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REGENIS DAIRY MANURE TREATMENT SYSTEM

Final report to the Washington state Conservation Commission—Distillation Grants Program

PUD #1 of Whatcom County

COLDSTREAM FARMS
Deming, Washington

REGENIS
AN ANDGAR COMPANY

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A. Executive Summary

Coldstream Farms, with an awarded grant of $930,305 from the Washington State Conservation Commission, partnered with Regenis, LLC and the Whatcom County PUD on installation and demonstration of a novel clean water treatment system, scaled to 15 gallons/minute, for treatment of a portion of their manure flow (Figures 1-2). Design outputs of the treatment system were a flocculated fine solids fertilizer (~20% vol., actual 24%); a liquid concentrate fertilizer (~30% vol., actual 33%), and filtered water (~50% vol., actual 43%) suitable for permitted discharge to the South Nooksack. Novel aspects of the system include unique pretreatment equipment and methodology designed to simplify the processing and removal of suspended solids for ultimate treatment in a membrane system designed for a greater degree of operational uptime and reduced maintenance via unique sequencing and cycling between nanofiltration and reverse osmosis membranes. Contracts were completed in June, construction and installation was completed in November; commissioning, operation, and troubleshooting accomplished through April; and testing, evaluation, open-house, and report writing completed in May/June. While operations, fine-tuning, discharge permitting, and evaluation continue, this report represents a final detailing of work and accomplishments for the intensive 1-year grant contract.

Figure 1. Clean Water System

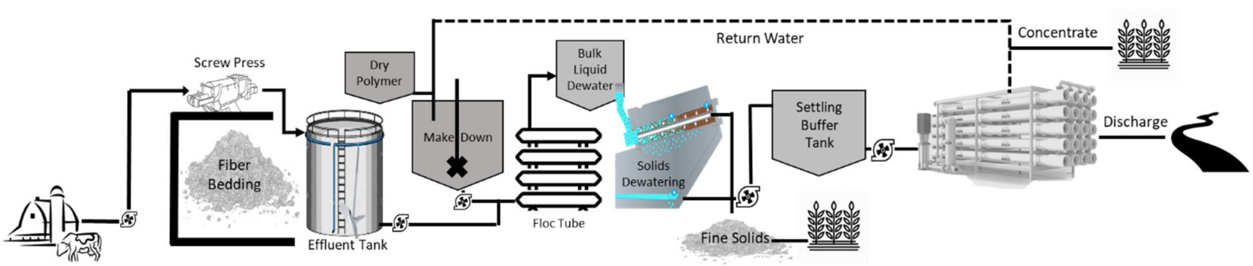

Figure 2. Schematic of the Clean Water System

Key results of the project, after the extended period of troubleshooting and resolution, include the following for the system as it operates into the future. Numbers are specific to the Coldstream Farms project and manure but should be generally applicable to other dairies with similar manure management.

- A scalable, robust, continuous-flow pretreatment system for stand-alone or combined membrane operation that successfully removes 99.5% of total suspended solids (TSS) from a 5% total solids (TS), raw, screened dairy manure. After determination of optimal chemical form/dosing, the system has performed with excellent operational uptime, producing a consistent clarified water (<200 mg/L TSS) with a relatively small footprint and low electrical and maintenance demand.

Figure 3. By-products and Co-Products Produced through the Process

- A stackable, solids co-product, representing 24% and 20% of input flow and mass, with a TS of 18% and density of 1,300 lbs./cubic yard, although evidence suggests that the parameter settings of the dewatering press can be adjusted for sustained production of +20% TS. Fertilizer value of the wet solid, reported as NPK dry values, is 5.3% nitrogen, 3.2% P_2O_5, 1.73% K_2O, 3.27% Ca, 0.67% Mg, and 41% C. A liquid effluent, if utilized without further membrane treatment, that would represent an excellent liquid fertilizer for use in irrigation systems—containing little TSS for clogging of irrigation systems and a fertilizer content of 10, 0.3, and 22 lbs. N, P_2O_5, and K_2O, respectively. Notably, the pretreatment is significant in partitioning nutrients (>95% and >60% of phosphorous and nitrogen (mostly organic) to the denser solids) for greater flexibility and possibly more precise delivery of nutrient to fields.

- A scalable, modular membrane system demonstrating excellent uptime and reduced maintenance, yielding an approximate 55/45 split of input to filtered water and concentrate (Figure 3). Quality of filtered water is excellent, yielding important water quality parameters of <3 mg/L TSS; <150 mg/L total dissolved solids; <1.65 MPN/100 mL of indicator fecal coliform and e-coli pathogens; negligible phosphorous; <40 mg/L BOD; and <30 mg/L ammonia. Refinements continue in further improving these water quality numbers and to finalizing the NPDES permitting for desired discharge and introduction of new water to the river.

- A mass balance accounting of a full treatment system, with discharge of produced water, and recycle of some concentrate for chemical solution preparation during pretreatment, yields an impressive reduction in required manure storage of approximately 75%, not including precipitation accumulated during storage. Production of a liquid concentrate suitable for fertilizer delivery with greater efficiency, containing fertilizer values of 18, 0.5, and 39 lbs./1,000 gallons N, P_2O_5, and K_2O, respectively.

- On a per HWCE basis, pretreatment, membrane and total system capital costs are $291, $1,000, and $1,291 for the 500-HWCE scale; $270, $940, and $1,210 for the 1,000-HWCE scale; and $200, $890, and $1,090 for the 2,500-HWCE scale. Operating costs for the full system, against the 500, 1,000, and 2,500 HWCE scales, are on the order of 2.5-3 cents/gallon input to the system. While the EQIP program is a target for partially offsetting these capital costs, considerable work is still needed in partnership with NRCS, to realize entry of this and other emerging technologies to their existing standards and cost cods. From an O&M perspective, reductions could be realized with improved polymer function and costs, however the primary driver is reduced polymer consumption costs through improved screw press separation, achieving input TS levels lower than the present 5%.

B. The Technology and its Performance

Technology

The technology installed is a combined fine solids separator and clean water membrane system. The first step is a fine solids separator consisting of a flocculant dosing system that feeds a proprietary sequence of equipment designed to efficiently separate the flocculated solids and water while dewatering the solids. The resulting 'tea water' with suspended solids removed, moves to a containerized membrane package comprised of a two-stage protective filter regime, followed by sequential treatment through multi-staged nanofiltration (NF) and then reverse osmosis (RO) membranes. Products from the membrane treatment are a highly purified water, representing approximately 55% of membrane flow, with water quality parameters suitable for discharge and representing new water. Approximately 45% of the membrane flow is rejected by the system, comprised of nearly all the dissolved nutrients and salts that entered the membrane, now in a concentrated form. The technology installed has several unique design aspects that have been developed from years of hard lessons learned earlier in Europe, bringing to the US, a system with a greater track-record—albeit in need of US demonstration for transparent delivery of those capabilities and adaptation to a new market. The demonstration system installed at Coldstream Farms is for 15 gallons per minute, which treats about 1/3rd of their manure flow rate. Specific unique aspects of the technology include:

- A simplified flocculation process, designed to reduce capital and maintenance costs while reliably yielding both a dewatered solid and a high-quality, suspended solids removed water to the membrane system;

- Within the membrane system, a two-pronged approach to minimizing a high salt pressure gradient between the inlet and outlets of the membranes—overcoming a factor that often leads to increasing and elevated pressure draws, which negatively impacts all aspects of reliability, performance and costs.

    - Use of a NF/RO sequence of membranes as opposed to the more common UF/RO sequence.
    - Use of a proprietary approach to recycling of various concentrate streams to further reduce and control potential salt-induced pressure gradients.

Performance

The goal of the pretreatment system is to ensure that a proper level of TSS is removed from the bulk liquid so that downstream membranes are not entrained with solids, negatively impacting their performance, uptime and maintenance. Table 1 and Figure 4 show the TSS removal performance of the pretreatment system, yielding a bulk-liquid that is well suited for downstream treatment. Importantly, once a proper chemical form/dosing is determined to optimally flocculate the solids, the system works continuously and efficiently, although the more consistent the flow and properties of delivered manure are, the better its operation (i.e. manure equalization tanks with mixers, consistent dairy operations). Figure 4 is an image of the pretreated liquid delivered to the membrane system. For added protection to the membranes, additional settling tanks and filters provide an extra level of protection in case of upset or accidental overloading of solids.

Figure 4. Pretreated Manure

Table 1. TSS removal of pretreatment system

	Influent Manure	Pretreated Liquid	% Reduction
TSS (mg/L)	36,500 +/- 2,550	185 +/- 60	99.5%

n= 5 random samples, reported as mean and standard deviation, testing at Exact Scientific, Ferndale WA

Importantly, removal of TSS to the dewatered solids, also carries with it removal of a large percentage of nutrients—partitioning nutrients to more dense solid forms and away from the liquid, for improved nutrient application flexibility and precision as well as potential reduction in required acres and liquid hauling to meet dairy nutrient management plans. Table 2 is a summary of the nutrient partitioning accomplished during pretreatment, as well as the fertilizer properties of the produced, dewatered solid. During testing, the dewatering press was not optimized to its full extent, with more testing on-going towards delivering a drier solid product, in the range of +20% TS.

Table 2. Nutrient partitioning during pretreatment and fertilizer quality of solid

	Influent Manure	Pretreated Liquid	% Partition *
Total Nitrogen (mg N/L)	3,160 +/- 107	1,210 +/- 239	63.5%
Total Phosphorous (mg P/L)	598 +/- 46	16.6 +/- 4.7	97.4%
Total Potassium (mg K/L)	2,960 +/- 218	2,202 +/- 106	29.1%
NPK (% DW)	5.33 N; 3.21 P_2O_5; 1.73 K_2O; 3.27 Ca; 0.67 Mg		

*adjusted for volume losses with reduction as a mass balance; n= 5 random samples, reported as mean and standard deviation, testing at Exact Scientific, Ferndale WA; dewatered solids averaged 18.37 +/- 0.97% TS and density of 1,315 +/- 135 lbs./cubic yard. pH of solids 7.53 +/- 0.23.

After pretreatment, the treated liquid is then sent to the membrane systems to partition the components into concentrate and filtered water fractions. Targets for the project were a 60/40 split during membrane treatment with 60% of influent volume converted to filtered water for desired discharge and 40%, containing, the nutrients, salts and bacteria, as concentrate for use as a dairy liquid fertilizer. Table 3 is a summary of the composition of the respective concentrate and filtered water fractions.

Table 3. Concentrate and filtered water properties

	Concentrate	Filtered Water
TS (%)	2.64 +/- 0.28	---
VS (% DW)	47.5 +/- 4.9	---
TSS (mg/L)	211 +/- 120	<3.0
TDS (mg/L)	---	129.0 +/- 15.56
BOD (mg/L)	---	38.80 +/- 5.66
EC (mmhos/cm)	30.95 +/- 5.45	0.43 +/- 0.01
pH	7.12 +/- 0.20	6.11 +/- 0.37
Total Nitrogen (mg N/L)	2,140 +/- 456	27.95 +/- 3.32
Total Phosphorous (mg P/L)	28.1 +/- 7.9	---
Total Potassium (mg K/L	3,858 +/- 1,162	37.14 +/- 3.31
Fecal Coliform (MPN/100 ml)	5,680,000 +/- 4,750,000	<1.65

n = 5 samples for concentrate and n = 2 samples for filtered water. Reported as mean and standard deviation, testing at Exact Scientific, Ferndale WA. Secondary and heavy metals tested but not reported for brevity, with extremely small to negligible levels of both secondary and heavy metals within the filtered water (exception being boron, at 0.38 +/- 0.14 mg/L but below desired drinking water limits of 0.5 mg/L).

More useful reporting of the concentrate is in typical farm liquid fertilizer values as summarized in Table 4. The liquid concentrate, with extremely low levels of TSS is an excellent product for use within pivot or even drip irrigation systems, with a relatively high concentration of nitrogen, almost all exclusively ammonia in nature.

Table 4. Concentrate fertilizer values

	Nitrogen lbs. N/1,000 gallons	**Phosphorous** lbs. P_2O_5/1,000 gallons	**Potassium** lbs. K_2O/1,000 gallons
Concentrate	17.86	0.54	38.80

n= 5 random samples, reported as mean and standard deviation, testing at Exact Scientific, Ferndale WA

The filtered water continues to undergo testing beyond the date of this report, as fine-tuning of the RO cycling is required to produce a more reliably low content—ammonia and BOD, so that permitted discharge to the Nooksack and its required NPDES permit are completed. With additional improvement in TAN and BOD as well as the already low and desired levels of TSS, turbidity, EC, phosphorous, pathogens, and heavy metals, the outlook is that a successful completion of NPDES permitting can be completed in the future.

Overall performance of the combined pretreatment and dual membrane system is summarized in Table 5, with results near to anticipated design outputs, and importantly, with continued refinement and adjustments to RO cycling, results are expected to further improve.

As can be seen from the table, for every 100 gallons of input to the membrane system, 16.6 gallons is added water/polymer chemicals to conduct the pretreatment, with the remaining volume being the input manure. Outputs of the system on a volumetric basis are solids (24%), concentrate (33%), and water (43%)—with 64%, 97%, and 29% of NPK nutrients partitioning to the solid. Future modifications of the system will make-down the polymer solution not with fresh water but with membrane outputs, significantly reducing this outside volumetric input—essentially making near 100% of the input material manure and recycled product. Under such a scenario and assuming year-round operation at full-scale and the filtered water being approved for discharge, nearly 75% of the baseline manure volume would be diverted from long-term liquid storage, drastically reducing the need/cost for lagoons, hauling costs for application of liquids to distant fields, and mitigating some of the climate, air, and water impacts associated with those costs. Additionally, if produced solids were to be sold and exported outside of the dairy, the gain in 75% liquid storage reduction would also be accompanied with a nearly 65% and +95% reduction in N and P nutrient loading to the dairy, further reducing costs for land and application as required by nutrient management plans.

Table 5. Flow and mass balance for system

	Inputs to System		Outputs to System		
	Manure	**Inputs ****	**Solids**	**Concentrate**	**Water**
Volume	83.4%	16.6%	24.1%	33.3%	42.6%
Wet Weight	83.4%	16.6%	19.5%	35.3%	45.2%
Dry Solids	95.1%	4.9%	76.1%	20.1%	3.8%
Total Nitrogen	100%	---	63.5%	35.9%	0.6%
*Ammonia **	*53.3%*	---	*32.3%*	*89.9%*	*100%*
*Organic **	*46.5%*	---	*67.7%*	*10.1%*	---
Phosphorous**	100%	---	97.4%	2.6%	---
Potassium	100%	---	29.1%	67.5%	3.4%

*Nitrite/nitrate values were considered negligible and not included in calculation. Phosphorous in water considered negligible. **In future design we will replace fresh water used for the make down of the polymer solution with outputs of the membrane treatment, thus significantly reducing the fresh water and % volume contribution from outside material, and positively impacting water/volume balance.

In summary, while time is required to correctly identify suitable chemicals and dosing rates for optimized pretreatment, both the pretreatment and membrane systems have proven to be robust, allowing for continuous plug and play operation, with little required maintenance. In particular, the membranes have operated without fail, thus far requiring no replacement, no reduction in performance regarding split/quality, nor any signs of increased pressure differential due to build-up or blockage on membrane surfaces.

Additional testing is required to convert to recycling of membrane outputs as make-down water for the chemicals as well as optimization of the RO cycling time to achieve required discharge levels for ammonia and BOD.

C. Capital and Operating Costs at Various Scales

Table 6 is a summary of capital costs for the pretreatment, membrane, and complete system equipment at three dairy scales. Cost are for equipment-only, additional costs would be required for installation (i.e. placement, connections, utility upgrades, equalization tanks, buildings, etc.). As can be seen, there is a degree of economies of scale for each of the components, as well as the full system. Total system capital costs are $291, $1,000, and $1,291 for the 500-HWCE scale; $270, $940, and $1,210 for the 1,000-HWCE scale; and $200, $890, and $1,090 for the 2,500-HWCE scale.

Table 6. Capital costs for systems at scales

	500 HWCE [a] 12 GPM at 5% TS	1,000 HWCE [a] 24 GPD at 5% TS	2,500 HWCE [a] 60 GPD at 5% TS
Pretreatment	$145,500	$270,000	$500,000
Membranes	$500,000	$940,000	$2,225,000
Total	$645,500	$1,210,000	$2,725,000

[a] HWCE refers to Holstein wet cow equivalent, with an assumed approximate 35 gallons/HWCE/day manure production rate and a 5% TS after primary solids separation

Table 7 is a summary of the operating costs as determined from operations at the Coldstream demonstration, with adjustments to the various scales in the table. As can be seen from the table, the highest cost category is the polymer chemical cost during pretreatment.

Table 7. Operating costs at various scales

100% Treatment	**500 HWCE [a] 12 GPM at 5% TS**	**1,000 HWCE [a] 24 GPD at 5% TS**	**2,500 HWCE [a] 60 GPD at 5% TS**
Pretreatment			
Chemical [b]	$111,332	$222,665	$556,662
Electrical [c]	$9,198	$12,877	$24,528
Labor [d]	$6,388	$7,665	$9,582
Maintenance [e]	$4,365	$8,100	$15,000
Sub-Total	$134,476	$255,618	$610,562
Ratio ($/ton TSS_r)	140	133	127
Membrane			
Chemical [f]	$1,625	$3,250	$8,125
Electrical [g]	$45,990	$66,686	$128,772
Labor [d]	$3,194	$3,833	$4,791
Maintenance [e]	$15,000	$28,200	$66,750
Sub-Total	$65,809	$101,969	$208,438
Total	$200,285	$357,587	$819,000
Ratio ($/gallon)	$0.032	$0.028	$0.026

[a] HWCE refers to Holstein wet cow equivalent, with an assumed approximate 35 gallons/HWCE/day manure production rate and a 5% TS after primary solids separation
[b] Polymer dosage rate at Coldstream using best performing co-polymer at a dry weight cost of $2.35/lb. Results will vary by dairy, manure, and TS loading—jar tests and pilot testing required to attain preferred type of polymer, concentration and dosing
[c] Electrical pricing assumed to be $0.07/kWh
[d] Demonstration estimates 0.5 and 0.25 hours per day of operational labor for pretreatment and membranes, respectively with an assumed $35/hour wage rate and a scaling rate of 1.2 and 1.5 for larger project sizes
[e] Demonstration allows for estimation of maintenance expenses to be 3% of capital costs to sub-system

Several factors influence this large chemical requirement. First, the manure being treated is raw dairy manure, not digested dairy manure, which has a higher total solids loading (i.e. 5% as compared to say <3%) and contains constituents that are higher in levels of dissolved solids, colloidal solids, and organic chemicals—all which negatively impact polymer reaction for suitable flocculation. For comparison, polymer dosage rates seen at digested dairy manure sites using dissolved air floatation (DAF) pretreatment systems have polymer usage efficiencies on the order of 0.5-1.0%, while the efficiency reported her is approximately 2.2%, which correlates well with the work by Vanotti et al (1999) that demonstrated polymer efficiencies for flocculation of raw swine manure being consistently around that same 2%. Second, many of the manure-based flocculation systems in commercial use target TSS removal rates of ~90%, while this project, requiring a higher degree of clarification for protection of membranes, targeted 99%, with the additional polishing requiring more difficult clarification and correspondingly higher rates of polymer dosage.

Membrane treatment is essentially the cost of operating high-pressure pumps for the pressure-driven separation across the membranes, and as such its costs are directly relatable to electricity and electricity pricing. While it is possible to reduce the number of membranes and recycle flows thereby reducing required horsepower and electrical cost, it is the belief of Regenis that historical operational uptime and cost concerns in membrane use for treatment of raw dairy manure, particularly at this TS loading, are a result of both insufficient pretreatment TSS removal and a tendency to reduce required membranes, membrane sequencing, and recycle. This assumption is in part validated by the very high degree of uptime and smooth operation (no noticeable increase in pressure differential within the membranes nor any increase in electrical consumption across time) witnessed with the demonstration.

In short, to realize high uptime, smooth operation, and consistent production at reduced levels of labor/maintenance, dedication to chemical pretreatment and use of suitable membranes with electrical draw are required. The overriding mechanism to reduce O&M costs is to reduce polymer usage through expanded dairy solids separation that is presently being achieved with the screw press. Any incremental reduction in TS loading to the system with increased solids removal from the screw presses and/or additional equipment will reduce chemical dosing and costs.

D. Co-Products and their Market Potential

The complete system, yields three co-products (solids, concentrate, and filtered water), each of which will be discussed in this section.

Solids

The system produces a nutrient-rich, wet, clay-like solid (Figure 5), with the mentioned dry weight fertilizer values of 5.33 N; 3.21 P_2O_5; 1.73 K_2O; 3.27 Ca; 0.67 Mg. From a nutrient partition perspective, the process and solids represent an efficient means to place the bulk of nutrients (~64% N; 97% P, and 29% K) in a more concentrated form that is more readily stored and transported.

The produced solid is a wet solid that limits its densification for reduction in transportation costs as well as its market value—with as-produced values of approximately 18-20% dry matter (80-82%

Figure 5. Wet Solids after Pretreatment

moisture) and a density in the range of 1,300 lbs./cubic yard. Importantly, value-added sales away from the farm-gate will require additional treatment (i.e. compost, drying, pyrolysis).


Figure 6. Product from Co-Compost with Wood Waste

As an example of upgrading the solids, a trial was completed whereby the produced solids were co-composted (1:1v/v) with stump grind/slash woody biomass, according to a modified compost operation like that conducted for municipal biosolids. The compost produced was of high and intriguing quality, yielding a high-nutrient compost (Figure 6). It holds some potential, like other business plans involving drying/pyrolysis, however, required capital and operating costs for upgrading are potentially burdensome to a potential price point achievable by the product(s). Specific to the compost trial completed, data and subsequent scale-up to farm numbers, while using typical industry turned-row capital and operating costs, shows an approximate need for >$25/cubic yard of finished product for appropriate payback.

Concentrate

A low TSS, liquid rejected by the cycling through the membranes is produced, called the concentrate. It is called concentrate as separation of the filtered water, yields a product with nearly all the chemical and biological constituents within a smaller volume of liquid (Figure 7). As it contains much of the original bacteria within the manure, this product is envisioned as a co-product for use on the farm, with application to its forage crops. Benefits, as compared to existing use of lagoon water as a crop fertilizer, are that the volume of concentrate is considerably lower than that of lagoon water (~75% less) and is of such low solids content and viscosity that it is more easily stored (little to no settling of solids in lagoon), more efficiently pumped or applied through irrigation systems (reduced pump pressure and/or no clogging), and requires less transportation mileage to distant fields.

Figure 7. Concentrate

Results from the demonstration were somewhat surprising to our initial design outputs, as an unexpectedly large percentage of total nitrogen (mostly organic nitrogen in form) was partitioned to the solids. Previous studies with flocculation of dilute and digested dairy manure with dissolved air flotation (DAF) systems showed a roughly 30-40% nitrogen separation. The larger separation is presumed to be the much larger degree of solids separation (98% TSS vs. 90% TSS) that took place in this project, for protection of the membranes. With so much nitrogen separation to the solids, less nitrogen was available for inclusion within the product, making it less concentrated in nitrogen than anticipated. The fertilizer properties of the produced concentrate are approximately 17.86, 0.54, and 38.8 lbs. N, P_2O_5, K_2O per 1,000 gallons, which compares to the baseline nutrient content of lagoon water (post separation, pre-inclusion of outside precipitation) of 14.5, 6.2, and 11.2 lbs. N, P_2O_5, K_2O per 1,000 gallons. Notably, the concentration of nitrogen has increased, although not to a large degree, while the NPK profile has significantly altered, limiting phosphorous to minimal levels.

Filtered Water

A key co-product of the system is a filtered water suitable for discharge to US waterways—with discharge required to complete the desired gains in reduced storage needs. While each region, state, and even stream has its own water quality standards, typical discharge standards have limits on key constituents, which include TSS/turbidity, BOD, pathogens, DO, pH, temperature, heavy metals, and nutrients. The Pacific Northwest with concerns for healthy salmonids has particularly tight standards, which are tailored to each respective stream, and require working with the Department of Ecology on an individual NPDES discharge permit. Table 8 and Figure 8 are summaries of the properties of the filtered water presently produced at the Coldstream demonstration, with a focus on the key constituents described.

Figure 8. NF/RO Filtered Water

Presently, minor modifications to the cycling of the membranes is being completed to tighten some of the concentrations of constituents, allowing for a more consistent production of low-constituent water. Results of these modifications with more complete testing will be on-going after submission of this report. Importantly, it is expected that modifications can improve the concentrations of these constituents, to achieve targeted values or below for pH, BOD, ammonia. Regarding, the physical properties of DO and temperature, the filtered water leaving the membrane will flow through an outfall and underground piping, which should increase DO levels while reducing temperature. After membrane cycling tests are completed, outfall/transport tests will be completed to update data relating to these parameters.

Table 8. NF/RO filtered water

	NF/RO Filtered Water	**Target Values**
TSS (mg/L)	3.0 +/- 1.41	30-45
BOD (mg/L)	38.8 +/- 5.7	30-45
Fecal Coliform (MPN/100 mL)	<1.65 +/- 0.21	<28
Dissolved Oxygen (mg/L)	3.65 +/- 0.03	9.5
pH	6.11 +/- 0.37	6-8
Temperature (^{o} C)	~ 1.5 ^{o} C above ambient	*
Total Ammonia (mg N/L)	27.95 +/- 3.32	<20
Total Nitrate (mg N/L)	<0.01	<0.1
Total Phosphorous (mg P/L)	<0.01	<0.1

n= 2 random samples, reported as mean and standard deviation, testing at Exact Scientific, Ferndale WA. Heavy metals tested were extremely low in concentration, not posing a concern to discharge. * Discharge is desired for the South Nooksack, which is under TMDL for temperature, and discussions continue with Ecology as it relates to target temperatures required.

In summary for discharge, the project team continues to work closely with the Department of Ecology and all other associated agencies as it relates to the technology and securing filtered water suitable for completion of a discharge permit. Work is on-going. The team has settled on and received approval to use an existing outfall to release water to the river and as of 7/1/19 Department of Ecology has our application and application fee and has plans to put the permit out for public comment. The target date for completion of the permit is the end of September 2019. Key lessons learned during the process, that will serve useful for future related projects include:

- Start the process early
- Carefully think about where you are going to put the water physically in the receiving water and ideally find a place where you can physically get water to the river easily and where there is consistent stream flow to get the benefit of a mixing factor.
- While permitting agencies were enjoyable to work with after learning what we are trying to accomplish, it must be understood that any time you are doing something new there is an educational step that needs to take place.

From a value-added perspective, discharge is not just desirous to reduce the dairy's storage requirements but is also important as a potential new source of water, for streams and communities that are struggling with stream health and water quantity issues. To that end, a project goal was to work with project partners on securing agency decisions on definition of the filtered water produced and potentially finding value for its use.

Project outcomes to date are that upon completion of discharge permitting, Whatcom Public Utility District #1 will assume ownership of the water discharged. Whatcom PUD, in discussion with DOE and the Attorney General Office at Washington State, has determined that the water being discharged from the system will be considered new water or foreign flow water. This determination will allow the PUD to make the water available to different uses, including stream flow augmentation, offset for additional exempt wells drilled in the south Fork sub-basin, and utilization by domestic as well as agriculture users downstream. The water quantity work and definitions completed in this Coldstream project is not only a specific benefit to the dairy and its stream and downstream partners but to future projects and possible replication across other areas of the County.

NF Filtered Water

An important side-note is the fact that the membrane system does not have to be a combined sequencing of NF and RO membranes but could instead be just NF. Under such a scenario, the resulting filtered water would not have suitable water quality properties for discharge but would make for an excellent fertigation liquid for human crops and potential valued sales. Table 9 and Figure 9 summarizes the key properties and appearance/turbidity of a filtered water processed through only NF membrane treatment, with its companion concentrate presumably used for dairy forage crops and of a somewhat similar nature to the concentrate already reported. As can be seen, the NF filtered water is negligible in pathogen counts as its filter blocks essentially all bacteria, shunting them to the concentrate, while also being high in nitrogen and other nutrients but with low TSS levels for use within drip or pivot irrigation.

Figure 9. Nanofiltration Water

Table 9. NF filtered water

	NF Filtered Water
TSS (mg/L)	9.75 +/- 4.6
Total Nitrogen (mg N/L)	1,150 +/- 99
% Ammonia (% of total N)	77.5
Total Phosphorous (mg P/L)	0.03 +/- 0.01
Total Potassium (mg K/L)	2,022 +/- 399
Fecal Coliform (MPN/100 mL)	<1.8
NPK Fertilizer (lbs./1,000 gallons)	9.6 N; Negligible P_2O_5; 20.3 K_2O

n= 2 random samples, reported as mean and standard deviation, testing at Exact Scientific, Ferndale WA

Thus, a possible permutation of the system is to filter only to an NF level, utilizing separated solids and NF concentrate on the dairy forage crops, while exporting high ammonia-N water to value-added crop producers such as the berry/potato seed industry. Although under such a scenario NF water would presumably require storage in dedicated lagoons until summer needs by the crops, thus not resolving storage concerns of the dairy, but allowing for gains in nutrient loading/transportation.

E. Assessment of Available Tax Credits and Cost Shares

The primary method for potential assistance with capital costs is NRCS EQIP funds, as the technology has potential for improving several environmental concerns related to climate and water, for which the program is designed. Unfortunately, for technologies such as this to qualify, they need to be an approved approach within existing standards, a process that will require time and effort from all. Hopefully, data from this demonstration can assist NRCS officials in supplying the required information and data to incorporate the technology into the standard(s). With respect to Washington dairies, as well as across the nation, it should be a concerted effort to try to facilitate standard entries, not only for this but other emerging technologies so the program enters the cutting-edge and opens doors to possibilities for farmers. Additional incentives for capital savings include tax credits, which have been recently passed in Washington state for nutrient management technologies.

Two of the most discussed pathways to offset some of the operating expenses are (1) nutrient trading and (2) biofertilizer incentive programs. A key concern with development of nutrient trading programs is that detailed data on actual impact to watershed water quality are required as opposed to simple data on partitioning. For example, while the data from this demonstration can quickly point to the impressive partitioning power of the pretreatment step (97%+ of total phosphorous to the solid stream), it does not supply data on the ultimate fate of that phosphorous upon subsequent field application of the solids and liquids. Thus, to further facilitate use of these technologies within a nutrient trading platform requires engagement of our university agronomists, soil scientists and watershed modelers to supply this missing data. Additionally, creative policy analysts and entrepreneurs are needed to develop robust trading mechanisms so that the program is viable. Unfortunately, these will take time, but it is important that Washington State work on funding/completing the necessary work to move forward. Co-products of these technologies are bio-fertilizers in their semi-raw state needing further treatment and refinement for value-added sales. In order to justify the costs of additional refinement needed for greater market interest, incentive programs for preferred use of bio-fertilizers will be required—again requiring engagement of our policy analysts for development and deployment.

F. Impacts to Soil, Water, Air and Climate

The single pretreatment and combined membrane system each have notable potential positive impacts to soil, water, air and climate. From a pretreatment-only perspective the key result of the treatment is partitioning of nutrients away from the liquid stream and into a denser solid product. A partitioning of nearly 63% of the total nitrogen and 97% of total phosphorous is an impressive result. The key is translating this partitioning into realized improvements to nutrient application to crops as well as reduction in fuel/transport costs to do so—outcomes that should be possible given appropriate adjustment and use of the now varied nutrient profiles. Also, for dairies in uniquely tight nutrient management plans and/or watersheds with specific overloading concerns, additional treatment of the solids to meet value-added criteria (i.e. dry product, PFRP, pelletized/granular, etc.) is of great importance in order to move the solids and its nutrient long-distance, away from the farm and watershed. Improvements that could be seen include:

- Improved management of phosphorous on traditionally overloaded dairy fields, with subsequent reductions in phosphorous losses to waterways, decreasing eutrophication potential
- Improved management of nitrogen, targeting ammonia and organic forms of nitrogen to specific fields, crops and application periods in order to reduce potential overloading of soils and therefore losses to waterways, as well as volatilization to the air.
- Reduced loading of solids to lagoons, thereby decreasing production of greenhouse gases from their anaerobic organic decay within the lagoons, while also reducing fuel usage for lagoon cleaning, pumping, and hauling.

From a membrane perspective, key environmental gains center on the concentration of remaining liquid nutrients into 75% less volume. Less volume requires less storage and all the emission concerns related to anaerobic storage, while discharge of filtered water allowing for less storage, generates new water to streams and communities facing water quantity issues. Lastly, less volume and greater concentration allows for less fuel use during hauling/application, positively impacting climate and air quality.

The system clearly holds potential to make notable gains in numerous soil, water, air and climate concerns, albeit with a need to appropriately adapt application practices to the new products and nutrient profiles. Of concern is not the potential to realize environmental savings, but the ability to install and operate with a positive economic impact—an impact that is realized not primarily through traditional revenue models but through offsets, cost of doing-business, and public/private partnerships in environmental protection.

G. Future Steps

Demonstration and refinement will continue at the Coldstream site, in particular for the noted tasks of (1) evaluating production of higher TS solids via refinement of the dewatering press settings, (2) altering the RO cycling ratios to improve target concentrations of ammonia and BOD for filtered water, (3) use of membrane concentrates as polymer make-down water, (4) and completion of the NPDES permitting process. Looking more forward, the project team will work with state, federal and dairy agencies to assist in moving along adoption of NRCS EQIP standards and cost codes for the technology for assistance in capital cost structures, refining overall system design and costs for next-stage commercial sales, and further exploring technologies and business plans for value-added sales of produced co-products.

H. References

Vanotti, M.B., and Hunt, P.G. (1999). Solids and nutrient removal from flushed swine manure using polyacrylamides. *Transactions of the ASAE, 42(6)*, 1833.