H2Ohio Technology Assessment Program (TAP)

Final Report

Assessment of Nutrient Management Technology Submission

QuickWash®

January 2022

TETRA TECH

EXECUTIVE SUMMARY

Applied Environmental Solutions (AES), of Madison, Ohio, submitted a technology proposal for QuickWash® Phosphorus Recovery (QW-P) to the Ohio Environmental Protection Agency' (Ohio EPA's) H_2Ohio Technology Assessment Program (TAP) for the purpose of addressing the Lake Erie algal blooms and associated nutrient loading. The TAP objective addressed by QW-P is to: 1) Reduce nutrient loading to rivers, streams, and lakes, 2) Recover nutrients from animal waste and 3) Improvement of nutrient removal in wastewater treatment systems. Tetra Tech, Inc. (Tetra Tech) was selected by the H2Ohio TAP Team to serve as a third party and provide an independent evaluation of each technology.

QuickWash® is a suite of United States Department of Agriculture (USDA) patented technologies focused on the recovery of both excessive phosphorus (QW-P), and most recently, ammonia (QW-N) nutrients. This evaluation focused on the QW-P technology.

AES provided studies and pilot projects that demonstrated how the QW-P technology has significantly reduced phosphorus (P) in multiple Ohio applications including municipal wastewater, agricultural manure (swine, dairy and egg operations), and lagoon based treatment systems. Through the reduction of excessive P, QW-P also has an impact on the reduction of algal bloom intensity as it removes excess P that could enter rivers, streams and lakes within the Western Lake Erie Basin (WLEB).

The QW-P process recovers P in the form of amorphous calcium phosphate (ACP) resulting in three co-product streams: 1) the resulting ACP; 2) dewatered manure; and 3) a treated water stream that contains significantly lower phosphorus which has been demonstrated to be an effective source of irrigation water on crop land. While primarily focused on P reduction, additional reductions in nitrogen have also been demonstrated.

Results from AES studies and pilot projects with regard to the cost analysis confirm multiple options exist to achieve the target economics of <$0.01/gallon treated for at least 50% reduction in P at all operation sizes modelled. Additionally, the cost differential to achieve maximum P reduction is slightly over the target cost for a 50% reduction and is likely to be close to the target cost if the value of co-products (ACP, treated water, and dewatered manure) produced are considered.

QuickWash® could provide a technology solution that allows for the movement of recovered P to other regions where a P deficits exist and/or reduces the need for Ohio farmers to purchase commercial grade phosphorus, thereby reducing the total P in the WLEB by the amount recovered from manure. Implementation of the QuickWash® technology could therefore enable Ohio producers to actively manage their waste on-site and at costs comparable to untreated land application.

This report evaluates QW-P against a suite of criteria identified by the TAP using information provided by AES and obtained elsewhere. Tetra Tech determines that QW-P is very likely to be effective at reducing nutrient loading to Lake Erie, in direct proportion to the number of livestock operations to which it is applied. Tetra Tech did not identify any negative impacts associated with environmental risks, supply chain limitations, or community perception. The estimated total costs are within <$0.01/gallon treated for phosphorus, which are within the range of other similar agricultural best management practices. Tetra Tech believes that the

QuickWash® suite of technologies offer a cost-effective means to recover phosphorus, and ammonia, from wastewaters and liquid manures.

The biggest barrier to applying QW-P at a scale large enough to make a significant impact is landowner willingness, which could be addressed through financial support provided by the H2Ohio Initiative. A demonstration project targeting widespread adoption of QW-P could evaluate the ability of financial incentives to spur landowners to use this technology and could also provide more detailed data about the potential value and markets for the co-products generated from to implementation of QW-P within the Lake Erie drainage basin.

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ACP	Amorphous Calcium Phosphate
AES	Applied Environmental Solutions
BOD	Biological Oxygen Demand
BOM	Bill of Materials
CAPEX	Capital Costs
COD	Chemical Oxygen Demand
FTE	Full Time Equivalents
HABs	Harmful Algal Blooms
ICP	Inductively Coupled Plasma
kwh	kilowatt hours
Kurtz	Kurtz Brothers, Inc.
lb./1,000 gal	pounds per 1,000 gallons
lb./ton	pounds per ton
LIFT	Leaders Innovation Forum for Technology
mg/L	milligrams per liter
MGD	Million Gallons per Day
NH3	Ammonia
NH4	Ammonium
NPDES	National Pollution Discharge Elimination System
NPV	Net Present Value
NRCS	Natural Resource Conservation Service
ODA	Ohio Department of Agriculture
Ohio EPA	Ohio Environmental Protection Agency
OPEX	Annual Operating Costs
OWDA	Ohio Water Development Authority
P	Phosphorus
P&ID	Piping and Instrumentation Diagram
P205	soluble phosphorus or phosphorus pentoxide

Acronyms/Abbreviations	Definition
PPE	Personal Protective Equipment
PWWTP	Perrysburg Wastewater Treatment Plant
QAPP	Quality Assurance Project Plan
QW-N	QuickWash® Ammonia Recovery
QW-P	QuickWash® Phosphorus Recovery
RFT	Request for Technology
RIN	Renewable Identification Numbers
RN	Renewable Nutrients
RNG	Renewable Natural Gas
SDS	Safety Data Sheet
TAP	Technology Assessment Program
TCO	Total Cost of Ownership
Tetra Tech	Tetra Tech, Inc.
TP	Total Phosphorus
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
WE&RF	Water Environment & Reuse Federation
WLEB	Western Lake Erie Basin

1.0 INTRODUCTION AND BACKGROUND

H2Ohio (http://h2.ohio.gov) is Ohio Governor Mike DeWine's comprehensive, data-driven water quality plan to reduce Harmful Algal Blooms (HABs), improve wastewater infrastructure, and prevent lead contamination. Governor DeWine's H2Ohio plan is an investment in targeted solutions such as :

- Reducing phosphorus runoff through increased implementation of agricultural best management practices and the restoration of wetlands;
- Improving wastewater infrastructure;
- Replacing failing home septic systems; and
- Preventing lead contamination in high-risk daycare centers and schools.

HABs have been a concern in Lake Erie for decades, and the State of Ohio has a long history of developing solutions to address them. In support of these efforts, state agencies are often presented with new approaches for addressing HABs. These approaches often involve technologies and products that are typically innovative, can be proprietary, and span multiple scientific disciplines. To evaluate these proposals for their efficacy and feasibility, the Ohio Environmental Protection Agency (Ohio EPA) worked with the Ohio Lake Erie Commission to create a public advisory council—the Technical Assessment Program (TAP) Team. The H2Ohio TAP Team is comprised of representatives from the private sector, public sector, trade associations, and non-profit companies. The H2Ohio TAP team is conducting an evaluation of technologies designed to treat, control, and reduce HABs in the Lake Erie watershed. H2Ohio initiated the TAP to solicit and evaluate technologies that support one or more of the following five goals:

1. Reduction of nutrient loading to rivers, streams, and lakes;
2. Removal of nutrients from rivers, streams, and lakes;
3. Reduction of the intensity or toxicity of algal blooms;
4. Recovery of nutrients from animal waste; and
5. Improvement of nutrient removal in wastewater treatment systems.

The H2Ohio TAP Team worked to solicit and prioritize technology proposals for further review. A Request for Technologies (RFT) was developed and issued by the Ohio EPA in November 2020 (H2Ohio TAP, 2020). The H2Ohio TAP conducted a thorough evaluation of the 40+ proposals received in response to the RFT and selected 10 technologies for further evaluation. The developers of these 10 technologies were given an opportunity to provide additional information and supporting data to allow an independent evaluation of their technology by a third party, Tetra Tech, Inc. (Tetra Tech).

As a contractor to the Ohio EPA, Tetra Tech conducted an independent third-party evaluation of the 10 technologies selected by the H2Ohio TAP team. The goal of the evaluation was to provide a general assessment of the potential effectiveness, implementability, readiness, and cost of deploying each technology. Select technologies may eventually be demonstrated in the field under future H2Ohio programs.

2.0 PURPOSE

The primary purpose of the technology assessment and evaluations was to conduct a comprehensive scientific evaluation of the selected technologies to determine if and how they could be utilized to address HABs in Lake Erie.

Most of the information provided in this report with regard to QuickWash® Phosphorus Recovery (QW-P) was provided by the vendor, Applied Environmental Solutions (AES), and Tetra Tech attempted to verify it using independent sources, when available. Tetra Tech focused its verification efforts on key aspects of the technology (e.g., effectiveness, cost) as well as any claims that seemed questionable. Otherwise, Tetra Tech assumed information provided by the vendor to be accurate. Instances where Tetra Tech is unsure of a claim being made by the vendor are noted in the report.

Based on input from Ohio EPA and the H2Ohio TAP team, Tetra Tech established primary (P1 & P2) and secondary (S1 & S2) objectives for the third-party evaluation program. The primary objectives are critical to the technology evaluation and involve conclusions regarding technology performance that are based on quantitative and semi-quantitative data. The primary objectives for the evaluations of the participating technologies are as follows:

- P1: Effectively assess the performance, cost-effectiveness, and reliability data gathered from each vendor with regard to one or more of the 5 H2Ohio goals:
  - Reduce nutrient loading to rivers, streams, and lakes:
  - Remove nutrients from rivers, streams, and lakes:
  - Reduce the intensity or toxicity of algal blooms
  - Recover nutrients from animal waste:
  - Improve nutrient removal in wastewater treatment systems, specifically with small (e.g. lagoon) and decentralized systems
- P2: Ensure that the evaluations are completed by appropriate personnel using a documented, consistent approach and level of detail, to include:
  - Proof of concept review
  - Fatal flaw analysis
  - Review of previous implementation of the technology or similar technologies
  - Review of data quality objectives
  - Review of quality assurance/quality control procedures and reports
  - Evaluation of scalability
  - Information gap evaluation
  - Evaluation of cost; both total and by unit, such as nutrient reduced/removed
  - Feasibility review for a proposed demonstration project
  - Feasibility review for full scale implementation
  - Statement of probability of success

The secondary objectives pertain to Tetra Tech's approach to assessing and presenting the information and thus support the primary objectives. The secondary objectives for Tetra Tech's evaluation are as follows:

- S1: Prepare Comprehensive Scientific Assessment and Recommendations Reports for each technology that will support potential users' ability to make sound judgements on the applicability of the technology to a specific site and to compare the technology to alternatives.
- S2: Ensure that project deliverables follow consistent format and similar levels of detail. Each report will contain:
  - A summary of the technology and results of past uses of the technology;
  - Results of conceptual model review, fatal flaw analysis, and information gap evaluation;
  - A statement of probability of success and scalability of the project;
  - Verification of cost estimates at various implementation levels;
  - Results of the feasibility review for a potential demonstration project and full-scale implementation of the technology;
  - Verification of claims made by applicants.

The technology evaluation consisted of the (1) collection; (2) evaluation; and (3) summarizing and reporting of data on the performance and cost of each technology. These data provided the basis for meeting the primary objectives.

Most data supporting these evaluations were provided by the technology developers and Tetra Tech attempted to verify it using independent sources, when available. Tetra Tech focused its verification efforts on key aspects of the technology (e.g., effectiveness, cost) as well as any claims that seemed questionable. Otherwise, Tetra Tech assumed information provided by the vendor to be accurate. Instances where Tetra Tech is unsure of a claim being made by the vendor are noted in the report. In some cases, information was also obtained from the peer-reviewed scientific literature. Tetra Tech worked with each developer to obtain the data necessary to meet the primary and secondary evaluation objectives.

Tetra Tech then completed an independent evaluation of the data provided by each developer and prepared separate reports for each technology evaluation, following a consistent report format. This report provides a summary of our review of QuickWash® Phosphorus Recovery.

3.0 TECHNOLOGY OVERVIEW

QuickWash® is a suite of United States Department of Agriculture (USDA) patented technologies focused on the recovery of both excessive phosphorus (QW-P), and most recently, ammonia (QW-N) nutrients. The relevant patent numbers are summarized in the following table (Vanotti and Szogi, 2005 & Szogi et al, 2014):

Table 1 - Applicable Patents

Application	Patent Number
Phosphorus	US 8,673,046
Ammonia (Liquid)	US 9,005,333
Ammonia (Liquid Divisional)	US 9,708,200

Application	Patent Number
Ammonia (Gaseous)	US 8,906,332
Combined Phosphorus & Ammonia	US 9,005,333

QW-P has been successfully vetted through the Water Environmental & Reuse Federation (WE&RF) Leaders Innovation Forum for Technology (LIFT) Technology Scan Process for Phosphorus Recovery (Treatment Plant Operator, 2017). QW-P has been demonstrated to significantly reduce phosphorus in multiple Ohio applications including municipal wastewater, agricultural manure (swine, dairy and egg operations), and lagoon-based treatment systems. QW-P also has an impact on the reduction of algal bloom intensity as it removes excess phosphorus that could enter rivers, streams and lakes.

The QW-P process recovers phosphorus in the form of amorphous calcium phosphate (ACP) resulting in two co-product streams: 1) the resulting ACP and 2) a treated water stream that contains significantly lower phosphorus which has been demonstrated to be an effective source of irrigation water on crop land. While primarily focused on phosphorus reduction, additional reductions in nitrogen have also been demonstrated (Renewablenutrients.com, n.d.). Through a companion technology to recover excessive ammonia (QW-N) in the form of an ammonium salt (such as ammonium sulfate or ammonium citrate), the QuickWash® suite of technologies offer a cost-effective means to recover both nitrogen and phosphorus from wastewaters and liquid manures. The University of Toledo with AES has been awarded a 2021 Ohio Water Development Authority (OWDA) Research Grant to explore application of QW-N to Ohio based waters of interest (University of Toledo, 2021).

4.0 TECHNOLOGY EVALUATION

This section of the report addresses each of the criteria identified by Ohio EPA to be included in the independent evaluation process.

4.1 CONCEPTUAL MODEL REVIEW

Originally developed by the USDA for application in poultry applications, QW-P has grown to be used wherever the need exists to reduce phosphorus regardless of the source of the phosphorus. Considerable data has been developed supporting its use in agricultural manure treatment, municipal side stream processes (such as sludge dewatering) and anaerobic digestate treatment. The main direct beneficiaries of the use of this technology will be clients with challenges associated with excessive phosphorus concentrations. Secondary beneficiaries include communities directly impacted by excessive nutrients such as watershed managers, source drinking water managers and landowners who are negatively impacted by the impact of excessive nutrients leading to HABs. Since the QW-P technology results in the recovery of phosphorus in the form of ACP, other beneficiaries would include industries looking to broaden their portfolio of cost-effective natural nutrient sources.

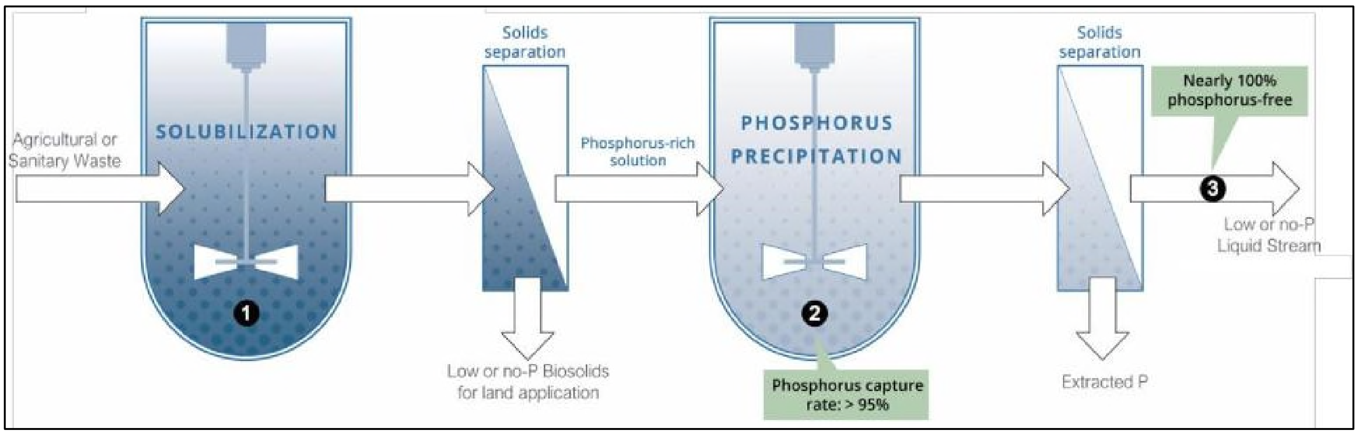
QW-P is primarily a two-stage, non-biological process (Renewablenutrients.com, n.d.):

Stage 1 - involves a conversion of the particulate phosphorus content to become soluble (solubilization). This is accomplished through acid hydrolysis.

Stage 2 - involves the precipitation of the soluble phosphorus into ACP through the use of hydrated lime (precipitation) leaving behind a treated water that is low in phosphorus (and nitrogen) content.

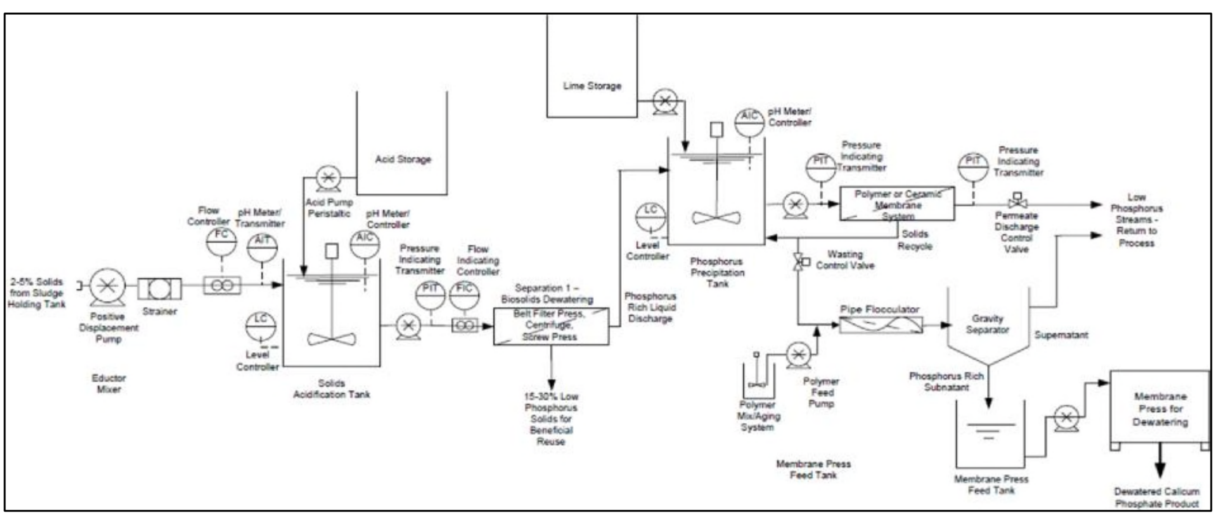
The resulting water after removal of the Stage 2 solids (ACP) is nearly phosphorus free. These stages are summarized in the following graphic. For agricultural applications, the solids separation step between Stage 1 and Stage 2 can be minimized or eliminated resulting in the solids removed following Stage 2 containing the organic material that might have been removed. The result is a well-balanced high phosphorus solids (i.e. fertilizer) type product.

Figure 1 - QW-P 2-Stage Process



Because the application of a QW solution is very flexible, each potential application can be provided a tailored solution that meets the clients' needs at the most economical cost possible. Because QW is equipment agnostic, reuse of existing infrastructure may also be possible. The following is a QW-P Generic Process Flow diagram (Civil West Engineering, n.d.).

Figure 2 - QW-P - Generic Process Flow Diagram



4.2 FATAL FLAW ANALYSIS

A formal fatal flaw analysis was not submitted by AES as part of their response to this evaluation, so a limited fatal flaw screening was completed based upon review of the information submitted and presented in this report. No obvious fatal flaws were identified with regard to the QuickWash® technology or its implementation.

However, several challenges to implementation were identified, especially when considering large scale or regional implementation. As will be discussed later in this report, the cost of implementation, equipment, and the ability of AES to provide enough experienced staff all represent potential challenges.

4.3 REVIEW OF PREVIOUS IMPLEMENTATION OF QUICKWASH®

AES provided 4 recent and relevant study reports/documents pertaining to successful projects conducted to evaluate the efficacy of the QW-P technology. Tetra Tech believes these studies demonstrate the feasibility and viability of this technology for use in Ohio to help reduce phosphorus and thus prevent it from entering the Lake Erie Watershed. Full copies of these reports can be provided by AES and are only summarized for the purposes of the evaluation.

4.3.1 Evaluation Summary – Dairy Digestate P Reduction through Recovery

This bench-scale evaluation was conducted to assess the ability of the USDA Patented QuickWash® technology to reduce excess phosphorus resulting from the anaerobic digestion of dairy and swine manure (AES, 2020). A 5-gallon sample of digestate was obtained from a dairy in Michigan and evaluated by AES.

The evaluation was conducted to investigate 4 different degrees of solubilization (low, low-medium, medium, and high) and for each degree of solubilization, 3 different levels of precipitation (low, high, and max) to map out the response of the digestate to the QuickWash® process. Estimated capital costs (CAPEX) and annual operating costs (OPEX) were determined for each of the 12 process conditions (4 x 3 matrix). A 10-year total cost of ownership (TCO) was also determined using a present worth analysis based on a 5% discount rate and an estimated sinking fund to account for maintenance and replacement parts for each condition. Finally, 2 different types of hydrated lime were evaluated for each condition to compare the process response to lime type. The 2 types of lime evaluated were identified as pure and mixed. The pure lime is a high purity calcium hydroxide mix (95% calcium hydroxide) and the mixed lime (dolomitic) was a 60/40 mix of calcium hydroxide/magnesium hydroxide blend.

At the conclusion of the initial matrix testing, a larger sample of water was treated with the optimum conditions to generate enough calcium phosphate for analysis. Both the calcium phosphate and decant waters were evaluated.

Upon completion of the evaluation, the following conclusions were made:

1. The use of QuickWash® can significantly reduce the amount of total phosphorus in the digestate tested. A range of ~78% up to ~96% reduction is possible under conditions used.
2. The least costly set of process conditions (low solubility, low precipitation, mixed lime) results in an estimated TCO estimate of $0.0085 cost/gallon treated and should achieve a 78% reduction in total

phosphorus. These conditions would achieve a daily production of 7,275 pounds of calcium phosphate with an estimated market value of $1,090 per day. (Note that 2021 data provided by AES estimates a 85% reduction)

3. From a compliance strategy perspective, should the incoming phosphorus load be higher than what was modelled, an alternative strategy may be to consider a capital installation which would include the ability to solubilize slightly more should it be needed. This would add an incremental OPEX of $0.003/gallon treated (to $0.0111/gallon treated) (Note 2021 data provided by AES estimates $0.0069/gallon treated). The incremental capital and potential operating cost increase (if executed for the full period) would result in a TCO estimated cost of $0.0116/gallon treated.
4. Even though the use of a mixed hydrated lime may require more lime to be used, the overall impact on cost is more favorable than using a lower volume of higher purity calcium hydroxide material.

4.3.2 Maumee River P Reduction through Recovery at Perrysburg WWTP

The Perrysburg Wastewater Treatment Plant (PWWTP) in Perrysburg, Ohio is an efficiently run major facility that discharges directly into the Maumee River. Through careful management of its processes, the facility is consistently discharging water well below their current National Pollution Discharge Elimination System (NPDES) permit limit of 1 mg/L total phosphorus. The City of Perrysburg has been a willing participant in researching innovative technologies which have the potential to significantly reduce the amount of phosphorus entering the Western Basin of Lake Erie. It is the belief of the City that by supporting the investigation of select innovative technologies which have the potential to improve the overall water quality of Lake Erie, it can play an important role in advancing the health and recovery of this important water body.

In fall 2017, the City of Perrysburg was awarded an OWDA 2017 Research Grant (City of Perrysburg, 2019) to investigate the effectiveness of the USDA patented QuickWash® solution to significantly reduce the side stream phosphorus loads which result from their current wastewater treatment process.

A 5-month Demonstration Program was conducted at the PWWTP to demonstrate the ability of QuickWash® to significantly reduce phosphorus loads being recycled in the overall treatment processes. Following a thorough assessment of the current PWWTP recycle streams and cataloging of polymer and metal salt coagulant usage and flows, a detailed analysis of phosphorus testing and solubilization and precipitation processes used in the QuickWash® Technology was established to ensure a solid correlation with both the PWWTP in-house lab and third-party lab (Jones and Henry Labs) used. Following an extensive conduct of smaller scale (~200 ml) bench top tests to characterize the response of the Collection Well filtrate streams (primarily made up of Belt Filter Press filtrate and Anaerobic Digester Supernate streams), as well as pre-dewatering municipal sludge, larger batch evaluations which ranged in volume from 65 gallons to 95 gallons were conducted and results measured by the third-party lab.

The results generated confirmed the following conclusions:

1. QuickWash® effectively removed and recovered over 93% of the soluble phosphorus made available from the Collection Well samples evaluated;

2. QuickWash® reduced the phosphorus content in biosolids coming off of a dewatering process by almost 40%. This reduction occurred primarily due to the solubilization of phosphorus into the filtrate stream produced;
3. QuickWash® recovered 99% of the soluble phosphorus in the dewatered filtrate stream resulting from solubilized sludge;
4. Bench testing of a highly loaded swine anaerobic lagoon stream demonstrated that QuickWash® could reduce phosphorus loading over 98% - confirming results observed at PWWTP;
5. It was demonstrated that a total of 147 pounds of phosphorus per day could be recovered from the treatment of PWWTP municipal sludge with QuickWash®. Of this, 8 pounds per day would normally return back to the headworks of the plant while the majority was in the form of reduced biosolids phosphorus which eventually would be land applied;
6. A detailed analysis of calcium phosphate produced show that it is an excellent fertilizer and liming agent confirming its beneficial reuse;
7. Economics around application of QuickWash® at a 5 million gallons per day (MGD) facility similar to PWWTP would cost approximately $0.80/pound of P removed on a 20 year Present Worth basis. A significant cost recovery component associated with the value of calcium phosphate produced, metal salt coagulant reduced usage and sludge management costs was identified, and
8. The KDS Separator used in the pilot program provided a consistent dewatered sludge cake of 15-16% or 10-11% when used as a thickener. Further, it was able to provide the same level of dewatered cake dryness with a 50% reduction in polymer usage.

4.3.3 Pilot Project – Blanchard Demonstration Farms

This report provided a detailed summary of an extended duration pilot project to evaluate the ability of 2 proven technologies (QuickWash® and KDS Rotating Disc Separator) to reduce the manure phosphorus load in a deep pit swine manure application located in McComb, Ohio (AES, 2019a). Specifically, the objective was to develop the economics around a solution that would result in an operating cost of less than $0.01/gallon treated for a 50% reduction in phosphorus, specifically soluble phosphorus or phosphorus pentoxide (P2O5). Upon completion of the pilot project the following conclusions were made:

1. The ability to meet the stated objectives of <$0.01/gallon treated for a minimum of 50% reduction in phosphorus. Further, the ability to reduce phosphorus to levels approaching 95%+ for the same approximate economics was demonstrated.
2. Both levels of phosphorus reduction were achieved through use of the QuickWash® process with no supplemental solubility of particulate phosphorus necessary (i.e. acid addition). Both high purity calcium hydrated lime and a mixed calcium/magnesium hydrated lime were effective in reducing phosphorus to the levels achieved.
3. The use of the QuickWash® process produces a secondary product stream of calcium phosphate. Third party lab data confirms this product to be an attractive phosphorus fertilizer with a market value of

$0.15-$0.30 per pound. Depending on the level of treatment (i.e. phosphorus reduction achieved), this represents a potential gross revenue of $0.028-$0.10/gallon treated.

4. In addition, depending on the level of treatment employed, a beneficial reuse of the decant water of the treated manure for a nitrogen fertilizer (with additional nutritional properties) is possible. This allows for its potential use as supplemental irrigation water.
5. A high-level process map was developed which allows for the treatment of swine manure from a variety of swine manure management processes. This high-level process map incorporates both the KDS Separator and the QuickWash® processes as tested.
6. A detailed economic model was developed which evaluated a total of 9 different combinations of technology integration for low phosphorus reduction (50% reduction, 5 models) and maximum phosphorus reduction (90%, 4 models). These economics included OPEX, CAPEX, a 10-year TCO, and estimated labor required. The estimated labor requirement ranged from a minimum of 1 hour per week up to 4 hours per week.
7. Estimated CAPEX ranged from a low of $176,000 up to $290,000 depending on the level of treatment desired. These estimates included provision for a building in which to house the equipment.
8. A significant range in raw manure quality was observed during the trial period (from February through August). This was directly related to the solids content of the manure tested. Solids ranged from 1.43% (August) up to a high of 3.53% (February). Corresponding P2O5 levels ranged from a low of 3.16 lb./1000 gallons (August) up to 36.97 lb./1000 gallons (February). In essence, during the active testing period of July, the program was treating the decant water off of the solids that had settled in the bottom of the pit. Consequently, in order to dewater manure tested, polymers were required. A total of 9 different flocculants/coagulants were evaluated at 2 different concentrations (0.1% and 0.4%) of treatment. Of these, 3 were successful at achieving a 50% reduction in soluble phosphorus at the lower treating concentration and 5 were able to achieve a 50% reduction at the higher concentration. However, none met the threshold cost of $0.01/gallon treated. Based on previous testing conducted during spring 2018 in Mercer County with agitated manure from a deep pit, it is possible to achieve the target economics if a lower dosage could be applied. Treatment dosages approaching 0.05% would be required to meet the desired economics.
9. The use of a hydrated lime slurry versus mixing the slurry on-site was evaluated. While more convenient, the use of a delivered hydrated lime slurry represented a more expensive alternative to mixing on-site. This was taken into account in the estimated operating, capital and labor costs. Additional evaluation of the current lime used by the farm was shown to not be effective at recovering the soluble phosphorus present. This is because this lime is based on a calcium carbonate versus a calcium hydroxide and consequently, it was not as “active” at forming calcium phosphate.
10. The use of agitation of the deep pit manure was not possible due to pigs being housed in the barn at the end of the pilot. The potential costs associated with phosphorus reduction with an agitated stream were not possible to be determined, but it is envisioned that agitating deep pit manure between pig rotations could offer additional phosphorus reductions and can be managed through the same overall high level process proposed.

Overall, the program was successful at demonstrating the ability to achieve targeted economics at defined levels of phosphorus recovery. A recommendation to consider a full scale, long term installation was included.

The objective of this would be to develop long-term operational experience to further refine the treatment model and to serve as a Demonstration Site to advance broader adoption as a component to a more comprehensive nutrient management program. During this time, economics around agitation of the deep pit could be further evaluated. Additionally, a major area of focus would be to establish the marketability and value of the secondary product, calcium phosphate.

4.3.4 Pilot Project – Ohio Dairy Producers Association

This report provided a detailed summary of a pilot project to evaluate the ability of 2 proven technologies (QuickWash® and KDS Rotating Disc Separator) to reduce the manure phosphorus load in a large dairy application located in Forest, Ohio (AES, 2019b). Specifically, the objective was to develop the economics around a solution that would result in an operating cost of less than \$0.01/gallon treated for a minimum 50% reduction in phosphorus. Upon completion of the pilot project the following conclusions were made:

1. Both technologies were successful at achieving both the technical objective (>50% reduction in P) and economic objective (OPEX <\$0.01/gallon treated).
2. Use of the KDS technology alone required a polymer to increase the P reduction, but of the 8 polymers (flocculants/coagulants) tested, 5 met the cost objective at a dosage of 0.1%, while 2 of these met the target at 0.05%. A 63% reduction in P was realized at an OPEX of \$0.0052/gallon treated.
3. The maximum phosphorus reduction observed was 91% at a dosage of 0.4% (1 polymer), while 6 polymers achieved 86-88% reduction at 0.3%.
4. The KDS unit was able to achieve a 22.6% solids cake when operated in a dewatering mode and 12.4% when operated as a thickener – both results without polymer. The KDS unit ran continuously the last week of the pilot with no issues or problems reported. The majority of the dewatered manure was sent to a potential off-taker for review and testing. No results were available as of the issuance of this final report.
5. QuickWash® performed consistent with historical performance achieving close to 90% phosphorus recovery with minimal solubilization required. Further, QuickWash® was able to treat 3 different levels of polymer treated filtrate (good, borderline, non-responsive) achieving 86% - 92% phosphorus recovery with minimal solubility required. An estimated annual OPEX of \$0.0075/gallon treated for QuickWash® only application (i.e.. no polymer usage) was estimated to meet the >50% reduction in P.
6. Third party lab testing confirmed the calcium phosphate produced has potentially beneficial nutrient value as a well balanced fertilizer.
7. A total of 9 different process models were evaluated from an annual OPEX, CAPEX and 10-year Net Present Value (NPV) basis. These 9 models were assessed for 3 different dairy herd size operations.

Overall, the pilot was considered a success as they were able to demonstrate several alternative options to meet the cost and performance criteria established. A recommendation to consider a full scale, long-term installation was included. The objective of this would be to develop long-term operational experience to further refine the treatment model and to serve as a Demonstration Site to advance broader adoption as a component to a more comprehensive nutrient management program. Additionally, a major area of focus would be to establish the marketability and value of the produced manure solids and calcium phosphate.

4.4 COST EVALUATION

When estimating costs for deployment and implementation of the QuickWash® technology, AES considers the following 3 categories of costs, which all have been evaluated during the pilot projects and other studies identified previously in Section 4.3:

1. Annual Operating Costs or OPEX, which consist of consumables (primarily acid, hydrated lime and polymer for dewatering of the final product) and estimated power consumption. Labor costs are not estimated as this is managed separately by each site, however, an estimate of labor required (in terms of Full Time Equivalents (FTE) is provided).
2. In-scope Capital Costs or CAPEX, which consist of the AES costs associated with the design and engineering costs in providing a solution. The in-scope supply can vary from site-to-site depending on whether or not AES is to include influent delivery in the project. In general, a capex estimate would cover the AES portion from receipt of the water to be treated to the delivery of a stackable product of recovered phosphorus. Exclusions to the cost estimate would include permitting costs, cost of construction, or site preparation. Also included in the capex is a contingency that is based on the degree of uncertainty on cost estimates, a general category for license and commission (if applicable) fees, detailed engineering fees, a commissioning fee to establish a performance guarantee, and margin.
3. The final category is an estimate of a Total Cost of Ownership (TCO). Historically, this has been based on a 20-year basis for municipal projects and a 10-year basis for industrial or agricultural projects. These are based on a 5% interest and take into account annual OPEX over the time period and CAPEX. For purposes of this calculation, an estimate of replacement costs and annual maintenance are included in the OPEX calculation. Initial cost estimates would use a 1% of CAPEX per year estimate. This calculation becomes more precise as a project advances through the acceptance process.

The following sections provide a more detailed description of each category of cost.

4.4.1 OPEX

OPEX consists of consumables and estimated power consumption. QuickWash® consumables consist of acid, hydrated lime and polymer for final dewatering of the recovered phosphorus product. Power consumption is estimated on the basis of estimated kilowatt hours (kwh) times a representative cost/kwh. The default cost is $0.08/kwh but can be changed to fit a particular region or application.

As for consumables, while many different types of acid can be used, sulfuric acid is the most common acid used due to its efficiency and overall cost. Other acids used (depending on the application of the recovered phosphorus) have been acetic or citric. Two types of hydrated lime are used depending on the desired type of recovered phosphorus product. The most efficient type used is a high calcium hydroxide lime, but a dolomitic blend (60/40 mix of calcium hydroxide/magnesium hydroxide, respectively) can also be used. While the high calcium hydroxide form of lime is generally the most efficient for the recovery of phosphorus, use of a dolomitic blend has also provided an incremental increase in nitrogen constituents.

The type of polymer used is dependent on the particular stream being treated. Generally, a higher charged cationic polymer is used. The dosage required is dependent on the type of final dewatering used – geobag, plate & frame, screw press, etc.

Consumables are determined on the basis of titration curves conducted during various stages of evaluation. These titration curves are typically run on a series of process control pH's for solubility (acid addition) and within each of these, various process control pH's for precipitation of recovered phosphorus (lime addition). From these curves, an estimate of acid and lime consumption can be determined to achieve a desired set of conditions. Since lime is introduced as a slurry (typically 30% w/v), the volume of lime slurry measured is converted to weight of lime required to achieve a given set of conditions. The concentration of acid used is also dependent on site preferences. Typically, a 30% sulfuric acid blend is modelled.

When estimating OPEX costs, consumable costs per unit are based on bulk pricing provided by a supplier. For acid pricing Brenntag is used and for hydrated lime Graymont is used. OPEX estimates are made at various stages of an investigation. The initial assessment is based on bench testing (primarily titration curves) of a sample provided by a client. In addition to a technical assessment of performance, an initial estimate of OPEX is made based on the following model costs:

- Sulfuric Acid: $1.84/gal
- High purity calcium hydroxide hydrated lime: $0.40/lb.
- Dolomitic hydrated lime: $0.25/lb.

As a project progresses, the estimate of consumables is reconfirmed at various stages (for example during an on-site pilot) using progressively larger sample sizes. One of the deliverables from the detailed engineering study is a firm quote on delivery of bulk quantities of consumables to the client's site. The default assumption on lime slurry preparation is that the slurry is generated on-site, however, during this detailed engineering phase, a decision would be made on whether use of a more expensive delivered slurry mixture would be used.

4.4.2 CAPEX

A template is used which groups major categories of potential line items used in estimating the in-scope CAPEX assumptions for implementation of the QuickWash® technology. An example CAPEX worksheet is shown in the following Figure. This worksheet is only a guide as each site installation is different, however, it provides the framework for an initial capex estimate. It should be noted that this template also includes CAPEX estimates for QuickWash®-Ammonia Recovery (QW-N) as well as QW-P.

Figure 3 - Example CAPEX Worksheet

Item No.	Description	Units	Quantity	Unit Price	Total Price	Notes/Comments
1	**Lime Solution Storage Tank and Feed System with piping**					
1a	Tank	gal				
1b	Feed Pump skid	ea.				
1c	Controls and instrumentation	LS				
1d	Mixing Chamber	LS				
2	**Sulfuric Acid Storage Tank and Feed System with piping**					
2a	Tank	gal				
2b	Mixing system	LS				
2c	Instrumentation	LS				
2d	Feed Pump Skid	ea.				
3	**Polymer Storage and Feed with piping**					
3a	Polymer Storage Tank	gal				
3b	Feed pump system	LS				
3c	Instrumentation and controls	LS				
4	**Solids Separation System with piping**					
4a	Salsnes-type Packaged Filtration System	LS				
4b	Controls and Instrumentation	LS				
4c	Piping and appurtenances	LS				
5	**Gas-Permeable Membrane, Feed System, Piping and Ammonia Separation Tank**					
5b	Gas Membrane Modules	LS				
5b	Process feed pump to/through membranes	LS				
5c	Controls and instrumentation including PLC	LS				
5d	Ammonia recovery system	LS				
6	**Lamella Clarifier Packaged System for Precipatation and recovery of Calcium Phosphate product**					
6a	Aluminum settling tank, Lamellas, scraper, sump, solids pump, tube settlers, launders - packaged	LS				
6b	Mixing system	LS				
6c	Instrumentation	LS				
	Total Equipment Cost				**$0.00**	
	Contingency	%			$0.00	
	Detailed Engineering	%			$0.00	
	License Fees/Royalties	%			$0.00	
	Commissioning Expense	%			$0.00	
	Margin	%			$0.00	
	Total Estimated Capital Expense				**$0.00**	

It should be noted that the template assumes a standard Lamella Clarifier (Category 6) as provided by Parkson for final stage recovery of the phosphorus product. This can be replaced with any number of devices which provide similar performance.

As noted earlier, the CAPEX estimate also includes several additional considerations whose estimates are dependent upon the complexity of the installation. These additional considerations are defined as:

- **Contingency:** To allow for possible unknowns in the design at the time of estimate preparation.
- **Detailed Engineering:** This includes engineering drawings to support installation and process flows. These would also include piping and instrumentation diagrams (P&ID) or other drawings required to support permit development. Also included would be development of a detailed Bill of Materials (BOM) with firm estimates on costs plus consumables. Based on the defined BOM, a more precise estimate of

annual maintenance and sinking fund account monies for critical replacement items would be developed.

- **License fees / royalties:** These cover all license fees and commission expenses (if applicable).
- **Commissioning expense:** This is an estimate of a more detailed commissioning expense, beyond normal startup expenses, that is used to support development of a performance guarantee.
- **Margin:** Self-explanatory.

4.4.3 TCO

The final estimate provided is a TCO based on the annual OPEX and CAPEX using a 5% discount rate for a given period of time. For municipal applications this is based on a 20-year life, while for industrial and agricultural applications this is based on a 10-year life. In addition, for purposes of this calculation, an estimate of annual maintenance and provisions for a sinking fund to allow for replacement of critical pieces of equipment is included in the OPEX category. Similar to OPEX and CAPEX, this estimate is refined during project progression. Prior to completion of a detailed engineering investigation, this maintenance and sinking fund account is assumed to be 1% of CAPEX per year.

4.4.4 Estimated Costs

In order to be considered economically viable, the annual QuickWash® OPEX must be competitive to alternative solutions, principally, the cost of land application for agricultural applications. In mid-Ohio, it is AES's understanding and experience that the general target cost, to be competitive versus non-treated land application, is to be able to treat liquid manure at approximately $0.010/gallon. This is based on recent costs in the Mercer/Auglaize/Darke County areas (west-central Ohio), which can be summarized as (Dirksen, 2021):

> "...If one was applying to land close to the facility using a dragline, the cost is $0.00667 per gallon. If you are draglining 1 to 4 miles away, the cost doubles to about $0.013 per gallon. If you are putting manure on trucks and going less than 5 miles, cost is around $0.01 per gallon. 5-10 miles $0.015 per gallon, 20 miles $0.02 per gallon."

In pilot projects discussed previously, cost of treatment was always a deliverable. An overall summary of operating costs is shown in the following table (AES, 2019b):

Table 2 - QuickWash® Operating Cost Overview

Scenario	Model	$/gallon treated			
		Swine	Dairy - 100 head	Dairy - 250 head	Dairy - 500 head
Volume Manure, gal/year		700,000	1,300,000	3,250,000	6,500,000
50% TP Removal	Polymer only	$ 0.0172	$ 0.0052	$ 0.0050	$ 0.0049
	Poly + Lime mix	$ 0.0184	$ 0.0075	$ 0.1186	$ 0.0052
	Poly + Lime slurry	$ 0.0259	$ 0.0052	$ 0.0128	$ 0.0127
	Lime mix only	$ 0.0014	$ 0.0075	$ 0.0071	$ 0.0070
	Lime slurry only	$ 0.0090	$ 0.1169	$ 0.1166	$ 0.1165
Max TP removal	Poly + Lime mix	$ 0.0293	$ 0.0129	$ 0.0122	$ 0.0129
	Poly + Lime slurry	$ 0.1935	$ 0.1222	$ 0.1216	$ 0.1187
	Lime mix only	$ 0.0123	$ 0.0127	$ 0.0112	$ 0.0110
	Lime slurry only	$ 0.1766	$ 0.1810	$ 0.1804	$ 0.1803

These costs reflect the cost/gallon to treat annual manure loads from various type of farms and also compares various treatment methods to achieve either a 50% or the maximum reduction for each option. The green shaded costs are for the preferred solution that resulted in the best overall economics based upon the pilot projects. Similarly, Table 3 summarizes the Capital Cost and Table 4 summarizes the TCO, both of these are on a 10-year basis.

Table 3 - QuickWash® Capital Cost Overview

Scenario	Model	$/gallon treated			
		Swine	Dairy - 100 head	Dairy - 250 head	Dairy - 500 head
Volume Manure, gal/year		700,000	1,300,000	3,250,000	6,500,000
50% TP Removal	Polymer only	$ 0.0252	$ 0.0183	$ 0.0093	$ 0.0070
	Poly + Lime mix	$ 0.0379	$ 0.0221	$ 0.0116	$ 0.0086
	Poly + Lime slurry	$ 0.0413	$ 0.0253	$ 0.0126	$ 0.0092
	Lime mix only	$ 0.0361	$ 0.0221	$ 0.0111	$ 0.0083
	Lime slurry only	$ 0.0394	$ 0.0241	$ 0.0120	$ 0.0089
Max TP removal	Poly + Lime mix	$ 0.0384	$ 0.0238	$ 0.0118	$ 0.0087
	Poly + Lime slurry	$ 0.0413	$ 0.0253	$ 0.0126	$ 0.0092
	Lime mix only	$ 0.0365	$ 0.0225	$ 0.0112	$ 0.0084
	Lime slurry only	$ 0.0394	$ 0.0241	$ 0.0120	$ 0.0089

Table 4 - QuickWash® TCO Overview

Scenario	Model	$/gallon treated			
		Swine	Dairy - 100 head	Dairy - 250 head	Dairy - 500 head
Volume Manure, gal/year		700,000	1,300,000	3,250,000	6,500,000
50% TP Removal	Polymer only	$ 0.0423	$ 0.0235	$ 0.0143	$ 0.0118
	Poly + Lime mix	$ 0.0564	$ 0.0297	$ 0.1302	$ 0.0138
	Poly + Lime slurry	$ 0.0672	$ 0.0305	$ 0.0254	$ 0.0219
	Lime mix only	$ 0.0375	$ 0.0296	$ 0.0182	$ 0.0153
	Lime slurry only	$ 0.0485	$ 0.1410	$ 0.1286	$ 0.1254
Max TP removal	Poly + Lime mix	$ 0.0676	$ 0.0367	$ 0.0240	$ 0.0217
	Poly + Lime slurry	$ 0.2347	$ 0.1475	$ 0.1342	$ 0.1279
	Lime mix only	$ 0.0488	$ 0.0351	$ 0.0224	$ 0.0194
	Lime slurry only	$ 0.2160	$ 0.2050	$ 0.1924	$ 0.1891

The metrics in Tables 2, 3, and 4 are shown as a cost/gallon due to the primary metric of being cost competitive with land application costs. To look at these relative to a cost/lb. of P removed, the following summary was prepared based on the following assumptions:

- The costs summarized were fairly detailed and comprehensive and are consistent with current estimated costs, so these were used as the total annual operating cost and capex estimates.
- Total phosphorus loads and recovery efficiencies from the most recent pilots were used. The pilots were from a large dairy and the current OWDA funded program underway on a deep-pit swine operation. The TP (expressed in mg/L) and % P recovered were similar to the conditions noted in the cost estimate summarized above and are summarized in Table 5:

Table 5 - Phosphorus Load & Recovery Percentages

Application	Total Phosphorus, mg/L	Phosphorus reduction, %
Dairy	287	90.8%
Swine	912	95.9%

From these calculations, the data in Table 6 are made which summarizes the cost / lb. P removed on an OPEX, CAPEX, and TCO basis for the applications modelled.

Table 6 - Cost/lb of P Removed for Maximum P Recovery

Application	Vol/yr, gal	Cost/lb P removed, max recovery		
		Opex	Capex	TCO
Swine	700,000	$ 1.67	$ 4.98	$ 6.66
Dairy - 100 head	1,300,000	$ 5.80	$ 10.30	$ 16.09
Dairy - 250 head	3,250,000	$ 5.13	$ 5.14	$ 10.27
Dairy - 500 head	6,500,000	$ 5.05	$ 3.84	$ 8.89

It is important to note that the estimated costs shown will vary by each individual application due to site and water (i.e. manure) characteristics. It is also important to note that these costs do not consider any potential cost recovery value with the recovered P or dewatered manure solids.

4.4.5 Cost Modeling from Pilot Project

To better understand the potential costs for the successful deployment of QuickWash®, AES provided an excellent example in their Pilot Project described previously in Section 4.3.4. Note that each potential project is unique and may have other costs required, however Tetra Tech believes this provides the order of magnitude needed to consider the overall cost/benefit of using this this technology to reduce P in the Western Lake Erie Basin (WLEB).

As part of this Pilot Project and for purposes of defining the economics around a particular solution, AES considered the following criteria:

- Even though the focus of the program was on determining operating costs, a 10-year present worth (5% discount rate) cost per gallon was also determined. Capital estimates were based solely on the capital associated with the particular technology modelled ("in-scope costs") and did not include infrastructure costs that may be necessary, such as site improvement or permitting costs;
- Operating costs on an annual basis would include operating costs associated with the operation of the technology modelled. This would include electrical and any other consumables required, such as polymers. Note that labor costs were not included in this estimate, however, an estimate of time required (in terms of hours per day) was estimated, and
- Modelling was conducted based on the need to treat 1,300,000 gallons per year per hundred head dairy operation. Analysis was conducted for a 100 head, 250 head and 500 head operation (1,300,000 / 3,250,000 / 6,500,000 gallons per year, respectively).

- Modelling did not include value of calcium phosphate, treated water, or the dewatered manure produced as co-products of the process Sale of these co-products would further reduce overall OPEX costs.

For this Pilot Project 2 different levels of total phosphorus reduction were modelled. Each of these scenarios estimated costs associated with different components of the process. All models developed an estimated annual operating cost, 10-year NPV, in-scope capital costs and the TCO on a NPV basis. The specific technology modules modelled are summarized in the Table below:

Table 7 - Pilot Project Technologies Modelled

Total Phosphorus Removed	Technology modules modelled
50% total phosphorus removed	Polymer only
	Polymer with lime mixing on-site
	Polymer with lime slurry
	Hydrated lime mixing on-site
	Hydrated lime slurry
Maximum total phosphorus removed	Polymer with lime mixing on-site
	Polymer with lime slurry
	Hydrated lime mixing on-site
	Hydrated lime slurry

It is worth noting that polymer use only would not achieve the maximum total phosphorus removed for an annual OPEX estimate of less than $0.04/gallon treated and hence was not modelled.

The following tables (AES, 2019b) summarize the results of the estimated costs for the 50% total phosphorus removed scenario and the results for the maximum total phosphorus removed scenario for the three dairy farm operation sizes (100, 250, and 500 head). To be able to compare the different scenarios modelled, a cost per gallon treated was calculated for operating costs, estimated capital costs and total cost of ownership for both scenarios. These are also included in each table (AES. 2019b):

Table 8 - Pilot Project - 100 Head Operation Model

100 Head Operation		***Maximum P Removal***				***50% P Removal***				
		Poly+ Lime Mix	**Poly + Lime Slurry**	**Lime Mix Only**	**Lime Slurry Only**	**Poly**	**Poly+ Lime Mix**	**Poly + Lime Slurry**	**Lime Mix Only**	**Lime Slurry Only**
Annual OpEx										
Total	$	$ 21,727.09	$ 205,648.65	$ 21,303.46	$ 304,683.24	$ 8,714.85	$ 12,690.97	$ 8,734.44	$ 12,575.77	$ 196,837.05
Cost of Capital	%	5%	5%	5%	5%	5%	5%	5%	5%	5%
OpEx Term Length	Years	10	10	10	10	10	10	10	10	10
OPEX NPV	**$**	**$ 167,770.81**	**$ 1,587,964.39**	**$ 164,499.70**	**$ 2,352,683.19**	**$ 67,293.76**	**$ 97,996.29**	**$ 67,445.03**	**$ 97,106.75**	**$ 1,519,923.55**
CapEx										
In-Scope CapEx	$	$ 309,126.79	$ 329,526.79	$ 292,272.31	$ 312,672.31	$ 238,127.03	$ 287,772.31	$ 329,526.79	$ 287,772.31	$ 312,672.31
Total CapEx		**$ 309,126.79**	**$ 329,526.79**	**$ 292,272.31**	**$ 312,672.31**	**$ 238,127.03**	**$ 287,772.31**	**$ 329,526.79**	**$ 287,772.31**	**$ 312,672.31**
TCO NPV	**$**	**$ 476,897.60**	**$ 1,917,491.17**	**$ 456,772.01**	**$ 2,665,355.50**	**$ 305,420.79**	**$ 385,768.60**	**$ 396,971.82**	**$ 384,879.05**	**$ 1,832,595.85**
		10 year cost/gallon treated								
	NPV	$ 0.0367	$ 0.1475	$ 0.0351	$ 0.2050	$ 0.0235	$ 0.0297	$ 0.0305	$ 0.0296	$ 0.1410
	Capex	$ 0.0238	$ 0.0253	$ 0.0225	$ 0.0241	$ 0.0183	$ 0.0221	$ 0.0253	$ 0.0221	$ 0.0241
	Opex	$ 0.0129	$ 0.1222	$ 0.0127	$ 0.1810	$ 0.0052	$ 0.0075	$ 0.0052	$ 0.0075	$ 0.1169

Table 9 - Pilot Project - 250 Head Operation Model

250 Head Operation		***Maximum P Removal***				***50% P Removal***				
		Poly+ Lime Mix	**Poly + Lime Slurry**	**Lime Mix Only**	**Lime Slurry Only**	**Poly**	**Poly+ Lime Mix**	**Poly + Lime Slurry**	**Lime Mix Only**	**Lime Slurry Only**
Annual OpEx										
Total	$	$ 51,476.64	$ 512,004.70	$ 47,123.14	$ 759,353.02	$ 21,059.75	$ 498,999.95	$ 54,017.63	$ 29,956.94	$ 490,824.71
Cost of Capital	%	5%	5%	5%	5%	5%	5%	5%	5%	5%
OpEx Term Length	Years	10	10	10	10	10	10	10	10	10
OPEX NPV	$	***$ 397,489.01***	***$ 3,953,564.56***	***$ 363,872.40***	***$ 5,863,522.71***	***$ 162,617.77***	***$ 3,853,145.37***	***$ 417,109.81***	***$ 231,319.55***	***$ 3,790,018.33***
CapEx										
In-Scope CapEx	$	$ 401,516.27	$ 427,916.27	$ 383,413.31	$ 409,813.31	$ 315,656.42	$ 397,016.27	$ 427,916.27	$ 378,913.31	$ 409,813.31
Total CapEx		***$ 401,516.27***	***$ 427,916.27***	***$ 383,413.31***	***$ 409,813.31***	***$ 315,656.42***	***$ 397,016.27***	***$ 427,916.27***	***$ 378,913.31***	***$ 409,813.31***
TCO NPV	$	***$ 799,005.28***	***$ 4,381,480.83***	***$ 747,285.71***	***$ 6,273,336.02***	***$ 478,274.18***	***$ 4,250,161.64***	***$ 845,026.08***	***$ 610,232.86***	***$ 4,199,831.64***
		10 year cost/gallon treated								
	NPV	$ 0.0246	$ 0.1348	$ 0.0230	$ 0.1930	$ 0.0147	$ 0.1308	$ 0.0260	$ 0.0188	$ 0.1292
	Capex	$ 0.0124	$ 0.0132	$ 0.0118	$ 0.0126	$ 0.0097	$ 0.0122	$ 0.0132	$ 0.0117	$ 0.0126
	Opex	$ 0.0122	$ 0.1216	$ 0.0112	$ 0.1804	$ 0.0050	$ 0.1186	$ 0.0128	$ 0.0071	$ 0.1166

Table 10 - Pilot Project - 500 Head Operation Model

500 Head Operation		***Maximum P Removal***				***50% P removal***				
		Poly+ Lime Mix	**Poly + Lime Slurry**	**Lime Mix Only**	**Lime Slurry Only**	**Poly**	**Poly+ Lime Mix**	**Poly + Lime Slurry**	**Lime Mix Only**	**Lime Slurry Only**
Annual OpEx										
Total	$	$ 108,933.72	$ 998,870.46	$ 92,737.65	$ 1,517,438.79	$ 41,153.97	$ 43,587.17	$ 107,217.82	$ 58,925.56	$ 980,804.15
Cost of Capital	%	5%	5%	5%	5%	5%	5%	5%	5%	5%
OpEx Term Length	Years	10	10	10	10	10	10	10	10	10
OPEX NPV	$	***$ 841,157.35***	***$ 7,713,012.93***	***$ 716,095.59***	***$ 11,717,260.09***	***$ 317,780.05***	***$ 336,568.54***	***$ 827,907.56***	***$ 455,007.55***	***$ 7,573,509.63***
CapEx										
In-Scope CapEx	$	$ 594,632.52	$ 624,632.52	$ 572,784.12	$ 602,784.12	$ 470,169.25	$ 588,632.52	$ 624,632.52	$ 566,784.12	$ 602,784.12
Total CapEx		$ 594,632.52	$ 624,632.52	$ 572,784.12	$ 602,784.12	$ 470,169.25	$ 588,632.52	$ 624,632.52	$ 566,784.12	$ 602,784.12
TCO NPV	$	***$ 1,435,789.87***	***$ 8,337,645.45***	***$ 1,288,879.71***	***$ 12,320,044.22***	***$ 787,949.30***	***$ 925,201.06***	***$ 1,452,540.09***	***$ 1,021,791.67***	***$ 8,176,293.75***
		10 year cost/gallon treated								
	NPV	$ 0.0221	$ 0.1283	$ 0.0198	$ 0.1895	$ 0.0121	$ 0.0142	$ 0.0223	$ 0.0157	$ 0.1258
	Capex	$ 0.0091	$ 0.0096	$ 0.0088	$ 0.0093	$ 0.0072	$ 0.0091	$ 0.0096	$ 0.0087	$ 0.0093
	Opex	$ 0.0129	$ 0.1187	$ 0.0110	$ 0.1803	$ 0.0049	$ 0.0052	$ 0.0127	$ 0.0070	$ 0.1165

Reviewing the data in Pilot Project Tables, the following summary of the top 2 options as defined as minimum annual OPEX can be developed.

Table 11 - Pilot Project – Top 2 Options Related to Annual OPEX

Size (Head)	**Maximum Phosphorus Reduction**		**50% Phosphorus Reduction**	
	Process	**Est Capex**	**Process**	**Est Capex**
100	Lime only ($0.0127) Poly/Lime ($0.0129)	$292K $309K	Poly only ($0.0052) Poly/Slurry ($0.0052)	$238K $330K
250	Lime only ($0.0112) Poly/Lime ($0.0122)	$383K $402K	Poly only ($0.0052) Lime only ($0.0071)	$316K $379K
500	Lime only ($0.0110) Poly/Lime ($0.0129)	$573K $594K	Poly only ($0.0049) Poly/Lime ($0.0052)	$470K $589K

Notes:
- OPEX includes consumables plus estimated annual power
- Only the 2 lowest cost processes to minimize annual OPEX are shown
- Numbers in parenthesis are estimated costs/gallon treated
- No labor costs are included
- No infrastructure improvement costs were included
- No permitting costs were included
- No costs associated with the sale of co-products were included

From the analysis summarized in the previous tables, AES made the following conclusions with regard to the cost analysis for this Pilot Project:

1. While attractive from an ease of operation perspective, the use of a hydrated lime slurry offers a significant OPEX, and consequently NPV, penalty on cost/gallon treated basis.
2. Multiple options exist to achieve the target economics of <$0.01/gallon treated for a 50% reduction in P at all operation sizes modelled.
3. The cost differential to achieve maximum phosphorus reduction is slightly over the target cost for a 50% reduction and is likely to be close to the target cost if the value of co-products produced are considered.
4. The data summarized does not include incremental benefits of co-product revenue produced or take into account potential current cost savings through adoption of the option(s) considered.

4.4.6 Additional Cost Benefits from Co-products

As noted in the assumptions on cost estimates, no value of the calcium phosphate, treated water, and dewatered manure produced was included. However, it should be noted that these co-products produced represent potentially viable cost recovery mechanisms.

To further clarify the benefit of phosphorus recovery technologies, like QuickWash®, one could ask if this technology actually reduces the phosphorus generated in the WLEB if it does not change the amount of total phosphorus in the WLEB. Meaning, if one of the calcium phosphate recovered from manure is placed back on the fields in the WLEB, then this could be considered a net zero situation. However, AES states that QuickWash® allows for the recovery of phosphorus from livestock operations so that it can be reapplied to areas that are deficient in phosphorus - whether in the WLEB or any other place in the country. This also means that generated co-product is able to replace purchased phosphorus in the WLEB. The total P2O5 in the WLEB, or any other region, is simply the sum of both purchased and applied manure based P2O5.

The total P2O5 produced in the WLEB based on the 2017 USDA Agricultural Guide (USDA, 2017) and OSU Bulletin 604 (OSU Extension, 2006) is estimated as shown in Table 12:

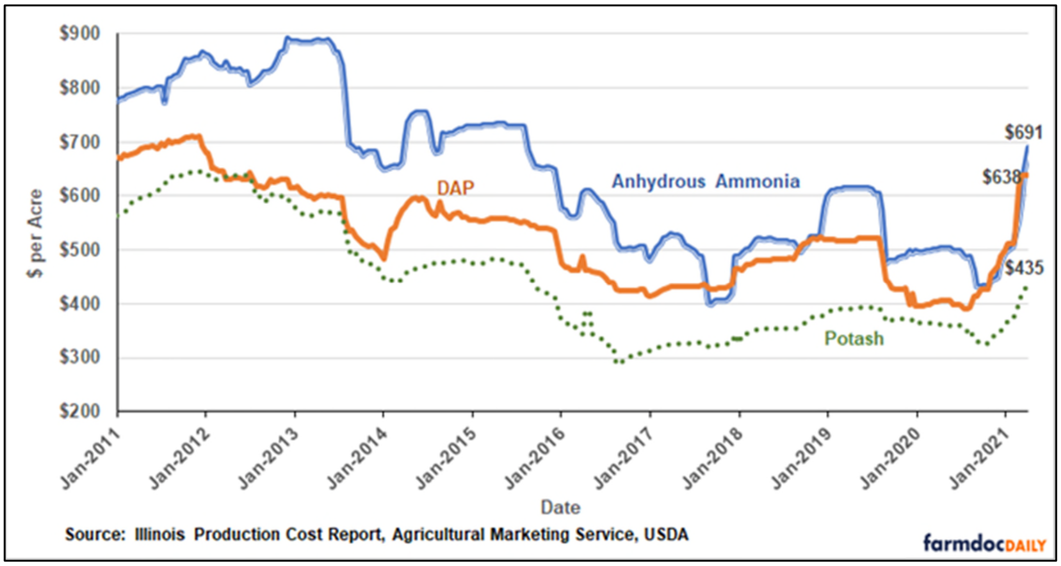
Table 12 - Estimated P2O5 Produced in WLEB

WLEB				
Livestock	**Farms**	**Est livestock**	**Annual P2O5 lbs.**	**P2O5 tons**
Hog	643	1,030,313	18,803,206	9,402
Beef	2,182	20,698	1,435,387	718
Dairy	290	57,850	6,144,553	3,072
Layer	907	2,513,284	2,476,841	1,238
Total	**4,022**	**3,622,145**	**28,859,987**	**14,430**

Based on data from OSU Extension Professor Greg Labarge, in 2018, there were 25,500 tons of P2O5 sold in the WLEB (Hanrahan et al., 2019). If manure is currently being applied to acreage with soil test phosphorus above the maintenance range outlined in the Tri-State Fertilizer Recommendations (Culman et al., 2020), manure phosphorus should be harvested and moved to acreage needing phosphorus. QuickWash® would provide a method of moving those nutrients while also offsetting the amount of commercial fertilizer needed in the WLEB.

For example, if QuickWash® was implemented by 25% in the WLEB alone, this would allow for roughly 3,600 tons of P2O5 (14,430 x 25%) to become available and would reduce the need for purchased P2O5 by that same amount. From a financial perspective, the cost of nutrients that farmers purchase has gone up significantly this past year as shown in the figure below, making the use of recovered phosphorus (rather than purchased phosphorus) an attractive alternative as well.

Figure 4 - Anydrous Ammonia, Diammonium Phosphate, and Potash Pricess in Illinois



Thus, QuickWash® could provide a technology solution that allows for the movement of recovered phosphorus to other regions where a deficit exists and reduces the need to purchase commercial grade phosphorus, thereby reducing the total P205 in the watershed by the amount recovered from manure.

Further discussion regarding the details of these co-products is included later in Section 4.16.

Tetra Tech and AES recommend that the efficacy and value of these co-products needs to be evaluated further. AES recently completed an OWDA Grant in Mercer County, Ohio that included evaluating this cost benefit of the co-products.

4.5 SCALABILITY EVALUATION

In discussions with AES, they identified several possible options and/or alternatives for larger scale implementation of QW-P within Northwest Ohio. These would be dependent on the type of stream to be treated (lagoon storage, large livestock operations with more concentrated phosphorus loads, anaerobic digestate, etc.). In general, the options can be summarized as:

4.5.1 Option 1: Lagoon Storage with Moderate TP Loads used to Support Irrigation

These would be lagoon-based systems that principally rely on the characteristics of a lagoon biological treatment of wastewaters generated in agricultural operations. An example would be lagoons used to treat water generated during egg wash operations or even in cases where a multi-staged lagoon is used to treat more heavily phosphorus loaded streams common in dairy applications. An example is shown in Figure 5.

Relevant characteristics of these applications are that the lagoons provide a natural biological treatment of the wastewater for constituents such as biological oxygen demand (BOD) or ammonia (NH3) and may incorporate aeration (Lagoon 1) and longer storage time (Lagoons 2,3). Ultimately, the water in the final lagoon (Lagoon 4) is land applied to adjacent fields and ideally, that level is drawn down by the end of the season. The unique nature of these is that Lagoon 4 becomes a holding lagoon for irrigation water and water discharged through irrigation needs to meet the appropriate Ohio Department of Agriculture (ODA) requirements, such as Natural Resource Conservation Service (NRCS) Practice 590 (Ohio State University Extension, n.d.). The phosphorus loads to be treated could be either moderate strength (Total Phosphorus [TP] less than 50 mg/L) or they may be higher (we have evaluated TP up to 325 mg/L). The key is that these applications have lower Total Suspended Solids (TSS) and final storage is used to support center-pivot irrigation.

Figure 5 - Lagoon Storage used to Support Center-Pivot Irrigation

The unique characteristics of these applications is that treatment equipment can be sized to accommodate longer treatment time and can allow for pre-siting of support infrastructure (tanks, collection bins, etc.) and to use a more portable skid to treat the water when needed. Further, since treatment can be potentially more seasonal, storage of recovered phosphorus can be better managed.

The other point worth noting with Option 1 is that the same approach could be applied to municipal or industrial lagoons. As stated previously QW-P has been piloted at a 10 MGD site (Perrysburg, Ohio) and in agricultural, industrial applications, so smaller municipal lagoons are a logical application. The only difference would be that rather than the water being used for center pivot irrigation, it would be a direct discharge application.

4.5.2 Option 2: Larger Livestock Applications

Larger livestock operations may be able to justify a dedicated treatment system. Examples would be larger dairies with a continuous manure stream requiring continuous treatment. Many times, these operations will include some sort of static manure storage pit where manure is stored until either further treated or pumped out for land application. An example is shown in the following figure.

Figure 6 - Larger Live Stock Application

These applications differ from Option 1 in that the manure characteristics are such that the manure is stored until disposed of – usually through direct land application. In this application, concentrated manure is usually stored in a collection pit (1) until applied. In some cases, provisions for further lagoon treatment (2) are provided where manure from the storage pit is allowed to age and eventually, is pumped into adjoining lagoons. In cases of larger dairy operations, it is also common to have a silage runoff lagoon (3) where runoff from silage storage is allowed to flow into and eventually, this is moved into one of the secondary lagoons (2).

Common in dairy applications, this manure stream is characterized by higher solids content manures with high fiber content. In most applications, sand is commonly used for bedding and is removed, usually through use of a sand lane or settling basin for further reuse in the dairy operation. Removed sand is allowed to further dry in a separate location (4). QW-P does not require the removal of fiber in order to be effective (AES, 2019b). This results in the final precipitated soluble phosphorus having a higher organic content resulting in a favorable soil amendment product.

Larger livestock operations would ideally involve a dedicated treatment building where equipment and tanks can be located. Because these operations are generally larger with considerable manure production, a separate location for storage of precipitated product would be required. Through its inclusion of fiber, the potential for reduction in existing fiber management costs may result.

4.5.3 Option 3: Anaerobic Digestate Treatment

The use of manure feedstocks offers a benefit to anaerobic digestors in support of the growing Renewable Natural Gas (RNG) market in California due to their likelihood of providing higher Renewable Identification Numbers (RIN) which serve as a form of “currency” in the Renewable Fuel market, similar in concept to nutrient trading credits. A higher RIN score allows for a higher contract price on gas produced. This growing market has resulted in the establishment of large community digester projects where multiple farms are paid to have their manure shipped to a central digester where the resulting gas is cleaned and pumped into a nearby pipeline for transport to the west coast. With Ohio’s large livestock base, this is creating opportunities for these projects, particularly in areas of high concentrations of livestock farms. The host site is a larger farm, usually a dairy as shown in following figure.

Figure 7 - Host Farm for Larger Community Digester Program

These applications are similar to those of Option 2 except for the volume and potential mix of manure. The most common livestock manures used as feedstocks are swine and dairy and are segregated during digestion to avoid mixing of different manures. As with all digestates, nutrients are concentrated and hence the need to manage the resulting digestate for compliance purposes is critical to a successful project. A further consideration is that almost all individual farm contracts include a provision where the recovered nutrients from the digestate are provided back to the farm supplying the feedstock as either usable product or a credit. Consequently, efficient recovery of nutrients from the digestate is important. A further benefit to the use of QW-P in these applications is that the treated water can potentially be used as a sand removal wash that may be required pre-digestion. With multiple farms feeding manure streams to a large host dairy, the streams cannot be economically mingled in a common sand lane for removal of sand from dairy farms supplying feedstocks. This is often managed through a number of different types of mechanical sand separators (such as a McLanahan Sand separator) where water is required to be periodically used to wash both the equipment and resulting sand. The final rinse must be fairly clean water, however, the treated water from QW provides adequate water quality for the majority of wash needs. The result is less fresh water needed to be managed at the host farm.

These applications also offer the opportunity for integration of additional technologies to manage the resulting digestate. Most digestate produced after QW-P removal of phosphorus is stored in a storage lagoon for eventual irrigation. During this storage, treatment for secondary constituents, such as nitrogen (i.e. high TKN), BOD, Chemical oxygen demand (COD) and methane control must be employed. QW-N is being explored by several potential developers as an add-on to QW-P during the nutrient removal phase.

While there is a trend towards larger community-type digester projects, the use of nutrient recovery on more conventional digester projects can also benefit from the use of QW-P. When used in a municipal digester, the potential for struvite prevention can be a resulting benefit.

4.5.4 Option 4: Small Farm Treatment

The majority of farms within Ohio are not considered large CAFO's. As shown in the following figure, these are often concentrated in regions across the state. The following figure is a map of individual farms in the greater Mercer/Auglaize/Darke County area (Mercer County Soil and Water Conservation District, n.d.). Each dot represents an individual farm and the color represents the livestock type at that location. The red line show gas pipelines. A livestock farm density profile like this is attractive to providers of consolidated anaerobic digester projects identified in Option 3.

The Western Lake Erie Basin (WLEB) consists of 24 different counties within Ohio. Reviewing the USDA 2017 Census data (USDA, 2017) , the number of farms containing livestock is estimated to be in excess of 4,000. Using a standard volume of P2O5 generated by each livestock type provided by The Ohio State University (OSU) (Ohio State University Extension, 2006), an estimate of the total potential P2O5 load in the WLEB can be developed. This analysis is summarized in Table 13 (AES, n.d.).

It should be noted that the actual number of livestock reported in the USDA Census is understated as many farms did not have the number of livestock identified due to it being considered confidential or proprietary information. This data suggests that the largest P2O5 livestock manure contribution in the WLEB comes from Hog and Dairy livestock operations (as defined by P2O5/farm).

Figure 8 - Farm Density in West Central Ohio

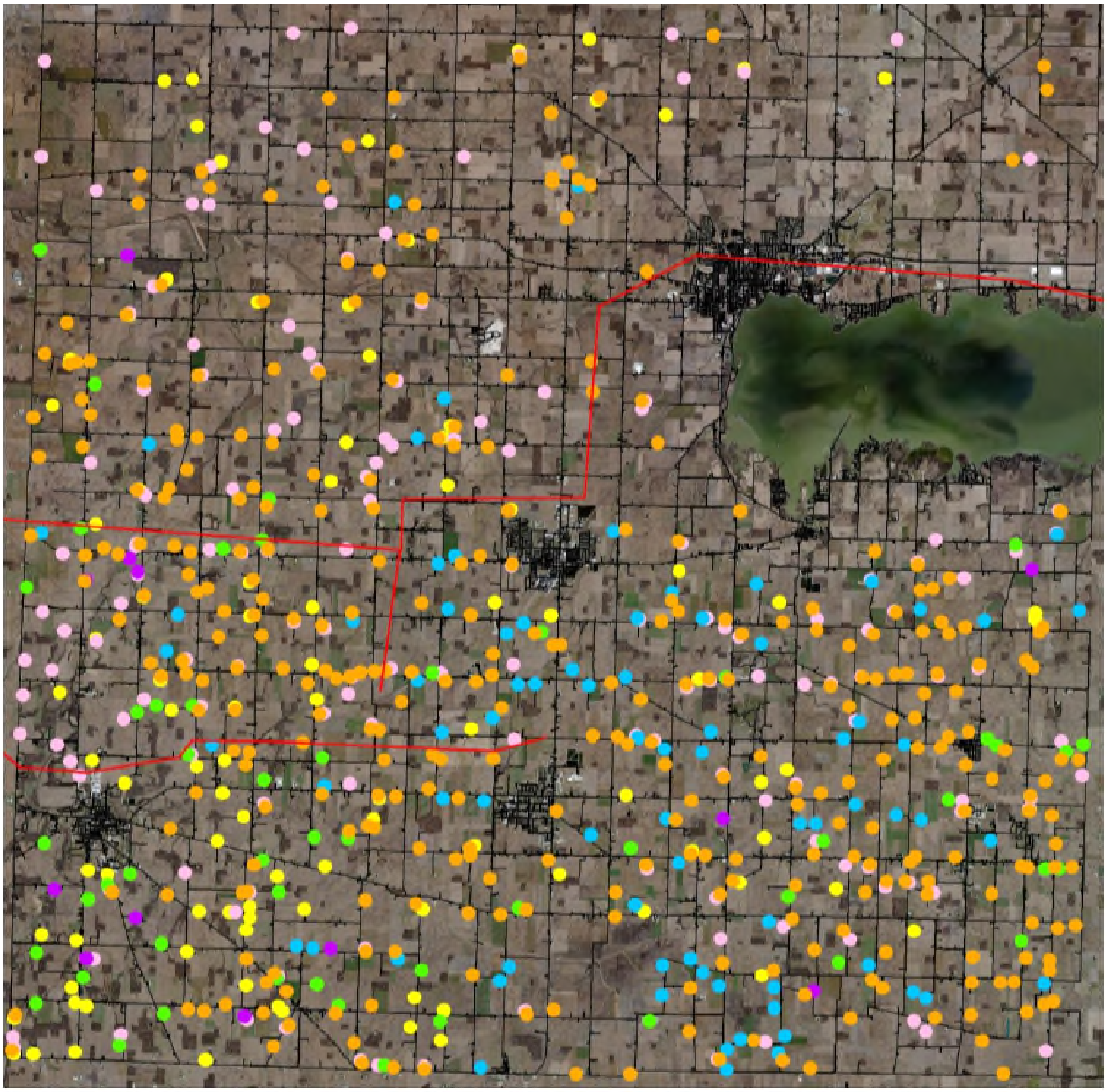


Table 13 - Estimated WLEB P205 Loading by Species

Livestock	Farms	Est livestock	Avg /farm	Annual P2O5	P2O5/Farm
Hog	643	1,030,313	1,602	18,803,206	29,232
Beef	2,182	20,698	9	1,435,387	658
Dairy	290	57,850	200	6,144,553	21,219
Layer	907	2,513,284	2,770	2,476,841	2,729

As was noted in Options 2 and 3, dairy operations store manure in some sort of physical basin or lagoon, while the majority of swine operations use a deep pit manure management design in which the manure is stored below the hogs for eventual pumping out for land application. The volume of these “pits” will vary depending on the size of the operation, but a typical 2,000 head grower operation will hold up to 700,000 gallons and is typically pumped out once or twice a year.

Option 4 would involve the development of a portable, or mobile, means of routinely treating these manures so that their treatment can be scheduled on an as needed basis and not necessarily be tied to weather or crop cycles. In this option, overall tankage costs for consumables would be minimized and could be placed on-site prior to a scheduled treatment. Dewatered solids could be provided directly to the farmer or through partnering with other technologies or be transported off-site for beneficial reuse. Recovered phosphorus would be produced on-site and result in a stackable product (20-25% solids content) that could further be processed for final use at a more centralized location – such as at a local co-op.

4.6 INFORMATION GAP EVALUATION

Based on AES's technology submission for QuickWash®, it is necessary to obtain more information about the value and potential markets for the three co-products (calcium phosphate, dewatered manure, and treated water). To Tetra Tech's knowledge, AES has just recently begun to look at this aspect of QuickWash®.

4.7 FEASIBILITY FOR LARGE-SCALE TECHNOLOGY DEMONSTRATION

A large-scale technology demonstration is very feasible with QuickWash®. The technology has already conducted several studies and pilot projects in Ohio, as discussed previously.

There are no known limitations for a broad adoption of QuickWash®. AES identified that the single most common question received from potential clients is "what is the value of the precipitated product and who will purchase?". As is noted below, this is a major area of focus of the in-progress OWDA grant with Mercer County (OWDA, 2020). Several potential off-takers have expressed some interest in this product but providing significant volumes of material for evaluation has been limited in advancing discussions to the next level until this program.

Because the technology is equipment agnostic, a wide array of existing equipment can be employed. Because of this, many times existing equipment that may be available at a potential clients' site can be repurposed. Examples would include any type of dewatering equipment or tankage which a client may have on-site.

The current areas of focus for AES, which could benefit from a large-scale demonstration project, are related to establishing channels to market for the secondary products that result from adoption of QuickWash® and establishing the operating costs of adoption of various dewatering approaches of the recovered phosphorus.

Examples of these on-going efforts that could be expanded via a large-scale demonstration project include, but are not limited to, the following:

- One of the co-product streams produced is dewatered manure solids from high solids content manure streams. AES is evaluating the use of the Regen Technology provided by Kurtz Bros. (Kurtz) to evaluate the potential use of dewatered dairy solids and dewatered swine manure solids. To date, approximately 16 yards of dewatered dairy solids and 20 yards of dewatered swine solids has been delivered to Kurtz for evaluation.

- As noted previously, the use of treated water is being evaluated against current irrigation water standards as a source of water to support center pivot irrigation. Additionally, use of the treated water is also being evaluated for potential use as wash water in support of fiber removal of dairy manure used in a large community anaerobic digester program.
- Considerable effort is currently underway to explore potential off-taker utilization of the recovered phosphorus material. The recently completed OWDA funded pilot in Mercer County resulted in 3 tons of stackable product being sent to various off-takers in the greater Fort Wayne, IN area for evaluation and an estimated 20 yards of precipitated material being applied to a wheat field in the greater Celina area. This is in addition to the material noted earlier that was submitted to Kurtz for review.
- Concentration of the recovered phosphorus slurry is under evaluation in the current OWDA funded project for the Mercer County Commissioners. This involves the performance and operating cost requirements for multiple approaches including:
  - The use of geotextile materials (provided by WaterSolve),
  - The use of a belt filter press (provided by MSD),
  - The use of a plate and frame device (provided by Evoqua), and
  - The use of a multi-disc screw press (provided by Ekoton based out of Akron).

AES has the experience and existing relationships (i.e. Kurtz Bros.) in the WLEB to successfully implement a large-scale project.

4.8 FEASIBILITY FOR FULL-SCALE IMPLEMENTATION

As stated in Section 4.8, based upon the USDA 2017 Census Data the number of livestock farms/operations exceeds 4,000 in the WLEB and the amount of phosphorus generated annually is, as we know, significant. The Pilot Projects and other studies conducted by AES clearly demonstrate the ability of the QuickWash® technology to significantly reduce the amount of phosphorus from manure while also generating potentially valuable and re-usable co-products (calcium phosphate, treated water, and dewatered manure). Based upon this information, it is feasible for QuickWash® to be implemented on a large scale within the WLEB.

However, several challenges to implementation were identified, especially when considering large scale or regional implementation. Specific challenges include the cost of implementation, equipment, and the ability of AES to provide enough experienced staff all represent potential challenges.

To help bridge the qualified and experienced staffing gap, AES reported that they actively participate in the University of Toledo co-op program through the regular hiring of chemical engineering or environmental engineering students. Most of these are repeat assignments to help develop a talent base AES can draw from. In 2021, AES employed 5 different students with several of these being repeat employees from 2020. All were involved in the application of QW on-site. AES expects to see a similar level of employees in 2022 with hiring of additional fulltime staff.

AES also maintains a development lab site at the University and are in the process of establishing a similar base of operations at Ohio University in Athens to provide another "center of excellence".

4.9 PROBABILITY OF SUCCESS

Previous studies of QuickWash® demonstrate that this technology will result in reducing nutrient loads that are contributing to the Lake Erie algal blooms if it is implemented on a large-scale basis. Once again, as stated in Section 4.8, based upon the USDA 2017 Census Data the number of livestock farms/operations exceeds 4,000 in the WLEB and the amount of phosphorus generated annually is, as we know, significant. This need to reduce phosphorus is a primary objective of AES and their QuickWash® technology . The probability of success is therefore high if it can be deployed at a sufficient scale, which in turn is dependent on the financial incentives offered to landowners and their greater awareness of the benefit of phosphorus reduction (and generation of valuable co-products) while also being economically competitive with currently utilized practices.

4.10 FINANCIAL VIABILITY

AES is a privately held, veteran and minority owned Ohio based company. The principals of AES (Rick Johnson and Stan Robinson) have extensive experience in the recovery of phosphorus with multiple technologies and strong financial acumen. AES continues to maintain a portfolio of solutions that are roughly 80% proven and 20% innovative in nature and under consideration for adoption. AES has been privately funded and has a list of potential investors willing to invest in proven solutions. Additionally, AES maintains an array of water quality solutions involving aeration, dewatering and carbon recycling technologies with an active pipeline across the Midwest. AES continues to invest in identifying solutions that will allow it to expand its solutions base in the agricultural sector, including ammonia recovery, passive phosphorus reduction for edge of field applications (2 separate technologies in evaluation), and more recently, methane mitigation with second generation solutions and adoption of high surface area media for beneficial biological uptake in passive settings as well as in decentralized treatment technologies.

4.11 QAPP

QW-P does not currently have a formal Quality Assurance Project Plan (QAPP) however, AES reported that the key principles of a QAPP are followed on each project they undertake. AES reported that the following steps are followed on all QW-P project proposals submitted to a client or agency before commencing:

1. A separate workbook is prepared that outlines key steps to be followed in development of a proposal. These include:
    a. A detailed workplan with tasks identified, deliverable from the task and responsible individual for the task. This workplan also includes a higher level Gantt chart for the entire proposal;
    b. Identification of the stakeholders for the project;
    c. A detailed budget estimate including assumptions made. Included in this is a milestone payment schedule linking milestone payments to clearly defined deliverables; and
    d. Identification of success criteria.
2. Before conducting any evaluation of QW-P, the following general outline is followed:

a. All instruments are calibrated against existing standards. If a particular instrument is routinely sent out to a third party for calibration (such as pipettes), a clearly identified label is affixed to the device;
b. Whenever possible, testing is confirmed through third-party labs. Depending on the parameter monitored, two Ohio Certified Labs (Alloway Labs in Lima, Ohio or Brookside Labs in New Bremen, Ohio) are used. Early into a testing program, a correlation between the internal AES testing results (using a Hach DR900) and the outside lab is established. The objective is to give AES confidence in the data being generated with its internal testing with that of the third-party lab. This correlation is updated regularly to provide confidence in the AES results. When a difference is considered less than desirable, no further testing is conducted until understood;
c. All AES employees who are involved with a given program involving phosphorus measurements also establish a correlation prior to testing. Additionally, for a period of time at the start of a program, duplicate operators evaluate samples until consistent results are obtained between the technicians;
d. A correlation among AES employees on titration curves is also developed;
e. Prior to deployment onsite for a program, detailed work instructions are developed and routinely monitored throughout the program. If necessary, revisions to the methods are updated; and
f. Following completion of a program, a post-study review is held with the AES operations team involved to review any opportunities for improvement and what could be done better the next time.

4.12 DATA VALIDATION

AES reported that they use third-party laboratory data on almost all studies as the “official” data – unless noted otherwise. Internal AES generated test results are used for process monitoring or for initial efforts to narrow down a field of investigation, but results reported to a client or used in studies are almost exclusively based on third-party data. AES typically conducts correlation studies between their data and a third-party lab early in an evaluation to give them confidence that their generated data can be reliably used for process monitoring. Additionally, all new AES employees are trained in critical test methods and a correlation established with other AES employees and/or the third-party lab.

AES reports that the other reason for ensuring that their results align with third-party results is for giving them confidence if they see a result from a third-party lab that is not consistent with their expectations. In those cases AES may challenge a result from the outside lab based on this and any differences reconciled. This also allows AES the opportunity to learn from the experience of the third-party lab to help identify any potential interferences which may be occurring so AES can more reliably evaluate results. For example, this approach helped AES to learn of a potential iron interference with a colorimetric test method used in monitoring of total phosphorus at a municipal wastewater plant investigation where the facility was using ferric chloride in its phosphorus mitigation strategy.

Another reason for developing this correlation is to give the third-party lab some indication of the potential phosphorus levels they may see in cases where they are working on a high phosphorus stream. This helps the third-party lab to be more efficient. An example of this is where AES is currently evaluating an industrial waste stream with very high total phosphorus levels (approximately 5000 mg/L with much of the phosphorus bound) and the internal lab was able to establish the appropriate dilution factor for this strength. This information was used by the third-party lab to refine its test method.

The Ohio Certified third-party labs typically used are either Alloway Labs or Brookside Labs. For most agricultural investigations, Brookside Labs is used due to its ability to evaluate manure-based wastewaters for a variety of different parameters. Alloway Labs is often used when the stream may have less solids content or when the particular constituent being evaluated (such as alkalinity) allows AES to link the result to historical studies conducted. In some programs, both labs may be used for the same constituent because the client may be more familiar with one lab over the other. An example was in a recent large dairy evaluation where the focus was on total phosphorus reduction. In these cases, data from both labs are summarized and a correlation between the two labs was shown. Since Alloway typically uses a colorimetric method for total phosphorus, Brookside uses an Inductively Coupled Plasma (ICP) method. Additionally, Alloway will typically report their phosphorus in milligrams per liter (mg/L) whereas Brookside will report the result as pounds per 1,000 gallons (lb./1000 gal) or pounds per ton (lb./ton) for a higher solid content material.

Since most of the data used to prepare this evaluation were provided by laboratories other than AES, the data are considered to be validated.

4.13 SUPPLY CHAIN

The QuickWash® technology relies on several generally available and components and consumables. Tetra Tech did not identify any supply chain risks associated with the implementation of the QuickWash® technology.

4.14 ENVIRONMENTAL RISKS

According to AES, if properly implemented and employed, QuickWash® poses no risks to the environment – either air, soil, surface water, ground water, plants or animals. The only consumables employed by QuickWash® are an acid, hydrated lime and perhaps polymer for use in dewatering of the recovered phosphorus.

4.14.1 Health & Safety

AES reports that a QW-P installation involves the use of rotating equipment (pumps and mixers) and common industrial chemicals (such as sulfuric acid and hydrated lime). Common safety practices around these are the only real safety protocols required for people. Person Protective Equipment (PPE) should include appropriate gloves, eye protection and dust masks. Detailed work instructions for the mixing of chemicals (i.e. adding acid to a stream or for mixing hydrated lime slurries) are provided and updated regularly as needed. Prior to the acceptance of any chemical, a Safety Data Sheet (SDS) is required and maintained. Storage of chemicals on-site during test programs include secondary containment (for acid) and pallet storage of bagged lime (typically 50 lb. bags).

In a commercial setting, an option to avoid mixing of a hydrated lime slurry (typically 30-35% w/v) are offered. These would involve the bulk receipt of a pre-mixed slurry.

Tetra Tech recommends a more formal and site-specific Health & Safety Plan be developed for each project to ensure all precautions and mitigation measures are taken prior to deploying the technology, especially if on a large scale basis with additional and new staff.

4.15 COMMUNITY PERCEPTION & DISPROPORTIONATE IMPACT

AES reports that the assessment of any potential risks or impacts on a community are assessed through intensive interactions and discussions with stakeholders in the communities where a project is being conducted. These stakeholders include regulatory personnel (such as ODA or Ohio EPA), relevant trade associations (such as Ohio Pork Producers or Ohio Dairy Producers Association), and farming support groups (such as Mercer County Ag Solutions and local Soil and Water Conservation Districts). When a demonstration or pilot program is conducted at a host farm, site visits are encouraged (subject to bio-security considerations) and if possible, presentations at local civic groups (such as local Rotary Clubs) are made on the objectives and basis of the technology evaluation. The objective is to educate stakeholders on QW and the benefits and proven results achieved.

These efforts have been conducted in advance of pilots conducted to date. The objective of these efforts is to understand the technical, as well as non-technical, concerns so that they can be addressed during the course of the pilot. For example, in advance of the initial Perrysburg, Ohio pilot, several conversations with both the City of Perrysburg and an environmental group (Lake Erie Waterkeepers) were held to be sure their questions were answered and that AES had an understanding of the challenges that needed to address. In advance of the current OWDA sponsored pilot several conversations were held with Mercer County Ag Solutions, the Ohio OWDA, the host farm and local suppliers of consumables (such as Mercer Landmark) to explain the QW-P technology, the objectives of the planned program and to answer any questions they may have.

As QW-P advances towards an implementation, these conversations will continue. Lessons learned from projects completed to date and detailed logistics associated with the recovered phosphorus product will be discussed and formalized.

Tetra Tech recommends inclusion of a more formal community outreach and survey plan for future deployment to document efforts and ensure all stakeholders are included in the process.

4.16 WASTE/BY-PRODUCT MANAGEMENT REQUIREMENTS

AES reports that QW-P generates no waste and the following 3 potential primary products: 1) Recovered Phosphorus; 2) Treated Water; and 3) Dewatered Manure.

4.16.1 Recovered Phosphorus

Phosphorus is recovered in the form of amorphous calcium phosphate (ACP). When combined with other fractions from the manure (such as nitrogen and trace minerals), the result is a well-balanced product having favorable fertilizer characteristics. QuickWash® could provide a technology solution that allows for the movement of recovered P to other regions where a P deficits exist and/or reduces the need for Ohio farmers to purchase commercial grade phosphorus, thereby reducing the total P205 in the WLEB by the amount recovered from manure. Considerable data exists on the beneficial characteristics of the recovered phosphorus. This has been confirmed by USDA in the following published information:

- *Agronomic Effectiveness of Calcium Phosphate Recovered from Liquid Swine Manure* (Bauer et al., 2007)
- *Fertilizer Effectiveness of Phosphorus Recovered from Broiler Litter* (Szogi et al., 2010)

AES provided the following table that summarizes the characteristics of an average of 14 different samples of the recovered phosphorus from their current OWDA funded pilot project. Note the high percentage of available phosphorus (P) in the solids. Also note a balance of nitrogen and potassium and beneficial sulfur, calcium and magnesium. All analysis were conducted by Brookside Labs.

Table 14 - Average Recovered P

Characteristic		Solids (n=14)
Moisture, %		84.85
Solids, %		15.15
Mineral Matter, %		6.11
Organic Matter, %		9.04
Units		lbs./ton
Total N		14.73
	Ammonium-N	5.40
	Nitrate-N	<0.010
	Organic-N	9.32
Total P		4.63
	Total as P205	10.62
	Available P	3.70
	Available as	8.47
Available P, %		79.78%
Potassium		5.68
Potassium as K20		6.84
Calcium		29.20
Magnesium		14.78
Sodium		2.03
Sulfur		3.15
Boron		0.015
Iron		0.504
Manganese		0.109
Copper		0.200

Characteristic	Solids (n=14)
Zinc	0.273

4.16.2 Treated Water

According to AES, the water remaining after precipitation of the recovered phosphorus solids has a number of beneficial reuse opportunities, including as a source of irrigation water. The following table is a summary of 10 different samples of treated water (also from the OWDA Pilot Project) compared to incoming manure to treat. Note the significant reduction in Total P (94.8%). The higher level of nitrogen, particularly ammonium, makes this a favorable irrigation water source for several row crops, such as corn and soybeans. This data was also generated at Brookside Labs.

Table 15 - Average Treated Water Analysis

Characteristic		Raw (n=10)	Filtrate (n=10)
Moisture, %		94.76	97.59
Solids, %		5.24	2.41
Mineral Matter, %		1.52	0.98
Organic Matter, %		3.72	1.43
Units		lbs./1000 gal	lbs./1000 gal
Total N		54.36	26.52
	Ammonium-N	42.97	24.91
	Nitrate-N	<0.010	<0.010
	Organic-N	11.40	1.71
Total P		7.62	0.34
	Total as P205	17.47	0.77
	Available P	6.12	0.18
	Available as P205	14.00	0.42
Available P, %		80.40%	52.96%
Potassium		31.45	22.73
Potassium as K20		37.88	27.39
Calcium		7.32	1.10
Magnesium		7.41	7.00
Sodium		11.26	8.42
Sulfur		7.47	6.89
Boron		0.040	0.023
Iron		0.726	0.063
Manganese		0.168	0.013
Copper		0.319	0.024

Characteristic	Raw (n=10)	Filtrate (n=10)
Zinc	0.457	0.024

Important with irrigation water is that the process used to treat the water does not contribute to any negative constituents (sodium or chlorides) that could impact soil quality.

The use of treated water from QW-P can also be used as a wash water for fiber separation equipment, such as McLanahan sand separators. To be usable, water quality must have a TSS level of less than 0.5% (TSS<5000 mg/L). The following table summarizes results of 15 different samples of QW treated water against this requirement. Testing was conducted at Alloway Labs on samples generated from the current OWDA funded pilot project.

Table 16 - Average TSS of Treated Water

Count	Average TSS, mg/L	Percent of target
15	1841	36.8

4.16.3 Dewatered Manure

AES reported that in the majority of evaluations conducted, incoming manure was first dewatered, or screened, to remove high solids. In these cases, no use of polymer was required. These dewatered manure solids represent a potentially usable product. The following table is a summary of 12 different weekly evaluations of manure cake left after pretreatment dewatering. These were produced in the current OWDA pilot project. Note the product solids content of 21.4%, making it stackable and the favorable Total Phosphorus and high available P. All data was generated at Brookside Labs.

Table 17 - Average Manure Cake Analysis

Characteristic		Cake (n=12)
Moisture, %		78.57
Solids, %		21.43
Mineral Matter, %		3.05
Organic Matter, %		18.38
Units		lbs./ton
Total N		12.80
	Ammonium-N	8.73
	Nitrate-N	<0.010
	Organic-N	4.08
Total P		3.70
	Total as P205	8.47
	Available P	3.29
	Available as P205	7.59
Available P, %		90.48%
Potassium		6.98

Characteristic	Cake (n=12)
Potassium as K20	8.41
Calcium	9.06
Magnesium	3.64
Sodium	2.46
Sulfur	3.10
Boron	0.018
Iron	0.239
Manganese	0.135
Copper	0.092
Zinc	0.149

4.16.4 Secondary Product Value

Establishing a value of these products is a major focus of the current OWDA funded pilot. As was noted previously, a large sample of 20 cubic yards of recovered phosphorus product was applied to a local wheat field and an additional 3 tons of stackable product was sent to various off-takers in the greater Fort Wayne, Indiana area for evaluation. Additionally, 20 yards of dewatered manure was sent to Kurtz Bros for evaluation through the Regen Process to establish a value on it. The expectation is that these products would have value similar to poultry manure as a minimum.

In determining value though, other considerations enter into the equation. Reducing the phosphorus of applied manure can result in a significant reduction in the land required to support land application of manure through the ability to apply at a lower nitrogen or potassium rate than a phosphorus rate as defined by the Tri-State Fertility Guide. Further, depending on how aggressively NRCS Practice 590 is applied, these benefits may be further valued.

In assessing the value of these secondary products, identification of reduced expenses associated with traditional manure or traditional fertilizer application needs to be factored into a net value estimate. An exhaustive evaluation has not formally been conducted to date but once undertaken, this evaluation would need to factor in the direct costs associated with traditional fertilizers, equipment depreciation, labor and/or storage (for manure). This storage cost would need to consider the cost of maintaining lagoon or storage bunkers/pits used to hold the manure until application. In addition to these, an estimate of the costs associated with timing of manure/fertilizer applications would need to be considered – such as in a year when heavy rain reduces the ability to either apply fertilizers or to plant, thereby resulting in limited plant uptake. This lost "opportunity cost" is likely the most difficult to estimate since it is very site and time dependent.

By minimizing the application of livestock manure, an additional watershed benefit is realized. The Ohio Lake Erie Phosphorus Task Force II Report (Lake Erie Commission, 2013) estimated that up to 20% of P is lost in runoff after manure application. By recovering manure P content, this product can either be exported or stored until more targeted application is required, resulting in a directional reduction in P runoff from applied, non-treated manure sources.

A final, less tangible, secondary product value for adoption of QW-P in an agricultural setting is related to future regulation. With QW-P, capital costs are primarily driven by volume to process. The degree of treatment required determines the annual operating costs. As regulations change, there is built-in scalability to meet these regulations. An increase of the consumables commensurate with the future regulation requirements is all that is needed. AES conducts an OPEX sensitivity analysis to changing degrees of consumables to achieve higher total phosphorus recovery. This data is generated as part of the initial stream assessment to identify the potential operating cost impact of achieving increasing phosphorus recovery targets.

5.0 LIST OF REMAINING DATA GAPS

As discuss previously, the only real data gap is determining value of the co-products generated by implementation of the QuickWash® technology and identifying the markets for them. AES is currently working on a OWDA Grant in Mercer County, Ohio that is evaluating this cost benefit of the co-products. However, additional research with regard to the markets for these products is also needed.

6.0 FINDINGS AND OPINIONS

Based on our review of the available information and discussions with AES, Tetra Tech has reached the following conclusions regarding QuickWash®:

- Research and Pilot Projects provided by AES clearly demonstrate the effectiveness of the QuickWash® technology with regard to reduction of phosphorus through recovery.
- Additional research is needed on the value and markets for the co-products generated by implementation of QuickWash®. This could be a goal of a pilot project funded by H2Ohio.
- QuickWash® is a cost-effective technology when compared to other practices intended to address nutrient loading, especially when the financial assistance available from NRCS and other sources for its planning, design, and implementation and the benefit/value of the co-products are considered. In mid-Ohio, AES has demonstrated the ability to be able to treat liquid manure at a cost of <$0.010/gallon. This is based on recent costs in the Mercer/Auglaize/Darke County areas (west-central Ohio).
- QuickWash® has strong potential for scalability, as there are numerous options within the WLEB where QuickWash® could be implemented on a variety of scales.
- Biggest barrier to widespread adoption of QuickWash® is landowner willingness, which could be further evaluated through a pilot project funded by H2Ohio.
- Costs to implement QuickWash® are significant at both the farm-scale and for the various “scale-up” scenarios. However, financial assistance from conservation program could offset a significant portion of these costs for a producer. However, as demonstrated by the detailed cost evaluations, QuickWash® demonstrates it is able to keep the cost of manure treatment similar to existing practices while significantly reducing phosphorus which current practices do not do.

- QuickWash® could provide a technology solution that allows for the movement of recovered P to other regions where a P deficits exist and/or reduces the need for Ohio farmers to purchase commercial grade phosphorus, thereby reducing the total P205 in the WLEB by the amount recovered from manure. Implementation of the QuickWash® technology could therefore enable Ohio producers to actively manage their waste on-site and at costs comparable to untreated land application

- The opportunity for QuickWash® implementation in WLEB is significant due to the urgent need to reduce and recover phosphorus generated by the over 4,000 livestock farms/operations.

- Additionally, the QuickWash® technology does not generate waste. All the co-products present a potential value and opportunity for re-use.

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