

Understanding Nutrient & Sediment Loss at Heisner Family Dairy



University of Wisconsin - Extension



DISCOVERY
FARMS

University of Wisconsin - Madison
www.uwdiscoveryfarms.org

Winter 2011-2012



Farm, Site and Study Design

On-farm research was conducted at Heisner Family Dairy, LLC, Mineral Point, WI, (2004-2007) to gain a better understanding of environmental challenges and opportunities for organic and grass-based dairies in the driftless region of southwestern Wisconsin (Figure 1). Heisner Family Dairy is a grass-based organic dairy located three miles northeast of Mineral Point in Iowa County, WI. The farm has been operated as a partnership between Jim and Jane Heisner, and their sons, Adam and Cyrus. As of early 2012, Jim and Jane have retired, leaving daily management and operation activities while still retaining property ownership. Jim and Jane bought the home farm in 1983. They intentionally operated this 320 acre parcel of cropland and pastureland without the use of herbicides or insecticides, to support their dairy enterprise. In 1997 the farm was expanded through the purchase of an adjoining 160 acre farm, adding both pasture and cropland. Heisner Family Dairy transitioned to become a certified organic dairy in 2000. All products produced (milk, meat and crops) and used (livestock feed, health products and crop inputs) on the farm conform to certified organic production standards.

Landscape

The farm has moderate to steep slopes, characteristic of unglaciated uplands in southwest Wisconsin. The predominant soils are Dodgeville and Dubuque silt loam. More rugged areas of the farm are managed as rotational grazing paddocks for the dairy herd. Some paddocks are quite steep with limestone bedrock very close to the surface. Others are bisected by a perennial stream; typical of this landscape. The farm is within the Pecatonica River Watershed where surface water eventually drains to the Mississippi River.

Grazing and dairy

The Heisner farm includes 140 acres

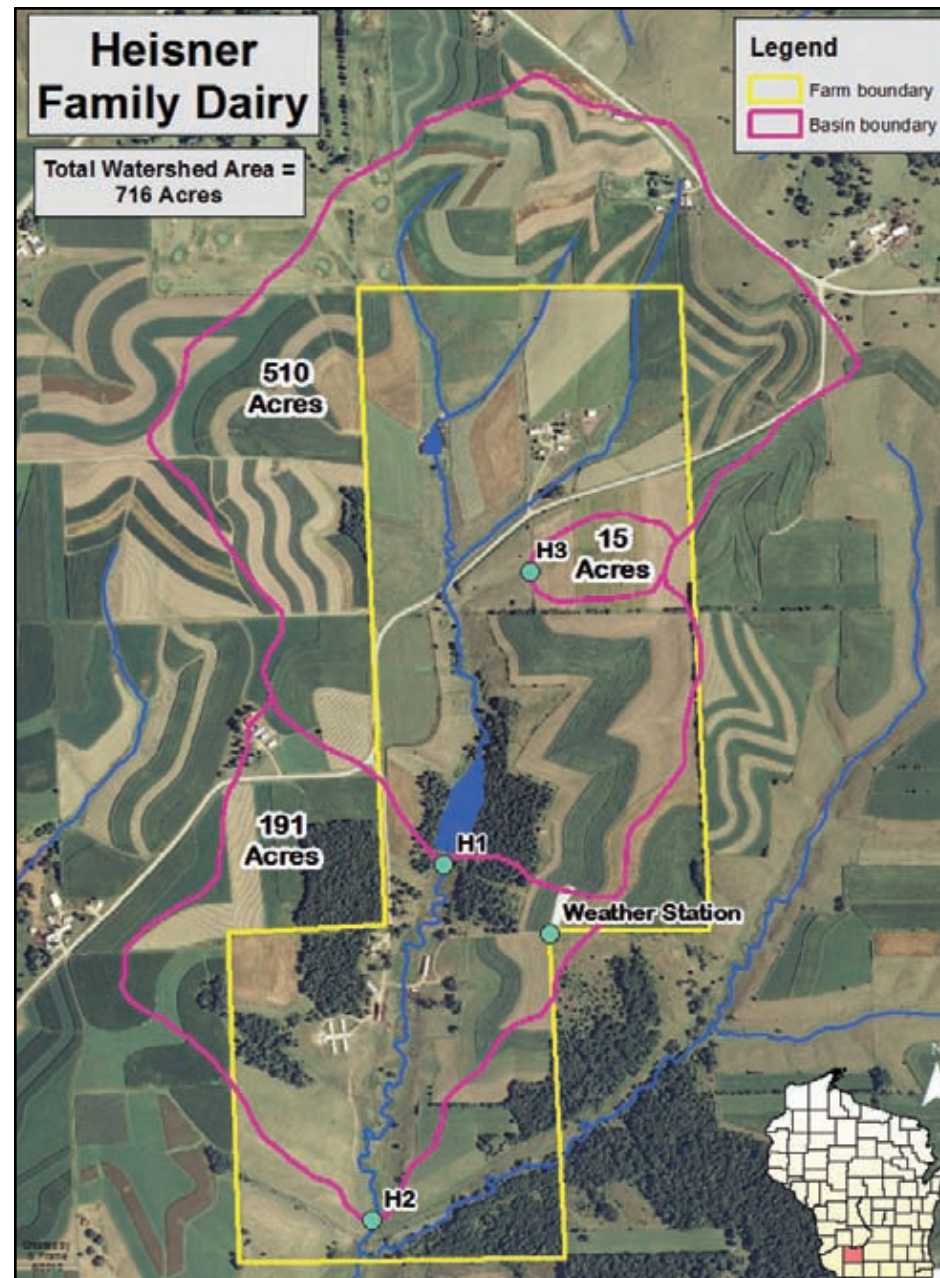


Figure 1. In-stream water monitoring basins H1 and H2 and edge-of-field water monitoring basin H3

of open pastureland, divided into 33 paddocks. Typical animal numbers on the farm are: 110 dairy cows, 50 heifers, and 20 calves (162 mixed animal units). Cows and heifers remain on pasture through the growing season, depositing manure as they rotationally graze. Pasture forage

management and animal movement into paddocks varies based on seasonal plant growth. After the cows move on to a fresh paddock, heifers move into the paddock vacated by the cows. Grazed paddocks receive a 30 day rest period. In this part of Wisconsin, the primary

grazing season is approximately 180 days.

The milking center features a swing-twelve pit parlor, retrofitted into the original dairy barn. Four 50-cow hoop barns are used for winter housing, and incorporate a drive-by feeding area (Figure 2). Manure collected from the hoop barns accounts for less than half of the total manure produced by the milking cows. Manure from the hoop barn areas is scraped daily and hauled to cropland weekly, as weather conditions permit. The farm does have a one week short term manure storage area, allowing flexibility to avoid spreading manure during inclement weather.

Cropland

Along with the grazing system, the Heisners manage 350 acres of certified organic cropland where they grow corn, small grain and hay. Their typical crop rotation is one year corn (silage or grain), followed by small grain with alfalfa / grass new seeding, and two years of hay. Tillage on the farm includes moldboard plow, chisel plow, disk, field cultivator, rotary hoe and row cultivator. Tillage, crop rotation and cover crops are methods of weed and insect control within this organic farming system. Crop nutrients are provided through livestock manure, rotated legume hay, and organically approved soil amendments. The current manure application rates are less than rotational P and K crop removal. One of the challenges for this farming system is to maintain soil fertility so P and K nutrition is adequate for crop production.

All field operations are conducted on the contour. Some fields are contour stripped. Grassed waterways are present. The farm has an approved soil and water conservation plan, as well as a nutrient management plan developed to meet the specifications outlined in the WI - NRCS Nutrient Management 590 Standard. The Heisners also cooperated with UW Discovery Farms and the NRCS to develop a Comprehensive Nutrient Management Plan (CNMP).



Figure 2. Hoop barns and drive by feeding

Farm selection and monitoring site layout

In the fall of 2003, the United States Geological Survey (USGS) and UW Discovery Farms staff toured the operation to evaluate the types of information that could be gained from

the farm. The project included two study designs; one with equipment installed in a grassed waterway to monitor sediment and nutrient loads in runoff water from a 15.8 acre watershed managed as organic cropland.

The second phase of the study involv-

ed two in-stream monitoring stations that were installed upstream and downstream respectively from the home farmstead.

This monitored area collected runoff event and base flow stream water from 191 acres, including the milking facility, winter housing barns and rotationally

grazed pastureland. In this area, cattle had limited access to the stream through a series of 10 paddocks, each grazed for 24 hours once every 30 days.

Equipment, Procedures and Sampling

In Wisconsin the spring thaw is an important period for both surface water runoff and groundwater recharge. To fully assess annual nutrient and sediment losses, year-round monitoring was conducted on the Heisner farm. Equipment was selected and procedures implemented that provide high-quality agricultural runoff and water quality data during a full range of weather conditions, including winter.

Data collection for this project began in the summer of 2004 for the edge-of-field site and in the early fall for the in-stream sites. Meteorological data was collected, beginning in April 2004.

Monitoring stations

At all three sampling locations, clam-style 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 3). A solar panel powered the equipment. A digital camera was programmed to take one photograph each day to track field conditions. The aluminum enclosure was locked to prevent unauthorized access.

Edge-of-Field Site: Edge-of-field surface-water runoff was measured in a grassed



Figure 3. Automated sampler

waterway near a fence line downslope from the fields (Figure 4). A fiberglass flume was attached to treated plywood and installed perpendicular to the flow at the watershed outlet. The plywood wing wall channeled runoff water through the flume so discharge could be measured.

In-Stream: In-stream surface water quality monitoring was measured at two locations in an unnamed tributary to Brewery Creek. The upstream site was positioned immediately below a controlled outlet stream-fed farm pond. The downstream site was located approximately 2,000 feet to the south (Figure 5). Due to continuous water flow in both cases, sheet piling was used to create a wingwall, directing water from the pond's splash pool and the stream through H-flumes similar to the edge-of-field site.

Equipment to measure water levels and collect water samples, including refrigerated ISCO sampler and CR10X data loggers were the same at both in-stream sites and the edge-of-field site. An automated, refrigerated, 24-bottle sampler was used to collect water samples. Flow and sample data were stored internally on the sampler. A datalogger was used to read and store precipitation and air temperature data.

Sample collection for runoff events

A runoff event was defined as the time from the onset of rainfall or snowmelt-induced surface water runoff until the time when runoff ceased. To properly characterize storms and water quality, sampling frequency was remotely controlled and adjusted to draw water samples from the beginning until the end of runoff events.

Water samples were generally retrieved within 24 hours, sample quantity and appearance was recorded, and equipment accuracy was checked and noted. Samples were placed in coolers and transported to the UW-Stevens Point Water and Environmental Analysis Lab for analysis (Figure 6). Samples were typically received by the lab within three days of a runoff event. Water was analyzed for: Suspended sediment, Nitrate/nitrite nitrogen, Ammonium nitrogen, Total Kjeldahl nitrogen, Total phosphorus, Dissolved reactive Phosphorus, and chloride.

Maintenance

Maintenance was vital to accurately

measure the annual quantity and quality of surface water runoff. During spring, summer and fall, stations were maintained by mowing around the gauge and along the wing walls. During winter, snow and ice were removed from the edge-of-field flume and a trench was dug in the snow upstream and downstream of the flume prior to anticipated runoff events. This ensured better water getaway conditions, minimized water backing up, and helped keep the sample-intake line from freezing; all of which would cause false water measurements.

Additional information

For detailed information on sampling materials and methods used on UW Discovery Farms projects see: Methods of Data Collection, Sample Processing, and Data Analysis for Edge-of-Field, Streamgaging, Subsurface-Tile, and Meteorological Stations at Discovery Farms and Pioneer Farm in Wisconsin, 2001–7. The report is available for download at <http://pubs.usgs.gov/of/2008/1015/>.



Figure 4. Edge-of-field site



Figure 5. Downstream monitoring site



Figure 6. Sample bottles from runoff event

Water Budget and Edge-of-field Runoff

Data presented in this report are based on a field year (FY), the 12-month period from October 1 through September 30. The monitoring activities coincide with the crop production cycle such that activities done on a field after harvest are attributed toward the following year's crop management. Frozen precipitation was converted to its liquid equivalent so both forms of precipitation can be used and analyzed equally.

Precipitation characteristics

On average, this location in Wisconsin receives 36 inches of annual precipitation (rainfall and snow-liquid equivalent) per year, including 42 inches of annual snowfall. During the study period, annual precipitation was below average for FY05 (29 inches) and 2006 (33 inches) and slightly above average for field year 2007 (37 inches) (Figures 7 & 8). Snowfall amounts were below average for all three years of the study. The three year total precipitation was 10 inches less than the 30 year average.

Edge-of-field runoff characteristics

During three years of monitoring (FY05-FY07), annual runoff was highly variable, ranging between 0.3% and 12.8% of annual precipitation (Figure 8).

Surface water runoff from the edge-of-field site occurred almost exclusively during frozen ground periods; 99% of the total runoff volume occurred when the ground was frozen. Over 90% of the total runoff volume occurred in February and March (Figure 9).

Year by year frozen ground runoff

During FY05, 99% of the annual runoff occurred from January – March, highly influenced by rain events on frozen ground. In January 2005, 2.4 inches of combined rain and snow resulted in 0.3 inches of runoff. Most of this precipitation infiltrated, saturating the upper soil profile with water, creating a condition where most soil pore spaces were occupied with frozen water. Subsequent rain-on-snow events in February and March 2005, generated more runoff than the total precipitation, as the concrete frost in the

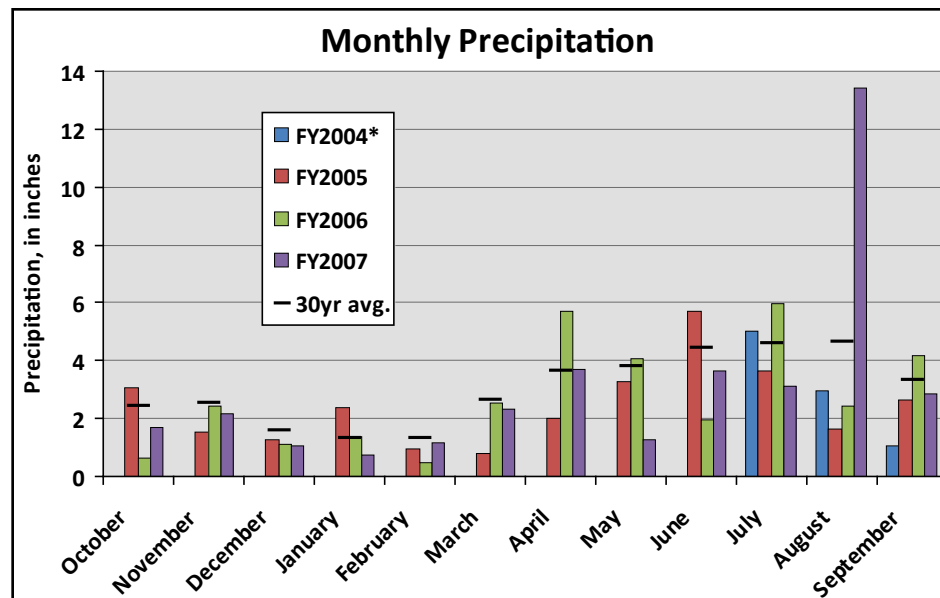


Figure 7. Monthly precipitation versus 30-year average

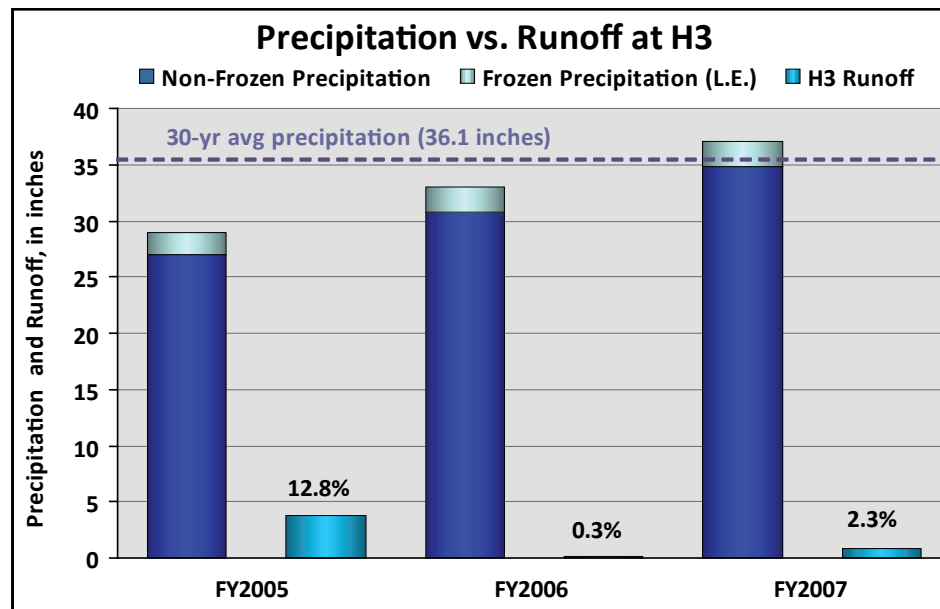


Figure 8. Annual precipitation and edge-of-field runoff at H3

soil prevented most infiltration. Therefore, both rain and melting snow contributed to the total volume of runoff.

During FY06, the edge-of-field monitoring site had only one runoff event for the whole year. This occurred in March, and was quite small (0.1 inches of surface water runoff, Figure 9). Several conditions contributed to this limited runoff, even though that winter had considerable

precipitation: 1) Early snowfall insulated the soil and led to a shallow frost depth (12 inches) through the winter; 2) Shallow frost and temperatures just above freezing led to slow snowmelt conditions, allowing the rain and melting snow to infiltrate the soil; and 3) The soil had adequate pore storage capacity due to a dry summer and fall of 2005.

During FY07, the edge-of-field runoff

was again unique from previous field years. The frozen ground runoff period in March was "pure" melting snow with little rainfall, resulting in lower frozen ground runoff totals compared to FY05.

Questions for non-frozen ground runoff

The lack of surface runoff at the edge-of-field site during non-frozen ground periods is particularly interesting. Of the three full years monitored, only 1% of the total runoff occurred during the non-frozen ground period, non-typical compared to other Discovery Farms edge-of-field sites. This was not due to a lack of large rainfall events, as evidenced by zero runoff measured during intense rainfall events of 2.6, 2.4, and 2.3 inches during July and August of 2007.

The factors behind the lack of runoff were not adequately determined during this study, and cannot be confidently attributed to crop grown, field management, or soil properties. The infiltration capacity of the soil should have been exceeded during the intense summer rainfalls in 2007. The lack of runoff during these events seems to indicate an opportunity for rapid infiltration; much greater than that afforded by the soil itself.

In this geologic setting, dolomite limestone is the uppermost bedrock material. Features of this shallow, fractured carbonate bedrock can allow for rapid infiltration of surface water. Water that percolates into this weathered dolomite limestone can become part of a stable, perched groundwater system, present across the local uplands, as documented by a study at Governor Dodge State Park near Dodgeville, WI (Carter, et al). Perched groundwater can resurface as spring flow somewhere lower in the landscape.

It is plausible that some precipitation, which in other circumstances would run off the surface, infiltrates into the upper aquifer, runs through a subsurface channel, and later emerges at another location in the form of a spring. Therefore,

it may be inaccurate to assume the low amount of runoff observed during the non-frozen ground period in this study is assessing the full amount of surface water leaving the landscape.

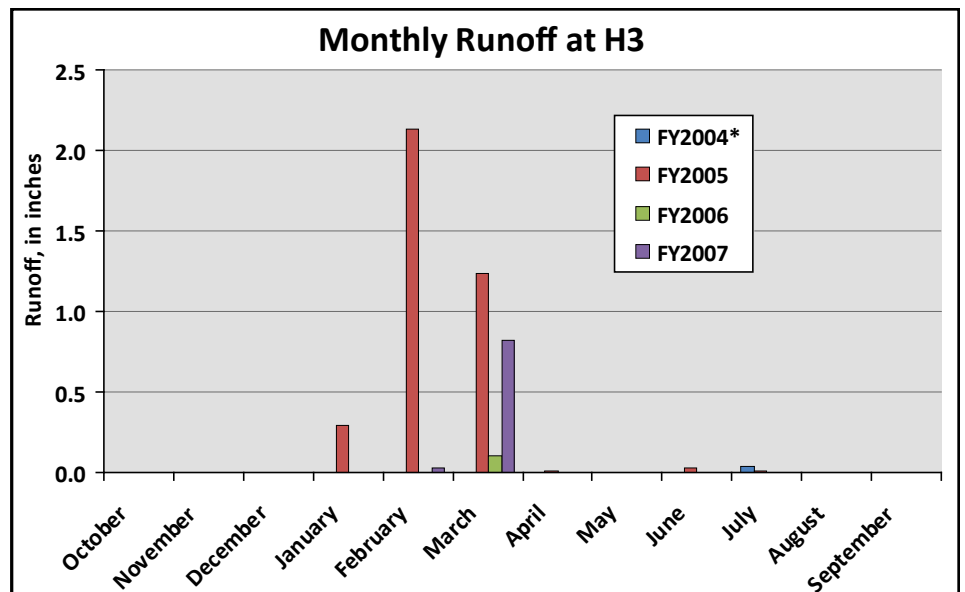
Conclusions

Nearly all surface water runoff at this edge-of-field monitoring site occurred when soils were frozen. The timing of this runoff was different for all three years monitored. Depth of snowpack, depth of frost, timing of rain-on-snow events,

and rate of snowmelt resulted in the differences between years.

The edge-of-field runoff data collected at this site also indicates that very little surface water runoff was observed when soils were thawed. This is non-typical compared to other Discovery Farms edge-of-field sites. Localized conditions, such as shallow fractured bedrock, could have caused rapid infiltration of surface water, particularly when soils were thawed.

Figure 9. Monthly runoff at edge-of-field site H3



Stream Flow at Heisner Family Dairy

In any one year, annual and monthly precipitation alone is not a good measure of the actual hydrologic conditions at monitoring sites. For example, precipitation for FY07 was well below average until August, when nearly 14 inches of rain fell, yet the overall annual precipitation amount was average.

Stream flow components

The stream sites had year-round flow. Much of this flow is considered base flow, mostly derived from groundwater. Another component of water moving through a stream is storm related flow which comes from surface water runoff and/or increased shallow groundwater flow in response to precipitation or snowmelt. Stream flow results for this study are presented separately for base flow and storm flow.

The farmstead contribution to the stream was the primary focus of this evaluation. Farmstead contribution was determined by subtracting the upstream data from the downstream data, leaving only the water flow impact and sediment / nutrients contributed by the (farmstead) area between the two sites.

Data was recorded every five minutes during storm flow periods and every 15 minutes during base flow periods. Flow events lasted from several hours to several days. Table 1 shows the results separated into base flow and storm flow components.

Table 1: Flow in Heisner Family Dairy stream sites

Site	Flow Type ¹	Monitoring Period			
		FY2005 - FY2007	FY2005	FY2006	FY2007
H1 Upstream (526 acres)	Base flow	156	41	16	99
	Storm flow	51	27	7	17
	Total flow	207	68	23	116
H2 Downstream (716 acres)	Base flow	348	125	65	158
	Storm flow	97	49	16	32
	Total flow	445	174	81	190
Farmstead ² (191 acres)	Base flow	192	84	49	59
	Storm flow	46	22	9	15
	Total flow	238	106	58	74

¹ Base flow, storm flow, and total flow in millions of gallons

² Farmstead contribution is the difference between downstream flow and upstream flow

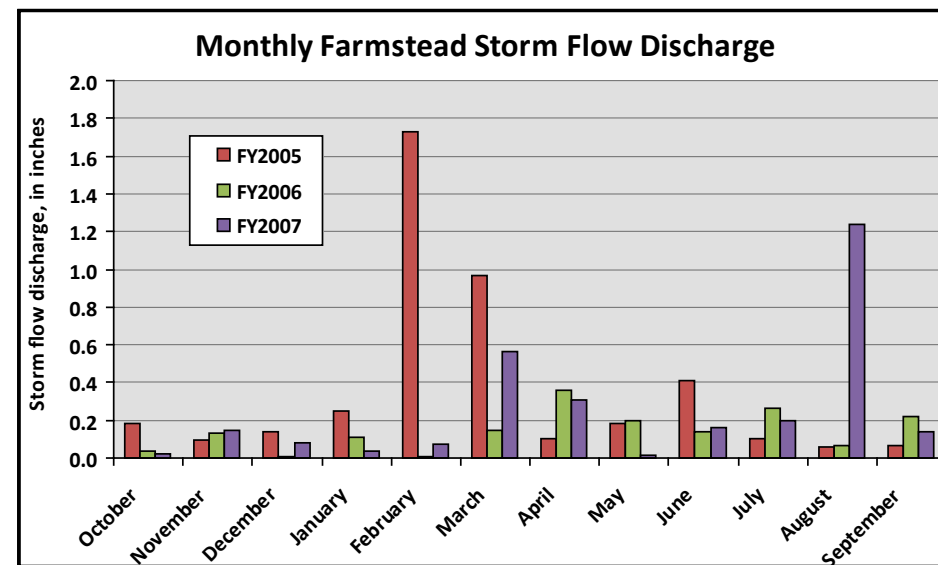


Figure 10. Monthly farmstead storm flow discharge

Farmstead flow volume

The farmstead was an important source of flow between the upstream and downstream sites (see basin configuration, Figure 1). During the three year period (FY05 – FY07), 53% of the total flow volume measured at the downstream site originated from the farmstead area (27% of basin acres), the remaining was contributed by areas above the upstream site (73% of basin acres). Total flow was highly variable between years. The farmstead had larger contributions to the downstream flow during FY05 (61%) and FY06 (71%) than in FY07 (39%).

Base flow

Of the total water contributed by the farmstead, about 80% was considered base flow (mostly spring flow) and 20% was considered storm flow (mostly overland flow). The average base flow was 0.27 cubic feet per second (about 120 gallons per minute).

Over the three year monitoring period, base flow at the downstream site was three times greater than the amount estimated based on increased drainage area (526 acres for H1 vs. 716 acres for H2). The assumed drainage area for the farmstead springs is likely larger than the identified surface area coming from the farmstead. Areas contributing water to the springs may come from regions outside of the surface water drainage area, in which case, management practices or

land use not documented on this farm may be contributing to the spring flow. Determining the exact sources of the spring water on the farmstead was outside the scope of the project.

Storm flow

The amount of runoff coming as storm

flow from the farmstead was only 20% of the total flow (Figure 10). Despite widely varying weather conditions, the runoff from the farmstead during storms was relatively consistent on an annual basis. Monthly storm flow values had spikes at different time periods throughout the study period that were linked to

precipitation trends.

Overall, the volume of runoff from the farmstead area generated during storms was evenly distributed between the frozen ground and non-frozen ground periods. However, the timing of storm flow was highly variable from year to year.

In FY05, 74% of all farmstead storm

flow occurred when the ground was frozen, while in FY06 and FY07, more than 70% was contributed when the ground was not frozen. The amount of flow contributed by the farmstead area was not strongly related to the ground being frozen or non-frozen.

Sediment Loss

By default, our use and management of farmland to produce crops disturbs soil and causes it to move with precipitation and surface water runoff events. Each farming system brings with it a unique cropping intensity that, along with soil and climate characteristics, influences the amount of soil that moves to lower spots within fields. Some of this soil will move all the way to concentrated water flow areas (waterways) and leave the field. Similarly, some of this moving soil, but not all, can systematically move down the landscape and be delivered into streams. The following information will focus on actual sediment measurements in either surface water leaving cropland (H3) and actual sediment measurements in stream flow water (H1 and H2).

Edge-of-field

The loss of sediment from cropland is dependent on the timing, intensity, and volume of runoff. The average annual sediment loss at the edge-of-field site (H3) was 30 lbs/acre. Of the 185 lbs/acre of total sediment loss over the three years of monitoring, approximately half came from two runoff events on July 16, 2004. Sediment loss at this edge-of-field site was low, compared to many other Discovery Farms sites.

Runoff volume and sediment loss correlated well on an annual scale, but not on a monthly basis. More than half of sediment loss occurred during the frozen ground period throughout the three years of monitoring, largely because nearly all surface water runoff at this site occurred when soils were frozen, instead of when soils were thawed. This is non-typical compared to other Discovery Farms edge-of-field sites. Localized conditions, such as shallow fractured bedrock, likely caused rapid infiltration of surface water, particularly when soils were not frozen.

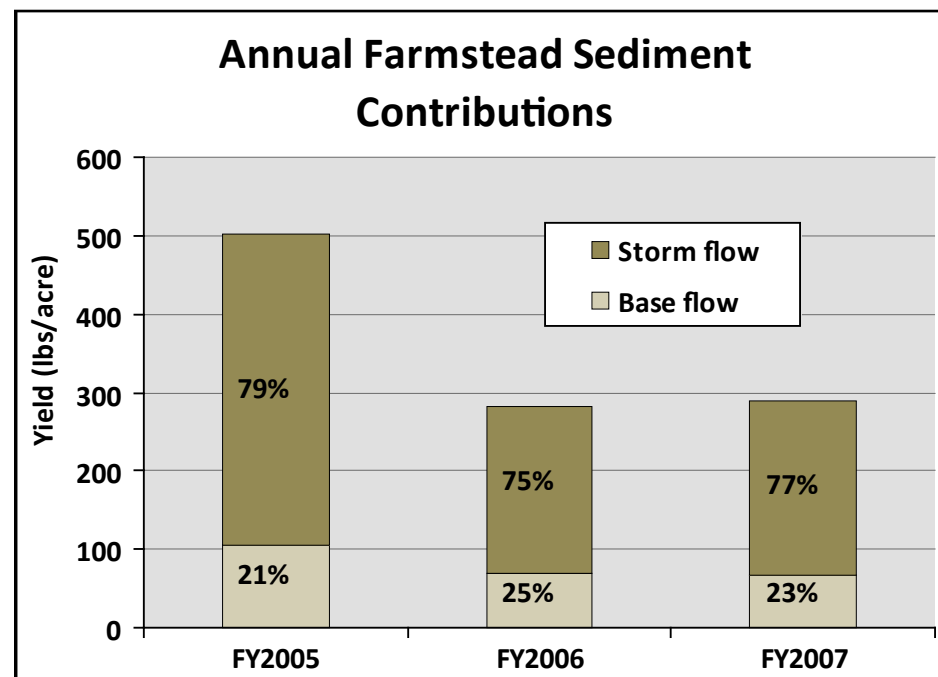


Figure 11. Annual sediment contributions

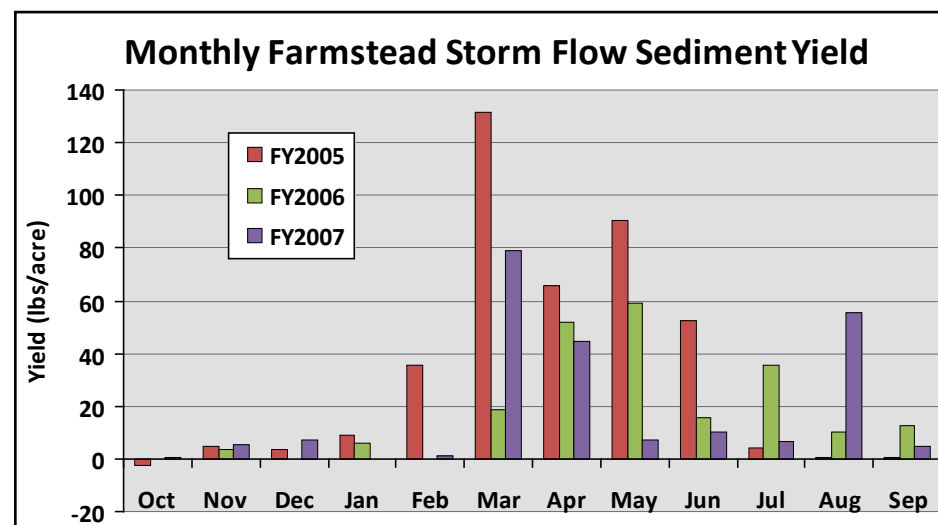


Figure 12. Monthly farmstead storm flow sediment yield

Storm intensity and storm volume are also important factors for runoff and sediment loss. The storms that caused sediment loss during the non-frozen ground period were typically high

volume and/or high intensity storms on bare ground, emerging crops or recently harvested alfalfa. The lack of vegetative growth allowed for the detachment and transport of soil particles.

Farmstead stream sediment contribution

Even though the volume of water from storm flow was much smaller than base flow (only 20% of total), the vast majority (77%) of sediment was delivered during storm flow (Figure 11). Storm flow sediment loads from the farmstead typically occurred during the spring and early summer months (Figure 12). The three year average sediment contribution to the stream from the farmstead area was 360 lbs/acre/year. Increased particle suspension and stream bank erosion occur when flow velocities are higher. Although some weak relationships were identified for some events, strong correlations in edge-of-field sediment loss and stream yield were not evident on this farm.

Sediment contributions in base flow were not as consistent through the seasons as storm flow yields. Overall, base flow losses were very low (Figure 13), and sometimes even less than zero when low stream flow resulted in sediment settling within the stream.

The differences seen annually in sediment yield may have been influenced by year to year differences in the amount of cultivation within the basin and how much perennial cover was present during the winter and spring months. However, visual observation indicated that much of the farmstead sediment was likely coming from farm and field roads, the barnyard area, the grazing paddocks adjacent to the stream, and the stream banks themselves. Livestock are allowed access to the stream to provide a water source while grazing nearby pastures. Hoof traffic can degrade the stream banks and increase sediment loading to the stream. The variability of livestock access to the stream may also explain some of the inconsistency in farmstead sediment yield data.

Even with the cattle having access to the stream and the increased potential for runoff because of the buildings, roads and travel lanes, the sediment loss from this area was low (a three year average of 360 lbs/acre/year).

Conclusions

Edge-of-Field site

- The average annual sediment loss was 30 lbs/acre, which is low compared to many other Discovery Farms sites.
- More than half of sediment loss occurred during the frozen ground time period, largely because nearly all surface water runoff occurred when the soil was frozen. Localized conditions, such as shallow fractured bedrock, likely caused rapid infiltration of surface water, particularly when soils were not frozen.

Stream sites

- The average annual farmstead sediment contribution to the stream was 360 lbs/acre.
- Storm flow supplied 77% of total farmstead sediment contributions to the stream.
- Storm flow sediment contribution from the farmstead typically occurred during the spring and early summer months and was similar all three years. Sediment in base flow occurred at different times throughout the year in each year monitored.
- Stream sediment contributions from the farmstead were higher during the non-frozen ground period for both storm flow and base flow.
- Although weak relationships were identified for some events, strong correlations in edge-of-field sediment loss and stream sediment yield were not evident.

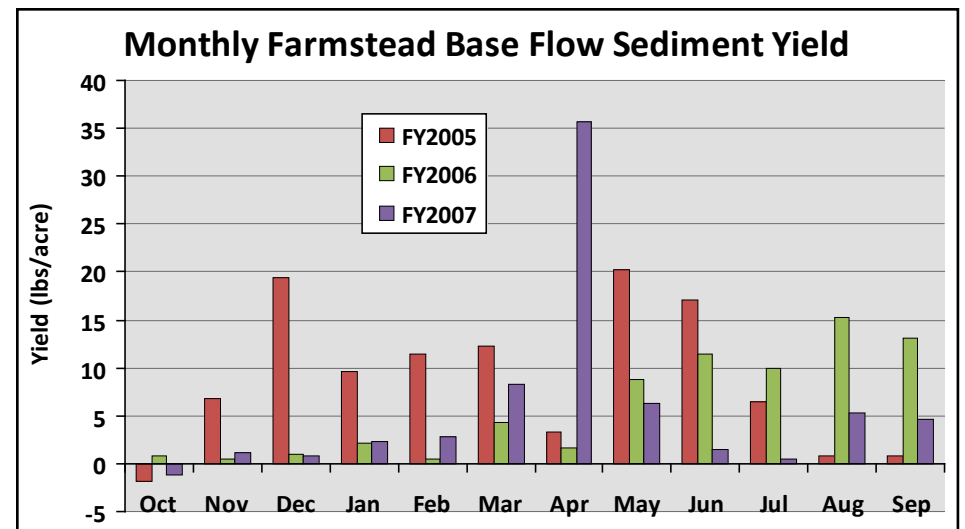


Figure 13. Monthly farmstead base flow sediment yield

Phosphorus Loss

Phosphorus is an essential plant nutrient. The loss of excess phosphorus from agricultural systems can be problematic in surface water aquatic environments. Similarly, phosphorus loss within cropping systems can hinder yields and lower profitability. As surface water travels over the soil, phosphorus can move from the landscape in two forms: 1) particulate phosphorus (bound to soil particles), or 2) dissolved (ortho) phosphorus.

Cropping practices

Tillage is the main weed control method used on this organic farm. Primary tillage includes moldboard and chisel plowing. A rotary hoe and row cultivator are used for weed control after planting. Manure is surface applied to fields that will be corn; and to established alfalfa fields after summer harvests.

Edge-of-field phosphorus loss

The average phosphorus loss at the edge-of-field site (H3) was 1.0 lbs/acre/year, but the loss varied greatly between the three study years. For each year, the timing and amount of phosphorus loss closely mirrored the timing and amount of

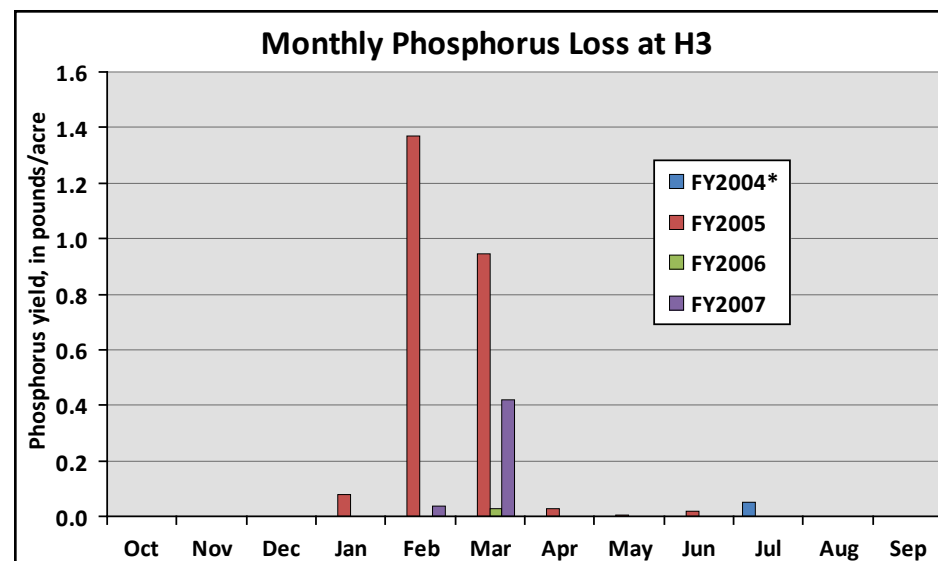


Figure 14. Monthly phosphorus loss at edge-of-field site H3

runoff (Figure 14).

The highest single year loss was nearly 2.5 lbs/acre, during FY05. Solid dairy manure was applied during January, February, March, April, May, and July in the monitored area. Most of the phosphorus loss (98%) in FY05 occurred while the ground was frozen. The elevated runoff volume and phosphorus loss in February and March 2005 are likely the consequence of "concrete frost" formation

resulting in little to no infiltration of water or nutrients into the soil.

During FY06 and FY07, phosphorus losses were quite low. This can largely be attributed to low runoff volume and few runoff events. Manure applications were made in the basin during the frozen ground period in both years. Most of the annual phosphorus loss in these years came while the ground was frozen, as did the vast majority of annual runoff volume.

This is atypical from phosphorus loss and water budgets at other Discovery Farm sites.

Most of the phosphorus lost at the edge-of-field site was in the dissolved form. A major influence on dissolved losses was the high proportion of runoff that occurred during the wintertime. Seasonal differences in dissolved versus particulate losses were observed. However, since such a low amount of runoff occurred during the non-frozen ground period, these differences are difficult to verify.

Farmstead stream phosphorus contribution

The three year average phosphorus contribution to the stream from the farmstead area was 1.6 lbs/acre/year. Manure applications were made to the monitored basin for each year of the study. However, delays between application and elevated yields and very slight differences in yield overall make it difficult to link any individual management or application with phosphorus loss as measured at the stream sites. Also, livestock have access

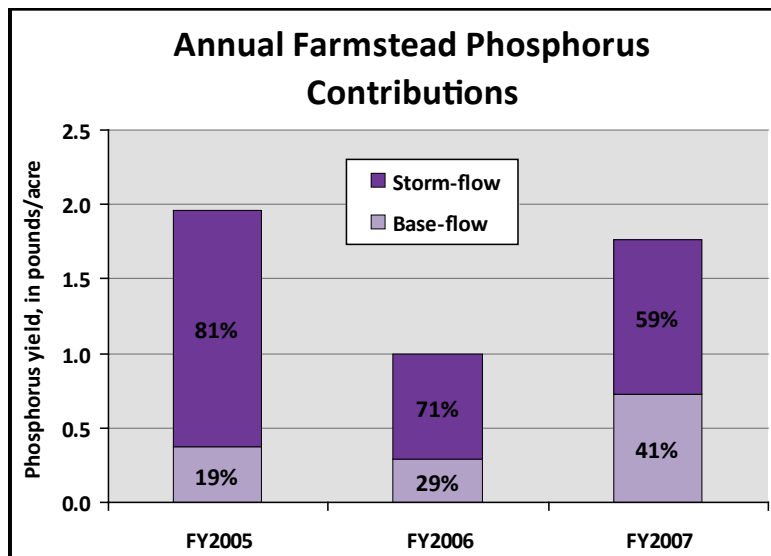


Figure 15. Annual farmstead phosphorus contributions

to the stream as a water source on many of the pastures. Hoof traffic and manure deposition can degrade stream banks and increase phosphorus loading. Other potential sources of phosphorus are milk-house waste and barnyard runoff. The variability of livestock access to the stream, milk-house waste, and barnyard runoff may explain some of the inconsistency in farmstead phosphorus yield data.

As was the case with sediment, phosphorus contributions from the farmstead area typically occurred during storm flow conditions in snowmelt events and in the spring months (Figures 15 & 16). Base flow phosphorus timing was mostly consistent, and showed no seasonal trends for any of the years monitored.

Stream phosphorus contributions were higher for the non-frozen ground period for both storm flow and base flow, unlike the edge-of-field site where phosphorus loss was highest during the frozen ground period.

Unlike edge-of-field losses, over half of the total phosphorus loss from the farmstead occurred in the particulate form (Figure 17). During storm flow, losses were mostly in the particulate form, while most of the loss during base flow was dissolved phosphorus. High particulate phosphorus loss during storm flow is likely from a combination of stream bank erosion and erosion from surface runoff. In both storm flow and base flow, particulate phosphorus loss was higher during spring and summer and dissolved phosphorus loss was higher during fall and winter.

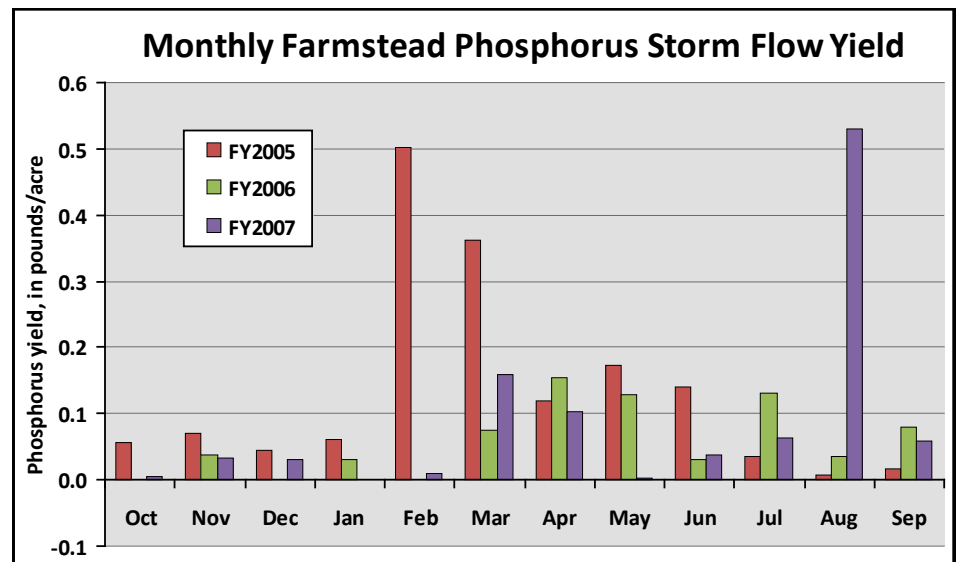


Figure 16. Monthly farmstead storm flow phosphorus yield

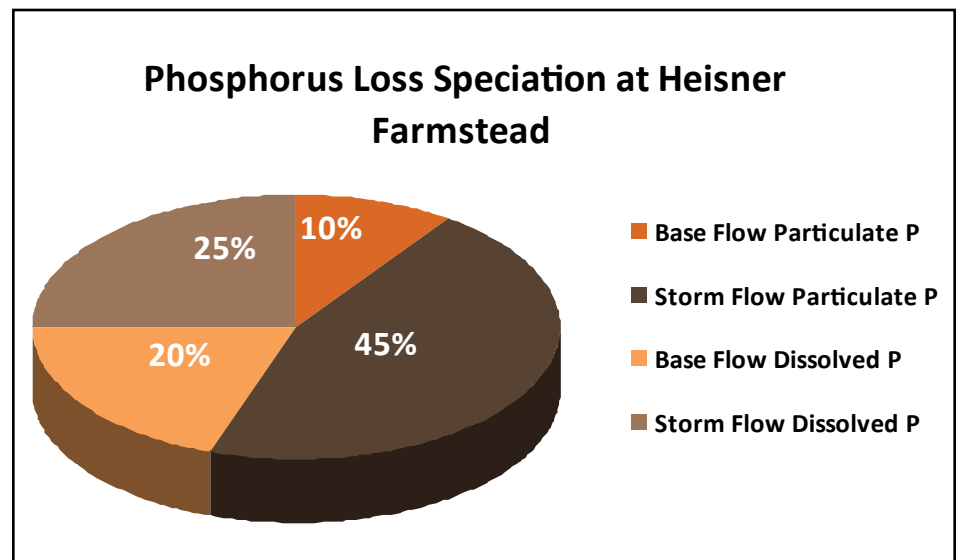


Figure 17. Farmstead phosphorus loss speciation

Nitrogen Loss

Nitrogen is an essential plant nutrient. The dynamics of the nitrogen cycle allow it to exist in many forms, including organic, gas, and ionic nitrate and ammonium. The loss of excess nitrogen from agricultural systems can be problematic in groundwater, fresh surface water and saltwater systems. Similarly, nitrogen loss within cropping systems hinders yields and lowers profitability.

Edge-of-field nitrogen loss

The average nitrogen loss at the edge-of-field site was 6.8 lbs/acre/year over three years, varying monthly and annually based on surface water runoff volume and

timing. Nitrogen losses from surface sites usually have a strong correlation to runoff amount and timing. This was also true at the Heisner Farm, as monthly and annual runoff volume closely mirrored nitrogen losses (Figure 18).

The highest annual total nitrogen loss, about 16 pounds per acre, was in FY05. Solid dairy manure was applied in January, February, March, April, May, and July in the monitored basin. The highest loss events were during February, as a result of rain combined with snowmelt. The applications made on frozen ground combined with the highest runoff volumes recorded during the three year

study influenced FY05 nitrogen loss.

In FY06 and FY07, manure was also applied to frozen ground. However, because of the low runoff volume and few runoff events, the total nitrogen loss was quite low during both years. The total loss for FY07 was about 4 pounds/acre, and most of this (83%) was due to a prolonged runoff event triggered by rain on snow in early March.

Most nitrogen loss and almost all total water runoff occurred during the frozen ground period. Runoff events in February and March resulted in 98% of the total nitrogen loss for the three year period.

The majority of nitrogen loss was in the organic (52%) and ammonium (47%) forms (Figure 19), largely because nitrogen loss occurred during the winter months. Ammonium losses are more typical while the ground is frozen as it is quickly converted to other nitrogen forms or utilized by plant roots during warmer months. Ammonium losses were higher than observed at other Discovery Farms sites. Higher losses of ammonium can be an indicator that manure was applied shortly before a runoff event.

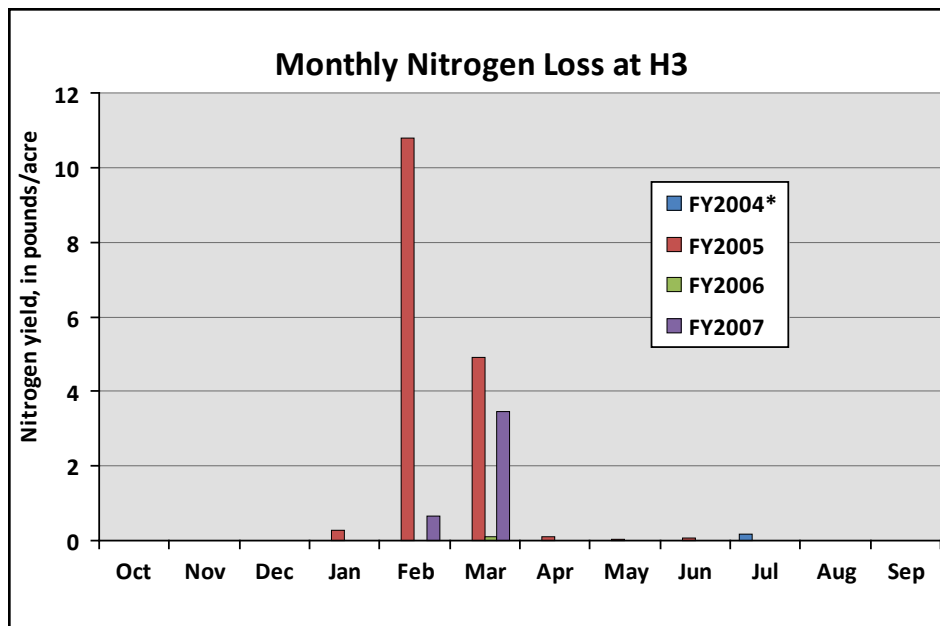


Figure 18. Monthly nitrogen loss at edge-of-field

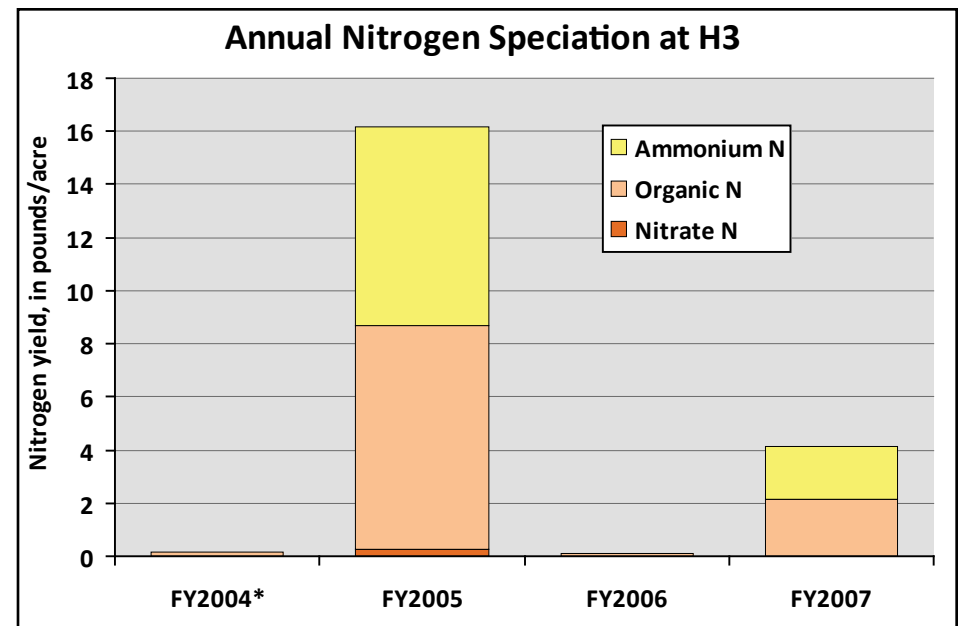


Figure 19. Annual nitrogen speciation at edge-of-field

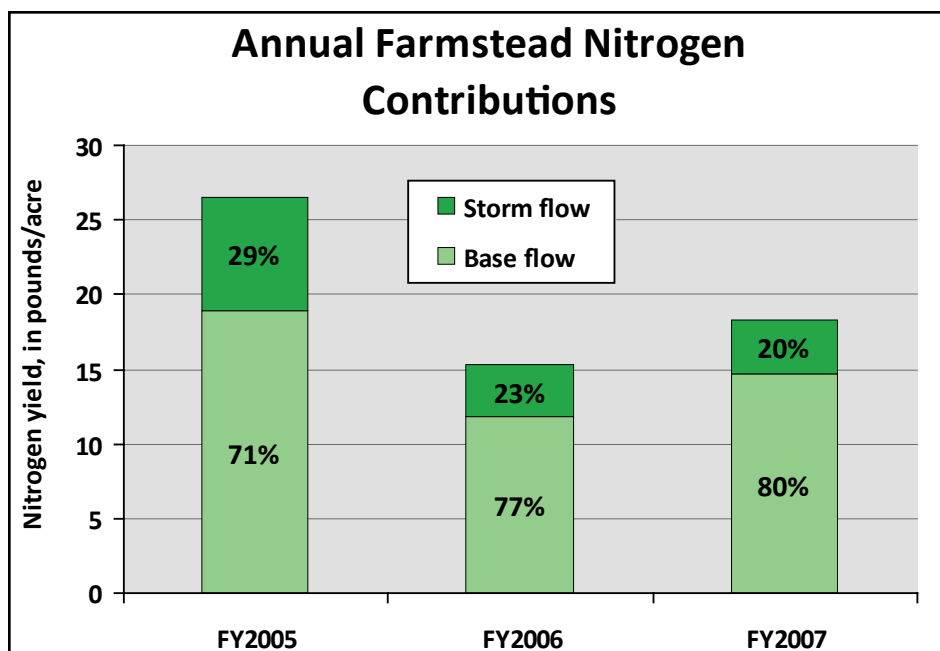


Figure 20. Annual farmstead nitrogen contributions

Farmstead stream nitrogen contribution

The average annual farmstead nitrogen contribution to the stream was 20 lbs/acre for the three year study period, 76% of which was measured during base flow conditions (Figure 20). With layered bedrock geology present, some areas in southwest Wisconsin have perched groundwater systems such that upper groundwater flows horizontally through the soil and discharges at the surface

as spring flow. With such a significant amount of nitrogen contributed by base flow, and the large number of springs present in the farmstead area, nitrogen contributions are likely not limited to the basin area defined by surface topography. Thus, increases or changes in nitrogen storm flow or base flow yield are not easily attributable to manure applications or other farm or cropland management performed within the basin.

Like other Discovery Farms stream

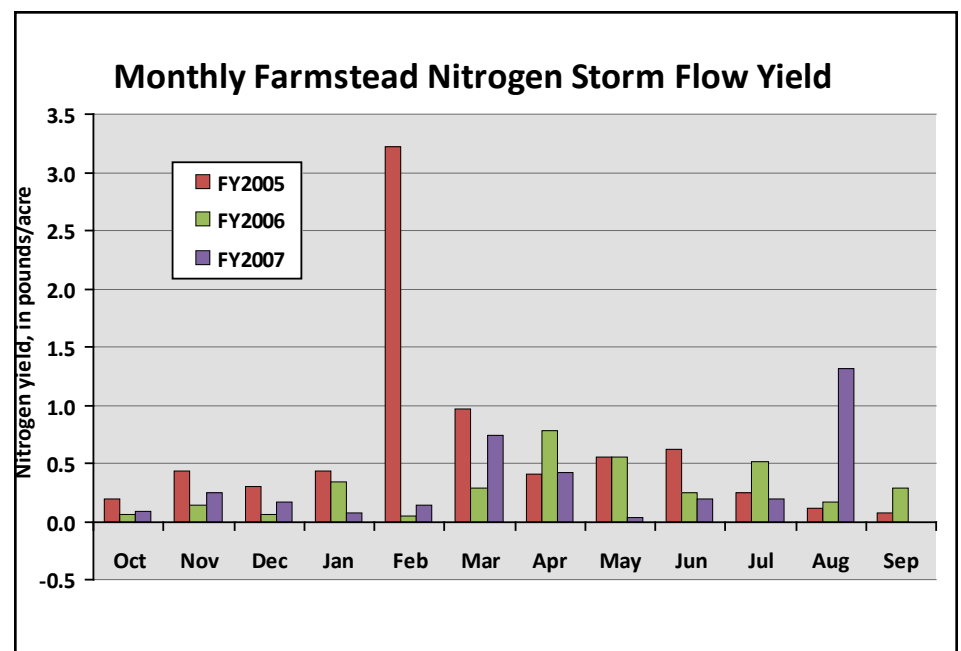


Figure 21. Monthly farmstead storm flow nitrogen yield

sites, nitrogen losses were generally higher under base flow conditions, and most (70%) of the total nitrogen loss occurred in the nitrate form. Most organic nitrogen losses came through storm flow. Organic nitrogen losses are typically related to soil loss or a combination of soil loss and manure application. Livestock grazing the nearby pastures have access to the stream as a water source on this farm. Through this interaction, manure deposition near the stream could increase

nitrogen loading.

Storm flow nitrogen losses were directly related to increases in flow volume from storm events. During the frozen ground period, storm events consisting of snowmelt, rain, or rain on snow led to increases in nitrogen loss (Figure 21). One 13-inch rain event in August 2007 also caused an increase in runoff volume and nitrogen loss.

Single Storm Event Loss Comparison to Total Annual Sediment and Nutrient Loss

Many times, the majority of sediment and nutrient loss from cropland can occur in one or two runoff events for any given year. To develop effective management practices that reduce sediment and nutrient loss from agricultural fields, it is important to understand what factors contribute to those losses.

The timing and magnitude of loss of sediment, phosphorus, and nitrogen were caused by a variety of environmental and management factors. Potential environmental factors include: precipitation timing, volume, and intensity; frozen versus non-frozen soil; snow pack; soil moisture; and others. Management factors include: crop type; tillage; surface residue; nutrient application amount and timing; and others. The combination of these factors can result in differences between relative loss of sediment, phosphorus, and nitrogen for a single event. The highest loss event for sediment, phosphorus, and nitrogen in a given field year was compared to the sum of all runoff events in that same year.

On the Heisner farm, another very important factor is the local geology. The landscape in this area of Wisconsin is characterized by an upper aquifer

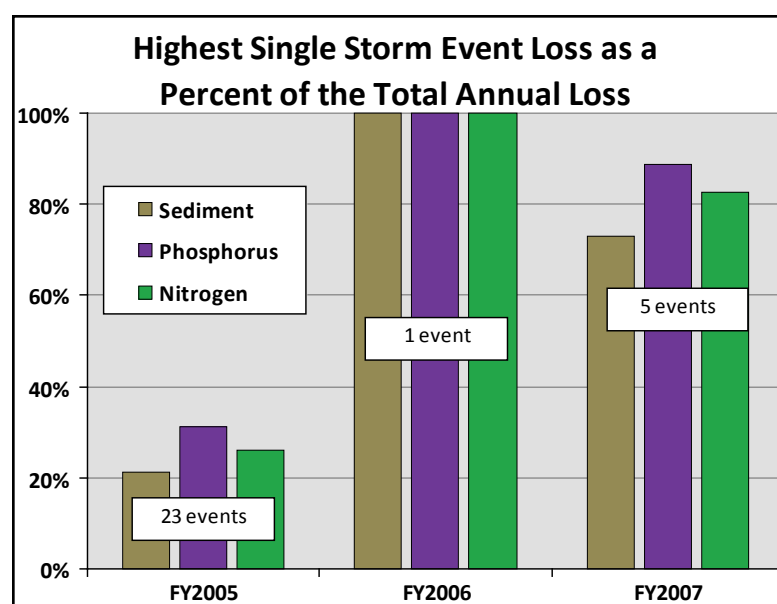


Figure 22. Single storm event loss and number of runoff events from edge-of-field monitoring site.

with an impermeable (aquitard) layer beneath. Water infiltrates the soil and often resurfaces as a spring somewhere further down in the landscape. In these landscapes, surface water can infiltrate rapidly because of shallow depth to bedrock or karst features, resulting in little to no surface runoff. This factor needs to be taken into consideration as we review surface losses from this edge-of-field site.

The first full year, FY05, had the highest

number of runoff events of all three years (Figure 22). The majority of FY05 losses were spread across 23 runoff events, and not a result of one single event. The event which contributed the highest sediment loss was not the event with the largest total runoff volume (Table 2). However, the highest phosphorus and nitrogen loss did occur during the runoff event with the highest volume.

In FY06 and FY07, there were very few

runoff events, and all of them occurred on frozen ground. Since only one runoff event occurred in FY06, all contributions were made during this storm (Figure 22). In FY07, the highest sediment, phosphorus and nitrogen loss all occurred during the same runoff event. This event accounted for 94% of the total flow volume (Table 2).

Conclusions

- The magnitude of single storm event loss varied substantially in this study as a result of the difference in runoff events in each of the three years.
- The highest single storm loss for sediment did not always occur during the largest runoff event. In FY05, the largest sediment loss (21%) occurred during one of the smallest runoff events.
- The highest single storm loss for phosphorus and nitrogen occurred during the largest runoff event for all three years.
- On average for the three year study, a single storm event was shown to provide 19% of the total sediment, 26% of the total phosphorus and 21% of the total nitrogen.

Table 2: Highest three annual single storm constituent losses with runoff percent and ranking at edge-of-field site H3

	Sediment			Phosphorus			Nitrogen		
	Date	Runoff (rank)	Percent of total	Date	Runoff (rank)	Percent of total	Date	Runoff (rank)	Percent of total
FY2005	4/19/05	0.1% (19)	21%	2/12/05	30% (1)	31%	2/12/05	30% (1)	26%
	3/7/05	3% (8)	13%	3/5/05	9% (4)	17%	2/5/05	24% (2)	19%
	2/12/05	30% (1)	11%	2/5/05	24% (2)	11%	3/5/05	9% (4)	12%
FY2006	3/8/06	100% (1)	100%	3/8/06	100% (1)	100%	3/8/06	100% (1)	100%
FY2007	3/9/07	94% (1)	73%	3/9/07	94% (1)	89%	3/9/07 18:00	94% (1)	83%
	2/21/07	1.8% (3)	12%	2/21/07	1.8% (3)	4%	2/21/07 12:00	1.8% (3)	8%
	2/22/07	1.5% (4)	10%	2/22/07	1.5% (4)	4%	2/22/07 11:30	1.5% (4)	7%

Delayed Flow Observations in Stream Discharge

During the initial farm evaluation, many springs were observed. The combination of surface runoff and these springs feed the stream running through the farm. It is believed that springs contribute significant water to both the headwaters and farmstead area on this farm. The Heisner farm is close to Governor Dodge State Park and based on soils and geology, it is likely part of the region with a perched groundwater system described by Carter et al. (2011). It is probable that at least some of the spring flow is derived from a perched system with characteristics of lateral flow.

Background

A study in the Governor Dodge State Park found the presence of a perched groundwater system in this region of Wisconsin. A perched groundwater system is defined as water that is separated from an underlying body of groundwater by unsaturated porous material. In the case of Carter's study, the perched groundwater is in the Galena Formation and separated by the Decorah-Platteville-Glenwood aquitard from the lower groundwater system in the St. Peter Formation.

The study showed that the groundwater within the perched system flows readily in a horizontal direction through the soil and discharges to the surface as spring flow (Figure 23). This perched system occurs throughout the year and over a large portion of the region (throughout the Galena Formation in Iowa County). Rain and snowmelt that recharges the aquifer sustains flow to upland springs. Flow direction can be influenced by the differences in the amount and timing of recharge.

A detailed study to determine the existence and size of a perched groundwater system was not performed on this farm. Surface topography may not accurately define the size and extent of the groundwater basin area contributing to spring flow and base flow within the stream. Perched systems can run for miles under the soil surface. Water can travel

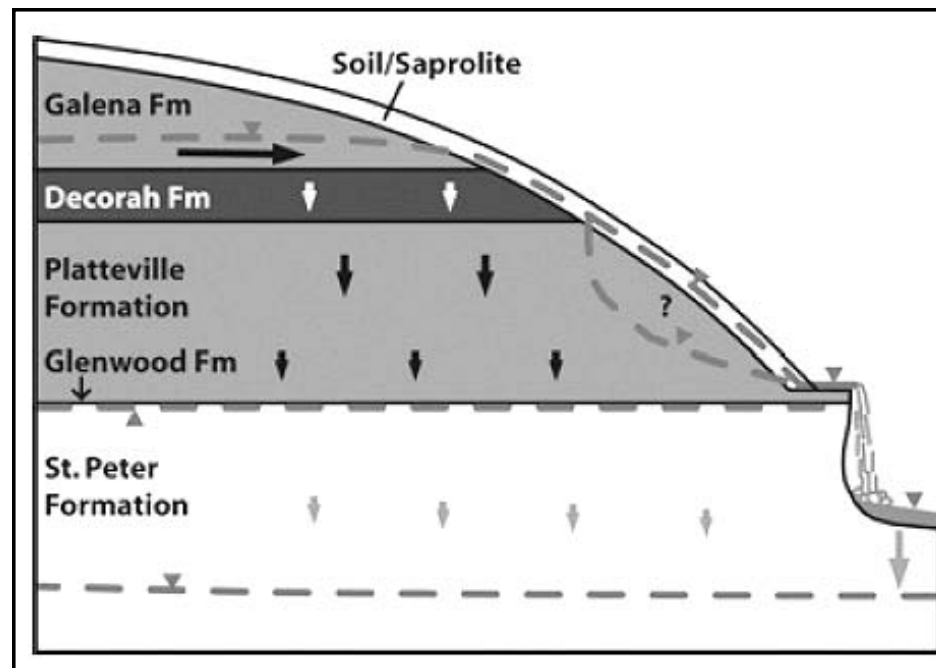


Figure 23. Hydrogeologic conceptual model of the study area. Groundwater flow is proportional to arrow length in the direction shown (Carter et al., 2011).

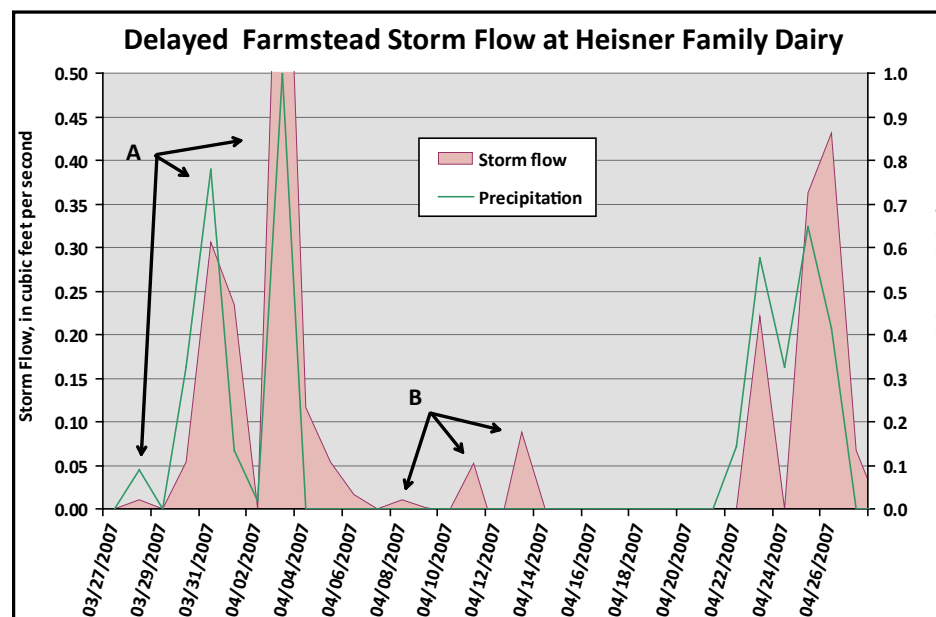


Figure 24. Delayed flow in farmstead stream measurements

a significant distance before coming out to the surface as a spring. The age of the water flowing from a spring may also vary substantially. Rain that fell miles from the farm can travel through the perched system for days, weeks or months before it appears as spring flow. From the study conducted by UW-Discovery Farms on

Heisner Family Dairy, the place of origin and age of all water flowing through the monitoring stations was not determined.

The existence of perched water flow beneath this farmland is supported by delayed storm flow seen in the stream. In Figure 24, there were three initial rain events shown by the letter "A". Storm

flow happened concurrently with rain events. About twelve days later, three more storm flow events occurred without any additional precipitation (letter "B"). Although smaller in magnitude, the flow volumes mirror the scale of both the rain and runoff events from the earlier storm ("A"). This is identified as delayed storm flow. Several of these events can be seen in data collected throughout the study period. With the varied timing of rain and snowmelt events in relation to each other, it is very difficult to determine delayed flow reactions to every event.

Madeline Gotkowitz, a hydrogeologist with the Wisconsin Geological and Natural History Survey, saw similar delayed flow occurrences in her research in this region and attributed it to the perched groundwater system. Delayed storm flow occurs because water takes different pathways of travel. Some precipitation water runs over the surface of the land and flows to the stream. When water travels through the ground, and infiltrates first into soil and/or fractured bedrock, it encounters more resistance and travels at a slower rate. The time difference in the observed delays ranged from 7 to 14 days. It is unclear why this range in delayed storm flow occurred, it may be from fluctuations in the water table affecting the head pressure, and therefore, the timing of the flow.

Conclusions

- The stream at the Heisner farm exhibited delayed storm flow.
- The farm is located in an area likely to have a perched groundwater system.
- Observed delays in storm flow ranged from 7 to 14 days.

Trained Local Sampler: Stream Water Sampling

This project also incorporated on-site stream water sampling, collected as defined by the Water Action Volunteer and Trained Local Samplers, UW-Extension and WI-DNR, <http://watermonitoring.uwex.edu/wav/>. Through this program, grab samples were collected biweekly at seven locations along the stream (Figure 25).

Trained Local Sampler Program

The Trained Local Sampler Program has three main objectives:

- Obtain high quality data to evaluate surface water quality trends on farms;
- Help farmers and area citizens learn about the role of agriculture within ecosystems;
- Bring farmers and other community interests together using study results for education.

A retired high school biology teacher monitored this stream on a biweekly basis, 2002-2007. To engage the local community, the volunteer sampler partnered with a local high school ecology teacher to teach students about stream monitoring (Figure 30).

Biotic index

Aquatic macro invertebrate species all react differently to varying levels of sediment, nutrients, and dissolved oxygen. A scoring system was applied that evaluated the variety of macro invertebrates as indicator species that are sensitive, semi-sensitive, semi-tolerant and tolerant to pollutants. The Biotic Index scoring ranges are: 1.0-2.0=poor; 2.1-2.5=fair; 2.6-3.5= good; and 3.6+ =excellent. Biotic Index scores in this stream ranged from 1.8 - 2.3 (poor-fair range).



Figure 25: Sampling locations for Trained Local Sampler

Turbidity

Turbidity, an indication of water clarity, was measured visually using a clear tube (Figure 31). At the stream headwaters (site 1), water clarity was excellent. Downstream water clarity at sites 2-7 was good except for occasional dates when cattle were noted to be in the water or rain or snowmelt runoff entered the stream.

Nitrate / Nitrite

The nitrate levels in the stream were measured on-site, as well as reconfirmed seasonally by lab analysis at UW-Stevens Point. Site 1 and 2 consistently had the highest nitrate levels. This was true regardless of test method. The natural

background nitrate level in Wisconsin groundwater is less than 0.2 mg/L. All stream sampling sites on this farm exceeded that level (Figure 26).

Phosphorus

The phosphorus levels in the stream were analyzed seasonally at UW-Stevens Point. Results show the highest reactive and total P levels at the downstream sites. The USGS recommends total P levels for rivers and streams be less than 0.1 mg/L. The upstream sampling sites on the Heisner farm remained below this level at all times while the two downstream sites approached or exceeded 0.1 mg/L total P (Figure 27).

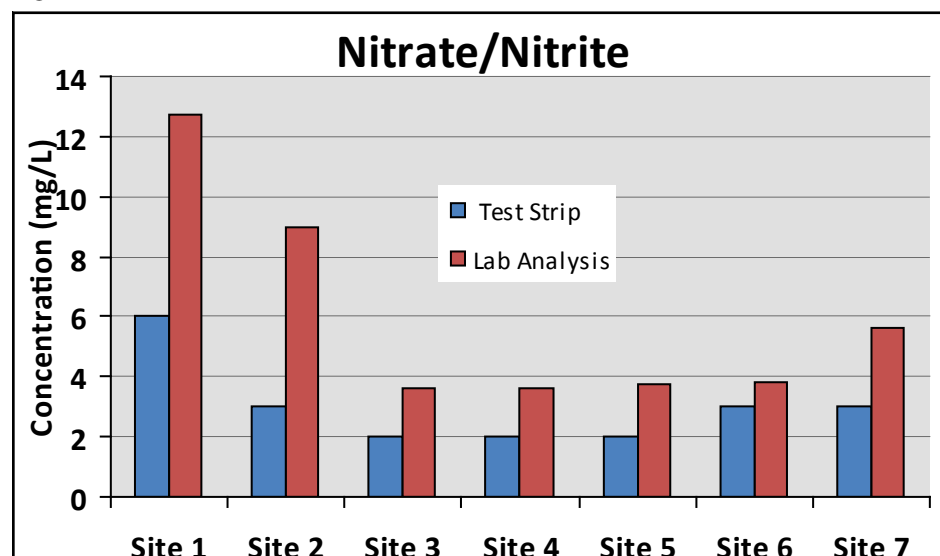


Figure 26: Median nitrate/nitrite test strip and lab analysis (mg/L)

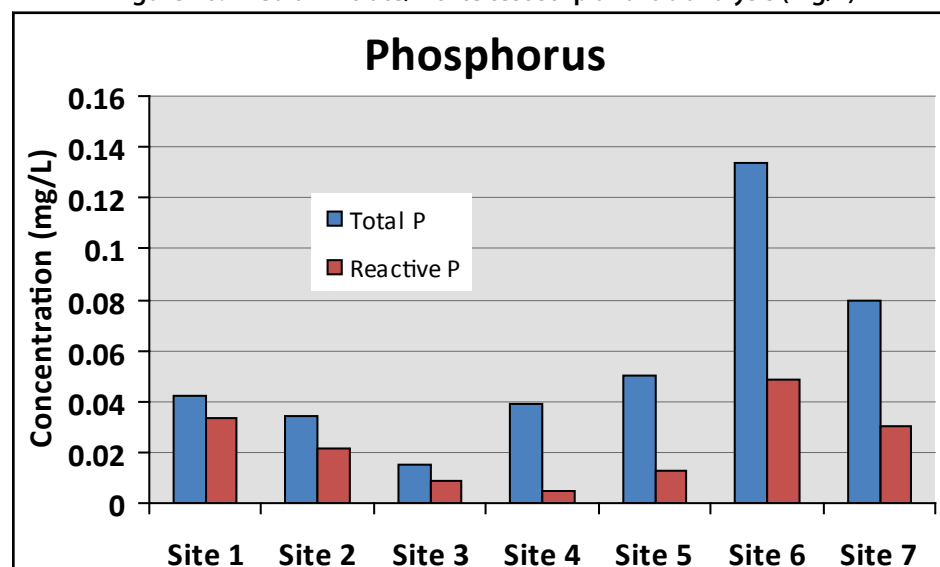


Figure 27: Median total and reactive P (mg/L)

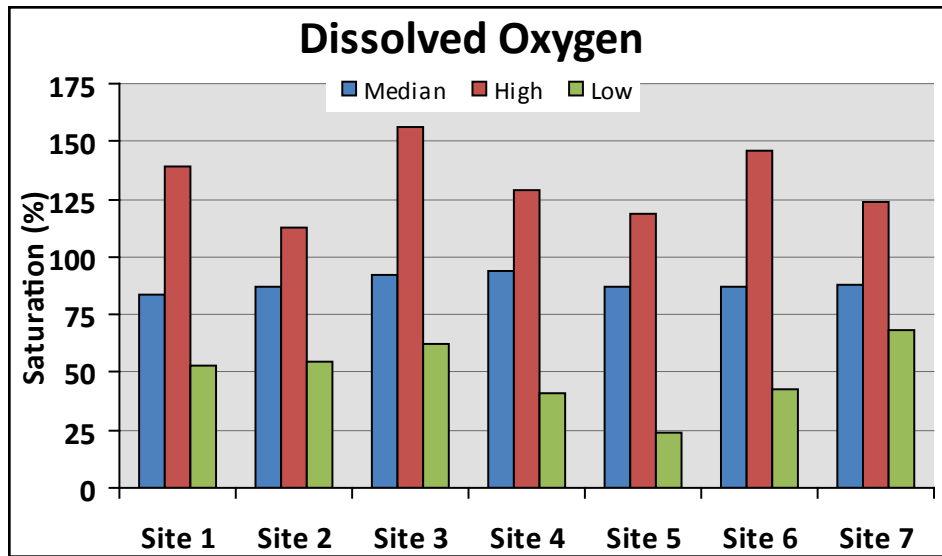


Figure 28: Median, High and Low Dissolved Oxygen (% Saturation)

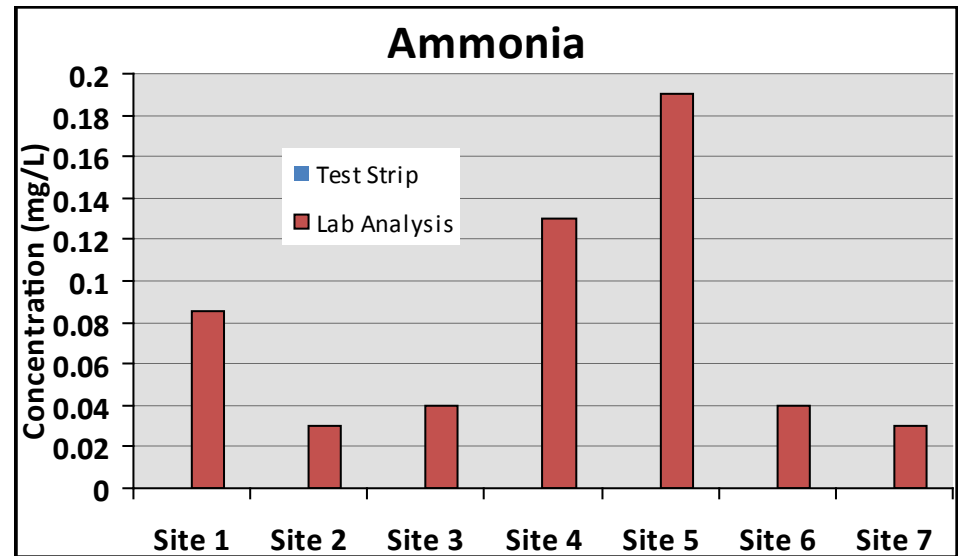


Figure 29: Median Ammonia Test Strip and Lab analysis (mg/L)

Dissolved oxygen

Dissolved oxygen (% saturation) describes the amount of oxygen that can be held in water at a given temperature and pressure. High temperature water holds less oxygen than cooler water. Waters that have between 80 – 120% saturation are considered good quality for aquatic organisms. The variability and ranges in dissolved oxygen levels measured in this stream may limit survival of high quality organisms (Figure 28).

Ammonia

Stream water ammonia levels were not able to be determined in the field due to the precision of the test strips used. Ammonia concentrations were measured through lab analysis by UW-Stevens Point. The presence of ammonia nitrogen within a flowing stream system is typically a result of organic matter decomposition. Ammonia levels that are less than 0.1 mg/L typically have minimal impact on watersheds. Most sites on this farm were

below that level. Sites 4 and 5 had slightly elevated ammonia levels (Figure 29).

Conclusion

The Trained Local Sampler Program on this farm was useful in assessing the biotic health of the stream. The constituent levels reported here indicate that several factors contribute to the stream's limitation in supporting organisms which require the highest water quality ratings for survival.

Concentrations, water volume, loads, and yields each have a role in describing the quality of water leaving agricultural fields that is important to researchers, policy makers, and producers. In order to accurately describe any type of event, both concentration and volume of the water in question are necessary. Furthermore, concentrations vary during a single event; therefore, samples should be taken at different periods throughout the event.



Figure 30: Teaching stream sampling



Figure 31: Conducting turbidity measurement

Impact of Study on Agricultural Management at Heisner Family Dairy, Public Perception, and Future Research Site Criteria

Major lessons learned

Water movement in southwest Wisconsin can be influenced by the layered bedrock geology. This complex water system, with rapid vertical and horizontal flow patterns, makes attributing water quantity / quality sources difficult. Water budget challenges on this farm included: delayed peaks in stream flow relative to rainfall, minimal edge-of-field runoff, and large water contributions to stream flow by springs.

An abnormally low amount of surface water runoff was observed at the edge-of-field site during non-frozen ground periods. Near-surface fractured bedrock may have allowed rapid water infiltration, particularly in thawed soils. Most sediment and nutrient loss was during frozen ground periods.

Farmstead facilities are located close to the stream, and cattle utilize stream water for drinking as they graze nearby paddocks. Over 50% of measured downstream flow volume originated from the farmstead area. Due to complex hydrology and numerous springs, correlating water quality with farmstead

activities was difficult.

This farm is the first core Discovery Farm to have project data analyzed to include stream storm flow versus stream base flow for water budgets and sediment and nutrient content. Analysis and interpretation of these data has helped define future in-stream monitoring study designs.

Changes in agricultural management

Management changes are an important aspect in defining project impact and results. It is important to note farm changes that may affect data during the study. The following changes were noted through this project:

- 1) Initially, cattle were kept on an outdoor bedded pack near the milking facilities. In year two, hoop barns were built for winter housing and season-long drive-by feeding. The new barns removed cattle from the stream corridor during winter months and provided a manure management option to avoid applications during time periods with a high risk for runoff.

- 2) As a grass-based organic dairy, crop and pasture nutrient needs are primarily supplied by manure and rotated legume hay. The hoop barn animal housing and temporary manure storage allowed more manure to be collected and spread on fields where nutrients are best utilized by crops and pasture forage.

- 3) Organic crop production controls weeds through tillage, crop rotations and cover crops. The crop rotation is typically corn (silage or grain), barley as a cover crop, and alfalfa/brome hay. Soybeans have recently been added on some fields, and reduced tillage is used when possible. Small grains and annual forage cover crops are used to reduce soil erosion, contribute green-manure nutrients and reduce weed competition.

Changes in public perception of agriculture

Through this project, educational events connected with a diverse audience and covered a variety of topics, including:

- 1) A farm tour as part of the UW-Extension Dairy Modernization in Iowa County project helped neighbors and others understand agriculture's role to protect water quality while producing commodity products.

- 2) The project incorporated volunteer, on-site stream monitoring. Associated training provided high school students with a learning opportunity focused on stream ecology, farming systems and water quality.

- 3) A local advisory committee was used to inform neighbors, local conservation staff and farm consultants about on-farm research being considered. This allowed local stakeholders to identify agriculture and environmental challenges in their locality and offer input toward the on-farm research and study design.

Changes in research site criteria for future Discovery Farms sites

Experiences from this project have improved our site selection criteria for future monitoring stations:



Figure 32: Solar powered edge-of-field site (H3)



Figure 33: Down stream site (H2) with sheet piling wing walls

Upstream/downstream design. As a result of the location of an upstream pond, raw stream water data may not exhibit “typical” values. The monitoring set-up reduced the influence of the pond on water quantity and quality. Future stream studies that have a feature that significantly changes flow volumes, etc. should utilize a study design to remove the influence of that feature or determine its effect on water quantity and quality.

Close to power and road access. All monitoring sites utilized solar power which was adequate for the edge-of-field site (Figure 32). Solar power was not adequate for in-stream sites, especially in winter. Use direct-wired, AC power when

possible. Both sites were near established field roads. Yet, winter access was difficult, requiring more labor to access the site. If possible, locate monitoring sites close to well established access roads.

Flume size and installation. The flumes selected for monitoring were correctly sized for the basins, enhancing accuracy. Sheet piling was used as wing walls at stream sites to ease water pressure on the flume (Figure 33).

Single field / basin land use. The edge-of-field basin had seven fields; the stream basin included crop fields, grazed paddocks and other land uses. Correlating land management to water quality was difficult at both sites. Basins with single

fields or smaller basins with less multi-land use would enhance data analysis. Complex sites such as farmsteads may need additional monitoring to single out sediment and nutrient sources.

Agronomic records. Multiple program staff collected agronomic data, resulting in inconsistencies and gaps. Consistent and accurate agronomic data collection is paramount to analyzing water quality data.

Daily photographs. Cameras were used at each site to take daily photos, verifying crop stage, weather conditions and land management. Remote cameras are inexpensive and should be utilized when possible.

Evaluate before and during monitoring.

A comprehensive field walk should be performed to look for potential problems both upstream and downstream of perspective monitoring sites. Although not evident before equipment installation, the edge-of-field site likely had surface water disappearing before it reached the flume. Springs existed in the stream basins. An analysis should have been done to trace and age spring water. Evaluate data annually to identify problems / unexpected values; adjust the study design while projects are on-going.

REFERENCE: Carter, J., M. Gotkowitz and M. Anderson. 2011. Field Verification of Stable Perched Groundwater in Layered Bedrock Uplands. Ground Water 49: 383-392.

By Eric Cooley, Aaron Wunderlin, Amber Radatz, Dennis Frame and Kevan Klingberg, UW-Extension/Discovery Farms

The University of Wisconsin - Discovery Farms Program would like to thank Jim, Adam, Cyrus and Ben Heisner and their families; United States Geological Survey – Wisconsin Water Science Center, Wisconsin Milk Marketing Board and our sponsors for their support and cooperation with this important study.

We would like to thank the many local businesses that provide valuable services and products for our farm operation. We especially thank the University of Wisconsin - Extension for assistance in decision making through 33 years of farming in Iowa County. We know that our capital intense occupation of farming comes with risk, some of which is beyond our control, and other parts of that risk we study and learn to manage. As we have networked with local grazing and sustainable agriculture groups, we continue to learn and think outside of the box to incorporate sustainability and profitability into our operation.

We wholeheartedly believe in encouraging and preparing young farmers to follow in our footsteps. Thank you, The Heisner Family Dairy.

University of Wisconsin – Extension
DISCOVERY
F A R M S
University of Wisconsin – Madison

The data presented in this article were provided by the U.S. Geological Survey as part of a cooperative agreement with the UW-Discovery Farms Program.

This project was conducted to gain a better understanding of environmental challenges and opportunities for organic and grass-based dairies in the driftless region of southwestern Wisconsin. On-farm research results are discussed in a set of eleven fact sheets which can be found on the web at: www.uwdiscoveryfarms.org or by calling the UW-Discovery Farms Office at 715-983-5668.