4. Sample 4 = Composite samples of bottles 12 - 16 (composite represents next 50,000 gallons, 10,000 gallons each sample)
5. Sample 5 = Composite samples of bottles 17 & 18 (composite represents next 40,000 gallons, 20,000 gallons each sample)
6. Sample 6 = Discrete sample bottle 19 (represents final 20,000 gallons)

In September 2013, budgetary restrictions resulted in the end of discrete sampling of the first and last samples. Bottle 1 was composited with bottles 2 - 6 and the last sample was composited in the interval that it fell. Limited discrete samples were analyzed on a discretionary basis to characterize unique flow trends in runoff flow.

Refrigerated samples were retrieved within 24 hours of the end of an event. Samples were labeled, placed in coolers with ice and shipped to the lab for analysis. Samples were typically received by the lab and analyzed within three days of an event.

2.5. Feed storage data

Feed storage management and storage activities can influence the timing and magnitude of leachate production and runoff potency. General feed storage management information was collected from producer records and site visits by Discovery Farms staff. Information on bunker, pad and particulate separation systems can be found in Table 5. Pad cleaning and spoil management refers to feed pad cleaning operations; while, system management refers to the near area above the collection tank and overflow sampling points. This included collection basins or sumps, flow paths, and particulate separation devices. A temporal schedule of these operations in relation to rain and runoff events was not collected. The method and type of feed covering, spoil pile management and particulate separation system and cleaning all differed between the three monitored farms.

Table 5: General feed storage management at each of the farms.

			Spoils management		System management*	
Farm	**Feed covering**	**Pad cleaning**	**Pile placement**	**Removal**	**Particulate separation**	**System cleaning**
A	- oxygen limiting barrier - black/white plastic, - secured with cut tires and sandbags, -wrapping side walls (haylage)	Daily	On site	2x per month	Strainer	Within days of an event
B	- wrapping side walls (2014) - oxygen limiting barrier - black/white plastic - green secure cover (corn) - secured with cut tires	Weekly	On site	Weekly	Float trap	Every 1-2 months
C	- black/white plastic - secured with cut tires	Every few days to every few months	On site (winter/spring)	Annually	None	n/a

*System management refers to the immediate vicinity upstream of sampling.

In addition to generalized feed storage management, detailed bunker filling information was collected to evaluate leachate and runoff concentrations (Table 6). Parameters include: harvest/fill date, crop type, estimated percent moisture at harvest, harvested tonnage, precipitation during filling, forage quality analysis, packing density, date(s) fed and estimated waste. From this information, a daily estimate of the quantity and type of stored feed was calculated for analysis of individual runoff event concentrations.

Table 6: Bunker filling information

Farm	Fill dates	Forage type	Moisture (%)	Tons harvested
A	9/25/2011	Corn	69	3000
	6/6/2012	Hay	58	1820
	7/18/2012	Hay	57	2130
	8/6/2012*	Hay	60	2100
	9/1/2012	Corn	55	2350
	9/6/2012	Hay	58	2060
	9/14/2012 - 9/18/12	Corn	60-62	7830
	6/8/2013	Hay	63	1524
	7/4/2013	Hay	58	1715
	7/18/2013	Hay (new seed)	68	238
	8/2/2013	Sorghum	58	217
	8/4/2013*	Hay	63	2485
	8/20/2013	Hay	53	585
	9/3/2013	Hay	60	1754
	9/6/2013	Sorghum	66	142
	9/24/2013	Hay	53	487
	9/29/13 - 10/2/13	Corn	66	2860
	10/9/13 - 10/16/13	Corn	60-65	8170
	10/16/13 - 10/28/13	Corn	65	14,820
	5/30/14 - 6/1/14	Hay	53	3136
	6/6/14 - 6/13/14	Tritacale	66	750
	6/27/14 - 6/29/14	Hay	59	1870
	7/23/14 - 725/14	Hay	58-60	2850
	8/27/14 - 9/4/14	Hay	60-61	3070
	10/21/14 - 11/1/14	Corn	65-68	13,450
	10/8/14 - 10/13/14	Corn	65-68	9580
B	6/3/2012	Hay	-	300
	7/3/2012	Hay	-	300
	8/1/2012	Hay	-	300
	8/25/2012 - 9/1/12*	corn	70	1490
	9/1/2012	Hay	-	300
	6/1/2013 - 6/3/13*	Hay	55-70	780
	7/3/2013	Hay	65	300
	8/1/2013*	Hay	55	300
	9/1/2013	Hay	65	300
	9/5/2013	Corn	69	300
	9/10/13 - 10/1/13*	Corn	65-68	1510
	11/1/2013*	Sorguhm	71	600
	6/5/2014*	Hay	45	640
	6/6/2014	Rye	45	200
	8/2/2014 - 8/28/14*	Hay	65-66	600
	9/4/2014 - 9/25/14*	Corn	60-69	1,654
	10/10/2014	Corn	63	264
	11/1/2014	Sorguhm	69	450
C	6/1/2012 - 6/29/12	Hay	60	1773
	7/24/2012	Hay	60	210
	8/22/2012	Hay	60	104
	9/13/2012*	Corn	68	3323
	6/14/2013	Hay	63	700
	7/15/2013	Hay	60	215
	8/16/2013	Hay	65	205
	10/13/2013	Corn	65	3400
		No data beyond 10/13/13		

* rained on before covering

Density for all farms = 0.01 ton/ft^3

2.6. Calculations and statistics

Sample nutrient concentration data was combined with event hydrograph data to calculate loading for each event. Each sample, both discrete and composite, represented the mid-point volume of a section of an event. Event loads were divided by their respective flow volumes for each event to determine event flow-weighted (FW) concentrations to identify trends in runoff information.

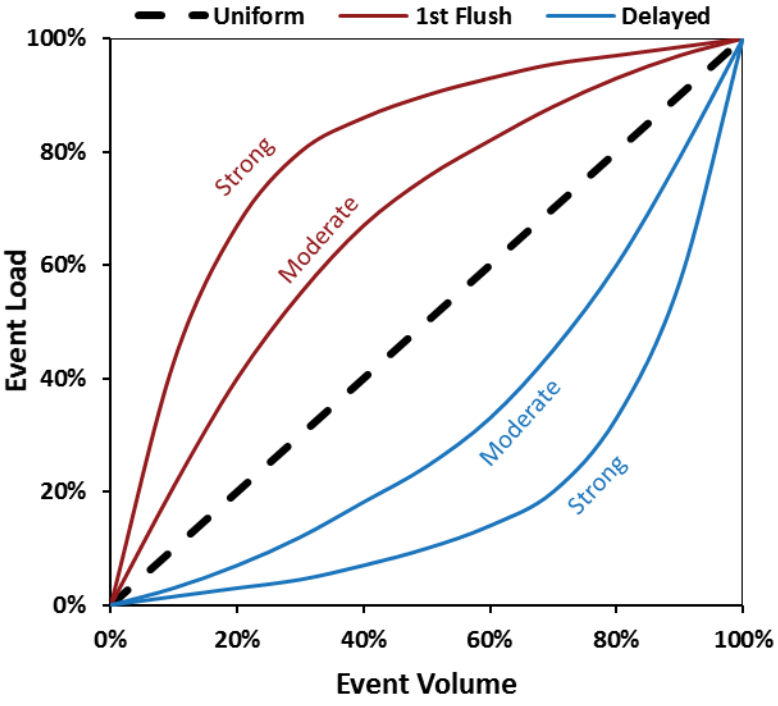


Figure 46: Mass-volume curve diagram.

Normalized cumulative loading curves were plotted for each event on a farm to analyze the loading per volume on an annual basis. The shape of the plotted cumulative load per cumulative volume percentages can be utilized to illustrate the strength of first flush (Figure 46). Many events had only one or two samples, not enough to fit a curve even using fixed 0%/0% and 100%/100% points. Specific criteria needed to be met for an event to be included. At all farms, three data points plus the endpoints were needed to be included in the first flush analysis. Tank and overflow data for each event were combined to form a single runoff event with which to form a mass-volume curve. When a normalized curve is compared to this line, a curve that goes above the bisector would be considered "first flush". Curve evaluation was performed in the general sense by using ±0.1 deviation from the bisector line. Later, more specific analysis used specified points on the plot, as defined by Bertrand-Krajewski et. al. (1998) and Deletic (1998), to compare the curves.

Statistics were performed using XLSTAT for Microsoft Excel. Site samples were compared to determine if they came from similar populations. A statistically significant difference would mean the results from one or more sites differ from the other sites. A multiple pair-wise comparison groups the sites that were similar. A correlation table for each of the constituents was developed to determine how they correlate to each other; while, linear regression was performed to determine the relationship between total phosphorus and conductivity and the relationship between total Kjeldahl nitrogen and conductivity.

3. Results

A general observation that is worthy of note, is that all events (any feed storage flow large enough to initiate sampling) were runoff events. Some leachate was observed coming from silage, but it was not substantial enough to result in detectable collection system level changes to initiate sampling. All events were classified as runoff and will be referred to as such when discussing these results unless otherwise stated.

3.1. Precipitation, runoff and sampling

Annual precipitation trends at Farms A and C where slightly greater than 30-year normal values in all monitored years, whereas Farm B was 8.7 inches less than normal in 2013 and 9.7 inches greater than normal in 2014 (Table 7). Seasonal variation in precipitation trends likely influence both the concentration and loading of liquid produced in feed storage facilities. At Farm A in 2013, spring precipitation was near normal, summer was relatively dry and fall was slightly wetter than 30-year averages. Farm A in 2014 had a relatively wet spring and near normal precipitation in summer and fall with a dry July and a wet August. At Farm B in 2013, April and May were greater than normal, but the remainder of the monitoring period experienced drier than normal values for the remainder of the year. In 2014, Farm B had significantly greater than normal precipitation in all monitored months except for July, September and October. At Farm C in 2013, all monitored months were above 30-year normal values with the exception of June and September; both October and November were greater than 1 inch above normal values. Although the annual and seasonal precipitation trends influence runoff from feed storage facilities, specific timing, intensity and magnitude of individual precipitation events also influence concentration and loading of runoff from feed storage facilities.

Table 7. Monthly precipitation compared to the 30-year average monthly precipitation.

	30-yr Avg.			Farm A			Farm B		Farm C		
	Farm A	Farm B	Farm C	2012	2013	2014	2013	2014	2012	2013	2014
Jan	1.14	0.71	1.14	.	2.03	1.09	0.60	1.35	.	2.15	0.28
Feb	0.94	0.71	0.98	.	2.38	0.79	0.81	0.90	.	2.11	0.78
Mar	1.65	1.50	1.85	.	1.67	0.84	1.87	1.32	.	1.95	1.23
Apr	2.72	2.72	2.60	.	2.64	4.35	3.96	4.50	.	3.16	4.11
May	3.31	3.74	3.19	.	3.73	3.37	4.50	7.50	.	3.78	.
Jun	3.94	4.33	3.58	.	3.19	5.03	3.38	9.97	.	3.20	.
Jul	3.78	4.37	3.23	.	3.79	1.70	1.13	1.98	.	3.93	.
Aug	3.31	4.76	3.19	.	1.68	5.05	0.45	5.42	.	4.17	.
Sep	3.39	3.66	3.70	.	2.65	3.17	1.67	1.51	.	1.35	.
Oct	2.72	2.76	2.80	4.92	4.15	2.75	2.42	1.14	3.67	3.96	.
Nov	2.05	1.54	2.20	0.78	2.66	2.39	0.86	5.05	0.97	4.21	.
Dec	1.38	0.94	1.69	1.60	1.70	1.16	1.40	0.80	1.70	1.46	.
Total	30.33	31.74	30.15	-	32.27	31.67	23.05	41.44	-	35.44	-

- Red values are precipitation data when collection systems were not operational

. Precipitation not monitored

Wisconsin NRCS Code 635.V.D.1 establishes that VTAs need to be designed to treat a minimum flow rate produced by the runoff from 25% of the peak flow of the 25-year, 24-hour storm event. Table 8 displays the three largest rain events for each farm based on total precipitation volume. The largest event at Farm A and Farm C exceeded the 25% criteria; however, at both farms the entire volume was treated by collection or VTA. Other events monitored during the study were not large enough to fully assess how these systems would handle the 25-yr storm runoff. It should also be noted in Table 8 that the peak flow ranking is not directly correlated to precipitation volume, thus intensity and duration of precipitation events influence peak flow.

Table 8. Top three rain events compared to the 25-yr, 24-hr rain event flow rate criteria.

		Rain (in)	Peak flow (gal/min)	25% of peak flow
Farm A	25 yr	4.33	9,789	2447
	1	2.51	3,746	38%
	2	2.13	1,391	14%
	3	2.08	1,440	15%
Farm B	25 yr	5.18	11,216	2804
	1	1.75	1,912	17%
	2	1.22	2,033	18%
	3	1.14	1,743	16%
Farm C	25 yr	4.06	1,827	457
	1	1.98	471	26%
	2	1.37	356	19%
	3	1.10	405	22%

Monitoring efforts on the three farms were dictated by the operation of the farm's collection system. The study design was set up to determine the load collected and load sent to the VTA. A "collection event" was defined each time the collection tank was pumped to manure storage or from the start of flow to the VTA until flow ceased.

Farm A's system operated year round. Though icing and ice damming would occur on occasion, thus effecting flow readings, hydrographs were corrected to accurately represent these events. Conversely, Farm B and Farm C idle collection systems during the wintertime months (approximately 3-4 months depending on the year) and sampling was idled. The collection tank at Farm B freezes and becomes non-functional. The pump at Farm C is pulled because the tank often freezes down to the level of the pump and could result in damage to the pump. Calculations were made using only the time period the systems were operational, so annual numbers represent the system's year not the calendar year.

Table 9: Duration, precipitation, runoff and sampling summary (only during system operation).

			Storage			**VTA**		
Farm	**Total months sampled**	**Total Precipitation (in)****	**Volume (gal)**	**Samples taken**	**Samples analyzed*****	**Volume (gal)**	**Samples taken**	**Samples analyzed*****
A	27	71.3	1,883,320	1,637	252	3,710,620	1,036	246
B*	19	61.1	559,020	563	122	4,225,130	656	177
C*	10	35.1	39,570	304	49	281,880	254	74

*not sampled during winter months when pumps were pulled
**includes frozen precip. liquid equiv.
*** "Samples analyzed" - discrete and/or composite

Of the 4,450 samples collected, 920 discrete or composite samples were analyzed between the three farms to characterize feed storage runoff (Table 9). Not all rainfall events produced feed storage runoff. During low volume rain events, it was sometimes difficult to determine if runoff occurred; if it did, samples were not always taken because not enough flow occurred to initiate sampling. Therefore, only rain events that resulted in runoff to the VTA were used for rain event statistics. In addition, differentiation between rain runoff and snowmelt runoff was impossible when snowmelt occurred while sampling status was active. Therefore, rain events that included snowmelt were not included in rain event statistics (Table 10).

Table 10: Rainfall and runoff statistics.

Farm		**Rainfall (in)****	**Rain duration (hr)****	**Average rain intensity (in/hr)****	**Runoff (gal)*****	**Average flow (gal/sec)*****	**Samples taken**	**Samples analyzed******
A	Mean	0.6	5.1	0.18	49,390	0.74	12.7	3.2
	Std. Dev.	0.5	4.4	0.19	51,150	0.47	6.9	1.8
	Min	0.02	0.2	0.02	360	0.05	1	1
	Max	2.5	19.3	1.12	209,010	2.15	32	8
B*	Mean	0.4	4.3	0.22	55,040	0.53	10.8	2.8
	Std. Dev.	0.3	5.5	0.38	51,450	0.47	6.1	1.5
	Min	0.02	0.2	0.01	2,220	0.06	2	1
	Max	1.7	33.4	2.52	216,480	2.07	31	7
C*	Mean	0.4	4.0	0.29	5,490	0.19	6.2	1.7
	Std. Dev.	0.3	3.8	0.64	5,810	0.15	4.1	0.9
	Min	0.1	0.1	0.02	220	0.01	1	1
	Max	1.4	18.0	3.85	23,820	0.74	16	4

* Not sampled during winter months when pumps were pulled
** Only rain events with overflow runoff
*** "Runoff" - only overflow vol.
**** "Samples analyzed" - discrete and/or composite

In bunker storage facilities, it was expected that a high percentage of the total precipitation would run off as a result of the impervious concrete or asphalt used for both the bunker and feed storage pads. The percentage of precipitation resulting in runoff from the three monitored feed storage sites ranged from 66 – 87% (Figure 47). In comparison to the 9% average annual runoff from edge of field monitoring performed by the Discovery Farms Program in Wisconsin, the average runoff from feed storage facilities was

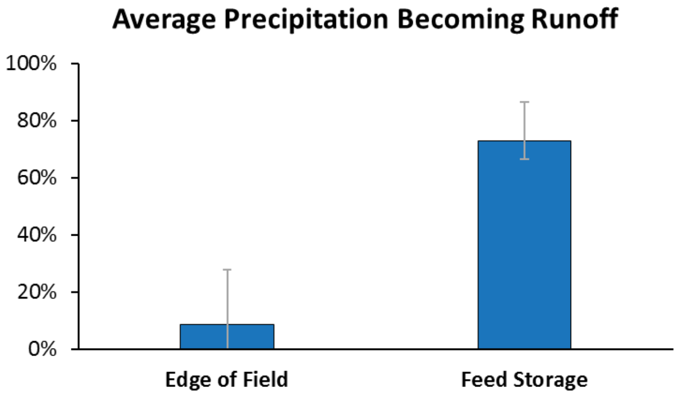


Figure 47: Average percent rainfall becoming runoff between edge of field and feed storage.

73%. It should be restated that annual runoff values were calculated during monitored periods for both precipitation and runoff. Farm A had continuous monitoring, whereas Farms B and C were only monitored when collection systems were operational and thus values may be slightly lower because there was no wintertime monitoring.

3.2. Runoff concentrations

The values/concentrations of sampled constituents had great variation between events and farms during the monitoring period (Table 11). Median concentrations in the collection tank were higher than those of the overflow. It should be noted that all collection tanks had a remaining volume in the tank after pumping. Remaining liquid came from a low level cutout, which is there to prevent the pump from being uncovered during the pump down, and backflow from liquid draining from the pipe after pump down. As a result of the sample points for the tanks at Farms A and C (Figures 17 and 38), this remaining liquid could influence nutrient concentrations in the subsequent event collection. High concentration runoff from the end of the previous storm and feed debris in the bottom of the tank could increase concentrations in the latent liquid remaining the tank. Although the collection tank at Farm B was sampled in the inflow to the tank, debris and liquid remaining in the flotate trap (Figures 17 and 38) could influence nutrient concentrations in initial flow to the tank much like Farms A and C.

Table 11: Characteristics of sampled constituents.

			pH	TS (%)	COD (mg/l)	TP (mg/l)	SRP (mg/l)	TKN (mg/l)	NH_3 (mg/l)
Farm A	**L1 Tank**	**Max.**	6.94	2.04	29,080	333.29	306.02	743.37	329.90
		Min.	4.55	0.15	820	18.83	21.05	23.05	23.91
		Median	5.39	0.65	9,360	73.02	68.48	288.21	100.09
	L2 VTA	**Max.**	6.32	3.35	28,060	249.74	248.64	988.69	168.19
		Min.	4.28	0.03	940	11.98	10.94	33.38	6.59
		Median	5.27	0.33	5,400	33.64	29.64	140.06	29.26
Farm B	**L3 Tank**	**Max.**	6.99	4.60	47,440	659.24	552.53	1,385.55	216.69
		Min.	3.99	0.11	920	11.74	9.70	55.76	10.26
		Median	5.24	0.44	6,225	46.43	39.95	206.74	65.83
	L4 VTA	**Max.**	7.11	3.18	40,000	460.05	392.43	1,086.57	204.44
		Min.	4.23	0.08	660	10.44	8.05	14.81	2.38
		Median	5.44	0.29	3,890	26.47	21.93	125.27	28.48
Farm C	**L5 Tank**	**Max.**	6.77	1.46	18,800	86.65	85.44	1,015.20	227.56
		Min.	4.83	0.08	820	10.82	10.05	41.61	8.02
		Median	5.47	0.42	5,770	35.55	30.50	220.95	60.25
	L6 VTA	**Max.**	6.24	1.05	61,210	70.93	70.93	798.03	122.06
		Min.	4.21	0.05	810	11.79	10.86	23.63	11.23
		Median	5.18	0.33	4,605	31.40	28.83	190.85	32.06

Statistical analysis using the Kruskal-Wallis non-parametric test for population similarity revealed that not all sites were statistically similar based on sample concentrations. The analysis used a confidence interval of 95% (alpha = 0.05). The p-values for each constituent was <0.0001. This means the sites are statistically different, because the p-values were less than the alpha value. The Dunn's pairwise comparison was used to exam the sites against each other. For all constituents except pH, the L1 tank site was statistically different than all other sites (using a Bonferroni corrected significance level of 0.0033 (alpha = 0.0033)). The L3 tank site was only different from all other sites in terms of phosphorus. The rest of the sites were statistically similar to at least one other site for each constituent. For most constituents, the overflow sites were all similar to each other. Detailed statistics on individual sites can be found in Appendices A and B.

Median concentrations at Farm A were greater in both the collection tank and overflow to the VTA as compared to similar monitoring locations on the other farms (Table 11). Although median concentrations were greater at Farm A, maximum concentration values were often lower in comparison to Farms B and C. The factors that resulted in greater peak concentrations at Farms B and C in comparison to Farm A could not be determined. It is likely that a combination of factors including precipitation, feed, and collection system design characteristics and management of bunkers and feed pad influenced observed constituent concentrations on individual farms. In addition, the system design combined with the selected monitoring locations may have also influenced the values observed on individual sites in this study.

At Farm A, sampling occurred in the tank versus at the inflow because of 1) lack of sampling options at the 4 inch pipe going from the sump to the tank (Figure 4) and 2) the lack of a sample point from tile drains entering the tank. Since the loading from both the surface and tile were required to determine loading of liquid sent to the manure storage system, sample collection of the mixed liquid in the tank was required. Farm A had carry over liquid from each event from a number of sources: 1) a potential of 1000 gallons of liquid remaining in the sump after the tank had filled, 2) approximately 2000 gallons of liquid remaining in the tank so the pump would remain covered with liquid (approximately 2 foot depth of liquid in the tank), 3) approximately 450 gallons of backflow liquid from piping to the manure storage once pump would shut off and 4) liquid from tile drainage systems emptying into the tank. In addition, particulate debris from the feed pad was observed in the bottom of the tank that could continually contribute to constituent concentrations. The 1000 gallon volume in the sump that was collected at the end of many runoff events is hypothesized to be particularly high in concentration based on visual observations. Observations indicated that the last of the flow coming from the feed pad and bunkers flowed through the amassed debris collected by the particulate strainer (Figure 3). All of these combined factors are believed to contribute to the high concentrations observed in the collection tank at Farm A. The sample collection point in the tank allowed for the accurate determination of constituent loading that was sent to the manure storage system, but resulted in challenges determining surface runoff concentrations to the tank for individual events.

At Farm B, a sampling option existed at the inflow to the tank to accurately characterize runoff flow concentrations to the tank (Figure 31); however, liquid in the tank was also influenced by tile inflow from under the feed pad (Figure 37). While this resulted in some sampling attempts when there was no surface inflow, sample volumes were matched with the samples actually taken so concentration changes could be determined. Originally, there were plans to monitor the tile inflow, but plans were halted due to budgetary restrictions. The debris and liquid remaining in the flotate trap (Figures 17 and 38) likely influenced nutrient concentrations in initial flow to the tank. In addition, the high concentration flow (from visual observations) at the end of a runoff event would remain in the flotate trap until a subsequent storm would force this liquid into the collection tank at the beginning of the next runoff event.

At Farm C, sampling occurred in the tank versus the inflow because of the lack of sampling options at the inflow to the tank (Figure 11). Tank concentration values should be relatively close to incoming surface runoff values as 1) there was no tile drainage from the feed pad coming into the tank and 2) there was adequate mixing of liquid as this was a flow-through tank to the VTA. It should be noted that during the initial year of data collection, the final pump down of the tank after a runoff event was manually initiated and would often contain high concentration liquid (from visual observations) as it would catch the last of the flow trickling off of the feed pad at the end of a runoff event.

At site L6 on Farm C the distribution pipe to the VTA and the VTA itself had low slopes which caused backwater at times. During these times when the area velocity flow meter was not operating normally, there was the appearance of flow when, in fact, there was none. This made determining the end of an event difficult. In these cases, the end of an overflow event was determined when the tank was pumped, and the liquid level within fell below the tank discharge to the VTA. During times when the stage in the culvert remained constant for an extended period of time and the tank was not pumped, approximations were made to determine the end of the event. Because this was not a common occurrence, it is not believed to have had a significant effect on overall analysis.

Flow weighted concentrations (FWC) allow for comparison of general water quality trends between farms, between monitoring locations on a single farm and temporal variations at individual sites. Average FWC values were calculated with only over full years of data for each farm so as not to have any seasonal bias for uncomplete years of data (Table 12). Appendix C lists individual event flow weighted concentrations for all sampled events.

With the exception of Farm B in 2013, collection tank FWC were greater compared to overflow to the VTA. It is likely that the combination of factors outlined in the previous section resulted in the FWC differences in the collection tanks between farms. Farm A had liquid and debris remaining after a pump down, inflow from tile under the feed pad and high concentration flow from the end of all storm events remaining in the collection sump that was the last liquid to flow into the collection tank after pumping. These factors resulted in the highest tank FWC of

Table 12: Average flow weighted concentrations for monitoring period.

	FWC (mg/l)	2013 COD	2013 TP	2013 SRP	2013 TKN	2013 NH_3	2014 COD	2014 TP	2014 SRP	2014 TKN	2014 NH_3
Farm A	**L1 Tank**	7,154	59.8	54.9	255.4	97.0	12,252	97.9	92.0	318.4	102.8
	L2 VTA	3,288	28.1	24.6	120.7	26.1	7,492	47.2	43.2	175.2	39.4
	Total	4,878	41.1	37.1	176.1	55.3	8,909	62.3	57.7	217.8	58.3
Farm B	**L3 Tank**	4,263	34.9	31.1	169.6	47.9	8,516	74.0	69.5	247.1	73.1
	L4 VTA	5,826	45.9	39.8	193.9	42.5	5,222	39.8	34.5	151.5	37.7
	Total	5,656	44.7	38.9	191.3	43.1	5,621	44.0	38.8	163.1	42.0
Farm C	**L5 Tank**	5,205	34.7	30.8	220.3	57.3	No Data Collected				
	L6 VTA	3,932	28.5	24.1	154.6	32.3					
	Total	4,082	29.2	24.9	162.3	35.2					

All farms	Overall Average COD	Overall Average TP	Overall Average SRP	Overall Average TKN	Overall Average NH_3
Total	5,829	44.3	39.4	182.1	46.8

the three farms. Although Farm B collected liquid at the inflow to the collection tank, high concentration liquid and debris that remained from the previous storm often remained in the flotate trap and was the first liquid to enter the collection tank from a subsequent storm, thus increasing tank FWC values. Residual debris in the flotate trap was substantially more evident in 2014 compared to 2013 and likely contributed to the elevated values in 2014.

3.3. Event and annual nutrient loading

Loading of nutrients to both storage and VTAs was the main focus of this study and is calculated by multiplying the constituent concentration by the volume. Leachate collection systems are installed to minimize the loading from high concentration flow to VTAs. The concern expressed by the US Environmental Protection Agency with VTAs is whether they have the capacity for the flow and loading from feed storage facilities that they were designed to treat.

Table 13 shows the single event loading values from the three farms. At all sites, median event loads were closer to the minimums than the maximums, indicating that small loading events were more common than large loading events. At all three farms, loading values were higher for the VTA site than collection site for the corresponding statistic except the median value for ammonia at Farm A.

Annual loading trends between the three farms was not only different between farms, but between years on individual farms. Farm A stored greater phosphorus and nitrogen in the collection system in 2013; however, greater phosphorus and nitrogen were sent to the VTA in 2014 (Table 14). This is likely the result of a combination of factors. The first factor is the relative lack of large events in 2014. Since this system is set up to collect the first flush from

Table 13: Annual summary of single event nutrient loading.

			2013				2014			
			TP (pounds)	SRP (pounds)	TKN (pounds)	NH_3 (pounds)	TP (pounds)	SRP (pounds)	TKN (pounds)	NH_3 (pounds)
Farm A	**L1 Tank**	Max.	11.8	11.2	42.6	20.9	21.0	19.3	46.9	19.6
		Min.	0.1	0.1	0.2	0.1	2.3	2.2	4.3	0.0
		Median	2.8	2.5	12.4	4.6	5.6	5.1	19.0	5.9
	L2 VTA	Max.	46.6	37.7	160.8	35.4	68.6	64.8	351.2	75.1
		Min.	0.2	0.2	0.8	0.2	0.1	0.1	0.2	0.0
		Median	4.8	3.9	18.9	4.3	15.7	14.6	56.1	12.2
Farm B	**L3 Tank**	Max.	1.4	1.3	9.7	1.8	10.7	5.3	24.6	2.8
		Min.	0.3	0.2	1.1	0.2	0.1	0.1	0.6	0.1
		Median	0.5	0.5	2.3	0.7	0.5	0.4	1.9	0.6
	L4 VTA	Max.	137.5	132.5	469.1	114.0	194.7	165.5	410.2	108.8
		Min.	0.4	0.4	1.6	0.3	1.8	1.4	6.8	1.3
		Median	4.9	3.7	21.2	3.7	12.5	10.7	64.9	15.3
Farm C	**L5 Tank**	Max.	0.4	0.4	4.9	1.0	No data collected			
		Min.	0.0	0.0	0.2	0.0				
		Median	0.1	0.1	0.9	0.2				
	L6 VTA	Max.	4.3	3.5	41.7	7.8				
		Min.	0.1	0.0	0.4	0.1				
		Median	0.8	0.8	4.5	1.0				

each event, regardless of event size, there is a set volume collected before the remaining runoff overflows to the VTA. Thus, larger events would result in increased flow to the VTA as compared to the volume collected. A control module for the pump failed in late March 2013 at Farm A, which may have impacted the total volume sent to manure storage. A new system of floats and a pump control module was installed in early April 2013 that allowed for pumping every 4 hours instead of the 24-hour design. Although the controller was correctly set in early May 2013, it allowed for multiple daily pumping events over a 30-day period.

Table 14: Annual loading distribution.

		2013						2014					
		Volume (gallons)	Vol (%)	TP (pounds)	TP (%)	TKN (pounds)	TKN (%)	Volume (gallons)	Vol (%)	TP (pounds)	TP (%)	TKN (pounds)	TKN (%)
Farm A	**L1 Tank**	941,100	41%	470	60%	2,007	60%	840,400	30%	687	47%	2,235	44%
	L2 VTA	1,347,600	59%	317	40%	1,359	40%	1,983,200	70%	782	53%	2,901	56%
	Total	2,288,700		786		3,366		2,823,600		1,469		5,135	
Farm B	**L3 Tank**	191,700	11%	56	9%	271	10%	367,300	12%	227	20%	758	18%
	L4 VTA	1,566,700	89%	601	91%	2,537	90%	2,658,400	88%	884	80%	3,362	82%
	Total	1,758,400		656		2,808		3,025,700		1,112		4,120	
Farm C	**L5 Tank**	32,700	12%	9	14%	60	16%	No Data Collected					
	L6 VTA	244,100	88%	58	86%	315	84%						
	Total	276,800		67		375							

At Farms B and C, the majority of both runoff and nutrients were sent to the VTA regardless of whether the system was automated or manually operated. The pump from the collection tank to manure storage at Farm B was not operational when this study began. For more than half of the study period, the pump was manually operated during and/or after a runoff event. It was not always feasible for the farmer to manually pump the tank during an event to mimic the automated pumping. Many events sent liquid to the VTA that might normally have been collected. At Farm C, the sonar level detector controlling the pump was not working and had been removed prior to this study. The farmer was diligent about making sure the collection tank was emptied often, even in the middle of the night. The farmer was working with someone to get a new automated pumping system installed before the second year of monitoring, but monitoring at this farm ended before that occurred.

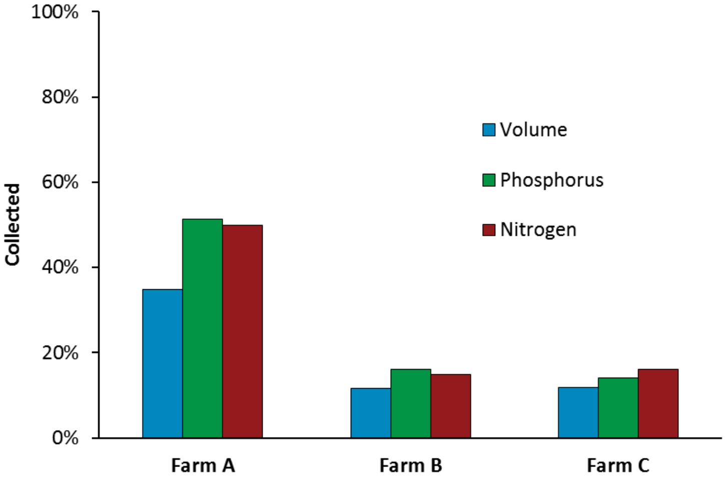


Figure 48: Percentage of liquid and nutrients collected during the monitoring period on each farm.

Figure 48 shows the percent of total feed storage runoff collected and the associated nutrient load collected at each site during the entire study period. Farms B and C are similar, but Farm A collects an appreciably larger volume and load. The greater volume collected contributes to the increased load collection; however, the difference in percent volume and percent load at Farm A compared to Farms B and C is also appreciably large. The design of Farm A's system enables it to capture 1000 gallons of liquid in the sump at the end of each event (Figure 5), typically low flow/high concentration; therefore, a higher load per volume is collected. In addition, if a very intense precipitation event occurred with a high initial flowrate, it would overwhelm the 4-inch line from the sump to the tank (Figure 4) and allow for high flow/low concentration liquid to be directed to the VTA (Figure 5) thus mitigating a portion of the dilute runoff collected.

3.4. Annual nutrient yield

To determine a relationship between the amount of stored feed and the yield of phosphorus and nitrogen, yield was calculated based on both the bunker area alone and the total contributing area. Nutrient yields between farms were expected to be more similar related to bunker area since bunker area should have a strong relationship with stored feed. Yet, the total nutrient yields were much more consistent with total contributing area as shown in Table 15.

Table 15: Annual yield by total contributing area.

		2013				2014			
	Yield (lbs/acre)	TP	SRP	TKN	NH3	TP	SRP	TKN	NH3
Farm A	**L1 Tank**	124	114	530	201	181	170	590	190
	L2 VTA	84	73	358	78	206	189	765	172
	Total	207	187	888	279	387	359	1,355	363
Farm B	**L3 Tank**	16	14	78	22	65	61	216	64
	L4 VTA	172	149	725	159	253	219	961	239
	Total	188	163	802	181	318	280	1,177	303
Farm C	**L5 Tank**	15	13	95	25	No Data Collected			
	L6 VTA	92	78	500	104				
	Total	107	91	595	129				

All farms	Overall Average			
	TP	SRP	TKN	NH3
Total	241	216	964	251

Although the annual values are greatest at Farm A, Farms B and C underestimate total annual yield as values only reflect monitored periods when collection systems were operational.

A more detailed analysis of monthly feed storage inventory was conducted to determine correlations between annual yield and stored feed, but even weaker relationships existed compared to contributing area. Analysis using feed storage inventory for both volume and type of feed may be better suited for event concentration and loading comparisons, but not annual yield.

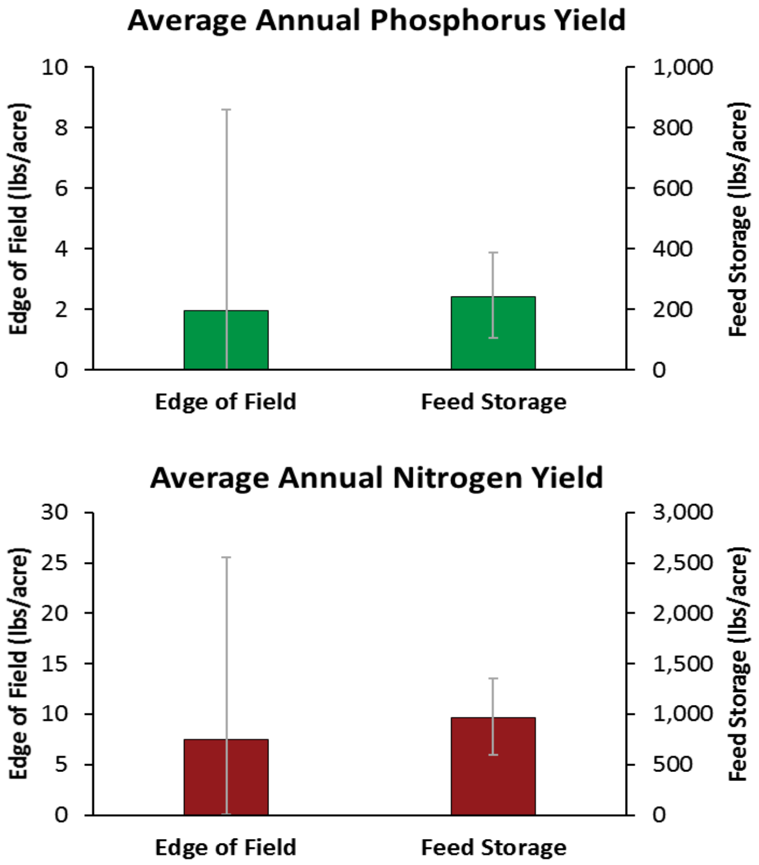


Figure 49: Average annual yield – Discovery Farms' edge of field vs. feed storage.

Yield analysis also allows for the comparison of feed storage and edge of field runoff. As previously shown in Figure 47, the impervious surface of feed storage facilities resulted in 73% of total precipitation runoff in comparison to 9% from edge of field sites. Similarly, both phosphorus and nitrogen loss from feed storage areas is significantly higher than edge of field sites. The average total phosphorus loss was 241 lbs/acre from feed storage as compared to 2 lbs/acre from the edge of field and TKN loss was 964 lbs/acre from feed storage as compared to 8 lbs/acre of total nitrogen loss from the edge of field (Figure 49).

3.5. Nutrient speciation

The speciation of both phosphorus and nitrogen are needed to understand runoff chemistry and VTA treatment capacity. Phosphorus was predominantly in the soluble form at both tank and overflow sites on all farms (Table 16). Soluble reactive phosphorus ranged between 85 and 93 percent of total phosphorus. This ratio is greater than the average edge of field losses monitored by Discovery Farms, where soluble phosphorus is approximately 50 percent of total phosphorus loss.

For nitrogen, the total Kjeldahl nitrogen is assumed to be near total nitrogen values because of the low nitrate/nitrite speciation in the flow (Dr. Becky Larson, UW-Madison Biological Systems Engineering, personal communication, May 7, 2012). Ammonia was between 23 and 37 percent of total nitrogen, which is similar to edge of field data. Therefore, it is assumed that the majority of the total nitrogen is in the organic form. Ammonia concentrations were slightly elevated in many instances during the winter and early spring months.

Table 16: Speciation of phosphorus and nitrogen.

	Load (lbs)	**TP**	**SRP**	**PP**	**TKN**	**NH_3**
Farm A	**L1 Tank**	1,204	93%	7%	4,412	35%
	L2 VTA	1,164	90%	10%	4,475	22%
Farm B	**L3 Tank**	283	91%	9%	1,029	32%
	L4 VTA	1,485	85%	15%	5,899	23%
Farm C	**L5 Tank**	13	88%	12%	78	28%
	L6 VTA	71	87%	13%	374	23%

4. Discussion - Considerations for runoff collection

4.1. First flush

To evaluate the monitored leachate collection systems, it is paramount to determine if first flush occurred as based on design criteria. Examination of changes in single event constituent for the first flush evaluation was done for total phosphorus and total Kjeldahl nitrogen. Since constituents are correlated (Section 4.3), examination of all sampled constituents would be redundant. Concentration defined first flush is not ideal for determining loading because high concentration does not necessarily indicate high load nor low concentration indicate small load.

Although concentration defined first flush is not the criteria that leachate collection systems are designed to capture, this information still provides insight on leachate concentration timing. Sixty-five percent of events did not have the highest concentration of nutrients in the first sample. On the contrary, 60% of those events had the highest concentration in the last sample. When examining the highest concentration with regards to the first 30% volume, more than half of the events had their highest concentration after 30% volume. In addition, nearly all events did not meet Batroney's (2007) #2 and/or #3 criteria (see page 4) of the sharp decline in initial concentration and a relatively low and constant concentration for the remainder of the event.

To address first flush from a loading perspective, mass-volume curves were plotted (Figure 50). Additional mass-volume curves for COD, TDP, and ammonia are in Appendix B. Initial analysis indicated that each farm experienced variation in these curves that ranged from first flush delivery to uniform delivery to delayed delivery; however, to categorize the events, interpretations is needed. To help differentiate the three categories in which to classify events, original analysis used a ±10% deviation. Any event curves within the range created by the ±10% deviation were considered linear, which suggests uniform loading. If the curves were above or below uniform, they were categorized as first flush or delayed, respectively. Of the events sampled, at 50% flow, 80% of events were uniform for both total phosphorus and total Kjeldahl nitrogen. Using this method shows each farm had events that could be classified as first flush events, but there is room for debate. Some curves went above uniform sooner than others; magnitude also varied. And some stayed above uniform longer than others. It is not appropriate to discuss the data using this criteria because it requires too much subjective interpretation.

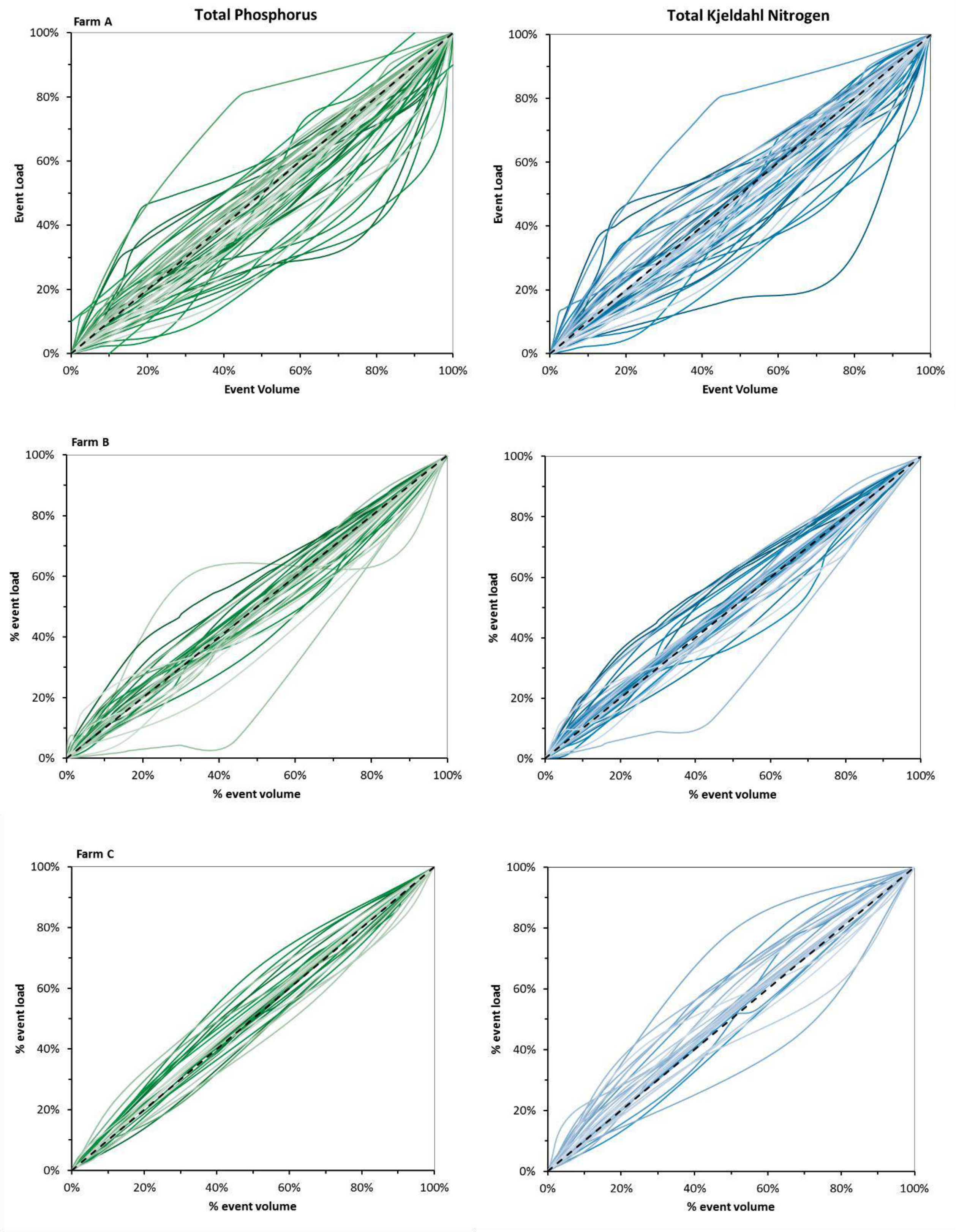


Figure 50: Mass-volume curves for total phosphorus and total Kjeldahl nitrogen at each farm.

Further analysis was performed to come up with a more definitive answer by using specific points with which to compare the curves. Since systems were designed based on urban environments, monitored events were evaluated based on defined points in urban research. Two such quantitative definitions where chosen from the literature, one stricter than the other. Bertrand-Krajewski et al (1998) used 80% of the event load occurring by 30% of the event volume (80/30). His definition was chosen because it was commonly cited in the literature. Deletic (1998) used 40/20, which is a more moderate definition of first flush. Both definitions were published in the same edition of the same journal (*Water Resources vol. 32 no. 8*) as Bertrand-Krajewski et al (1998), which shows that a quantitative definition of first flush is not standard even for studies published at the exact same time.

Quantitatively, very few events were first flush. The results in Table 17 were determined by plotting the defined values with the mass-volume curves from feed storage. If the curve went through or above one of the defined points, it was considered a first flush event. However, Betrand-Krajewski et al (1998) explains that his definition was arbitrary and any numbers could be chosen. Very few events were first flush events when using Deletic's (1998) moderate definition. In fact, at 20% of the volume, the average percent load was 23% versus the defined 40%. From another point-of-view, the average percent volume at approximately 40% load was 43% as opposed to 20%. It is clear from all analysis performed that first flush is rare in feed storage areas. Unlike in urban systems, the sources of constituents (feed, litter, and spoil piles) do not wash away easily, so there is a continuous contribution of constituents throughout an event. Other than volume, concentrations appear to be influenced by contact and residence time with stored feed, feed litter, and spoilage piles.

Table 17**:** First flush prevalence compared to urban definitions.

Strict (80/30)[a]		**Moderate (40/20)**[b]	
TP	TKN	TP	TKN
0	0	3	3
0%	0%	3%	3%

[a] Bertrand-Krajewski et al (1998)

[b] Deletic (1998)

TPn = 116 TKNn = 118

Many of the events from Farm A did not include samples from the tank as part of the normalized curves since the fluid sampled was not limited to the event being sampled and would not accurately reflect initial concentrations from individual storms. Tank samples that were included were based on criteria related to beginning tank volume and the point in time when the sample was taken. Farm A's collection tank had to have less than 3000 gallons (approximately 1/3 its capacity) at the start of an event. Any volume less eliminated almost all tank events. Also, samples needed to be taken before overflow sampling (some rain events were intense enough that flow into the collection sump was greater than the inflow rate to the tank). Since the overflow is the more accurate measure of an event's loading to the VTA, any tank samples within the bounds of overflow samples would be unnecessary and were not used. To determine the impact this had, applicable events from Farm A were plotted with and without the tank samples. Differences could be seen, but only a few of the events changed to a first flush designation when using the general mass-volume curve criteria (Figure 51) while no change in designation was seen when using either the strict or moderate quantitative criteria. It is unclear whether the changes seen were the result of higher concentration flow or residual liquid in the tank.

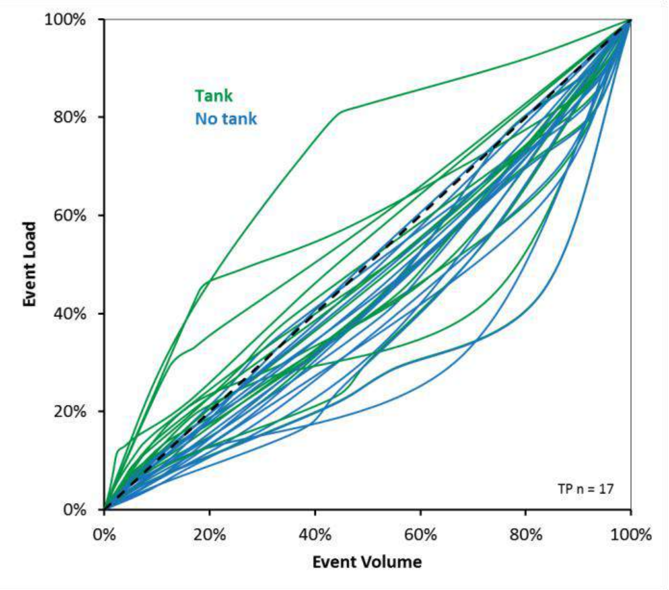


Figure 51: Mass-volume curves for Farm A with and without tank samples included.

Farm B is estimated to have higher than actual first flush occurrence because of the design of the collection sump (flotate trap). The particulate separation design of the sump resulted in large amounts of debris retained in the sump before flow goes to collection or the VTA. This debris builds up over a period of time between cleanings resulting in potential release of nutrients in stagnant liquid. This may result in higher concentrations at subsequent events because there is a source for fluid to pick up more nutrients not associated with the current event, particularly early in the event. The collection tank at Farm C would be most representative of feed storage area flow because of the flow-through system design that allowed for continuous mixing of liquid.

4.2 Concentration versus flow

First flush collection may not be the best method for collecting the highest load because of the concentration versus flow relationship. Concentrations are highly dependent on flow. The dominant trend was higher concentrations during lower flow periods in the same event (Figures 52 and 53). This is a concern because the low flow periods typically make up a considerable amount of an event and are typically at the end.

Figure 52 is an example of a first flush event. In this event, a considerable time at the beginning of the event is low flow. Concentrations are high at the beginning and are reduced when flow increases; however, once flow subsides concentrations increase. First flush collection would be effective in this case as the resulting loading is higher at the beginning of the event. Loading during low flow has the potential to be greater than high flow periods, which are typically at the beginning of an event.

Figure 53 is an example of an event without a first flush and is indicative of most events monitored in this study. Initial flow is high while concentrations are low. When flow subsides, concentrations increase. A second pulse in flow decreases concentrations. Concentrations at the beginning of this event are not high enough for loading to be greater in the initial part of the event. In this case, first flush collection would not be as effective; whereas, collection when flow is low would be more efficient. In many events, concentration values increased from the beginning of an event through the end of an event. Indicating first flush collection may not be ideal.

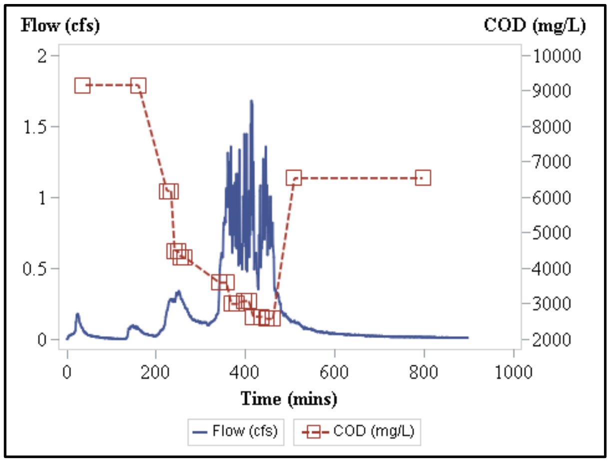


Figure 52: Relationship between concentration and flow with first flush. (Dr. Becky Larson and Mike Holly)

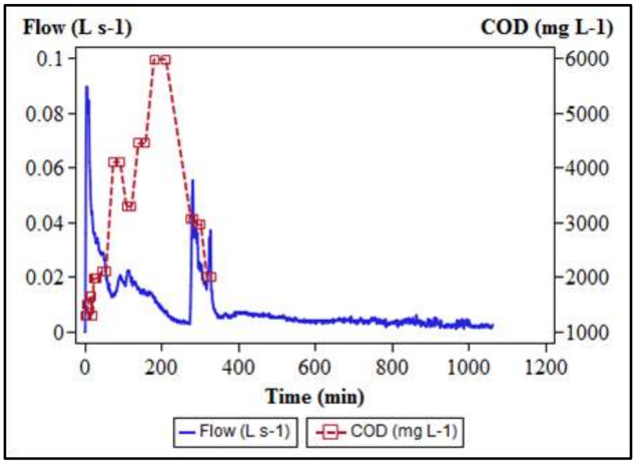


Figure 53: Relationship between concentration and flow without first flush. (Dr. Becky Larson and Mike Holly)

Concentrations are inversely related to flow, but flow cannot be used to measure or predict what concentrations will be. Flow comes from a different source than the constituents, and many variables can affect flow without affecting concentrations. Each farm would have its own factors affecting flow; therefore, each farm would need individual modeling to determine flow and concentration correlations.

Sampling scheme for the overflow was incrementally expanded so as cumulative volume increased, more volume passed before another sample was taken. In addition, a majority of events used composite samples rather than discrete (Table 4). Despite these facts, sample concentrations were similar to flow patterns to Dr. Becky Larson's research using discrete samples except that the trends were not as well defined. The sampling scheme for this study represented an event relatively well. More samples per event would have added more detail to an event, which may or may not have revealed a trend or correlation not already found.

4.3 Correlation of monitored parameters

All constituents monitored were statistically correlated with each other, except for pH, as a predictor of the other (Table 18). Coming from a common source, constituent concentrations fluctuate similarly with changes to flow volume. Overall, conductivity correlated best with all of the other parameters. As a result, the potential exists to utilize one of the measured constituents to meter flow concentrations and direct flow to be collected or sent to VTA based on potency.

Table 18: R-square correlation table for monitored parameters.

	pH	*TS*	*COD*	*TP*	*TDP*	*NH_3*	*TKN*	*Lab Conductivity*	*Real-time Conductivity*
pH	1	0.139	0.373	0.395	0.595	0.389	0.267	0.401	0.403
TS	0.139	1	0.759	0.703	0.649	0.510	0.717	0.748	0.734
COD	0.373	0.759	1	0.828	0.846	0.732	0.811	0.924	0.948
TP	0.395	0.703	0.828	1	0.991	0.732	0.678	0.872	0.847
TDP	0.595	0.649	0.846	0.991	1	0.748	0.720	0.921	0.888
NH_3	0.389	0.510	0.732	0.732	0.748	1	0.634	0.845	0.717
TKN	0.267	0.717	0.811	0.678	0.720	0.634	1	0.892	0.851
Lab Conductivity	0.401	0.748	0.924	0.872	0.921	0.845	0.892	1	0.936
Real-time Conductivity	0.403	0.734	0.948	0.847	0.888	0.717	0.851	0.936	1

Midway through the study, the strong correlation between parameters was identified. Therefore, conductivity probes (Decagon®) were installed in the overflow conduit to the VTA at Farms A and B to track real-time conductivity readings. Real-time conductivity readings correlated strongly with laboratory conductivity probe analysis and remained viable throughout the remaining 6-month monitoring period.

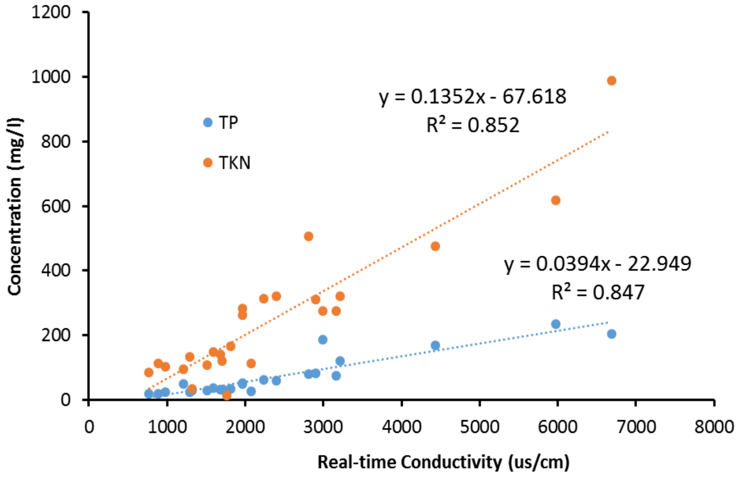


Figure 54: Linear regression for TP and TKN with real-time conductivity.

In order to use conductivity as a means to meter flow, the relationship between conductivity and the constituents of concern must be identified. Linear regression was used to establish the relationship between real-time conductivity and both TP and TKN (Figure 54). The identified equations could be used to predict TP and TKN concentrations using conductivity. Since real-time conductivity would be used, in situ, it was used for the equations instead of lab analysis conductivity. Determining an acceptable concentration for these parameters is important for engineers, so systems could be designed to divert liquid at a given conductivity threshold.

4.4 Alternative leachate collection system design comparison

Data collected shows first flush is rare in the systems that were monitored. This determination is similar to data that was collected by Holly and Larson (2014). The implications of these studies is that the current system designs are not as effective as initially thought. Because concentration is related to flow, alternative designs may be more efficient. Figure 55 illustrates two alternative design concepts to the current first flush design.

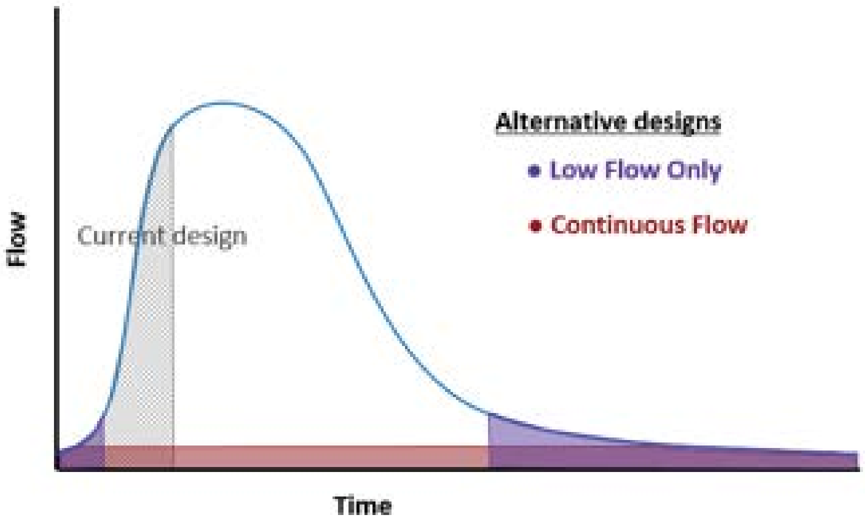


Figure 55: Alternative system design concepts.

To test these alternative designs, analysis was performed to compare how much load would be collected in a first flush system, continuous flow system, and low flow only system given an equal volume collected. The results in Table 19 indicate that either of the alternative designs would be more efficient at Farm A. There was more variation in event loading at Farm A in comparison to the other two farms as indicated in the mass-volume curves in Figure 50. Conversely, Farm B indicated near similar efficiencies and Farm C had slightly reduced efficiency. The mass-volume curves show less variation in loading as compared to Farm A and nearly linear loading for Farm C for both nutrients. If the percent load is the same as the percent volume at any point in the event, it would not matter how much volume is collected, the loading would be similar regardless of system design. More comprehensive sample collection of individual runoff events may provide more detail in the efficiencies of alternative system designs.

Table 19: Design comparison - percent total load collected given an equal volume as compared to first flush.

	Farm A		Farm B		Farm C	
	LFO	CF	LFO	CF	LFO	CF
Phosphorus	141%	136%	105%	106%	96%	94%
Nitrogen	131%	127%	104%	102%	84%	81%

*First flush = 100%

A low flow only collection design is the most efficient of the alternative designs. To collect low flow only, a metering device to measure the high concentration liquid or a predetermined flow rate to direct flow to collection or the VTA once a threshold is exceeded could be used. For either method, identifying a cost effective and durable solution to perform concentration or flow activation could prove difficult. Leachate and feed storage runoff as well as weather conditions can be hard on equipment. A meter designed to withstand harsh environments would be needed to ensure proper function. The real-time conductivity probe used for this study, designed for use in wastewater systems, remained viable and accurate for the 6-month monitoring period, but additional testing would be required to determine the longer term effectiveness of this and other potential probes. Flowrate monitoring devices could also be used, but would also have to be evaluated for effectiveness and longevity in feed storage runoff environments. Either the concentration or flow methods may have challenges with particulate debris from feed storage and icing conditions during wintertime months.

The alternative design option of collecting a constant flowrate throughout an event was slightly less efficient than the low flow only option. The flowrate could either be established by an orifice or low-rate continuous pumping. During a runoff event, all flow would be collected as long as flow is low enough as to not overwhelm the orifice or pump rate. When flow is greater than the established rate it would bypass collection and be sent to the VTA. An advantage of this system design is that it would require no metering devices that could fail. This system design would still have the challenge of particulate debris and icing conditions during wintertime months. Specific to the orifice method, there would be additional challenges because as system size decreased, so would orifice size, which would increase the potential for clogging.

4.5 Conductivity modeling of alternative system designs

It can be difficult finding equipment that can withstand the harsh, acidic feed storage environment and climatic conditions in Wisconsin. Conductivity metering is used in many environments with similar harsh conditions, i.e. waste streams. As previously mentioned, real-time conductivity probes were installed at Farm A and B when correlation of conductivity to other constituents became evident. The selected probes were designed for wastewater systems and were also relatively low cost (approximately $200). The installation of the conductivity probes would allow for real-time identification of runoff potency.

Shortly after installation, it became apparent that conductivity metering may be a viable option for metering. The expected trend of low flow/high concentration and high flow/low concentration were evident in initial conductivity readings. Once plotted, the inverse flow to conductivity reading was evident in the data (Figure 56). Consistency in the readings at both farms has proven conductivity metering’s potential as a viable option.

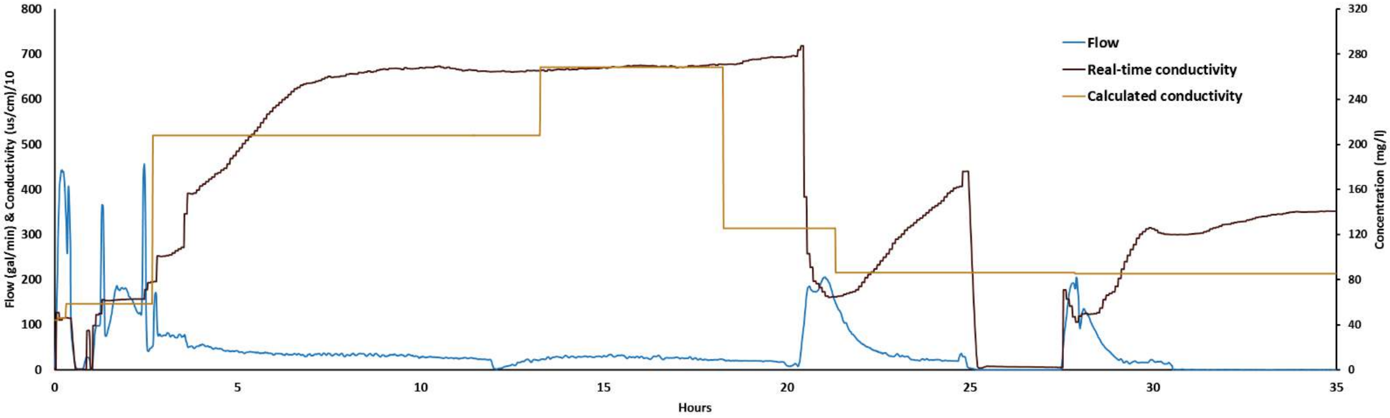


Figure 56: Real-time conductivity and calculated conductivity from sample midpoints relationship to flow.

The real-time conductivity readings allowed for a more detailed analysis of alternative system efficiency as compared to the coarse composite sample representation. In order to evaluate entire runoff events and properly assess annual load, samples were taken at relatively larger volume intervals as volume increased. Because of sample analysis costs, it was not feasible to analyze every sample as a discrete sample. Many of the samples taken became part of a composite sample representing an extended “block” of volume during an event that was centered on the mid-point volume for that block.

To properly compare the nutrient concentrations to conductivity, conductivity needed to be represented in the same way, therefore the real-time conductivity readings were compiled and divided by the volume that the composite sample represented to give equal loadings for that flow period. As evidenced in Figure 56, the mid-point conductivity calculation has much less detail of conductivity changes as compared to real-time conductivity readings.

Modeling of the real-time versus mid-point, or calculated, conductivity values was performed using the six months of available data that had real-time conductiviy metering . As can been observed in Table 20, the real-time data had increased efficiency at both farms for both of the alternative system designs as compared to the first flush design. This is a result of the detailed relationship between conductivity and flow that is lost in the sampling scheme for the project as evidenced in Figure 56.

	Farm A		**Farm B**	
	LFO	**CF**	**LFO**	**CF**
Real-time	149%	143%	105%	100%
Mid-point	140%	133%	99%	97%

*First flush = 100%

Table 20: Predicted percent collected using real-time and mid-point, or calculated, conductivity.

4.6 Statistical significance of factors influencing runoff concentration

If there are time periods that influence load, targeting them would be beneficial. Several factors were analyzed with correlation statistics to determine which factors influenced runoff loses. Factors analyzed include: rain volume, rainfall duration, average rainfall intensity, 5 minute maximum rainfall intensity, flow volume, concentrations and loads, season of the year, feed type, feed volume, and time of an event in relation to the last bunker filling. Despite seeing trends in the general trend analysis, statistically, none of the factors listed were correlated to losses. None of these factors are a main driver for losses. Multiple factors have an influence runoff losses, and different combinations of factors, their interactions, and the magnitudes of the different factors impact losses differently. It can be concluded that none of the factors in which data was collected for this analysis stood out as more influential than the others.

4.7 Influence of seasonality, forage ensiling and rain volume on runoff concentrations

Although statistical analysis did not indicate that the influence of the time of year or the proximity of runoff event to bunker filling were statistically significant, trends in observed loading might still be linked to either or both factors. If there is an influence from season or forage ensiling on runoff concentrations, it would be beneficial, in terms of water quality protection, to collect more runoff at those time.

To determine if any general trends related to bunker filling or season were identifiable, these factors were compared to storm size for separate runoff events. Each farm was assessed individually as each farm had different feed pad and system management schedules (Table 5). This adds other variables when trying to determine factors that influence loading in individual events. Bunker covering type and method, feed litter management and spoilage pile management all likely influence constituent concentrations in feed storage runoff.

Figures 57-59 show annual cumulative loading at each farm. There are noticeable increases in the cumulative load plot. In general, these increases, or loading “steps”, appear to be associated with several factors. In the spring, increases appear to be associated with large volumes of runoff caused by snowmelt and rain. During the summer, large increases seem to have some association with haylage harvest or large rain events (or multiple rain events in a short period of time). In fall, increases appear to be associated with harvest for corn silage or large rain events (or multiple rain events in a short period of time), similar to that of summer.

To illustrate this, Tables 21-25 list a description of the increases in loading in Figures 57-59. Individual event flow weighted average concentrations can be found in Appendix C and can be used in conjunction with the figures for trend analysis. Not all increases are included in these tables, indicating there is a lot unknown, but many steps in the cumulative loading curves in Figures 57-59 can be attributed to rain/snowmelt events, relatively large rain events, or events shortly after (within 2 weeks) bunker filling.

Both Farms A and B had noticeable loading steps during snowmelt (Figures 57 and 58 and Tables 21 and 23). Typically snow plowed during winter would contain debris from the feed pad which builds up over time. Snowmelt and rain come into contact with this debris in addition to the other contact with feed, litter, or spoilage on the pad.

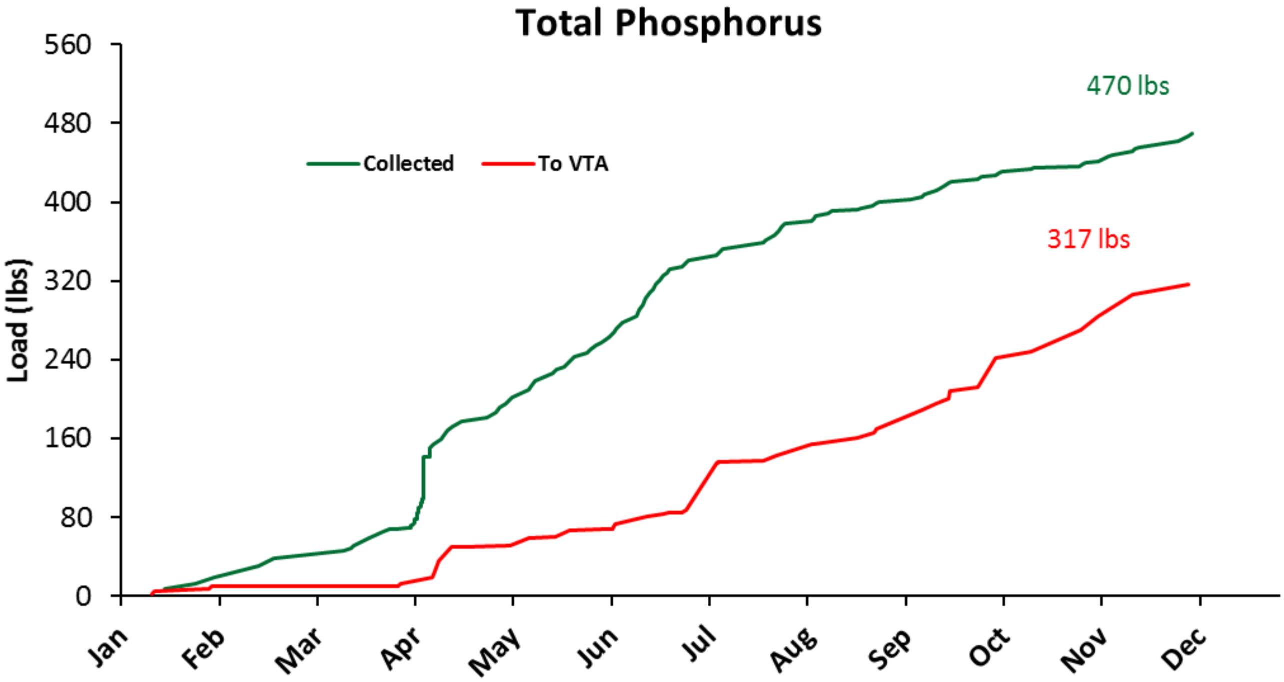
Large rain events have more water to move constituents from feed storage. As seen in Tables 21 and 22, rain events at Farm A had to be greater than 0.9 inch in 2013 and 0.5 inch in 2014 before a noticeable loading step occurred. The only loading step at Farm B in 2013 was associated with a two inch rain-only event (Table 23); however, in 2014, half of the loading steps were associated with rain-only events and all were greater than one inch (Table 24). All loading steps attributed to rain-only events at Farm C, were greater than one inch (Table 25). Although there was no feed data in late October and November of that year, observation while visiting revealed no filling occurred after mid-October of that year.

Increases in loading within a couple of weeks after filling bunkers appear to be somewhat consistent at all farms. Once harvest season starts, few events with loading steps occurred without being within a few weeks of bunker filling. It should be noted that harvesting and bunker filling occurs every month, so at least half of the harvest season will be within two weeks after filling. If the same rain events did not occur near filling, would the loading steps still have occurred? Farm B (2014) and Farm C indicate it is possible; however, those rain events were relatively large in comparison (Table 25). At Farm B in 2013, there are several small but noticeable steps in the cumulative loading curve (Figure 58a) that despite being a drier fall, can likely be attributed to bunker filling (Table 23). Additionally, another noticeable loading step trend is that loading steps near bunker fillings required less rain to show an appreciable increase in loading (Tables 21-25). As little as 0.2, 0.4, and 0.3 inches of rain, at Farms A, B, and C, respectively, within days of filling bunkers resulted in sharp loading increases. The magnitude of sharp loading steps in Figures 57b and 58b and Tables 22 (Aug. 29 – Sept. 4) and 24(multiple events in August and September) may be associated with rainfall while actively harvesting and filling bunkers.

Comparing loading jumps to flow weighted mean concentrations for each event in Appendix C, also indicates a relationship with rainfall and bunker filling. During time gaps listed in Tables 21-25, event concentrations typically increased from beginning to end when there were multiple days with rain events and runoff. There also appears to be increased event concentrations when events occurred closer to bunker filling, the closer the event after filling the more likely the concentration would increase. These general trends can be observed in most events, but there were also instances that these trends did not appear.

There were several events with concentration increases near filling that did not show a notable increase in loading. There were also several concentration increases that were not associated with larger rain events or timing of filling. In some cases, an event within days of filling does not cause an appreciable loading increase, but an event a few weeks later did. There are likely other factors that when combined influence when loading steps occur.

2013 Farm A



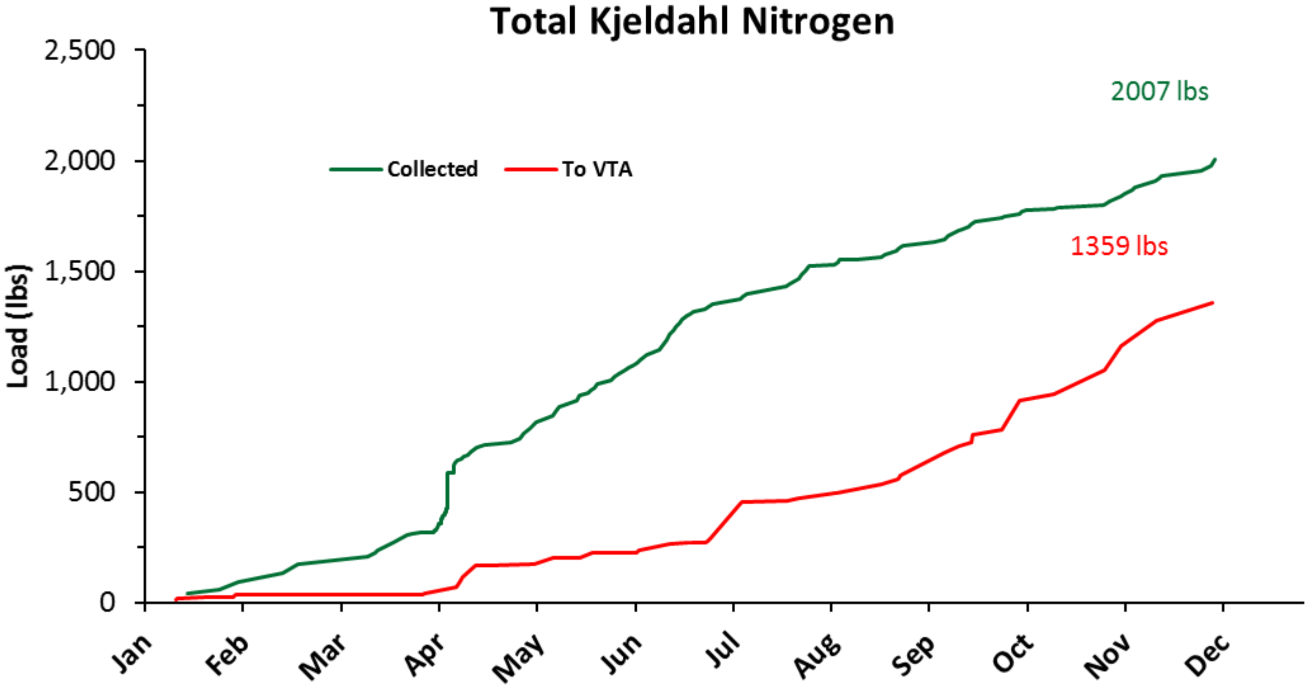
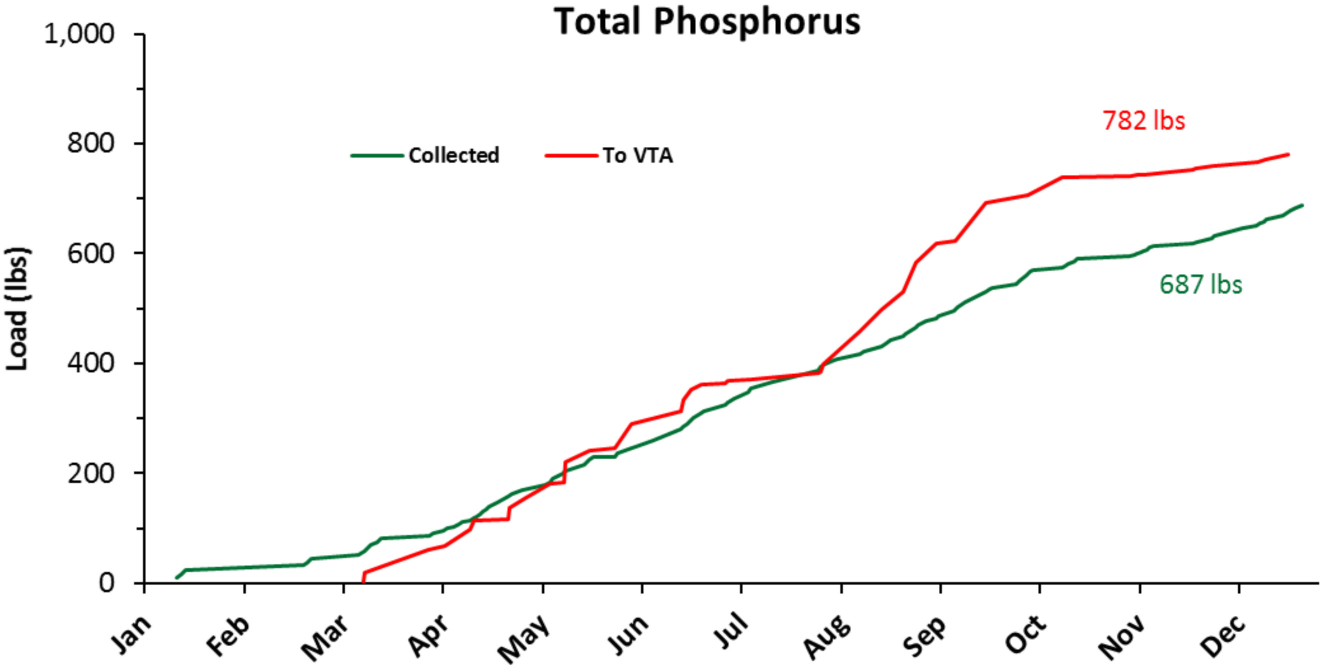


Figure 57a: Farm A 2013 annual loading curves.

2014 Farm A



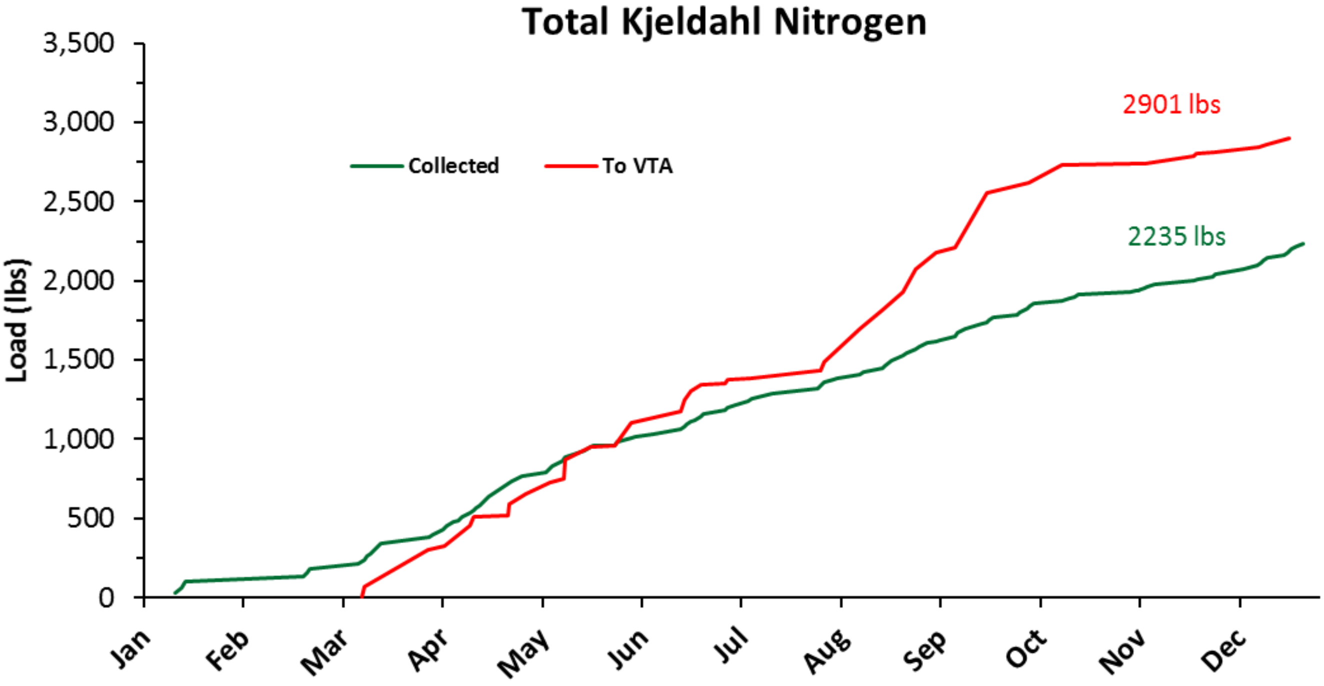
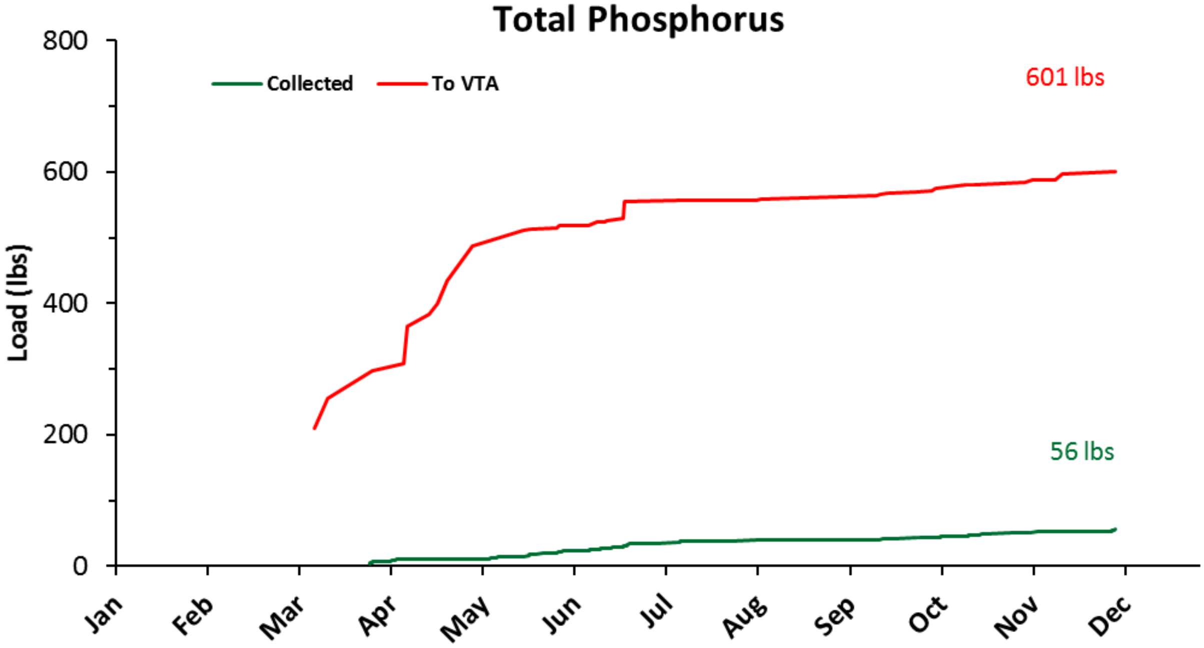


Figure 57b: Farm A 2014 annual loading curves.

2013 Farm B



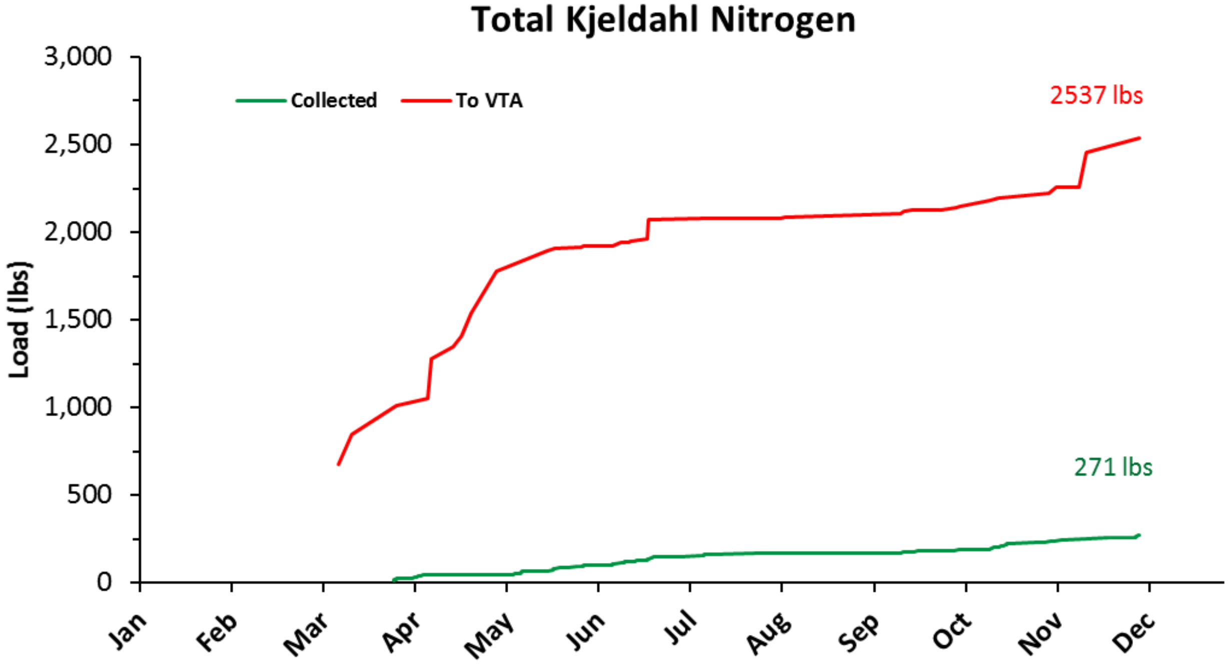
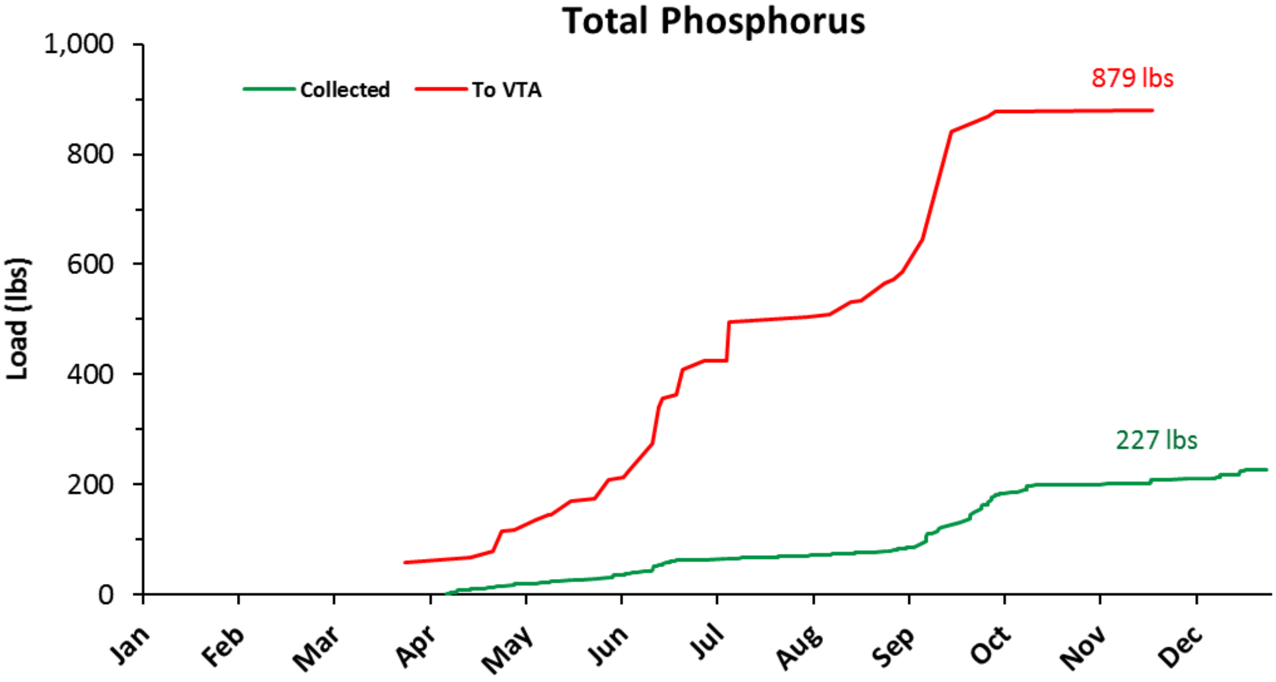


Figure 58a: Farm B 2013 annual loading curves.

2014 Farm B



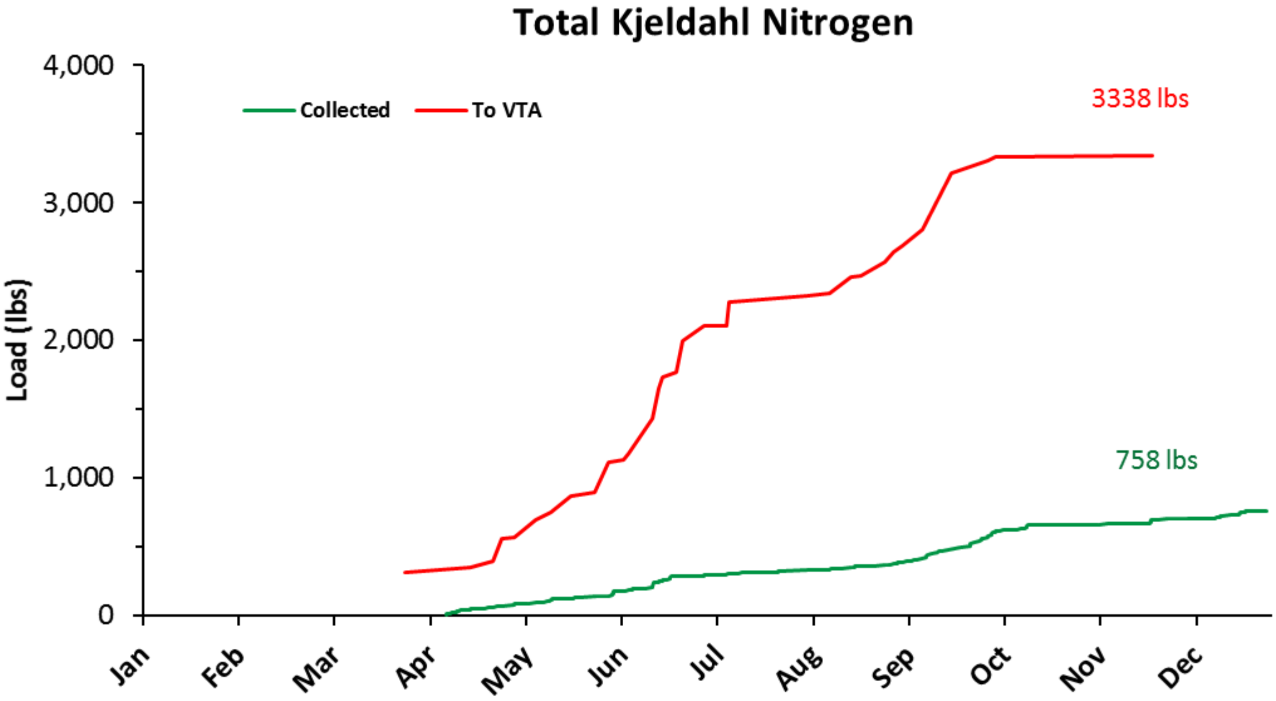
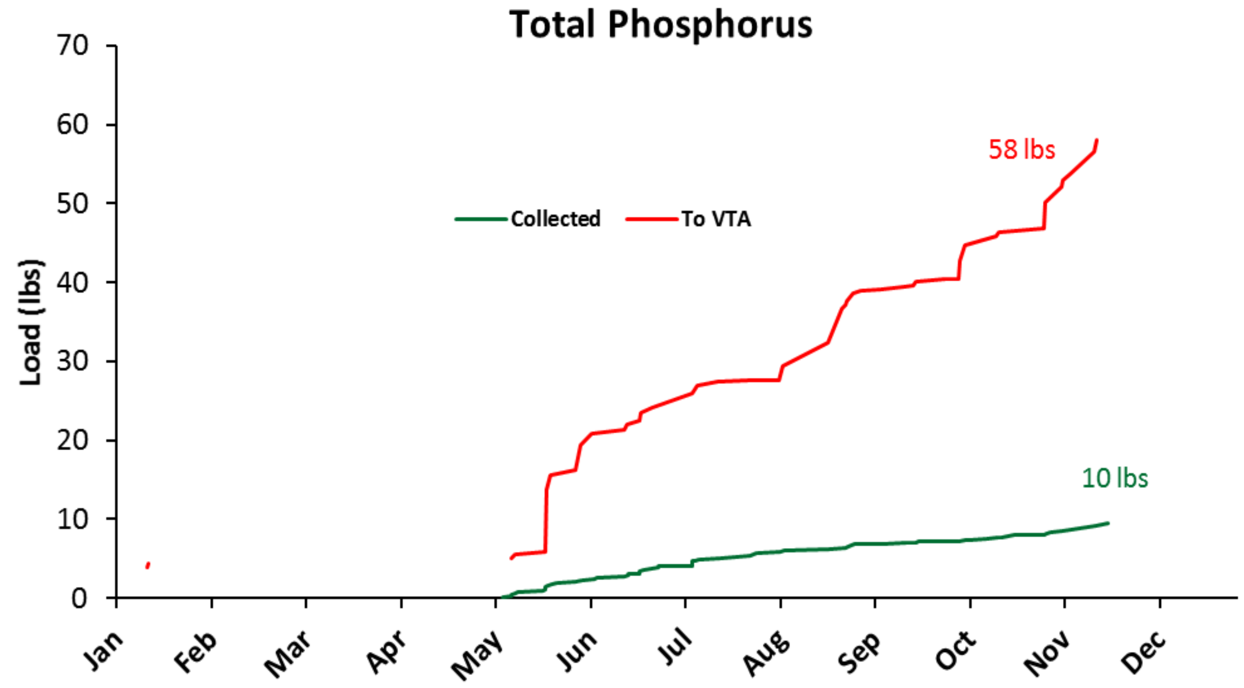


Figure 58b: Farm B 2014 annual loading curves.

2013 Farm C



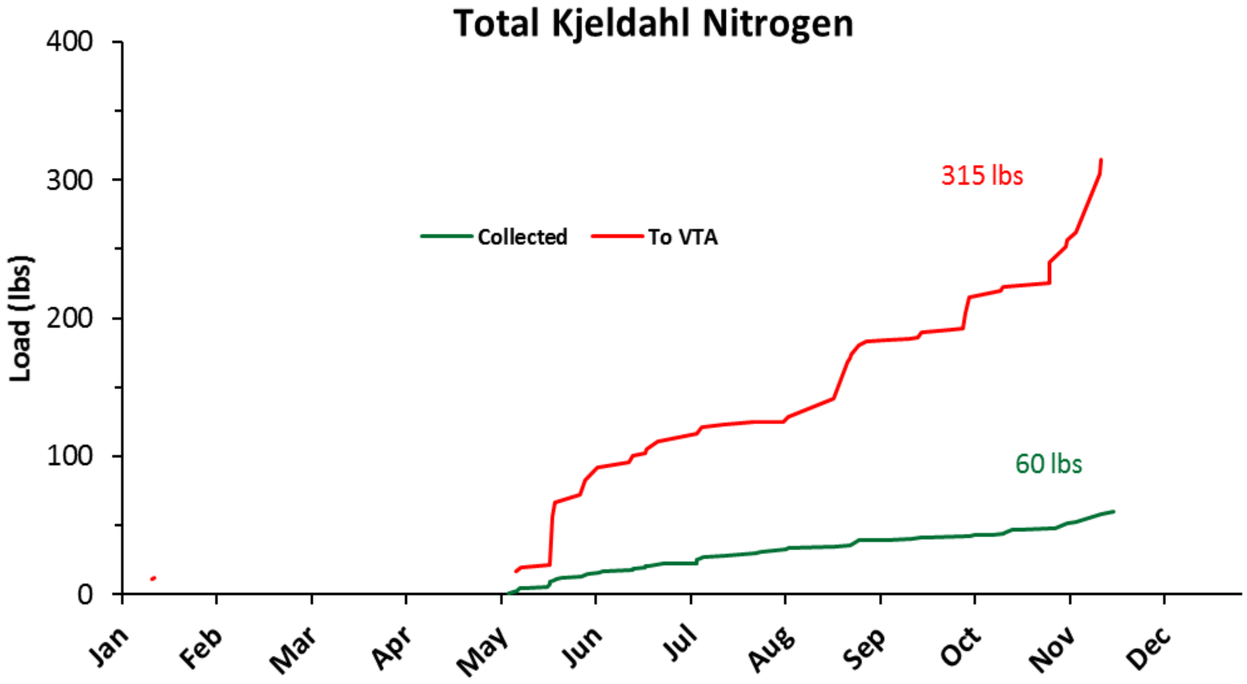


Figure 59: Farm C 2013 annual loading curves.

Table 21: Description of load increases for Farm A 2013 “To VTA”.

Time gap	Description
Jan. 28-29	Rain (0.9”) with snowmelt
April 4-15	Rain (2.0”) with snowmelt
May 9	Rain (0.9”)
May 21-22	Rain (1.6”)
June 4-6	Rain (0.9”)
June 27 – July 8	Rain (2.5”) w/in a few days of hay
Aug. 27 – Sept. 10	Rain (0.9”) w/in a week of hay/sorghum
Sept. 10 – Sept. 19	Rain (0.6”) w/in 2 weeks of hay/sorghum
Sept. 28 – Oct. 4	Rain (0.2”) w/in a few days of corn

Table 22: Description of load increases for Farm A 2014 “To VTA”.

Time gap	Description
March 7 – April 8	Rain (0.6”) with snowmelt
April 12-14	Rain (3.0”)
April 24	Rain (0.5”)
May 11-12	Rain (1.5”)
May 27 – June 1	Rain (1.7”) w/in days of hay
June 17-23	Rain (2.4”) w/in a week of triticale
July 1	Rain (0.3”) w/in days of hay
July 29-30	Rain (1.0”) w/in a week of hay
Aug. 11-12	Rain (2.1”)
Aug. 29 – Sept. 4	Rain (2.0”) filling hay
Sept. 10-20	Rain (1.5”) w/in 2 weeks of hay
Oct. 3-13	Rain (2.0”) filling corn

Table 23: Description of load increases for Farm B 2013 “To VTA”.

Time gap	Description
March 8-13	Rain (0.4”) with snowmelt
March 28	Rain (0.4”) with snowmelt
April 8-16	Rain (1.5”) with snowmelt
June 12	Rain (0.4”) w/in 2 weeks of hay
June 21-22	Rain (2.0”)
Aug. 6	Rain (0.4”) w/in a week of hay
Sept. 14-18	Rain (1.1”) filling corn
Oct. 3	Rain (1.0”) w/in a few days of corn
Nov. 4	Rain (0.4”) w/in a few days of sorghum
Nov. 14-16	Rain (0.4”) w/in 2 weeks of sorghum

Table 24: Description of load increases for Farm B 2014 “To VTA”.

Time gap	Description
April 24-27	Rain (1.3”)
May 1-11	Rain (3.0”)
May 11-19	Rain (2.0”)
May 27-31	Rain (2.5”)
June 7-14	Rain (1.3”) w/in a week of hay/rye
June 14-18	Rain (3.8”) w/in 2 weeks of hay/rye
June 18-24	Rain (1.5”)
July 7-11	Rain (1.2”)
Aug. 11-18	Rain (1.9”) filling hay
Aug. 18-29	Rain (2.2”) filling hay
Sept. 1-10	Rain (1.5”) filling corn
Sept. 10-19	Rain (0.4”) filling corn
Oct. 1	Rain (0.5”) w/ in 2 weeks of corn

Table 25: Description of load increases for Farm C 2013 “To VTA”.

Time gap	Description
May 21-22	Rain (2.5”)
May 30 – June 5	Rain (1.3”)
June 15-16	Rain (0.3”) w/in a few days of hay
June 21	Rain (0.6”) w/in a week of hay
July 8-9	Rain (1.6”)
Aug. 5-7	Rain (1.2”)
Aug. 21	Rain (0.8”) w/in a week of hay
Aug. 27 – Sept. 1	Rain (2.4”) w/in 2 weeks of hay
Oct. 3-5	Rain (2.6”)
Oct. 15	Rain (0.5”) w/in a few days of corn
Oct. 31 – Nov. 6	Rain (2.6”) [no feed data]
Nov. 16-17	Rain (1.4”) [no feed data]

5. Conclusions

All feed storage facility runoff events during this study were precipitation induced. Although some leachate was observed coming from silage, it was not substantial enough to initiate sampling. Concentrations for all monitored constituents varied greatly between events, sites, and farms. All constituents monitored were statistically correlated with each other, except for pH, and had an inverse relationship with flow. Laboratory and real-time conductivity correlated best with all of the other parameters monitored. As a result, the potential exists to use one of the measured constituents to meter flow concentrations and direct flow to be collected or sent to the VTA based on potency.

Collected data indicated a lack of first flush, for which current collection systems are designed. Loading with respect to flow was relatively uniform throughout events. In some instances events exhibited a delayed flush. Runoff concentrations were highly dependent on flow and were likely influenced by contact and residence time with stored feed, feed litter, and spoilage piles.

Alternative system designs that target low flow collection have the potential to collect greater load than the current first flush system design. Two alternative systems were modeled to determine efficiency when collecting silage runoff only when flow is low or collecting a low flowrate continuously throughout an event. Holding the collection volumes equal, two of three farms showed increased load collection efficiency with both alternative system designs.

Since the focus of the study was on annual loading trends, all events were adequately sampled but samples were composited to reduce analysis costs. Composite samples represented a “block” of volume around a mid-point. This leaves out detail in modeling to determine the efficiency of alternative system designs. Real-time conductivity monitoring was installed at two farms near the end of the study and allowed for more accurate characterizations of runoff events. Real-time versus mid-point conductivity readings were modeled to determine changes in alternative system design efficiency. Real-time conductivity modeling exhibited an increased efficiency at both farms where data was collected. The composite sample methodology underestimates the modeled efficiency of alternative system designs calculated in this study.

Determining which factors influence nutrient loading in runoff during the year can help target collection to increase collection system efficiency. Some general trends appear linking loading increases to snowmelt, high volume rain events, and rain events shortly after filling bunkers. Statistical analysis was performed using multiple factors, but there were no measured factors that stood out as statistically having more influence than any other factor. The aforementioned factors as well as other variables interact with feed storage and affect loading in runoff. It is a complex system. Many variables influence constituent concentrations in feed storage runoff. Additional research on feed storage runoff will enhance the characterization concentration trends within individual events and factors that influence leachate concentrations on a temporal basis.

Although this study, combined with a concurrent study by Becky Larson from UW Biological Systems Engineering, provides much needed information on runoff characteristics from diverse feed storage facilities throughout Wisconsin, additional research would supply information to further aid in the design of runoff collection systems. Some of these suggested research needs include:

1) Longer term monitoring to evaluate the concentrations of storms in excess of the 25% of the 25-year, 24-hour storm treatment criteria.
2) Additional yield analysis between farms to determine if stored feed or other factors play a role in observed yield variations.
3) Correlation analysis between losses and additional factors not monitored in this study to determine if there is a factor or set of factors that significantly influence losses. This would include a more detailed tracking of pad litter, spoilage piles, bunker covering, and volume and surface area of stored feed.
4) More effective monitoring of volume and constituent concentration at all inputs (including tile) to collection systems to more comprehensively understand loading inputs. This is very challenging to accomplish without interfering with normal operation of the system or daily farm operations.
5) Treatment effectiveness at the outlet of VTAs. This was impossible on participating farms and may need to occur at a research facility.
6) Enhanced modeling of constituent concentrations and flow rates that could be optimized for alternative system designs to improve the efficiency of future system designs.
7) Evaluation of metering device options for durability, longevity and cost effectiveness for operating alternative low flow only collection systems.

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This technical report along with other leachate materials can be found online at: www.uwdiscoveryfarms.org. For questions regarding this document call 715.983.5668 or email aaron.wunderlin@ces.uwex.edu.

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Appendix A: Kruskal-Wallis analysis

Kruskal-Wallis test (**pH**):

K (Observed value)	26.545
K (Critical value)	11.070
DF	5
p-value (Two-tailed)	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

- As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
- The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Kruskal-Wallis test (**Total Solids**):

K (Observed value)	190.759
K (Critical value)	11.070
DF	5
p-value (Two-tailed)	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

- As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
- The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Kruskal-Wallis test (**COD**):

K (Observed value)	175.881
K (Critical value)	11.070
DF	5
p-value (Two-tailed)	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

- As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
- The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Kruskal-Wallis test (**TP**):

K (Observed value)	277.405
K (Critical value)	11.070
DF	5
p-value (Two-tailed)	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

- As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
- The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Kruskal-Wallis test (**SRP**):

K (Observed value)	286.044
K (Critical value)	11.070
DF	5
p-value (Two-tailed)	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

- As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
- The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Kruskal-Wallis test (**TKN**):

K (Observed value)	202.918
K (Critical value)	11.070
DF	5
p-value (Two-tailed)	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

- As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
- The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Kruskal-Wallis test (**Ammonia**):

K (Observed value)	356.526
K (Critical value)	11.070
DF	5
p-value (Two-tailed)	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

- As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
- The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Summary statistics:

Variable	Observations	Obs. w/ missing data	Obs. w/o missing data	Min.	Max.	Mean	Std. dev.
pH | L1	252	0	252	4.55	6.94	5.42	0.45
pH | L2	246	0	246	4.28	6.32	5.29	0.45
pH | L3	122	0	122	3.99	6.99	5.28	0.62
pH | L4	177	0	177	4.23	7.11	5.49	0.69
pH | L5	49	0	49	4.83	6.77	5.58	0.51
pH | L6	74	0	74	4.21	6.24	5.22	0.44
Total Solids | L1	252	2	250	0.146	2.038	0.703	0.311
Total Solids | L2	246	1	245	0.034	3.346	0.435	0.362
Total Solids | L3	122	2	120	0.106	4.595	0.711	0.840
Total Solids | L4	177	0	177	0.082	3.180	0.451	0.515
Total Solids | L5	49	0	49	0.084	1.460	0.510	0.317
Total Solids | L6	74	0	74	0.048	1.047	0.377	0.221
COD | L1	252	1	251	820	29080	10295	5404
COD | L2	246	2	244	940	28060	6450	4783
COD | L3	122	8	114	920	47440	8581	7588
COD | L4	177	7	170	660	40000	5647	5600
COD | L5	49	0	49	820	18800	6444	3965
COD | L6	74	0	74	810	61210	5431	6998
TP | L1	252	6	246	18.834	333.288	82.412	44.121
TP | L2	246	6	240	11.976	249.743	47.472	38.283
TP | L3	122	4	118	11.740	659.236	79.712	108.985
TP | L4	177	4	173	10.440	460.050	47.023	70.432
TP | L5	49	4	45	10.817	86.650	38.636	18.031
TP | L6	74	7	67	11.789	70.934	33.376	11.827
SRP | L1	252	26	226	21.050	306.016	76.611	41.934
SRP | L2	246	20	226	10.938	248.635	42.038	35.820
SRP | L3	122	17	105	9.696	552.530	59.205	77.543
SRP | L4	177	16	161	8.054	392.428	35.753	51.077
SRP | L5	49	2	47	10.053	85.440	36.493	19.969
SRP | L6	74	3	71	10.861	70.934	30.644	12.353
TKN | L1	252	3	249	23.046	743.370	306.783	130.925
TKN | L2	246	7	239	33.375	988.688	182.258	130.073
TKN | L3	122	1	121	55.762	1385.551	287.552	248.388
TKN | L4	177	2	175	14.813	1086.572	178.677	172.109
TKN | L5	49	2	47	41.609	1015.197	268.670	210.270
TKN | L6	74	3	71	23.627	798.031	209.709	127.486
Ammonia | L1	252	13	239	23.911	329.903	115.203	62.508
Ammonia | L2	246	3	243	6.586	168.186	39.487	28.244
Ammonia | L3	122	7	115	10.260	216.690	75.088	44.909
Ammonia | L4	177	4	173	2.383	204.440	41.506	37.354
Ammonia | L5	49	3	46	8.015	227.563	72.233	49.065
Ammonia | L6	74	3	71	11.227	122.061	42.434	24.215

Appendix B: Dunn's pairwise comparison

pH

Sample	Frequency	Sum of ranks	Mean of ranks	Groups		
pH | L6	74	28395.500	383.723	A		
pH | L3	122	50955.500	417.668	A	B	
pH | L2	246	105155.500	427.461	A	B	
pH | L1	252	123232.000	489.016		B	C
pH | L4	177	88645.500	500.822		B	C
pH | L5	49	27276.000	556.653			C

Table of pairwise differences:

	pH | L1	pH | L2	pH | L3	pH | L4	pH | L5	pH | L6
pH | L1	0	61.554	71.348	-11.806	-67.637	105.293
pH | L2	-61.554	0	9.793	-73.361	-129.192	43.738
pH | L3	-71.348	-9.793	0	-83.154	-138.985	33.945
pH | L4	11.806	73.361	83.154	0	-55.831	117.099
pH | L5	67.637	129.192	138.985	55.831	0	172.930
pH | L6	-105.293	-43.738	-33.945	-117.099	-172.930	0

p-values:

	pH | L1	pH | L2	pH | L3	pH | L4	pH | L5	pH | L6
pH | L1	1	0.010	0.015	0.651	0.103	**0.003**
pH | L2	0.010	1	0.739	0.005	**0.002**	0.214
pH | L3	0.015	0.739	1	0.008	**0.002**	0.386
pH | L4	0.651	0.005	0.008	1	0.193	**0.001**
pH | L5	0.103	**0.002**	**0.002**	0.193	1	**0.000**
pH | L6	**0.003**	0.214	0.386	**0.001**	**0.000**	1

Bonferroni corrected significance level: 0.0033

Total Solids

Sample	Frequency	Sum of ranks	Mean of ranks	Groups			
Total Solids | L4	177	59408.500	335.641	A			
Total Solids | L6	74	26179.000	353.770	A	B		
Total Solids | L2	245	92108.500	375.953	A	B		
Total Solids | L5	49	22843.000	466.184		B	C	
Total Solids | L3	120	59103.000	492.525			C	
Total Solids | L1	250	159428.000	637.712				D

Table of pairwise differences:

	Total Solids | L1	Total Solids | L2	Total Solids | L3	Total Solids | L4	Total Solids | L5	Total Solids | L6
Total Solids | L1	0	261.759	145.187	302.071	171.528	283.942
Total Solids | L2	-261.759	0	-116.572	40.312	-90.231	22.183
Total Solids | L3	-145.187	116.572	0	156.884	26.341	138.755
Total Solids | L4	-302.071	-40.312	-156.884	0	-130.542	-18.129
Total Solids | L5	-171.528	90.231	-26.341	130.542	0	112.413
Total Solids | L6	-283.942	-22.183	-138.755	18.129	-112.413	0

p-values:

	Total Solids | L1	Total Solids | L2	Total Solids | L3	Total Solids | L4	Total Solids | L5	Total Solids | L6
Total Solids | L1	1	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Total Solids | L2	**< 0.0001**	1	**< 0.0001**	0.122	0.029	0.527
Total Solids | L3	**< 0.0001**	**< 0.0001**	1	**< 0.0001**	0.557	**0.000**
Total Solids | L4	**< 0.0001**	0.122	**< 0.0001**	1	**0.002**	0.620
Total Solids | L5	**< 0.0001**	0.029	0.557	**0.002**	1	0.021
Total Solids | L6	**< 0.0001**	0.527	**0.000**	0.620	0.021	1

Bonferroni corrected significance level: 0.0033

COD

Sample	Frequency	Sum of ranks	Mean of ranks	Groups		
COD | L6	74	23682.500	320.034	A		
COD | L4	170	54909.000	322.994	A		
COD | L2	244	97322.000	398.861	A		
COD | L5	49	20598.000	420.367	A	B	
COD | L3	114	55552.500	487.303		B	
COD | L1	251	155189.000	618.283			C

Table of pairwise differences:

	COD | L1	COD | L2	COD | L3	COD | L4	COD | L5	COD | L6
COD | L1	0	219.422	130.980	295.289	197.916	298.249
COD | L2	-219.422	0	-88.442	75.867	-21.507	78.827
COD | L3	-130.980	88.442	0	164.309	66.935	167.269
COD | L4	-295.289	-75.867	-164.309	0	-97.373	2.960
COD | L5	-197.916	21.507	-66.935	97.373	0	100.334
COD | L6	-298.249	-78.827	-167.269	-2.960	-100.334	0

p-values:

	COD | L1	COD | L2	COD | L3	COD | L4	COD | L5	COD | L6
COD | L1	1	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**
COD | L2	**< 0.0001**	1	**0.003**	0.004	0.598	0.023
COD | L3	**< 0.0001**	**0.003**	1	**< 0.0001**	0.133	**< 0.0001**
COD | L4	**< 0.0001**	0.004	**< 0.0001**	1	0.021	0.935
COD | L5	**< 0.0001**	0.598	0.133	0.021	1	0.037
COD | L6	**< 0.0001**	0.023	**< 0.0001**	0.935	0.037	1

Bonferroni corrected significance level: 0.0033

Total Phosphorus

Sample	Frequency	Sum of ranks	Mean of ranks	Groups			
TP | L4	173	49083.000	283.717	A			
TP | L6	67	20099.500	299.993	A	B		
TP | L5	45	15858.000	352.400	A	B		
TP | L2	240	91388.500	380.785		B		
TP | L3	118	58363.500	494.606			C	
TP | L1	246	160812.500	653.709				D

Table of pairwise differences:

	TP | L1	TP | L2	TP | L3	TP | L4	TP | L5	TP | L6
TP | L1	0	272.924	159.103	369.993	301.309	353.717
TP | L2	-272.924	0	-113.821	97.069	28.385	80.793
TP | L3	-159.103	113.821	0	210.889	142.206	194.613
TP | L4	-369.993	-97.069	-210.889	0	-68.683	-16.276
TP | L5	-301.309	-28.385	-142.206	68.683	0	52.407
TP | L6	-353.717	-80.793	-194.613	16.276	-52.407	0

p-values:

	TP | L1	TP | L2	TP | L3	TP | L4	TP | L5	TP | L6
TP | L1	1	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**
TP | L2	**< 0.0001**	1	**< 0.0001**	**0.000**	0.496	0.023
TP | L3	**< 0.0001**	**< 0.0001**	1	**< 0.0001**	**0.002**	**< 0.0001**
TP | L4	**< 0.0001**	**0.000**	**< 0.0001**	1	0.110	0.660
TP | L5	**< 0.0001**	0.496	**0.002**	0.110	1	0.290
TP | L6	**< 0.0001**	0.023	**< 0.0001**	0.660	0.290	1

Bonferroni corrected significance level: 0.0033

Soluble Reactive Phosphorus

Sample	Frequency	Sum of ranks	Mean of ranks	Groups			
SRP | L4	161	39679.500	246.457	A			
SRP | L6	71	21712.500	305.810	A	B		
SRP | L5	47	16632.500	353.883	A	B		
SRP | L2	226	82278.500	364.064		B		
SRP | L3	105	47358.500	451.033			C	
SRP | L1	226	142204.500	629.223				D

Table of pairwise differences:

	SRP | L1	SRP | L2	SRP | L3	SRP | L4	SRP | L5	SRP | L6
SRP | L1	0	265.159	178.190	382.767	275.340	323.414
SRP | L2	-265.159	0	-86.969	117.608	10.181	58.254
SRP | L3	-178.190	86.969	0	204.577	97.150	145.223
SRP | L4	-382.767	-117.608	-204.577	0	-107.426	-59.353
SRP | L5	-275.340	-10.181	-97.150	107.426	0	48.073
SRP | L6	-323.414	-58.254	-145.223	59.353	-48.073	0

p-values:

	SRP | L1	SRP | L2	SRP | L3	SRP | L4	SRP | L5	SRP | L6
SRP | L1	1	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**
SRP | L2	**< 0.0001**	1	**0.002**	**< 0.0001**	0.793	0.076
SRP | L3	**< 0.0001**	**0.002**	1	**< 0.0001**	0.022	**< 0.0001**
SRP | L4	**< 0.0001**	**< 0.0001**	**< 0.0001**	1	0.007	0.084
SRP | L5	**< 0.0001**	0.793	0.022	0.007	1	0.290
SRP | L6	**< 0.0001**	0.076	**< 0.0001**	0.084	0.290	1

Bonferroni corrected significance level: 0.0033

Total Kjeldahl Nitrogen

Sample	Frequency	Sum of ranks	Mean of ranks	Groups			
TKN | L4	175	53846.000	307.691	A			
TKN | L2	239	83654.000	350.017	A	B		
TKN | L6	71	30570.000	430.563		B	C	
TKN | L5	47	22542.000	479.617			C	
TKN | L3	121	61919.000	511.727			C	
TKN | L1	249	154722.000	621.373				D

Table of pairwise differences:

	TKN | L1	TKN | L2	TKN | L3	TKN | L4	TKN | L5	TKN | L6
TKN | L1	0	271.357	109.646	313.682	141.756	190.810
TKN | L2	-271.357	0	-161.711	42.325	-129.600	-80.547
TKN | L3	-109.646	161.711	0	204.036	32.110	81.164
TKN | L4	-313.682	-42.325	-204.036	0	-171.926	-122.872
TKN | L5	-141.756	129.600	-32.110	171.926	0	49.054
TKN | L6	-190.810	80.547	-81.164	122.872	-49.054	0

p-values:

	TKN | L1	TKN | L2	TKN | L3	TKN | L4	TKN | L5	TKN | L6
TKN | L1	1	**< 0.0001**	**0.000**	**< 0.0001**	**0.001**	**< 0.0001**
TKN | L2	**< 0.0001**	1	**< 0.0001**	0.102	**0.002**	0.022
TKN | L3	**0.000**	**< 0.0001**	1	**< 0.0001**	0.473	0.037
TKN | L4	**< 0.0001**	0.102	**< 0.0001**	1	**< 0.0001**	**0.001**
TKN | L5	**0.001**	**0.002**	0.473	**< 0.0001**	1	0.317
TKN | L6	**< 0.0001**	0.022	0.037	**0.001**	0.317	1

Bonferroni corrected significance level: 0.0033

Ammonia

<table>
<tr><th>Sample</th><th>Frequency</th><th>Sum of ranks</th><th>Mean of ranks</th><th colspan="3">Groups</th></tr>
<tr><td>Ammonia | L4</td><td>173</td><td>51485.500</td><td>297.604</td><td>A</td><td></td><td></td></tr>
<tr><td>Ammonia | L2</td><td>243</td><td>72881.000</td><td>299.922</td><td>A</td><td></td><td></td></tr>
<tr><td>Ammonia | L6</td><td>71</td><td>24199.500</td><td>340.838</td><td>A</td><td></td><td></td></tr>
<tr><td>Ammonia | L5</td><td>46</td><td>22960.000</td><td>499.130</td><td></td><td>B</td><td></td></tr>
<tr><td>Ammonia | L3</td><td>115</td><td>60484.500</td><td>525.952</td><td></td><td>B</td><td></td></tr>
<tr><td>Ammonia | L1</td><td>239</td><td>161817.500</td><td>677.061</td><td></td><td></td><td>C</td></tr>
</table>

Table of pairwise differences:

<table>
<tr><th></th><th>Ammonia | L1</th><th>Ammonia | L2</th><th>Ammonia | L3</th><th>Ammonia | L4</th><th>Ammonia | L5</th><th>Ammonia | L6</th></tr>
<tr><td>Ammonia | L1</td><td>0</td><td>377.139</td><td>151.108</td><td>379.457</td><td>177.930</td><td>336.223</td></tr>
<tr><td>Ammonia | L2</td><td>-377.139</td><td>0</td><td>-226.030</td><td>2.318</td><td>-199.209</td><td>-40.916</td></tr>
<tr><td>Ammonia | L3</td><td>-151.108</td><td>226.030</td><td>0</td><td>228.348</td><td>26.822</td><td>185.114</td></tr>
<tr><td>Ammonia | L4</td><td>-379.457</td><td>-2.318</td><td>-228.348</td><td>0</td><td>-201.526</td><td>-43.234</td></tr>
<tr><td>Ammonia | L5</td><td>-177.930</td><td>199.209</td><td>-26.822</td><td>201.526</td><td>0</td><td>158.292</td></tr>
<tr><td>Ammonia | L6</td><td>-336.223</td><td>40.916</td><td>-185.114</td><td>43.234</td><td>-158.292</td><td>0</td></tr>
</table>

p-values:

<table>
<tr><th></th><th>Ammonia | L1</th><th>Ammonia | L2</th><th>Ammonia | L3</th><th>Ammonia | L4</th><th>Ammonia | L5</th><th>Ammonia | L6</th></tr>
<tr><td>Ammonia | L1</td><td>1</td><td>< 0.0001</td><td>< 0.0001</td><td>< 0.0001</td><td>< 0.0001</td><td>< 0.0001</td></tr>
<tr><td>Ammonia | L2</td><td>< 0.0001</td><td>1</td><td>< 0.0001</td><td>0.928</td><td>< 0.0001</td><td>0.236</td></tr>
<tr><td>Ammonia | L3</td><td>< 0.0001</td><td>< 0.0001</td><td>1</td><td>< 0.0001</td><td>0.548</td><td>< 0.0001</td></tr>
<tr><td>Ammonia | L4</td><td>< 0.0001</td><td>0.928</td><td>< 0.0001</td><td>1</td><td>< 0.0001</td><td>0.231</td></tr>
<tr><td>Ammonia | L5</td><td>< 0.0001</td><td>< 0.0001</td><td>0.548</td><td>< 0.0001</td><td>1</td><td>0.001</td></tr>
<tr><td>Ammonia | L6</td><td>< 0.0001</td><td>0.236</td><td>< 0.0001</td><td>0.231</td><td>0.001</td><td>1</td></tr>
</table>

Bonferroni corrected significance level: 0.0033

Appendix C: Event flow weighted concentrations

Farm A, Site L1 (collection tank)

Event	Volume (gal)	COD (mg/l)	TP (mg/l)	SRP (mg/l)	TKN (mg/l)	NH3 (mg/l)
10/13/12 15:39	10,360	1,840	16.00	12.10	41.06	18.47
10/15/12 18:18	10,560	5,848	56.65	52.15	193.37	54.78
10/18/12 12:52	9,760	11,160	108.25	100.05	437.42	129.45
10/19/12 12:21	4,360	9,408	104.90	93.70	329.40	118.66
10/23/12 10:12	4,360	6,728	69.20	57.60	199.01	69.89
10/26/12 13:13	10,160	4,580	40.35	34.95	139.47	42.26
11/6/12 9:09	1,360	11,200	130.90	130.05	344.37	272.00
11/12/12 12:04	9,360	7,030	59.80	52.55	240.89	93.79
12/4/12 12:06	3,360	13,400	108.40	99.50	444.30	218.90
12/11/12 18:45	2,960	9,170	67.40	59.30	419.20	38.31
12/15/12 10:36	8,960	5,720	48.63	39.88	39.51	63.02
12/17/12 11:24	9,360	3,010	23.69	20.43	129.71	23.18
12/26/12 9:49	3,760	11,390	90.33	88.80	458.29	192.62
1/14/13 13:20	9,360	14,580	102.30	96.83	545.29	267.52
1/24/13 8:58	4,760	14,160	111.85	109.25	406.78	232.89
1/30/13 14:04	10,560	8,640	73.60	67.20	406.78	110.69
2/13/13 10:03	10,360	17,040	135.99	129.97	431.84	241.24
2/18/13 9:40	9,160	25,130	97.18	95.06	531.39	211.31
3/12/13 11:19	11,760	9,540	75.95	73.34	347.98	119.84
3/14/13 16:41	4,360	11,580	91.50	84.43	438.15	135.49
3/15/13 13:38	4,160	9,640	73.49	69.64	369.31	111.66
3/20/13 9:58	9,960	10,960	85.40	78.56	389.77	125.16
3/24/13 19:13	9,560	11,860	91.82	83.65	447.07	135.59
3/26/13 12:44	2,560	12,650	101.70	95.29	443.91	170.94
3/28/13 19:45	960	2,425	25.71	23.90	108.73	37.02
4/1/13 11:01	1,360	4,950	46.40	45.76	170.34	68.09
4/1/13 15:08	160	5,440	47.76	46.12	189.70	86.83
4/1/13 16:32	400	5,580	49.74	46.82	211.67	82.99
4/2/13 0:30	160	6,240	53.54	50.16	150.92	96.59
4/2/13 8:57	160	6,080	54.91	52.69	235.16	102.68
4/2/13 12:10	160	6,680	58.33	56.05	200.94	114.59
4/2/13 13:37	160	6,780	58.97	56.64	254.18	117.62
4/2/13 20:43	360	6,620	60.64	59.40	243.56	124.96
4/3/13 14:40	3,960	7,550	62.31	61.03	288.21	94.75
4/3/13 19:26	160	5,950	52.64	51.56	247.77	74.29
4/4/13 11:12	160	6,400	55.87	54.72	224.81	83.09

4/4/13 14:56	760	8,100	80.29	79.61	253.78	85.22
4/4/13 21:01	160	6,620	66.49	65.54	211.47	64.35
4/5/13 10:00	160	5,920	59.84	57.25	197.64	70.27
4/5/13 13:27	1,360	5,880	59.09	58.01	220.09	69.77
4/5/13 16:02	760	5,780	58.65	56.37	220.87	85.07
4/6/13 1:15	160	5,360	51.85	46.36	174.20	64.95
4/6/13 6:36	400	6,560	59.35	52.94	208.48	77.91
4/6/13 10:38	160	5,600	64.80	58.27	279.62	76.16
4/6/13 11:56	360	7,360	64.65	56.02	277.02	53.66
4/6/13 13:31	160	7,140	63.75	55.71	241.33	52.89
4/8/13 11:02	1,360	4,840	45.40	33.67	164.77	35.62
4/8/13 21:46	5,760	5,120	45.65	39.24	194.51	45.61
4/9/13 22:16	5,760	5,800	53.75	43.82	206.12	61.90
4/10/13 22:46	5,760	4,960	46.05	40.09	153.51	55.90
4/11/13 23:16	5,760	7,200	63.95	60.12	208.67	67.39
4/12/13 23:46	5,760	8,850	75.17	62.40	210.79	77.13
4/14/13 6:09	5,560	11,020	93.07	77.02	316.63	95.92
4/15/13 20:54	5,560	8,740	93.23	89.99	327.73	101.88
4/18/13 10:07	7,560	10,280	83.75	79.57	233.17	90.71
4/26/13 12:44	2,760	16,500	133.20	130.79	371.67	149.01
4/30/13 12:04	7,560	11,240	77.17	70.81	377.96	88.99
5/2/13 16:17	7,560	8,600	65.35	62.41	321.94	85.08
5/4/13 17:37	7,560	5,780	50.11	45.25	216.32	50.32
5/9/13 18:49	7,160	14,620	117.04	116.36	473.34	142.62
5/10/13 19:28	7,560	8,500	65.38	62.00	274.06	71.40
5/11/13 20:09	7,560	10,840	80.09	78.10	336.78	96.76
5/17/13 11:00	7,160	15,780	125.20	123.52	494.85	139.53
5/18/13 11:39	7,560	8,700	72.44	69.32	346.45	72.20
5/21/13 1:31	7,560	4,560	41.99	39.13	198.54	38.58
5/22/13 2:10	7,760	5,180	47.30	44.67	193.12	61.62
5/23/13 2:51	7,560	4,520	45.13	41.56	161.76	55.26
5/28/13 9:15	7,360	9,000	72.58	69.95	330.16	79.44
5/29/13 9:54	5,560	8,825	70.29	67.98	303.26	85.12
6/1/13 19:05	7,360	6,230	52.66	50.34	214.50	58.72
6/2/13 19:44	7,760	4,750	43.89	38.66	159.02	63.76
6/4/13 14:15	7,560	6,650	59.74	52.54	210.52	100.64
6/5/13 14:55	7,560	6,200	55.11	52.19	207.91	79.29
6/6/13 15:35	7,560	6,510	56.92	52.41	194.22	78.81
6/8/13 11:03	7,560	13,520	110.21	107.52	327.79	105.19
6/13/13 20:04	7,560	11,860	93.12	85.35	373.94	129.11
6/14/13 20:44	7,560	11,750	92.57	86.95	376.67	161.50
6/15/13 21:24	7,760	11,170	92.49	87.79	338.21	173.62
6/17/13 22:45	7,560	7,860	71.11	66.69	291.15	153.24
6/21/13 9:51	7,560	6,970	69.23	59.13	230.37	136.97
6/22/13 10:31	7,560	5,760	53.16	50.23	164.61	83.63

6/23/13 11:11	7,560	5,020	46.09	40.22	141.40	66.08
6/27/13 5:05	7,560	6,130	51.94	44.70	200.15	116.54
6/28/13 5:45	7,560	5,660	45.63	40.18	167.72	109.04
6/29/13 6:25	7,560	6,370	43.95	38.41	168.37	83.09
7/8/13 5:47	7,360	11,320	90.16	80.10	390.54	295.97
7/9/13 6:26	7,560	6,410	54.84	50.99	204.59	117.09
7/10/13 7:06	7,560	6,680	55.83	49.71	188.47	137.61
7/22/13 21:34	7,560	13,480	98.19	84.73	477.86	289.27
7/26/13 15:21	7,560	5,720	-	-	-	-
7/27/13 16:01	7,560	5,590	-	-	-	-
7/29/13 18:29	7,560	4,620	-	-	-	-
8/7/13 1:16	7,560	3,940	35.90	29.30	142.63	83.91
8/12/13 15:08	7,360	4,915	39.00	32.58	23.05	74.98
8/21/13 20:57	7,760	3,260	26.40	21.05	163.15	57.09
8/26/13 11:11	7,360	4,495	42.80	34.85	273.73	156.28
8/27/13 11:50	7,560	4,460	38.18	36.05	238.64	132.90
9/10/13 23:48	7,560	3,160	38.30	36.47	186.02	150.42
9/12/13 0:28	7,560	2,760	37.37	35.44	231.37	136.68
9/15/13 9:03	7,560	7,580	60.96	57.06	365.60	150.59
9/18/13 8:14	7,360	4,820	43.66	42.98	201.86	92.15
9/20/13 9:33	7,560	4,300	38.80	35.60	146.04	111.45
9/28/13 20:41	7,560	820	41.35	39.66	245.70	122.11
10/4/13 10:55	7,560	3,280	34.96	26.04	181.24	109.54
10/6/13 12:15	7,560	2,240	23.17	21.77	104.02	63.10
10/16/13 12:05	7,560	4,500	31.91	29.99	115.65	83.44
10/30/13 20:20	6,160	3,340	33.03	32.51	174.81	119.65
10/31/13 21:00	7,560	5,140	25.57	24.34	139.19	39.23
11/5/13 17:54	7,560	6,960	18.83	-	325.94	62.85
11/6/13 18:34	7,560	3,960	31.98	31.79	195.16	34.55
11/9/13 1:20	7,560	4,880	41.28	39.46	305.78	49.45
11/10/13 2:00	7,560	3,900	32.01	31.50	201.43	53.75
11/16/13 13:52	7,360	7,380	56.43	53.25	410.61	84.86
11/18/13 15:12	7,560	4,060	35.30	33.27	196.04	44.43
11/30/13 23:07	7,360	12,880	91.73	89.76	379.77	142.42
12/4/13 7:24	7,360	11,200	84.43	80.66	379.37	99.71
12/5/13 8:03	7,760	5,800	49.90	48.70	457.26	57.71
1/10/14 22:17	6,760	17,500	172.44	144.62	546.72	329.90
1/12/14 18:58	6,160	16,820	133.42	127.23	604.30	214.41
1/13/14 19:38	7,160	18,140	142.35	135.62	632.32	200.46
2/19/14 15:12	7,160	13,140	124.50	120.53	564.58	248.24
2/20/14 18:45	7,360	9,940	95.53	88.83	382.78	128.97
3/8/14 16:13	7,360	23,700	142.49	134.99	575.31	273.27
3/10/14 12:56	7,560	21,680	92.75	91.63	378.65	130.41
3/11/14 13:36	7,560	23,320	89.61	82.28	352.64	105.30
3/12/14 14:17	7,160	24,820	82.47	82.40	317.05	111.65

3/14/14 13:50	7,360	26,780	106.66	105.90	560.61	258.68
3/30/14 17:20	6,760	17,720	96.24	94.98	627.92	277.70
4/1/14 1:15	6,360	12,040	66.46	64.70	422.29	174.30
4/4/14 6:25	7,360	13,300	81.14	68.20	468.89	196.53
4/7/14 10:49	6,760	11,060	65.63	57.98	402.52	149.68
4/8/14 19:22	7,360	7,370	66.65	60.03	163.48	163.08
4/10/14 5:42	6,960	6,220	59.81	58.85	357.95	132.18
4/12/14 11:31	7,560	7,860	71.25	66.26	428.70	158.02
4/13/14 12:11	7,560	5,900	54.47	48.31	237.57	86.12
4/17/14 14:51	7,560	9,820	71.81	69.56	308.52	159.51
4/24/14 9:41	7,560	19,780	181.62	164.81	743.37	167.20
4/25/14 10:21	7,560	9,480	73.28	70.24	344.06	94.07
4/28/14 18:30	7,560	15,060	112.36	103.30	423.94	122.11
5/5/14 23:11	6,960	12,340	142.52	128.68	472.31	143.17
5/7/14 6:24	7,560	11,180	105.90	97.11	336.88	82.62
5/8/14 7:04	7,560	6,780	76.31	71.05	264.44	59.30
5/11/14 4:06	7,560	13,480	148.58	129.80	547.44	116.70
5/12/14 4:46	7,560	7,760	70.27	65.54	338.69	67.95
5/13/14 5:26	7,560	5,960	54.83	50.02	199.50	49.39
5/18/14 2:20	6,560	16,400	152.65	160.96	471.25	127.25
5/19/14 19:02	7,560	16,740	174.03	151.09	386.75	88.81
5/20/14 19:42	7,560	7,400	74.45	70.74	216.56	55.88
5/28/14 10:47	7,560	16,660	102.55	102.14	300.71	83.48
6/1/14 17:58	7,360	8,980	142.24	128.95	353.00	105.21
6/2/14 18:37	7,560	6,900	48.94	46.88	132.81	51.75
6/8/14 8:05	6,160	23,800	224.49	224.16	438.17	141.74
6/17/14 1:41	7,560	24,300	313.37	298.06	472.41	175.51
6/18/14 2:21	7,560	10,580	84.12	77.95	194.52	72.20
6/19/14 3:01	7,560	7,920	84.62	75.35	250.41	71.37
6/20/14 3:43	6,760	10,640	102.80	100.60	310.65	63.26
6/21/14 4:23	7,560	6,200	67.28	61.72	173.30	48.17
6/23/14 5:05	7,560	10,300	104.06	98.10	299.56	65.76
6/24/14 5:45	7,560	12,080	71.29	68.76	269.98	47.47
6/30/14 19:35	7,560	17,100	207.28	207.28	404.15	202.79
7/1/14 20:15	7,560	11,700	82.26	82.26	269.97	100.89
7/3/14 22:03	6,360	9,080	117.69	117.69	344.61	156.38
7/8/14 0:03	7,560	12,220	166.69	166.69	343.82	107.34
7/9/14 0:43	7,560	10,200	101.11	101.11	311.30	110.88
7/15/14 16:02	6,760	19,140	229.15	218.15	441.71	222.57
7/29/14 16:15	7,560	29,080	333.29	306.02	608.81	310.38
7/30/14 16:55	7,560	14,000	111.60	100.98	334.06	115.73
7/31/14 17:35	7,760	10,760	80.46	76.90	221.42	98.08
8/3/14 14:30	7,560	13,360	89.06	86.04	254.65	0.00
8/4/14 15:10	7,560	9,280	53.79	46.69	185.77	93.95
8/11/14 21:55	7,360	15,260	125.69	-	396.68	0.00

8/12/14 22:34	7,560	9,560	71.53	67.65	222.10	89.58
8/18/14 17:09	7,360	15,220	148.51	133.87	400.69	0.00
8/19/14 17:48	7,760	8,840	69.12	63.29	230.31	127.05
8/21/14 13:23	7,560	17,080	119.20	110.95	524.25	142.09
8/25/14 7:02	7,560	16,980	118.01	112.04	445.13	0.00
8/26/14 7:42	7,560	12,340	72.77	71.95	250.81	141.51
8/29/14 3:24	6,960	15,860	192.15	180.88	456.81	0.00
8/30/14 4:03	7,560	9,820	81.05	76.07	245.06	109.25
9/1/14 12:41	7,360	15,520	110.15	103.15	407.13	0.00
9/4/14 13:23	7,560	8,600	88.25	77.61	129.13	0.00
9/5/14 14:03	7,560	6,680	62.96	50.69	185.81	96.78
9/10/14 7:18	7,560	15,360	144.70	-	389.13	0.00
9/11/14 7:58	7,560	12,660	110.02	-	327.31	132.00
9/12/14 17:05	7,560	10,680	79.33	-	242.75	111.47
9/13/14 17:45	7,560	9,040	52.26	-	195.94	84.45
9/18/14 14:37	7,360	16,440	222.01	-	398.63	0.00
9/20/14 3:32	7,560	9,980	98.27	-	211.25	84.58
9/21/14 4:12	7,760	3,780	58.34	-	227.88	79.72
9/29/14 15:03	7,360	13,020	112.04	-	317.69	118.52
9/30/14 15:42	7,560	13,240	100.80	0.00	280.63	110.17
10/2/14 18:05	7,360	14,620	140.25	140.23	366.38	124.81
10/3/14 18:44	7,760	11,420	97.51	77.51	260.38	98.61
10/4/14 19:25	7,560	10,660	54.55	-	209.50	85.50
10/13/14 17:19	7,360	11,240	58.71	58.69	211.38	98.71
10/14/14 17:59	7,560	8,380	46.80	45.99	125.38	59.72
10/15/14 18:39	7,560	10,860	58.42	53.64	135.81	59.52
10/17/14 16:35	7,360	15,820	89.98	87.02	172.25	82.12
10/18/14 17:14	7,560	9,360	57.29	55.72	272.94	54.40
11/3/14 23:29	7,560	12,340	74.96	72.65	199.00	78.55
11/5/14 11:17	7,560	9,760	57.75	57.36	99.44	71.88
11/6/14 3:43	7,560	7,520	41.59	41.56	67.69	44.60
11/7/14 4:23	7,560	7,360	35.77	34.66	135.38	43.18
11/8/14 5:03	7,760	7,320	39.28	38.85	139.06	36.86
11/9/14 5:44	7,560	6,540	40.00	39.19	140.88	43.01
11/10/14 6:24	7,560	6,940	41.38	40.14	130.00	44.12
11/11/14 12:16	7,360	7,420	45.16	42.82	132.44	39.51
11/23/14 15:28	7,360	14,420	91.17	49.03	283.50	77.77
11/24/14 16:07	7,560	7,680	45.61	-	148.38	49.88
11/29/14 11:50	7,360	15,900	108.69	-	338.25	113.34
11/30/14 12:29	7,760	10,240	54.89	-	203.31	64.21
12/9/14 0:30	7,160	219	218.65	218.56	583.63	23.91
12/13/14 12:14	7,560	17,340	97.36	95.02	352.06	86.71
12/14/14 12:54	7,560	10,060	59.19	55.52	219.38	57.81
12/16/14 14:14	7,560	13,520	77.30	73.21	295.94	65.82

Farm A, Site L2 (overflow to VTA)

Event	Volume (gal)	COD (mg/l)	TP (mg/l)	SRP (mg/l)	TKN (mg/l)	NH3 (mg/l)
10/13/12 3:58	90,364	961	9.83	7.25	33.46	8.51
10/14/12 4:43	192,081	1,150	12.46	9.79	37.15	8.21
10/17/12 21:29	55,145	2,208	22.69	18.34	92.33	23.16
10/25/12 17:08	8,299	1,073	11.00	7.57	39.19	10.48
11/11/12 16:39	21,700	1,391	14.56	10.92	52.12	12.49
12/15/12 14:35	904	2,622	25.56	22.42	104.29	18.27
1/10/13 21:12	10,656	3,432	30.10	28.04	119.62	29.46
1/11/13 8:58	9,351	4,187	32.33	28.84	95.08	25.88
4/9/13 12:58	26,706	3,184	32.25	24.73	109.68	21.67
4/10/13 1:20	33,395	1,866	20.55	13.93	59.32	9.02
4/11/13 11:58	18,877	8,319	66.67	52.31	215.35	59.48
4/15/13 11:29	26,155	8,661	66.57	54.92	225.94	63.24
5/2/13 17:23	3,319	2,390	24.43	20.04	100.86	23.13
5/3/13 19:11	5,275	1,760	21.93	17.40	71.56	15.55
5/9/13 22:58	45,150	1,727	21.13	17.88	74.13	18.29
5/18/13 8:27	921	8,030	66.07	61.65	306.10	63.30
5/22/13 11:17	37,598	1,557	21.85	16.46	62.10	13.83
6/1/13 20:35	2,876	2,350	27.30	22.06	93.17	18.49
6/5/13 9:42	364	8,040	68.22	65.51	255.88	56.20
6/6/13 1:16	18,417	2,436	30.53	24.65	78.73	17.56
6/21/13 10:52	8,548	2,110	25.80	21.47	79.91	18.64
6/22/13 23:49	7,481	2,000	23.52	19.05	65.64	15.10
6/27/13 4:37	1,271	3,080	28.33	21.82	107.92	17.09
6/27/13 18:49	6,186	1,680	20.02	14.39	58.89	12.05
6/28/13 16:57	12,415	2,085	22.00	18.78	101.49	17.83
7/8/13 5:52	203,023	2,295	27.11	22.10	89.81	21.44
7/8/13 11:15	500	19,420	146.10	142.81	672.25	168.19
7/8/13 13:57	5,982	3,257	30.19	24.95	114.88	58.20
7/22/13 22:23	1,241	5,640	45.30	38.76	233.29	30.91
7/26/13 20:30	38,678	3,765	-	-	-	-
8/7/13 1:14	29,250	5,007	45.34	39.77	98.95	28.15
8/21/13 20:39	20,620	4,250	33.94	31.37	203.95	39.38
8/27/13 1:15	17,638	3,915	30.89	28.12	183.01	53.50
8/27/13 9:23	3,092	6,020	47.83	45.23	264.34	90.41
8/27/13 19:59	12,637	3,398	28.01	27.13	106.58	45.68
9/10/13 23:54	56,912	4,069	39.95	35.54	210.41	44.72
9/15/13 11:14	19,015	4,084	42.16	41.42	175.82	44.08

9/19/13 8:25	20,721	3,060	29.13	26.79	112.82	24.71
9/19/13 19:43	26,644	5,456	37.82	36.85	163.25	56.97
9/28/13 22:21	14,463	4,625	31.89	31.42	172.44	43.31
10/4/13 10:46	145,725	2,956	24.15	20.26	109.14	25.77
10/15/13 12:30	28,333	3,087	26.11	24.85	112.08	24.37
10/31/13 5:10	178,294	3,216	14.86	13.99	75.08	16.18
11/5/13 18:51	72,385	3,191	24.55	19.50	176.36	23.21
11/16/13 19:18	82,679	3,237	31.20	29.12	171.94	28.32
12/4/13 10:46	28,722	4,561	42.18	41.03	337.86	33.11
4/4/14 10:29	10,837	5,133	55.84	51.73	270.61	75.24
4/12/14 13:05	103,933	3,411	36.52	32.59	145.78	43.65
4/13/14 18:50	101,406	1,660	19.43	18.52	69.76	21.89
4/24/14 11:26	3,500	6,540	51.15	48.47	188.96	42.20
4/24/14 15:01	50,973	5,370	46.60	44.80	174.16	48.31
5/7/14 6:42	37,155	6,822	79.18	66.36	224.60	39.27
5/11/14 19:10	9,466	5,019	43.37	42.16	254.26	44.14
5/12/14 5:28	101,283	5,953	42.59	38.41	303.76	26.79
5/19/14 19:49	56,009	4,688	46.88	44.01	170.30	33.01
5/27/14 10:24	3,978	14,320	89.35	84.14	277.51	57.36
6/1/14 19:10	168,664	10,694	30.77	26.21	101.50	19.57
6/17/14 1:57	47,891	8,752	59.96	53.11	166.82	40.06
6/18/14 2:11	57,136	5,522	44.50	37.67	150.53	27.99
6/20/14 5:55	32,988	6,471	62.62	55.71	203.72	27.42
6/23/14 7:19	15,971	7,796	70.18	64.46	350.56	56.98
7/1/14 0:39	1,535	17,200	167.32	167.32	534.24	101.76
7/1/14 18:11	10,861	6,540	62.85	62.85	218.38	40.76
7/8/14 20:55	9,849	3,311	37.36	37.36	160.23	27.03
7/29/14 16:31	27,204	8,604	50.60	45.33	197.56	31.70
7/30/14 11:15	118	21,000	249.74	248.64	463.06	84.56
7/31/14 14:47	71,356	5,799	26.33	24.42	93.52	23.10
8/11/14 21:56	150,797	5,922	47.63	45.57	162.82	31.32
8/18/14 17:13	102,177	5,314	46.08	44.27	149.96	42.78
8/25/14 7:02	65,384	8,971	59.94	56.00	204.06	52.74
8/29/14 6:18	58,804	15,897	105.97	101.68	283.47	69.66
9/4/14 13:21	99,420	4,910	40.70	29.82	130.26	35.67
9/10/14 11:21	12,831	9,254	57.74	-	254.14	43.91
9/20/14 3:18	89,689	13,316	91.65	109.65	468.99	64.76
10/3/14 4:03	54,236	7,549	29.99	-	137.47	27.97
10/13/14 18:09	116,838	6,319	32.77	31.84	116.82	30.37
11/4/14 0:34	13,641	6,903	37.55	36.65	60.09	34.62
11/6/14 6:30	1,173	5,900	37.52	34.70	67.88	30.44
11/8/14 4:18	238	5,740	32.33	29.54	121.63	23.18
11/23/14 16:40	41,994	9,716	28.29	17.06	124.31	32.24
11/24/14 11:43	14,154	5,135	27.39	-	121.15	24.35
11/29/14 22:32	12,278	7,135	31.18	-	137.91	35.12

12/13/14 16:48	17,066	8,770	47.24	43.47	192.06	42.26
12/16/14 2:18	19,305	11,569	35.79	34.98	132.17	28.02

Farm B, Site L3 (collection tank)

Event	Volume (gal)	COD (mg/l)	TP (mg/l)	SRP (mg/l)	TKN (mg/l)	NH3 (mg/l)
3/27/13 18:50	2,310	18,391	155.51	153.47	510.31	119.41
3/28/13 11:47	1,925	5,900	45.06	43.06	193.04	86.41
5/20/13 14:34	3,465	5,800	45.40	39.94	270.11	31.81
5/20/13 17:38	1,540	7,075	59.63	56.98	292.15	66.65
5/22/13 14:03	3,465	4,383	39.05	35.31	155.37	28.06
5/28/13 19:08	1,155	6,310	51.57	50.12	192.05	45.41
5/29/13 23:06	1,155	4,380	39.54	31.00	169.26	28.78
5/30/13 11:16	1,540	3,780	34.86	27.31	124.98	32.23
5/30/13 20:29	1,155	5,250	33.74	23.54	149.60	17.17
6/12/13 10:12	1,540	4,500	33.46	23.14	205.07	34.78
6/13/13 11:58	1,540	4,810	41.86	36.83	161.56	49.76
6/13/13 15:01	1,540	5,600	46.95	43.35	167.00	68.45
6/13/13 18:04	1,155	6,140	50.57	46.83	214.47	107.14
6/17/13 9:05	2,310	3,083	31.37	27.43	116.63	34.07
6/21/13 8:38	2,310	3,080	33.94	28.84	109.10	30.95
6/21/13 11:59	1,155	3,140	34.46	29.52	116.17	37.67
6/22/13 16:02	1,540	6,420	56.29	51.48	199.79	90.25
6/23/13 9:27	1,540	3,840	37.26	30.41	134.89	40.65
7/10/13 10:40	1,925	5,280	48.35	42.28	234.74	109.36
7/13/13 12:22	1,925	3,190	38.48	31.19	141.11	44.06
8/11/13 20:55	1,540	3,750	33.45	27.15	91.45	39.90
9/15/13 19:17	3,465	2,020	16.80	15.78	72.96	46.69
9/18/13 12:07	3,080	1,860	16.82	15.31	78.02	25.70
9/29/13 17:16	2,310	1,360	17.75	12.19	55.76	14.36
10/4/13 11:20	3,850	920	11.74	9.70	58.19	10.26
10/15/13 12:34	3,465	3,220	21.24	21.08	133.23	25.09
10/18/13 14:07	1,925	3,180	22.82	20.16	168.22	38.12
10/21/13 0:24	1,155	5,320	33.76	33.13	263.78	67.49
11/8/13 7:51	4,235	2,960	17.59	16.00	172.35	21.65
11/16/13 14:39	1,540	2,420	19.91	19.29	175.79	41.34
12/3/13 7:36	1,155	5,460	43.44	42.37	249.09	110.22
12/4/13 8:13	1,540	6,820	55.30	53.37	275.11	67.77
4/9/14 22:26	770	6,230	53.70	51.37	294.47	124.30
4/10/14 12:13	1,155	5,500	68.20	45.30	250.20	106.95
4/16/14 18:05	1,155	-	58.45	54.88	299.21	80.18
4/22/14 13:00	770	8,820	70.52	65.95	216.15	120.63
4/24/14 6:25	770	8,380	67.30	63.24	288.77	74.64
4/26/14 16:26	770	7,620	59.71	58.00	236.94	105.91

4/27/14 4:59	1,155	8,460	64.42	64.08	206.06	112.76
4/30/14 22:53	770	4,640	28.75	26.25	133.31	26.21
5/1/14 0:58	1,155	3,360	27.26	24.92	112.25	24.29
5/1/14 17:11	770	4,740	35.51	34.52	140.25	40.58
5/5/14 11:51	770	6,660	45.32	43.48	210.69	79.44
5/9/14 17:09	770	6,000	23.45	31.79	206.13	74.04
5/10/14 15:01	770	5,340	39.35	35.23	207.44	78.14
5/12/14 15:38	3,465	3,980	28.37	27.27	173.50	34.45
5/12/14 21:21	1,155	5,300	34.75	32.24	179.94	45.06
5/19/14 12:10	1,155	3,420	29.94	26.72	155.13	27.32
5/20/14 10:21	3,080	6,300	47.02	44.63	211.06	59.81
5/20/14 14:34	770	6,220	43.57	42.10	202.25	61.23
5/21/14 14:04	1,155	6,280	47.27	48.78	216.63	70.80
5/27/14 11:35	3,465	8,000	51.07	50.96	282.33	88.40
5/31/14 18:28	1,155	9,060	40.09	37.07	187.05	66.04
6/1/14 23:52	1,925	18,560	63.51	58.88	355.97	173.99
6/2/14 3:02	1,155	14,600	66.96	66.31	381.23	203.89
6/2/14 6:05	770	13,880	56.36	54.43	368.40	162.85
6/2/14 9:22	1,155	7,520	32.44	29.50	194.06	65.83
6/5/14 22:10	1,155	8,980	43.69	38.07	178.40	63.02
6/5/14 22:19	1,155	8,980	43.69	38.07	178.40	63.02
6/7/14 3:23	1,155	10,900	47.74	45.46	234.59	133.77
6/8/14 10:45	770	10,120	60.17	60.01	199.03	89.62
6/12/14 8:10	770	13,140	96.44	93.65	303.34	109.10
6/14/14 16:16	1,155	9,420	63.08	61.85	241.32	60.53
6/15/14 1:14	1,155	5,380	20.18	18.62	91.77	23.52
6/16/14 19:47	1,540	13,260	87.34	86.13	288.39	70.40
6/18/14 1:55	1,155	12,560	82.31	77.39	350.52	151.34
6/20/14 10:58	1,925	11,920	79.49	79.28	379.85	117.56
6/20/14 13:06	1,155	16,980	114.05	106.85	524.25	185.67
7/8/14 9:25	3,465	2,660	28.39	28.39	124.09	41.32
7/8/14 11:51	385	2,180	39.20	36.20	180.06	46.27
7/11/14 9:50	1,540	4,180	38.95	36.34	183.94	50.26
7/13/14 21:03	770	5,040	23.82	16.58	124.00	97.24
7/25/14 7:19	770	6,680	46.49	-	214.94	58.21
7/25/14 10:27	1,155	5,820	50.09	-	201.25	42.72
8/5/14 6:01	1,155	7,380	37.64	34.52	170.09	99.62
8/12/14 0:13	1,155	4,384	31.03	28.85	141.67	60.95
8/18/14 1:20	1,925	5,640	45.03	44.94	206.74	137.38
8/19/14 6:25	1,925	10,220	56.77	56.09	316.38	151.13
8/20/14 10:49	770	6,740	44.07	42.53	229.50	103.36
8/21/14 7:21	1,540	2,900	18.59	15.73	114.13	28.02
8/21/14 14:17	1,155	5,840	29.00	28.95	138.88	76.08
8/29/14 4:21	1,155	-	32.39	30.20	110.81	38.87
8/30/14 10:29	1,155	5,820	46.81	39.95	188.31	95.67

9/1/14 0:16	1,155	4,920	33.61	31.10	129.56	37.35
9/2/14 6:24	1,155	5,560	35.29	31.62	158.81	103.96
9/3/14 13:41	770	6,260	46.36	41.72	91.69	76.42
9/3/14 21:23	2,310	5,220	27.09	20.99	220.69	39.26
9/5/14 3:34	1,540	8,660	63.04	59.55	269.81	91.56
9/11/14 12:08	1,925	-	660.24	-	1,145.06	-
9/15/14 9:48	1,155	-	443.97	-	967.13	-
9/22/14 11:30	3,465	-	369.02	-	851.19	-
9/25/14 15:30	1,155	-	603.50	552.53	1,386.13	-
9/25/14 17:36	770	-	492.23	458.49	975.75	-
9/29/14 12:19	1,155	-	340.41	-	929.88	158.43
10/1/14 9:46	1,155	27,080	261.62	-	624.25	103.66
10/2/14 12:46	3,080	14,060	124.13	119.85	331.13	57.50
10/2/14 15:28	1,155	17,820	141.82	-	416.25	91.46
10/2/14 21:00	770	9,800	64.83	-	224.75	43.47
10/3/14 13:40	770	16,660	136.14	-	404.44	100.65
10/4/14 0:15	1,155	12,260	76.33	-	187.44	51.60
10/5/14 5:42	1,925	10,760	67.50	-	175.38	56.54
10/5/14 6:47	1,155	10,760	67.50	-	175.38	56.54
10/13/14 23:26	770	27,940	227.09	-	553.13	159.68
10/14/14 1:32	1,155	9,800	79.58	-	200.00	52.13
10/14/14 5:43	1,155	11,680	69.26	-	225.69	58.06
11/6/14 3:45	770	12,260	76.33	-	187.44	51.60
11/22/14 17:29	770	10,260	59.88	32.46	253.75	91.87
11/23/14 0:41	770	10,040	58.04	32.53	218.25	60.05
11/23/14 5:55	1,155	8,600	46.94	26.85	204.50	49.70
12/13/14 15:46	770	7,480	73.05	71.64	236.69	90.14
12/15/14 15:01	770	17,040	124.45	122.98	420.75	108.93
12/16/14 2:10	770	7,300	44.26	43.74	145.69	39.97
11/18/13 12:41	3,465	3,720	30.29	27.86	336.37	37.57

Farm B, Site L4 (overflow to VTA)

Event	Volume (gal)	COD (mg/l)	TP (mg/l)	SRP (mg/l)	TKN (mg/l)	NH3 (mg/l)
1/11/13 2:04	68,598	18,200	108.41	128.89	355.14	111.78
3/8/13 22:48	112,124	21,507	150.43	144.56	501.06	121.77
3/13/13 12:42	67,513	11,008	82.27	80.00	348.50	112.45
3/28/13 14:58	111,832	4,855	43.16	37.91	170.10	58.76
4/9/13 11:00	167,395	4,826	40.71	31.09	158.83	43.67
4/16/13 14:16	66,736	4,019	32.92	28.18	125.46	34.11
4/19/13 15:00	62,744	3,915	32.29	26.75	119.08	33.00
4/22/13 16:05	129,900	2,701	30.91	22.05	118.84	18.26
5/18/13 10:31	90,410	4,642	31.22	25.30	158.10	21.23
5/21/13 0:48	9,417	2,960	29.46	24.96	124.58	18.29
5/30/13 1:53	5,161	3,160	30.89	21.43	135.19	18.76
5/30/13 20:32	19,772	1,880	21.87	13.69	67.51	7.97
6/12/13 10:25	22,316	2,852	28.05	21.33	101.24	24.62
6/15/13 1:17	2,216	2,060	22.34	21.86	84.97	13.74
6/15/13 16:45	4,131	2,450	25.79	25.12	97.18	20.41
6/21/13 3:47	24,819	2,299	21.96	16.36	85.67	15.70
6/21/13 20:35	92,870	3,576	29.96	22.19	126.02	27.62
7/9/13 9:07	11,068	3,050	34.47	20.17	107.06	15.49
8/6/13 21:20	3,657	2,990	31.45	24.98	105.07	43.00
9/14/13 19:16	51,104	1,254	13.88	9.42	55.12	8.72
9/16/13 8:00	16,824	2,427	14.80	11.59	72.83	7.42
9/28/13 12:51	12,663	9,266	87.96	11.26	380.15	6.39
10/3/13 12:30	18,652	2,244	16.49	15.09	62.82	15.36
10/5/13 0:42	25,034	1,382	13.40	11.36	45.23	10.36
10/15/13 0:45	45,290	1,946	14.19	11.89	85.62	13.65
10/18/13 3:45	7,610	2,860	23.07	20.09	166.24	29.05
11/4/13 4:46	14,694	3,900	26.51	24.59	240.97	29.55
11/16/13 16:27	21,654	9,520	48.21	34.56	1,086.57	38.65
3/26/14 18:46	305,528	4,803	23.60	20.11	124.71	44.23
4/16/14 19:25	45,372	-	21.47	17.44	83.73	24.62
4/24/14 7:30	43,007	3,388	30.03	27.29	134.23	25.06
4/27/14 5:15	185,051	3,417	24.61	21.12	107.68	23.82
5/1/14 3:09	10,672	2,500	20.20	18.92	75.82	14.50
5/8/14 1:13	111,451	3,868	20.18	14.82	132.96	19.67
5/11/14 23:18	75,148	2,212	14.60	12.96	90.52	16.64
5/19/14 12:23	146,585	2,522	18.93	16.57	101.96	18.94
5/27/14 3:30	29,072	2,714	19.61	16.32	102.19	21.39
5/31/14 18:51	216,478	8,508	19.47	15.65	121.91	19.62

6/5/14 14:22	15,717	5,962	26.06	23.21	110.52	36.48
6/7/14 6:47	63,622	5,105	22.01	18.57	92.20	24.15
6/18/14 3:50	99,824	5,218	79.26	57.98	400.66	27.05
6/22/14 13:58	22,891	3,680	31.02	27.92	177.66	29.06
6/24/14 17:30	167,792	4,331	35.59	32.43	177.53	63.14
7/1/14 16:24	114,577	3,362	21.43	21.43	143.02	38.30
7/9/14 21:37	62,675	1,612	136.87	148.40	320.65	17.66
8/3/14 23:51	46,580	5,272	21.06	16.73	117.67	22.30
8/11/14 2:35	19,098	3,496	23.23	21.20	108.65	30.83
8/21/14 7:20	12,920	3,427	23.80	21.38	126.94	30.73
8/29/14 4:21	120,302	4,073	30.36	27.09	101.45	55.67
9/1/14 0:58	42,322	3,700	22.05	21.97	206.69	58.02
9/3/14 21:25	44,755	5,038	35.84	31.03	118.63	50.11
9/10/14 5:17	48,120	10,913	147.65	-	283.76	79.50
9/19/14 20:29	58,750	-	396.87	-	836.26	-
10/1/14 10:04	59,549	9,557	57.57	-	187.33	40.61
10/4/14 1:00	26,225	6,994	39.42	-	103.97	30.28
11/23/14 21:15	10,461	5,184	25.48	16.39	102.02	24.99

Farm C, Site L5 (collection tank)

Event	Volume (gal)	COD (mg/l)	TP (mg/l)	SRP (mg/l)	TKN (mg/l)	NH3 (mg/l)
10/13/12 14:21	500	3,448	26.40	23.70	120.74	41.11
10/15/12 3:05	419	8,104	73.50	68.70	227.77	30.49
10/17/12 3:10	157	22,840	193.05	183.60	610.73	75.13
10/19/12 10:30	500	6,488	48.55	45.75	212.49	32.53
10/20/12 3:17	419	5,370	52.90	47.65	136.29	29.30
10/23/12 9:18	107	5,136	42.45	37.90	154.88	43.07
10/24/12 3:26	279	3,070	22.70	20.30	103.78	16.64
10/26/12 3:32	500	2,770	21.15	12.60	94.62	11.06
11/11/12 3:28	500	4,170	34.30	32.10	129.85	33.27
11/12/12 3:08	500	8,110	59.78	50.60	301.77	35.14
11/27/12 9:16	232	9,385	70.45	63.30	373.45	82.95
12/4/12 10:03	419	10,690	84.05	66.20	456.61	82.31
5/10/13 4:43	259	7,420	46.91	42.34	303.59	69.65
5/12/13 4:30	419	7,580	45.70	43.03	243.82	54.60
5/21/13 3:14	579	5,340	36.64	31.88	246.49	44.73
5/21/13 3:52	579	8,980	53.77	48.50	551.54	65.18
5/22/13 2:28	500	6,890	47.53	44.59	199.42	42.09
5/23/13 4:19	332	5,140	39.25	36.75	203.89	47.93
5/31/13 3:29	500	7,300	41.48	32.80	229.98	95.59
6/2/13 3:38	419	14,880	63.41	61.16	541.86	115.39
6/6/13 2:45	500	7,090	41.29	37.55	238.45	75.24
6/7/13 2:41	500	3,280	32.08	26.73	113.32	31.76
6/16/13 3:36	419	5,320	39.26	35.12	261.99	183.54
6/17/13 2:24	419	7,515	39.45	35.63	262.24	53.56
6/17/13 4:30	500	3,710	33.50	30.20	152.14	34.93
6/21/13 2:32	500	3,240	30.84	25.97	132.27	85.79
6/21/13 4:11	419	3,180	29.30	26.38	115.75	26.47
6/22/13 3:28	500	3,090	27.93	24.03	111.35	29.68
6/27/13 2:20	2,979	1,830	16.88	11.67	57.33	8.02
7/8/13 3:13	259	2,300	24.79	20.06	103.83	82.65
7/8/13 3:34	1,539	2,580	24.06	19.41	93.92	18.23
7/8/13 3:53	1,379	2,780	27.06	21.63	107.16	21.74
7/10/13 3:14	500	5,080	30.53	24.83	222.13	104.60
7/17/13 2:57	500	4,470	29.44	22.45	179.08	86.17
7/27/13 3:22	500	4,540	-	-	-	-
7/29/13 3:27	419	7,590	-	-	-	-
8/6/13 3:24	500	13,200	71.20	66.45	441.97	127.71
8/7/13 3:27	500	3,880	26.30	21.70	51.90	55.93
8/22/13 3:23	500	4,770	47.13	24.40	220.95	86.18

8/27/13 3:22	579	5,770	35.55	30.50	276.07	84.38
8/28/13 3:06	419	7,230	52.10	45.45	332.27	99.86
8/30/13 3:54	500	12,400	55.53	53.03	533.47	227.56
9/8/13 3:44	500	2,440	22.45	20.73	166.65	75.78
9/16/13 3:32	500	3,360	21.34	19.44	158.26	79.19
9/19/13 4:50	500	2,840	21.05	19.60	127.83	52.49
9/20/13 3:52	500	2,400	19.12	16.39	103.54	30.73
10/3/13 6:43	500	3,180	18.12	17.67	136.26	38.95
10/5/13 3:54	1,219	1,840	14.11	13.19	85.07	22.65
10/6/13 13:34	500	820	10.82	10.05	41.61	10.07
10/16/13 3:45	419	6,560	28.04	30.76	246.27	59.76
10/31/13 3:47	419	6,600	20.43	17.83	108.42	42.41
11/1/13 4:03	419	8,500	30.60	26.58	81.58	25.53
11/6/13 3:33	500	8,880	45.60	41.76	771.77	60.75
11/17/13 3:58	579	12,640	83.81	78.15	1,015.20	96.25
11/21/13 3:48	500	11,220	76.11	74.37	569.25	87.30
4/25/14 13:33	500	18,800	86.65	85.44	790.40	205.72

Farm C, Site L6 (overflow)

Event	Volume (gal)	COD (mg/l)	TP (mg/l)	SRP (mg/l)	TKN (mg/l)	NH3 (mg/l)
10/17/12 23:48	7,895	7,070	63.05	57.60	172.17	37.95
10/25/12 16:18	7,248	3,861	33.29	27.28	122.60	15.91
11/10/12 7:31	11,301	5,030	32.95	21.60	191.36	22.96
1/10/13 22:06	5,298	3,758	86.81	43.06	239.71	54.08
5/9/13 22:23	1,940	6,944	38.68	35.29	265.58	63.42
5/11/13 9:21	1,960	7,556	49.97	47.07	283.70	60.14
5/21/13 1:45	778	7,180	42.48	40.47	287.52	47.06
5/21/13 3:43	224	5,120	33.57	30.39	226.88	35.35
5/21/13 14:53	20,929	4,190	34.23	32.08	185.89	30.68
5/22/13 15:30	4,393	7,681	49.06	48.08	286.92	68.59
5/30/13 20:49	1,478	10,590	45.86	41.59	398.86	71.50
6/1/13 13:44	13,221	2,174	21.94	18.00	72.61	16.26
6/5/13 12:45	3,447	8,920	52.70	49.18	327.87	80.88
6/15/13 21:48	1,694	7,940	45.10	40.43	314.97	66.74
6/16/13 23:15	2,231	6,320	35.85	31.67	236.27	49.60
6/21/13 2:20	1,352	4,250	30.23	27.25	140.06	32.06
6/21/13 9:27	5,756	2,050	21.36	17.53	71.30	16.63
6/25/13 5:23	2,361	6,450	38.35	32.15	250.66	50.63
7/8/13 3:30	8,312	2,300	24.93	18.75	79.05	18.07
7/9/13 19:12	5,221	2,797	23.26	17.60	113.99	40.29
7/16/13 15:13	1,245	5,900	38.84	32.25	224.76	41.21
7/26/13 10:14	23,801	2,390	-	-	-	-
8/5/13 12:26	230	4,800	29.80	25.80	190.85	51.71
8/7/13 0:06	8,793	1,331	11.99	9.89	27.59	13.69
8/21/13 18:47	7,748	1,900	31.40	16.75	112.45	23.87
8/26/13 6:54	23,825	1,041	8.62	7.37	56.47	16.04
8/27/13 7:05	2,633	2,450	27.45	19.55	128.25	34.88
8/27/13 15:42	1,271	6,121	45.85	38.00	276.73	94.22
8/29/13 22:58	2,736	5,697	38.93	34.28	256.81	83.14
9/1/13 10:15	1,298	6,340	40.80	40.65	263.17	94.88
9/7/13 15:56	950	1,580	17.90	16.84	137.02	23.98
9/15/13 8:34	1,072	3,860	27.10	23.80	154.44	46.69
9/19/13 10:04	3,017	3,302	24.21	20.07	142.38	22.85
9/28/13 20:15	1,785	2,640	20.29	19.63	129.77	24.03
10/31/13 5:45	18,258	5,969	25.52	23.11	114.81	19.37
11/5/13 19:08	6,069	5,257	37.37	36.12	235.44	28.70
11/6/13 7:27	2,210	5,100	42.32	41.66	258.72	29.81
11/9/13 0:11	3,048	4,800	36.05	34.47	216.61	30.95
11/16/13 16:23	8,971	4,651	36.72	35.18	556.85	29.00

11/17/13 10:05	4,695	4,980	37.68	37.13	281.33	28.39
4/13/14 20:40	4,638	3,562	28.27	27.12	159.31	40.21
4/14/14 10:45	1,851	4,950	37.89	36.15	167.35	44.59
4/17/14 0:21	1,326	7,020	47.08	44.96	224.08	65.53
4/24/14 13:18	3,565	8,460	47.17	46.46	357.65	73.66

Appendix D: Mass-volume curves for COD, SRP, and Ammonia