Vermont Phosphorous Innovation Challenge
FINAL REPORT

Ultrafiltration of Dairy Manure for Phosphorus and Pathogen Control

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Introduction

Digested Organics is pleased to provide you with our Final Report on Stage 2 of VPIC as well as our Stage 3 proposal. Our project aimed to demonstrate the efficacy of a stainless steel ultrafiltration (UF) system to concentrate phosphorus, suspended solids, and pathogens in raw and digested dairy manure so these components could be cost effectively transported and processed while maximizing their utility and reducing their environmental impact. To accomplish this, we partnered with three dairy farms, one composting operator, and a composting technology provider. We demonstrated through our trial work that our UF technology can remove greater than 80% (and typically greater than 90%) of the phosphorus in dairy manure and that the concentrated product is an excellent additive for existing composting operations. Our Stage 3 proposal presents our plans for rollout of this technology in a hub-and-spoke model in Vermont.

Our key partners in this project included:

- Dairy Farms (supplied manure for testing):
    - Fosters Brothers Farms (Middlebury, VT)
    - Monument Farms (Weybridge, VT)
    - Dubois Farm (Addison, VT)
- Composting Operator (supplied testing location)
    - Vermont Natural Ag Products (Middlebury, VT)
- Composting Technology Provider (provided composting technology and know-how)
    - Agrilab Technologies (Enosburg Falls, VT)

We were fortunate to work with three dairy farms in Vermont that provided manure and digested manure for testing. This allowed us to demonstrate the efficacy of our technology on numerous different manure samples, as well as the day-to-day variability from testing at the same farm multiple days in a row. Manure samples were brought to Vermont Natural Ag Products (VNAP), where our pilot filtration system was setup and operated by Sam Bagchi with assistance from Matthew Biette. We collected the concentrated material from the UF system and then composted it along with dairy manure fibers (from a screw-press) and wood chips utilizing a static aerated pile technology provided by Agrilab Technologies. We believe concentrating manure phosphorus with onsite UF and then composting it with other commonly composted materials at a centralized location is a cost effective and promising solution for reducing phosphorus contamination in Vermont. By combining our polymer-free concentration technology with the unique composting technology that Agrilab has, we can convert phosphorus in manure into a low-moisture, highly stabilized compost that is differentiated in the marketplace, transportable, and less likely to cause nutrient runoff.

Phosphorus Challenge

Phosphorus is an essential plant nutrient, but it is often used in a manner that leads to contamination of surface waters. This has become widely apparent in Vermont and many other watersheds across the United States. While many industries contribute to this problem, non-point source pollution from farming is certainly a major contributor. Manure has fertilizer value, but it is inherently challenging to use mainly because it is very dilute, resulting in high costs for transportation (and therefore pressure to use it closer to the source) and high likelihood that it will runoff fields, especially on cold or frozen ground and after rain events. For many crops it also does not contain a balanced ratio of N-P-K, meaning farmers may aim to apply enough of one nutrient and inadvertently over-apply another. These concerns related to manure have been known for over 50-years, and while farms are increasingly regulated today and many must follow detailed Nutrient

Management Plans, in many cases this has not been enough to reduce phosphorus loading to sensitive watersheds. Our technology allows manure-producing farms to concentrate the phosphorus and organic nitrogen in manure into ~20-30% of its original volume while creating a transparent liquid (UF permeate or tea-water) that is free of pathogens, suspended solids, and nearly all phosphorus.

The key benefits of our UF technology for farm owners include:

- Reduced hauling and spreading costs, especially for bringing manure nutrients to fields that are further away
- Potential to use lower cost spreading methods for UF permeate (with no suspended solids or pathogens, spreading through irrigation equipment is greatly improved and can be done at lower cost)
- Potential for new revenue source from sale of concentrated fertilizer to composters, fertilizer manufacturers, nearby crop growers, and/or organic producers
- Potential for higher crop yields due to improved agronomic practices that reduce runoff
- Future potential for phosphorus-trading credits (or some monetary incentive to reduce phosphorus in watersheds)

The key benefits of our UF technology for the environment/watershed include:

- Reduced runoff of phosphorus into nearby surface waters due to improved agronomic practices (application timing to maximize uptake, application to soils with lowest phosphorus levels, placement of concentrated fertilizer onto fields is less mobile than more dilute manure)
- Reduction in the spreading of *E. coli* and other pathogens into groundwater and surface bodies
- Reduced soil compaction due to improved spreading practices
- Reduced truck traffic on roads (improved air quality from fewer diesel emissions, community benefits)

Overall, we believe our work to date has shown that this technology is a cost-effective solution for improving water quality in Vermont while concurrently helping farms become more economically sustainable. The data collected and the outreach done (through tours and educational events) has helped educate nearby farmers and others about this technology, which we hope will contribute to increasing its rate of adoption. This work also provides the foundation upon which to build a hub-and-spoke system in which dairy farms use onsite UF to concentrate phosphorus and then transport some or all of it to a central location for processing (which may include composting, blending, drying, packaging, etc.). We believe this approach will ultimately provide the most benefits for the farm, the local economy, and the waterways of Vermont.

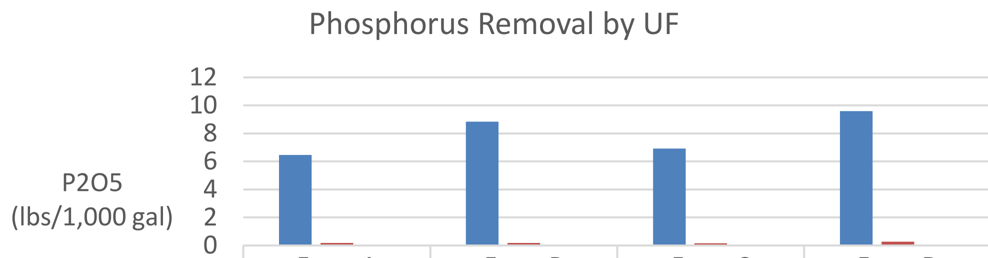
Technology Description:

Digested Organics has pioneered the use of a unique stainless-steel UF system for dairy manure over the last three years of R&D and commercial experience. We have installed a full-scale commercial system at Majestic Crossing Dairy (850 cows) in Sheboygan Falls, WI that has now been operational for over 1,000 days with excellent results. Unlike other technologies that aim to separate phosphorus and suspended solids from dairy manure using chemicals/polymers (e.g. centrifuges, dissolved air flotation, belt filter, etc.), our system uses no chemicals for separation. Instead, liquid manure is pumped through a series of porous stainless steel tubes with an average pore size of 0.02 microns. Particles larger than 0.02 microns remain inside the tube, while water and dissolved solids pass through the wall of the tubes as "UF Permeate" or "tea-water", an amber-colored liquid shown in the picture below. Through testing on dozens of manures, our filtration technology routinely produces UF permeate with 90-95% less phosphorous, 99% fewer total suspended solids, and 99.9% fewer pathogens compared to the raw liquid manure. Typically, 70-80% of the volume of the raw liquid manure can be recovered as UF permeate, with 20-30% recovered as UF concentrate. As a result, phosphorus is highly concentrated into a small volume as a pumpable, high-solids slurry.

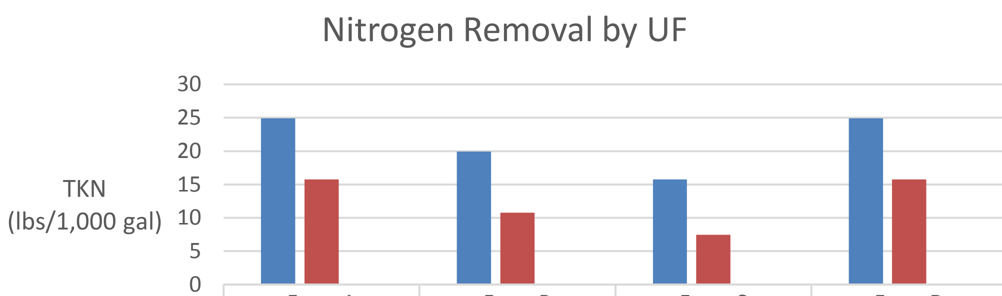
Picture of Ultrafiltration module installed at Majestic Crossing Dairy.

The system is also very simple with few moving parts (just two centrifugal pumps), so it is robust and built to last on a farm for 10-15 years without requiring replacement parts. It also achieves a higher level of phosphorus removal than any other process we are aware of. While adaptive management strategies like buffer strips and cover crops can be helpful, we believe actually separating the phosphorus from the manure and then either applying it very strategically and precisely so as to minimize runoff or collecting it at a centralized composting facility is a more cost effective and guaranteed strategy for water quality improvements. Please see the brochure we submitted on the UF technology for additional information.

Prior to completing this work, we filtered numerous other manures. The graphs below show the concentration of nitrogen and phosphorus in digested manure (the "UF Feed") and UF permeate from four dairy farms in Wisconsin. These data show that **the UF system removes about 97-98% of the phosphorus and 36-52% of the total nitrogen** (mainly the organic fraction), producing a tea-water ideal for irrigation/spreading along with a smaller concentrate product for targeted land application or use in compost/fertilizer manufacturing.



	Farm A	Farm B	Farm C	Farm D
UF Feed	6.47	8.83	6.93	9.59
UF Permeate	0.19	0.17	0.16	0.27
% Reduction	97.1%	98.1%	97.7%	97.2%



	Farm A	Farm B	Farm C	Farm D
UF Feed	24.9	19.92	15.77	24.9
UF Permeate	15.77	10.79	7.47	15.77
% Reduction	36.7%	45.8%	52.6%	36.7%

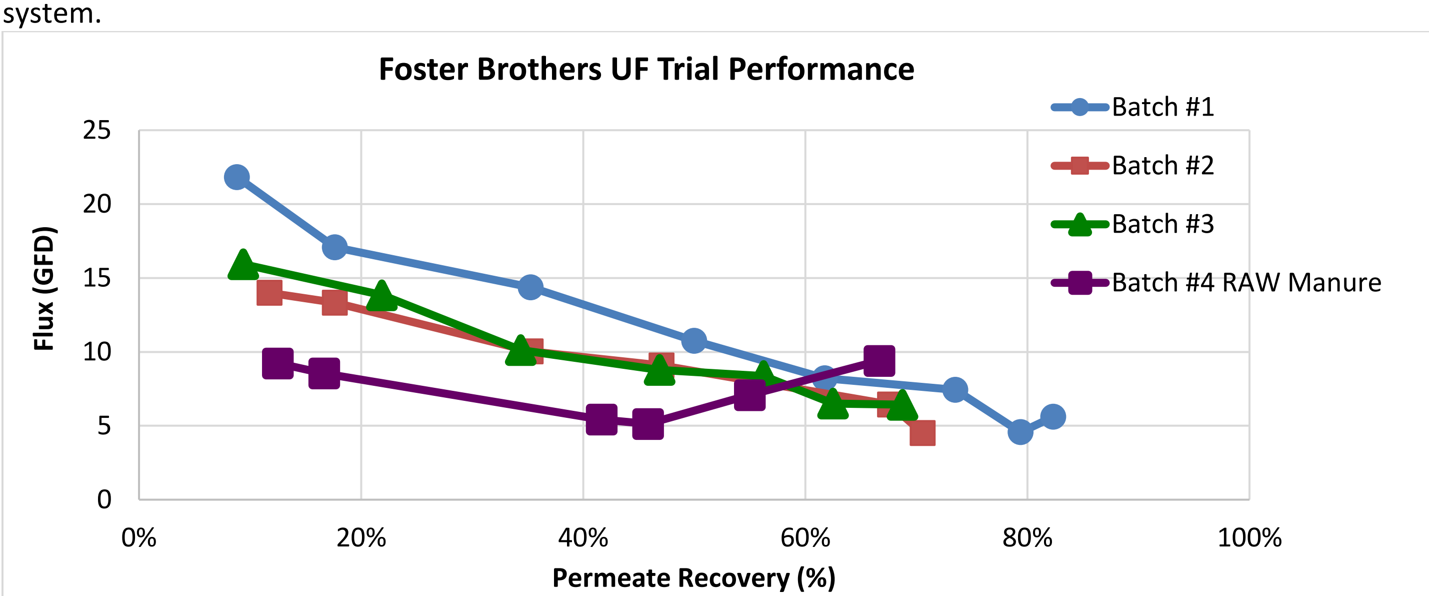
Stage 2 Results: Onsite Ultrafiltration Pilot Testing

Digested Organics assembled a pilot-scale UF system and transported it to Vermont for testing. The unit was setup at Fosters Brothers Farms in Middlebury, VT on May 29, 2019 and used to perform numerous test runs over a period of three weeks. We collected raw manure and lagoon effluent from Fosters Brothers Farms, digested manure directly after a screw press (pressate) as well as from manure lagoons at Monument Farms, and digested manure from the lagoon at Dubois Farm. We performed four UF trials with material from each farm to better understand day-to-day variability. Each trial consisted of filtering 35 gallons of screened manure or digestate, with all relevant performance data from the equipment recorded (e.g., flow rates, pressures, temperature, etc.) and samples collected. Each trial produced a transparent liquid filtrate ideal for field application (70-80% of the initial manure volume) and a concentrated fertilizer that is readily transportable (20-30% of the initial manure volume). Detail results from each farm are described below.

UF Pilot Skid at Fosters Brothers Farms, Middlebury, VT

Fosters Brothers Farms, Middlebury, VT

We ran four UF batches from Foster Brothers Farm that included 3 batches of lagoon manure and 1 batch of raw manure taken directly from the manure collection pit. For lagoon manure, ~75% of the original volume was recovered as filtrate with an average flux of 13-14 GFD (flux defined as the gallons of UF permeate produced per square foot of porous filtration area per day and abbreviated GFD) as shown in the graph below as a function of the permeate recovery. As expected, the raw manure ran at a much lower average flux of 9 GFD and only 67% of the original volume was recovered as filtrate before the material become very thick. This indicates that taking manure from lagoons, which allow some settling and biological treatment to occur, is preferred to increase the speed at which the manure filters and hence reduce the cost of the treatment system.



The UF Feed, Permeate and Concentrate from each batch was analyzed at Midwest Laboratories to determine its composition. As can be seen from the results below, the lagoon manure was about 2.8% total solids and the UF produced a permeate with about 1% total solids that had 80% less phosphorous and 91% less organic N than the initial lagoon manure samples. The UF concentrate was a thickened product with 7.8% total solids. While 80% removal of phosphorus is still high, it is less than we typically see, which may indicate there was some sampling or laboratory error, or that something about the animal diet or lagoon conditions at this farm resulted in higher levels of truly dissolved phosphate (also called reactive phosphate) which was able to pass through the UF tube wall. Higher phosphorus capture rates were found on the other farms.

Analysis of UF Process Streams for Lagoon Manure Batches (showing average of three batches)

Parameter	Unit	UF Feed	UF Permeate	UF Concentrate	Percent Removal
Total solids	mg/L	28,000	10,307	78,000	63%
Ammoniacal Nitrogen	mg/L	867	815	1,167	6%
Organic Nitrogen	mg/L	967	88	2,867	91%
Total Kjeldahl Nitrogen (TKN)	mg/L	1,833	903	4,033	51%
Phosphorus (as P2O5)	mg/L	1,133	228	2,300	80%
Potassium (as K2O)	mg/L	1,733	1,623	2,000	6%
Sulfur	mg/L	400	61	500	85%

Lagoon Manure Sample Collection at Foster Bros

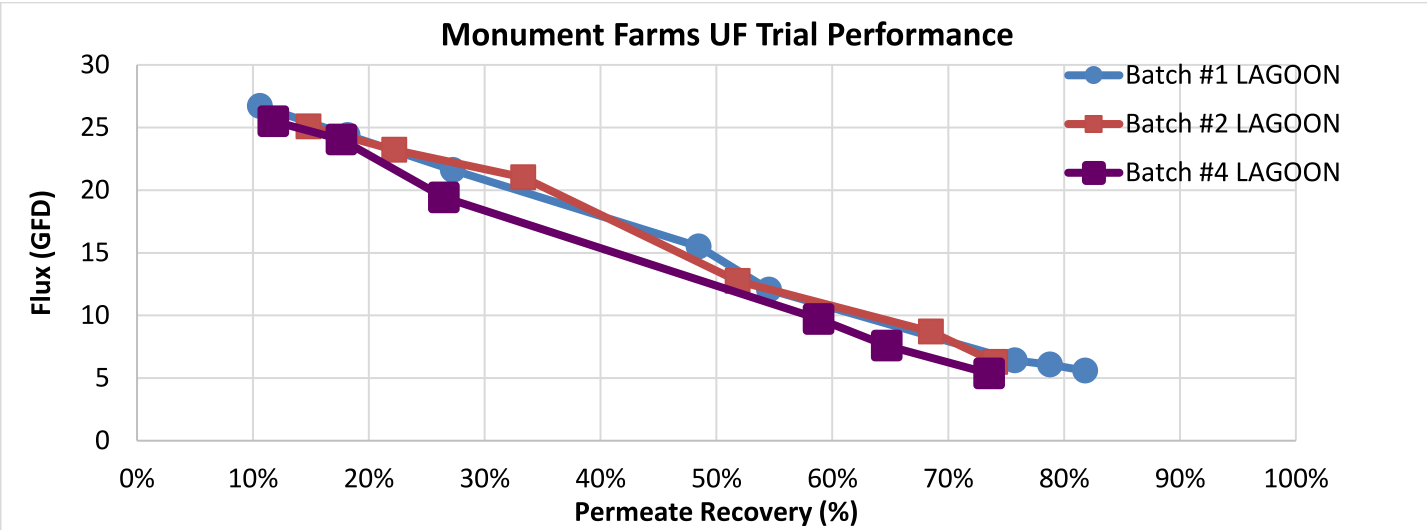
UF Permeate in Viewing Glass

UF Feed, UF Permeate and Concentrate (Foster Bros)

Manure in Feed Tank

Monument Farms, Weybridge, VT

We ran four UF batches from Monument Farms that include 3 batches of lagoon digestate and 1 batch of pressate. For lagoon digestate, ~81% of the original volume was recovered as filtrate with an average flux of 15 GFD as shown in the graph below as a function of the permeate recovery. The data collected at Monument again confirms that lagoon pre-treatment of material is preferred for filtration.



The UF Feed, Permeate and Concentrate from each batch was analyzed at Midwest Laboratories to determine N, P and other element concentrations. As can be seen from the results, the digested manure taken from the lagoon was about 2.6% total solids, the UF permeate was 0.98% total solids, and the concentrate was 7.7% total solids. The UF permeate had 93% less phosphorus and 84% less organic nitrogen compared to the digestate.

Analysis of UF Process Streams for Lagoon Manure Batches (showing average of three batches)

Parameter	Unit	UF Feed	UF Permeate	UF Concentrate	Percent Removal
Total solids	mg/L	26,333	9,860	77,667	63%
Ammoniacal Nitrogen	mg/L	1,367	1,227	1,733	10%
Organic Nitrogen	mg/L	833	130	3,100	84%
Total Kjeldahl nitrogen (TKN)	mg/L	2,200	1,357	4,833	38%
Phosphorus (P2O5)	mg/L	700	48	2,367	93%
Potassium (K2O)	mg/L	2,000	1,747	2,167	13%
Sulfur	mg/L	200	40	733	80%

Manure Lagoon at Monument Farms

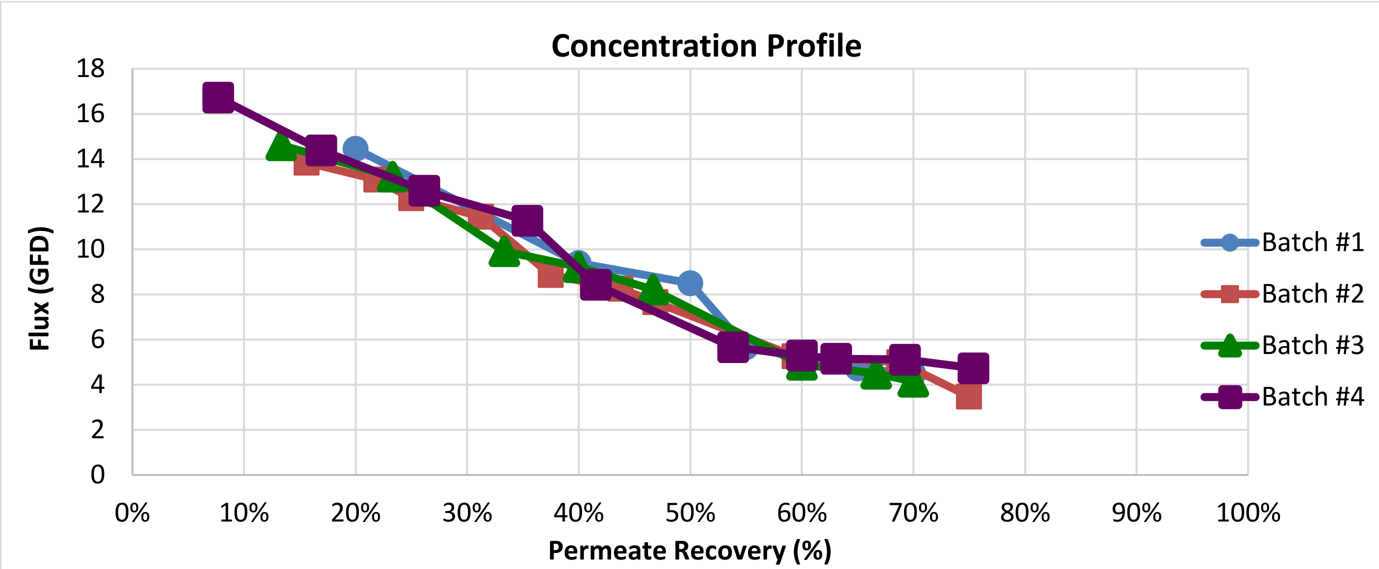
UF Permeate in Viewing Glass

UF Permeate and Concentrate (Monument)

Manure in Feed Tank

The Dubois Farm, Addison, VT

For Dubois Farm, all four UF batches were for lagoon manure (digested) and ~75% of the original volume was recovered as filtrate with an average flux of 11-13 GFD as shown in the graph below as a function of the permeate recovery.



UF Feed, Permeate and Concentrate from each batch was analyzed at Midwest Laboratories to determine its composition. As can be seen from the results below, this material was the thickest we tested (4.7% total solids) so the permeate had correspondingly higher total solids (1.5%). The UF concentrate was 11.3% total solids and contained 98% of the phosphorus.

Analysis of UF Process Streams for Lagoon Manure Batches (showing average of four batches)

Parameter	Unit	UF Feed	UF Permeate	UF Concentrate	Percent Removal
Total solids	mg/L	47,025	15,200	113,750	68%
Ammoniacal Nitrogen	mg/L	2,618	2,448	3,050	6%
Organic Nitrogen	mg/L	1,565	235	4,225	85%
Total Kjeldahl nitrogen (TKN)	mg/L	4,183	2,683	7,275	36%
Phosphorus (P2O5)	mg/L	1,343	28	3,750	98%
Potassium (K2O)	mg/L	3,790	3,740	3,400	1%
Sulfur	mg/L	304	78	725	74%

UF Concentrate and Permeate (DuBois)

Manure in Feed Tank

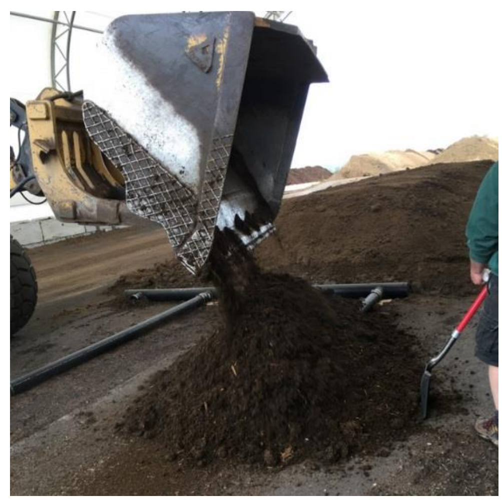
Composting of UF Concentrate

In order to demonstrate how the UF concentrate can be processed into a value-added compost product, we mixed all the concentrates collected from all UF trial runs and combined them into one ~100 gallon lot (~0.5 cubic yards). The analysis of this material is presented in the table below; it was about 10.5% total solids. If labeled as a fertilizer, it would be a 0.6-0.28-0.28 (N-P-K). Another way to describe its nutrient content is that it contained 50.7 lbs/1000 gal total nitrogen, 23.7 lbs/1000 gal P2O5, and 23.7 lbs/1000 gal K2O. Note that phosphorus can be expressed as P2O5 (as it commonly is on manure reports) or as total phosphorus (TP); to convert one pound P2O5 to P, multiply by 0.4364. So **this material contained 10.3 lbs/1000 gal TP**. This material (~0.5 yards) was then mixed into a compost recipe along with 4 yards of separated dairy fibers (70% moisture) and 1 yard of wood chips.

UF Concentrate Analysis used in Composting

Parameter	Unit	UF Feed
Total solids	%	10.5
Ammoniacal Nitrogen	mg/L	2,300
Organic Nitrogen	mg/L	3,700
Total Kjeldahl nitrogen (TKN)	mg/L	6,000
Phosphorus (P2O5)	mg/L	2,800
Potassium (K2O)	mg/L	2,800
Sulfur	mg/L	600

Two compost piles were setup identically. The control pile utilized the same amount of dairy fiber and woodchips but 100 gallons of water was added instead of 100 gallons of UF concentrate. The experimental pile contained the UF concentrate. Both were mixed and setup identically as aerated static piles in collaboration with Agrilab Technologies at VNAP. Brian Jerose oversaw compost mixing and assisted with collection of the samples. Samples were taken from both piles when they were setup on 6/13/19, again on 6/25/19, and finally on 8/2/19. The data from both piles is presented in the table on the next page. Observers noted that the experimental pile with the UF concentrate had no manure odor and handled well.



One additional benefit of composting UF concentrate is that compost piles reach a sufficient temperature to kill pathogens. Since the UF system has a membrane with pores smaller than bacteria and nearly all pathogens, the UF permeate is free of living organisms. Any pathogens concentrated into the UF concentrate will now be destroyed during the composting process, producing a pathogen-free final product. While E. coli contamination of ground water due to manure spreading may not be a large concern in Vermont today, it is in many parts of the country were dairy farms are highly concentrated and it could be a future challenge for communities near dairy farms that this technology readily addresses.

Compost Pile Data

As-Received Analysis	6/13/19		6/25/19		8/2/19			
	Control	Treated	Control	Treated	Control	Treated		Percent Diff. on 8/2
Moisture (%)	66.8	65.7	71.5	64.9	43.8	17.1		61%
Loss on ignition (OM) (%)	27.3	27.1	22.9	25.6	39.2	62.2		59%
Ash (%)	5.5	6.3	4.9	9	16	19.6		23%
Carbon (total) (%)	13.42	13.59	12.36	14.22	19.72	31.8		61%
Carbon nitrogen ratio (C/N)	25:1	21:1	21:1	17:1	21:1	15:1		29%
Conductivity 1:5 dilution (mS/cm)	6.36	7.1	2.44	5.68	3.73	6.43		72%
pH (S.U.)	8.08	8.27	7.93	7.95	8.31	8.23		1%
Nitrogen (total) (%)	0.53	0.64	0.58	0.85	0.94	2.14		128%
Ammonium nitrogen (total) (%)	0.094	0.149	0.001	0.009	0.002	0.003		50%
Nitrate-nitrogen (%)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.		
Phosphorus (total) (%)	0.13	0.19	0.14	0.24	0.23	0.62		170%
Phosphate (P2O5) (%)	0.3	0.44	0.32	0.55	0.53	1.42		168%
Potassium (total) (%)	0.25	0.35	0.23	0.39	0.46	0.99		115%
Potash (K2O) (%)	0.3	0.42	0.28	0.47	0.55	1.19		116%
Sulfur (total) (%)	0.1	0.14	0.1	0.17	0.19	0.42		121%
Sodium (total) (%)	0.07	0.12	0.06	0.13	0.13	0.35		169%
Calcium (total) (%)	1.04	1.37	1.72	1.74	4.15	4.36		5%
Magnesium (total) (%)	0.16	0.23	0.18	0.28	0.65	0.72		11%
Chloride (%)	0.07	0.12	0.08	0.08	0.13	0.38		192%
Manganese (total) (ppm)	59.1	72	65	84.6	125	233		86%
Copper (total) (ppm)	122	201	129	226	196	524		167%
Zinc (total) (ppm)	40.1	90.2	70.1	110	71.4	240		236%
Boron (total) (ppm)	n.d.	105	n.d.	n.d.	n.d.	n.d.		
Iron (total) (ppm)	325	573	544	726	1650	1670		1%

These data reveal that there we substantial differences between the control pile and treated pile, including:

- Both piles started out with nearly the same moisture content, but as the trial progressed, **the treated pile achieved a lower final moisture content**, which may have been due to the accelerated biological activity from the UF concentrate addition. A lower final moisture content is desirable for stability, transportation costs, and efficiency of application. At the final sample event, the treated pile also had substantially more organic matter on an as-received basis.
- **The treated pile had about twice the total nitrogen, three times the total phosphorus, and twice the total potassium as compared to the control pile.** This indicates that the addition of the UF concentrate made a substantial difference in the nutrient content of the final compost product.
- **The treated pile had substantially more trace minerals compared to the control pile**, which may be a selling point as growers are regularly looking for trace mineral products to boost yields.

Mass Balance, Cost Estimates, and Hub-and-Spoke Model:

To better understand how this technology can address phosphorus contamination of Vermont waterways, we have modeled the mass balance for a typical 500-head dairy farm with an expected volume of liquid manure (after screw-pressing) of about 15,000 GPD. Using the average analyses from our work at Monument farms for the liquid manure and UF permeate, and assuming 75% of the liquid manure is recovered as permeate, we have modeled the pounds of nutrients that would be partitioned each day in an ultrafiltration system. To create a mass balance that closes perfectly, we then calculated the nutrient content of the UF concentrate, which was very close to the actual data we collected (the error was less than 10% on each nutrient). Note this liquid manure contained 2.53 lbs/1,000 gal TP.

As shown in the table below, 95% of the pounds of phosphorus in the liquid manure were concentrated into the concentrate product. Of the course of the year, **instead of the farm's 31,755 lbs of P2O5 (or 13,857 lbs of TP) being distributed in 5,475,000 gallons of manure, now nearly all of that phosphorus is in just 1,368,000 gallons of UF concentrate**. This makes the phosphorus easier to manage, more transportable, and less likely to end up in Vermont's waterways.

Estimated Mass Balance of Ultrafiltration System for 500-Head Dairy

Total Solids	Volume (GPD)	Concentration (lbs/1000 gal)	Concentration (%)	Amount (lbs/day)	Mass Percent of UF Feed
Liquid Manure	15,000	220	2.6	3,300	
UF Permeate	11,250	85	1.0	956	29%
UF Concentrate	3,750	625	7.5	2,344	71%
TKN					
Liquid Manure	15,000	18.4	0.2204	276	
UF Permeate	11,250	11.3	0.135	127	46%
UF Concentrate	3,750	40	0.475	149	54%
P2O5					
Liquid Manure	15,000	5.8	0.0695	87	
UF Permeate	11,250	0.40	0.005	5	5%
UF Concentrate	3,750	22	0.3	83	95%
K2O					
Liquid Manure	15,000	16.7	0.2000	251	
UF Permeate	11,250	14.6	0.17	164	66%
UF Concentrate	3,750	23	0.28	86	34%

Some of the opportunities this UF system presents include:

- Precision application of phosphorus-rich UF concentrate to fields owned by the farm, including those further away from the farm that are typically lower in phosphorus (and therefore more likely to absorb the phosphorus instead of letting it runoff)
- Lower-cost irrigation of UF permeate which is low in phosphorus (and devoid of suspended solids and pathogens)
- Sales of the UF concentrate to nearby farmers or other businesses that may benefit from its use
- Transport and sale of the UF concentrate to nearby fertilizer manufacturers and/or composters, who will use it to top-dress piles or boost the nutrient content of their products

Estimated Capital and Operating Costs

Based on the performance data we collected during these trials, if we assume a ~10 GFD average flux rate, then a 500-head farm would require a membrane system with about 950 to 1,150 square feet of stainless steel filtration area to achieve the target volume of permeate generated each day. We manufacture an 18" diameter x 20' long double-pass module that contains 1,048 ft^2, which would be ideal for this application. To achieve the highest efficiencies and simplify the automation and process control, we would recommend a repeat batch process, which would work like this:

- Manure would be pumped from the lagoon or screw-presses into a batch tank
- The UF system would pull manure out of the batch tank, recycling the concentrate back to the tank while the permeate was removed and sent to onsite storage (e.g., lagoon)
- As the system ran and permeate was removed, the volume in the batch tank would go down and the material in the tank would thicken.
- By the end of the day, the tank would be filled with about 25% of the initial manure volume as a thickened slurry, which will then be transferred to a Concentrate Storage Tank to await hauling offsite.
- The tank will then refill with fresh manure and the batch process will repeat. If needed the system will rinse out with water or water mixed with cleaning chemicals to maintain the highest flux possible.

An UF system this size would cost approximately $415,000. Depending on the site, there would be additional costs for tanks, onsite piping, installation, and commissioning. Our intention is to work with the appropriate agencies to certify that the UF is a Best Management Practice (BMP) so participating farms can utilize the Vermont Capital Equipment Assistance Program (CEAP) to acquire this equipment for the purpose of phosphorus concentration.

An UF system this size would require a 5 hp feed pump and 60 hp recirculation pump, which we predict would consume on average 1,025 kWh/day. The table below shows the operating cost for electricity for the UF system at four different prices per kWh. By far, electricity is the biggest operating cost of the system (over 95% of total annual expected operating costs) and finding the lowest cost 3-phase power is ideal to help reduce the operating costs.

UF Electricity Cost	$0.10/kWh	$0.12/kWh	$0.14/kWh	$0.16/kWh
$/day	$102.50	$123.00	$143.50	$164.00
$/year	$37,412.50	$44,895.00	$52,377.50	$59,860.00
$/gal manure	$0.0068	$0.0082	$0.0096	$0.0109
$/gal perm	$0.0091	$0.0109	$0.0128	$0.0146
$/gal concentrate	$0.0273	$0.0328	$0.0383	$0.0437
$/lb TP in UF Concentrate	**$2.85**	**$3.42**	**$3.99**	**$4.56**

These data reveal that at common electric rates in VT, the cost to concentrate a pound of phosphorus from manure is approximately $2.85-$4.60/lb. If we amortize the capital cost of the equipment over a 10-year operating life and assume 36 lbs/day TP concentrated multiplied by 3,650 days, this comes to $3.15/lb phosphorus. If we combine the operating cost range detailed above plus the amortized capital cost and add a

10% contingency, we find that the **all-in cost to concentrate a pound of phosphorus from manure is approximately $6.60-$8.48/lb.** Obviously this will vary from site to site and depend on several conditions, but we believe this provides an accurate range of expected costs that can be used by the evaluation committee and state policy makers to understand the true cost of phosphorus removal from manure.

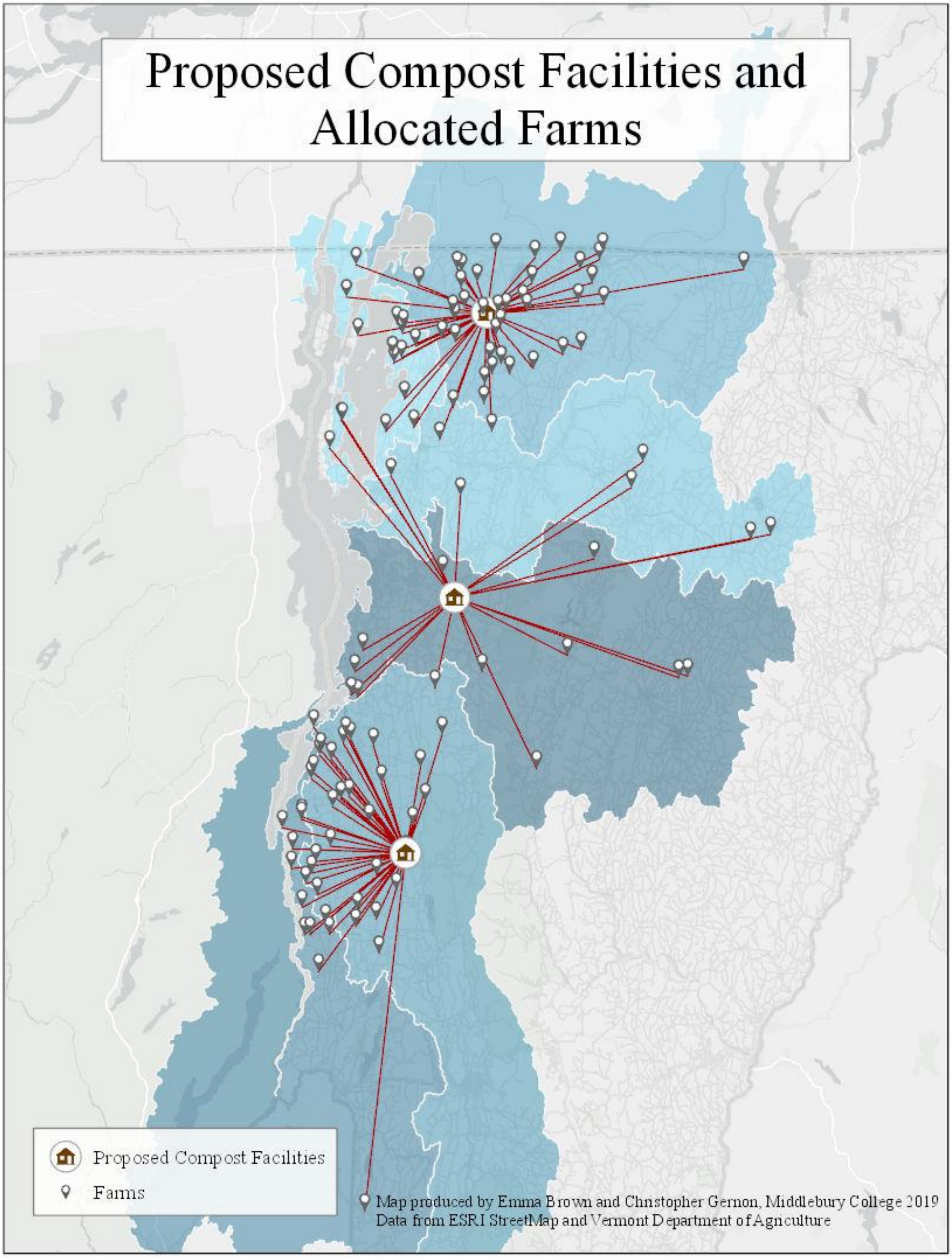
While concentrated manure phosphorus could be used on the farm at which it is generated and still provide substantial watershed and farmer benefits, for this project we focused on the benefits of composting the UF Concentrated in partnership with Agrilab Technologies. This envisions transportation of UF concentrate from satellite farms to the composting hub by 5,000 to 6,000 gal tanker trucks (called to the farm automatically when the level in the UF concentrate tank rises above a setpoint). To better understand how this hub-and-spoke model might work, and to determine some average costs, we used GIS Mapping software in collaboration with a team at Middlebury College.

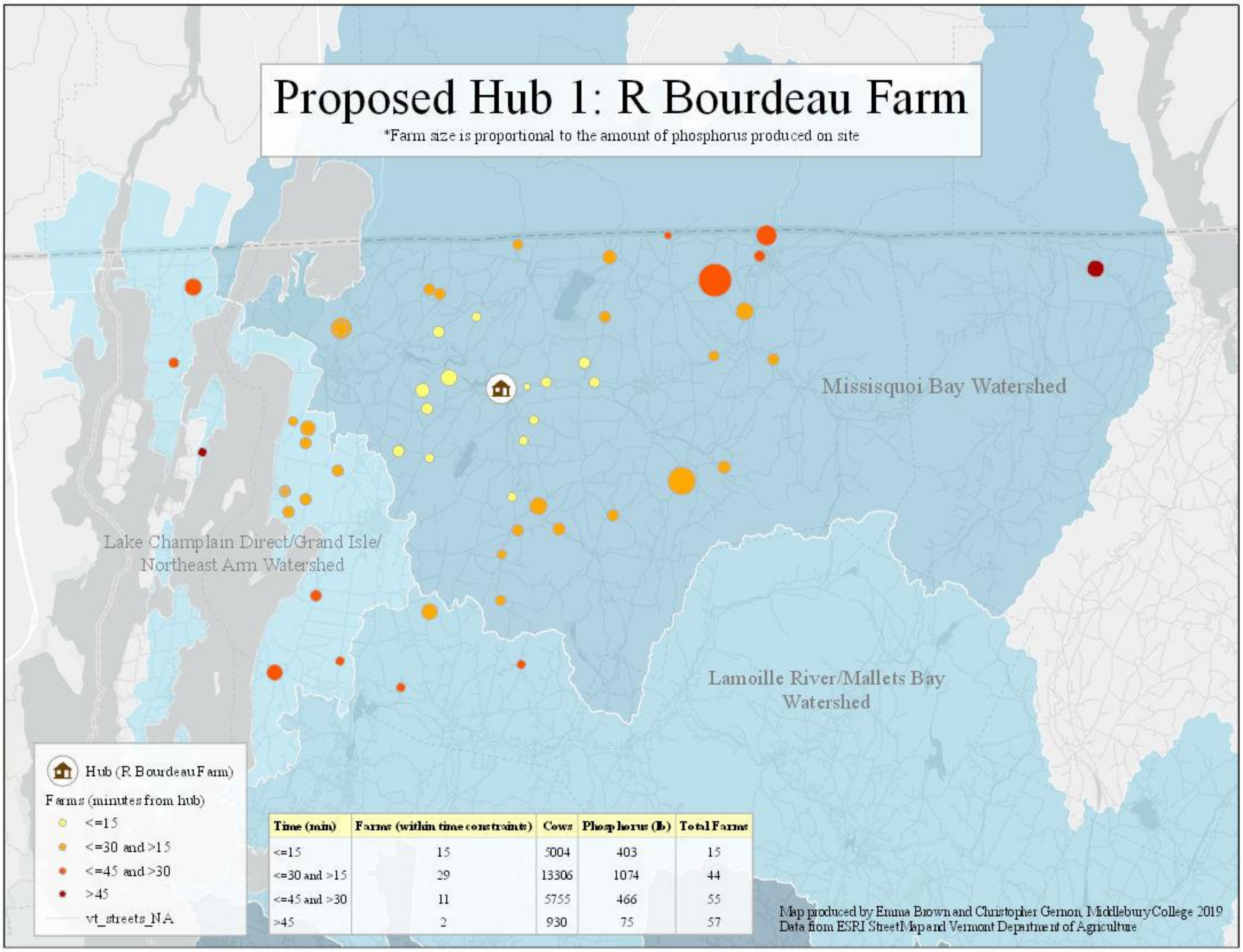
GIS Mapping Exercise to Optimize Hub-and-Spoke Model

To quantify the opportunity for manure filtration in VT as well as the best way to setup the hub-and-spoke model, we enlisted the help of two students and Professor William Hegman from Middlebury College to generate detailed maps of the dairy farms in Vermont and determine the most ideal locations for a hubs. On the following pages you will find our preliminary analysis. Please note that we based our decisions for locating a hub based on the mathematical model, not on the reality of talking to the farm selected and determining if they were interested or a good fit. Hence, this analysis should be used for illustration only, and we plan to refine it in collaboration with Agrilab technologies once actual sites are selected. Nevertheless, we hope you see it as a powerful tool we can use to identify how best to optimize phosphorus capture.

We have provided an overview map showing all three proposed hubs as well as three more detailed maps (one for each hub). The following methodology was employed:

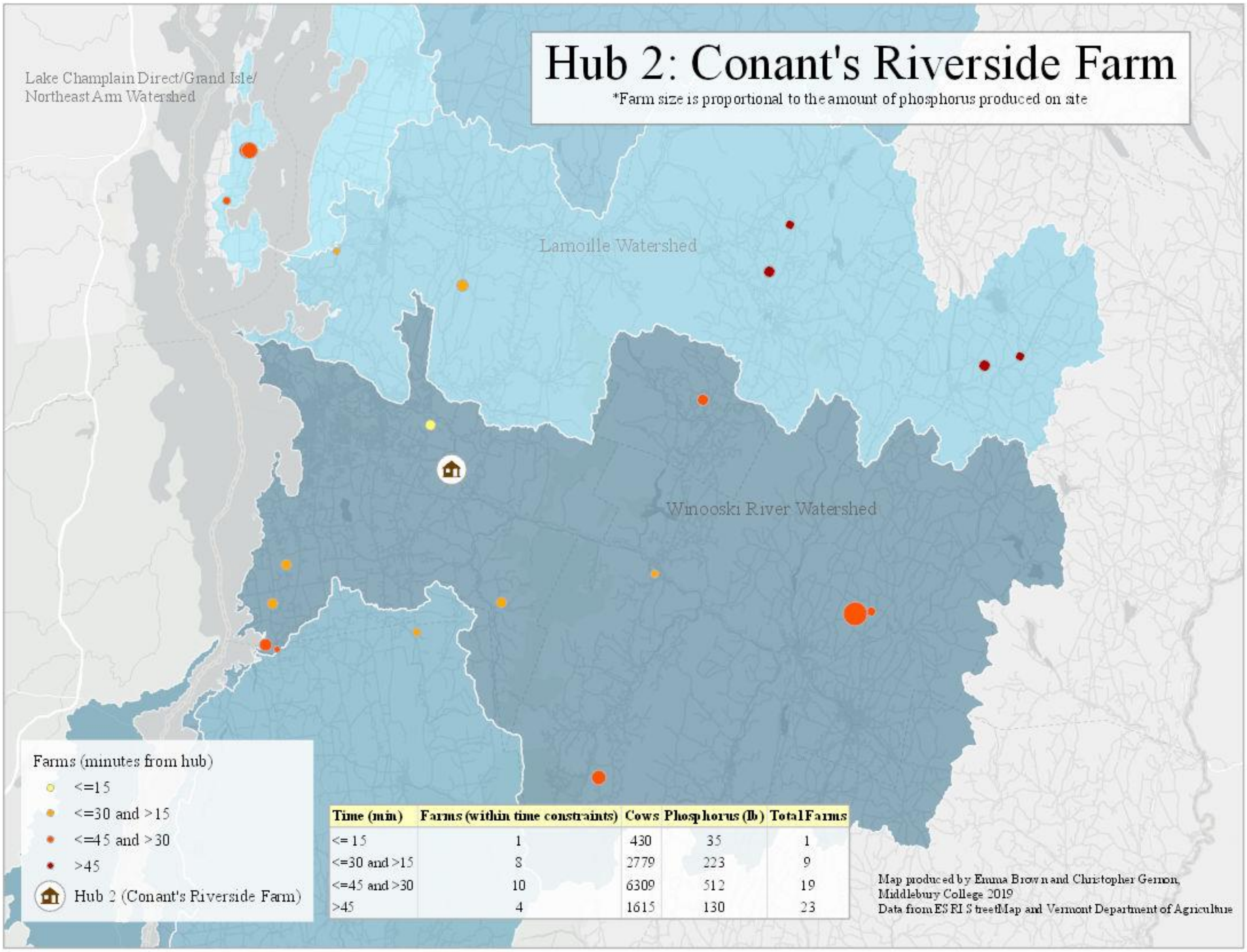
- Dairy farm locations within the Lake Champlain basin were mapped along with pertinent data such as the number of mature dairy cows at each site.
- A GIS network analysis was carried out to identify the optimal location for three composting facilities (each a “hub”) that would minimize the travel time between each farm and the facility while maximizing the amount of phosphorus delivered.
- This analysis assumes:
    - A mature dairy cow produces 27 gallons of liquid manure (from a screw-press either before or after digestion)
    - The liquid manure contains 3 pounds of phosphorus per 1,000 gallons
    - The liquid manure is processed at each farm by a UF system which produces 250 gallons of UF concentrate for every 1000 gallons of liquid manure.
    - The UF concentrate contains 95% of the total pounds of phosphorus from each site.
    - The UF concentrate is stored in a 5,000 gal tank at each farm and a liquid tanker truck is dispatched to each site from the hub whenever the tank fills up.


Proposed Compost Facilities and Allocated Farms
Proposed Compost Facilities
Farms
Map produced by Emma Brown and Christopher Gernon, Middlebury College 2019
Data from ESRI StreetMap and Vermont Department of Agriculture

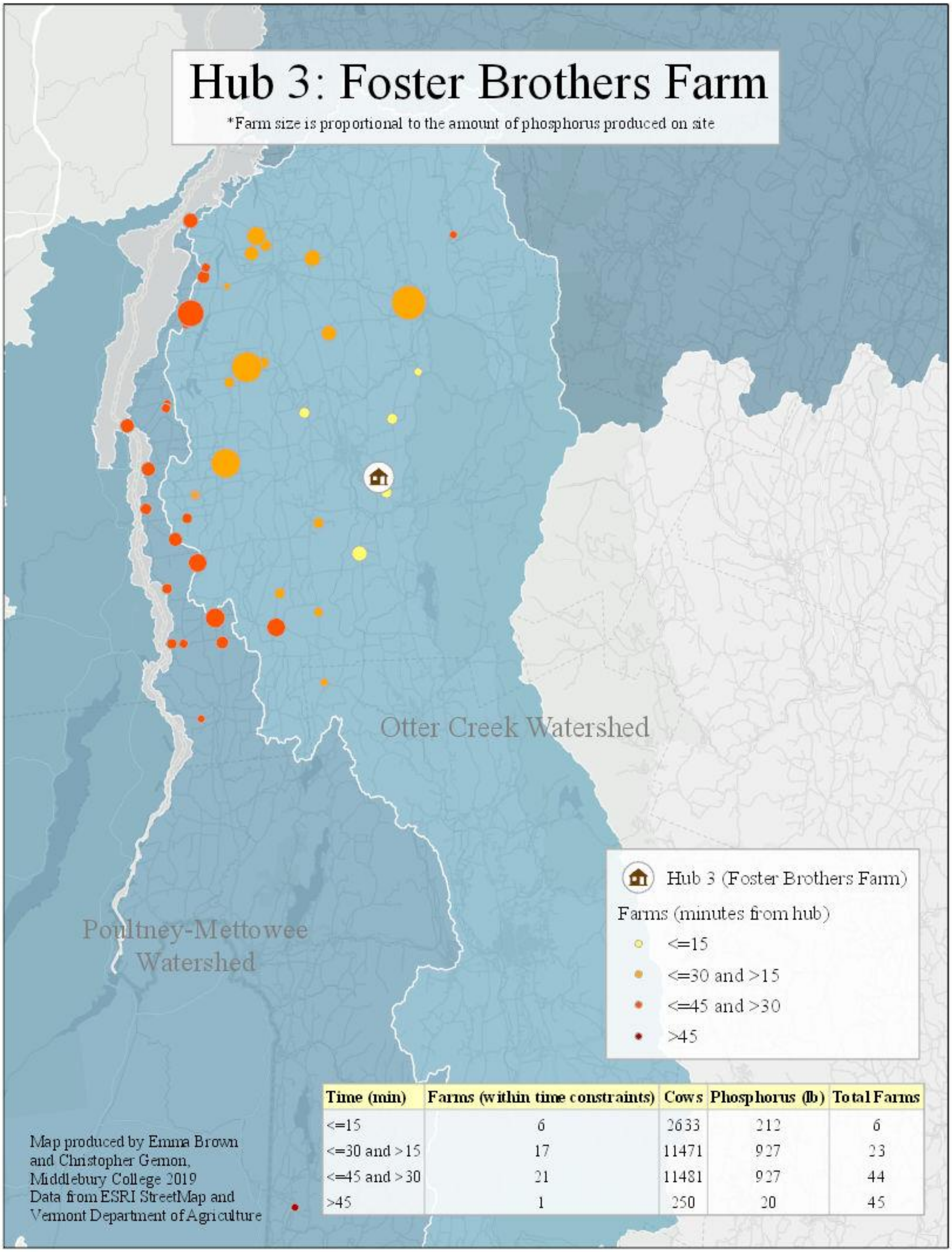

Proposed Hub 1: R Bourdeau Farm
*Farm size is proportional to the amount of phosphorus produced on site
Missisquoi Bay Watershed
Lake Champlain Direct/Grand Isle/ Northeast Arm Watershed
Lamoille River/Mallets Bay Watershed
Hub (R Bourdeau Farm)
Farms (minutes from hub)
<=15
<=30 and >15
<=45 and >30
>45
vt_streets_NA

Time (min)	Farms (within time constraints)	Cows	Phosphorus (lb)	Total Farms
<=15	15	5004	403	15
<=30 and >15	29	13306	1074	44
<=45 and >30	11	5755	466	55
>45	2	930	75	57

Map produced by Emma Brown and Christopher Gernon, Middlebury College 2019
Data from ESRI StreetMap and Vermont Department of Agriculture



Time (min)	Farms (within time constraints)	Cows	Phosphorus (lb)	Total Farms
<= 15	1	430	35	1
<=30 and >15	8	2779	223	9
<=45 and >30	10	6309	512	19
>45	4	1615	130	23



Time (min)	Farms (within time constraints)	Cows	Phosphorus (lb)	Total Farms
<=15	6	2633	212	6
<=30 and >15	17	11471	927	23
<=45 and >30	21	11481	927	44
>45	1	250	20	45

To get a rough idea of the transportation cost for a pound of phosphorus from the farm to each hub, we assumed that initially the hub begins operating with only those sites that are less than 30 minutes away. To be conservative, we assume here that each farm is the maximum time away (i.e. 15 min or 30 min) even though many sites are actually closer. We also assume that the tanker truck can drive 50 miles in an hour on average with a fuel economy of 5 miles/gal, with diesel costing $3.00/gallon. Finally, we assume the trucking company charges an additional $120/hour for the truck.

While each hub has a different number of farms and cows within a 15 min or 30 min radius, **the average cost to haul a pound of phosphorus to the hub is about $1.32/lb at the 15 min radius or $2.63/lb at the 30 min radius.** Altogether, if all three hubs were active with sites within 15 minutes, the state would see 226,500 pounds of phosphorus captured each year. At the 30 minute radius, about 774,000 additional pounds could be captured for a total of about **1,000,000 pounds of phosphorus per year captured from 76 farms**.

Hub 1	Less than 15 min	15 to 30 min
Number of farms	15	29
Number of cows	5,004	13,306
Total TP captured (lbs/year)	140,546	373,722
Total UF Concentrate (gal/year)	12,328,605	32,782,658
Total number of truck trips per year	2,466	6,557
Truck Hours on the Road	1,233	6,557
Annual Cost for Transportation	$184,929	$983,480
Cost per pound of phosphorus	$1.32	$2.63

Hub 2	Less than 15 min	15 to 30 min
Number of farms	1	8
Number of cows	430	2,779
Total phosphorus captured (lbs/year)	12,077	78,053
Total UF Concentrate (gal/year)	1,059,413	6,846,761
Total number of truck trips per year	212	1,369
Truck Hours on the Road	106	1,369
Annual Cost for Transportation	$15,891	$205,403
Cost per pound of phosphorus	$1.32	$2.63

Hub 3	Less than 15 min	15 to 30 min
Number of farms	6	17
Number of cows	2,633	11,471
Total phosphorus captured (lbs/year)	73,952	322,183
Total UF Concentrate (gal/year)	6,487,054	28,261,676
Total number of truck trips per year	1,297	5,652
Truck Hours on the Road	649	5,652
Annual Cost for Transportation	$97,306	$847,850
Cost per pound of phosphorus	$1.32	$2.63

Conclusion of Stage 2

Our Stage 2 work successfully demonstrated how onsite ultrafiltration of dairy manure can be effectively used to concentrate phosphorus into about 25% of the manure's original volume. This concentrate can be cost effectively transported to a composting operation and blended into typical composting recipes to create higher value composts and soil amendment products. Since our process uses no polymers or additives, the concentrated product is certified for use in organic agriculture and will command a higher value in the marketplace. We have estimated the combined capital and operating expenses for ultrafiltration at about \$6.60-\$8.48/lb phosphorus with transportation costs ranging from \$1.32/lb to \$2.63/lb phosphorus at 15 or 30 min respectively from a composting site. Of course, there are other costs involved in composting the material and then distributing it (either in bulk or bagged), but there is also significant value in the final product that will generate revenue for the composting operation.

We believe this technology presents an attractive path forward for the state to remove about 90+% of phosphorus from manure and stabilize it in a compost product. Not only is it cost effective, it is 100% verifiable through routine sampling of the filtration system products. By combining lab analyses with flow meter data on the gallons of concentrate produced, we will know with a high degree of certainty exactly how many pounds of phosphorus have been isolated, transported, and composted. This significantly differentiates this technology from several other current management practices.

Stage 3 Business Plan

The goal of Stage 3 is to implement a single hub-and-spoke model with one composting site in Franklin County and one or two satellite farms running UF systems. Brian Jerose of Agrilabs has identified an ideal composting site at Magnan Brothers Maquam Shore Dairy in St. Albans, VT and there are two nearby farms that have expressed interest in participating (Choiniere Farm and Does Leap Farm). We believe this will be an excellent model for future expansion throughout the state. In this scenario, the two satellite farms would install UF systems and concentrate would be hauled to the composting operation at Magnan Brothers.

Digested Organics has discussed the business model with Agrilabs and there is good synergy between what both companies want: Digested Organics is principally a manufacturer of filtration equipment and has limited experience with composting, whereas Agrilabs has historically been a manufacturer of composting equipment but is now interested in owning and operating a composting facility. With this in mind, we intend to support Agrilab's business development plans as they pursue setting up and operating a composting facility at Magnan Brothers, but Digested Organics is not currently planning on being an owner or investor in the operation. Instead, Digested Organics will provide the satellite farms with filtration equipment, help develop plans for storage and hauling of the concentrate, help identify cost savings to the farm related to onsite ultrafiltration, and support Agrilabs with personnel time and effort (both from CEO Bobby Levine and Digested Organic's engineering staff). Digested Organics is also willing to discount our ultrafiltration equipment at the first two sites as well as supply labor for installation, training, and commissioning free of charge for the project as an in-kind contribution.

Our understanding from Brian is that the initial equipment at Magnan will be sized to process 16,000 cubic yards (CY) per year of raw materials, yielding about half that, or 8,000 CY, of finished compost. Based on the recipe we used in our pilot testing, which involved 0.5 CY of UF concentrate per 5.5 CY total batch size, this size facility could handle approximately 1,450 CY of UF concentrate, which is equivalent to about 290,000 gallons of UF concentrate per year. At roughly 10 lbs/1,000 gal TP in the UF concentrate, this composting facility could process 2,900 lbs of additional manure phosphorus each year, which is equivalent to the phosphorus from about 110 cows if 95% of it was captured year-round. Of course, different recipes could be used to maximize phosphorus capture and a larger farm may wish to send only a fraction of their UF concentrate to the compost site, reserving some for their own use on fields further from the barns.

We believe the final compost from this facility will be highly desirable as an organic-certified product. Due to our limited experience with composting in the Northeast, we refer you here to Brian's proposal which covers the compost market in more depth. It is worthwhile noting that there is also strong interest from VNAP to participate in this project, and it may be that compost from the Magnan Brother's site will be trucked to VNAP in Middlebury for final curing, blending, and bagging. Digested Organics, through its business development consultant Matthew Biette in Middlebury, will support both Agrilabs and VNAP in marketing this unique compost blend.

Digested Organic's near-term plans for Stage 3 include the following:

- Work with Rob Achilles and other agency personnel to get our UF system approved so farmers can apply to cover 90% of the cost through the Vermont Capital Equipment Assistance Program (CEAP).
- Work with farms nearby Magnan Brothers, including those already identified by Brian Jerose, to determine their herd counts, manure volumes, short term and long term business plans, and complete site assessments to determine where best to put the UF system, connect to utilities, etc. This will also allow us to firm up equipment proposals for these sites.
- Work with Brian and the farmers to determine the best business case for the compost site as well as the farmer. If 90% of the capital cost can be covered by CEAP for the UF system, then the biggest concern to the farm will be ongoing operating costs and nutrient management planning to account for nutrients removed from the farm by hauling away the UF concentrate. We hope there is a business model where the farm is paid for the UF concentrate by the composter, and this revenue stream helps cover the operating costs. The farm will have reduced hauling and spreading costs from both the volume of UF concentrate hauled away as well as the opportunity to spread the UF permeate on lands closer to the barns and at higher rates per acre.

Digested Organics has identified two other unique funding sources that we would like to incorporate into this project:

- NativeEnergy offers carbon credits for installation of screw-presses since fiber removal results in fewer methane emissions during lagoon storage of manure. A similar concept applies to ultrafiltration as well as even more volatile solids are removed from lagoon storage and put into an aerobic composting process. We have had preliminary conversations with NativeEnergy's team and they can supply 10-years worth of carbon credits up-front, which typically can cover the cost of a screw-press (~$50,000) and would help with an ultrafiltration system (exact amount to be determined but likely $12,500-$25,000 for a 200-cow dairy).

- Dairy Farmers of America (DFA) is a cooperative that counts about two-thirds of VT dairies as members. They have funding available for pilot programs that help DFA members improve sustainability and they have expressed interest in supporting a project installation in VT on a DFA member farm.

Digested Organics can supply filtration equipment to a site in about 2-3 months, so as soon as Agrilabs finalizes plans for the composting operation and our equipment gets approval for CEAP, we can implement a solution relatively quickly.

We look forward to working with our partners at Agrilabs, the State of Vermont, and Vermont's farmers to help address this critical issue.

Letters of Support

Letter of Support

From: Robert Foster
Foster Brothers Farm
58 Lower Foote Street
Middlebury, VT 05753

To: Robert Levine
Digested Organics
PO Box 3386
Ann Arbor, MI 48103

Re: Vermont Phosphorus Innovation Challenge

Dear Dr. Levine,

We appreciate you reaching out to our facility regarding your innovative ultrafiltration system for dairy manure. As you know, we produce thousands of gallons of liquid manure each day and it is rich in phosphorus, a nutrient we need to help grow our crops. Yet we are also aware that phosphorus can leach from soils and end up in our waterways and lakes, where it can lead to algae growth and impair recreation. As a family who has farmed in this watershed for many years, we would like to help keep our waterways and lakes clean.

We understand that your company produces a stainless-steel ultrafiltration system that can process liquid dairy manure, turning 100 gallons of manure into about 75 gallons of filtrate and 25 gallons of concentrate. Your data suggests that the filtrate contains very low levels of phosphorus (typically <0.3 lbs/1000 gal), as well as no pathogens and no suspended solids. We believe this technology could be used to help remove phosphorus from the majority of our liquid manure while concentrating the phosphorus into a product we can apply to our composting piles. As you are aware, we run a composting facility that is uniquely suited to process this material and help develop formulations appropriate for sales and export. We see this as an opportunity to grow our business and be a centralized processing facility for concentrate produced on farms nearby.

We would be excited to host a demonstration of this technology at our farm and/or composting facility. We understand that this will entail a small trailer-mounted unit being onsite and plugged in and that we would provide liquid manure to this system on a daily basis. We will also accept concentrated manure produced on other farms and show how this can be appropriately composted.

Overall, we are excited to help participate in the Vermont Phosphorus Innovation Challenge and we look forward to working with you.

Sincerely,

Robert Foster

Letter of Support

From: Monument Farms Inc.

To: Robert Levine
Digested Organics
PO Box 3386
Ann Arbor, MI 48103

Re: Vermont Phosphorus Innovation Challenge

Dear Dr. Levine,

We appreciate you reaching out to our farm regarding your innovative ultrafiltration system for dairy manure. As you know, we produce thousands of gallons of liquid manure each day and it is rich in phosphorus, a nutrient we need to help grow our crops. Yet we are also aware that phosphorus can leach from soils and end up in our waterways and lakes, where it can lead to algae growth and impair recreation. As a family who has farmed in this watershed for many years, we would like to help keep our waterways and lakes clean.

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We would be excited to host a demonstration of this technology at our farm. We understand that this will entail a small trailer-mounted unit being onsite and plugged in and that we would provide liquid manure to this system on a daily basis.

Overall we are excited to help participate in the Vermont Phosphorus Innovation Challenge and we look forward to working with you.

Sincerely, Robert W Amos
Monument Farms Inc.

From: Dubois Farm, Inc.
2038 Route 17 E
Addison, VT 05491

To: Robert Levine
Digested Organics
PO Box 3386
Ann Arbor, MI 48103

Re: Vermont Phosphorus Innovation Challenge

Dear Dr. Levine,

We appreciate you reaching out to our farm regarding your innovative ultrafiltration system for dairy manure. As you know, we produce thousands of gallons of liquid manure each day and it is rich in phosphorus, a nutrient we need to help grow our crops. Yet we are also aware that phosphorus can leach from soils and end up in our waterways and lakes, where it can lead to algae growth and impair recreation. As a family who has farmed in this watershed for many years, we would like to help keep our waterways and lakes clean.

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Overall we are excited to help participate in the Vermont Phosphorus Innovation Challenge and we look forward to working with you.

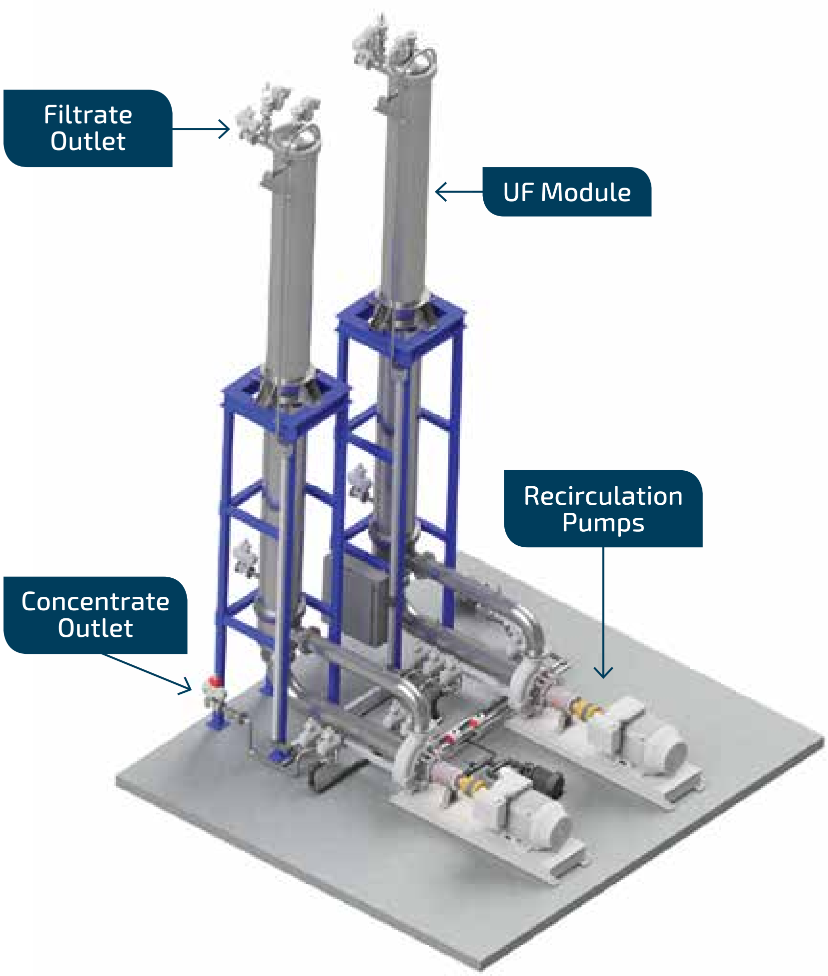
Sincerely, Bernice M. Dubois
Dubois Energy LLC

ULTRAFILTRATION

STAINLESS-STEEL TUBULAR FILTRATION FOR THE MOST DEMANDING APPLICATIONS

HOW UF WORKS

Our stainless-steel ultrafiltration (UF) systems are the toughest on the market today. With a 3/4" internal diameter tubular membrane made of 316L stainless steel, our membranes are abrasion resistant, handle extremes in temperature and pH, and can produce very thick concentrates. If we can pump it, we can filter it!



1. Material to be filtered is pumped into the UF modules by the Feed Pump.

2. The material is recirculated through the tubes in the UF modules by the Recirculation Pumps. Multiple modules can typically arranged in series to provide the required filtration area.

3. Filtrate passes through the wall of the tubes and fills the module shell, exiting at the top of the module. The thickened concentrate exits through a flow control valve.

Technology Highlights

POROUS STAINLESS-STEEL

3/4" tubular membranes with internal titanium dioxide coating are abrasion, temperature, and chemically resistant.

WELDED & BOLTED CONSTRUCTION

ASME code-stamped pressure vessel available in any diameter to accommodate any size project.

DESIGNED TO LAST

Made to last 10-15 years in challenging applications with little downtime, maintenance or repair.

NO INTERNAL MOVING PARTS

Simple, robust system with no internal moving parts and efficient externally mounted pumps.

FLEXIBLE & TUNABLE

Can operate in batch-mode or continuously and be mounted horizontally or vertically.

Ultrafiltration Applications:

- FOOD & BEVERAGE MANUFACTURING
- DISTILLERIES
- BREWERIES
- FARMS
- INDUSTRIAL & MUNICIPAL
- LANDFILLS & COMPOSTERS

Benefits:

- Create highly concentrated or perfectly clarified products with ease
- Combine with aerobic or anaerobic systems to create a Membrane Bioreactor (MBR)
- Fully automated systems require little operator attention
- Handles high temperature, high solids, and oily liquids that most other filters cannot
- Proudly manufactured in the USA

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info@DigestedOrganics.com

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Call to learn how an Ultrafiltration System can help your facility.

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We will pilot test your material at our facility in Michigan or bring our equipment onsite, providing you with a thorough report and proposal for a full-scale system.

IMPLEMENTING *Filtration*

We deliver, install, and commission your new filtration system and teach employees how it works, ensuring it meets your expectations.

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Our filtration equipment will become an integral part of your facility and allows you to streamline and expand your operations while reducing wastewater treatment costs and producing value-added co-products.

VPCI Stage 3 Ultrafiltration System

Key Concepts:

- Vibratory screen to remove fibers in raw or digested dairy manure
- 2-stage feed-and-bleed system for continuous filtration of liquid manure/digestate
- Horizontally-oriented modules on plug-and-play ready skid (easy to roll on castors for relocation)
- Designed to filter the manure from about 100 cows

System Components:

- Vibratory Screen for fiber removal
    - 18" Diameter unit with solid and solids discharge chute
    - Small plastic tank to collect liquid for ultrafiltration
- Stainless Steel UF Filtration Modules (0.02 micron average pore size rating)
    - Eight 4" diameter x 10' long modules with 14 tubes each (304 SS shell, 316L SS tubes)
    - 26.4 ft^2 filtration area per module; 211 ft^2 filtration area total
    - Four modules per stage
- One Stainless UF Feed pump with VFD (5 HP)
- Two Stainless UF Recirculation pumps with VFDs (15 HP)
- Flow meters for UF permeate (2) and UF concentrate (1)
- Pressure sensors for UF module inlet (2), module outlet (2) and UF permeate (1)
- Pump Run-Dry protection level switch (1)
- Automated UF concentrate flow control valve (actuated positioner for continuous flow control)
- Automated ball valves for easy start-up and Clean-In-Place
- Painted steel skid with castors
- NEMA-4X Electrical enclosures
- PLC/HMI for easy operation, data logging, and remote access (internet connection required)

Price: $275,000

- Terms:
    - 50% with sales contract
    - 25% with approval drawings
    - 25% at factory acceptance testing