APPLICATION FOR COMPONENT ADDITION TO NRCS

NRCS Practice Standard 629

For Acceptance of Wastewater Aeration Technology

STUDY PREPARED BY:

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Wastewater Aeration Technology

REQUEST

Natural Resources Conservation Service (NRCS) Conservation Practice Standard 629 (CPS 629) for Waste Treatment covers a broad range of methods that alter manure and agricultural waste using 'innovative mechanical, chemical or biological technologies.' The standard includes established and accepted components and importantly, is open to the continued inclusion of new components. This application is for inclusion of a new general component category called "Wastewater Aeration Technology."

BRIEF DESCRIPTION OF COMPONENT CLASS

Wastewater aeration technology introduces aeration into waste treatment ponds to enhance microbial activity, particularly aerobic bacteria responsible for rapid and thorough breakdown of organic matter. By efficiently oxygenating the water, this technology promotes aerobic treatment, creating an environment hostile to anaerobic bacteria and preventing the formation of malodorous compounds like methane, a notable greenhouse gas, and ammonia. The continuous aeration process ensures effective homogenization of pond effluent, facilitating the decomposition of solids while retaining valuable nutrients like nitrogen (N).

DETAILED DESCRIPTION

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) assessments are standard procedures used to measure oxygen consumption levels in wastewater analysis. These assessments are crucial for ensuring compliance with effluent standards, which are regulatory limits set on the levels of pollutants that can be discharged into the environment. Traditional animal waste treatment systems often struggle to meet these effluent standards, leading to the common practice of land application of manure instead of direct discharge. Processes that encourage the growth of either aerobic or anaerobic bacteria can help manage manure organics and oxygen demand. Using anaerobic systems in combination with aerobic systems can further enhance waste treatment by reducing overall COD, decreasing sludge volume, and stabilizing nutrients for safer land application.

Mixing, facilitated by aeration systems, plays a crucial role in this process by keeping organic matter suspended in the wastewater. This suspension helps prevent the formation of a dense sludge layer at the bottom of the pond, ensuring continuous aerobic decomposition and improved nutrient retention. Additionally, aeration aids in the oxidation of dissolved components such as organic acids, phenols, indoles, nitrogen, sulfur compounds, low molecular weight proteins, and other compounds responsible for offensive odorous gases like methane and ammonia. Solids in manure both increase the amount of oxygen needed and escalate the energy required for mixing, therefore solid separation is common prior to the slurry entering the manure storage facility. The degree of oxidation depends on the oxygen provided through the aeration system and the reaction time allowed in the treatment process.

Main Components Aeration Systems [**Figure 1**]:

- *Aeration Mechanism*: The central component responsible for introducing oxygen into the pond environment. This mechanism may vary depending on the specific system, ranging from diffusers to surface aerators.
- *Oxygen Source*: Typically provided using compressors or blowers, which deliver oxygen to the aeration mechanism.
- *Control System*: Allows for the regulation of oxygen levels and other operational parameters to optimize performance and efficiency.

Two main types of mechanical aerators are commonly employed in pond aeration systems: the surface pump and the diffused air system. The surface pump, which floats on the manure storage facility’s surface incorporates air into the liquid profile creating a circulation within the system, ensuring a thorough air-water mixture. Conversely, the diffused air system involves the introduction of air into the pond's bottom, facilitating circulation and elevating oxygen levels across the entire water column, though it is generally less cost-effective than the surface pump. Various factors, including pond size, water depth, and nutrient composition, influence system performance and dictate the selection of an appropriate aeration system, emphasizing the necessity for tailored solutions to meet specific operational needs.

Figure 1. PondLift aeration mechanism.

HOW PROPOSED SYSTEM ACCOMPLISHES PURPOSES OF THE STANDARD

Newtrient (www.newtrient.com), a company sponsored by the dairy industry and dedicated to reducing dairy's environmental footprint in an economically viable manner, has conducted a thorough assessment of various technology classes within manure management, including wastewater aeration systems, and their influence on critical environmental factors, specifically water quality. A comprehensive review, including quantitative analysis, detailed discussion, and references to peer-reviewed literature, has been compiled for wastewater aeration technology and is provided as Appendix A in this submission.

Additionally, this discussion expands upon the findings outlined in Appendix A, focusing on the significant impact of wastewater aeration technology on key environmental indicators such as water quality, and overall environmental sustainability, all of which are relevant to the objectives of Standard 629.

Moreover, Appendix B supplements this discussion by presenting empirical data from a commercial installation at Hood Farms Family Dairy in Paw Paw, MI, illustrating the visual and nutrient profile improvements achieved through the integration of wastewater aeration systems into the broader manure management framework.

Furthermore, Appendix C contains the complete report of the study conducted by Michigan State University. This report focuses on the commercial installation, providing scientific data and insights into the effectiveness of wastewater aeration technology.

Wastewater aeration systems fulfill the objectives outlined in the NRCS Practice Standard 629 Waste Treatment (CPS 629) by catering to its fundamental purposes, which are as follows:

Reducing the nutrient content and organic strength of the liquid stream

By aerating the manure storage facility, aerobic microorganisms thrive with the oxygen necessary for aerobic decomposition, leading to the metabolic breakdown of organic compounds. This aerobic degradation process results in the reduction of organic strength but also promotes the suspension of organic matter within the manure storage facility. This suspension facilitates the stabilization of flushed manure, thereby preventing sedimentation and ensuring the efficient retention and recovery of nitrogen and phosphorus (P).

Reducing odor and gaseous emissions

Aerated manure storage facilities have the potential to diminish the emission of odors, methane, and ammonia by circumventing the anaerobic treatment settings where malodorous compounds are generated. However, there are challenges associated with aerated facilities. Inadequate oxygen levels can result in unstable manure and the proliferation of anaerobic conditions, leading to increased odors. Conversely, excessive oxygen input due to lack of proper calibration may trigger the release of ammonia and other gases. Nitrous oxide emissions from manures can result from both nitrification and denitrification processes, both of which largely depend on the oxygen supply provided by aeration. It is commonly believed that greater oxygen availability inhibits denitrification activity, although nitrification and denitrification can proceed simultaneously under aerobic conditions (Molodovskaya et al. 2008).

Facilitating desirable waste handling and storage

Mechanically aerated manure storage facilities lead to the conversion of complex organic compounds into simpler forms, reducing the overall sludge layer and minimizing odors. Additionally, aeration helps to maintain homogeneity within the slurry, preventing stratification and ensuring uniform distribution of nutrients and organic matter. As a result, aerated slurry storage facilities effectively mitigate potential environmental impacts associated with waste accumulation, such as nutrient runoff and groundwater contamination. Moreover, these manure storage facilities provide a practical solution for long-term waste storage, engineered to efficiently store liquid waste until it can be utilized.

Producing value added byproducts that facilitate manure and waste utilization

Aerated wastewater manure storage facilities offer a couple of by-products or downstream benefits, including:

Nutrient-rich irrigation water: The liquid fraction stored in aerated manure storage facilities contain valuable nutrients such as nitrogen, phosphorus, and potassium (K). This nutrient-rich water can be utilized for irrigation, providing crops with essential nutrients and reducing the need for chemical fertilizers.

For center pivot irrigation systems, waste separation may be needed before the influent enters the waste storage facility to reduce the risk of irrigation nozzles getting clogged.

Recycled flush water: Some dairy farms use manure storage facility water for flushing manure from barns. By repurposing wastewater for flushing, farms can minimize water usage and lower overall water costs.

RANGE OF VOLUMETRIC AND MASS FLOW CAPACITIES AS WELL AS HYDRAULIC RETENTION TIME

The following section provides an overview of key parameters related to the performance of wastewater aeration systems:

> *Volumetric Flow*: The volumetric flow of aerated manure storage facilities is influenced by several key factors. Manure storage facility size and geometry play a significant role, with larger facilities accommodating higher flow rates and variations in geometry affecting flow patterns and residence times. Additionally, the aeration rate is crucial for promoting microbial activity, impacting biological oxygen demand (BOD) and maintaining optimal conditions for waste degradation, directly impacting volumetric flow by enhancing mixing and circulation within the storage facility. Influent composition, including the concentration of solids, nutrients, and organic matter, also affects the viscosity and density of the slurry, thus altering volumetric flow dynamics. Temperature and environmental conditions, such as ambient temperature and sunlight exposure, can further impact microbial activity and biochemical processes within the storage facility, consequently influencing volumetric flow rates. Lastly, the hydraulic loading rate, representing the rate at which waste is introduced into the storage facility, directly influences volumetric flow, highlighting the importance of balancing inflow rate with the manure storage facility's capacity to maintain optimal flow conditions and waste treatment efficiency.
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> In the Hood Farms Family Dairy study, the flow rate of the manure inflow stream

was approximately 300 gallons per minute when the pump was running and 0 gallons per minute when the pump was off.

- *Mass Flow*: When considering the mass flow in aerated manure storage facilities, it's essential to evaluate the amount of organic matter and nutrients entering the system and their subsequent decomposition and removal. The mass flow rate would encompass the inflow of flushed manure into the storage facility, the rate of organic decomposition facilitated by aeration, and the removal of nutrient-rich solids from the manure storage facility. Proper management of mass flow involves ensuring that the organic load entering the manure storage facility does not exceed its capacity for aerobic decomposition, which can lead to the accumulation of excess solids and nutrients. Additionally, efficient aeration systems play a critical role in promoting the breakdown of organic matter and enhancing nutrient removal, contributing to the overall management of mass flow within the manure storage facility system.

  During the Hood Farms Family Dairy CIG trial, the aeration system employed a technology known as Widespreading Induced Surface Exchange (WISE) to facilitate water movement at rates ranging from 20,000 to 30,000 gallons per minute as reported by the manufacturer. This technology focused on continuously directing water flow towards the surface, promoting outward spreading. Surface exchange mechanisms facilitated the ingress of oxygen into the effluent, while the consistent flow pattern ensured thorough mixing throughout the pond. Consequently, the pond environment became enriched with aerobic conditions, creating an inhospitable habitat for anaerobic bacteria.

- *Hydraulic Retention Times (HRT):* Hydraulic retention time is the average duration that wastewater remains in the treatment system, calculated by dividing the volume of the treatment unit by the influent flow rate. It is a crucial parameter for assessing the effectiveness of wastewater treatment and ensuring sufficient contact time between the wastewater and aeration system for adequate oxygenation and microbial activity. Proper consideration of factors such as waste loading rates, manure storage facility volume, and inflow-outflow dynamics is essential for optimizing HRT and treatment efficiency. The HRT influences the degree of organic degradation, nutrient removal, and overall treatment efficiency. Longer HRTs generally result in more thorough treatment but may require larger treatment volumes and longer retention times.

DESIRED FEEDSTOCK CHARACTERISTICS

The ideal feedstock for mechanically aerated slurry ponds typically consists of organic waste materials, with dairy manure from flush systems being a common source. This feedstock often undergoes solid-liquid separation processes prior to entering the aerated manure storage facility to remove coarse solids and excess water, resulting in a more homogeneous and pumpable slurry. After solid-liquid separation, the feedstock typically contains a certain percentage of Total Solids, which may vary depending on the specific separation method used.

The desired feedstock for mechanically aerated slurry ponds ideally contains a balanced combination of organic matter, nutrients, and moisture content to support effective aerobic digestion processes within the manure storage facility. Additionally, the efficiency of solid-liquid separation processes can have a huge impact on the overall performance of the aeration system. The organic matter in the feedstock serves as the primary substrate for microbial activity, facilitating the breakdown of complex organic compounds into simpler forms. Nutrients present in the feedstock, such as nitrogen, phosphorus, and potassium, contribute to the nutrient content of the slurry, enriching it with essential elements for plant growth and soil fertility.

The percentage of Total Solids in the feedstock is an important parameter to consider, as it affects the viscosity, density, and flow characteristics of the slurry within the manure storage facility. While specific Total Solids content may vary depending on operational requirements and treatment objectives, an optimal range is typically targeted to ensure efficient mixing, aeration, and treatment within the manure storage facility. By providing a well-balanced and homogeneous substrate, this feedstock optimizes the performance and effectiveness of the aerated manure storage facility system.

EXPECTED SYSTEM PERFORMANCE

The performance of wastewater aeration systems can be assessed based on various criteria, including oxygen transfer efficiency, mixing effectiveness, nutrient removal rates, and overall system reliability. By maximizing aeration efficiency and promoting favorable conditions for microbial activity, these systems aim to achieve high levels of waste degradation and odor control.

- *Changes in form or handling characteristics*
    - The aeration unit in mechanically aerated wastewater ponds primarily influences the biological and chemical characteristics of the waste stream rather than transforming its physical form. By promoting microbial activity and organic matter decomposition, aeration facilitates the breakdown of complex compounds, resulting in a reduction in slurry viscosity and

    improved pumpability. Additionally, the introduction of oxygen into the slurry promotes homogeneity and prevents stratification, ensuring uniform distribution of nutrients and organic matter throughout the manure storage facility. While the aeration unit may not directly alter the physical consistency of the waste stream, it does have an impact on slurry handling characteristics.

- *Nutrient fate or end use projections*
    - Aeration treatment may enhance nutrient availability in the slurry by promoting organic matter decomposition, nutrient mineralization, and microbial activity. However, the specific effects of aeration on nutrient concentrations would depend on various factors such as aeration intensity, duration, slurry composition, and environmental conditions.
    - The Hood Farms Family Dairy study showed that the installation of the PondLift equipment did not significantly affect nutrient concentrations in the slurry pond. Although direct evidence is lacking, aeration treatment may indirectly affect phosphorus and potassium availability through changes in pH, microbial activity, and organic matter decomposition. Lab analysis of the samples from the Hood Farms Family Dairy did not include an evaluation of the conversion from organic to inorganic nutrient availability. Aeration could influence the solubility and mobility of phosphorus and potassium within the slurry, impacting their concentrations and availability for plant uptake upon land application.
- *Macro-nutrient reductions or transformations*
    - See 'Nutrient fate or end use projections' above.
- *Pathogen reductions or eliminations*
    - Mechanical aeration can impact pathogen reduction through several mechanisms. First, it introduces oxygen into the slurry, creating aerobic conditions that are unfavorable for the survival and proliferation of anaerobic pathogens. Mechanical aeration systems also facilitate mixing and homogenization of the slurry, ensuring even distribution of oxygen and reducing the likelihood of anaerobic "hot spots" where pathogens may persist. Moreover, the breakdown of organic matter promoted by aeration processes contributes to a reduction in pathogen levels, as pathogens often reside within organic material. Increased oxygen levels support the growth of beneficial aerobic microorganisms, which can outcompete and suppress pathogenic bacteria and parasites. While

mechanical aeration alone may not completely eliminate pathogens, it plays a crucial role in reducing pathogen levels in slurry storage facilities.

- *Air emissions*
    - By maintaining optimal oxygen levels and promoting efficient mixing, properly designed and operated aeration systems can significantly reduce the release of gases such as methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), volatile organic compounds (VOCs), and hydrogen sulfide (H_2S). Enhanced aerobic conditions encourage the aerobic decomposition of organic material, minimizing the formation of anaerobic byproducts responsible for odors and harmful emissions. Additionally, strategic aeration management can promote methane oxidation, converting methane into less potent greenhouse gases like carbon dioxide (CO_2).
    - The Hood Farms Family Dairy study data highlights variations in odor and gaseous emissions, particularly ammonia nitrogen levels, influenced by biological activities and seasonal changes. Ammonium nitrogen concentrations exhibited random fluctuations, with higher levels observed during warmer months, likely due to increased biological activity. These fluctuations underscore the challenges in managing odor and gaseous emissions in livestock aerated manure storage facilities. While the installation of PondLift equipment led to significant reductions in solids and organic concentrations, differences in odor-related parameters between inflow and storage samples could not be definitively assessed without air emission samples. Some inferences might be possible based on ammonium-N levels. Further research and monitoring are necessary to comprehensively evaluate strategies for reducing odor and gaseous emissions in livestock aerated manure storage facilities.
- *Water emissions*
    - When properly managed and optimized, aeration systems can indirectly contribute to mitigating water quality concerns. Extending the storage duration of manure is inherently advantageous, as it allows for natural biological processes to break down nitrogen and phosphorus into forms that are readily available for plants. Aeration enhances this process by introducing oxygen and promoting mixing within the slurry manure storage facility. Aeration and mixing facilitate the suspension of organic matter, promoting its stabilization. Consequently, this aids in the retention of nitrogen. By carefully controlling aeration intensity, duration, and timing, farmers can minimize the risk of runoff and leachate generation

while still maintaining effective aerobic conditions for organic matter decomposition and providing readily available nutrients to crops.

PROCESS MONITORING AND CONTROL SYSTEM REQUIRMENTS

For the mechanical aeration of dairy wastewater, specific monitoring and control system requirements may not be applicable depending on the system design and operational needs. However, in cases where monitoring and control are necessary, the integration of sensors and control equipment facilitates efficient operation and optimization of aerobic processes within the slurry manure storage facility.

- *Required monitoring*—Oxygen levels are continuously measured to ensure the maintenance of aerobic conditions, which are crucial for effective organic matter decomposition and nutrient management. Regular monitoring of temperature allows for the optimization of microbial activity, as temperature directly influences the rate of biological processes. Additionally, monitoring pH levels is vital as pH affects microbial activity and nutrient availability, ensuring optimal conditions for biological activity and nutrient transformations.

- *Required control*— Operators of dairy wastewater treatment systems benefit from adjustable controls for aeration intensity and duration, facilitating the regulation of optimal conditions for biological processes. These controls enable operators to tailor aeration parameters based on factors such as temperature, pH, and oxygen levels, ensuring efficient organic matter decomposition. Furthermore, control over mixing equipment is essential for promoting uniform distribution of oxygen and organic matter within the manure storage facility, thereby preventing stratification. By adjusting the speed and pattern of mixing, operators can maintain homogeneous conditions throughout the manure storage facility, maximizing the effectiveness of biological processes and optimizing nutrient management.

- *Equipment included for monitoring*— Dissolved oxygen (DO) sensors continuously monitor oxygen levels within the slurry storage, providing real-time data for process control and optimization. This information enables operators to adjust aeration intensity and duration to maintain aerobic conditions necessary for effective organic matter decomposition. Temperature probes are utilized to measure the temperature of the slurry, allowing operators to optimize microbial activity by adjusting aeration and mixing parameters accordingly. Additionally, pH meters monitor pH levels in the manure storage facility, enabling operators to maintain optimal conditions for biological processes. By integrating these monitoring technologies, operators can effectively manage dairy wastewater treatment systems.

- *Equipment included for controlling*— Aeration system controls, such as control panels or software, provide operators with the capability to adjust aeration intensity, duration, and sequencing based on real-time feedback from monitoring sensors. Similarly, mixing equipment controls, including Variable Frequency Drives (VFDs) or motor controllers, regulate the speed and operation of mixing equipment.

TYPICAL OPERATIONS/MAINTENANCE PLAN WITH MONITORING REQUIREMENTS AND REPLACEMENT SCHEDULE

A typical operations and maintenance plan for wastewater aeration technology includes regular monitoring requirements and a replacement schedule to ensure reliable and efficient operation of the system.

Monitoring Requirements:

1. *Daily Monitoring*: Daily monitoring of dissolved oxygen (DO) levels within the manure storage facility to ensure consistent aerobic conditions for biological processes. Regular checks of aeration system operation and performance to verify proper functioning and address any issues promptly.
2. *Regular Sampling*: Aeration systems do not require regular sampling; however, it may be beneficial to sample manure storage facility water annually for laboratory analysis, including pH, nutrient levels, and microbial activity, to assess treatment effectiveness and identify any deviations from desired parameters.
3. *Sludge Depth Inspection*: Regularly check the depth of the sludge layer within the manure storage facility. Ensure that the volume of accumulated solids is within design parameters. When sludge nears the design volume, remove half of the accumulated solids to maintain optimal storage capacity and prevent overflow.
4. *Data Logging*: Utilize a data acquisition system to continuously log and store monitoring data for analysis and trend identification. Monitor trends in performance indicators over time to identify any deviations or potential issues.

Replacement Schedule:

1. *Wear Parts*: Identify and maintain a schedule for the replacement of worn parts, such as filters, blowers, and aeration harness. Replace these components based on manufacturer recommendations or when signs of wear and deterioration are observed.

2. *Maintenance Intervals*: Schedule regular maintenance intervals for cleaning and inspection of critical components. Follow the manufacturer's guidelines for maintenance tasks and frequency.
3. *Sensor Calibration*: Calibrate monitoring sensors, probes, and meters periodically to ensure accurate measurement and reliable data.

The operations and maintenance plan should be tailored to the aeration model and manufacturer recommendations. Adherence to the plan, along with regular monitoring and timely replacement of worn components, will help maximize the longevity, efficiency, and performance of the aeration system. Regular maintenance and monitoring allow for early detection of potential issues, reducing downtime and improving overall operational reliability.

CHEMICAL INFORMATION

In typical wastewater aeration systems, there are usually no specific chemicals used in the treatment process. However, in certain circumstances, operators may choose to incorporate chemicals such as pH adjustment agents or microbial additives to enhance treatment effectiveness. pH adjustment agents can help maintain optimal pH levels for biological processes, while microbial additives may be utilized to promote the growth of beneficial microorganisms or control the proliferation of harmful pathogens. The decision to use chemicals in the system is often based on specific treatment goals, water quality requirements, and regulatory considerations. When implementing chemical additives, it is essential to follow proper handling, dosing, and storage procedures to minimize environmental impacts and ensure treatment efficiency. Regular monitoring and assessment of chemical usage and their effects on system performance are also important aspects of responsible wastewater management practices.

ESTIMATED INSTALLATION AND OPERATION COST

Industry averages provide a general estimate of the expenses involved in acquiring and installing wastewater aeration technology. It is important to note that these costs are subject to variation based on specific project requirements and market conditions.

Equipment and Installation Capital Costs

The equipment costs include the purchase of the aeration system, and as of 2024, industry averages suggest that the capital cost of an aeration system for an 800-cow dairy farm with coarse solids separation is between $90,000 to $120,000 or more, depending on locality, capacity, design specifications, and additional features. However, startup and installation costs will vary depending on the type of system and vendor.

Operation and Maintenance Costs (O&M)

As of 2024, industry estimates for operation and maintenance costs for a wastewater aeration system on an 800-cow dairy farm with solids separation is between $15,000 - $25,000 annually, depending on involvement and cost of power.

- ***Electrical—*** Electrical consumption constitutes a significant component of operational costs, encompassing the power requirements of the aeration unit, auxiliary equipment, and control systems. The exact electrical costs depend on factors such as equipment size, efficiency, operating hours, local electricity rates, and any energy-saving measures implemented. Typically, monthly electrical costs can range from a few hundred to several thousand dollars, reflecting the system's scale and utilization.

  Pondlift's energy-efficient design—especially its ability to operate at half speed while using only 500 watts of power—reduces energy consumption while maintaining high-performance aeration. The use of Variable Frequency Drives adds an additional layer of control, enabling users to adjust the system to meet specific needs without sacrificing power. Additionally, its compatibility with both 220v single-phase and three-phase power ensures broad applicability and easy integration into existing setups (Newtrient, 2024).

- ***Labor—*** Labor costs associated with aeration systems are generally minimal compared to other operational expenses. While there may be some labor required for basic system monitoring, routine maintenance, and occasional troubleshooting, the time commitment is typically limited. Due to the automated nature of many aeration systems and their relatively simple operation, the need for extensive labor involvement is reduced. In some cases, operators may only need to dedicate a few hours per week to ensure the proper functioning of the system. Additionally, regular manure storage facility maintenance, including sludge removal, is required to maintain benefits.

- ***Maintenance Replacement—*** These costs may include the periodic replacement of components such as motors, blowers, diffusers, and other mechanical parts. The frequency and extent of maintenance requirements vary based on factors such as equipment manufacturer recommendations, operating conditions, and system utilization. Proper budgeting for ongoing maintenance replacement ensures the continued efficiency and reliability of the aeration system, minimizing downtime and preserving treatment effectiveness.

EXAMPLE WARRANTY

The warranty for a wastewater aeration system can vary depending on the manufacturer and the specific terms and conditions of the warranty agreement. Typically, aeration equipment manufacturers provide warranties to cover defects in materials and workmanship for a specified period. As an example, a typical warranty for a wastewater aeration system may include:

1. *Equipment Warranty*: The aeration equipment is warranted against defects in materials and workmanship for a specific period, typically ranging from one to three years. During this period, the manufacturer will repair or replace any components or parts that are found to be defective due to manufacturing issues.
2. *Performance Warranty*: Some manufacturers may offer a performance warranty that guarantees the system's performance and functionality. This warranty ensures that the aeration system will meet or exceed certain performance specifications, as specified in the warranty agreement.
3. *Extended Warranty Options*: Manufacturers may provide the option to purchase extended warranties for additional coverage beyond the standard warranty period. These extended warranties can offer continued protection and peace of mind for an extended duration, typically for an additional cost.

It is important to carefully review the warranty terms and conditions provided by the manufacturer to understand the coverage, exclusions, and any specific requirements or limitations. It is also advisable to maintain proper documentation, such as records of maintenance and service performed, to comply with the warranty requirements.

It is worth noting that warranty coverage may differ between different components or parts of the aeration system, therefore, it is essential to review the warranty details for each specific component included in the system.

Overall, the warranty provides assurance that the aeration system is free from defects and will perform as intended within the specified warranty period. It is recommended to consult with the manufacturer or authorized dealers for the specific warranty information pertaining to the aeration system being considered.

RECOMMENDED RECORD KEEPING

Recommended record-keeping for a mechanically aerated manure storage facility typically includes:

1. *Operational Logs*: Maintain detailed operational logs documenting daily activities such as start-up and shutdown times, length and frequencies of downtimes, aeration system performance, mixing patterns, adjustments made to system settings, and any other observations or issues experienced during operation.

These records help track system performance, identify trends, and provide valuable insight towards troubleshooting and system optimization.

2. *Maintenance Records*: Keep records of all maintenance activities to ensure maintenance is performed properly and regularly to promote the reliability of the wastewater aeration system, including routine inspections, repairs, component replacements, and calibration checks. Note the date, time, nature of the maintenance performed, and any issues identified during inspections.
3. *Monitoring Data*: Record and retain data from monitoring equipment to help identify trends in operation and controls as well as troubleshoot causes for disruptions in operation such as dissolved oxygen (DO) meters, temperature probes, and pH meters. Document measurements taken at regular intervals and any deviations from target values.
4. *Liquid Level Monitoring*: Maintain a weekly record of the liquid levels in the manure storage facility. Tracking these fluctuations is essential due to variable precipitation patterns, which can affect the need for irrigation or field application to prevent overflows or address additional water requirements for optimizing the wastewater aeration system. Rainfall can cause rapid increases in the manure storage facility's volume, while evaporation can lead to gradual decreases.
5. *Chemical Usage and Dosage Records*: If chemicals are used in the manure storage facility (e.g., pH adjustment agents), maintain records of chemical inventory, dosage rates, application frequencies, and any associated safety precautions to ensure proper usage and compliance.
6. *Compliance Documentation*: Keep records related to regulatory compliance, including discharge permits, effluent quality monitoring reports, and any correspondence with regulatory agencies.
7. *Incident Reports*: Document any incidents, accidents, lengths and frequencies of downtimes, or operational disruptions, along with corrective actions taken to address the issues and prevent recurrence.
8. *Training Records*: Maintain records of dates and frequencies of personnel training and certification related to manure storage facility operation, safety protocols, and emergency procedures.
9. *System Design and Operating Manuals*: Keep copies of system design specifications, operating manuals, and manufacturer recommendations for reference purposes.

ALTERNATIVES FOR THE USE OF BYPRODUCTS

The byproducts of a mechanically aerated manure storage facility, such as sludge and treated effluent, can have several alternative uses:

1. *Soil Amendment:* For any sludge remaining in the storage pond, it can be utilized as a soil amendment due to its nutrient-rich content. When properly treated and stabilized, the sludge can improve soil fertility, enhance water retention capacity, and provide essential and readily available nutrients to support plant growth.
2. *Fertilizer Production:* Sludge from the manure storage facility can be processed into organic fertilizers or soil conditioners. Through composting, drying, or other treatment methods, the sludge can be converted into a valuable nutrient source for agricultural or horticultural applications.
3. *Irrigation Water:* Treated effluent from the storage pond can be used for irrigation purposes, providing water for agricultural fields, landscaping, or other non-potable water needs. Aeration of the effluent reduces odors. Furthermore, aerobically treated manure, when knifed in or sprayed onto the soil, exhibits enhanced absorption and assimilation into the soil compared to untreated manure.
4. *Recycled Water:* Aerobically treated effluent from mechanically aerated manure storage facilities on dairy farms can be used for non-potable purposes such as irrigation, barn flushing, dust control, crop cooling, and landscaping, contributing to water conservation and sustainable farm management practices.

Exploring and implementing alternative uses for the byproducts produced from the wastewater aeration technology can further reduce waste while also presenting opportunity for value-added products, additional revenue streams, resource recovery, and energy generation. Suitability for alternative uses of byproducts generated from wastewater aeration systems are dependent on market access and demand, byproduct characteristics, and regulations.

INDEPENDENT VERIFIABLE DATA DEMONSTRATING RESULTS/CREDENTIALS

Appendix A is a summary of the independent review of peer-reviewed and technical data available for this class of technology and is available through Newtrient. The Newtrient work involves an internal peer-review, comprised of ten national experts in the field of manure management, with the final output presently being prepared for external peer-review and publication. While the reference list is not a complete listing of all related peer-reviewed literature it does highlight key references specific to this class of technology and how it relates to key performance indicators within this NRCS Standard 629.

Appendix B is a summary of data obtained during a Newtrient-managed third-party review of a PondLift Aeration system at Hood Farms Family Dairy in Paw Paw, MI. The information was from a 52-week analysis of the system and its performance by Michigan State University—the work has not been peer-reviewed.

Appendix C is the complete Michigan State University report detailing the third-party review at Hood Farms Family Dairy in Paw Paw, MI.

CONTACT INFORMATION—VENDOR

While not a conclusive list, the list below identifies vendors that are active in the application of this class of technology on manure projects within the US.

1. ***Aequion Water Technologies***
   Address: 8220 W Doe Ave. Visalia, CA
   Phone: (800) 385-0713
   Website: https://aequion.com/
   Contact: info@aequion.com
   Company Information: Aequion is on a mission to expedite the adoption of sustainable water practices by the industries responsible for feeding the world population. Inspired by Nikola Tesla's works on magnetic theory, EMOH™ Technology was developed with the intention of remediating aquatic environments, as well as improving irrigation water for food production. Eight years of field research and collaboration among physicists, biochemists, and universities would evolve to EMOH™ Water Treatment Systems and the founding of Aequion Water Technologies.

2. ***Khubeka Construction***
   Address: 4 Laing St., George South, George, Western Cape, South Africa
   Phone: +27 (0)44 874 1584
   Website: https://www.khubeka.co.za/#bioaire
   Contact: admin@khubeka.co.za
   Company Information: Khubeka was founded in 2001 with the intent to design, sell and maintain a high volume, efficient aeration unit to clean and de-sludge wastewater holding ponds. Their aim is to support clients in maintaining environmental compliance, and effectively recycling wastewater produced through their treatment processes.

3. ***Aerator Solutions***
   Address: 11765 N Main St. Roscoe, IL
   Phone: (815) 623-5111
   Website: https://www.aeratorsolutions.com/product-overview/

Contact: sales@aeratorsolutions.com
Company Information: A leader in aeration technology, Aerator Solutions is a provider of top-quality aerators and mixers for industrial, municipal, and agricultural wastewater treatment operations. Known all over the world for their history of effective technology, they believe it all begins with aerator design. Their original aerator, which is now known as the EcoJet™ aerator, was developed and introduced in 1963. Throughout the past fifty years, competitors have copied this technology but have never duplicated or surpassed its effective productivity. Recognized worldwide for service and expertise in wastewater treatment, Aerator Solutions is the sought-out resource for agricultural, industrial, and municipal wastewater treatment equipment expertise. They assist in design, planning, and implementation of their products to meet your process requirements.

4. ***Newterra (Aeration Industries)***
Address: 1555 Coraopolis Heights Rd. Suite 4100, Coraopolis, PA
Phone: (724) 703-3020
Website: https://www.aireo2.com/
Contact: aii@aero2.com
Company Information: Aeration Industries International, now Newterra, has the expertise and aeration equipment to provide a full range of wastewater treatment solutions to optimize municipal and industrial wastewater treatment applications; from process water supply to wastewater treatment, sludge management to produced water return. Newterra also offers customized pond designs to support oxygen dispersion for aquaculture farms. Newterra combines patented technologies with engineering expertise to develop complete and customized water treatment solutions.

5. ***Dairypower***
Address: Unit 4 Block 11000, Blarney Business Park Blarney, Co. Cork T23 P237, Ireland
Phone: +1 226 962 3875
Website: https://www.dairypower.com/
Contact: info@dairypower.com
Company Information: Dairypower Equipment is a leading Irish designer and manufacturer of high-quality agricultural manure handling equipment. Specializing in manure management solutions for cattle, hogs, and poultry, Dairypower exports their systems to over 30 countries Worldwide. They are

passionate about what they do, continuously looking at ways to improve and develop products and are committed to helping the future of today's farmers.

6. ***Wastewater Compliance Systems***
   Address: 333 E. Main St. #367, Lehi, UT
   Phone: (888) 232-9111
   Website: https://wastewater-compliance-systems.com/
   Contact: Wade@WCS-Utah.com
   Company Information: Wastewater Compliance Systems, Inc. (WCS) is a provider of submerged bio-reactors used to enhance the biological activity of treatment systems in order to reduce ammonia, BOD and TSS concentrations. WCS' goal is to help communities comply with state and federal environmental regulations without resorting to expensive mechanical plants. Whether yours is an existing system, or new construction, Bio-Domes can help minimize the expense of your treatment system.

CONTACT INFORMATION—USER

Commercial facilities presently operating in the U.S. with this class of technology are identified above. The list is a best effort but may not be completely inclusive of all installations.

Aeration Technology

We do not have individual user information to display for this class of technology.

OTHER CONSIDERATIONS

The NRCS documentation specifies that a third-party review shall contain 15 specific items that comprise the report above, but as part of working with the farm(s) and the technology provider during the 52-week evaluation period there are often other important and valuable learnings that may be helpful for NRCS and others as they consider this technology. Below is a list of Other Considerations that should be included in the evaluation of this technology:

- **Importance of Solids Separation:** Efficient solids separation before effluent enters the pond is critical for optimizing the performance and effectiveness of aeration technologies in dairy wastewater management. Solids separation helps reduce the organic load and suspended solids content in the influent, minimizing the accumulation of sludge and promoting better mixing and aeration within the pond. By removing solids before entering the pond, the aeration system can operate more effectively, enhancing oxygen transfer and microbial activity for improved nutrient management and wastewater treatment. Additionally, solids separation prevents the buildup of sludge, reducing the frequency of maintenance.

CONCLUSION

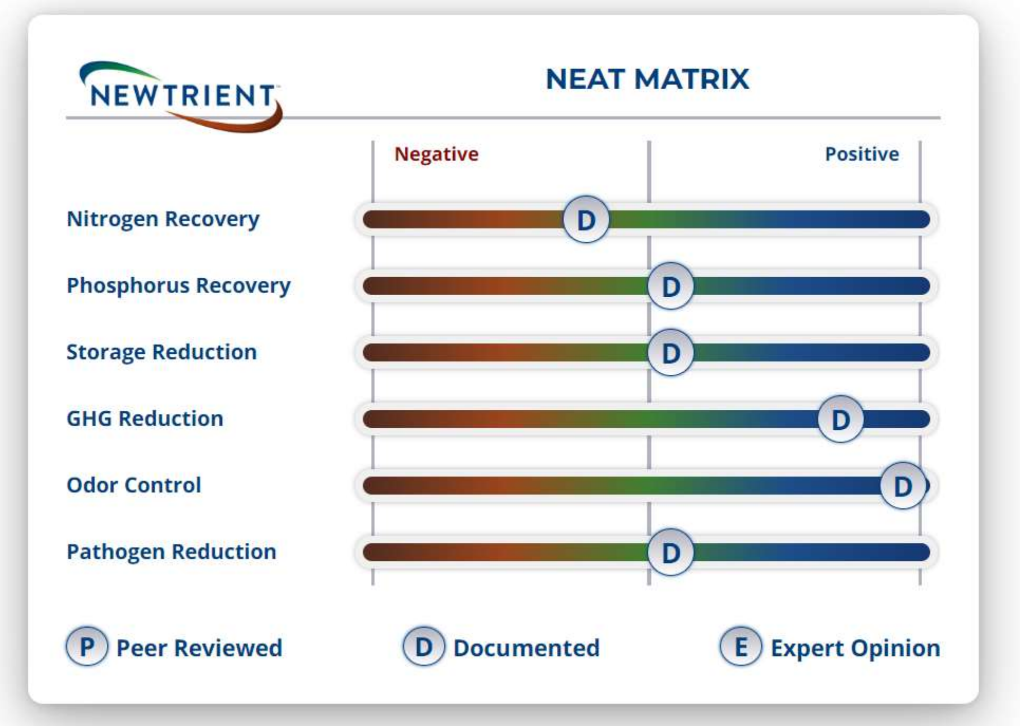
Mechanically aerated storage ponds can play a critical role in transforming raw manure into stable sludge and effluent while minimizing odors and ammonia emissions. However, they alone cannot produce effluent suitable for direct discharge into surface or ground water. Understanding the components of aerated storage ponds, including sludge storage, effluent storage, and treatment volume, is essential for optimizing their effectiveness.

Expanding the size of aerated ponds can exacerbate environmental challenges associated with wastewater handling systems, necessitating careful assessment of environmental risk criteria to determine suitable farm sizes for implementing this technology. Efforts to enhance aerated pond performance should focus on promoting the growth of specific microbial communities involved in waste degradation, rather than solely reducing influent parameters like organic load and BOD.

Recognizing the cyclic nature of effluent storage, biological activity, and organic matter accumulation is crucial for improving aerated pond design and operation. Weather conditions and temperature fluctuations significantly impact these cycles, affecting the overall performance and efficiency of aerated pond systems. Further research and innovation are essential for maximizing the efficiency and effectiveness of aerated manure storage facility technology in agricultural wastewater management.

Appendix A

NEWTRIENT CRITICAL INDICATOR ANALYSIS—Aeration



Overall Summary

Primary Application: Surface aeration finds its primary application in flush systems post-primary solids separation, especially in regions where long-term storage facilities pose concerns regarding local odor emissions. This technology holds relevance for dairy operations in urbanizing areas.

Economic/Return on Investment Considerations: While capital costs for mechanical surface aerators and their platforms/electrical connections are moderate, operating costs can be high due to continuous operation of energy-intensive aerators, leading to high utility costs.

Industry Uptake: Unlike swine, dairy manure's unique conditions (characteristics, location, production timing) have limited interest in surface aeration. Additionally, economic factors have further hindered adoption. Consequently, very few dairy operations have adopted aeration technology to address manure-related odor issues.

Technology Maturity: Surface aeration is a well-researched, understood, and engineered system with multiple vendor platforms available across industries, including manure treatment. Various types of aerators suited for dairy operations are available in the market.

Primary Benefits: Surface aeration effectively controls odor, particularly volatile fatty acids (VFA), a major contributor to odor. It also reduces methane emissions from manure storage facilities.

Secondary Benefits: Secondary benefits include the loss of total nitrogen due to volatilization of ammonia, which can be beneficial for dairies with nitrogen-limited field applications. Air quality is impacted correspondingly. Additionally, aeration can lead to reductions in total solids, volatile solids, and COD/BOD reduction in the storage facility.

How it Works: In surface aeration applications, mechanical aerators are placed on surface platforms to continuously or intermittently aerate the manure storage facility, creating a stratified pond helping to reduce the sludge layer. Mechanical aeration is the most common method used to supply oxygen, shifting the oxidation/reduction potential (ORP), and allowing for aerobic bacterial growth and subsequent degradation of organic material without releasing odorous gases attributed to anaerobic action.

Pretreatment and/or Post-treatment Required: Systems are ideal with low total solids content, around 1% TS, necessitating flush management alongside solids/liquid separation to keep costs down. No post-treatment is required.

Limitations: Surface aeration is energy-intensive, leading to higher utility costs. Maintenance of aeration equipment, especially during winter months, is necessary. Regular maintenance, including sludge removal, is also required to maintain benefits. Concerns about nitrogen loss through volatilization and increased sludge generation in the manure storage facility exist.

Other Considerations: Specification requirements for aeration equipment and installation depend on farm size, manure characteristics, and odor mitigation goals of the dairy farm.

References

Molodovskaya, M., Singurindy, O., Richards, B. K., & Steenhuis, T. S. (2008). Nitrous oxide from aerated dairy manure slurries: Effects of aeration rates and oxic/anoxic phasing. Bioresource Technology, 99(18), 8643-8648. https://doi.org/10.1016/j.biortech.2008.04.062.

Appendix B

Third-Party Review of PondLift Aeration System at Hood Farms Family Dairy – Paw Paw, MI (Evaluation Summary)

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MAY 2024

BACKGROUND

Effective management of slurry storage represents a pivotal aspect of dairy farming operations, significantly influencing both farm productivity and environmental sustainability. As dairy farms seek to optimize their waste management strategies, the storage of slurry—an amalgamation of liquid manure and water—emerges as a critical challenge. The proper handling and storage of slurry is essential not only for regulatory compliance but also for harnessing its potential downstream use. Moreover, creating conducive conditions within slurry storage facilities is paramount to foster the development of specific microbial communities capable of efficiently breaking down bacteria.

Mechanical aeration systems, such as PondLift aerators, have emerged as possible tools in this endeavor, offering a means to enhance aerobic biologic activities within slurry storage ponds. By facilitating the proliferation of beneficial microbes and accelerating the breakdown of organic matter, these systems not only mitigate odors but also promote the generation of homogenous, nutrient-rich material suitable for land application. By implementing mechanical aeration systems, manure storage ponds can experience improvements in various aspects, including decreased sludge volumes, increased nutrient availability, and mitigation of odor formation.

Within the framework of the USDA-NRCS Conservation Innovation Grant (CIG) project, Newtrient initiated a 52-week evaluation to assess the efficacy of PondLift aerators in reducing sludge accumulation and increasing plant-available nutrients in a slurry manure pond at Hood Farms Family Dairy in Paw Paw, MI. At the conclusion of this study in the fall of 2023, PondLift ceased manufacturing the aerators and discontinued operations; however, this had no impact on the study's findings or outcomes.

INTRODUCTION

Pond systems serve as integral components in dairy farm wastewater management, primarily aimed at reducing the organic content in effluent discharged from dairy operations. The quantification of organic matter in effluent, typically measured as biochemical oxygen demand (BOD), holds significant importance in monitoring pond performance. Mechanical aeration involves the introduction of oxygen into wastewater systems through the use of specialized equipment, such as aerators and agitators. This process fosters aerobic biologic activities, facilitating the breakdown of organic compounds by beneficial microorganisms.

While various types of mechanical aeration systems exist, each with their own unique design and functionality, this evaluation focuses specifically on the PondLift aeration system, a surface aeration system. The PondLift equipment includes a motor, typically situated above the water surface, powering the aerators. These aerators are equipped with propellers or impellers, generating agitation by creating an upward current that lifts water and solids from the pond bottom and disperses them across the surface, suspending solids in the liquid. This action facilitates the acceleration of oxygen intrusion into the pond water, essential for promoting aerobic bacterial metabolism, which efficiently metabolizes organic matter in manure.

Figure 1. PondLift floating aerator.
Source: Livestock and Poultry Environmental Learning Community (LPELC.org), 2019.

KEY COMPONENTS OF PONDLIFT AERATION SYSTEMS:

1. **Aerators:** The PondLift system includes aerators equipped with a motor and propeller or impeller. These aerators are designed to float on the water surface of the pond, ensuring ease of installation and maintenance.
2. **Poly cords and stands:** The aerators are positioned within the pond using poly cords attached to stands. This setup ensures stability and proper alignment of the aerators.
3. **Number of aerators:** In the specific case of Hood Farms Family Dairy, there were initially nine aerators installed in the pond. However, the number of aerators changed over time due to repairs and maintenance needs. Although the manufacturer of the aerators used in this study went out of business, the dairy continued using them until the study concluded. At the time of

the final sampling, seven aerators were still in operation.

METHODOLOGY

This evaluation summary presents findings from a comprehensive analysis of samples collected over a 52-week period from a slurry manure storage pond at Hood Farms Family Dairy. With a herd of 500 cows, the farm utilizes sand bedding in its barns and has extensive land for feed production. Given the nature of this operation, efficient management of manure and wastewater becomes imperative. The dairy's wastewater treatment begins with a sand separation process followed by an aeration-equipped storage pond. Prior to sampling, weather conditions were recorded, and notes on the pond's operational status including filling, emptying, and land application were taken, with any abnormal observations noted.

Over the course of a year, two or three samples (16 ounces each) were collected per week depending on the status of the waste manure storage facility (Table 1). Sampling locations included various scenarios such as when the facility was filling, during land application, and when the facility was emptied, with composite liquid samples collected from inflow and outflow points, as well as from sludge material. Composite samples, comprising samples from 3 different locations during the periods that the banks of the pond allowed access, were mixed in a bucket for analysis. Special measures were taken during periods when the inflowing stream was inaccessible, such as during summer when plants obstructed access. Samples were collected using a pole with a plastic bottle attached to avoid sludge contamination and properly stored for transportation and analysis.

The flow rate of the inflow stream was constant at 300 gallons per minute (gpm) when the motor was running and 0 gpm when the motor was off. Additionally, liquid flow rates were measured to calculate average flow rates, while sludge thickness and clean water additions were noted. Detailed records were kept, documenting any changes in weather, operations, influent conditions, or anomalies throughout the study period.

Table 1. The sampling protocol is based on the operation of pond.

Operation status	Samples to be collected
Waste Storage Filling	1.Composite liquid entering the pond 2.Composite liquid from the pond
Land Applying from the Manure Storage Facility	1. Composite liquid entering the pond 2.Composite liquid from irrigation water
Manure Storage Facility Emptied	1. Composite liquid entering the pond 2. Composite liquid from the pond 3. Composite sample of sludge

Following data analysis, which involved the removal of any outliers using Box-Whisker plots, trends and differences in storage samples compared to the manure added to the pond were determined through statistical tests.

DISCUSSION OF RESULTS

KEY BENEFITS OF AERATION

The study conducted at Hood Farms Family Dairy provides valuable insights into the efficacy of the PondLift aeration system. By examining trends, observations, and precipitation data gathered during the study, this research provides meaningful information about the system's performance and its impact on dairy farm operations.

Storage and Handling: One key benefit of the PondLift aeration system is its ability to enhance flush water quality by reducing solids content consistently over time. This improvement was not only validated through personal communications with the landowner but also proved critical in preventing water line clogging during transfer and irrigation processes. Consequently, the owner prioritized the maintenance and operation of the aerators, ensuring they remained functional by conducting repairs and fixes as long as the necessary parts were obtainable.

Additionally, data analysis using Box-Whisker plots revealed a notable reduction in solids content in stored samples compared to inflow samples, as evidenced by a smaller variation from the median value in the former. Paired sample permutation test results further supported this observation, indicating a statistically significant difference ($p<0.05$) in solids content between inflowing manure and stored samples throughout the study period.

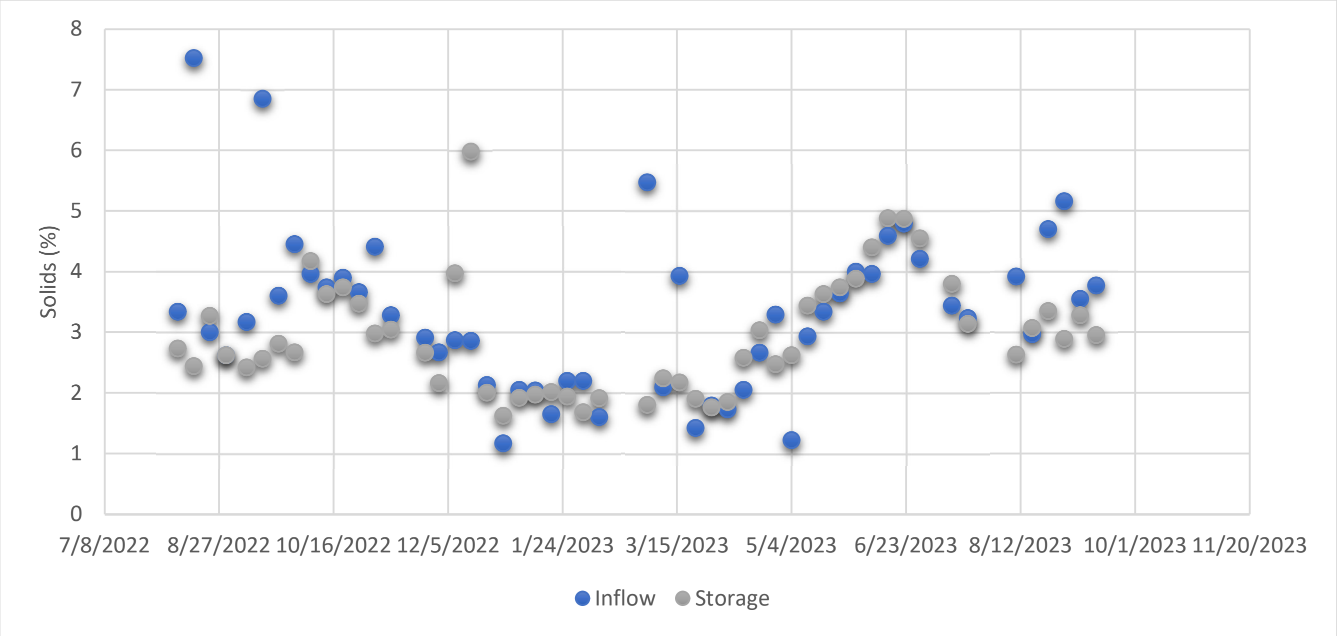


Figure 2. Solids content of the samples during the study period.

Odor Reduction: High organic content in slurry can contribute to foul odors due to the decomposition of organic matter, especially when stored in anaerobic conditions. Reducing organic content can help mitigate odor issues, improving the environmental quality of the surrounding area. Although this study did not evaluate air emissions directly, it did find a reduction in organic content. Paired sample permutation test results revealed that, on average, the organic content of the inflow samples was higher than that of the storage samples throughout the entire year of monitoring (Figure 3). This difference was found to be statistically significant, meaning that it was unlikely to have occurred by random chance alone ($p<0.05$). However, when specifically looking at the organic carbon (C) content within the samples, no significant variation was observed between the inflow and storage samples (Figure 4).

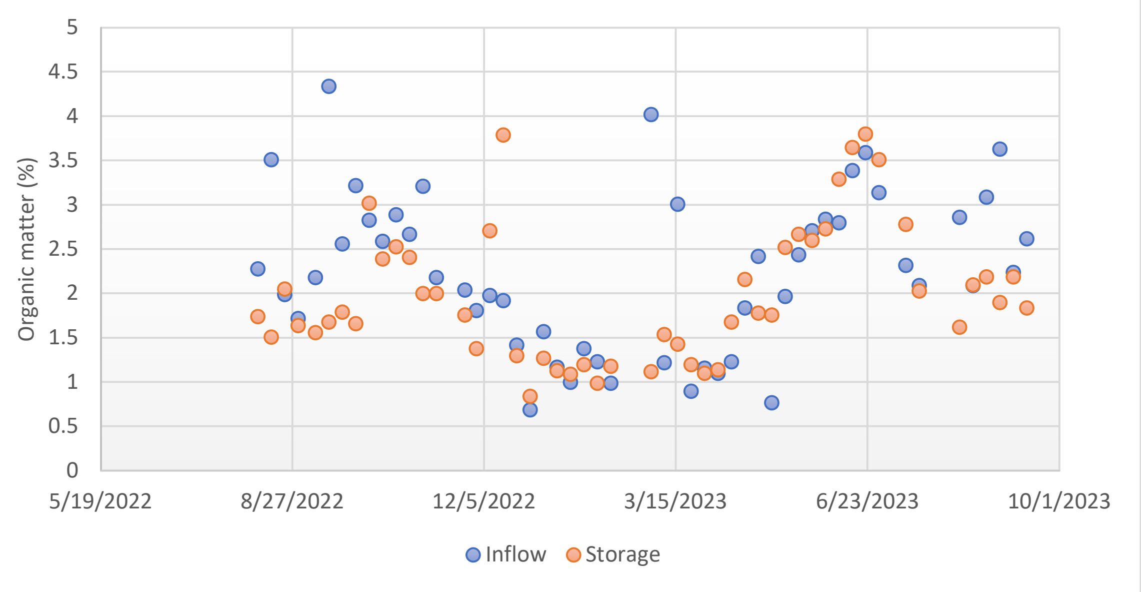


Figure 3. Organic matter of the samples during the study period.

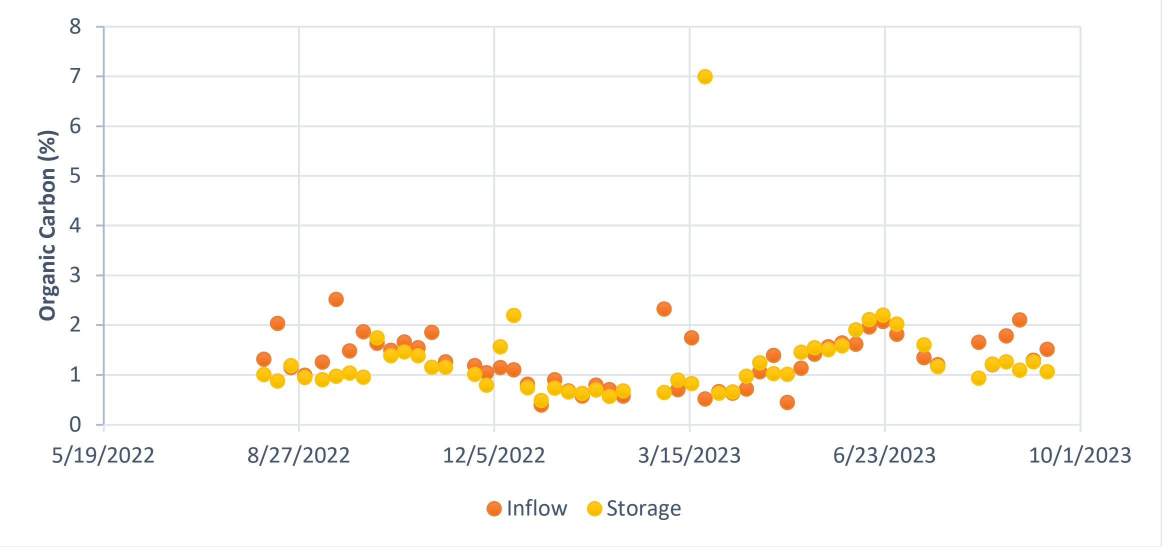


Figure 4. Organic C content of the samples during the study period.

Potential for Crop Irrigation: Storage of manure over extended periods already aids in containing nitrogen (N) and phosphorus (P), allowing them to undergo beneficial biological activities and break down into plant-available forms. The PondLift aeration system further enhances this process by introducing oxygen and facilitating mixing, which helps suspend organic matter in the liquid, ensuring its stabilization within the manure flushed into the pond. This contributes to the retention and recovery of N and P, thus reducing the risk of their runoff and leaching into freshwater sources. While the nutrient and element concentrations in the stored samples did not significantly differ from those in the inflow samples (Table 2), the presence of organic matter and essential nutrients in the slurry still holds value. Additionally, the reduction of clogging issues in the irrigation system makes the technology more practical for real-world agricultural applications.

Table 2. The composition of inflow, storage, and outflow samples during land application of slurry manure.

	9/15/2022			12/8/2022		
	Inflow	Storage	Outflow	Inflow	Storage	Outflow
Moisture (%)	93.15	97.44	96.25	97.13	96.03	97.43
Solids (%)	6.85	2.56	3.75	2.87	3.97	2.57
Ash @ 550 C (%)	2.51	0.88	1.18	0.89	1.26	0.86
Organic Matter (LOI @ 550 C) (%)	4.34	1.68	2.57	1.98	2.71	1.71
Organic Carbon (LOI @ 550 C) (%)	2.52	0.98	1.49	1.15	1.57	0.99
Nitrogen, Total Kjeldahl (TKN) (%)	0.233	0.17	0.199	0.195	0.215	0.188
Nitrogen, Ammonium (NH4-N) (%)	0.1	0.1	0.1	0.11	0.12	0.11
Nitrogen, Organic (N) (%)	0.133	0.07	0.099	0.085	0.095	0.078
Phosphorus (P) (%)	0.049	0.029	0.04	0.032	0.057	0.029
Potassium (K) (%)	0.179	0.135	0.153	0.162	0.175	0.14
Sulfur (S) (%)	0.03	0.02	0.02	0.02	0.03	0.02
Magnesium (Mg) (%)	0.08	0.04	0.05	0.05	0.07	0.04
Calcium (Ca) (%)	0.19	0.09	0.12	0.09	0.15	0.09
Sodium (Na) (%)	0.06	0.06	0.07	0.05	0.05	0.05
Aluminum (Al) (ppm)	72	32	47	38	66	32
Copper (Cu) (ppm)	36	24	39	35	49	32
Iron (Fe) (ppm)	226	80	133	100	171	91
Manganese (Mn) (ppm)	22	12	16	15	22	13
Zinc (Zn) (ppm)	16	9.3	13	16	18	11

KEY ISSUES AND CHALLENGES

Two key issues emerged during the study period underscoring the need for further investigation and highlighting potential implications for effective pond management and manure storage system efficacy.

Sand Accumulation in the Sludge Layer: Since the pond was not emptied throughout the study period, measurements of sludge thickness and composition were not possible. However, towards the conclusion of the sampling, samples were collected from the bottom of the storage sample collection location to gain insights into the composition of the accumulated material. The results of compositional analyses, shown in Table 3, revealed that the ash content of the sludge samples closely resembled the solids content. This similarity suggests that the sludge may predominantly consist of soil or sand, indicating a potential accumulation of sand within the sludge layer. This finding highlights the need for further investigation into the composition and buildup of sediment within the pond, as sand accumulation can have implications for pond management and overall effectiveness of the manure storage system. It should be noted that a sand settling lane was used during the study; however, it was not being operated properly, resulting in a significant amount of sand entering the holding pond. No other solid-liquid separation method was used, which contributed to a high organic and solids loading rate within the manure storage facility.

Table 3. The composition of sludge samples during filling operation.

	8/24/2023			9/7/2023			9/14/2023		
	Inflow	Storage	Sludge	Inflow	Storage	Sludge	Inflow	Storage	Sludge
Moisture (%)	95.3	96.65	49.22	96.45	96.72	56.82	96.23	97.05	51.06
Solids (%)	4.7	3.35	50.78	3.55	3.28	43.18	3.77	2.95	48.94
Ash @ 550 C (%)	1.61	1.16	44.65	1.31	1.09	39.14	1.15	1.11	45.86
Organic Matter (LOI @ 550 C) (%)	3.09	2.19	6.13	2.24	2.19	4.04	2.62	1.84	3.08
Organic Carbon (LOI @ 550 C) (%)	1.79	1.27	3.56	1.3	1.27	2.34	1.52	1.07	1.79
Nitrogen, Total Kjeldahl (TKN) (%)	0.227	0.231	0.339	0.222	0.203	0.164	0.213	0.207	0.179
Nitrogen, Ammonium (NH4-N) (%)	0.11	0.12	0.07	0.12	0.12	0.07	0.12	0.12	0.05
Nitrogen, Organic (N) (%)	0.117	0.111	0.269	0.102	0.083	0.094	0.093	0.087	0.129
Phosphorus (P) (%)	0.043	0.043	0.217	0.032	0.036	0.127	0.039	0.034	0.097
Potassium (K) (%)	0.208	0.234	0.219	0.186	0.216	0.243	0.218	0.227	0.217
Sulfur (S) (%)	0.03	0.03	0.09	0.02	0.02	0.05	0.02	0.02	0.04
Magnesium (Mg) (%)	0.08	0.07	0.4	0.06	0.07	0.24	0.07	0.07	0.29
Calcium (Ca) (%)	0.12	0.11	1.25	0.1	0.11	0.68	0.12	0.11	0.87
Sodium (Na) (%)	0.06	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.05
Aluminum (Al) (ppm)	56	46	884	117	50	3602	79	59	2617
Copper (Cu) (ppm)	33	35	151	37	39	106	37	37	83
Iron (Fe) (ppm)	161	130	2272	183	126	3867	160	129	3309
Manganese (Mn) (ppm)	20	18	182	17	17	187	18	17	156
Zinc (Zn) (ppm)	16	15	84	13	19	60	16	14	45

Sampling Limitations: One of the key issues encountered during the study pertains to the limited frequency of sample collection from the outflow and sludge. Due to operational constraints at the farm during the days of sample collection, only a few sampling occasions were feasible for these specific types of samples. As a result, there was insufficient data available to conduct thorough statistical analyses and report on trends or changes in the composition of these samples over time. This limitation impacts the comprehensiveness of the study findings, particularly regarding the assessment of the outflow and sludge composition. Without a more robust dataset, it becomes challenging to draw meaningful conclusions or insights regarding the dynamics of these critical components of the manure management system.

IMPLICATIONS

The evaluation at Hood Farms Family Dairy has shed light on the potential of mechanical aeration systems, such as PondLift, in enhancing dairy farm wastewater management. While the study demonstrated some benefits such as improved flush water quality, reduced solids content, optimized storage and handling, capability for crop irrigation, and potential odor mitigation, it also highlighted key challenges and avenues for further exploration.

Despite the discontinuation of PondLift operations, other companies offer similar technologies, suggesting ongoing interest and potential for adoption within the industry. However, research on such systems remains limited, warranting further investigation to better understand their efficacy and economic feasibility for dairy farm operations. Moving forward, future research should prioritize addressing gaps in knowledge, including the assessment of air quality impacts and more comprehensive data on water quality benefits. For additional information on aeration technology, visit www.newtrient.com.

Funding for this project was provided by the Natural Resources Conservation Service (NRCS) through a Conservation Innovation Grant (CIG). The views and findings presented in this publication are those of the author(s) and do not necessarily reflect the official views or policies of NRCS or the U.S. Department of Agriculture.

REFERENCES

Livestock and Poultry Environmental Learning Community (LPELC.org), 2019.

Appendix C

Third-Party Review of PondLift Aerobic Treatment for Manure and Domestic Treatment Ponds System at Hood Farms Family Dairy in Paw Paw, MI. (Full Report)

Hood Farms Family Dairy

41488 County Road 358 Paw Paw, MI 49079

Anaerobic Digestion Research and Education Center

Michigan State University

Researchers: Blake Smerigan, Nathan VandeWeert

Report prepared by: Sibel Uludag-Demirer

December 19, 2023

This report is prepared to summarize the results from the compositional analyses of the samples collected from a slurry manure storage pond in Hood Farms Family Dairy (Paw Paw, MI) during a one-year period. The pond was equipped with PondLift to aerate the manure slurry to enhance aerobic biologic activities which may yield homogenous and nutrient rich material suitable to pump and land apply.

1. PondLift Technology: Numerous technologies have been designed and implemented in manure storage facilities to improve the management and quality of wastewater. The patented PondLift aeration system is installed in manure storage ponds to decrease sludge volumes and increase the availability of manure nutrients by solubilization via microbial reactions in aerobic conditions. The manure storage ponds are aerated and agitated using PondLift equipment, which creates an upward current lifting water and solids from the bottom and spreads them over the surface of the pond. This accelerates the oxygen intrusion into pond water, which is used by aerobic bacteria to metabolize the organics. Aeration and mixing also prevents odor formation. The PondLift aerators with motor and propeller/impeller can float on the water surface and they are positioned in the pond by using poly cords attached to a stand.

2. PondLift Technology in Hood Farms Family Dairy: The Hood Farms Family Dairy is in Paw Paw, Michigan. The farm has 500 cows and 900 acres for corn, alfalfa, and silage. The farm uses sand bedding in the barns. The manure flushed with recycled water from the pond is sent to sand separation processes (Figure 1) for the removal and recovery of sand. The effluent from sand separation is transferred to the pond (Figure 2) where PondLift equipment is installed. The clarified and pre-decomposed manure slurry is used as liquid fertilizer on the farm.

Figure 1. Sand separation unit in Hood Family Dairy

Figure 2. Pond with aerators installed.

There were 9 aerators installed in the pond located in Hood Farms Family Dairy during the study. The number of aerators changed during the study due to the repairs and maintenance as needed. The company discontinued manufacturing the aerators; however, Hood Farms Family Dairy continued using the aerators until the completion of the study. The last sampling was made on September 14, 2023 and there were 7 aerators operating at the time.

3. The Objective of the Study

The primary objective of this study is to evaluate the performance and effectiveness (reduced sludge layer, increase in the plant available nutrients) of the PondLift aerators in a pond fed by slurry manure after sand separation operating in Hood Farms Family Dairy based on the parameters specified by Newtrient. The Anaerobic Digestion Research and Education Center (ADREC) in Michigan State University (MSU) acted as an independent party in the collection of samples from the pond and shipped the samples to an external lab (A and L Great Lakes Laboratories, Fort Wayne, IN) for their analyses. This report displays the measurement results of the samples collected from the pond used as a storage for slurry manure between August 9, 2022, and September 14, 2023. The results from the reports submitted by the external lab are organized in tables and plots for trend observation accompanied with the precipitation data in this study.

4. Sampling Procedure

The sampling protocol is described in Appendix 1. Sampling was made weekly from the pond at Hood Farms Family Dairy in Paw Paw, MI (Figure 3). Researchers from MSU prepared a transportation receptacle for safe and controlled movement of samples by using the plastic containers with lids provided by the A and L Great Lakes Laboratories. The samples were kept in a cooler with ice packs during the transportation and shipment. Except during the holidays, the samples were sent out for their analyses in 24 hours. To be able to stop biological activities in samples, they were frozen during long storage in ADREC lab.

Figure 3: Hood Dairy Farms Aerial Map and Pond Location

Prior to sampling, weather conditions were recorded for the given sampling date and notes on operational status of the pond (filling, emptying, and land application) were taken. Any abnormal or important observations were made. The operational status of the pond was important to determine which samples were to be collected (Table 1). The flow rate of the inflow stream was constant at 300 gallons per minute when the motor was running and 0 gallons per minute when the motor was off. Therefore, there was no change in inflow rate of manure slurry. Weather data for the site were obtained from the station located at Rzonca Station (Paw Paw, MI) (Elevation: 774 ft, 42.19 °N, 85.88 °W) (https://www.wunderground.com/dashboard/pws/KMIPAWPA17).

Table 1. The sampling protocol based on the operation of pond

Operation status	Samples to be collected
Manure Storage Filling	1.Composite liquid entering the pond 2.Composite liquid from the pond
Land Applying from the Manure storage facility	1. Composite liquid entering the pond 2.Composite liquid from irrigation water
Manure storage facility Emptied	1. Composite liquid entering the pond 2. Composite liquid from the pond 3. Composite sample of sludge

Samples were collected from the inflowing stream to the pond and storage at the locations shown below in Figures 4 and 5 respectively. The storage samples were composite by mixing the samples collected from 3 different locations during the periods that the banks of the pond allowed access (Figure 5). Especially during summer, when the inflowing stream was not accessible due to plants, inflow stream samples were collected from the sand separation process outflow as shown in Figure 6. In the case of land application, a sample was collected from the outflow sample location as shown in Figure 7. Samples were collected using a long metal pole with a plastic bottle attached to avoid collecting any sludge from the top of the manure storage facility (Figure 8). They were then carefully poured into a labeled sampling bottle and stored in the cooler for transportation.

Figure 4: Inflow Sample Location

Figure 5: Storage Sample Location

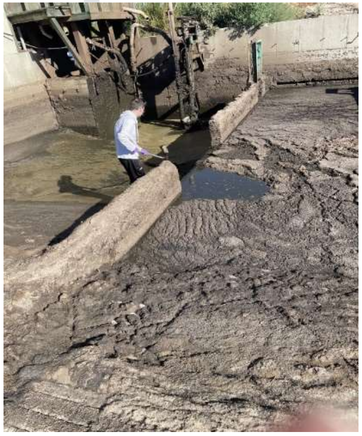


Figure 6. Sampling from inflow stream located at the exit of sand separation.

Figure 7. Sampling point during land application

Figure 8. The metal pole and plastic bottle used for sample collection.

5. Sample Analyses

The samples were analyzed for the parameters listed in Table 2 using the Standard Methods in the A and L Great Lakes Laboratories (Fort Wayne, IN). The results were typically received in a week and entered into an Excel spreadsheet in a shared folder.

Table 2. List of the parameters measured in the samples.

Parameter	Unit
Moisture	%, pounds per gallon
Solids	%, pounds per gallon
Ash at 550 C	%, pounds per gallon
Organic Matter (LOI at 550 C)	%, pounds per gallon
Organic Carbon (LOI at 550 C)	%, pounds per gallon
Carbon:Nitrogen Ratio	unitless
Total Kjeldahl Nitrogen (TKN)	%, pounds per gallon, first year availability in lb/1000 gal*
Ammonium Nitrogen (NH4-N)	%, pounds per gallon, first year availability in lb/1000 gal*
Organic nitrogen	%, pounds per gallon, first year availability in lb/1000 gal*
Phosphorus (P)	%, pounds (as P_2O_5) per gallon, first year availability in lb (as P_2O_5)/1000 gal*
Potassium (K)	%, pounds (as K_2O) per gallon, first year availability in lb (as K_2O)/1000 gal*
Sulfur (S)	%, pounds per gallon, first year availability in lb/1000 gal#
Magnesium (Mg	%, pounds per gallon, first year availability in lb/1000 gal#
Calcium (Ca)	%, pounds per gallon, first year availability in lb/1000 gal#
Sodium (Na)	%, pounds per gallon
Aluminum (Al)	ppm, pounds per gallon, first year availability in lb/1000 gal#
Copper (Cu)	ppm, pounds per gallon, first year availability in lb/1000 gal#
Iron (Fe)	ppm, pounds per gallon, first year availability in lb/1000 gal#
Manganese	ppm, pounds per gallon, first year availability in lb/1000 gal#
Zinc (Zn)	ppm, pounds per gallon, first year availability in lb/1000 gal#

Notes: Estimate of first year availability does not count for incorporation losses. Consult MWPS, “Livestock Waste Facilities Handbook (1993)” for additional information. *Source: MWPS-18, Livestock Waste Facilities Handbook, 1993. #Source: A3411, “Manure Nutrient Credit Worksheet”, University of Wisconsin. Manure density assumed to be 8.33 lb/gallon in pounds per 1000 gal.

6. Results

6.1 Weather Data

The weekly average temperature and precipitation are shown in Figure 9 and 10 respectively. The data used to plot the Figures can be found in the shared Excel file.

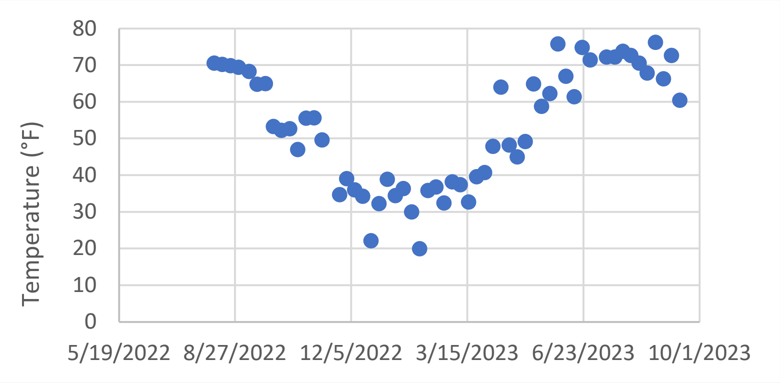


Figure 9. Temperature change during the study period

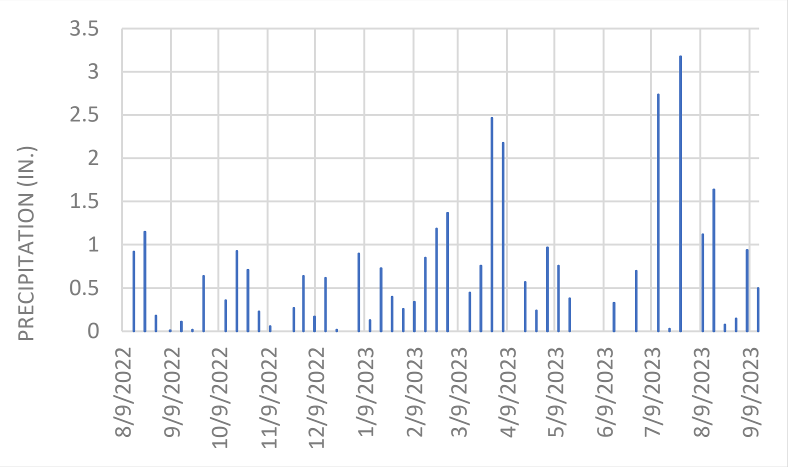


Figure 10. Precipitation during the study period

The seasonal changes in temperature and precipitation were important to evaluate the dilution of manure slurry stored in the pond via loss and gain of water respectively. There were a few unusual precipitation events during Summer 2023 adding more than 2.5 in precipitation. The other events were noted to be normal for Michigan.

6.2 Quality Data

In this section, the parameters measured in the inflowing and stored manure samples are reported for a period of a year. The results were analyzed after removing any outlying data (Box-Whisker plot) to determine trends and differences of storage samples from the manure added to the pond using statistical tests.

The PondLift system improved flush water quality in its solids contents throughout the year, which was also confirmed by the landowner in personal communications. The benefits of PondLift system were critical for keeping water lines from clogging both during transfer and irrigation. Therefore, the owner maintained the aerators running by repairing and fixing if the parts of the PondLift system were available.

6.2.1-Moisture and solids: The measurement results are shown in Figures 11, 12, and 13 for moisture, solid content and ash content of the samples respectively. The moisture content of the samples from inflow and storage varied with the change in temperature and precipitation at the location. The solids contents of the samples followed a confirmatory trend with moisture and were high during summer months due to evaporation. The ash content (% based on dry solids) in the inflow and storage samples were similar throughout the sampling period.

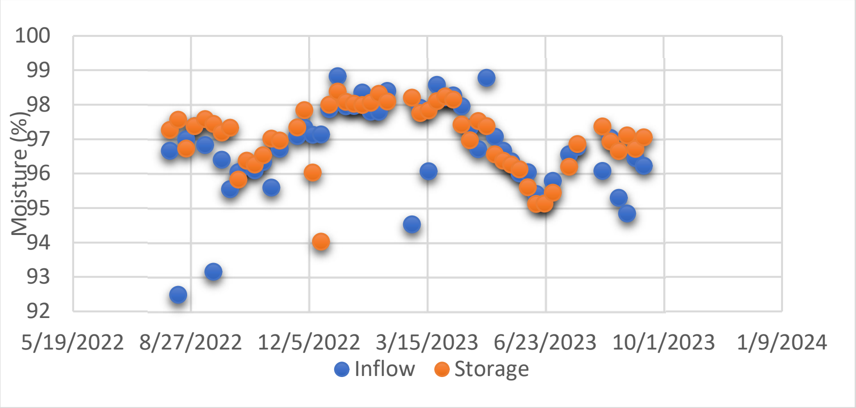


Figure 11. Moisture content of the samples during the study period

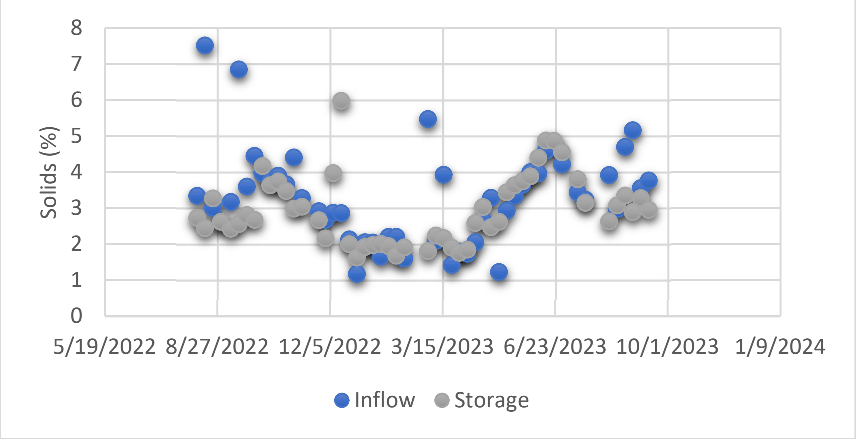


Figure 12. Solids content of the samples during the study period

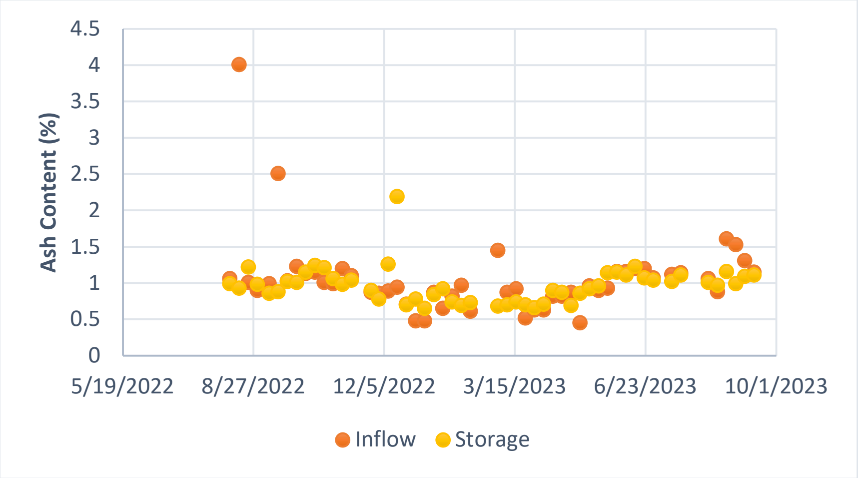


Figure 13. Ash content of the solids in the samples during the study period

The Box-Whisker plot of the data showed a few outliers for the parameters (Appendix 2) and it was observed the data distribution was not normal for the physical parameters. Distribution statistics are listed in Appendix 2. One of the major observations was that the variation from the median value was smaller in the storage samples than inflow samples. Paired sample permutation test results showed that there was no difference between the moisture content and ash content of inflow and storage samples (Appendix 2). However, the solids content of the samples collected from inflowing manure and storage was statistically different ($p<0.05$, see Appendix 2). The solids content of inflow was higher than the storage samples during the study period.

6.2.2-Organic Matter: Organic matter in the samples collected from inflow and storage showed a variation like solids content (Figure 12) as shown in Figure 14 indicating the high contribution of particulate organic content to the sample quality. The results showed an increase in organic content during warm periods due to water loss via evaporation and increased biological activity. The organic C was similar throughout the study period fluctuating between 0.5 and 2% excluding the outlying measurement around 7% (see Figure 15).

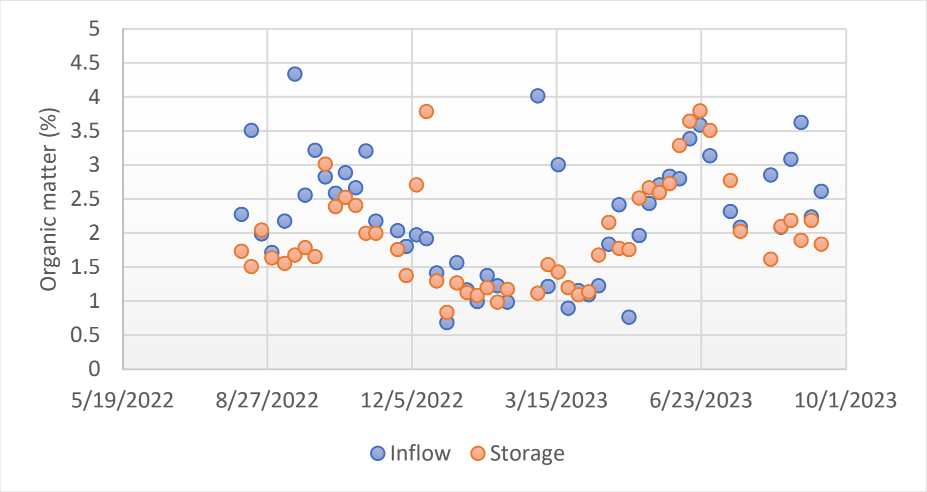


Figure 14. Organic matter of the samples during the period of the study

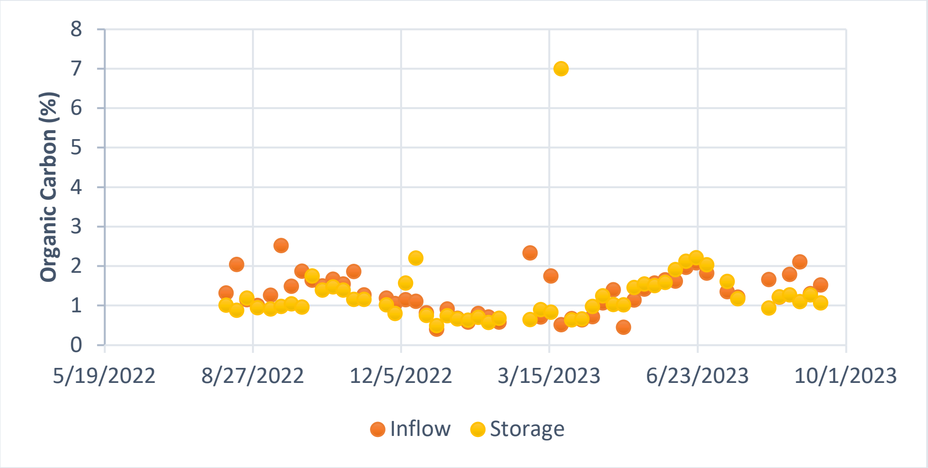


Figure 15. Organic C content of the samples during the study period

The Box-Whisker plots (Appendix 2) were used to eliminate the outlier data and they showed that the data was not normally distributed. Paired sample permutation test showed that the organic content of the inflow samples was higher than storage samples during the entire year of monitoring ($p<0.05$, Appendix 2). However, organic C content of the inflow and storage samples did not vary significantly.

6.2.3-Nutrients: The concentration of TKN, NH4-N, total organic nitrogen, and total phosphorus is plotted and shown in Figures 16, 17, 18, and 19 respectively. The changes in the concentrations of total nutrients associated with particulate matter (TKN, TN_org, and TP), except ammonium nitrogen, follow a trend based on the water balance and solids content in the pond during the year. Only the concentration of total organic nitrogen was at a lower level in the storage than inflow samples throughout the study. The concentration of ammonium nitrogen varied randomly, and it was higher during the warmer months, which could be due to higher rates of biological activities (Figure 18).

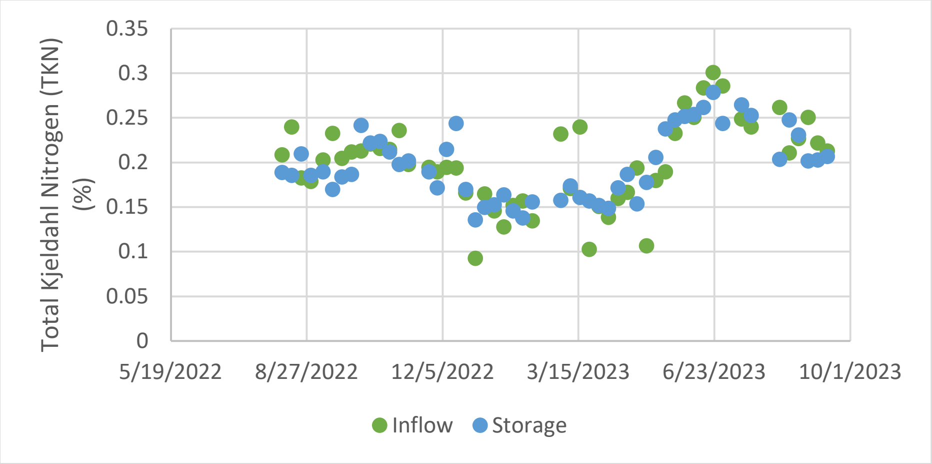


Figure 16. TKN content of the samples during the study period

The Box-whisker plots and statistics showed that the distribution of data was not normal (Appendix 2). The difference between the storage and inflow samples was not statistically significant for the nutrient components of the sample composition based on the paired sample permutation test (Appendix 2).

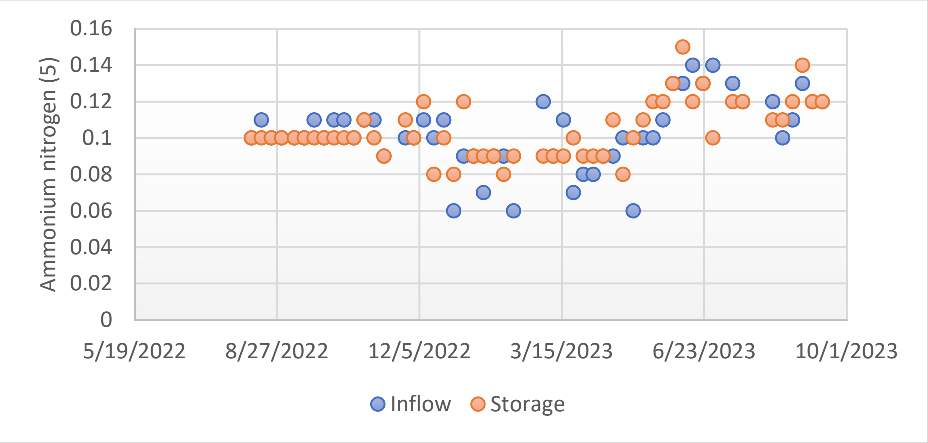


Figure 17. Concentration of NH4-N in the aqueous phase of the samples during the study period

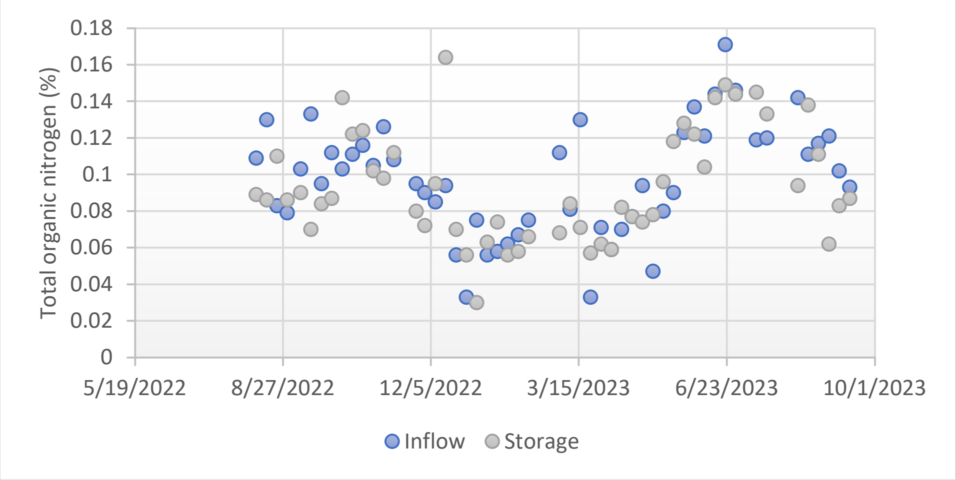


Figure 18. TN_org concentration in the samples during the study period

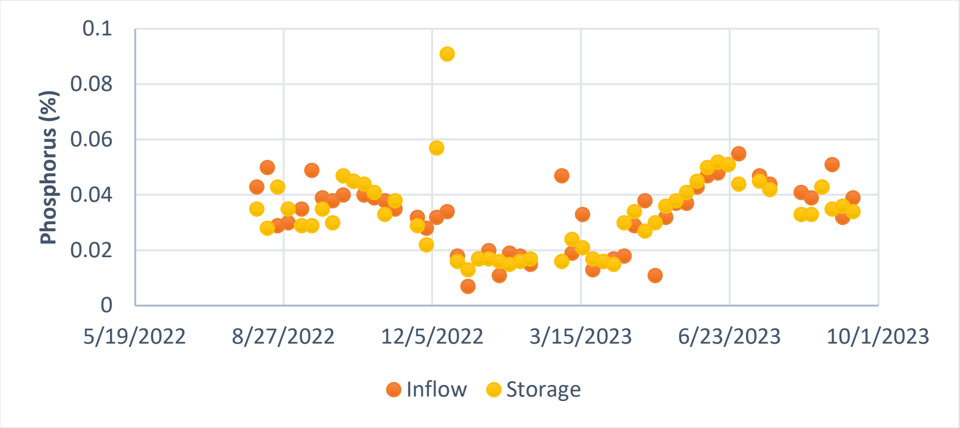


Figure 19. Total P concentration in the samples during the study period

6.2.4- Elemental analyses: The concentration of elements in the inflow and storage samples is shown in the Figures from Figure 20 to Figure 29. The concentration of potassium, sodium, and sulfur varied without a trend during the study period and there was no difference between inflowing manure and stored manure samples. However, the concentration of magnesium, calcium, aluminum, copper, iron, manganese, and zinc was measured at lower levels during cold months than warm months in inflow and storage samples.

The Box Whisker plots and statistics are summarized in Appendix 2 for each parameter. The results were not normally distributed and the difference between the inflow and storage sample concentrations was not statistically significant based on paired sample permutation test (Appendix 2).

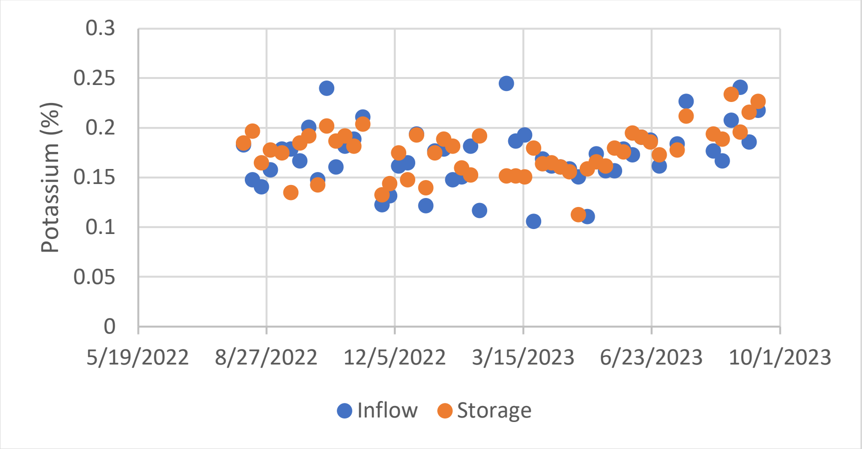


Figure 20. Potassium (K) concentration in the samples during the study period

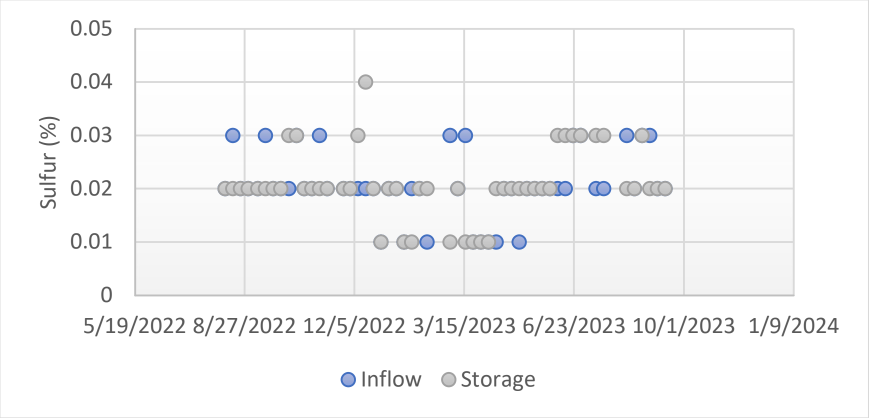


Figure 21. Sulfur (S) concentration in the samples during the study period

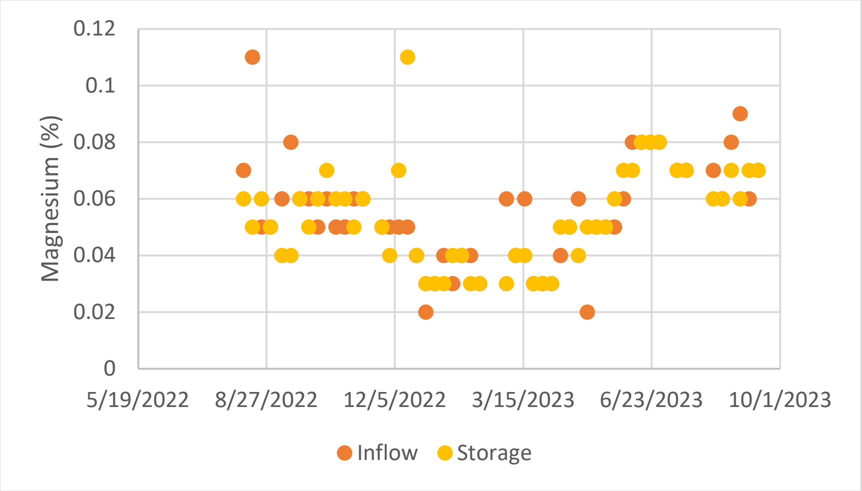


Figure 22. Magnesium (Mg) concentration in the samples during the study period

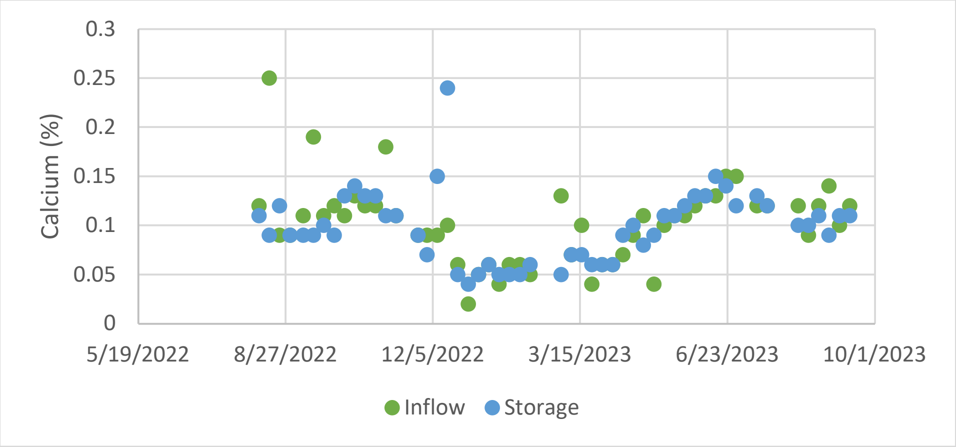


Figure 23. Calcium (Ca) concentration in the samples during the study period

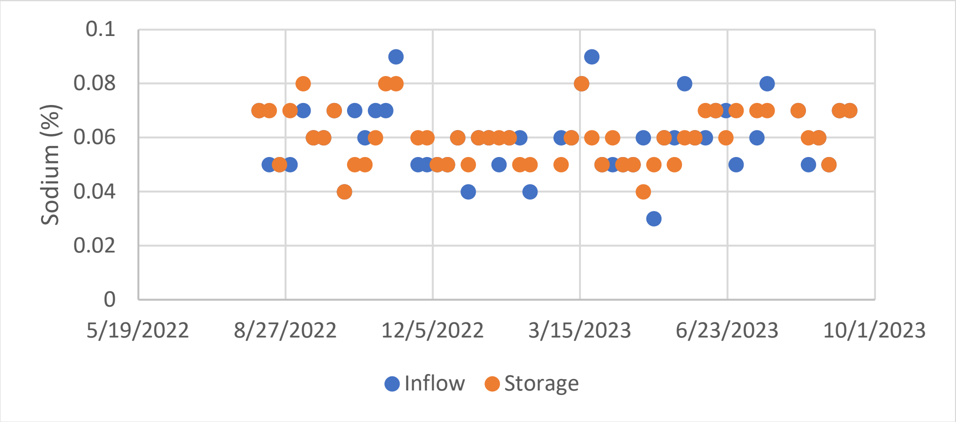


Figure 24. Sodium (Na) concentration in the samples during the study period

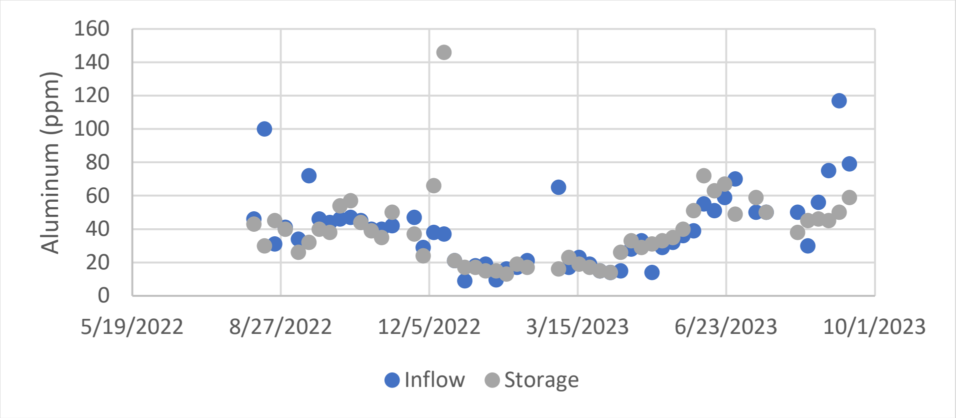


Figure 25. Aluminum (Al) concentration in the samples during the study period

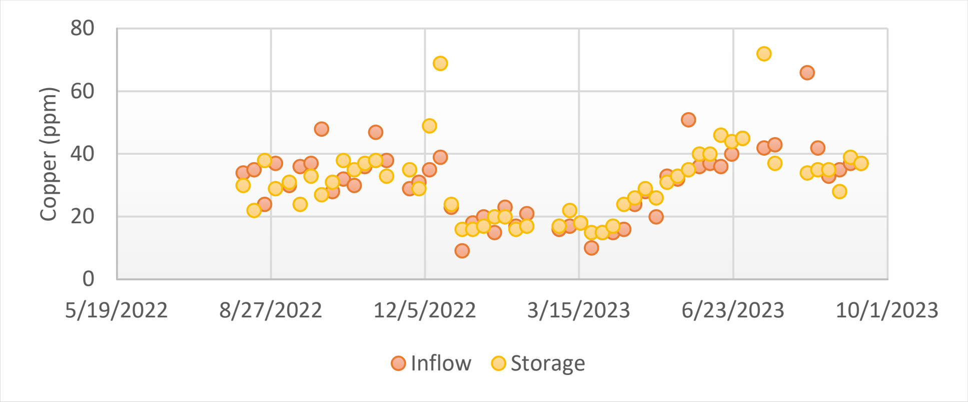


Figure 26. Copper (Cu) concentration in the samples during the study period

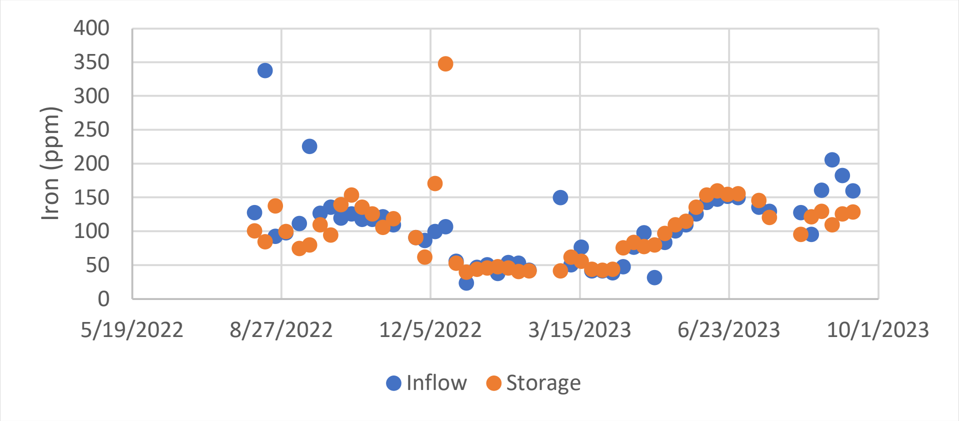


Figure 27. Iron (Fe) concentration in the samples during the study period

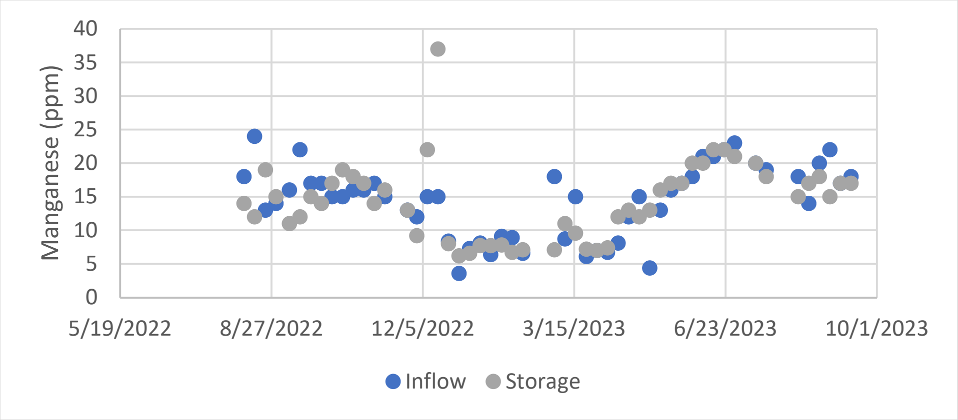


Figure 28. Manganese (Mn) concentration in the samples during the study period

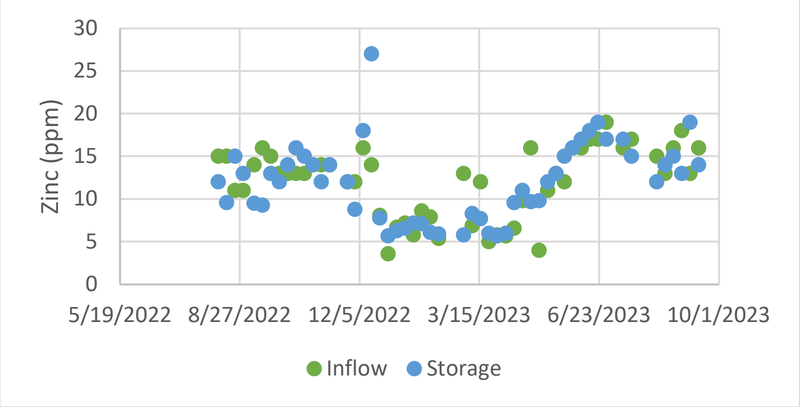


Figure 29. Zinc (Zn) concentration in the samples during the study period

6.3 Additional samples and their analyses

The sampling from the outflow stream was made on the 15th of September and 8th of December, 2022. This sampling was important to understand the quality of manure applied to land. The two samplings from the outflow showed that it has similar composition to storage samples taken on the same dates (Table 3).

Table 3. The composition of inflow, storage and outflow samples during land application of slurry manure

	9/15/2022			12/8/2022		
	Inflow	Storage	Outflow	Inflow	Storage	Outflow
Moisture (%)	93.15	97.44	96.25	97.13	96.03	97.43
Solids (%)	6.85	2.56	3.75	2.87	3.97	2.57
Ash @ 550 C (%)	2.51	0.88	1.18	0.89	1.26	0.86
Organic Matter (LOI @ 550 C) (%)	4.34	1.68	2.57	1.98	2.71	1.71
Organic Carbon (LOI @ 550 C) (%)	2.52	0.98	1.49	1.15	1.57	0.99
Nitrogen, Total Kjeldahl (TKN) (%)	0.233	0.17	0.199	0.195	0.215	0.188

Nitrogen, Ammonium (NH4-N) (%)	0.1	0.1	0.1	0.11	0.12	0.11
Nitrogen, Organic (N) (%)	0.133	0.07	0.099	0.085	0.095	0.078
Phosphorus (P) (%)	0.049	0.029	0.04	0.032	0.057	0.029
Potassium (K) (%)	0.179	0.135	0.153	0.162	0.175	0.14
Sulfur (S) (%)	0.03	0.02	0.02	0.02	0.03	0.02
Magnesium (Mg) (%)	0.08	0.04	0.05	0.05	0.07	0.04
Calcium (Ca) (%)	0.19	0.09	0.12	0.09	0.15	0.09
Sodium (Na) (%)	0.06	0.06	0.07	0.05	0.05	0.05
Aluminum (Al) (ppm)	72	32	47	38	66	32
Copper (Cu) (ppm)	36	24	39	35	49	32
Iron (Fe) (ppm)	226	80	133	100	171	91
Manganese (Mn) (ppm)	22	12	16	15	22	13
Zinc (Zn) (ppm)	16	9.3	13	16	18	11

The pond has not been emptied during the period of the study. Therefore, neither sludge thickness nor composition were measured during the study. However, prior to the end of the sampling campaign samples were collected from bottom of storage sample collection location. The results from compositional analyses of the samples are provided in Table 4 below along with inflow and storage sample composition. The ash content of the sludge samples was similar to solids content, which may point out the sludge sample may have been mainly composed of soil or sand.

Table 4. The composition of sludge samples during filling operation

	8/24/2023			9/7/2023			9/14/2023		
	Inflow	Storage	Sludge	Inflow	Storage	Sludge	Inflow	Storage	Sludge
Moisture (%)	95.3	96.65	49.22	96.45	96.72	56.82	96.23	97.05	51.06
Solids (%)	4.7	3.35	50.78	3.55	3.28	43.18	3.77	2.95	48.94
Ash @ 550 C (%)	1.61	1.16	44.65	1.31	1.09	39.14	1.15	1.11	45.86
Organic Matter (LOI @ 550 C) (%)	3.09	2.19	6.13	2.24	2.19	4.04	2.62	1.84	3.08
Organic Carbon (LOI @ 550 C) (%)	1.79	1.27	3.56	1.3	1.27	2.34	1.52	1.07	1.79
Nitrogen, Total Kjeldahl (TKN) (%)	0.227	0.231	0.339	0.222	0.203	0.164	0.213	0.207	0.179
Nitrogen, Ammonium (NH4-N) (%)	0.11	0.12	0.07	0.12	0.12	0.07	0.12	0.12	0.05
Nitrogen, Organic (N) (%)	0.117	0.111	0.269	0.102	0.083	0.094	0.093	0.087	0.129
Phosphorus (P) (%)	0.043	0.043	0.217	0.032	0.036	0.127	0.039	0.034	0.097
Potassium (K) (%)	0.208	0.234	0.219	0.186	0.216	0.243	0.218	0.227	0.217
Sulfur (S) (%)	0.03	0.03	0.09	0.02	0.02	0.05	0.02	0.02	0.04
Magnesium (Mg) (%)	0.08	0.07	0.4	0.06	0.07	0.24	0.07	0.07	0.29
Calcium (Ca) (%)	0.12	0.11	1.25	0.1	0.11	0.68	0.12	0.11	0.87
Sodium (Na) (%)	0.06	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.05
Aluminum (Al) (ppm)	56	46	884	117	50	3602	79	59	2617
Copper (Cu) (ppm)	33	35	151	37	39	106	37	37	83
Iron (Fe) (ppm)	161	130	2272	183	126	3867	160	129	3309
Manganese (Mn) (ppm)	20	18	182	17	17	187	18	17	156
Zinc (Zn) (ppm)	16	15	84	13	19	60	16	14	45

7. Summary

The monitoring of the manure storage facility, pond, in Hood Farm Family Dairy during a one-year period showed solid content of the inflowing manure and stored manure had similar seasonal changes correlating well with water balance in the pond. The installation of PondLift equipment reduced the concentration of solids and organics significantly ($p<0.05$) in the pond. However, the other parameters, including nutrients, showed no statistically significant difference between inflow and storage samples. The sample collection from outflow and sludge was made only a few times during the study because of the operations in the farm during the day of sample collection. Therefore, it was not possible to report a trend and change in the composition of these samples using statistical tests.

Appendix 1- Sampling Protocol for Third Party Evaluation Project: PondLift system at Hood Dairy, Paw Paw, MI

Location: 41488 County Road 358, Paw Paw, MI 49079

Purpose: Hood Dairy Farm uses PondLift system to improve the management and water quality for waste storage facilities. The PondLift system aerates the manure storage facility and reports that it reduces the sludge volume and makes the nutrients suspended in the water, which makes it more available for plants during land application.
This study aims to evaluate the performance of PondLift system employed in Hood Dairy Farm. For this purpose, two or three samples (16 oz) will be collected per week for a yearlong period. The number of samples will be determined based on whether the manure storage facility is pumped down or not.
Sampling locations are described below:

Manure storage facility Filling:

1) A composite liquid sample* will be collected from the inflow entering the manure storage facility
2) A composite liquid sample from the manure storage facility

Land Application from the Manure storage facility:

1) A composite liquid sample will be collected from the inflow entering the manure storage facility
2) Composite liquid sample of irrigation water

Manure storage facility is Emptied

1) A composite liquid sample will be collected from the inflow entering the manure storage facility
2) A composite liquid sample from the manure storage facility
3) Composite sample from the sludge material

*Composite sample: 3 1-L samples over an hour period mixed in a bucket
Samples will be collected in plastic containers (16 oz) and labelled. They will be carried back to ADREC in a cooler with ice packs.
Labelling: mm/dd/yy, sampling site (inflow, outflow, storage, or sludge), 63570, Initials)

Other measurements

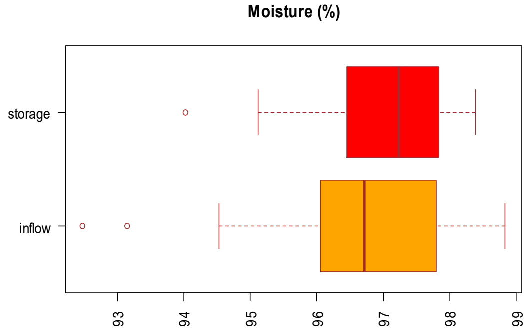
Liquid flow rates should be measured at least 3 times to calculate the average flow rate. This can be carried out using a sampling bottle and timer.
Sludge thickness or depth will be determined when possible.
The volume of clean water additions will be noted. This addition could be due to precipitation or as a part of the operation (ask farm management about the changes in operation).
A log will be kept to document changes in weather, operations, influent conditions, upsets etc.

Appendix 2: Data analysis

The data analysis is made after the removal of outlying values (Tukey's 1.5IQR method) from the time series for each parameter. The Box-Whisker plots and statistics were used to identify the outlying results and to determine data distribution, mean and median values of the parameters during the study period. The data were not normally distributed for any of the parameters in the samples collected.

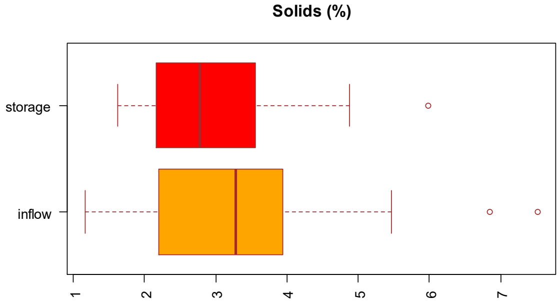
Box-Whisker plots and data statistics (R package ggplot2)

1) Moisture



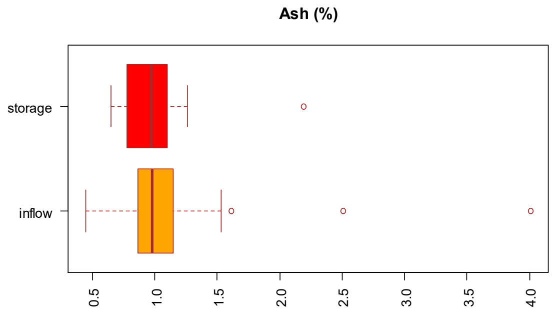
```
        n  mean   sd   median trimmed  mad   min   max   range  skew kurtosis  se
inflow  52 96.70 1.30  96.72   96.79  1.00 92.48  98.83  6.35  -0.83   1.19   0.18
storage 52 97.05 0.95  97.23   97.15  1.02 94.02  98.38  4.36  -0.85   0.48   0.13
```

2) Solids



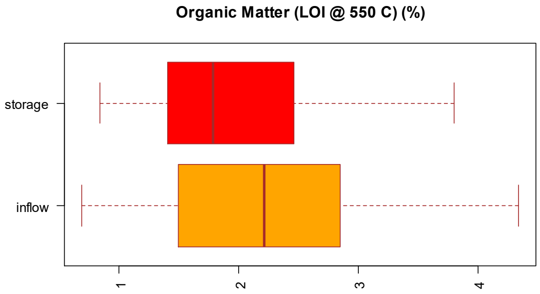
```
          n mean   sd   median trimmed  mad  min   max  range skew  kurtosis  se
inflow   52 3.30  1.30   3.29    3.21  1.00 1.17  7.52  6.35 0.83   1.19    0.18
storage  52 2.95  0.95   2.77    2.85  1.02 1.62  5.98  4.36 0.85   0.48    0.13
```

3) Ash



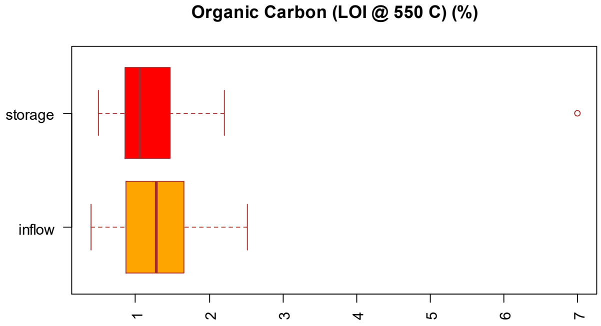
```
         n mean   sd  median trimmed  mad  min  max  range skew kurtosis   se
inflow  52 1.05  0.53   0.98   0.98  0.24 0.45  4.01  3.56 3.59  16.58    0.07
storage 52 0.97  0.25   0.98   0.95  0.20 0.65  2.19  1.54 2.16   9.05    0.03
```

4) Organic matter



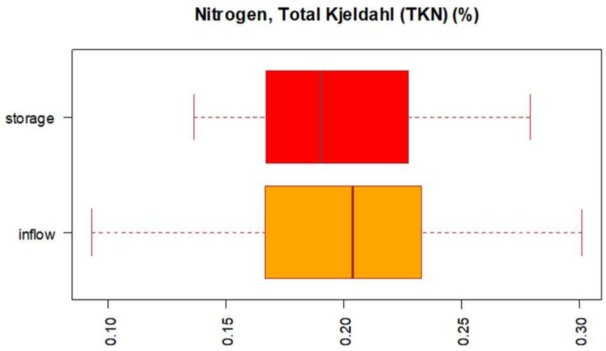
```
         n mean   sd  median trimmed  mad  min  max  range skew kurtosis   se
inflow  52 2.25  0.89   2.21   2.22  0.96 0.69  4.34  3.65 0.16  -0.74    0.12
storage 52 1.98  0.76   1.79   1.90  0.74 0.84  3.80  2.96 0.77  -0.15    0.10
```

5) Organic Carbon



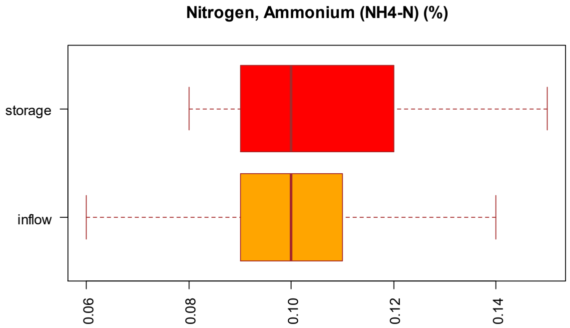
```
         n mean   sd  median trimmed  mad  min  max range skew kurtosis   se
inflow  52 1.30  0.51   1.29   1.29  0.56 0.40 2.52  2.12 0.16   -0.74  0.07
storage 52 1.27  0.92   1.06   1.13  0.46 0.49 7.00  6.51 4.66   26.22  0.13
```

6) Total Kjeldahl Nitrogen



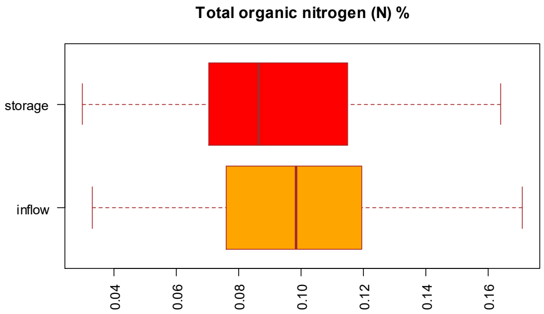
```
n mean   sd  median trimmed  mad  min  max range  skew kurtosis   se
inflow  52  0.2  0.05   0.20   0.2   0.05 0.09 0.30  0.21 -0.19   -0.37  0.01
storage 52  0.2  0.04   0.19   0.2   0.05 0.14 0.28  0.14  0.30   -1.04  0.01
```

7) Ammonium Nitrogen



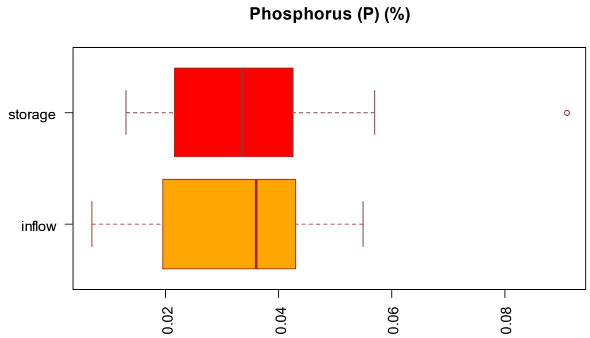
```
         n  mean   sd median trimmed  mad  min  max range  skew kurtosis se
inflow  52  0.1   0.02  0.1     0.1  0.01 0.06 0.14  0.08 -0.30  -0.10   0
storage 52  0.1   0.02  0.1     0.1  0.01 0.08 0.15  0.07  0.65   0.11   0
```

8) Total organic nitrogen



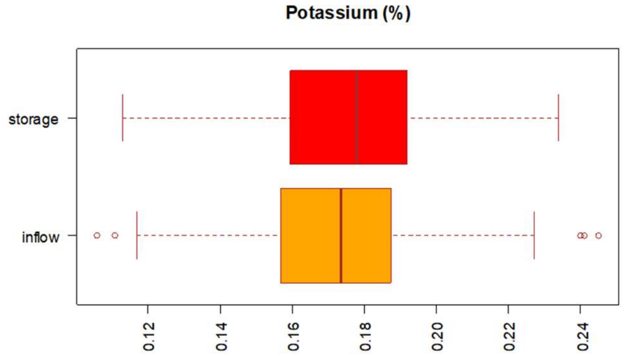
```
         n mean   sd   median trimmed  mad  min  max range  skew  kurtosis se
inflow  52 0.10  0.03   0.10   0.10   0.03 0.03 0.17  0.14  -0.07   -0.45  0
storage 52 0.09  0.03   0.09   0.09   0.03 0.03 0.16  0.13   0.45   -0.64  0
```

9) Phosphorus



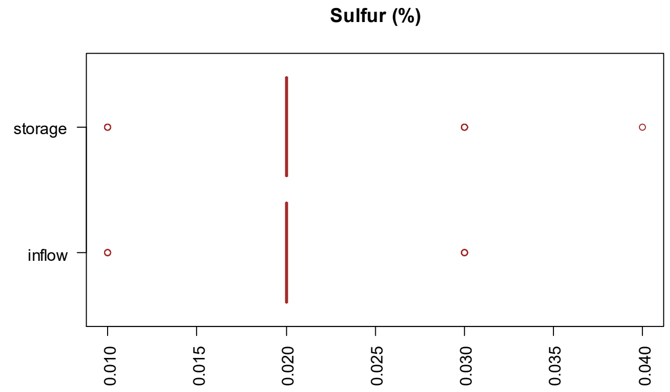
```
         n mean   sd  median trimmed  mad  min  max range  skew kurtosis se
inflow   52 0.03 0.01   0.04    0.03 0.01 0.01 0.06  0.05 -0.37   -0.99  0
storage  52 0.03 0.01   0.03    0.03 0.01 0.01 0.09  0.08  1.14    3.20  0
```

10) Potassium



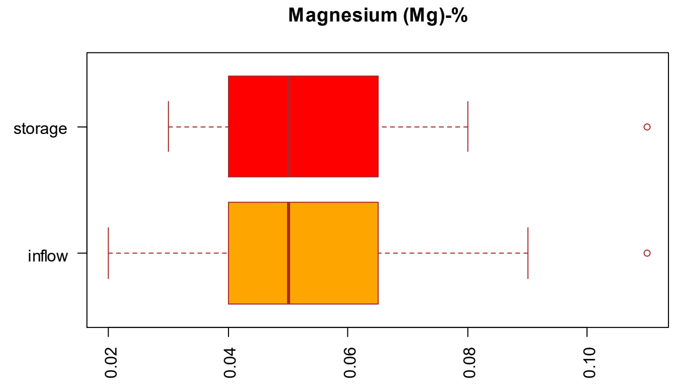
```
         n mean   sd  median trimmed  mad  min  max range  skew kurtosis se
inflow   52 0.17 0.03   0.17    0.17 0.02 0.11 0.24  0.14  0.19    0.11  0
storage  52 0.18 0.02   0.18    0.18 0.02 0.11 0.23  0.12 -0.07   -0.04  0
```

11) Sulfur



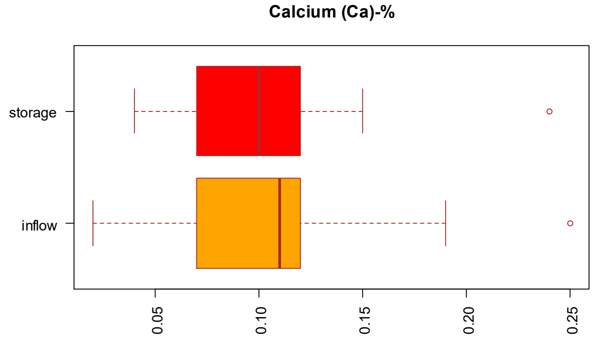
```
          n mean   sd  median trimmed mad  min  max range  skew kurtosis se
inflow   52 0.02 0.01    0.02    0.02   0 0.01 0.03  0.02 -0.02    -0.36  0
storage  52 0.02 0.01    0.02    0.02   0 0.01 0.04  0.03  0.34     0.37  0
```

12) Magnesium



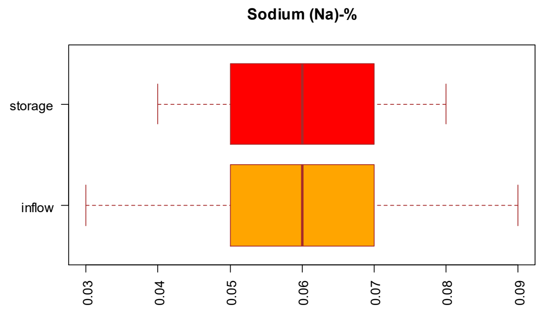
```
          n mean   sd median trimmed  mad  min  max range skew kurtosis se
inflow   52 0.06 0.02   0.05    0.05 0.01 0.02 0.11  0.09 0.37     0.16  0
storage  52 0.05 0.02   0.05    0.05 0.01 0.03 0.11  0.08 0.58     0.48  0
```

13) Calcium



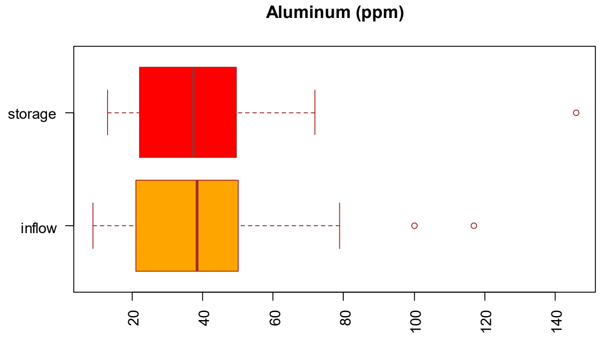
```
         n mean   sd median trimmed  mad  min  max range skew kurtosis   se
inflow  52  0.1 0.04   0.11     0.1 0.03 0.02 0.25  0.23 0.74     1.84 0.01
storage 52  0.1 0.04   0.10     0.1 0.04 0.04 0.24  0.20 0.96     2.62 0.00
```

14) Sodium



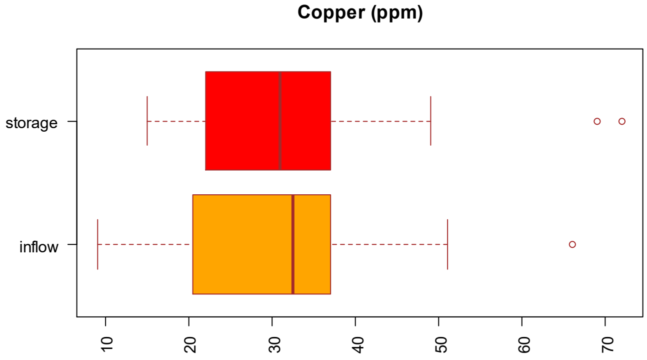
```
        n mean   sd median trimmed  mad  min  max range skew kurtosis se
inflow  52 0.06 0.01   0.06    0.06 0.01 0.03 0.09  0.06 0.28     0.10  0
storage 52 0.06 0.01   0.06    0.06 0.01 0.04 0.08  0.04 0.19    -0.65  0
```

15) Aluminum



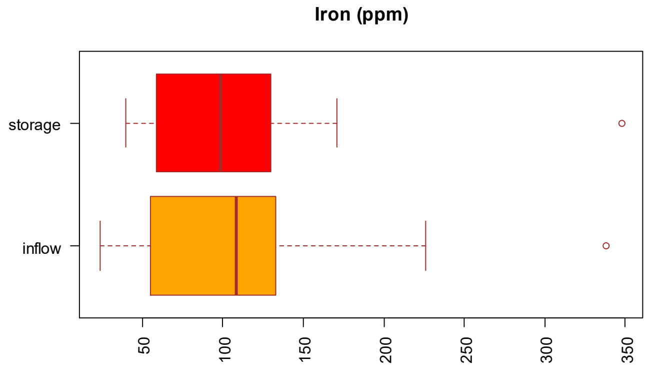
```
        n  mean    sd median trimmed   mad min max range skew kurtosis   se
inflow  52 39.93 22.40   38.5   37.43 17.79   9 117   108 1.13     1.59 3.11
storage 52 38.56 21.97   37.5   36.17 18.53  13 146   133 2.21     8.57 3.05
```

16) Copper



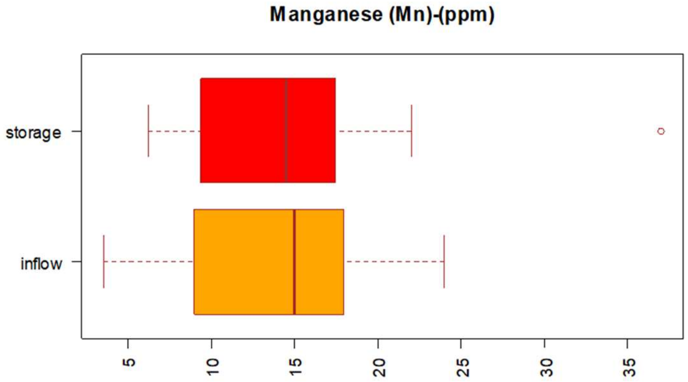
```
        n  mean    sd median trimmed   mad  min max range skew kurtosis   se
inflow  52 30.69 11.50   32.5   30.36 11.86  9.1  66  56.9 0.28     0.13 1.60
storage 52 31.04 12.05   31.0   29.88 10.38 15.0  72  57.0 1.15     2.17 1.67
```

17) Iron



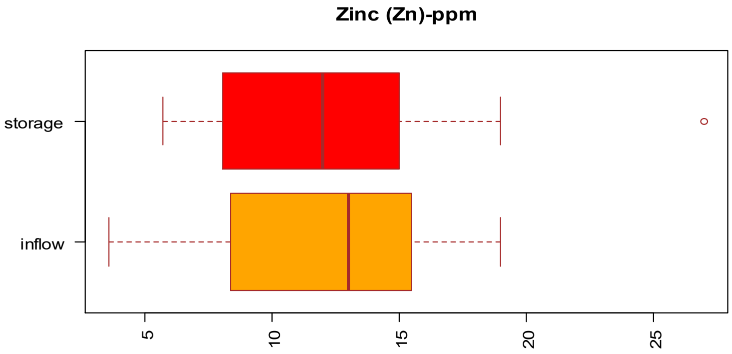
```
          n   mean    sd    median trimmed  mad   min  max range skew kurtosis  se
inflow   52 107.56 56.37  108.5  102.48    46.70  24   338  314   1.31    3.53 7.82
storage  52 101.33 52.37   98.5   96.93    54.11  40   348  308   1.88    7.03 7.26
```

18) Manganese



```
         n  mean   sd median trimmed  mad min  max range  skew kurtosis   se
inflow   52 14.39 5.28   15.0   14.48 4.45 3.6   24  20.4 -0.27   -0.93  0.73
storage  52 14.29 5.74   14.5   13.95 5.19 6.2   37  30.8  0.99    2.59  0.80
```

19) Zinc



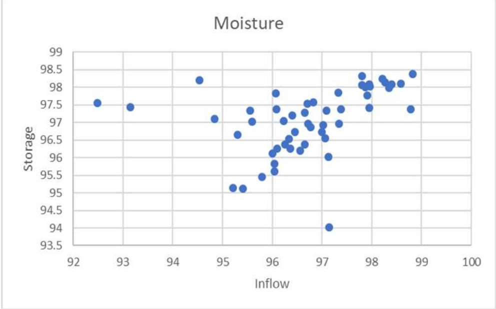
```
         n  mean   sd  median trimmed  mad min  max range  skew kurtosis   se
inflow  52 12.08  4.09     13   12.30 4.45 3.6   19  15.4 -0.50   -0.94  0.57
storage 52 11.97  4.51     12   11.72 4.45 5.7   27  21.3  0.58    0.49  0.63
```

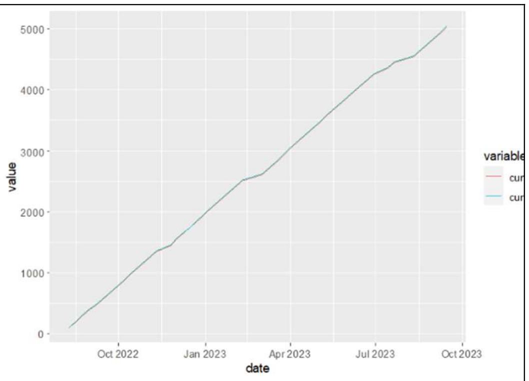
The scatter plot of the results of inflow and storage samples (see below) showed a relationship between the samples during the study period and due to this correlation paired sample t-test, such as, nonparametric Wilcoxon signed rank test, was considered in this study. However, the time dependence of the results of the samples from the same locations required the use of paired sample permutation test instead due to autocorrelation of the results for both samples during the monitoring period.

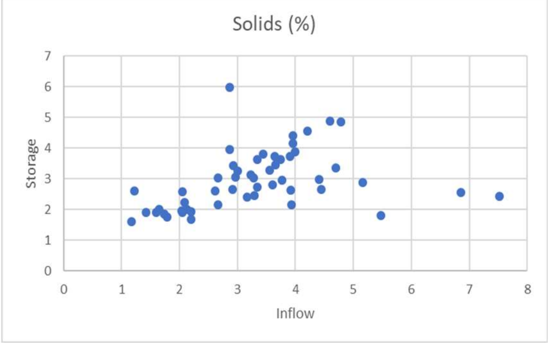
To observe the difference between the inflow and storage series, the cumulative values are plotted during the test period (see below). Equality of the medians is tested by paired sample permutation test, which is used for autocorrelated sample pairs.

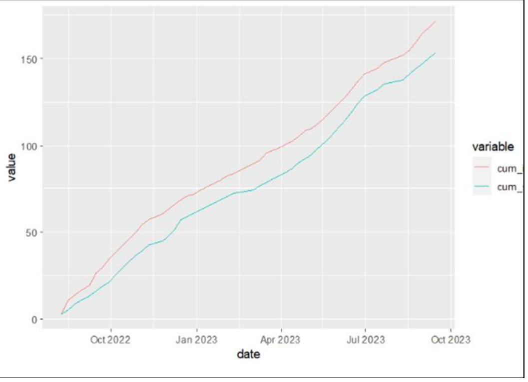
The correlation between samples and cumulative values of each parameter over a year period and p-values for significance are provided below.

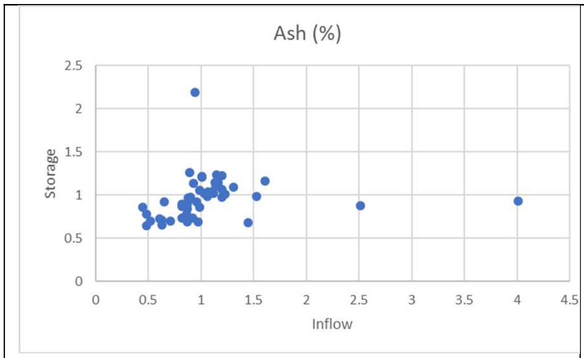
Scatter and cumulative plots of the measured parameters:

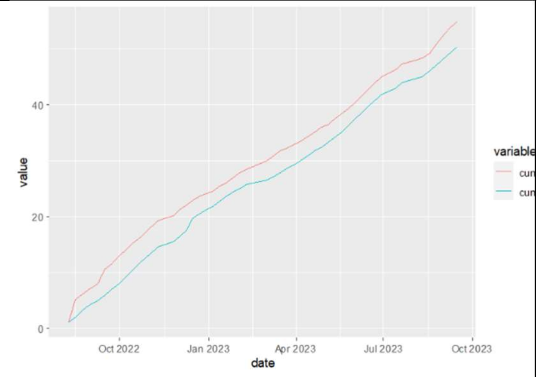


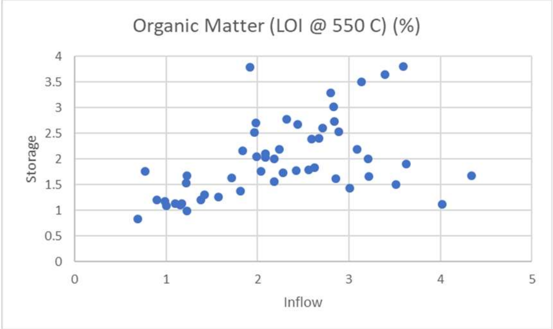


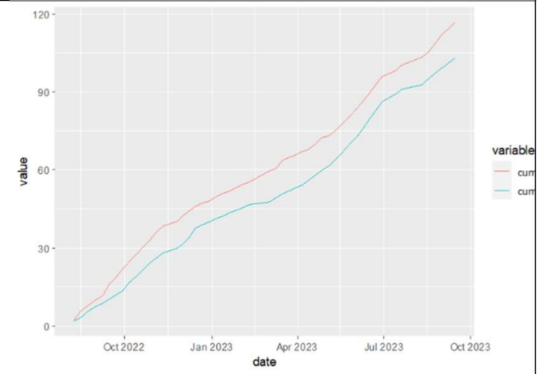


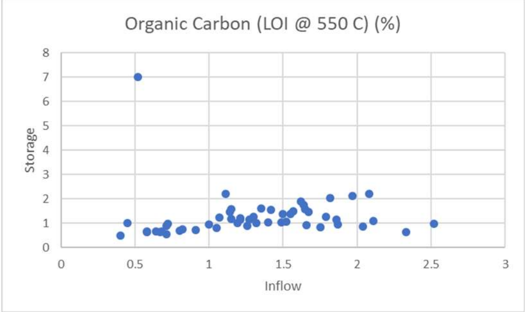


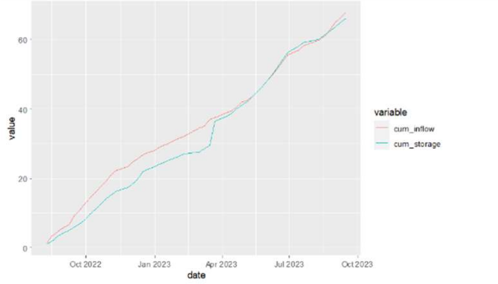

Ash (%)
Storage
Inflow
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

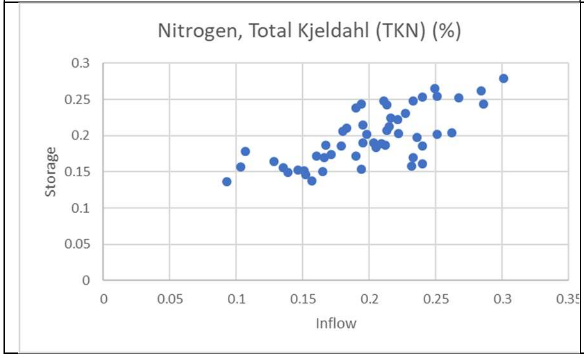

value
date
0
20
40
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
variable

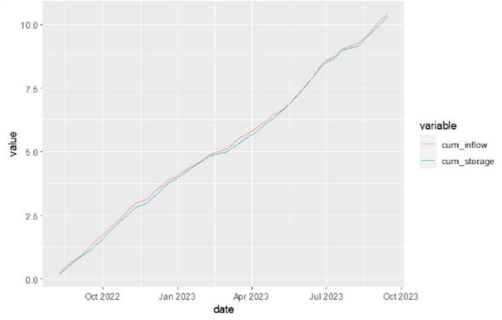

Organic Matter (LOI @ 550 C) (%)
Storage
Inflow
0
0.5
1
1.5
2
2.5
3
3.5
4
5

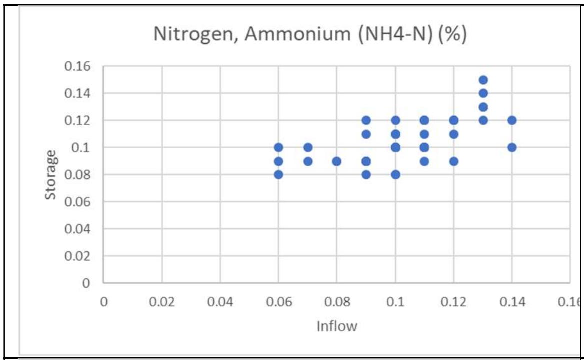

value
date
0
30
60
90
120
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
variable

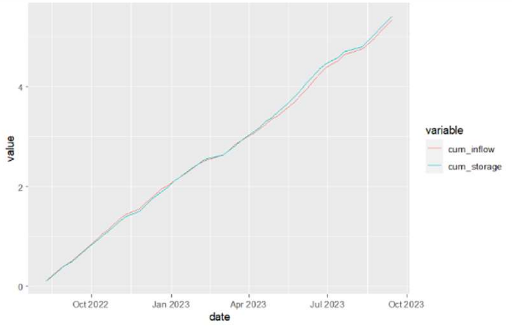

Organic Carbon (LOI @ 550 C) (%)
Storage
Inflow
0
1
2
3
4
5
6
7
8
0.5
1.5
2.5

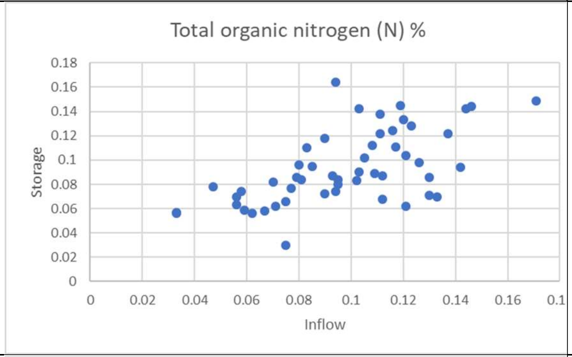

value
date
0
20
40
60
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
variable
cum_inflow
cum_storage

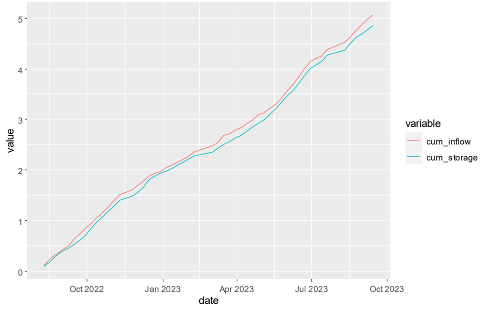

Nitrogen, Total Kjeldahl (TKN) (%)
Storage
Inflow
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

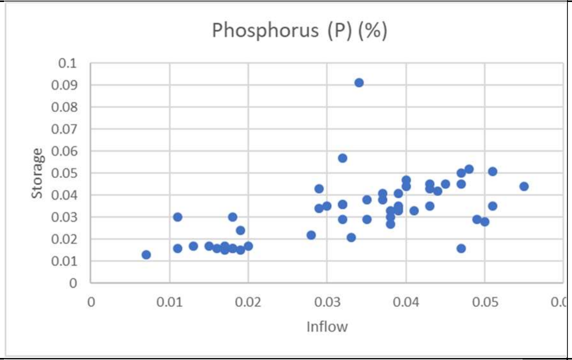

value
date
0.0
2.5
5.0
7.5
10.0
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
variable
cum_inflow
cum_storage

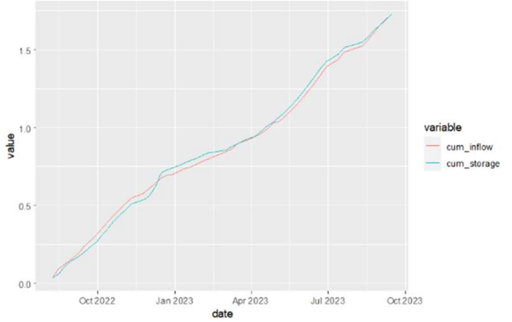

Nitrogen, Ammonium (NH4-N) (%)
Storage
Inflow
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16

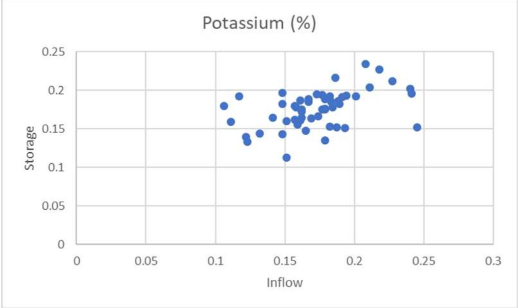

value
date
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
0
2
4
variable
cum_inflow
cum_storage

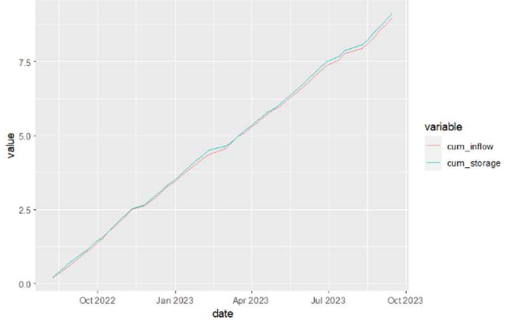

Total organic nitrogen (N) %
Storage
Inflow
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18

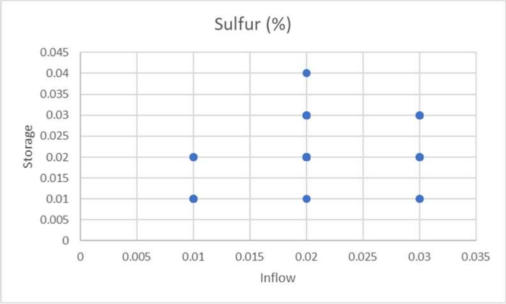

value
date
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
0
1
2
3
4
5
variable
cum_inflow
cum_storage

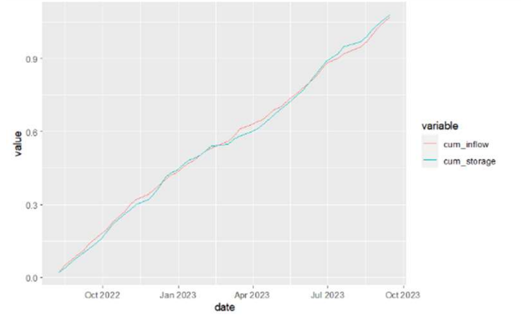

Phosphorus (P) (%)
Storage
Inflow
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

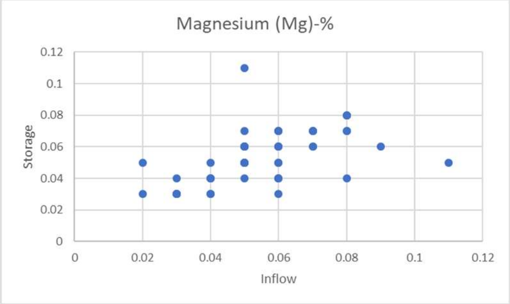

value
date
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
0.0
0.5
1.0
1.5
variable
cum_inflow
cum_storage

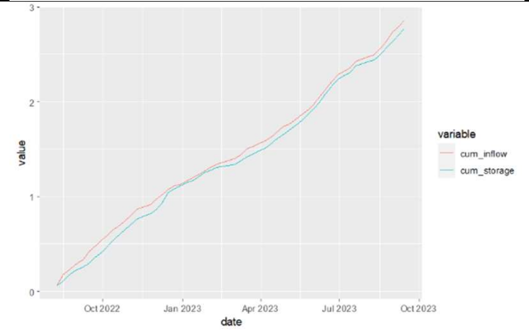

Potassium (%)
Storage
Inflow
0
0.05
0.1
0.15
0.2
0.25
0.3

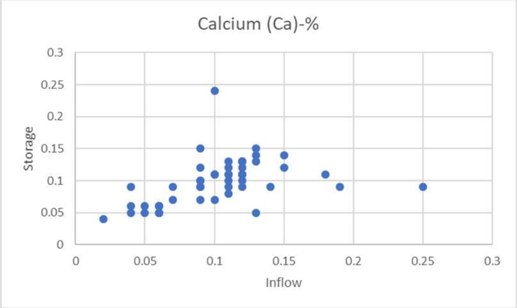

value
date
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
0.0
2.5
5.0
7.5
variable
cum_inflow
cum_storage

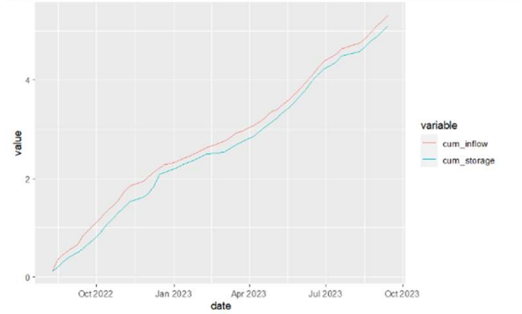

Sulfur (%)
Storage
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
Inflow

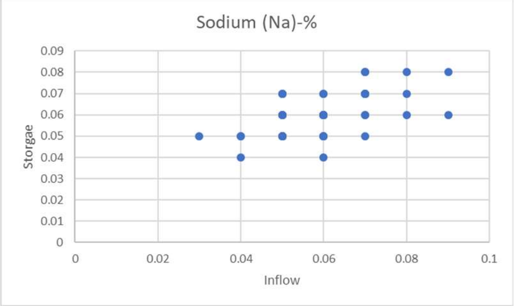

value
0.0
0.3
0.6
0.9
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage

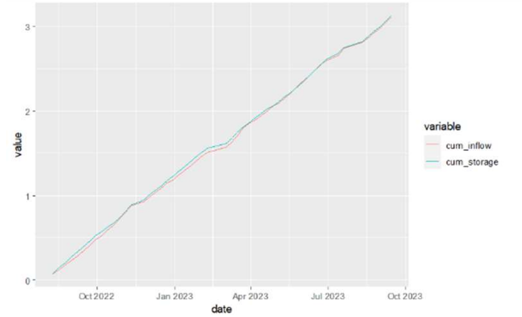

Magnesium (Mg)-%
Storage
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.02
0.04
0.06
0.08
0.1
0.12
Inflow

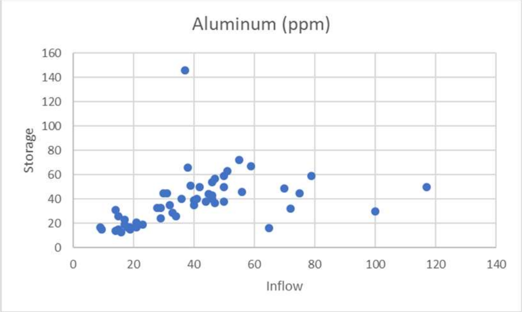

value
0
1
2
3
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage

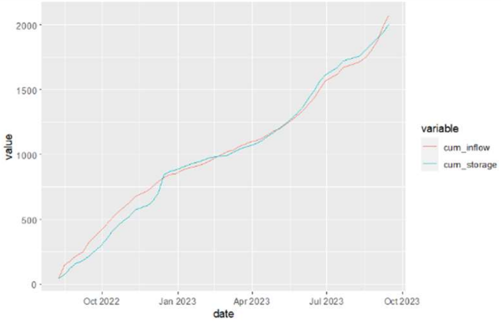

Calcium (Ca)-%
Storage
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Inflow

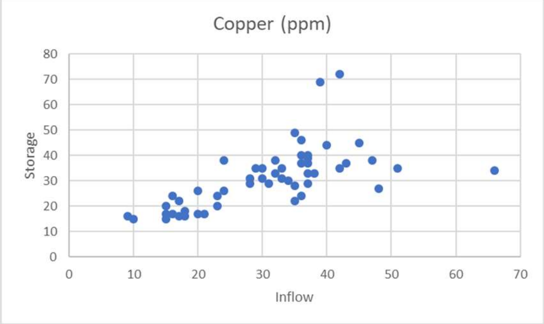

value
0
2
4
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage

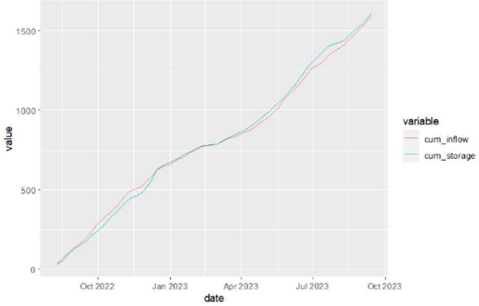

Sodium (Na)-%
Storgae
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.02
0.04
0.06
0.08
0.1
Inflow

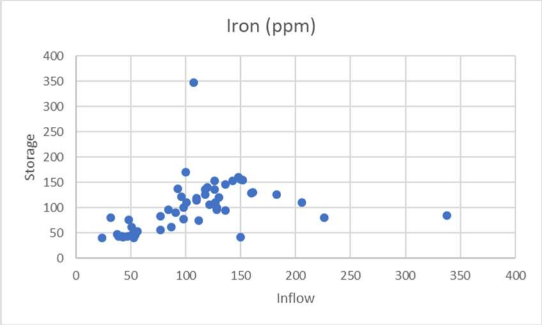

value
0
1
2
3
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage

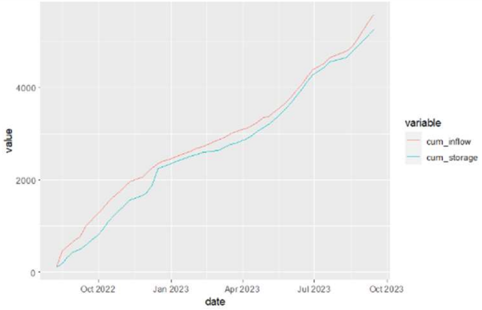

Aluminum (ppm)
Storage
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Inflow

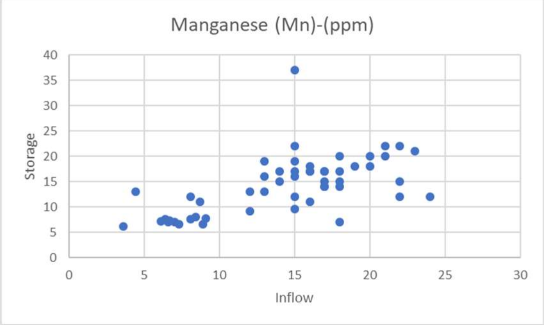

2000
1500
1000
500
0
value
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage

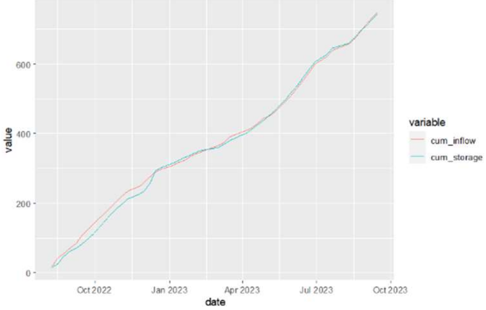

Copper (ppm)
Storage
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
Inflow

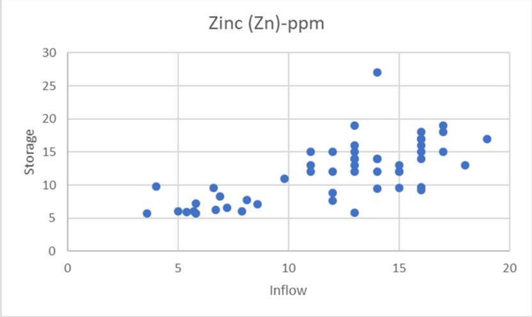

1500
1000
500
0
value
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage

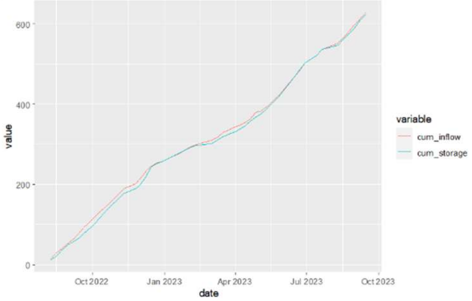

Iron (ppm)
Storage
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
Inflow


4000
2000
0
value
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage


Manganese (Mn)-(ppm)
Storage
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Inflow


600
400
200
0
value
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage


Zinc (Zn)-ppm
Storage
30
25
20
15
10
5
0
0
5
10
15
20
Inflow


600
400
200
0
value
Oct 2022
Jan 2023
Apr 2023
Jul 2023
Oct 2023
date
variable
cum_inflow
cum_storage

Results of the Hypothesis Test (Paired Sample Permutation Test)

The statistical calculations were made using R (package EnvStats). The example of the calculation results (for moisture) is shown below:

```
Null Hypothesis:                 Mean (Median) of Differences = 0

Alternative Hypothesis:          True Mean (Median) of Differences is great
er than 0

Test Name:                       Paired-Sample Permutation Test
                                 (Based on Sampling
                                 Permutation Distribution
                                 10000 Times)

Estimated Parameter(s):          Mean (Median) of Differences = -0.3540385

Data:                            x = moistureinflow
                                 y = moisturestorage

Sample Size:                     52

Test Statistic:                  Sum(x-y) = -18.41

P-value:                         0.9751
```

The p-values of each parameter for the significance of median value difference between inflow and storage samples are listed below in Table A2.1.

Table A2.1. The p-values of the median value difference between inflow and storage samples for the parameters measured (n=52, p level=0.05)

Parameter	P-value
Moisture	0.9751
Solids	0.0270
Ash at 550 C	0.1559
Organic Matter (LOI at 550 C)	0.0141
Organic Carbon (LOI at 550 C)	0.4462
Total Kjeldahl Nitrogen (TKN)	0.2845
Ammonium Nitrogen (NH4-N)	0.7395
Organic nitrogen	0.1328
Phosphorus (P)	0.4962
Potassium (K)	0.7749
Sulfur (S)	0.6453
Magnesium (Mg	0.2527
Calcium (Ca)	0.2443
Sodium (Na)	0.6199
Aluminum (Al)	0.3471
Copper (Cu)	0.5990
Iron (Fe)	0.2415
Manganese	0.4442
Zinc (Zn)	0.4106